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Book Contents

CHAPTER ONE

FUSELAGE, WINGS AND STABILISING SURFACES

Contents

DEFINITIONS, LOADS APPLIED TO AIRCRAFT STRUCTURES

Tension

A tension, or tensile load is one which tends to stretch a structural member. Components designed to resist tensile loads are known as **ties.**

Figure 1.1: Tensile.

Compression

Compressive loads are the opposite of tensile loads and tend to shorten structural members. Components designed to resist compressive loads are known as **Struts.**

Figure 1.2: Compression.

Shear

Shear is a force which tends to slide one face of the material over an adjacent face. (See Figure 1.3.) Riveted joints are designed to resist shear forces.

Figure 1.3: Shear.

COMBINATION LOADINGS

Bending

Bending of the structure involves the three basic loadings:

- Tension as the outer edge stretches.
- Compression as the inner edge squeezes together.
- Shear across the structure as the forces try to split it.

Torsion

Torsion or twisting forces produce tension at the outer edge, compression in the centre and shear across the structure.

Stress

Stress is the internal force inside a structural member which resists an externally applied force and, therefore, a tensile load or force will set up a tensile stress, compression loads compressive stresses etc.

Stress is defined as the **force per unit of area** and is measured in units of **N/mm^2 or MN/m^2.**

Strain

When an external force of sufficient magnitude acts on a structure, the structural dimensions change. This change is known as strain and is the ratio of the change in length to the original length and is a measure of the deformation of any loaded structure.

The relationship between stress and strain for an elastic material is generally a constant known as Young's Modulus of Elasticity.

Buckling

Buckling occurs to thin sheet materials when they are subjected to end loads and to ties if subjected to compressive forces.

Aircraft components are subjected to some or all of the above stresses and these will tend to elongate, compress, bend, shear or twist the component. However, providing the resulting deformation is within the **elastic limit** of the material, the component will return to its original dimension once the deforming load has been removed. If any load takes the structure beyond the elastic limit the deformation will be permanent.

Design Limit Load (DLL)

This is the maximum load that the designer would expect the airframe or component to experience in service. The standard DLL's are: For Transport Aircraft 2.5. For Utility Aircraft 3.4-3.8, and for Aerobatic Aircraft, 6. These values are based on 'G'-Forces and derived from failure values determined experimentally at the design stage.

Design Ultimate Load (DUL)

The DUL is the **DLL x the safety factor**. The **minimum safety factor** specified in design requirements is **1.5.** The structure must withstand DUL without collapse.

Safety factor

The **safety factor** is the ratio of the **ultimate load** to the **limit load**.

DESIGN PHILOSOPHIES

The aircraft manufacturer will attempt to design an aircraft to take into account all the loads that it may experience in flight. There are various guidelines, formulae and experience to guide them in the design of a good fail safe/damage tolerant structure.

Safe Life

The safe life of an aircraft structure is defined as the minimum life during which it is known that no catastrophic damage will occur. Life-counts for components of assemblies may be recorded as number of flying hours, cycles of landing or pressurization events or even on a calendar basis. After the elapsed life-count or fatigue cycle (typically pressurisations or landings has been reached, the item is replaced or overhauled. In the interim (operational life) of the Aircraft, and to minimise the chances of failure due to fatigue, aircraft designers apply the principle of **Fail safe** construction or **Damage tolerance.**

Fail Safe or Damage Tolerant Structure

Large modern Aircraft are designed with a **Fail-safe** or **Damage-tolerant** structure. This can be described as a structure in which a failure of a particular part is compensated for by an alternative load-path provided by an adjacent part that is able to carry the loads for a **limited time period.** Typically this is a structure which, after any single failure or crack in any one structural member can **safely** carry the normal operating loads until the **next periodic inspection**. True dualling of load-paths in common practice could be found in wing attachments and also in vertical stabiliser and horizontal stabiliser attachment points.

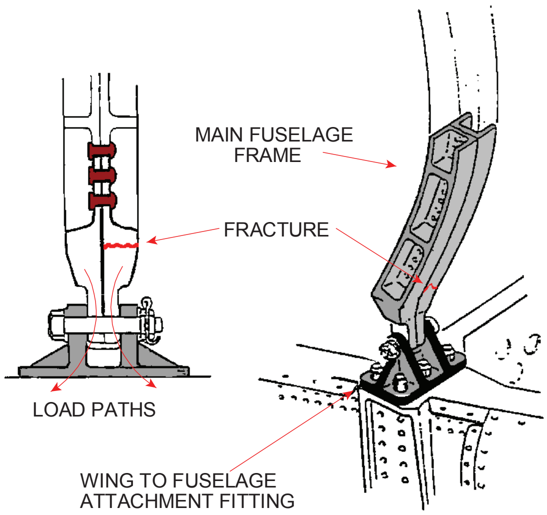


Figure 1.4:

Detection of faults is reliant upon a planned inspection programme capable of finding such failures. In order to gain access to the vulnerable areas a certain amount of dismantling is necessary although the use of non-destructive testing (NDT) may be employed in less critical areas. The disadvantage of true dualling of load-paths is that it is fundamentally very heavy.

Modern concepts of construction employ the **'Stressed-Skin'** or **'Semi-Monocoque'** style of construction where each piece of the Aircraft has its part to play in spreading loads throughout the Airframe and is tolerant to certain amount of damage. The programmed inspection cycle periodicy is determined on the basis that if a crack of detectable length has been missed at the first inspection, the structure will allow this crack to develop until a subsequent inspection before it becomes critical. The criteria of inspection cycles, Design Limit Loads, and Design Ultimate Loads are agreed at the time of certification.

Damage Tolerant Structure

Fail safe structures are rather heavy due to the extra structural members required to protect the integrity of the structure. Damage tolerant structure eliminates the extra structural members by spreading the loading of a particular structure over a larger area. This means that the structure is designed so that damage can be detected during the normal inspection cycles before a failure occurs.

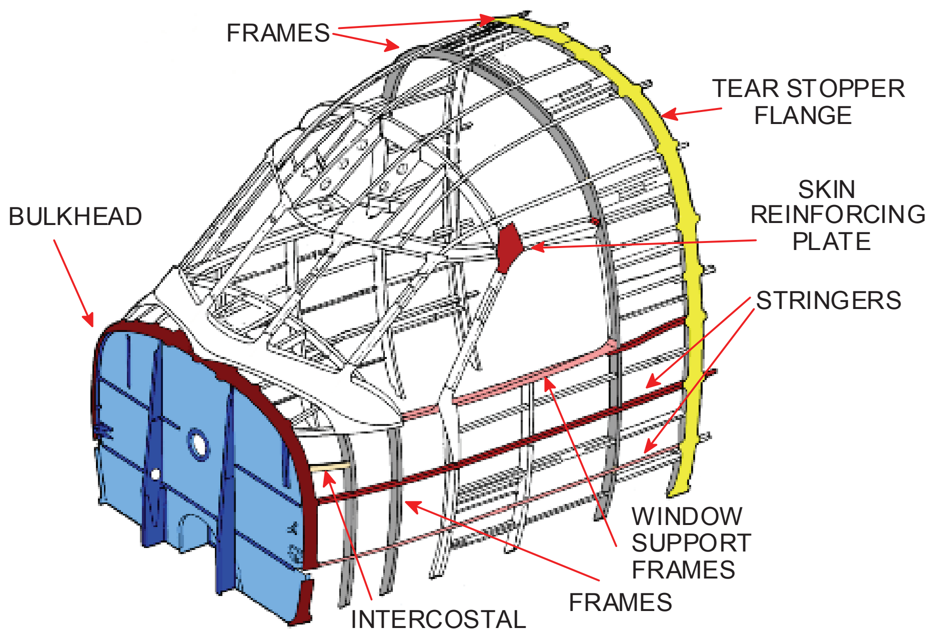


Figure 1.5: Damage tolerant structure.

Fatigue

A structure which is subjected to continual reversals of loading will fail at a load of less than would be the case for a steadily applied load. This is known as **Fatigue.** The failing load will depend on the number of reversals experienced. It can be seen in the example below that if the applied stress was 80% of the ultimate stress, the specimen could expect to fail after 100 applications but if the applied stress was reduced to 20% the failure would not occur until 10 million applications.

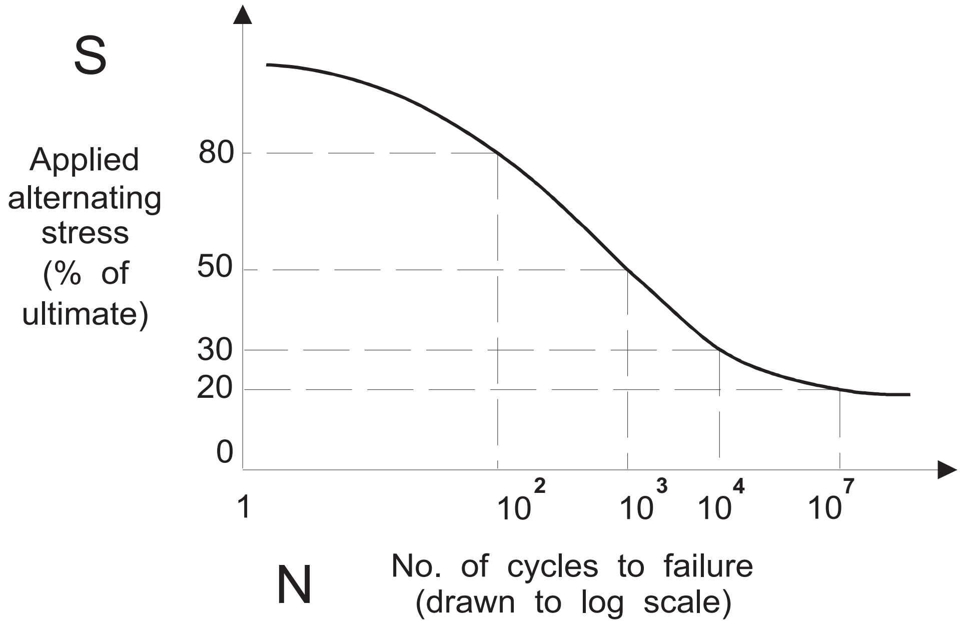


Figure 1.6: Fatigue.

Station Numbers

A method of locating components on the aircraft must be established in order that maintenance and repairs can be carried out. This is achieved by identifying reference lines and **station numbers** for fuselage, wings, empennage, etc. Fuselage station lines are determined by reference to a **zero datum line (fuselage station 0.00)** at or near the forward portion of the aircraft as defined by the manufacturer. Station numbers are given in inches forward (negative and given a - sign) or aft (positive and with a +sign) of the zero datum. Wing stations are measured from the centre line of the aircraft and are also given in inches left or right of the centre line. Vertical position from a ground line or horizontal datum can be known as a **Water Line (WL) or Buttock Line**, given as a dimension in inches from the horizontal datum.

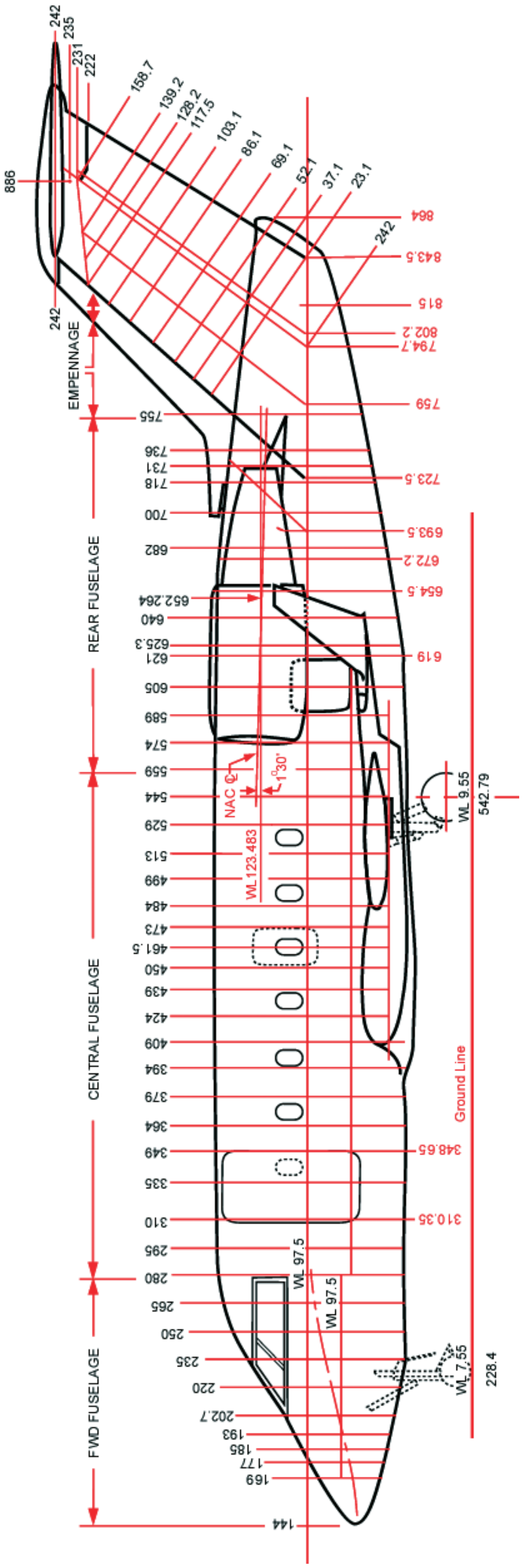


Figure 1.7: Various stations on a corporate jet aircraft.

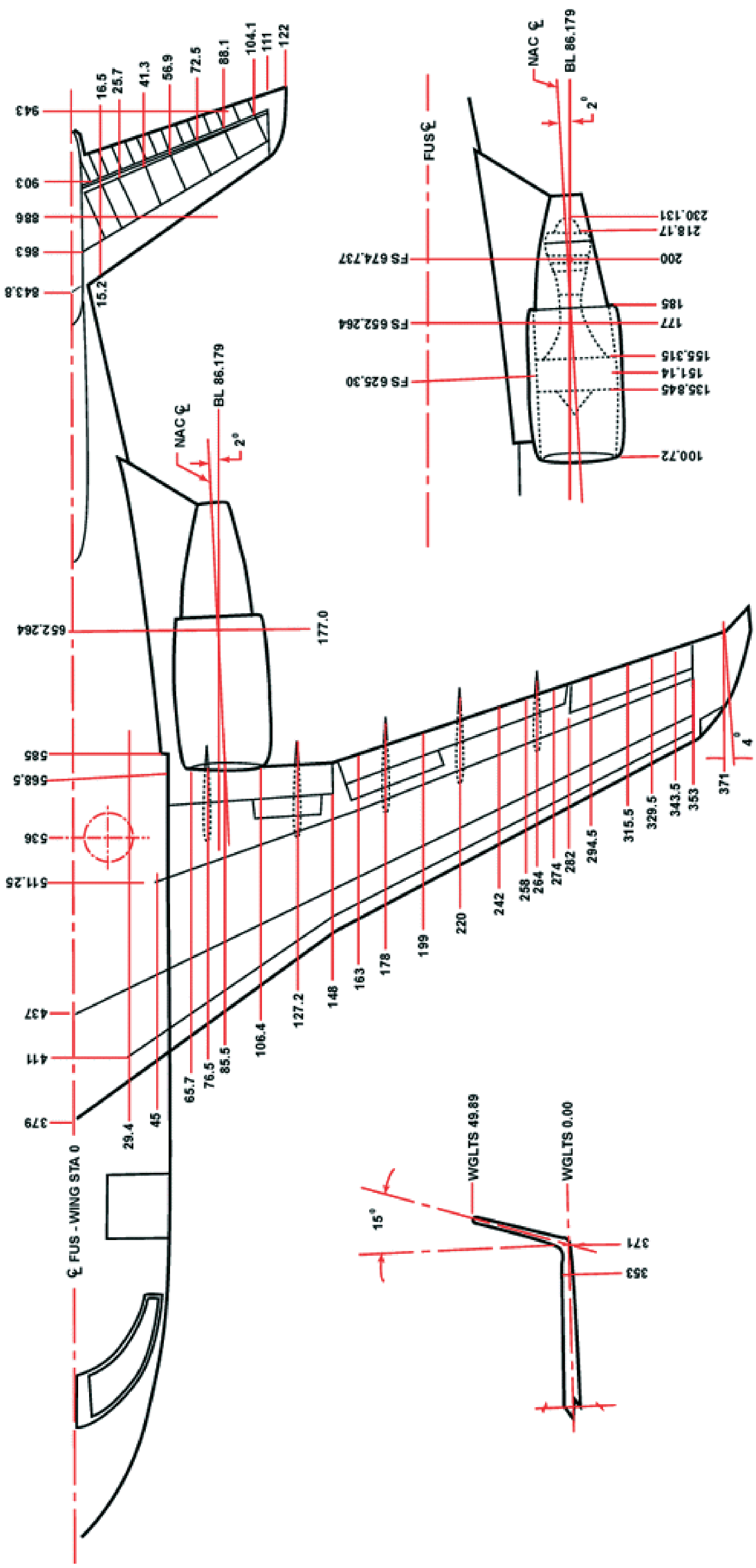


Figure 1.8: Various stations on a corporate jet aircraft.

Fuselage

The fuselage is the main structure or body of the aircraft and carries the aircraft payload i.e. the passengers and/or freight as well as the flight crew and cabin staff in safe, comfortable conditions.

It also provides the flight crew with an effective position for operating the aircraft and space for controls, accessories and other equipment. It transfers loads to and from the main planes (wings), tailplanes, fin, landing gear and, in certain configurations, the power plants. Pressurised aircraft structures must also be capable of supporting the axial and hoop stresses imposed by the pressurisation forces.

Axial Stress

Axial or longitudinal stresses are set up in the fuselage of aircraft when pressurised and tend to elongate the fuselage.

Hoop Stress

Hoop or radial stresses are set up in addition to axial stress and tend to expand fuselage cross section area. The internal pressures that set up these stresses can be as high as 65.5 KN/m2 (9.5psi).

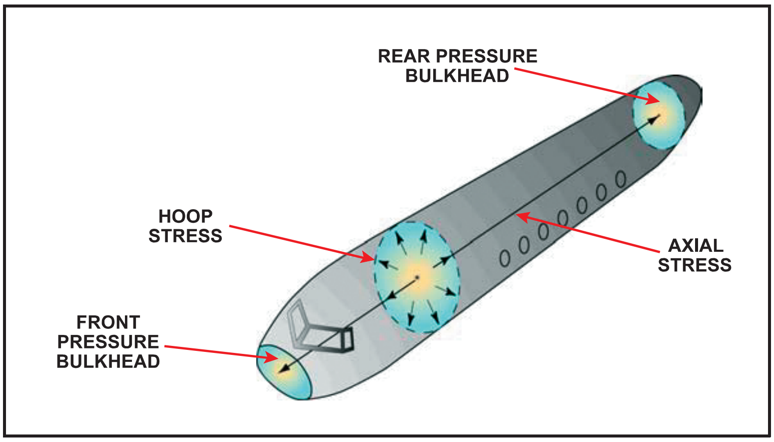


Figure 1.9:

FUSELAGE CONSTRUCTION

There are two main types of construction in use:

- **Truss or framework** type generally used for light, non pressurised, aircraft.
- **Monocoque** or the more widely used **Semi-Monocoque** which is in use on most other aircraft. This type of structure is more generally referred to as Stressed Skin.

FRAMEWORK

The framework consists of light gauge steel tubes welded together to form a space frame of triangular shape to give the most rigid of geometric forms with each tube carrying a specific load the magnitude of which depends on whether the aircraft is airborne or on the ground. It is a strong, easily constructed and relatively trouble free basic structure. The framework is covered by a lightweight aluminium alloy or fabric skin to give an enclosed, aerodynamically efficient load carrying compartment.

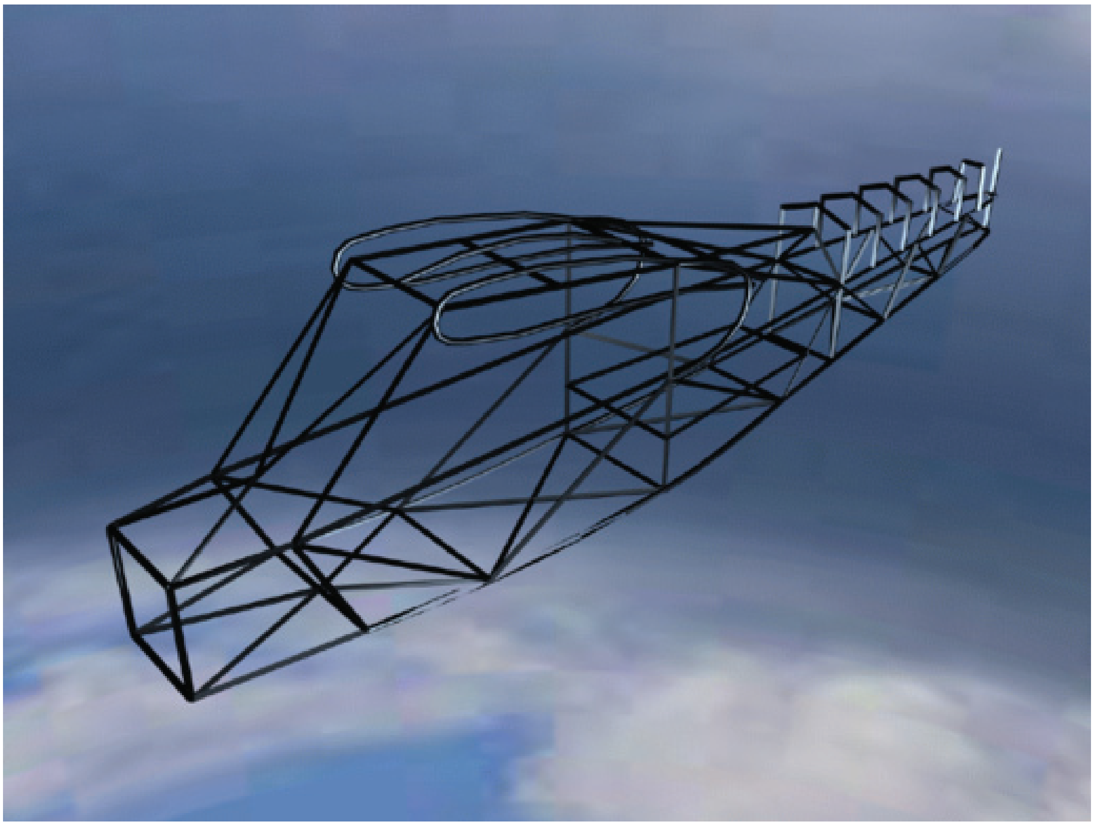


Figure 1.10: The Auster.

MONOCOQUE CONSTRUCTION

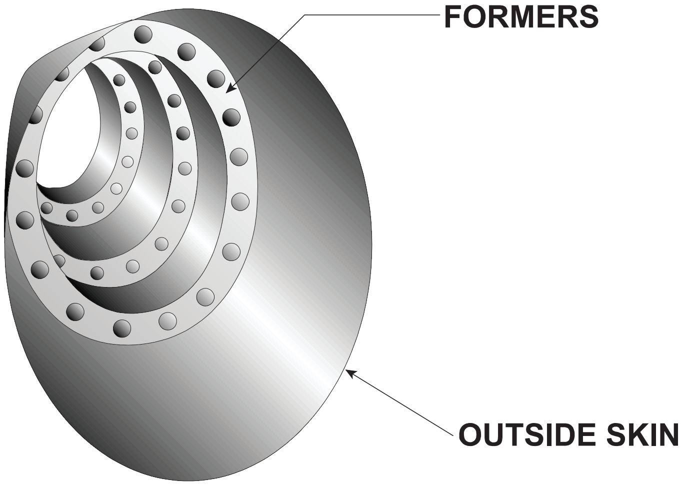


Figure 1.11:

In a monocoque structure all the loads are taken by the skin with just light internal frames or formers to give the required shape. Even slight damage to the skin can seriously weaken the structure. Sandwich construction, a honeycomb core with a skin of composite material (GRP or CFP) or aluminium alloy, can be used to provide rigidity and strength and is seen in aircraft such as the **Beech Starship**.

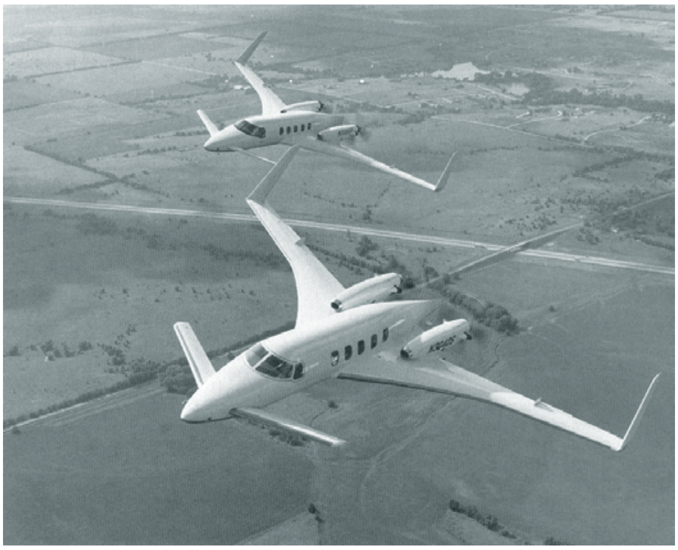


Figure 1.12: Beech Starship turbo-prop executive aircraft with all-composite airframe.

SEMI-MONOCOQUE CONSTRUCTION

As aircraft became larger and the air loads greater the pure monocoque structure was not strong enough and additional structural members known as stringers (stiffeners) and longerons were added to run lengthwise along the fuselage joining the frames together. The light alloy skin is then attached to the frames and stringers by rivetting or adhesive bonding. Stringers stiffen the skin and assist the sheet materials to carry loads along their length. Good examples of longerons are the seat rails of passenger aircraft.

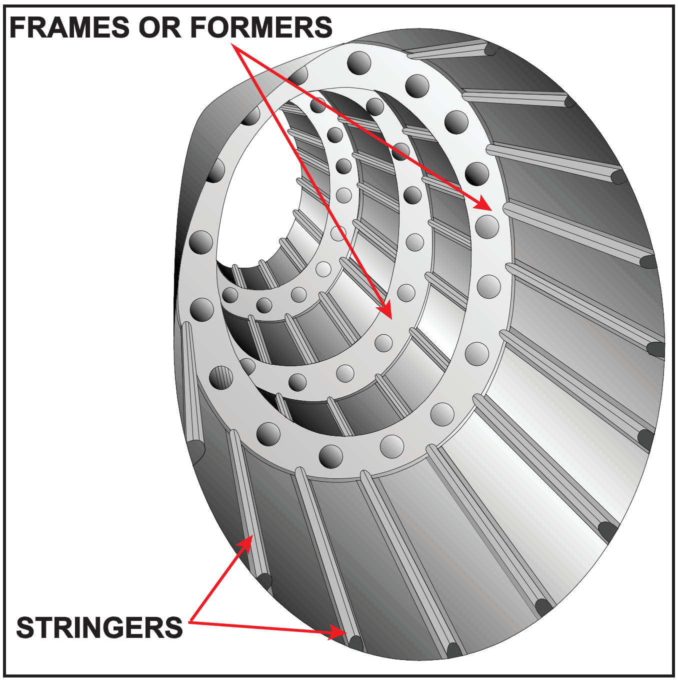


Figure 1.13: Semi-monocoque structure.

When cut-outs are made to stressed skin structures, for example to provide access panels, passenger windows or when repairs are required to damaged areas, reinforcement, in the form of DOUBLERS or backing plates, is required around the cut-out. If the skin is machined from the solid the skin around windows etc. is left thicker than the rest of the skin to provide the required reinforcement.

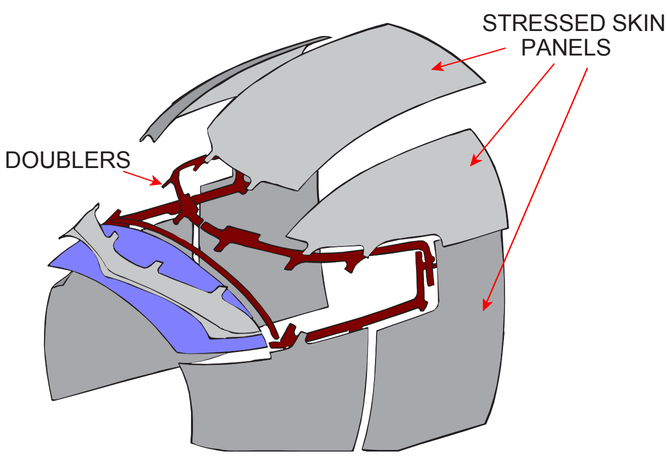


Figure 1.14:

FLIGHT DECK AND PASSENGER CABIN WINDOWS

Flight deck windows.

The flight deck windows fitted to pressurised aircraft must withstand both the loads of pressurisation and impact loads from birdstrikes. They are constructed from toughened glass panels attached to each side of a clear vinyl interlayer. An electrically conducting coating, applied to the inside of the outer glass panel is used to heat the window. This prevents ice from forming and makes the window more resilient and able to withstand birdstrikes.

The shock loading of a birdstrike impact is absorbed by the ability of the vinyl interlayer to stretch and deform should the impact be great enough to shatter the glass. Windscreens are attached to the frame by bolts passing through the edge of the windscreen.

The aircraft, and therefore by implication the windscreen, must be capable of continued safe flight and landing after impact with a 4lb(2kg) bird when the velocity of the aeroplane is equal to Vc (design cruise speed) at sea level, or 0.85 Vc at 8,000 ft, which ever is the most critical. i.e. the windscreen must be able to withstand impact under these conditions without penetration.

The vertical and horizontal angles of the windscreen are specified so that each pilot has a sufficiently extensive, clear and undistorted view so that they can safely perform any manoeuvres within the operating limitations of the aeroplane. An opening window may be provided in the control cabin to enable the pilot to land the aircraft safely should forward vision be restricted. On light aircraft the flight compartment windows are generally perspex.

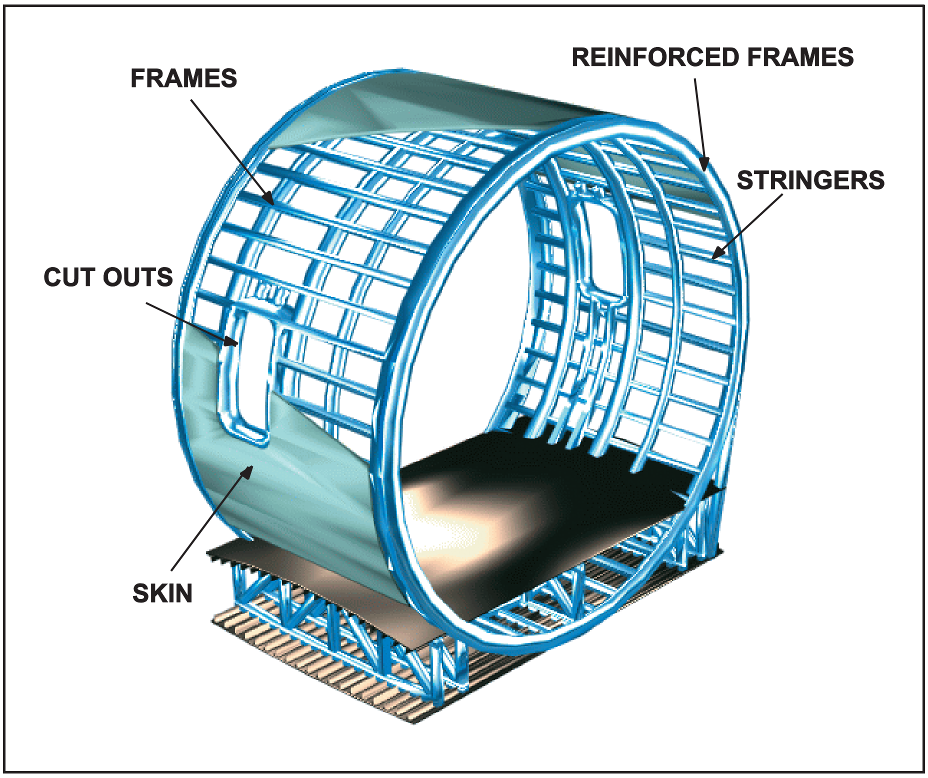


Figure 1.15:

Passenger cabin windows.

These are designed to be 'fail safe' and normally have two panes of acrylic plastic mounted in an airtight rubber seal fitted into a metal window frame. The inner and outer panes are each capable of taking the full cabin pressurisation load. If one pane fails the other will prevent loss of cabin pressure.

MAINPLANES (WINGS)

The wings support the weight of the aircraft in the air and so must have sufficient strength and stiffness to be able to do this. The strength and stiffness are determined by the thickness of the wing, with the thickness and type of construction used being dependent on the speed requirements of the aircraft. The types of construction are:

- Bi-plane
- Braced monoplane
- Cantilever monoplane

Bi-Plane

Very few bi-planes fly at more than 200 knots in level flight and so the air loads are low, which means that the truss type design covered in fabric is satisfactory. The wing spars, interplane struts and bracing wires form a lattice girder of great rigidity which is highly resistant to bending and twisting.

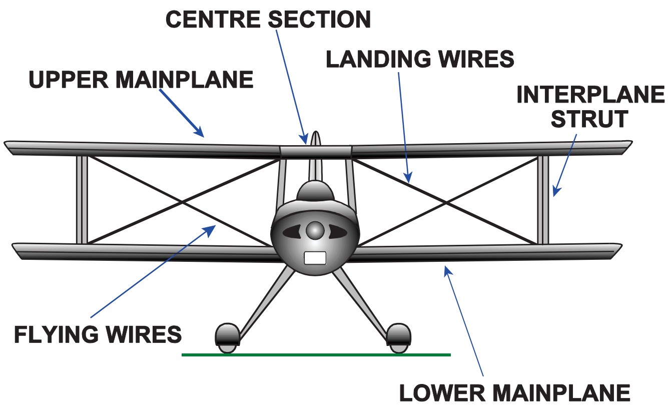


Figure 1.16:

Braced Monoplane.

This type of design is also used on low speed aircraft.

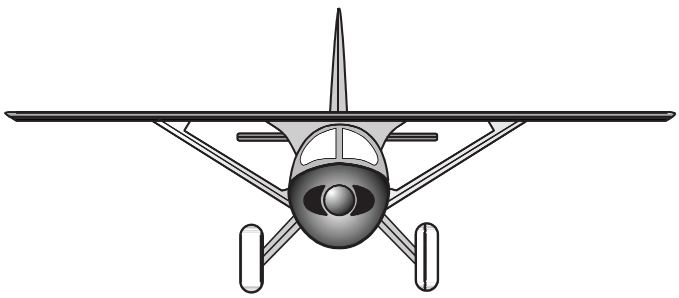


Figure 1.17:

Cantilever Monoplane

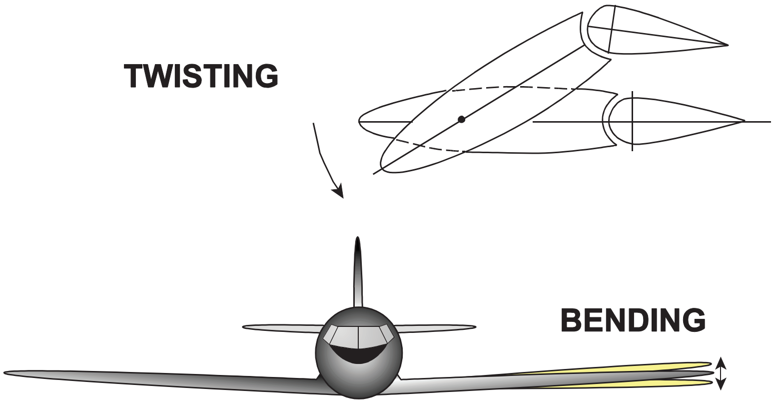


Figure 1.19:

The mainplanes have to absorb the stresses due to lift and drag in flight and, if of cantilever design, their own weight when on the ground.

This is achieved by building the wing around one or more main load bearing members known as spars, which are constructed so that they will absorb the downwards bending stresses when on the ground and the upwards, rearwards and twisting stresses when in flight.

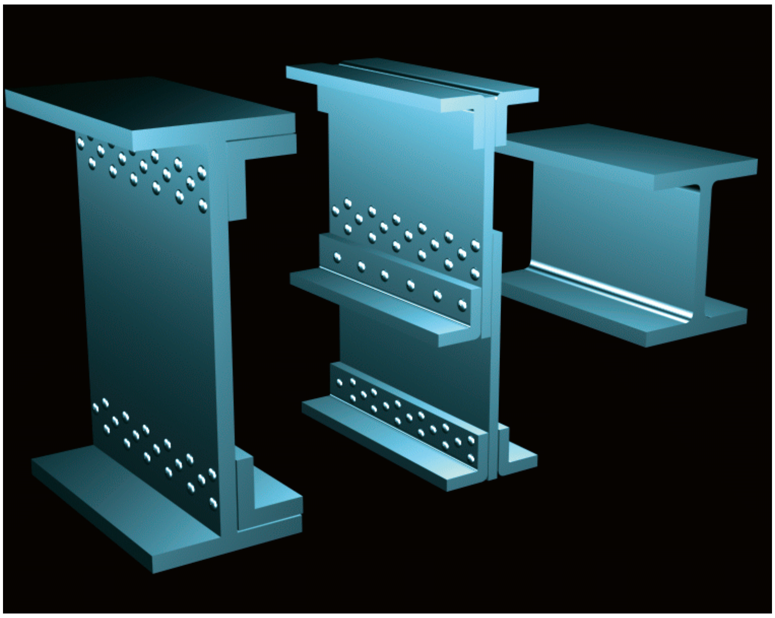


Figure 1.20: Typical spar sections.

Bending stress relief is also provided by mounting the engines on the wing and positioning the major fuel tanks within the wing. During flight the fuel in the wing tanks is the last to be used.

This is particularly important at high all up weights when the outer wing fuel tanks are full. As the fuel is used the weight of the aircraft decreases which reduces the required lift and therefore the bending moments.

Note: The maximum bending moment occurs at the wing root.

The engine position also acts as a mass balance to reduce wing flutter.

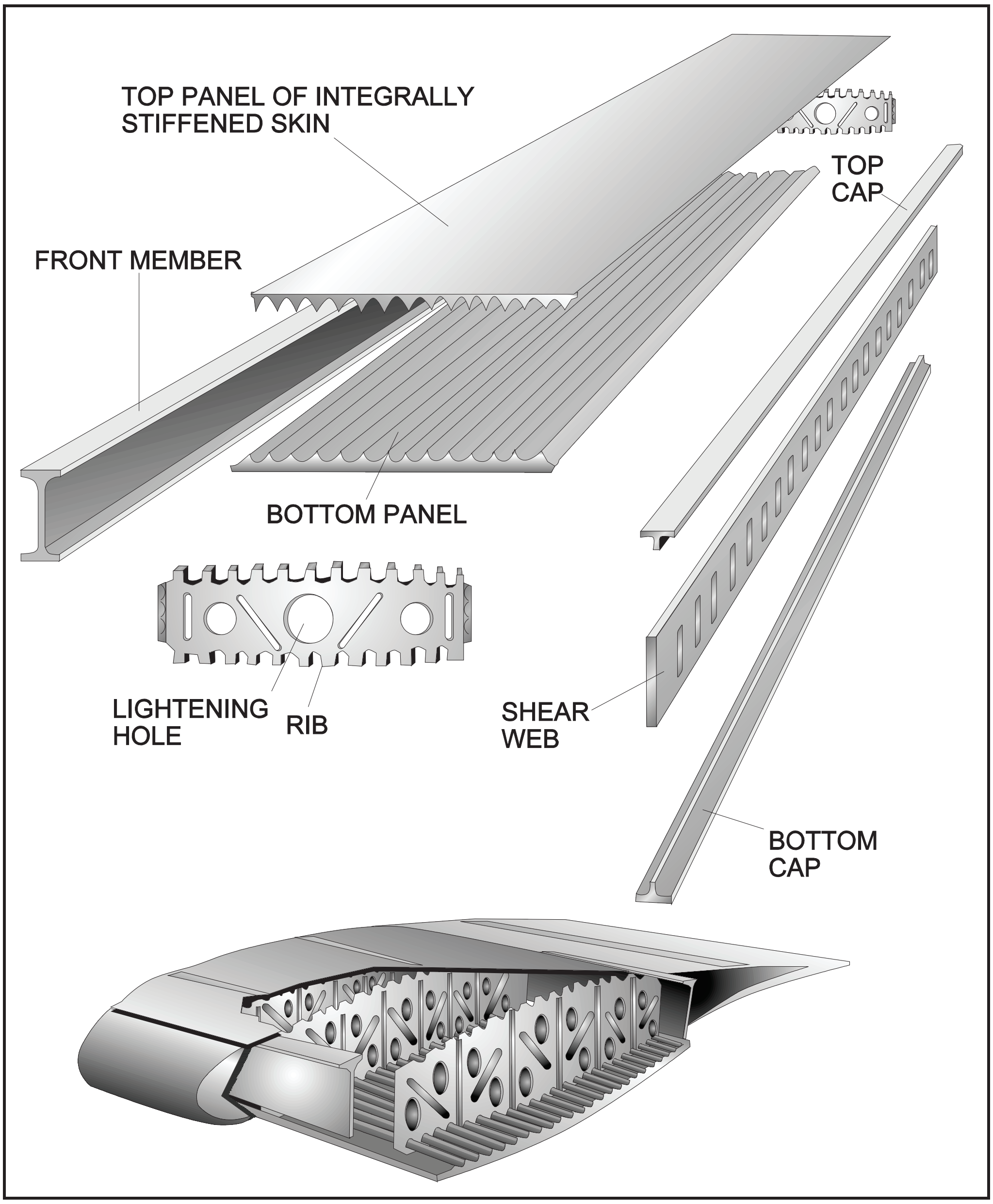


Figure 1.21: Wing torsion box structure.

The **Maximum Zero Fuel Mass (MZFM**) is defined as the '**maximum permissible mass of an aeroplane with no usable fuel'**.

This is significant because the added fuel (almost always carried in the wing) does not add to the wing structural weight.

The main-planes may be of single spar, twin spar or multi-spar construction. A conventional structure would consist of front and rear spars, the metal skin attached to the spar booms, the ribs and stringers. These four main component parts form the **'torsion box'**.

There is a form of construction that uses a series of small spars to replace the main spars. Other main-plane components are:

Skin: takes the loads due to differences in air pressures and the mass and inertia of the fuel (if any) in the wing tanks. It generates direct stresses in a span-wise direction as a response to bending moments and also reacts against twisting (torsion) .

Stringers: are span-wise members giving the wing rigidity by stiffening the skin in compression.
Ribs: these maintain the aerofoil shape of the wings, support the spars, stringers and skin against buckling and pass concentrated loads from engines, landing gear and control surfaces into the skin and spars.

The major structural components of the wings are generally manufactured from aluminium alloys with composite materials such as GRP (glass reinforced plastic), CRP (carbon reinforced plastic) and honeycomb structures used for fairings, control surfaces, flaps etc.

STABILISING SURFACES

There are many different designs of the empennage (tail unit) i.e. Conventional, T-tail, H-tail, V-tail. (see *Figure 1.22*).

The tail units provide, in most cases, the longitudinal and directional stability and the means of longitudinal control. Some aircraft have their longitudinal stability and control provided by foreplanes (canards).

The horizontal surfaces, which are known as the **tailplane or horizontal stabiliser**, provide longitudinal stability by generating upwards or downwards forces as required.

The vertical surface(s), **vertical stabiliser or fin,** generate sideways forces as required. Longitudinal control is provided by the **elevators or moving tailplane** with directional control provided by the **rudder.** Both the tailplane and the fin are subject to both bending and torsional stresses.

Structurally the tail unit components are generally smaller versions of the mainplanes in that they use spars, ribs, stringers and skin in their construction. On some aircraft they may also be sealed to provide fuel tanks, particularly those used for longitudinal and / or mach trim. They also use the same basic materials i.e. aluminium alloys, composites with honeycomb structures or high density expanding foam being used for control surfaces, to provide greater stiffness at lower weight .

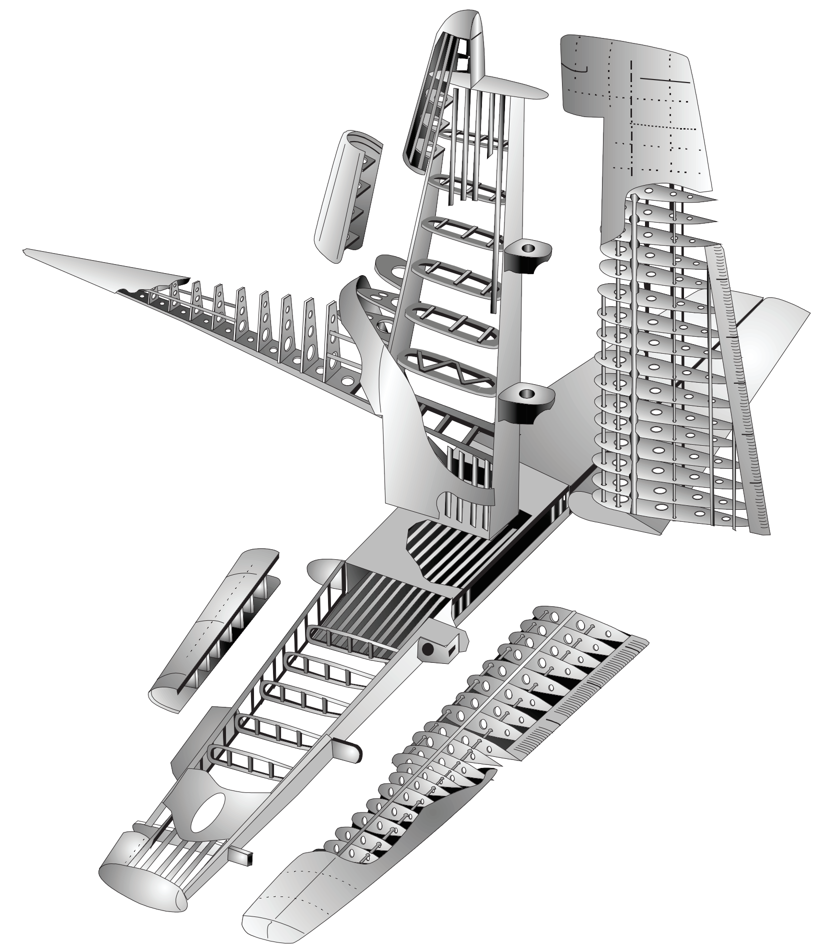


Figure 1.22: The empennage.

CONTROL SURFACE FLUTTER

Flutter is the rapid and uncontrolled oscillation of a flight control (or the surface to which it is attached) which occurs as a result of an unbalanced surface.

Flutter is caused by the interaction of aerodynamic forces, inertia forces and the elastic properties of the surface or structure and can lead to the catastrophic failure of the structure.

Flutter must not occur within the normal flight operating envelope of the aircraft. Flutter can be prevented by **mass balancing** control surfaces to alter the moment of inertia of the surface and therefore the period of vibration (move the control surface C of G closer to the hinge).

Poorly maintained aircraft, particularly those with excessive control surface backlash (play) or flexibility may mean that flutter could occur at speeds below the limit airspeed.

Flutter of the mainplanes may be prevented by using the engines as mass balances, placing them on pylons forward of the wing leading edge.

MATERIALS USED

Modern aircraft are constructed mainly of aluminium and its alloys with smaller amounts of steel and titanium for the major structural components with composite materials used extensively for more lightly loaded structures. However many of the latest aircraft make use of modern composites for the empennage, cabin floor panels, flying control surfaces, engine cowlings and fairings.

Each material is chosen for its particular properties with regard to fatigue strength, wear resistance, strength to weight ratio, fire resistance etc.

Aluminium and its alloys are the most widely used metals for structural use due to a good strength to weight ratio with 'duralumin' type alloys predominating due to their good fatigue resistance. Duralumin is an aluminium and copper based alloy which has poor corrosion resistance except when clad with pure aluminium. It also has good thermal and electrical conductivity and is difficult to weld.

Steel and its alloys are only used where strength is vital and weight penalties can be ignored.

Titanium is much lighter than steel and can be used where fire protection is required i.e. firewalls. It has good strength and retains this and its corrosion resistance up to temperatures of 400°C.

Magnesium alloys are also used, their principal advantage being their weight. This gives an excellent strength to weight ratio (aluminium is one and a half times heavier) . The elastic properties of magnesium are not very satisfactory so its use in primary structures is limited.

Composite materials have good resistance to corrosion and can easily be formed into complex shapes but their fatigue behaviour is different to that of conventional metal alloys and is not generally a consideration at stress cycles below approximately 80% of ultimate stress. Metal structures suffering fatigue retain their design strength up to a critical point after which failure occurs rapidly whereas composites loose their properties gradually. Interest in composites for structural use is due to their high specific strength and specific stiffness and their ability to retain these properties at elevated temperatures.

CORROSION

Introduction

Corrosion may be regarded as the slow destruction of a metal by electro-chemical action. Considerable research by chemists and metallurgists is continually being carried out to find more effective methods of preventing this destruction, but corrosion remains a major problem.

General

Most metals are unstable, corrosion is the tendency of the metal to return to a stable state similar to that of the metallic ore from which it originated. With corrosive attack the metal is converted into metallic compounds such as oxides, hydroxides, carbonates, sulphates or other salts.

Corrosion is largely electro-chemical in character, and occurs in conditions that permit the formation of minute electrical cells in or on the attacked metal, in the presence of an electrolyte. It will also occur when a difference in potential exists between the different constituents of an alloy, or where dissimilar metals are in contact.

When a metal is exposed to the air, oxygen reacts with the bare metal to form an oxide film which adheres to the metal surface. This oxide film forms a barrier between the air and the metal surface which protects the underlying metal against further attack.

This is all the protection required by some metals, however, the oxides may react chemically or combine with water to produce a film that is not impervious to the passage of further oxygen through it. The oxide film may crack or flake exposing the surface to further oxidation, or the oxides may volatize if the metal is subject to heat.

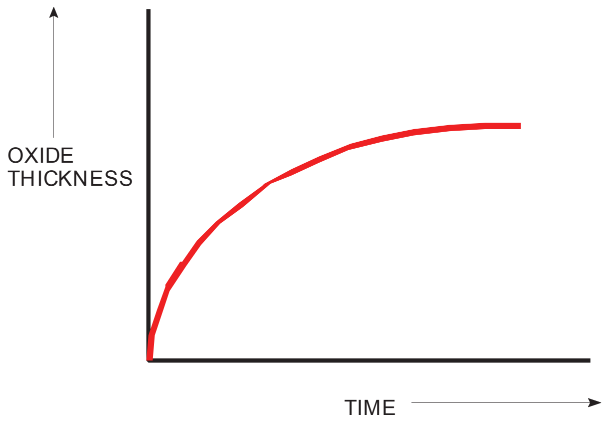


Figure 1.23: Oxidation.

With the exception of oxidation, corrosion takes place when the metal is in contact with water, either as a liquid or as moisture in the atmosphere. The degree of corrosion is proportional to the impurities in the water, the impurities being due to industrial pollution which has a high sulphur content, or air-bourne salt particles when operating over the sea. The resultant action is that the metal undergoes chemical change, the metal is converted into a chemical compound whilst the other metal remains untouched.

Evidence of Corrosion

The attack may extend over the entire surface of the metal or it may penetrate locally forming deep pits, or follow grain boundaries inside the core of the metal. The weakening effect can be aggravated by stresses in the metal, due to external loads, or they may be residual stresses from the manufacturing process or method of assembly.

Types of Corrosion

The process of corrosion are complex and the various types of corrosion seldom occur separately. One type of corrosion frequently leads to another so that two or more types can exist simultaneously in the same piece of metal.

In aeronautical engineering the need to keep the weight of the aircraft structure to a minimum commensurate with safety has lead to the development of high strength alloys, most of which contain aluminium or magnesium. These alloys suffer damaging corrosion unless effectively protected, the rate of deterioration under unfavourable conditions can be very rapid.

Aircraft operate under widely varying climatic conditions in all parts of the world some of the environments being highly conductive to corrosive attack.

RATE OF CORROSION	TYPE OF ATMOSPHERE		
Highly conductive to corrosion	Tropical	Industrial	Marine
Moderate corrosion	Temperate	Suburban	Inland
Low rate of corrosion	Arctic	Rural	

Corrosion is one of the most persistent defects found in aircraft, rectification of advanced corrosion has been known to take thousands of man hours. It is therefore essential that corrosion is recognised at the earliest possible stage and effective preventative measures taken.

Surface Corrosion

This is fairly uniform attack which slowly reduces the cross sectional thickness of the sound material, and so weakens the structure. The attack is recognised by etching or pitting of the surface, the products of corrosion are recognised as:

Steels

Ferrous metals other than stainless steel become covered with reddish brown powder commonly known as rust.

Aluminium and Magnesium

Corrosion produces powdery deposits and the colour of which varies between white and grey. Corrosion of magnesium may take the form of deep pitting or may be fluffy or granular.

Copper Alloys

Copper corrosion in its most common form produces a blue-green salt deposit.

Surface corrosion is the least damaging form of corrosion since there is evidence of the attack, so that it can be detected and rectified at an early stage.

Intergranular Corrosion

An intergranular (or inter-crystalline) corrosion penetrates the core of the metal along the grain boundaries. As the material at the grain boundaries are usually anodic to the grain centres, the production of corrosion are concentrated at the boundaries. The rate of attack is not limited by the lack of oxygen, and is accelerated if applied or residual stresses are present. Repeated fluctuating or tensile stresses cause separation of the grain boundaries accelerating the spread of the corrosion. As a result higher stress concentrations occur in the remaining sound material, this production cracks, which spread leading to complete failure.

It is probably the most dangerous form of corrosion as detection is difficult, and serious weakening may occur before any external evidence is visible. The only surface indication is a series of hair line cracks, these are usually only visible through a magnifying glass.

There is no effective method of determining or limiting the loss of strength that will occur, so that when detected, parts must be immediately rejected.

Stress Corrosion

A combination of steady tensile load and corrosive conditions produce a form of metal fatigue known as stress corrosion cracking. The stresses may be built in during manufacture of the part, or introduced during assembly, or may be due to operational or structural loads.

A metal under stress corrodes more rapidly than unstressed parts, initially there is pitting of the surface. Loss of the metal at the corrosion pit intensifies the stress at this point, producing a crack which extends under the combined action of corrosion and load until failure occurs. There is generally little visible evidence of corrosion and no apparent loss of metal.

HEAVY LANDINGS

Aircraft landing gear is designed to withstand landing at a particular aircraft weight and vertical descent velocity (the maximum is 10ft/sec or 3.15m/sec at maximum landing weight). If either of these parameters are exceeded during a landing then damage may have been caused to the landing gear or supporting structure and these loads can be transmitted to the fuselage and main planes. Overstressing may also be caused by landing with drift or landing in an abnormal attitude, e.g. nose or tail wheels striking the runway before the main wheels.

Some aircraft are fitted with heavy landing indicators, which give a visual indication that specific "G" forces have been exceeded but in all cases of suspected heavy landings the flight crew should give details of the aircraft weight, fuel distribution , landing condition and whether any noises indicative of structural failure were heard.

The damage which may be expected following a heavy landing would normally be concentrated around the landing gear, its supporting structure in the wings or fuselage, the wing and tailplane attachments and the engine mountings. Secondary damage may be found on the fuselage upper and lower skin and structure, depending on the configuration and loading of the aircraft.

On some aircraft it is specified that, if no damage is found in the primary areas, the secondary areas need not be inspected; but if damage is found in the primary areas, then the inspection must be continued.

The precise details vary from aircraft to aircraft so reference must be made to the appropriate maintenance manual.

FAILURE STATISTICS

The following pages are an extract from the EASA CS-25 document which details the EASA policy on Failure Conditions.

6. *BACKGROUND*

a. *General.*

For a number of years aeroplane systems were evaluated to specific requirements, to the "single fault" criterion, or to the fail-safe design concept. As later-generation aeroplanes developed, more safety-critical functions were required to be performed, which generally resulted in an increase in the complexity of the systems designed to perform these functions. The potential hazards to the aeroplane and its occupants which could arise in the event of loss of one or more functions provided by a system or that system's malfunction had to be considered, as also did the interaction between systems performing different functions. This has led to the general principle that an inverse relationship should exist between the probability of a Failure Condition and its effect on the aeroplane and/or its occupants (see Figure 1). In assessing the acceptability of a design it was recognised that rational probability values would have to be established. Historical evidence indicated that the probability of a serious accident due to operational and airframe-related causes was approximately one per million hours of flight. Furthermore, about 10 percent of the total were attributed to Failure Conditions caused by the aeroplane's systems. It seems reasonable that serious accidents caused by systems should not be allowed a higher probability than this in new aeroplane designs. It is reasonable to expect that the probability of a serious accident from all such Failure Conditions be not greater than one per ten million flight hours or 1×10^{-7} per flight hour for a newly designed aeroplane. The difficulty with this is that it is not possible to say whether the target has been met until all the systems on the aeroplane are collectively analysed numerically. For this reason it was assumed, arbitrarily, that there are about one hundred potential Failure Conditions in an aeroplane, which could be Catastrophic. The target allowable Average Probability per Flight Hour of 1×10^{-7} was thus apportioned equally among these Failure Conditions, resulting in an allocation of not greater than 1×10^{-9} to each. The upper limit for the Average Probability per Flight Hour for Catastrophic Failure Conditions would be 1×10^{-9} , which establishes an approximate probability value for the term "Extremely Improbable". Failure Conditions having less severe effects could be relatively more likely to occur.

b. *Fail-Safe Design Concept.*

The Part 25 airworthiness standards are based on, and incorporate, the objectives and principles or techniques of the fail-safe design concept, which considers the effects of failures and combinations of failures in defining a safe design.

(1) The following basic objectives pertaining to failures apply:

(i) In any system or subsystem, the failure of any single element, component, or connection during any one flight should be assumed, regardless of its probability. Such single failures should not be Catastrophic.

(ii) Subsequent failures during the same flight, whether detected or latent, and combinations thereof, should also be assumed, unless their joint probability with the first failure is shown to be extremely improbable.

(2) The fail-safe design concept uses the following design principles or techniques in order to ensure a safe design. The use of only one of these principles or techniques is seldom adequate. A combination of two or more is usually needed to provide a fail-safe design; i.e. to ensure that Major Failure Conditions are Remote, Hazardous Failure Conditions are Extremely Remote, and Catastrophic Failure Conditions are Extremely Improbable:

(i) *Designed Integrity and Quality,* including *Life Limits*, to ensure intended function and prevent failures.

(ii) *Redundancy* or *Backup Systems* to enable continued function after any single (or other defined number of) failure(s); e.g., two or more engines, hydraulic systems, flight control systems, etc.

(iii) *Isolation and/or Segregation of Systems, Components, and Elements* so that the failure of one does not cause the failure of another.

(iv) *Proven Reliability* so that multiple, independent failures are unlikely to occur during the same flight.

(v) *Failure Warning or Indication* to provide detection.

(vi) *Flight crew Procedures* specifying corrective action for use after failure detection.

(vii) *Checkability:* the capability to check a component's condition.

(viii) *Designed Failure Effect Limits*, including the capability to sustain damage, to limit the safety impact or effects of a failure.

(ix) *Designed Failure Path* to control and direct the effects of a failure in a way that limits its safety impact.

(x) *Margins or Factors of Safety* to allow for any undefined or unforeseeable adverse conditions.

(xi) *Error-Tolerance* that considers adverse effects of foreseeable errors during the aeroplane's design, test, manufacture, operation, and maintenance.

c. *Highly Integrated Systems.*

(1) A concern arose regarding the efficiency and coverage of the techniques used for assessing safety aspects of highly integrated systems that perform complex and interrelated functions, particularly through the use of electronic technology and software based techniques. The concern is that design and analysis techniques traditionally applied to deterministic risks or to conventional, non-complex systems may not provide adequate safety coverage for more complex systems. Thus, other assurance techniques, such as development assurance utilising a combination of process assurance and verification coverage criteria, or structured analysis or assessment techniques applied at the aeroplane level, if necessary, or at least across integrated or interacting systems, have been applied to these more complex systems. Their systematic use increases confidence that errors in requirements or design, and integration or interaction effects have been adequately identified and corrected.

(2) Considering the above developments, as well as revisions made to the CS 25.1309, this AMC was revised to include new approaches, both qualitative and quantitative, which may be used to assist in determining safety requirements and establishing compliance with these requirements, and to reflect revisions in the rule, considering the whole aeroplane and its systems. It also provides guidance for determining when, or if, particular analyses or development assurance actions should be conducted in the frame of the development and safety assessment processes. Numerical values are assigned to the probabilistic terms included in the requirements for use in those cases where the impact of system failures is examined by quantitative methods of analysis. The analytical tools used in determining numerical values are intended to supplement, but not replace, qualitative methods based on engineering and operational judgement.

7. *FAILURE CONDITION CLASSIFICATIONS AND PROBABILITY TERMS*

a. *Classifications.* Failure Conditions may be classified according to the severity of their effects as follows:

(1) *No Safety Effect:* Failure Conditions that would have no effect on safety; for example, Failure Conditions that would not affect the operational capability of the aeroplane or increase crew workload.

(2) *Minor:* Failure Conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities. Minor Failure Conditions may include, for example, a slight

reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to passengers or cabin crew.

(3) *Major:* Failure Conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to the flight crew, or physical distress to passengers or cabin crew, possibly including injuries.

(4) *Hazardous:* Failure Conditions, which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating, conditions to the extent that there would be:

(i) A large reduction in safety margins or functional capabilities;

(ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or

(iii) Serious or fatal injury to a relatively small number of the occupants other than the flight crew.

(5) *Catastrophic:* Failure Conditions, which would result in multiple fatalities, usually with the loss of the aeroplane. (Note: A "Catastrophic" Failure Condition was defined in previous versions of the rule and the advisory material as a Failure Condition which would prevent continued safe flight and landing.)

b. *Qualitative Probability Terms.*

When using qualitative analyses to determine compliance with CS 25.1309(b), the following descriptions of the probability terms used in CS 25.1309 and this AMC have become commonly accepted as aids to engineering judgement:

(1) Probable Failure Conditions are those anticipated to occur one or more times during the entire operational life of each aeroplane.

(2) Remote Failure Conditions are those unlikely to occur to each aeroplane during its total life, but which may occur several times when considering the total operational life of a number of aeroplanes of the type.

(3) Extremely Remote Failure Conditions are those not anticipated to occur to each aeroplane during its total life but which may occur a few times when considering the total operational life of all aeroplanes of the type.

(4) Extremely Improbable Failure Conditions are those so unlikely that they are not anticipated to occur during the entire operational life of all aeroplanes of one type.

c. *Quantitative Probability Terms.*

When using quantitative analyses to help determine compliance with CS 25.1309(b), the following descriptions of the probability terms used in this requirement and this AMC have become commonly accepted as aids to engineering judgement. They are expressed in terms of acceptable ranges for the Average Probability Per Flight Hour.

(1) Probability Ranges.

(i) Probable Failure Conditions are those having an Average Probability Per Flight Hour greater than of the order of 1×10^{-5}.

(ii) Remote Failure Conditions are those having an Average Probability Per Flight Hour of the order of 1×10^{-5} or less, but greater than of the order of 1×10^{-7}.

(iii) Extremely Remote Failure Conditions are those having an Average Probability Per Flight Hour of the order of 1×10^{-7} or less, but greater than of the order of 1×10^{-9}.

(iv) Extremely Improbable Failure Conditions are those having an Average Probability Per Flight Hour of the order of 1x 10^{-9} or less.

8. *SAFETY OBJECTIVE.*

a. The objective of CS 25.1309 is to ensure an acceptable safety level for equipment and systems as installed on the aeroplane. A logical and acceptable inverse relationship must exist between the Average Probability per Flight Hour and the severity of Failure Condition effects, as shown in Figure 1, such that:

(1) Failure Conditions with No Safety Effect have no probability requirement.

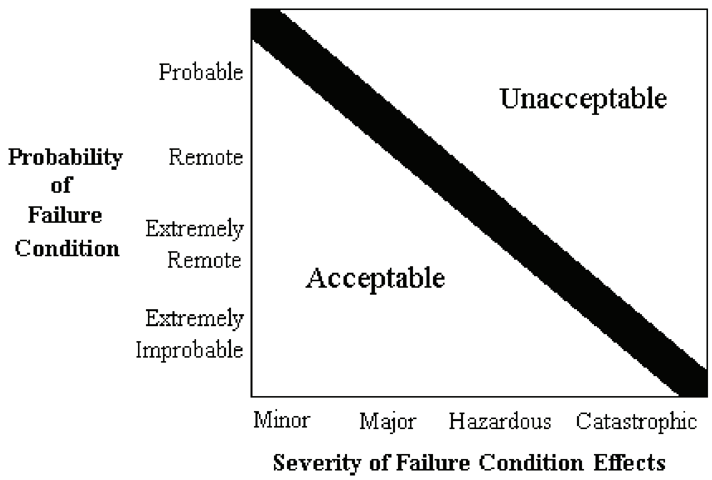
(2) Minor Failure Conditions may be Probable.

(3) Major Failure Conditions must be no more frequent than Remote.

(4) Hazardous Failure Conditions must be no more frequent than Extremely Remote.

(5) Catastrophic Failure Conditions must be Extremely Improbable.

Figure 1: Relationship between Probability and Severity of Failure Condition Effects



b. The safety objectives associated with Failure Conditions are described in Figure 2.

Figure 2: Relationship Between Probability and Severity of Failure Condition

Effect on Aeroplane	No effect on operational capabilities or safety	Slight reduction in functional capabilities or safety margins	Significant reduction in functional capabilities or safety margins	Large reduction in functional capabilities or safety margins	Normally with hull loss
Effect on Occupants excluding Flight Crew	Inconvenience	Physical discomfort	Physical distress, possibly including injuries	Serious or fatal injury to a small number of passengers or cabin crew	Multiple fatalities
Effect on Flight Crew	No effect on flight crew	Slight increase in workload	Physical discomfort or a significant increase in workload	Physical distress or excessive workload impairs ability to perform tasks	Fatalities or incapacitation
Allowable Qualitative Probability	No Probability Requirement	<---Probable---- >	<----Remote---- >	Extremely <------------------> Remote	Extremely Improbable
Allowable Quantitative Probability: Average Probability per Flight Hour on the Order of:	No Probability Requirement	<------------------> $<10^{-3}$ Note 1	<------------------> $<10^{-5}$	<------------------> $<10^{-7}$	$<10^{-9}$
Classification of Failure Conditions	No Safety Effect	<-----Minor------ >	<-----Major------ >	<--Hazardous-->	Catastrophic
Note 1: A numerical probability range is provided here as a reference. The applicant is not required to perform a quantitative analysis, nor substantiate by such an analysis, that this numerical criteria has been met for Minor Failure Conditions. Current transport category aeroplane products are regarded as meeting this standard simply by using current commonly-accepted industry practice.					

c. The safety objectives associated with Catastrophic Failure Conditions, may be satisfied by demonstrating that:

(1) No single failure will result in a Catastrophic Failure Condition; and

(2) Each Catastrophic Failure Condition is Extremely Improbable.

d. Exceptionally, for paragraph 8c(2) above of this AMC, if it is not technologically or economically practicable to meet the numerical criteria for a Catastrophic Failure Condition, the safety objective may be met by accomplishing all of the following:

(1) Utilising well proven methods for the design and construction of the system; and

(2) Determining the Average Probability per Flight Hour of each Failure Condition using structured methods, such as Fault Tree Analysis, Markov Analysis, or Dependency Diagrams; and

(3) Demonstrating that the sum of the Average Probabilities per Flight Hour of all Catastrophic Failure Conditions caused by systems is of the order of 10^{-7} or less (See paragraph 6a for background).

9. *COMPLIANCE WITH CS 25.1309.*

This paragraph describes specific means of compliance for CS 25.1309. The applicant should obtain early concurrence of the certification authority on the choice of an acceptable means of compliance.

a. *Compliance with CS 25.1309(a).*

(1) Equipment covered by 25.1309(a)(1) must be shown to function properly when installed. The aeroplane operating and environmental conditions over which proper functioning of the equipment, systems, and installation is required to be considered includes the full normal operating envelope of the aeroplane as defined by the Aeroplane Flight Manual together with any modification to that envelope associated with abnormal or emergency procedures. Other external environmental conditions such as atmospheric turbulence, HIRF, lightning, and precipitation, which the aeroplane is reasonably expected to encounter, should also be considered. The severity of the external environmental conditions which should be considered are limited to those established by certification standards and precedence.

(2) In addition to the external operating and environmental conditions, the effect of the environment within the aeroplane should be considered. These effects should include vibration and acceleration loads, variations in fluid pressure and electrical power, fluid or vapour contamination, due either to the normal environment or accidental leaks or spillage and handling by personnel. Document referenced in paragraph 3b(1) defines a series of standard environmental test conditions and procedures, which may be used to support compliance. Equipment covered by (CS) Technical Standard Orders containing environmental test procedures or equipment qualified to other environmental test standards can be used to support compliance. The conditions under which the installed equipment will be operated should be equal to or less severe than the environment for which the equipment is qualified.

(3) The required substantiation of the proper functioning of equipment, systems, and installations under the operating and environmental conditions approved for the aeroplane may be shown by test and/or analysis or reference to comparable service experience on other aeroplanes. It must be shown that the comparable service experience is valid for the proposed installation. For the equipment systems and installations covered by CS 25.1309(a)(1), the compliance demonstration should also confirm that the normal functioning of such equipment, systems, and installations does not interfere with the proper functioning of other equipment, systems, or installations covered by CS 25.1309(a)(1).

(4) The equipment, systems, and installations covered by CS 25.1309(a)(2) are typically those associated with amenities for passengers such as passenger entertainment systems, in-flight telephones, etc., whose failure or improper functioning in itself should not affect the safety of the aeroplane. Operational and environmental qualification requirements for those equipment, systems, and installations are reduced to the tests that are necessary to show that their normal or abnormal functioning does not adversely affect the proper functioning of the equipment, systems, or installations covered by CS 25.1309(a)(1) and does not otherwise adversely influence the safety of the aeroplane or its occupants. Examples of adverse influences are: fire, explosion, exposing passengers to high voltages, etc.

b. *Compliance with CS 25.1309(b).*

Paragraph 25.1309(b) requires that the aeroplane systems and associated components, considered separately and in relation to other systems must be designed so that any Catastrophic Failure Condition is Extremely Improbable and does not result from a single failure. It also requires that any Hazardous

Failure Condition is extremely Remote, and that any Major Failure Condition is Remote. An analysis should always consider the application of the Fail-Safe design concept described in paragraph 6b, and give special attention to ensuring the effective use of design techniques that would prevent single failures or other events from damaging or otherwise adversely affecting more than one redundant system channel or more than one system performing operationally similar functions.

(1) *General*. Compliance with the requirements of CS 25.1309(b) should be shown by analysis and, where necessary, by appropriate ground, flight, or simulator tests. Failure Conditions should be identified and their effects assessed. The maximum allowable probabilityof the occurrence of each Failure Condition is determined from the Failure Condition's effects, and when assessing the probabilities of Failure Conditions appropriate analysis considerations should be accounted for. Any analysis must consider:

(i) Possible Failure Conditions and their causes, modes of failure, and damage from sources external to the system.

(ii) The possibility of multiple failures and undetected failures.

(iii) The possibility of requirement, design and implementation errors.

(iv) The effect of reasonably anticipated crew errors after the occurrence of a failure or Failure Condition.

(v) The effect of reasonably anticipated errors when performing maintenance actions.

(vi) The crew alerting cues, corrective action required, and the capability of detecting faults.

(vii) The resulting effects on the aeroplane and occupants, considering the stage of flight and operating and environmental conditions.

(2) *Planning.* This AMC provides guidance on methods of accomplishing the safety objective. The detailed methodology needed to achieve this safety objective will depend on many factors, in particular the degree of systems complexity and integration. For aeroplanes containing many complex or integrated systems, it is likely that a plan will need to be developed to describe the intended process. This plan should include consideration of the following aspects:

(i) Functional and physical interrelationships of systems.

(ii) Determination of detailed means of compliance, which may include the use of Development Assurance techniques.

(iii) Means for establishing the accomplishment of the plan.

(3) *Availability of Industry Standards and Guidance Materials.* There are a variety of acceptable techniques currently being used in industry, which may or may not be reflected in Documents referenced in paragraphs 3b(3) and 3b(4). This AMC is not intended to compel the use of these documents during the definition of the particular method of satisfying the objectives of this AMC. However, these documents do contain material and methods of performing the System Safety Assessment. These methods, when correctly applied, are recognised by the Agency as valid for showing compliance with CS 25.1309(b). In addition, Document referenced in paragraph 3b(4) contains tutorial information on applying specific engineering methods (e.g. Markov Analysis, Fault Tree Analysis) that may be utilised in whole or in part.

(4) *Acceptable Application of Development Assurance Methods.* Paragraph 9b(1)(iii) above requires that any analysis necessary to show compliance with CS 25.1309(b) must consider the possibility of requirement, design, and implementation errors. Errors made during the design and development of systems have traditionally been detected and corrected by exhaustive tests conducted on the system and its components, by direct inspection, and by other direct verification methods capable of completely characterising the performance of the system. These direct techniques may still be appropriate for simple systems which perform a limited number of functions and which are not highly integrated with other aeroplane systems. For more complex or integrated systems, exhaustive testing may either be impossible because all of the system states cannot be determined or impractical because of the number of tests which must be accomplished. For these types of systems, compliance maybe shown by the use of Development Assurance. The level of Development Assurance should be determined by the severity of potential effects on the aeroplane in case of system malfunctions or loss of functions.

QUESTIONS

1. What is the purpose of the wing main spar?

   a. To withstand bending and torsional loads.
   b. To withstand compressive and torsional loads.
   c. To withstand compressive and shear loads.
   d. To withstand bending and shear loads.

2. What is the purpose of wing ribs?

   a. To withstand the fatigue stresses.
   b. To shape the wing and support the skin.
   c. To house the fuel and the landing gear.
   d. To provide local support for the skin.

3. What is the purpose of stringers?

   a. To absorb the torsional and compressive stresses.
   b. To produce stress risers and support the fatigue metres.
   c. To prevent buckling and bending by supporting and stiffening the skin.
   d. To support the primary control surfaces.

4. The airframe structure must remain substantially intact after experiencing:

   a. the design ultimate load times a 1.5 safety factor.
   b. the design limit load plus the design ultimate load.
   c. three times the safety factor.
   d. the design limit load times a 1.5 factor of safety.

5. In the construction of airframes the primary purpose of frames or formers is to:

   a. provide a means of attaching the stringers and skin panels.
   b. oppose hoop stresses and provide shape and form to the fuselage.
   c. form the entrance door posts.
   d. support the wings.

6. How can wing bending moments be reduced in flight?

   a. By using aileron 'up-float' and keeping the centre section fuel tanks full for as long as possible.
   b. By using aileron 'up-float' and using the fuel in the wings last.
   c. By having tail-mounted engines and using aileron 'down-float'.
   d. By having wing-mounted engines and using the wing fuel first.

7. Regarding a safe life structure:

   1. will only fail after a known number of operations or hours of use.
   2. should not fail until a predicted number of fatigue cycles has been achieved.
   3. has a programmed inspection cycle to detect and rectify faults.
   4. is changed before its predicted life is reached.

   a. 1 and 2 apply.
   b. 1 and 3 apply.
   c. 2, 3 and 4 apply.
   d. all of the above apply.

8. A fail safe structure:

   1. has a programmed inspection cycle to detect and rectify faults.
   2. is changed before its predicted life is reached.
   3. has redundant strength which will tolerate a certain amount of structural damage.
   4. is secondary structure of no structural significance.

   a. 1 and 2 apply.
   b. 1 and 3 apply.
   c. 3 and 4 apply.
   d. all of the above apply.

9. The skin of a modern pressurised aircraft:

   a. is made up of light alloy steel sheets built on the monocoque principle.
   b. houses the crew and the payload.
   c. provides aerodynamic lift and prevents corrosion by keeping out adverse weather.
   d. is primary load bearing structure carrying much of the structural loads.

10. The primary purpose of the fuselage is to:

   a. support the wings.
   b. house the crew and payload.
   c. keep out adverse weather.
   d. provide access to the cockpit.

11. Station numbers (Stn) and water lines (WL) are:

   a. a means of locating airframe structure and components.
   b. passenger seat locations.
   c. runway markings for guiding the aircraft to the terminal.
   d. compass alignment markings.

12. Flight deck windows are constructed from:

   a. an amalgam of strengthened glass and vinyl with rubber pressure seals.
   b. strengthened glass with shock absorbing clear vinyl interlayers and rubber pressure seals.
   c. strengthened clear vinyl with an electrical conducting coat for de-icing and rubber pressure seals.
   d. strengthened glass with rubber seals.

13. A cantilever wing:

    a. is externally braced with either struts and/or bracing wires.
    b. is supported at one end only with no external bracing.
    c. has both an upper an lower airfoil section.
    d. folds at the root section to ease storage in confined spaces.

14. A torsion box:

    a. is a structure within the fuselage to withstand compression, bending and twisting loads.
    b. is a structure formed between the wing spars, skin and ribs to resist bending and twisting loads.
    c. is a structure within the wing for housing the fuel tanks, flight controls and landing gear.
    d. is a structure designed to reduce the weight.

15. A lightening hole in a rib:

    a. prevents lightning strikes damaging the fuselage.
    b. provides a means of passing cables and controls through a pressure bulkhead.
    c. collects and disposes of electrical charges.
    d. lightens and stiffens the structure.

16. Control surface flutter:

    a. provides additional lift for take off and landing in the event of engine failure.
    b. occurs at high angles of attack.
    c. is a destructive vibration that must be damped out within the flight envelope.
    d. is a means of predicting the critical safe life of the wing.

17. Control surface flutter is minimised by:

    a. reducing the moment of the critical engine.
    b. aerodynamic balance of the control cables.
    c. changing the wings before they reach their critical life.
    d. mass balance of the control surface.

18. A damage tolerant structure:

    a. has degree of structural strength redundancy spread over a large area.
    b. is light, non load bearing structure, damage to which will not adversely affect the aircraft.
    c. is replaced when it reaches its predicted life.
    d. need not be repaired until the aircraft undergoes deep maintenance.

19. Aircraft structures consists mainly of:

a. light alloy steel sheets with copper rivets and titanium or steel materials at points requiring high strength.
b. magnesium alloy sheets with aluminium rivets and titanium or steel at points requiring high strength.
c. aluminium alloy sheets and rivets with titanium or steel materials at points requiring high strength.
d. aluminium sheets and rivets with titanium or steel materials at points requiring high strength.

20. The Maximum Zero Fuel Mass (MZFM) of an aircraft is:

a. the maximum permissible take off mass of the aircraft.
b. the maximum permissible mass of an aircraft with no useable fuel.
c. the maximum permissible mass of an aircraft with zero payload.
d. the maximum permissible landing mass.

ANSWERS

1. A
2. B
3. C
4. D
5. B
6. B
7. C
8. B
9. D
10. B
11. A
12. B
13. B
14. B
15. C
16. D
17. D
18. A
19. C
20. B

CHAPTER TWO

BASIC HYDRAULICS

Contents

INTRODUCTION

Hydraulics is the science relating to the behaviour of liquids under various conditions and in aircraft the hydraulic system provides a means of operating large and remote components that it would not be possible to operate satisfactorily by other means. Aircraft systems provide a means of power transmission through the medium of hydraulics i.e. transmission of power through an incompressible fluid via pipelines and actuators. Hydraulic systems provide the power for the operation of components such as landing gear, flaps, flight controls, wheel brakes, windshield wipers and other systems that require high power, accurate control and rapid response rates.

PASCAL'S LAW

Pascal was a 17th century mathematician who stated that:

"If a force is applied to a liquid in a confined space, then this force will be felt equally in all directions".

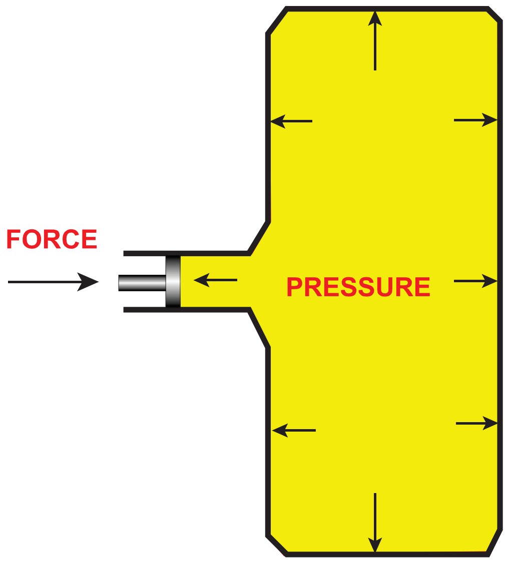


Figure 2.1:

The force employed when a hydraulic system is operated is caused by "**Pressure**".

This force is not delivered by the hydraulic pump. Hydraulic pressure is created only when an attempt is made to compress fluids, therefore, if a flow of oil is pumped through an open-ended tube there will be no pressure, but, if the end of the tube is blocked and the oil cannot escape, pressure will at once build up.

Without some form of restriction there can be no pressure.

PRESSURE	=	FORCE PER UNIT AREA	=	$\frac{\text{FORCE}}{\text{AREA}}$
FORCE	=	TOTAL LOAD AVAILABLE		
FORCE	=	PRESSURE x AREA		

A pump is required to deliver a flow of fluid into the system and some form of restriction is required to obtain pressure. In hydraulic systems this restriction is provided by movable pistons which travel backwards and forwards in cylinders, these assemblies being known as hydraulic jacks or actuators. As the power required for operating different services, such as: undercarriage, flaps, spoilers, nosewheel steering, Power Flying Control units etc. varies according to their size and loading, a "gearing" effect must be provided and this is easily achieved by varying the size of the actuator pistons, while the hydraulic pressure remains constant.

BRAMAH'S PRESS

This principle was discovered by Joseph Bramah (1749 - 1814) who invented a hydraulic press and, in doing so, observed two facts:

- the **smaller** the area under **load**, the greater the pressure generated.
- the **larger** the area under **pressure**, the greater will be the load available.

Refer to Figure 2.2. If a force of 1000 N is applied to piston "A", whose area is 0.002m^2 it will produce a pressure of 500 kPa in the fluid.

If piston "B" has an area of 0.004 m^2 it will support a load of 0.004 m2 x 500 kPa = 2000 N (i.e. F = P x A)

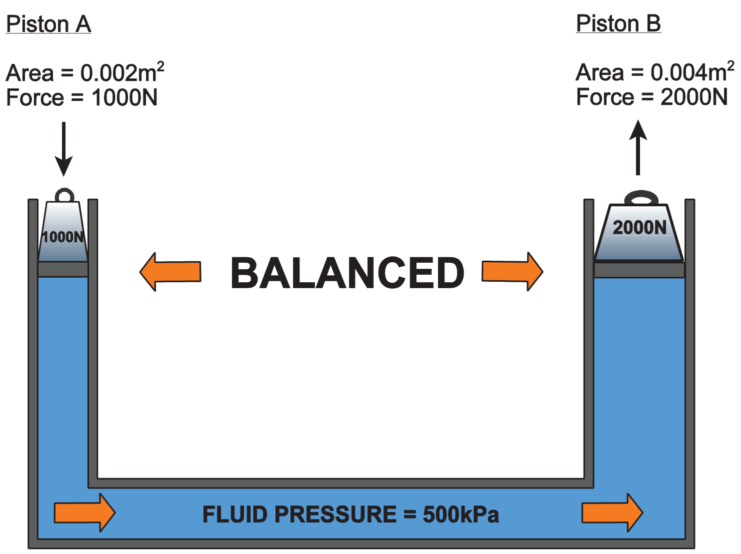


Figure 2.2: The Bramah press.

The **WORK DONE** by a machine = **FORCE** applied x **DISTANCE** moved

Then if piston "A" is moved through a distance of 0.6m, and since work done in the system must be constant,(assuming no frictional losses), then:

FORCE x DISTANCE (piston A) = FORCE x DISTANCE (piston B)

1000 x 0.6 = 2000 x the distance moved by piston 'B'

so the **distance** moved by piston 'B' = 0.3m

(1000 x 0.6 = 600) = (2000 x 0.3 = 600 Joules)

Thus, for a given fluid pressure the force produced can be varied by adjusting the piston area and the resultant linear motion will vary in inverse proportion to the area.

This would constitute a **Passive Hydraulic System** where a force is applied to a piston (piston A) only when it is desired to move the load (piston B). thereby only generating pressure when it is required rather than generating and maintaining pressure all of the time and only using it when something needs to be moved.

A good example of this would be a light aircraft braking system which has a master cylinder to generate the pressure when the brake pedal is pressed, and a slave cylinder to 'do the work' of moving a piston and applying the brakes. See *Figure 2.3.*

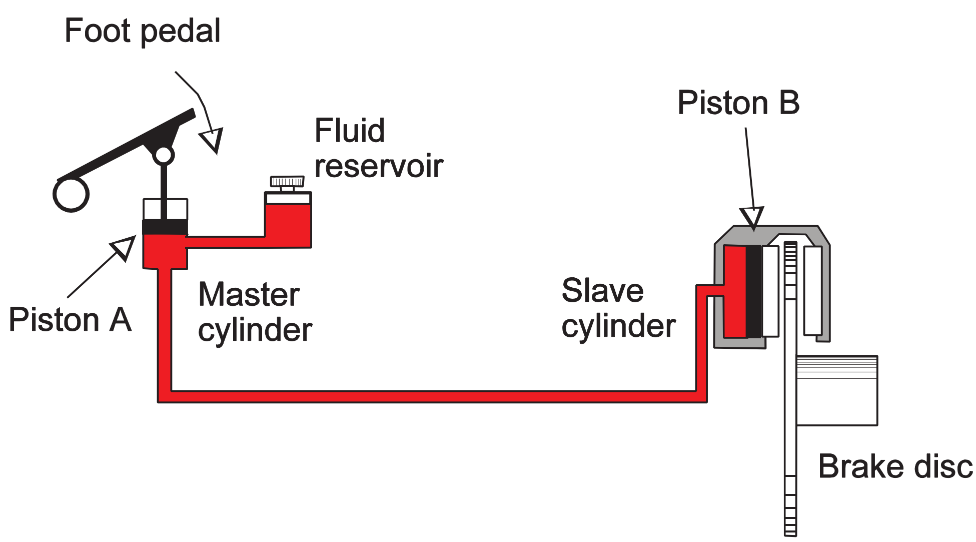


Figure 2.3: A typical light aircraft braking system (only one wheel shown).

HYDRAULIC FLUIDS AND PIPELINES

The efficiency of a hydraulic system is governed by the resistance to motion encountered by the fluid and, for all practical purposes, hydraulic fluids are considered to be incompressible except at high pressures, i.e. 27.6 MN/m^2 and above (276.7 bar or 4,300 pounds/square inch).

If a container with a certain volume of liquid has a pressure of 34.6 MN/m^2 (346 bar) applied it can be seen that its reduction in volume is small as against a similar air container.

- Liquid is compressed by only 1% of its original volume, and 99% remains.
- Air is compressed by 99% of its original volume and 1% (1/300) remains.

It should be noted that the pressure in both fluids will be felt equally in all directions.

In practice a certain amount of force is expended in overcoming static resistance, that is friction between:

- pistons and cylinders
- piston rods and bearings/seals or glands
- fluid and the pipe walls

Large bore pipes and frictionless pistons would allow nearly 100% of the force to be utilised but would incur large weight and cost penalties.

Friction between pistons and cylinders, piston rods and bearings cannot be completely eliminated, it can only be lessened by good design and workmanship. The friction between the walls of the pipes and the fluid depends upon:

- velocity of the fluid in the pipes.
- length, bore and the internal finish of the pipes.
- number of bends.
- viscosity of the oil.

The variation of the above factors governs the amount of friction and therefore resistance and, as it is necessary to use glands, seals and backing rings etc to prevent leakage, the most practical way to counteract this loss in efficiency is to use the correct fluid.

SEALS

Seals perform a very important function in a hydraulic system, in preventing leakage of fluid. Static seals, gaskets and packing are used in many locations, and these effect a seal by being squeezed between two surfaces. Dynamic seals, fitted between sliding surfaces, may be of many different shapes, depending on their use and on the fluid pressures involved. "U" and "V" ring seals are effective in one direction only, but "O" rings and square section seals are often used where pressure is applied in either direction.

Dynamic seals require lubrication to remain effective, and wetting of the bearing surface, or a slight seepage from the seals, is normally acceptable. Where high pressures are used, an "O" ring is normally fitted with a stiff backing ring, which retains the shape of the seal and prevents it from being squeezed between the two moving surfaces.

Seals are made in a variety of materials, depending on the type of fluid with which they are to be used; if a seal of an incorrect material is used in a system, the sealing quality will be seriously degraded, and this may lead to failure of the component. Seals are easily damaged by grit, and a wiper ring is often installed on actuators to prevent any grit that may be deposited on the piston rod from contaminating the seals.

The choice of an aircraft's hydraulic fluid is influenced by the materials used for glands, seals, rings, seats etc There are two in common use.

- **D.T.D. 585** - a refined mineral based oil (Petroleum). Colour - red. Used with synthetic rubber seals (Neoprene). Note: DTD 585 is an obsolete specification.
  DEF STAN 91-48 replaces D.T.D 585 as the British specification.
  Other specifications are H515 NATO, OM15 Joint Service, MIL-H-5606F U.S., all for super clean grades.

- **SKYDROL** - a phosphate ester based oil. Colour - Type 500A purple, Type 700 green. Used with synthetic rubber seals (Butyl). Is fire resistant and less prone to cavitation because of its higher boiling point.

Hydraulic fluids should be handled with care as they have a deleterious effect on skin, paintwork, sealing compounds, rubber materials, perspex etc., and they should never be mixed.

It is of major importance that only the specified hydraulic oil or its approved alternative is used in a hydraulic system. If the incorrect fluid is added to a system breakdown of the seals is likely causing fluid leakage, both internally within components and externally from the actuators. The colouring of the fluids **assists** in their identification and also assists in finding hydraulic leaks but the specification can only be confirmed by:

- consulting the aircraft manual

- only using fluid from sealed containers or the appropriate replenishment rig.

The ideal properties of a hydraulic fluid are:

- be relatively incompressible, i.e. up to 27.6 MN/m2 (276 Bar), so ensuring instantaneous operation.
- have good lubricating properties for metal and rubber.
- have good viscosity with a high boiling point (helps prevent vapour locking and cavitation) and low freezing point e.g. temperature range +80°C to -70°C.
- have a flash point above 100°C.
- be non-flammable.
- be chemically inert.
- be resistant to evaporation.
- have freedom from sludging and foaming.
- have good storage properties.
- be non-corrosive.
- be reasonably priced and readily available.

BASIC SYSTEM

As shown in *Figure 2.4* there are six main components common to all hydraulic systems:

- a reservoir of oil, which delivers oil to the pump and receives oil from the actuators.
- a pump, either hand, engine or electrically driven.
- a selector or control valve, enabling the operator to select the direction of the flow of fluid to the required service and providing a return path for the oil to the reservoir.
- a jack, or set of jacks or actuators, to actuate the component.
- a filter, to keep the fluid clean.
- a relief valve, as a safety device to relieve excess pressure.

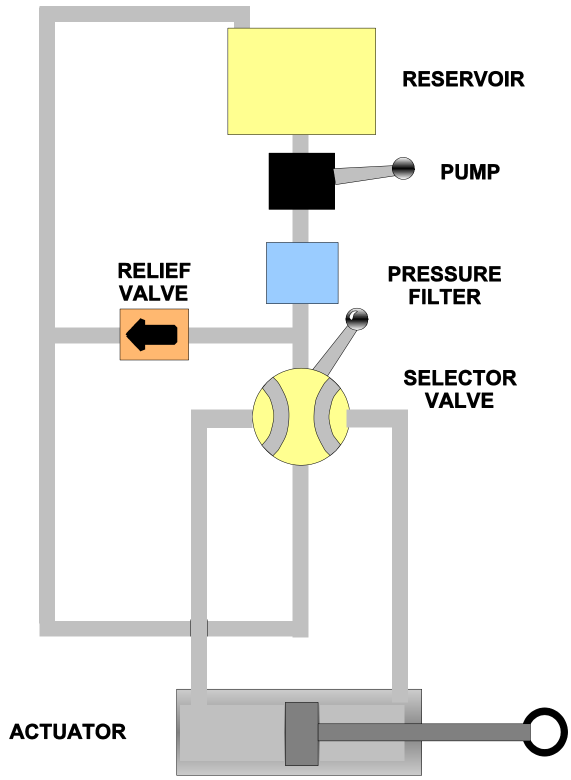


Figure 2.4: Basic hydraulic system.

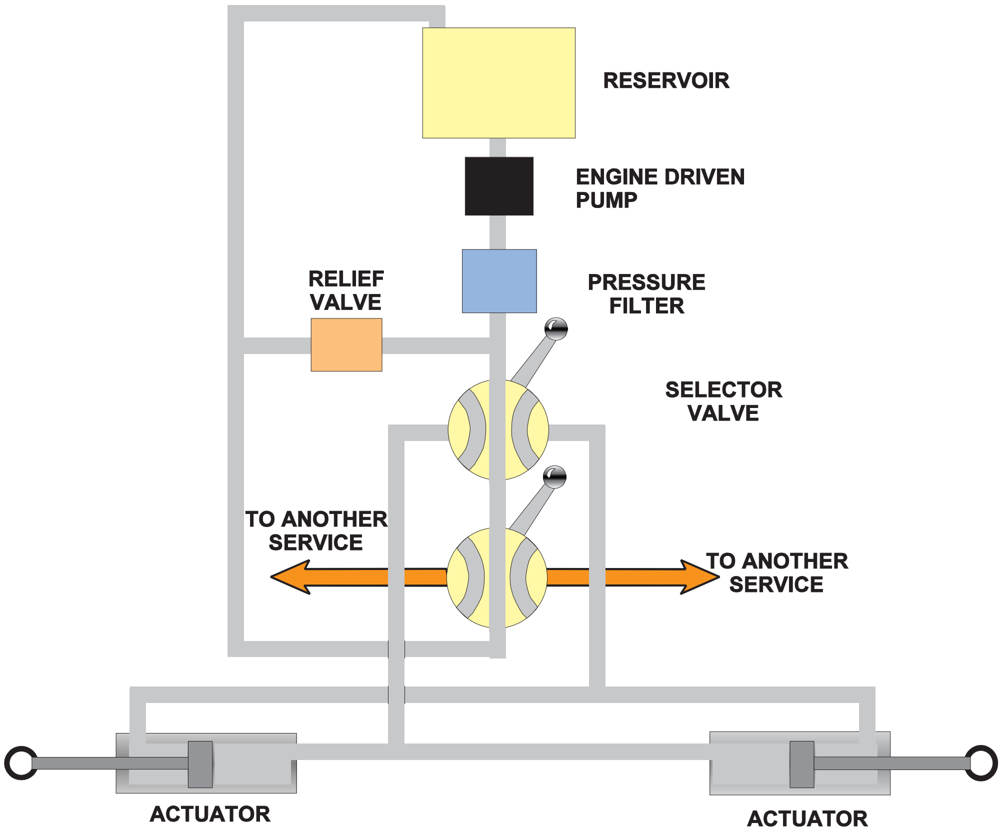


Figure 2.5: Open centre system.

OPEN-CENTRE SYSTEM

The main advantage of this system is that it is simple, the main disadvantage is that only one service can be operated at a time. As shown in *Figure. 2.5*, fluid is passed directly to the reservoir when no services are being operated, this allows the engine driven pump to run in an 'off loaded' condition as little pressure is generated but there is still a flow of oil through the pump to cool and lubricate it.

On selection of a user system the fluid is directed to the actuator, which will move. When the actuator reaches the end of its travel pressure will build up to a value when the selector is returned to neutral in order to off load the pump and allow alternative selections to be made. the relief valve will relieve excess pressure if the selector does not return to its neutral position.

This type of system is popular in many light aircraft which do not require a constant pressure to be maintained all the time as only items like landing gear and flaps will be powered for short periods of time each flight.

Light aircraft may alternatively be fitted with a self contained **power pack**, the pack may operate the landing gear retraction system, they are also be used on large aircraft as emergency systems or to operate freight doors, etc.

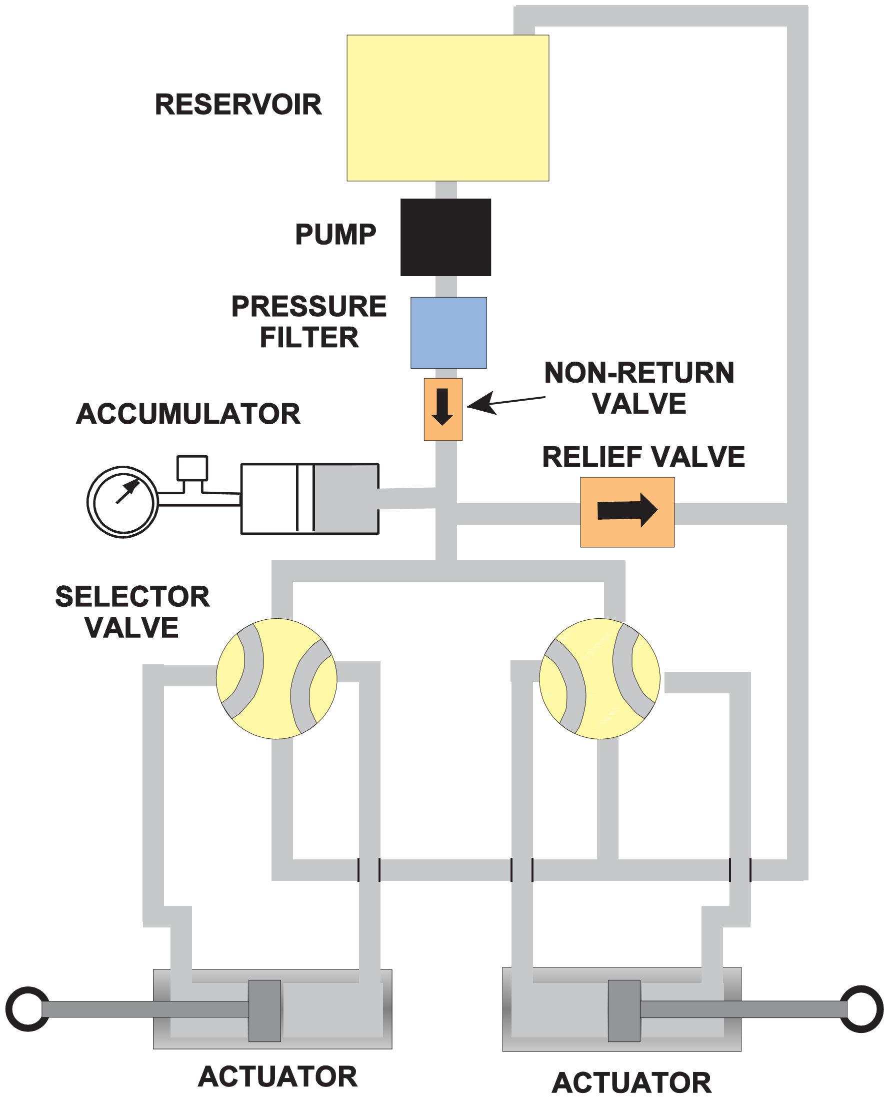


Figure 2.6: Closed system.

CLOSED SYSTEM

With this type of system, operating pressure is maintained in that part of the system which leads to the selector valves, and some method is used to prevent over-loading the pump. In systems which employ a fixed volume pump (constant delivery) an automatic cut-out valve is fitted, to divert pump output to the reservoir when pressure has built up to normal operating pressure. In other systems a variable volume pump (constant pressure) is used, delivery being reduced as pressure increases, whilst in some simple light aircraft systems, operation of an electrically-driven pump is controlled by a pressure-operated switch. A simple closed system is illustrated in *Figure 2.6*.

RESERVOIRS

A reservoir provides both storage space for the system fluid, and sufficient air space to allow for any variations of fluid in the system which may be caused by:

- jack (actuator) ram displacement, since the capacity of the jack is less when contracted than extended.
- thermal expansion, since the volume of oil increases with temperature.
- it provides a head of fluid for the pump.
- it compensates for small leaks.

Most reservoirs are pressurised, to provide a positive fluid pressure at the pump inlet, and to prevent air bubbles from forming in the fluid at high altitude. The fluid level will vary according to:

- the position of the jacks.
- whether the accumulators are charged.
- temperature.

Air pressure is normally supplied from the compressor section of the engine, or the cabin pressurisation system.

Refer to *Figure. 2.7*.
A reservoir also contains a relief valve, to prevent over pressurisation; connections for suction pipes to the pumps, and return pipes from the system; a contents transmitter unit and a filler cap; and, in some cases, a temperature sensing probe. In systems which are fitted with a hand pump, the main pumps draw fluid through a stack pipe in the reservoir. This ensures that, if fluid is lost from that part of the system supplying the main pumps, or supplied solely by the main pumps, a reserve of fluid for the hand pump would still be available.

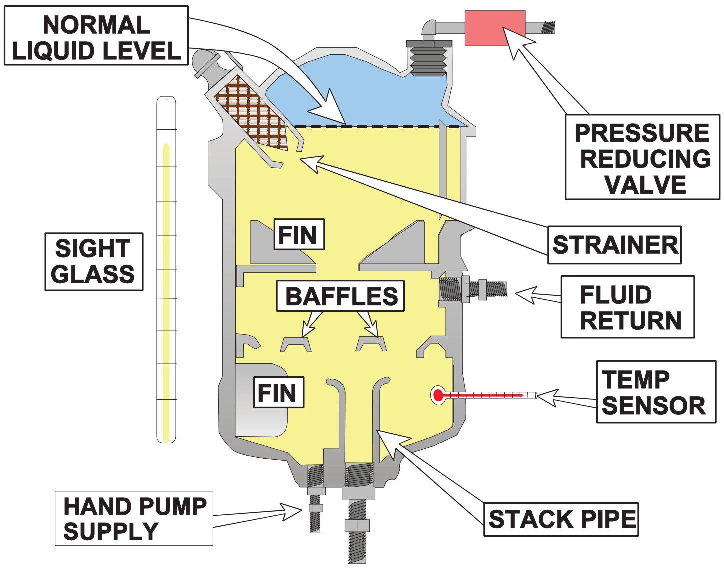


Figure 2.7: Resevoir.

FILTERS

Filters are fitted in both suction and pressure lines i.e. both sides of the pump and sometimes in the return line to the reservoir; a suction filter to protect the pump, and a pressure filter to ensure the cleanliness of fluid during use. They remove foreign particles from the fluid, and protect the seals and working surfaces in the components. In addition, individual components often have a small filter fitted to the inlet connection, and constant pressure pumps will have a "case drain filter" to help monitor pump condition.

Some filters are fitted with a device which senses the pressure differential across the filter element, and releases a visual indicator, in the form of a button or illuminates a warning lamp, when the pressure differential increases as a result of the filter becoming clogged. False indication of element clogging, as a result of high fluid viscosity at low temperature, is prevented by a bi-metal spring which inhibits indicator button movement at low temperatures.

Other filters are fitted with a relief valve, which allows unfiltered fluid to pass to the system when the element becomes clogged; this type of filter element must be changed at regular intervals. Paper filter elements are usually discarded when removed, but elements of wire cloth may usually be cleaned. Cleaning by an ultrasonic process is normally recommended, but if a new or cleaned element is not available when the element becomes due for check, the old element may be cleaned in trichloroethane as a temporary measure.

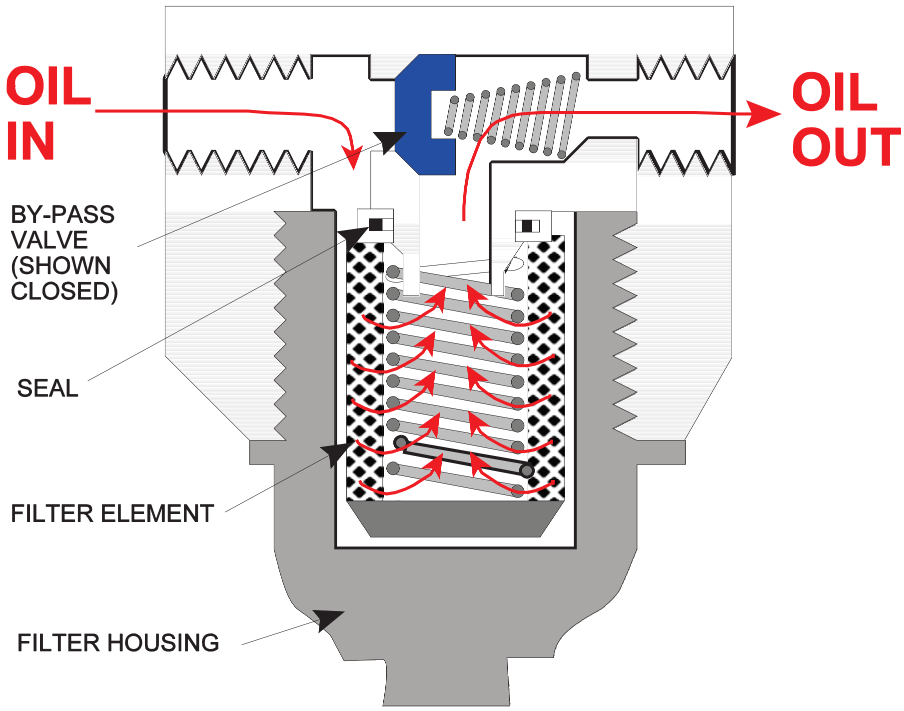


Figure 2.8: Filter.

PUMPS

Draw oil from the reservoir and deliver a supply of fluid to the system. Pumps may be:

- hand operated
- engine driven
- electric motor driven
- pneumatically (air turbine motor) (ATM)
- e)ram air turbine (HYDRAT or RAT)
- hydraulically (Hyd. motor driving a hyd. pump) Known as a Power Transfer Unit or PTU.

In most cases the ATM, RAT or PTU is used to provide an alternate supply as part of the redundancy provision for the safe operation of the aircraft.

Hand Pumps may be the only source of power in a small, light hydraulic system, but in larger aircraft are employed:

- to allow ground servicing to take place without the need for engine running.
- so that lines and joints can be pressure tested.
- so that cargo doors etc., can be operated without power.

The hand pump is usually a **double acting pump** (delivers oil on both strokes) in a very compact body. It incorporates non-return valves, and a relief valve which can be set to relieve at any required pressure, typically this is about 10% above normal system pressure. Refer to *Figure 2.9.*

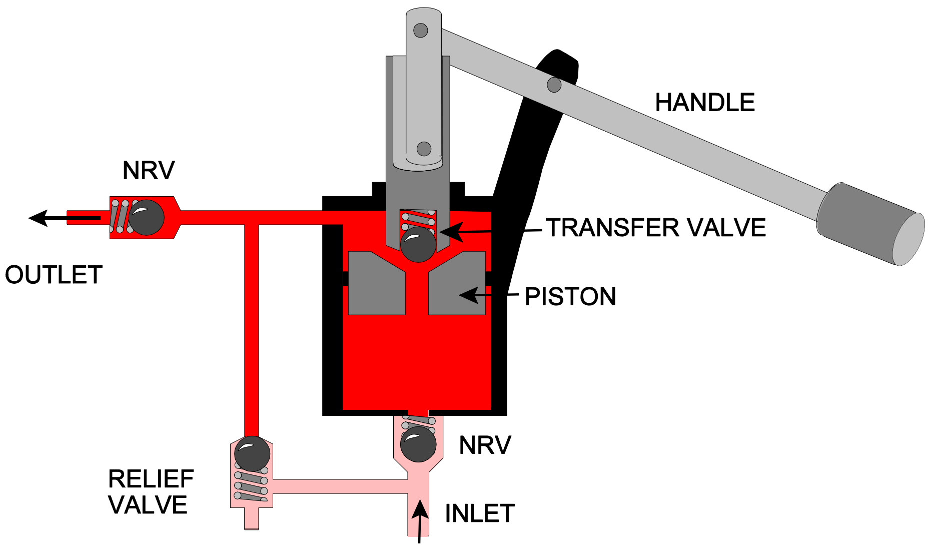


Figure 2.9: Hand pump.

Engine driven pumps (EDP) or electrically driven pumps may be classified as follows:

- **Constant Delivery (Fixed Volume) Type Pump**. This pump supplies fluid at a constant rate and therefore needs an automatic cut-out or relief valve to return the fluid to the reservoir when the jacks have reached the end of their travel, and when the system is not operating, it requires an idling circuit. The pump gives a large flow at small pressure and is usually a single or double stage gear pump.

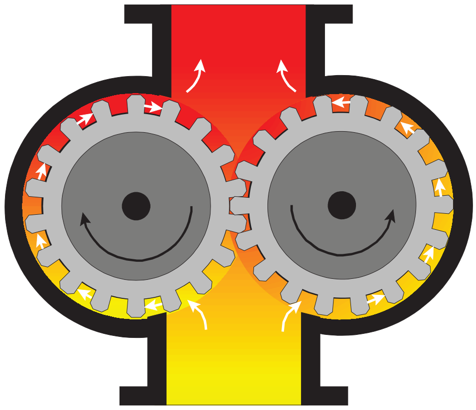


Figure 2.10: A spur gear type oil pump.

- **Constant Pressure (Variable Volume) Pump**. This pump supplies fluid at a variable volume and controls its own pressure, this type of pump is typically fitted in modern aircraft whose systems operate at 3,000-4,000 psi.. The cylinder block and drive shaft are co-axial and rotate carrying the pistons with them which slide up and down in the cylinder block. The pistons are attached to shoes which rotate against a stationary yoke, and the angle between the yoke and cylinder block is varied to increase or decrease piston stroke thus increasing or decreasing pump output.

Figures 2.11 and 2.12 shows the operation of the pump. When pressure in the system is low, as would be the case following selection of a service, spring pressure on the control piston turns the yoke to its maximum angle, and the pistons are at full stroke, delivering maximum output to the system. When the actuator has completed its stroke, pressure builds up until the control piston moves the yoke to the minimum stroke position; in this position a small flow through the pump is maintained, to lubricate the working parts, overcome internal leakage and dissipate heat. On some pumps a solenoid-operated depressurising valve (off load valve) is used to block delivery to the system, and to off- load the pump. System pressure is maintained and the pump output falls to 50 - 200 psi approx allowing oil to circulate, lubricating and cooling the pump. The solenoid is energised when the pump is off-loaded.

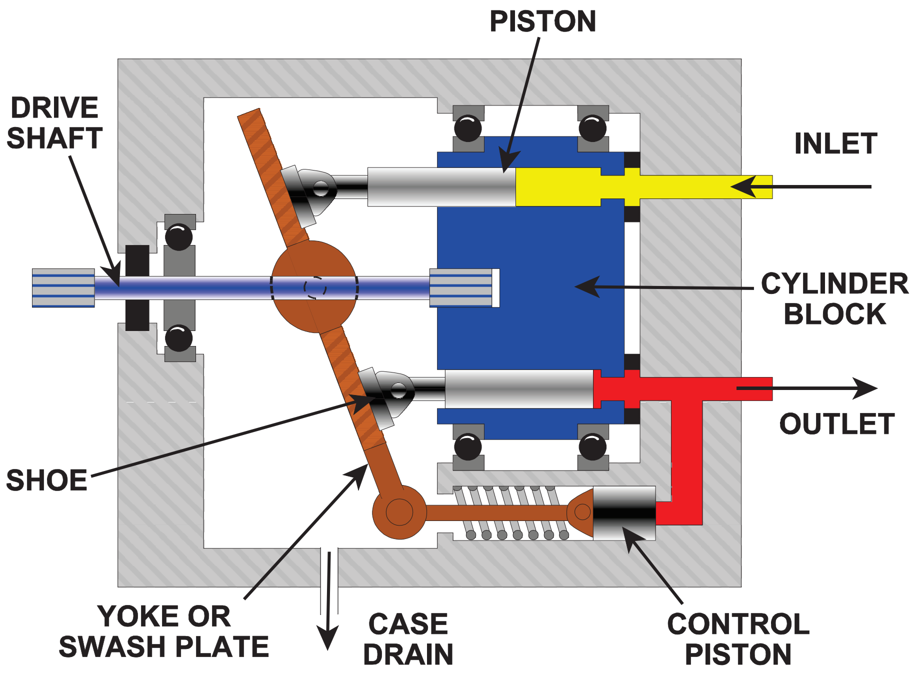


Figure 2.11: Constant pressure pump at maximum stroke.

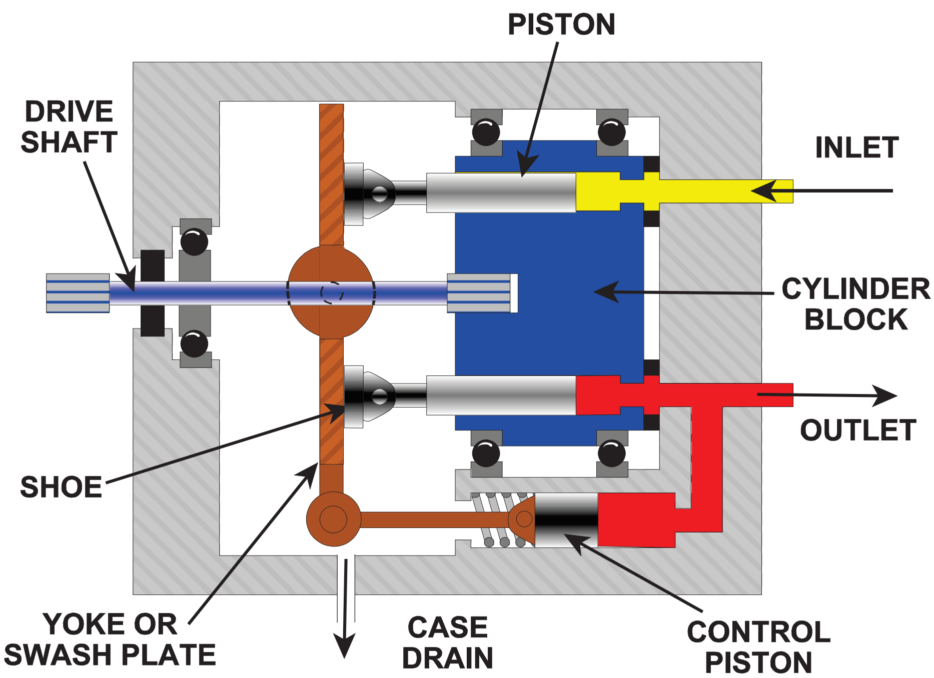


Figure 2.12: Constant pressure pump at minimum stroke.

AUTOMATIC CUT OUT VALVES (ACOV)

A automatic cut-out valve (ACOV) is fitted to a system employing a constant delivery (fixed volume) pump, to control system pressure and to provide the pump with an idling circuit when no services have been selected. An accumulator is fitted as part of the power system when a cut- out is fitted, since any slight leakage through components, or from the system, would result in frequent operation of the cut-out, and frequent loading and unloading of the pump. The accumulator maintains the system pressure when the pump is in its 'cut out' position.

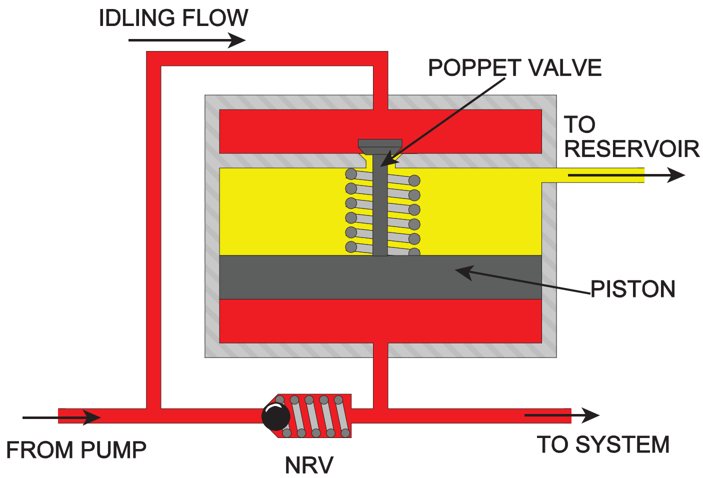


Figure 2.13: Automatic cut out valve (ACOV).

The automatic cut-out valve in its 'cut in ' position allows the delivery from the pump to pass through the non return valve and pressurise the system. When system pressure has been reached the piston is forced upwards by the pressure acting underneath it and opens the poppet valve allowing the output of the pump to pass to the reservoir at low pressure. The ACOV is now in its 'cut out' position allowing the pump to be off loaded but still maintaining a lubricating and cooling flow.

The NRV holds system pressure with the aid of the accumulator. If system pressure falls, due to a service being selected, the piston falls, closing the poppet valve and allowing the rising pump pressure to be delivered through the NRV to the system again (cut in).

The time between cut-out (off-load) and cut-in (on-load) (periodicy) of the ACO valve is a good indication of the condition of the system.

- External leakage will cause a reduction in the operating period with frequent loading and unloading of the pump; also with a loss of system fluid.

- Internal leakage, usually caused by a piston seal failure, will also cause frequent loading and unloading of the pumps; although with no fluid loss there could be an increase in fluid temperature.

HYDRAULIC ACCUMULATORS

An accumulator is fitted:

- to store hydraulic fluid under pressure.
- to dampen pressure fluctuations.
- to allow for thermal expansion.
- to provide an emergency supply of fluid to the system in the event of pump failure.
- to prolong the period between cut-out and cut-in time of the ACOV and so reduce the wear on the pump.
- provides the initial fluid when a selection is made and the pump is cut-out.

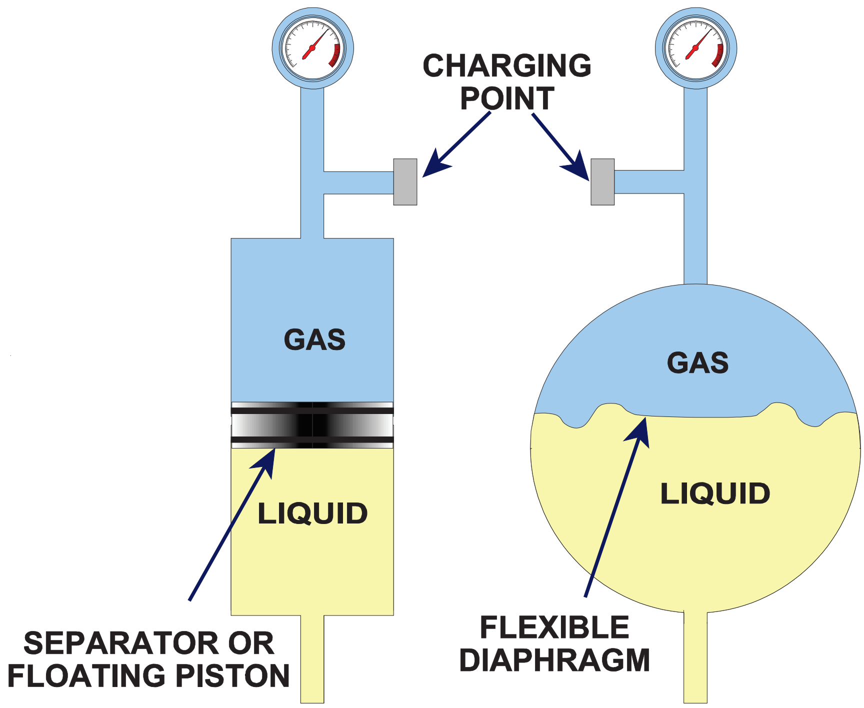


Figure 2.14: Hydraulic accumulators .

A non-return valve fitted upstream of an accumulator, prevents fluid from being discharged back to the reservoir. Two different types of accumulator are illustrated in *Figure. 2.14* but many other types are used. The accumulators shown are the most commonly used.

The gas side of the accumulator is charged to a predetermined pressure with air or nitrogen. As hydraulic pressure builds up in the system, the gas is compressed until fluid and gas pressures equalise at normal system pressure. At this point the pump commences to idle, and system pressure is maintained by the accumulator. If a service is selected, a supply of fluid under pressure is available until pressure drops sufficiently to bring the pump on line.

The initial gas charge of the accumulator is greater than the pressure required to operate any service, and the fluid volume is usually sufficiently large to operate any service once; except that brake accumulators permit a guaranteed number of brake applications, or the ability to stop the aircraft during a rejected take off.

The gas side of an accumulator is normally inflated through a charging valve, which may be attached directly to the accumulator, or installed on a remote ground servicing panel and connected to the accumulator by means of a pipeline. The charging valve usually takes the form of a non-return valve, which may be depressed by means of a plunger in order to relieve excessive pressure. To pre-charge or check, the gas pressure, the system pressure should be released (off-loaded). This will allow the gas pressure to move the floating piston to the bottom of the accumulator.

Incorrect pre-charge pressure of the main accumulator can cause the ACOV to cut in and out too frequently. This may cause rapid fluctuations of system pressure which can be felt and heard as 'hammering' in the system.

HYDRAULIC JACKS (ACTUATORS)

Purpose: To convert fluid flow into linear or rotary motion, see *Figure 2.15*.

Construction: They vary in size and construction depending on the operating loads, but all consist of:

> An outer cylinder in which slides a piston and seal assembly. Attached to the piston is a piston rod (or ram) which passes through a gland seal fitted into the end of the cylinder.

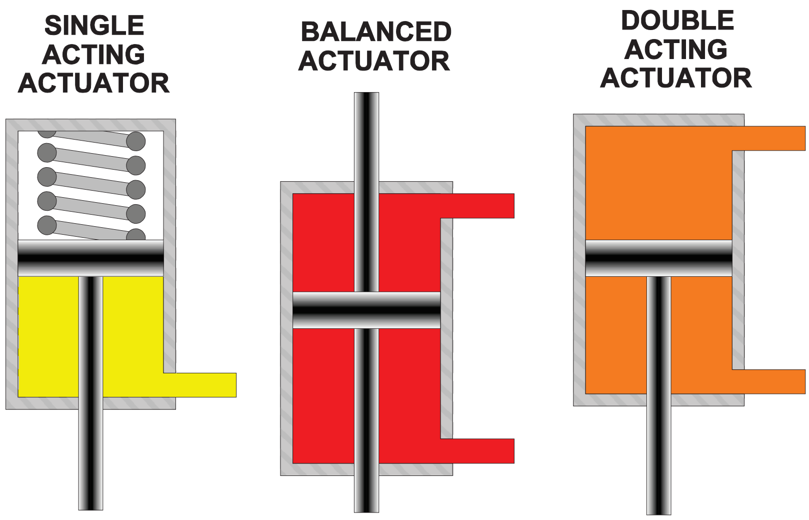


Figure 2.15: Hydraulic actuators.

Types of Jacks (Actuators). Three types of jack are used for different purposes in an aircraft system. Details of a particular jack should be obtained from the relevant maintenance manual.

Single Acting. Is normally used as a locking device, the lock being engaged by spring pressure and released by hydraulic pressure. A typical application is a landing gear up-lock.

Double Acting Unbalanced. Is used in most aircraft systems. Because of the presence of the piston rod the area of the top of the piston is greater than the area under it. Consequently, more force can be applied during extension of the piston rod. Therefore, the operation which offers the greater resistance is carried out in the direction in which the piston rod extends; for example, in raising the landing gear.

Differential Areas. It should be noted that the area of the upper side of the piston is greater than the area of the lower side by the amount equal to the area of the piston rod; therefore the force acting on it will be greater on the larger area.

Double Acting Balanced Jack. A balanced actuator, in which equal force can be applied to both sides of the piston, is often used in applications such as nose-wheel steering and flying control boost systems. Either one or both sides of the piston rod may be connected to a mechanism.

HYDRAULIC LOCK

When fluid is trapped between the piston of the jack and a non-return valve, a "hydraulic lock" is said to be formed. Because the fluid is incompressible and is unable to flow through the system, the piston cannot move even if a load is applied to it and is therefore locked in its position.

HYDRAULIC MOTORS

These are a form of rotary actuator, and are sometimes connected through gearing to operate a screw jack, or to drive generators or pumps. In some aircraft they are used for driving a hydraulic pump unit, thus enabling power to be transferred from one hydraulic system to another without transferring fluid. The construction of a hydraulic motor is generally similar to the construction of a variable volume multi-piston pump. The speed of a hydraulic motor is dependent on the flow rate of oil into it.

PRESSURE CONTROL

Maximum system pressure is often controlled by adjustment of the main engine-driven pump, but a number of other components are used to maintain or limit fluid pressures in various parts of a hydraulic system. (Typical system pressure; small aircraft 1500 psi, large aircraft 3000 psi).

Relief valves are used for:

- expansion (thermal relief).
- ultimate system protection (full flow relief).
- mechanical overload protection (flap relief).

All act as safety devices to relieve excess pressure in the system back to reservoir. In the case of a flap relief valve, this valve is fitted to prevent excessive air loads damaging the flaps or flap attachments by allowing the flaps to blow back to the 'UP' position if the air loads are excessive, i.e. flaps selected 'down' at too high an airspeed.

Thermal relief valves are usually fitted into lines isolated by NRV's or selectors and are adjusted to blow off at a pressure slightly higher than normal system pressure, typically 10%

In some systems a full flow relief valve or high pressure relief valve is fitted down stream of the pump to by-pass full pump output to the reservoir in the event of failure of the cut out valve or blockage elsewhere in the system.

Pressure Maintaining Valves. A pressure maintaining valve, or priority valve, is basically a relief valve which maintains the pressure in a primary service at a value suitable for operation of that service, regardless of secondary service requirements.

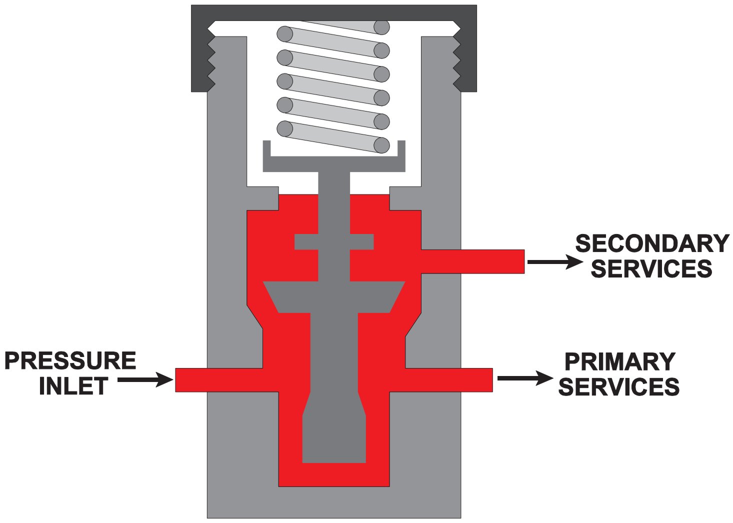


Figure 2.16: Pressure maintaining valves.

Pressure Reducing Valves. A pressure reducing valve is often used to reduce main system pressure to a value suitable for operation of a service such as the wheel brakes.

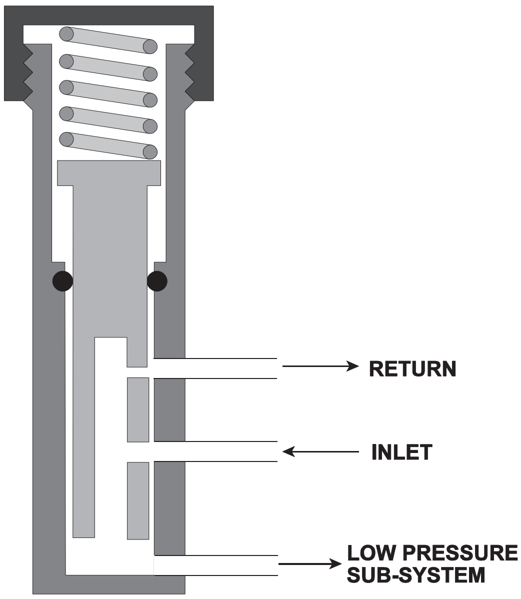


Figure 2.17: Pressure reducing valve.

Brake Control Valves. A brake control valve is essentially a variable pressure reducing valve, which controls pressure in the brake system according to the position of the pilot's brake pedals, the anti-skid system and auto-brake selections as required.

FLOW CONTROL

The components described in this paragraph are used to control the flow of fluid to the various services operated by the hydraulic system.

Non-return Valves. The most common device used to control the flow of fluid is the non-return valve, which permits full flow in one direction, but blocks flow in the opposite direction (in a similar way to a diode in electrical circuits). Simple ball-type non-return valves are included in *Figure. 2.18*. When a non-return valve is used as a separate component, the direction of flow is indicated by an arrow moulded on the casing, in order to prevent incorrect installation. This valve is also known as a One Way Check valve or Non Reversible valve.

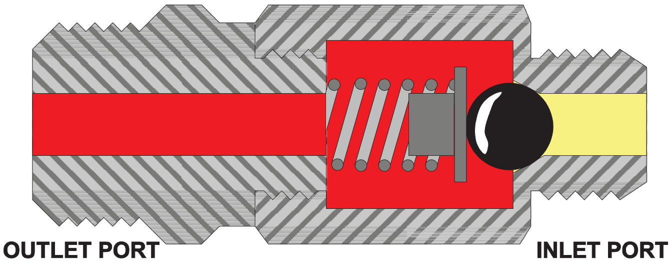


Figure 2.18: A simple non-return valve.

Restrictor Valves (or choke). A restrictor valve may be similar in construction to a non-return valve, but a restrictor valve is designed to permit limited flow in one direction and full flow in the other direction; the restriction is usually of fixed size, as shown in *Figure 2.19*. A restrictor valve is used in a number of locations in order to limit the speed of operation of an actuator in one direction only. It may, for instance, be used to slow down flap retraction or landing gear extension.

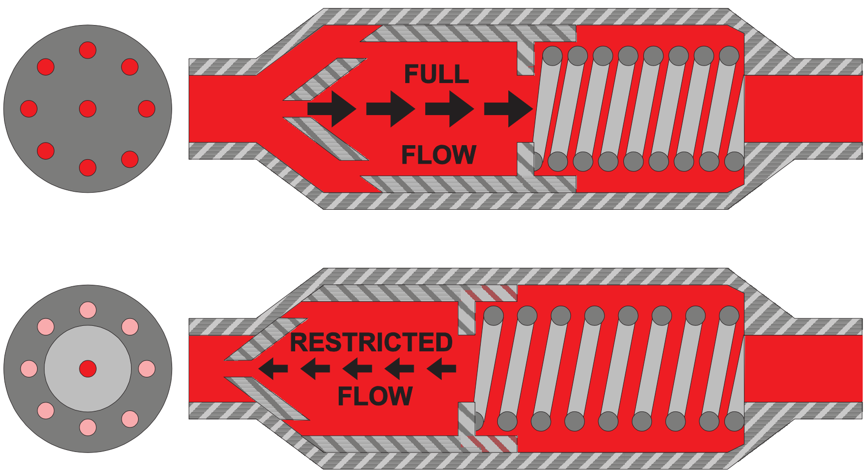


Figure 2.19: Restrictor valve.

Selectors. The purpose of a selector is to direct fluid to the appropriate side of an actuator, and to provide a return path for fluid displaced from the opposite side of that actuator.

Electrically-operated Selectors. It is sometimes convenient to locate a selector valve at a position remote from the crew compartment. To eliminate the need for extensive mechanical linkage the selector is operated electrically, it may be a motor driven or solenoid controlled selector.

Shuttle Valves. These are often used in landing gear and brake systems, to enable an alternate system to operate the same actuators as the normal system. During normal operation, free flow is provided from the normal system to the service and the alternate line is blocked. When normal system pressure is lost and the alternate system is selected, the shuttle valve moves **across** because of the pressure difference, blocking the normal line and allowing the alternate supply to operate the brakes. A typical shuttle valve is shown in *Figure. 2.20.*

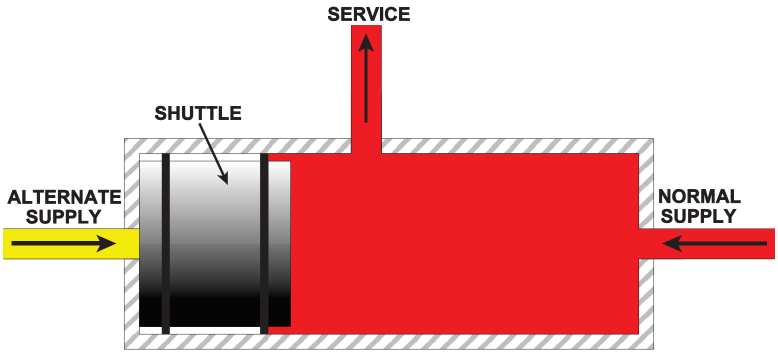


Figure 2.20: Shuttle valve.

Sequence Valves. Sequence valves are often fitted in a landing gear circuit to ensure correct operation of the landing gear doors and jacks. Refer to *Figure 2.21.*

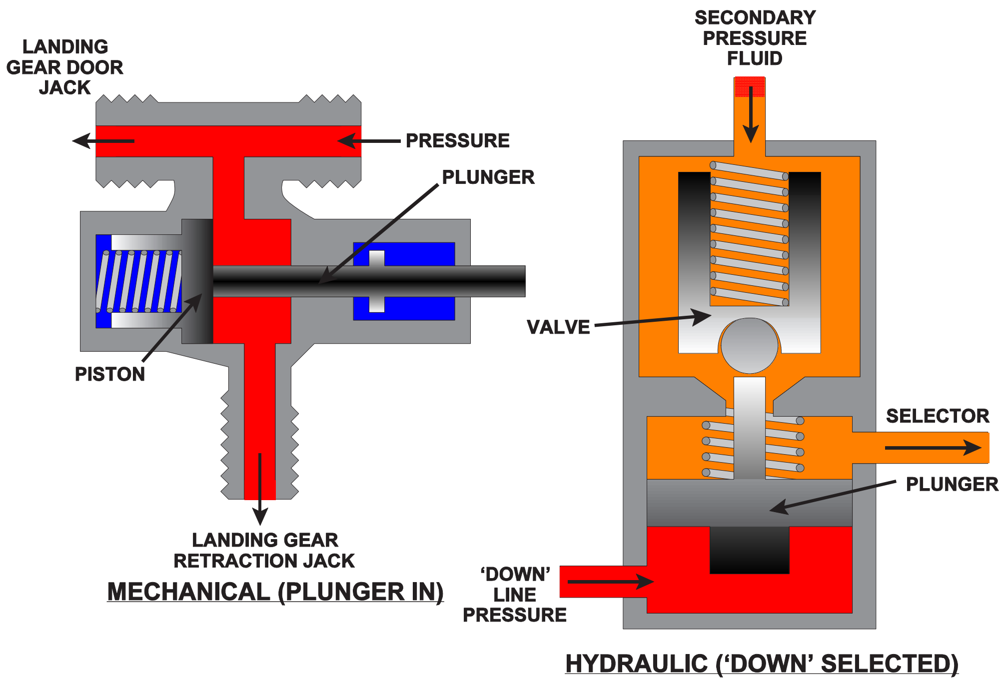


Figure 2.21: A sequence valve.

Modulators. A modulator is used in conjunction with the anti-skid unit in a brake system. It allows full flow to the brake units on initial brake application, and thereafter a restricted flow.

Flow Control Valves. A flow control valve may be fitted in a hydraulic system to maintain a constant flow of fluid to a particular component; it is frequently found upstream of a hydraulic motor which is required to operate at a constant speed.

Fuses. Modern jet aircraft are dependent on their hydraulic systems, not only for raising and lowering the landing gear, but for control system boosts, thrust reversers, flaps, brakes, and many auxiliary systems. For this reason most aircraft use more than one independent system; and in these systems, provisions are made to fuse or block a line if a serious leak should occur.

Of the two basic types of hydraulic fuses in use, one operates in such a way that it will shut off the flow of fluid if sufficient pressure drop occurs across the fuse.

A second type of fuse, does not operate on the principle of pressure drop, but it will shut off the flow after a given amount of fluid has passed through the line.

Normal operation of the unit protected by this fuse does not require enough flow to allow the piston to drift completely over and seal off the line. If there is a leak, however, sufficient fluid will flow that the piston will move over and block the line. Wheel brakes are invariably protected by fuse units.

INSTRUMENTATION

Indication of system condition and functioning is required in the cockpit or Flight Deck. Light aircraft utilise some form of warning lamp, indicating the operation of the electric (pump) motor in addition to undercarriage and flap warning lights or indicators. Larger aircraft will have the means of indicating contents, pressure and temperature of the system and, generally, varying means of dealing with abnormal operating conditions.

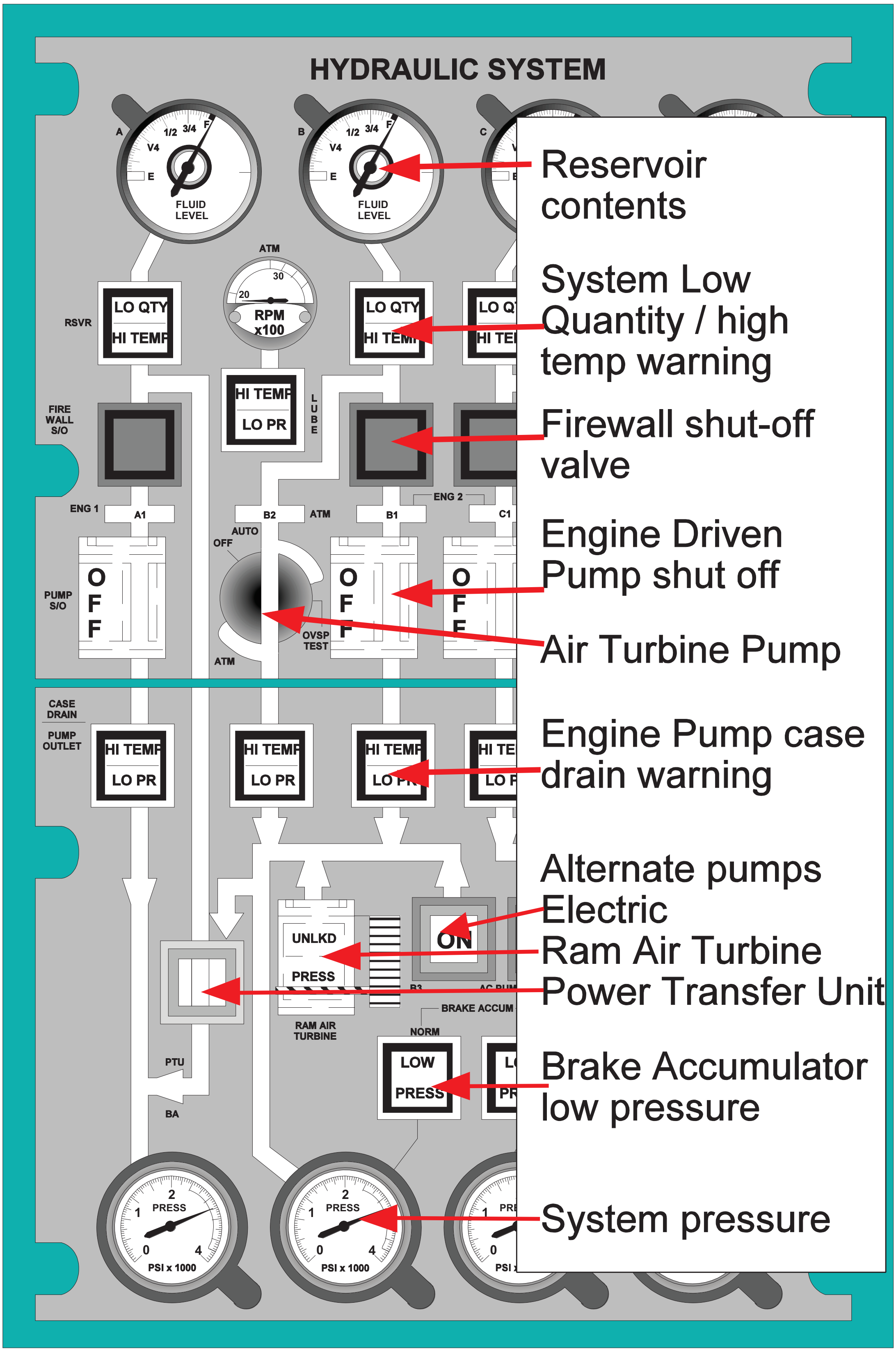
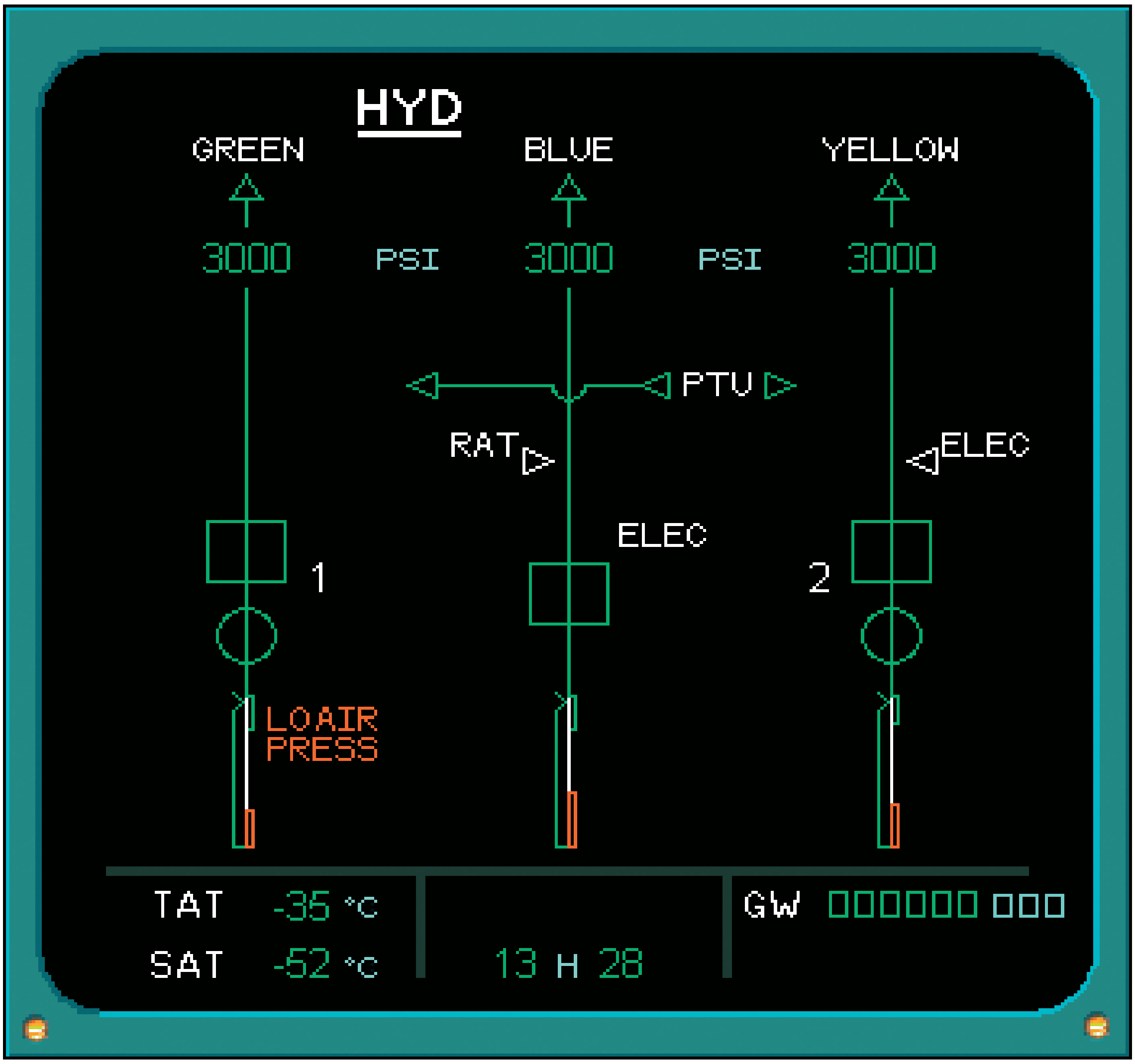


Figure 2.22: Quantity indicators.



Courtesy of Airbus Industrie

Figure 2.23: Modern pressure indicators.

The diagram above shows an electronic display from an Airbus aircraft displaying the hydraulic system configuration and indications. Three separate systems can be seen along with relevant valve positions, quantity, pump status and pressures. The accumulator for the 'green' system is showing a low air pressure caption.

Quantity Indicators. A clear window fitted in the reservoir provides a means of checking fluid level during servicing, but the reservoir may also be fitted with a float-type contents unit, which electrically signals fluid quantity to an instrument on the hydraulics panel in the crew compartment.

Pressure Relays. A pressure relay is a component which transmits fluid pressure to a direct reading pressure gauge, or to a pressure transmitter which electrically indicates pressure on an instrument on the hydraulics panel (See *Figure 2.23*, opposite).

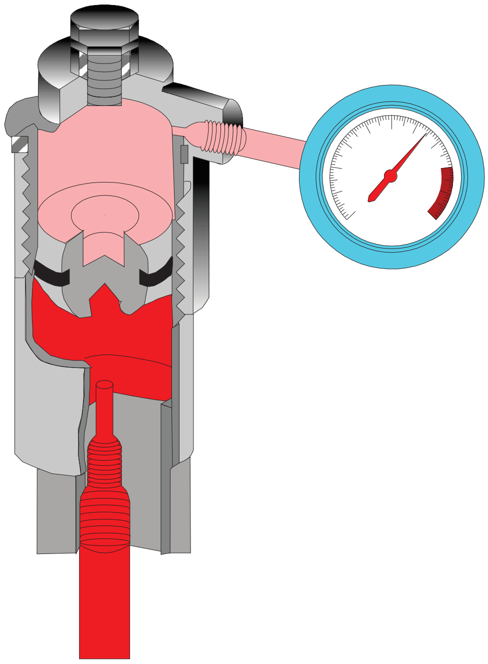


Figure 2.24: Pressure relays.

Pressure Gauges. Electrically operated pressure gauges are fitted on the hydraulics panel, to register main and emergency system pressure. Direct reading gauges are often fitted to the accumulators and reservoirs, to enable servicing operations to be carried out.

Pressure Switches. Pressure switches are often used to illuminate a warning lamp, and to indicate loss of fluid pressure, or loss of air pressure in a reservoir.

Flow Indication. A flow indicator valve is often fitted in the outlet line from a constant delivery pump, and is used to provide warning of pump failure.

Temperature Indication. Warning of fluid overheating is normally provided by a temperature sensing element in the reservoir. Warning of overheating of electrical motors which are used to operate emergency pumps, is normally provided by fitting a similar element in the motor casing.

COMPONENTS FOR SERVICING PURPOSES

A number of components are included in the hydraulic system specifically to facilitate servicing. These components are normally located in the hydraulic equipment bay.

Quick-disconnect and Ground Servicing Couplings. In positions where it is necessary to frequently disconnect a coupling for servicing purposes, a self-sealing, quick- disconnect coupling is fitted. The coupling enables the line to be disconnected without loss of fluid, and without the need for subsequent bleeding.

Pressure Release Valves or Off Load Controls. Are fitted to enable pressure to be released from the system for servicing purposes. The valves are manually operated, and used prior to checking and setting pre change pressures or reservoir levels.

Drain Cocks (valves). Drain cocks (valves) are generally simple manually operated spherical valves, and are located in the hydraulics bay at the lowest point in the system to enable the fluid to be drained.

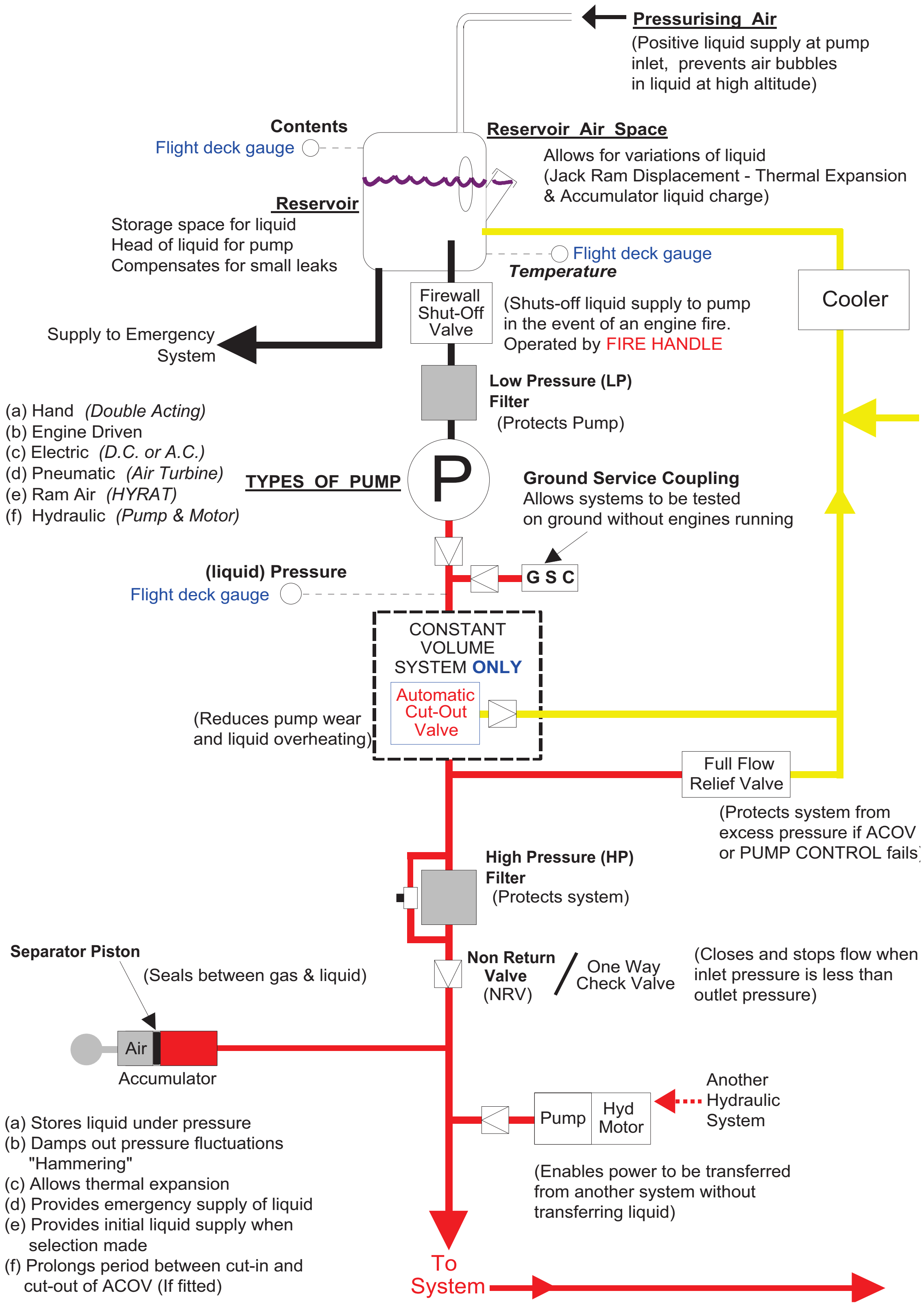
Shut-off Valves. These are fitted at the engine bulkhead (firewall) and will enable the fluid supply to the engine driven pumps to be stopped in the event of engine fire or component replacement. They are usually spherical ball cocks,(valves) which allow unrestricted flow when open.

Fluid Sampling Points. Fluid sampling points are suitably positioned in the suction and pressure lines, to enable samples of fluid to be removed for analysis.

POWERED FLYING CONTROLS

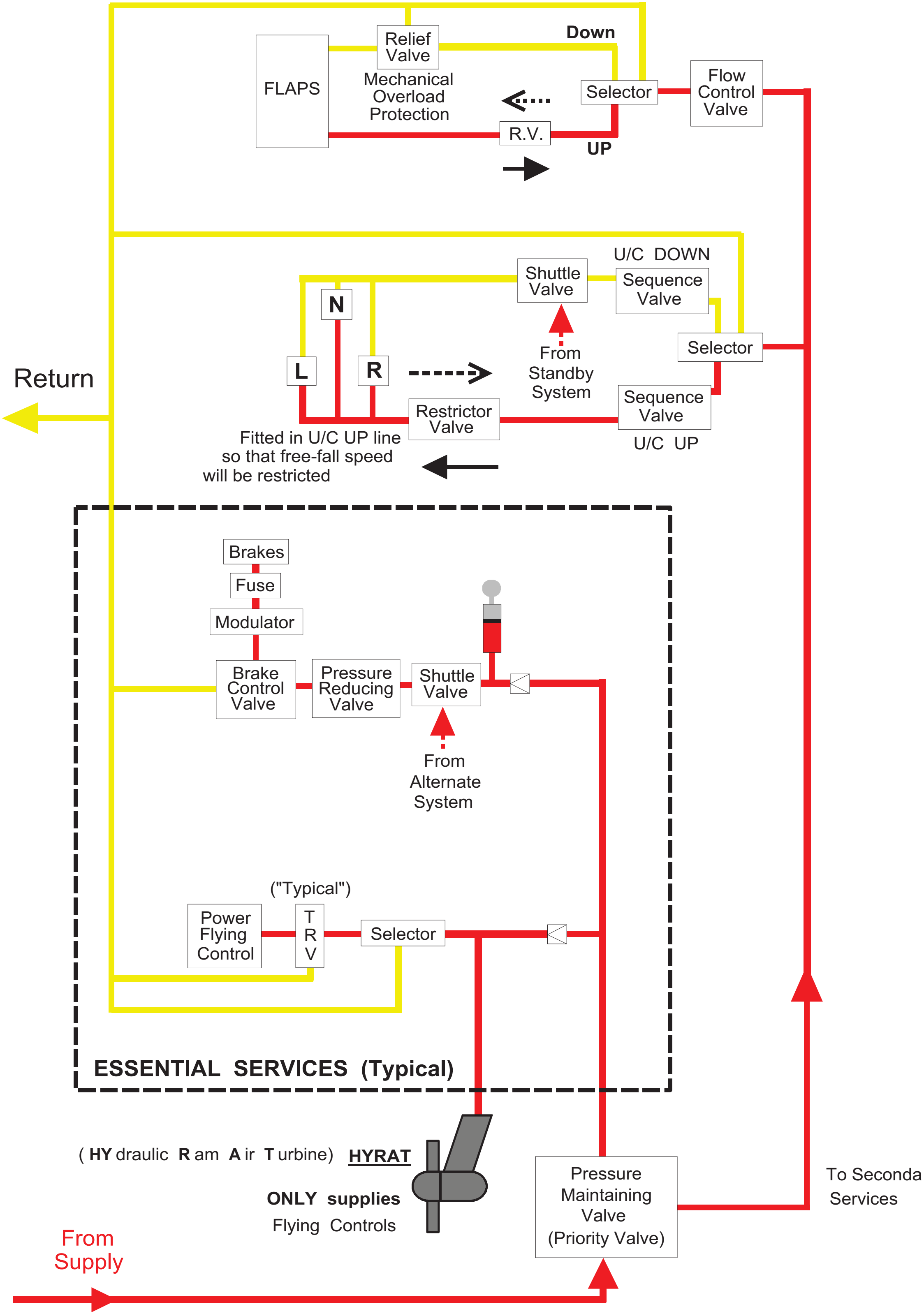
Sub-system. A hydraulic sub-system for the operation of the flying controls, is often fed through a priority valve or pressure maintaining valve, which ensures that fluid under pressure is always available; the sub-system may also have a separate accumulator. Most modern aircraft will have alternate hydraulic supplies available for flight controls. Two, three or even four independent hydraulic systems can simultaneously supply power for primary flying controls.

A complete system is shown in *Figures 2.25 and 2.26*, overleaf. The position and purpose of the major components are illustrated.



Pressurising Air
(Positive liquid supply at pump inlet, prevents air bubbles in liquid at high altitude)
Contents
Flight deck gauge
Reservoir Air Space
Allows for variations of liquid (Jack Ram Displacement - Thermal Expansion & Accumulator liquid charge)
Reservoir
Storage space for liquid
Head of liquid for pump
Compensates for small leaks
Flight deck gauge
Temperature
Cooler
Supply to Emergency System
Firewall Shut-Off Valve
(Shuts-off liquid supply to pump in the event of an engine fire. Operated by FIRE HANDLE
Low Pressure (LP) Filter
(Protects Pump)
(a) Hand (Double Acting)
(b) Engine Driven
(c) Electric (D.C. or A.C.)
(d) Pneumatic (Air Turbine)
(e) Ram Air (HYRAT)
(f) Hydraulic (Pump & Motor)
TYPES OF PUMP
P
Ground Service Coupling
Allows systems to be tested on ground without engines running
(liquid) Pressure
Flight deck gauge
G S C
CONSTANT VOLUME SYSTEM ONLY
Automatic Cut-Out Valve
(Reduces pump wear and liquid overheating)
Full Flow Relief Valve
(Protects system from excess pressure if ACOV or PUMP CONTROL fails)
High Pressure (HP) Filter
(Protects system)
Separator Piston
(Seals between gas & liquid)
Non Return Valve (NRV)
One Way Check Valve
(Closes and stops flow when inlet pressure is less than outlet pressure)
Air
Accumulator
Pump
Hyd Motor
Another Hydraulic System
(a) Stores liquid under pressure
(b) Damps out pressure fluctuations "Hammering"
(c) Allows thermal expansion
(d) Provides emergency supply of liquid
(e) Provides initial liquid supply when selection made
(f) Prolongs period between cut-in and cut-out of ACOV (If fitted)
(Enables power to be transferred from another system without transferring liquid)
To System

Figure 2.25:



Relief Valve
Down
FLAPS
Mechanical Overload Protection
Selector
Flow Control Valve
R.V.
UP
U/C DOWN
Shuttle Valve
Sequence Valve
N
Selector
L
R
From Standby System
Return
Restrictor Valve
Sequence Valve
Fitted in U/C UP line so that free-fall speed will be restricted
U/C UP
Brakes
Fuse
Modulator
Brake Control Valve
Pressure Reducing Valve
Shuttle Valve
From Alternate System
("Typical")
Power Flying Control
T R V
Selector
ESSENTIAL SERVICES (Typical)
(HY draulic R am A ir T urbine) HYRAT
ONLY supplies Flying Controls
Pressure Maintaining Valve (Priority Valve)
To Seconda Services
From Supply

Figure 2.26:

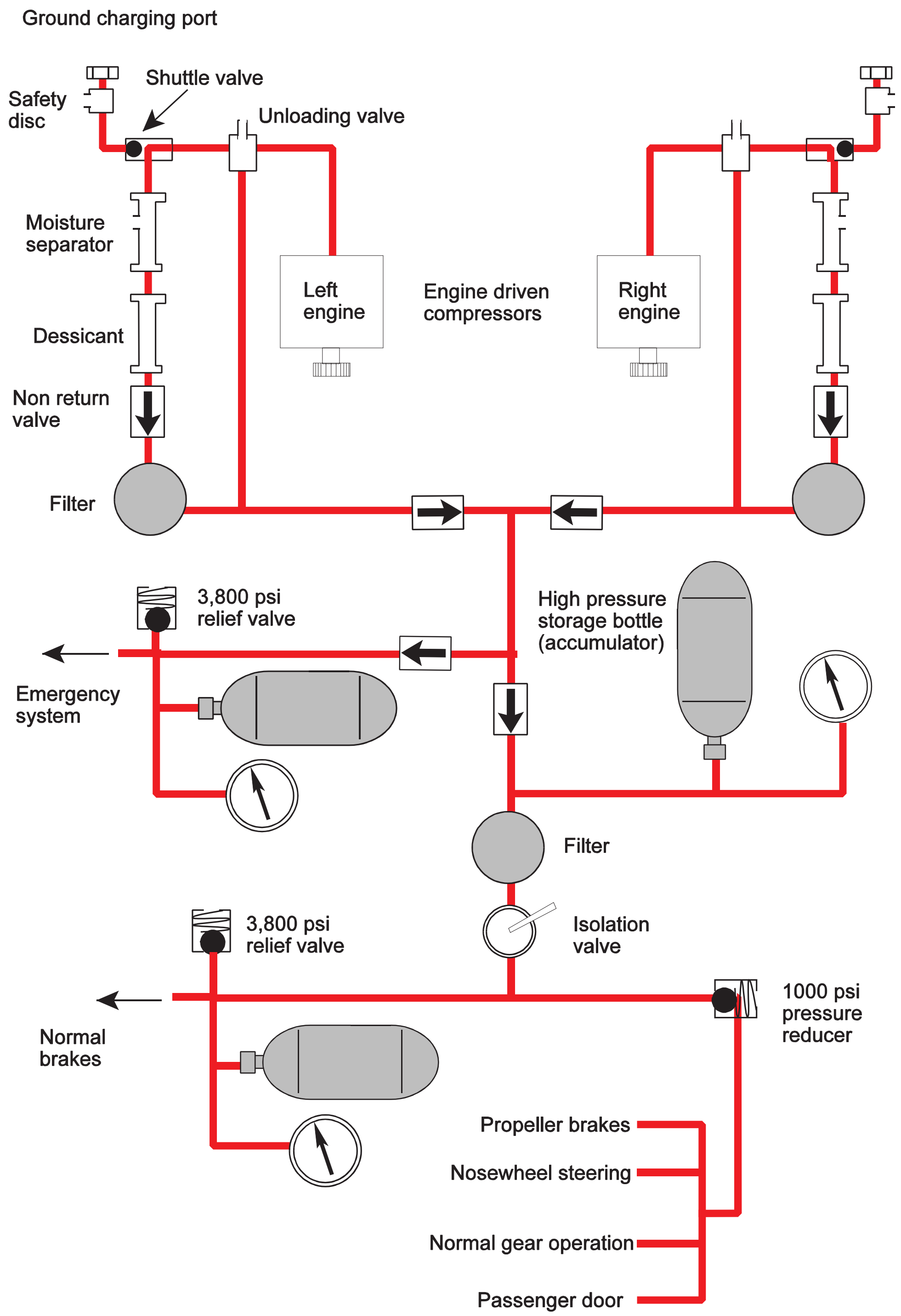


Figure 2.27: F27 High Pressure Pneumatic System

HIGH PRESSURE PNEUMATIC SYSTEMS

High pressure pneumatic systems are not generally used on modern transport aircraft as large components such as landing gear are raised and lowered more efficiently by hydraulic power. However these systems are still in use on aircraft such as the F.27. Compressed air has some advantages over other systems e.g.

- Air is universally available and is FREE.
- Air is lighter than hydraulic fluid.
- No fire hazard.
- No viscosity problems with changes of temperature.
- The system is lighter because no return lines are required

The major disadvantage of air is its compressibility.

The diagram shown in *Figure 2.27, page 67*, depicts the high pressure, closed centre system used on the F.27. The four stage compressor is driven from the accessory gearbox of the turbo-prop engines. The unloading valve ensures that the system pressure is maintained at 3,300psi. A shuttle valve enables the system to be charged from an external source.

Two components provide protection against the possibility of water freezing in the system :

- A moisture separator, which removes 98% of the water present in the air.
- A dryer which removes the remaining water using a desiccant such as silica gel or anhydrous aluminium silicate.

A 10 micron filter ensures that the air is clean before it enters the system. Three air bottles (reservoirs, accumulators) are provided to store the hp air ready for instant use. The 750 cubic inch for the main system, a 180 cubic inch for the brakes and a 180 cubic inch for emergency use. Most of the components operate with a pressure of 1,000 psi, so the air is passed through a reducing valve before being used by the landing gear, passenger door, nose wheel steering and propeller brake.

INTENTIONALLY LEFT BLANK

QUESTIONS

1. A force of 100N is applied to 2 separate jacks, the area of one is $0.02m^2$ and the other is $0.04m^2$:

   a. the smaller jack will exert a pressure of 2,000Pa and the larger 4,000 Pa.
   b. the smaller jack will exert a pressure of 5,000 Pa and the larger 2,500 Pa.
   c. both jacks will move at the same speed.
   d. both have the same load.

2. A pre charge pressure of 1,000 bar of gas is shown on the accumulator gauge. The system is then pressurised to 1,500 bar, so the accumulator will read:

   a. 500 bar.
   b. 1,000 bar.
   c. 1,500 bar.
   d. 2,500 bar.

3. The pressure gauge of an hydraulic system provides information regarding the pressure of:

   a. the air in the accumulator.
   b. the air and hydraulic fluid in the system.
   c. the proportional pressure in the system.
   d. the hydraulic fluid in the system.

4. A shuttle valve:

   a. is used to replace NRVs.
   b. allows two supply sources to operate one unit.
   c. allows one source to operate two units.
   d. acts as a non-return valve.

5. Def. Stan 91/48 is ---------- and is ------------- based:

   a. red , mineral
   b. red , synthetic
   c. green, mineral
   d. purple, synthetic

6. A restrictor valve:

   a. is used to restrict the number of services available after loss of system pressure.
   b. controls the rate of movement of a service.
   c. controls the rate of build up of pressure in the system.
   d. controls the distance a jack moves.

7. With a hyd lock there is:

   a. flow, but no jack movement.
   b. no flow but jack continues to move under gravitational effects.
   c. no flow, jack is stationary.
   d. constant flow.

8. The hydraulic fluid is changed, but the wrong fluid is replaced. This would lead to:

a. high operating fluid temperature.
b. system failure from leaks and blocked filters, high temp and possible corrosion.
c. a rise in the reservoir fill level.
d. normal operation, it does not matter which fluid is used.

9. Accumulator floating piston:

a. pushes the fluid up when being charged.
b. pushes the fluid down when being charged.
c. provides a seal between the gas and fluid.
d. prevents a hydraulic lock.

10. A relief valve:

a. relieves below system pressure.
b. maintains pressure to a priority circuit.
c. relieves at its designed pressure.
d. prevents excessive pressure through increased fluid temperature.

11. The primary purpose of a hydraulic reservoir is:

a. to compensate for leaks, displacement and expansion.
b. to allow a space into which spare fluid may be stored.
c. to indicate system contents.
d. to maintain fluid between a jack and the accumulator.

12. With air in the hydraulic system you would:

a. ignore it because normal operation would remove it.
b. bleed the air out of the system.
c. allow the accumulator to automatically adjust itself.
d. expect it to operate faster.

13. The pressure filter in a hydraulic system:

a. filters the fluid returning to the tank.
b. is fitted down stream of the pump.
c. can be by passed when maximum flow is required.
d. clears the fluid as it leaves the reservoir.

14. Pascal's law states that:

a. pressure is inversely proportional to load.
b. liquid is compressible.
c. oxygen can be used to charge the accumulators.
d. applied force acts equally in all directions.

15. A constant pressure hydraulic pump is governed by:

a. an automatic cut out.
b. engine RPM.
c. a control piston.
d. a swash plate that senses the fluid temperature.

16. A high pressure hydraulic pump:

a. needs a positive fluid supply.
b. does not need a positive fluid supply.
c. outlet pressure is governed by centrifugal force.
d. does not need a cooling fluid flow.

17. Case drain filters are:

a. fitted to prevent debris from the reservoir reaching the system.
b. designed to allow hydraulic pump lubricating fluid to drain to atmosphere.
c. to enable pump lubricating fluid to be used to monitor pump condition.
d. fitted in the reservoir outlet.

18. The purpose of an accumulator is to:

a. relieve excess pressure.
b. store fluid under pressure.
c. store compressed gas for tyre inflation.
d. remove air from the system.

19. With a one way check valve (NRV):

a. flow stops when input pressure is greater than output pressure.
b. flow stops when the thermal relief valve off loads the hand pump.
c. flow starts when input pressure is less than output pressure.
d. flow stops when input pressure is less than output pressure.

20. A restrictor valve is physically fitted in the:

a. u/c up line and flap up line.
b. u/c down line and flap up line.
c. u/c down line and flap down line.
d. supply line to the u/c retraction actuator.

21. In the case of a failure of a cut-out valve:

a. a full flow relief valve is fitted down stream of it.
b. a full flow relief valve is fitted upstream of it.
c. a full flow relief valve is not required.
d. the terminal pressure will be controlled by adjusting the pump RPM.

22. Hydraulic pressure of 3,000Pa is applied to an actuator, the piston area of which is $0.02m^2$ and the same pressure is exerted on actuator whose area is $0.04m^2$:

a. both have the same force.
b. both jacks will move at the same speed.
c. the smaller jack will exert a force of 600N and the larger 1,200N.
d. the smaller jack will exert a force of 60N and the larger 120N.

23. A separator in an accumulator:

a. isolates the gas from the fluid.
b. reduces the size of the accumulator required.
c. removes the dissolved gases from the fluid.
d. maintains the fluid level in the reservoir.

24. In an operating hydraulic actuator the pressure of the fluid will be:

a. greatest near to the actuator due to the load imposed on the jack.
b. greatest at the opposite end to the actuator due to the load imposed on the actuator.
c. high initially, falling as the actuator completes its travel.
d. the same at all points.

25. The contents of the hydraulic fluid reservoir are checked. They indicate that the reservoir is at the full level. The system is then pressurised. Will the contents level:

a. fall below the "full" mark.
b. fall to a position marked 'full accs charged'.
c. remain at the same level.
d. rise above the "full" mark.

26. A pressure maintaining or priority valve:

a. enables ground operation of services when the engines are off.
b. is used to ensure available pressure is directed to essential services.
c. is used to control pressure to services requiring less than system pressure.
d. is used to increase pressure in the system.

27. A hydraulic lock occurs:

a. when the thermal RV operates.
b. when fluid by passes a system and returns to the tank.
c. when flow is stopped and the actuator is not able to move.
d. when fluid and air enters the cylinder and only fluid is allowed to bypass to the reservoir.

28. In an enclosed system pressure is felt:

a. more at the piston head than the rest of the cylinder.
b. more at the cylinder end than the piston head.
c. more when the piston is moving than when it is stationary.
d. the same at both ends between the piston and the cylinder head.

29. A non return valve:

a. can only be fitted if provided with a by pass selector.
b. closes if inlet pressure exceeds outlet pressure.
c. opens if inlet pressure equals outlet pressure.
d. closes if inlet pressure ceases.

30. Low gas pressure in accumulator causes:

a. rapid jack movements.
b. no effect on system.
c. rapid pressure fluctuations while system is operating.
d. rapid and smooth operation of system.

31. Hammering in system:

a. is normal and does not affect the systems efficiency.
b. is caused by pipe diameter fluctuations.
c. is an indication that a further selection is necessary.
d. is detrimental to the system.

32. The specification of hydraulic fluids, mineral, vegetable or ester based is:

a. always distinguishable by taste and smell.
b. generally distinguishable by colour.
c. generally distinguishable by colour only if they are from the same manufacturer.
d. cannot be distinguished by colour alone.

33. An ACOV will:

a. provide an idling circuit when a selection is made.
b. extend the life of the accumulator.
c. provide an idling circuit when the accumulator is fully charged.
d. ensure the pump is always on load.

34. The purpose of a hydraulic fuse is to:

a. allow the parking brake to remain on overnight if required.
b. allow a reduced pressure to the wheel brake system to prevent the wheels locking.
c. prevent over-pressurising the reservoir as altitude increases.
d. prevent total loss of system fluid if the brake pipeline is ruptured.

35. A shuttle valve will allow:

a. the accumulator to be emptied after engine shut down.
b. the pressure pump to off-load when the system pressure is reached.
c. two independent pressure sources to operate a system/component.
d. high pressure fluid to return to the reservoir if the Full Flow Relief Valve fails.

36. The purpose of a reservoir is to:

a. compensates for temperature changes.
b. compensates for small leaks, expansion and jack displacement.
c. compensates for fluid loss.
d. to minimise pump cavitation.

37. When the hydraulic system pressure is released:

a. reservoir air pressure will increase.
b. reservoir fluid contents will rise if reservoir is lower than other components in the system.
c. reservoir fluid contents will fall if reservoir is the highest point in the system.
d. reservoir contents are dumped overboard.

38. Hydraulic pressure in a closed system:

a. is greater in pipes of larger diameters.
b. is greater in pipes of smaller diameters.
c. does not vary with pipe diameter.
d. varies in direct proportion to the system demands.

39. Skydrol hydraulic fluid:

a. needs no special safety precautions or treatment.
b. is flame resistant but is harmful to skin, eyes and some paints.
c. is highly flammable and harmful to skin, eyes and some paints.
d. is highly flammable but not harmful in any other way.

40. Skydrol hydraulic fluid can be used to replenish:

a. any hydraulic system without restriction.
b. hydraulic systems that have butyl rubber seals only.
c. any hydraulic system in an emergency.
d. hydraulic systems that have neoprane seals only.

41. A variable displacement pump on system startup will be at:

a. minimum stroke.
b. an optimised position depending on fluid viscosity.
c. maximum stroke.
d. mid stroke.

42. The purpose of a reservoir is:

a. to provide a housing for the instrument transmitters.
b. to enable the contents to be checked.
c. to allow for fluid displacements, small leaks, thermal expansion and contents monitoring.
d. to provide a housing for the main system pumps and so obviate the need for backing pumps.

43. Hydraulic Thermal Relief Valves are fitted:

a. to release all the pressure back to return in an overheat situation.
b. to release half the pressure back to return in an overheat situation.
c. to relieve excess pressure back to the actuator in an overheat situation.
d. in isolated lines only to relieve excess pressure caused by temperature rises.

44. A main system hydraulic pump:

a. does not need a positive fluid supply if primed before startup.
b. always needs a positive fluid supply in order to prevent cavitation.
c. does not need a positive fluid supply in order to prevent cavitation.
d. can be run dry without causing any damage.

45. Different diameter actuators supplied with the same pressure at same rate:

a. exert the same force.
b. will lift equal loads.
c. will move at the same speed.
d. exert different forces.

46. A force of 1,500 N is applied to a piston of area $0.002m^2$ and generates a force of-----(1)------Non a piston of area $0.003m^2$. The pressure generated is -----(2)-----and, if the smaller piston moves 0.025m, the work done is-----(3)------.

a.	(1) 56.25J	(2) 750,000Pa	(3) 750,000N
b.	(1)750,000N	(2) 2,250 P	(3) 56.25J
c.	(1) 225N	(2) 75,000Pa	(3) 562.5 J
d.	(1) 2,250N	(2) 750,000Pa	(3) 37.5 J

47. The following statements relate to hydraulic accumulators. The function of a accumulator is to:

1. Store fluid under pressure
2. Dampen pressure fluctuations
3. Allow for fluid expansion
4. Replace the need for a reservoir
5. Absorb some of the landing loads
6. Allow for thermal expansion
7. Prolong the period between pump cut-in and cut-out
8. Provide the initial pressure when a selection is made and the pump is cut out
9. Provide an emergency reserve of pressure in the event of pump failure

Which of the following applies?

a. All of the statements are correct.
b. None of the statements are correct.
c. Statements 1, 2, 3, 4, 5, 8 and 9 are correct.
d. Statements 1, 2, 3, 6, 7, and 9 are correct.

48. The seal materials used with hydraulic fluids to DEF/STAN 91-48 and SKYDROL 700 specification are respectively:

a. natural rubber and neoprene.
b. neoprene and natural rubber.
c. butyl and neoprene.
d. neoprene and butyl.

49. To prevent cavitation of the pump a hydraulic reservoir may be:

a. pressurised.
b. bootstrapped.
c. above the pump.
d. all of the above.

50. A hand pump is **usually** fitted:

a. for ground servicing purposes.
b. lowering the landing gear in an emergency.
c. pressurising the oleo struts in the air.
d. retracting the gear after take-off.

ANSWERS

1.	B	26.	B
2.	C	27.	C
3.	D	28.	D
4.	B	29.	D
5.	A	30.	C
6.	B	31.	D
7.	C	32.	D
8.	B	33.	C
9.	C	34.	D
10.	C	35.	C
11.	A	36.	B
12.	B	37.	B
13.	B	38.	C
14.	D	39.	B
15.	C	40.	B
16.	A	41.	C
17.	C	42.	C
18.	B	43.	D
19.	D	44.	B
20.	A	45.	D
21.	A	46.	D
22.	D	47.	D
23.	A	48.	D
24.	D	49.	D
25.	A	50.	A

CHAPTER THREE

LANDING GEAR

Contents

INTRODUCTION

The functions of the landing gear are:

- To provide a **means of manoeuvring** the aircraft on the ground.
- To **support the aircraft** at a convenient height to give clearance for propellers and flaps, etc. and to facilitate loading.
- To **absorb the kinetic energy of landing** and provide a means of controlling deceleration.
-

LANDING GEAR DESIGN

Once airborne, the landing gear serves no useful purpose and is dead weight. It would be ideal to replace it with some ground based equipment, but while in the first two cases above this may be possible, no satisfactory alternative exists for the third case. For this reason a vast amount of research has gone into the design of undercarriage units in order to reduce their weight and stowed volume when retracted.

LANDING GEAR TYPES - FIXED OR RETRACTABLE

With slow, light aircraft, and some larger aircraft on which simplicity is of prime importance, a fixed (non-retractable) landing gear is often fitted, the reduced performance caused by the drag of the landing gear during flight is offset by the simplicity, reduced maintenance and low initial cost. With higher performance aircraft, drag becomes progressively more important, and the landing gear is retracted into the wings or fuselage during flight, there are, however, penalties of increased weight, greater complication and additional maintenance.

FIXED LANDING GEAR

There are three main types of fixed landing gear, those which have a **spring steel leg**, those which employ **rubber cord** to absorb shocks, and those which have an **oleo-pneumatic strut** to absorb shocks. Exceptions include aircraft with rubber in compression, spring coil, and liquid spring struts.

Spring Steel Legs. Spring steel legs are usually employed at the main undercarriage positions. The leg consists of a tube, or strip of tapered spring steel, the upper end being attached by bolts to the fuselage and the lower end terminating in an axle on which the wheel and brake are assembled.

Rubber Cord. When rubber cord is used as a shock-absorber, the undercarriage is usually in the form of tubular struts, designed and installed so that the landing force is directed against a number of turns of rubber in the form of a grommet or loop.

Oleo-pneumatic Struts. Some fixed main undercarriages, and most fixed nose undercarriages, are fitted with an oleo-pneumatic shock absorber strut. The design of individual struts varies considerably, but one point worthy of consideration is the fitting of **spats** to oleo-pneumatic strut. Spats are an aerodynamic fairing which may be required to minimise the drag of the landing gear structure. One drawback to their use is the problem of them picking up mud when landing or taking off from grass airfields. This can add considerably to the weight of the aircraft and may affect take off performance. To avoid this eventually, if any mud has been picked up, **the spats must be removed, cleaned and replaced before the next take off.**

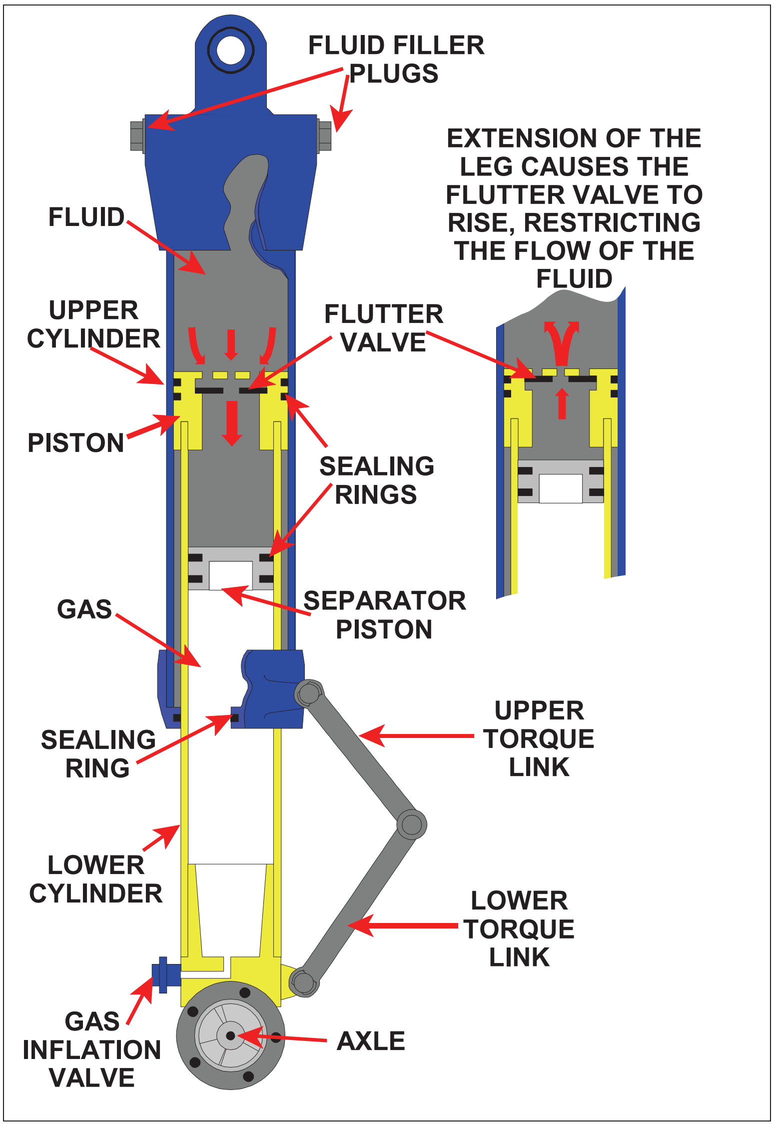


Figure 3.1: An oleo-pneumatic strut.

CONSTRUCTION OF OLEO-PNEUMATIC STRUTS

Figure 3.1. shows the construction of a simple oleo-pneumatic strut, in this instance a nose undercarriage which also includes a steering mechanism. The outer cylinder is fixed rigidly to the airframe structure by two mounting brackets, and houses an inner cylinder and a piston assembly, the interior space being partially filled with hydraulic fluid and inflated with compressed gas (air or nitrogen). The inner cylinder is free to rotate and move up and down within the outer cylinder, but these movements are limited by the **torque links**, (scissor-links) which connect the inner cylinder to the steering collar. The steering collar arms are connected through spring struts to the rudder pedals, and a **shimmy damper** is attached to the steering collar.

OLEO-PNEUMATIC STRUT OPERATION

- Under static conditions the weight of the aircraft is balanced by the strut gas pressure and the inner cylinder takes up a position approximately midway up its stroke.
- Under compression (e.g. when landing), the strut shortens and fluid is forced through the gap between the piston orifice and the metering rod, this restriction **limiting the speed of upward movement** of the inner cylinder.
- As the internal volume of the cylinders decreases, the gas pressure rises until it balances the upward force.
- As the upward force decreases, the gas pressure acts as a spring and extends the inner cylinder. **The speed of extension is limited** by the restricted flow of fluid through the orifice.
- Normal taxying bumps are cushioned by the gas pressure and dampened by the limited flow of fluid through the orifice.
- Movement of the rudder pedals turns the nose wheel to facilitate ground manoeuvres, the spring struts being provided to allow for vertical movement of the nose wheel, and prevent shocks from being transmitted through the rudder control system.

NOTE: *Evidence of strut gas pressure leakage will be given by the strut not extending as far as it should, uneven amounts of* ***Fescalized*** *metal showing on each main gear. Fescalized metal is the shiny material which forms the hard outer coating of the strut.*

RETRACTABLE LANDING GEAR

The majority of modern transport aircraft, and an increasing number of light aircraft, are fitted with a retractable landing gear, for the purpose of improving aircraft performance.

Retraction is normally effected by a hydraulic system, but pneumatic or electrical systems are also used. In some instances power is used for retraction only, extension being effected by gravity and slipstream. Retractable landing gear is also provided with mechanical locks to ensure that each undercarriage is locked securely in the retracted and extended positions; devices to indicate to the crew the position of each undercarriage; and means by which the landing gear can be extended in the event of failure of the power source.

In addition, means are provided to prevent retraction with the aircraft on the ground, and to guard against landing with the landing gear retracted. Undercarriage wells are normally sealed by doors for aerodynamic reasons.

DESIGN AND CONSTRUCTION OF RETRACTABLE GEAR

The geometrical arrangement and physical location of undercarriage units on aircraft is by no means standard.

The type, size and position is decided at the design stage, having already taken into account the many factors that must be considered.

Most aircraft use the "**tricycle layout**", where the two main undercarriage units are positioned just aft of the C of G and support up to 90% of the aircraft's weight and all initial landing shocks.

The nose wheel unit keeps the aircraft level, and in most cases also provides a means of steering. One advantage that the "tricycle" gear has over the "tail dragger" type is that there is no danger of it tipping over onto its nose while taxying in a strong tail wind and also that there is much less danger of it ground looping.

FACTORS AFFECTING DESIGN AND CONSTRUCTION

Of the many factors taken into consideration, the main ones are listed below:

- Size of aircraft.
- Weight of aircraft.
- Role of aircraft.
- High or low wing.
- Performance.
- Construction of aircraft and associated stowage problems.

OTHER FACTORS

Modern concepts of aircraft design have been greatly influenced by the need to keep the cost down and the requirements for them to be multi-role. Dual freight and passenger carrying roles have resulted in the high wing monoplane type where the floor of the aircraft needs to be as close to the ground as possible for ease of freight loading.

However, with some wings being as high as 20 feet off the ground, it became impossible to build an undercarriage of sufficient strength to reach that far, so the modern trend has been to incorporate the main undercarriage in the fuselage.

UNDER WING LANDING GEAR UNITS

For aircraft with the standard underwing fitted undercarriage, an example is shown in Figure 3.2, the units comprise basically:

- A leg, pin-jointed to the aircraft structure.
- A wheel(s).
- A means of absorbing landing shocks.
- A means of controlling deceleration of the aircraft.
- A means to withstand turning and braking stresses
- Large aircraft (Boeing 747) have the ability to turn part of the main gear to assist with steering during tight turns (body gear steering)

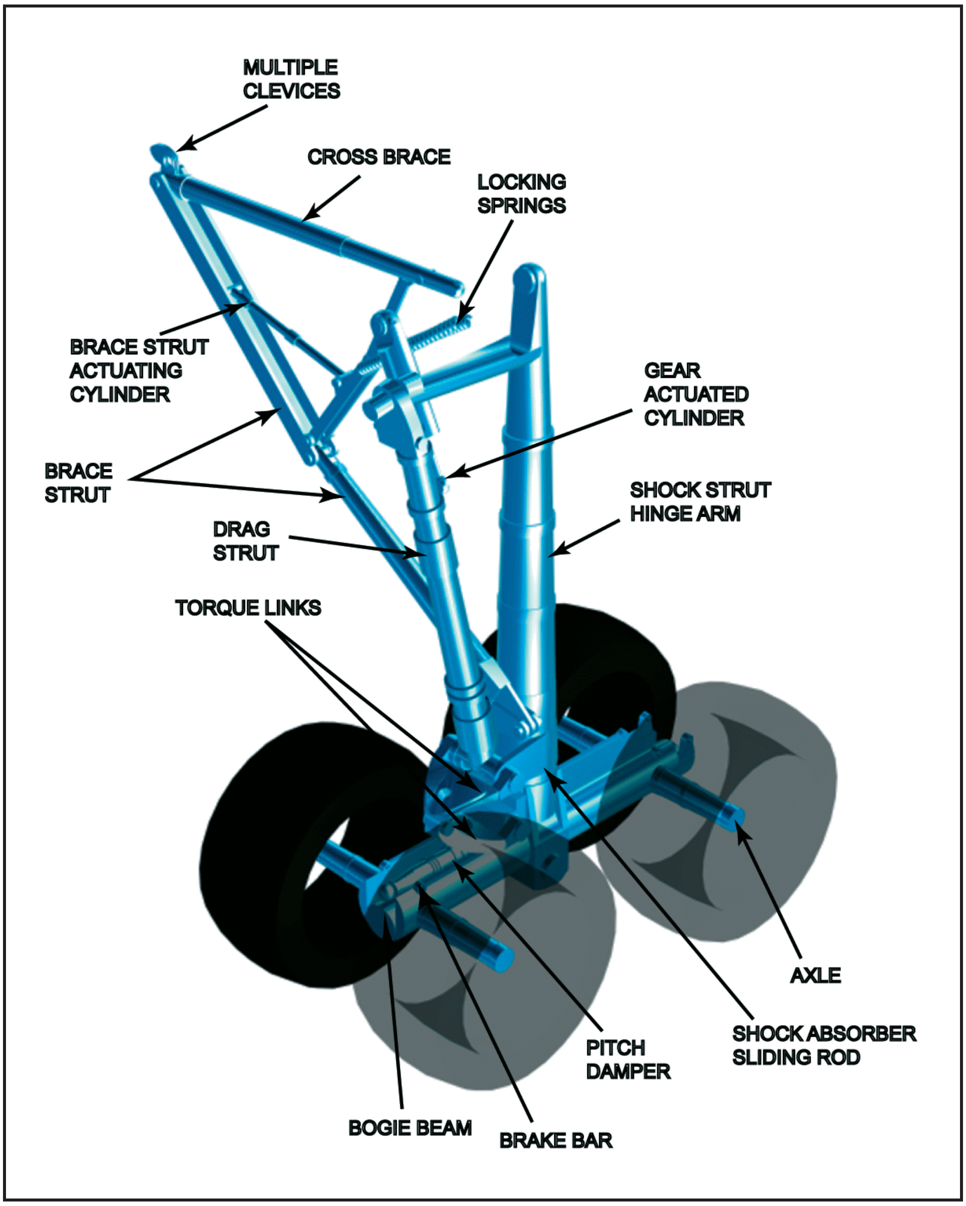


Figure 3.2: A wing mounted landing gear assembly.

FUSELAGE MOUNTED LANDING GEAR

For aircraft with the undercarriage built into the fuselage, the requirements are basically the same as those for the wing mounted landing gear, except that:

- With no geometric lock available, provision has to be made for locking the undercarriage up and down.
- Depending on wheel layout, each wheel may require its own shock absorber unit, and possibly even a steering motor.
- Ease of access to the undercarriage in flight allows manual lowering of the udercarriage in emergency.

LOADS SUSTAINED BY THE LANDING GEAR

An undercarriage unit has to withstand varying loads during its life. These loads are transmitted to the mountings in the aircraft structure, so these too must be very strong. The loads sustained are:

- Compressive (Static and on touch down)
- Rearward bending.
- Side (During cross wind landings, take offs, and taxying)
- Forwards (during push back).
- Torsional (Ground Manoeuvring).

NOSE UNDERCARRIAGE

A nose undercarriage unit, like the one shown in *Figure 3.3.*, is usually a lighter structure than a main unit since it carries less weight and is usually subject only to direct compression loads. It does, however, carry the attachment for the towing equipment and so must withstand shear loads as well. Its design is complicated by several requirements:

- Castoring.
- Self centering.
- Steering.
- Anti-shimmy.
- Withstand shear loads.

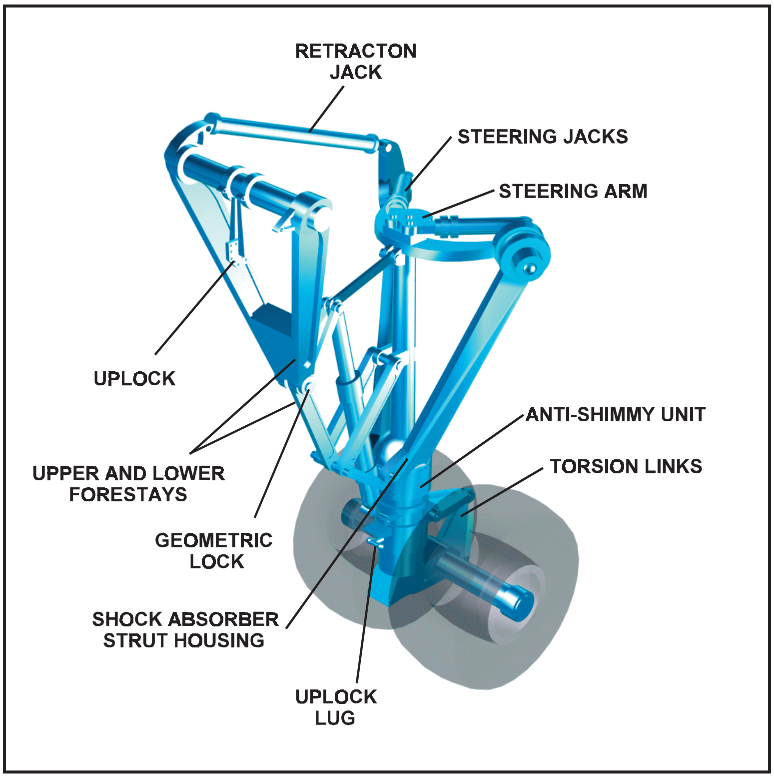


Figure 3.3: A nose landing gear.

CASTORING

To enable the aircraft to be manoeuvred about the airfield the nose wheel must castor freely though subjected to compressionand shear loading, which presents a problem in the bearing design.

Castoring is the ability of the nose wheel to turn to either side in response to the results of differential braking or aerodynamic forces on the rudder.

SELF CENTERING

Automatic self centering of the nose wheel is essential prior to landing gear retraction. If the nose gear is not in a central position prior to its retraction, the restricted space available for its stowage will not be sufficient and severe damage may be caused to the aircraft structure as the hydraulic system forces the gear upwards.

Centering is achieved by either a spring loaded cam or a hydraulic dashpot.

NOSE WHEEL STEERING

A method of steering is required to enable the pilot to manoeuvre the aircraft safely on the ground. Early methods involved the use of differential braking.
Powered steering using hydraulic systems are now common to most large commercial aircraft, allowing the engines to be set at the minimum thrust for taxying, thereby saving fuel, an important consideration with large jet engines.
This method of steering is more accurate and also reduces tyre and brake wear and noise pollution.
To allow free castoring of the nose undercarriage when required, i.e. towing, a by-pass is provided in the steering system hydraulics to allow fluid to transfer from one side to the other. When steering is selected this by-pass is closed by hydraulic pressure.
Steering is controlled, depending on the type of aircraft, by:

- A separate steering wheel.
- Operation of rudder pedals.

Incorporated in the steering system are;-

- Self-Centering jack.
- Shimmy damper.

POWER STEERING SYSTEMS

Although light aircraft use a simple steering system, where the nose wheel is mechanically linked to the rudder pedals, larger aircraft require powered steering arrangements. Within a power steering system, the nose wheel is rotated by electric, pneumatic, or most commonly, hydraulic power.

This last type of system would include a cockpit steering wheel or tiller, a control valve, steering cylinders to turn the nose gear, a mechanical feedback device to hold the steering at the selected angle and a power source, normally the aircraft hydraulic supply fed from the engine driven pumps.

NOSE WHEEL STEERING OPERATION

Normal nose wheel steering operating pressure is derived from the undercarriage ‘down’ line, and a limited emergency supply is provided by a hydraulic accumulator. In the system shown in *Figure 3.4.*, hydraulic pressure passes through a change-over valve, which ensures that the steering system is only in operation when the nose undercarriage is down.

Steering Operation. Pressure is directed through the control valve to the steering jacks, which retract or extend to rotate the nose shock absorber strut within its housing. Movement of the steering wheel is transmitted through mechanical linkage to the control valve, in accordance with the amount and direction of turn required.

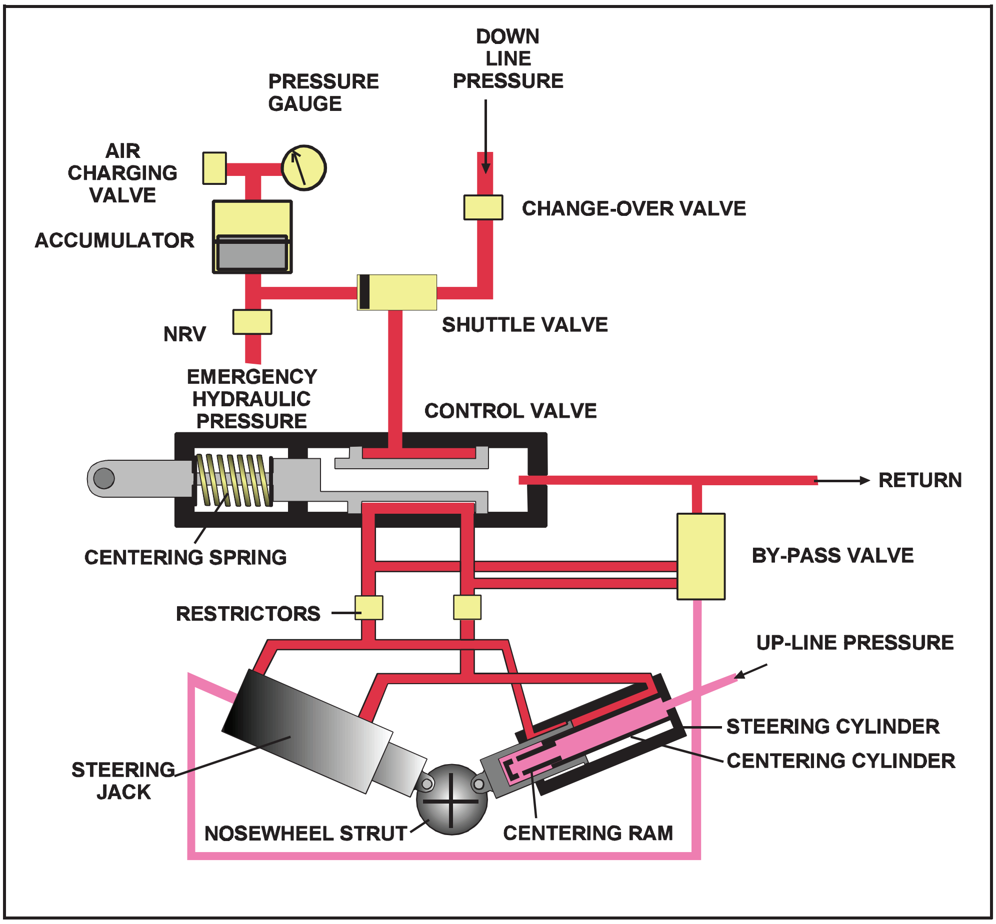


Figure 3.4: The hydraulic layout of a typical nose wheel steering system..

A follow-up linkage from the nose undercarriage gradually resets the control valve as the nose wheel turns. When the steering wheel is released, the control valve returns to neutral under the action of its centering springs, and the nose wheel is free to castor.

Self Centering operation. An inner cylinder in each steering jack is connected to the landing gear ‘up’ line and is supplied with fluid under pressure when the landing gear is selected up. The steering jacks extend equally to centralise the nose wheel before pressure is applied to the nose retraction jack, and the by-pass valve allows fluid from the steering jacks to flow to the return line.

Castoring. Whenever the control valve is in its neutral position, fluid is free to flow between the steering jacks, thus allowing the aircraft to be towed, or the nose wheel to return to the central position after a turn has been initiated with the steering wheel. Angular movement of the nose wheel during towing will be transmitted through the follow-up linkage to the steering wheel. Some form of **quick-release pin** is often provided to enable the steering jacks to be disconnected so that the nose wheel may be turned through large angles during ground servicing.

Damping. Restrictors in the pipelines between the control valve and the steering jacks provide damping for the nose wheel steering operation.

NOSE WHEEL SHIMMY

Due to the flexibility of tyre side walls, an unstable, rapid sinusoidal oscillation or vibration known as **shimmy** is induced into the nose undercarriage.

Excessive shimmy, especially at high speeds, can set up vibrations throughout the aircraft and can be dangerous.

Worn or broken torque links, wear in the wheel bearings and uneven tyre pressures can all increase the tendency to shimmy.

Shimmy can be reduced in several ways:

- Provision of a hydraulic lock across the steering jack piston.
- Fitting a hydraulic damper.
- Fitting heavy self-centering springs.
- Double nose wheels.
- Twin contact wheels.

UNDERCARRIAGE CONFIGURATION

The increase in size and all up weight (A.U.W.) of modern aircraft has led to an increase in wheel loading; this is defined as the static load on each wheel of the landing gear at aircraft take off weight. Since the main undercarriage carries a large proportion of the aircraft weight, main wheels are the greatest problem. Wheel loading, in lbs/unit area, has a direct bearing on the type of surface from which the aircraft can operate, thus the role of the aircraft directly effects the undercarriage configuration. An aircraft with a high wheel loading would damage the surface of a low strength runway.

As it is very expensive to strengthen the very long runways required for modern transport aircraft, undercarriages which confer low wheel loadings are in considerable use. These replace large single wheels using high pressure tyres with a number of small wheels using low pressure tyres: the larger aircraft (B747, B777 and A340) may have 10 to 18 wheels in their landing gear. More than two main legs may be provided to spread the load, wing and body gear on a 747, 777 and A340 for example

The actual configuration chosen for the aircraft is determined by the problem of stowage when retracted as well as the load spreading consideration.

Multi-wheeled units have advantages other than just reduction of wheel loading. These are:

- **Weight.** The greater the number of wheels, the lighter the unit can become as the wheels are smaller. This point is hard to prove, since with the size of todays modern aircraft, a single wheel unit would be impracticable anyway.

- **Ease of Servicing**. Although the whole unit is more complex, the changing of wheels or brake units is easier than on a single wheel U/C and individual components are much nearer the ground.

- **Greater Safety Factor**. In the event of a burst tyre there will be one or more serviceable wheels remaining to carry the load.

- **Ease of On Board Stowage**. Multi-Wheel units are easier to stow, however, most undercarriages are designed to fit in the space available. The thickness of the wing plays a big part, thin wings mean that specially designed folding and swivelling bogies have to be used, which in turn escalates the costs and makes general routine servicing more complex. Some aircraft tend to have their U/C as part of the fuselage, thus easing the design problem, and allowing the gear to be raised and lowered vertically.

The main **disadvantage** of multi-wheel bogie units is that they have a large footprint area, which causes the unit to **crab** whilst turning. Due to this unfortunate side effect, the turning radius has to be increased with the resultant manoeuvring problems on the ground.

Tyre wear caused by scrubbing also occurs because the forces applied to the tread are considerable, and the smaller the radius of the turn the greater are these forces. the tread of the tyre becomes torn and can split to expose the casing fabric.

To minimise this occurrence it is recommended that the aircraft be manoeuvred on the ground using the largest turning circle possible, tight turns are to be avoided if at all possible and the aircraft should be moved in a straight line for a short distance before stopping.

LANDING GEAR OPERATION ON CONTAMINATED RUNWAYS

Problems have occurred on aircraft which have taken off from runways contaminated with **slush**, a mixture of water, wet snow and ice. It has been found, on more than one occasion, that because of slush deposited on the gear during the take off run freezing in the landing gear bay during the climb and cruise, the crew have been unsuccessful in lowering the gear upon arrival at their destination.

If it is absolutely essential that you take off in such poor conditions, then you are advised to **cycle the gear just after take off**, selecting the gear **UP, DOWN,** and then **UP** again. It is considered that the shocks inflicted on the gear during this cycle should be sufficient to remove any deposits from it.

A HYDRAULIC GEAR RETRACTION SYSTEM

A hydraulic system for retracting and extending a landing gear normally takes its **power from engine driven pumps**, alternative system being available in case of pump failure. On some light aircraft a self-contained 'power pack' is used, which houses a reservoir and selector valves for the landing gear and flap systems; an electrically driven pump may also be included, or the system may be powered by engine driven pumps. This type of system normally provides for powered retraction of the landing gear, **extension being by 'free-fall'**, with the assistance of spring struts.

SYSTEM RETRACTION

Operation of the system is as follows:-

Figure 3.5a. When the landing gear selector is moved to the 'up' position fluid is directed to the 'up' line and a return path is created for 'down' line fluid.

'Up' line fluid flows to the Nose Landing Gear (NLG) Down (DN) Lock which is released. Simultaneously fluid goes to the NLG Jack which retracts. Fluid is also ported through the one way restrictor (Free Flow) to Sequence Valve 1 (SV1), where it waits for the the Main Landing Gear (MLG) down lock which releases and to the MLG Jack which **extends** and raises the Main Undercarriage.

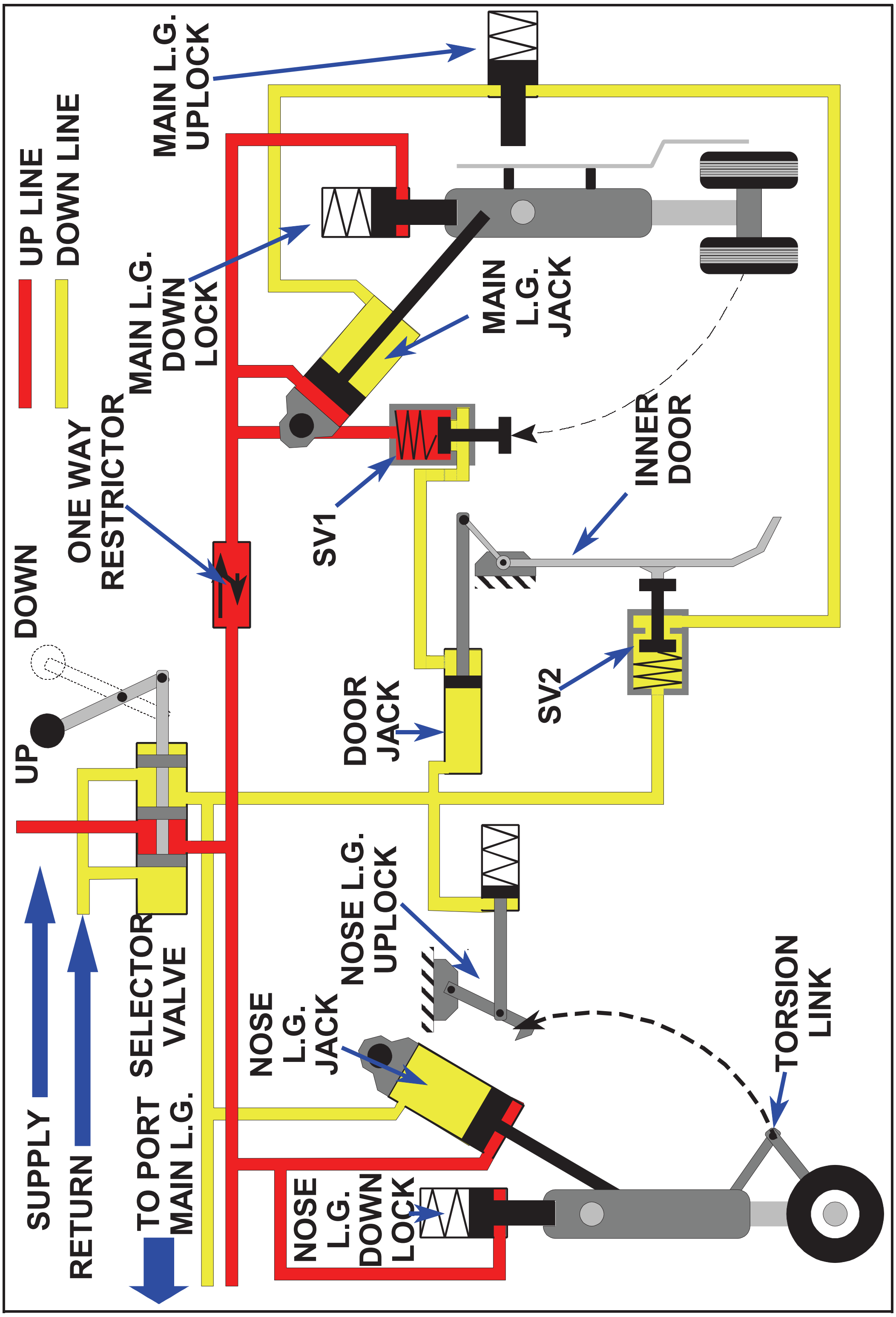


Figure 3.5a: The initial retraction sequence.

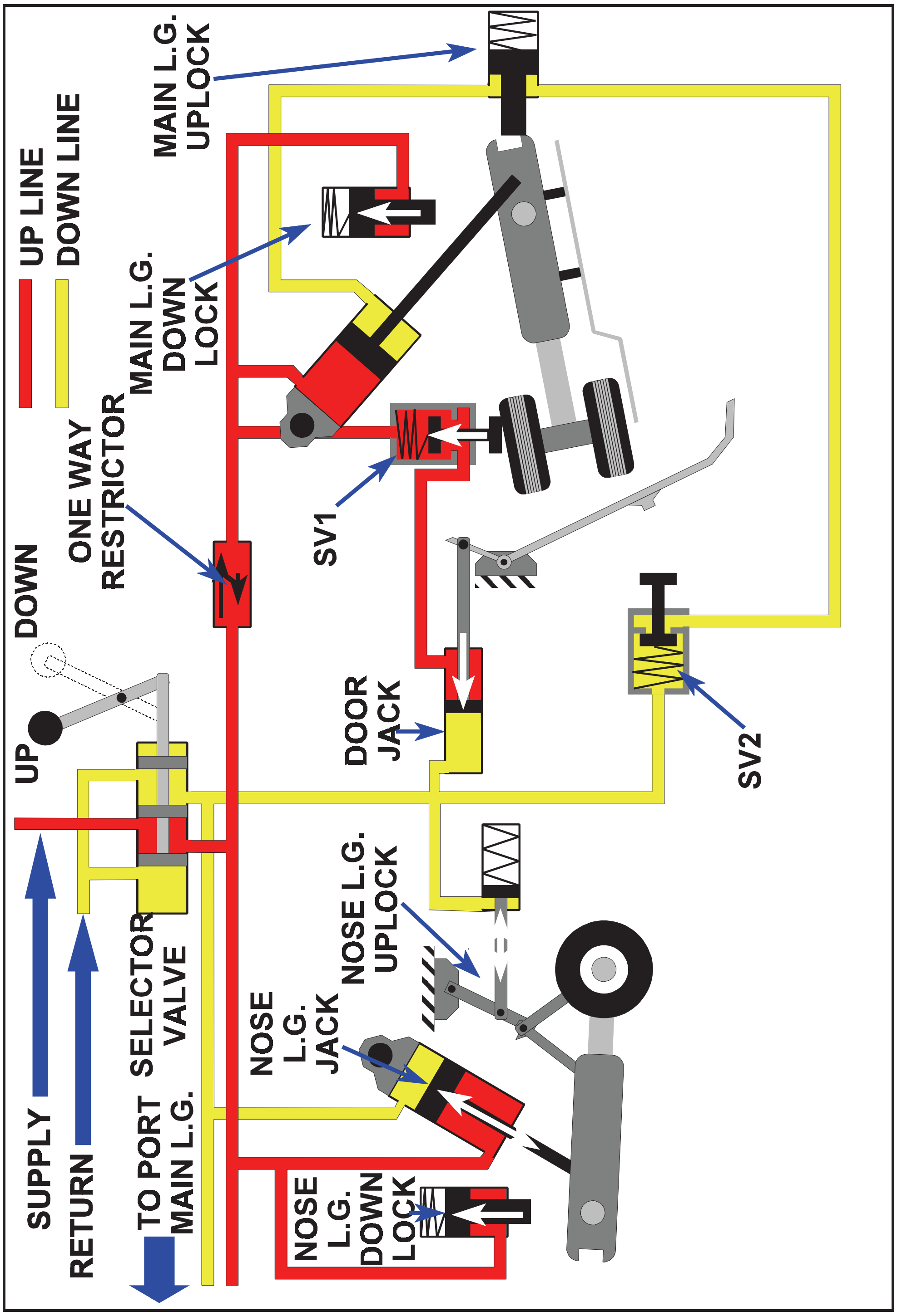


Figure 3.5b: The gear locking up.

When the nose undercarriage is fully retracted, it is retained in position by the NLG Uplock (Hydraulically Released-Spring Applied). As the MLG reaches full retraction it activates SV1, which allows the supply of fluid to the Door jack - which retracts, closing the Main Undercarriage Door. Finally the MLG up lock (Hydraulically Released-Spring Applied) engages, locking the gear up. (On some aircraft the selector valve is placed in the neutral position after the U/C is raised, leaving the gear un-pressurised for the period of the cruise, so extending component life.)

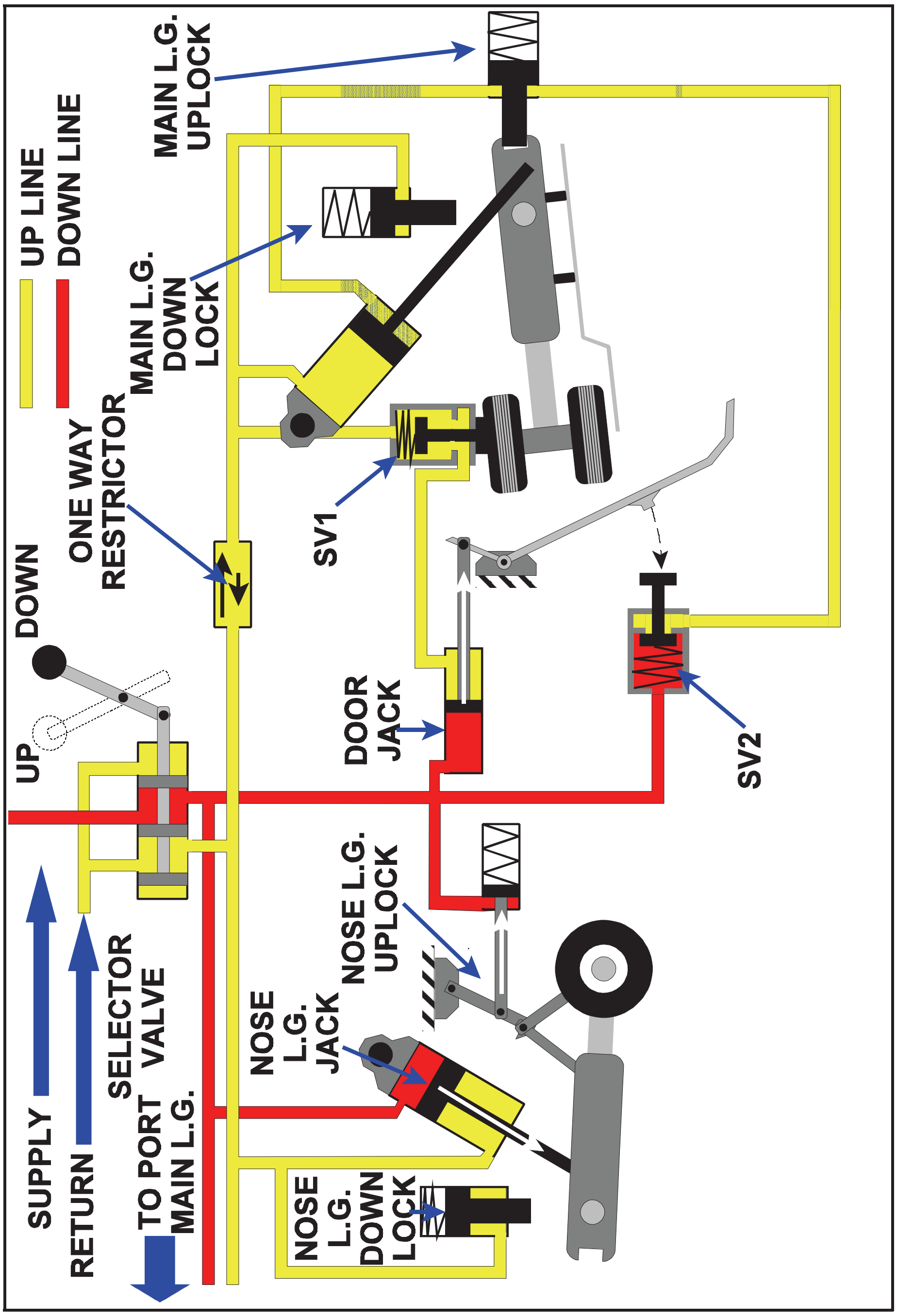


Figure 3.5c: Initial movement when 'gear down' selected.

When the selector is moved to the 'down' position, fluid is directed to the NLG up lock, which is released, and to the NLG jack which extends and lowers the Nose gear. At the same time fluid is ported to Sequence Valve 2 (SV2), where it waits and to the Door Jack which will extend to open the door. The door jack return fluid passes through SV1 and the One Way Restrictor (Restricted Flow) which restricts the rate of fluid return acting as a door speed damper.

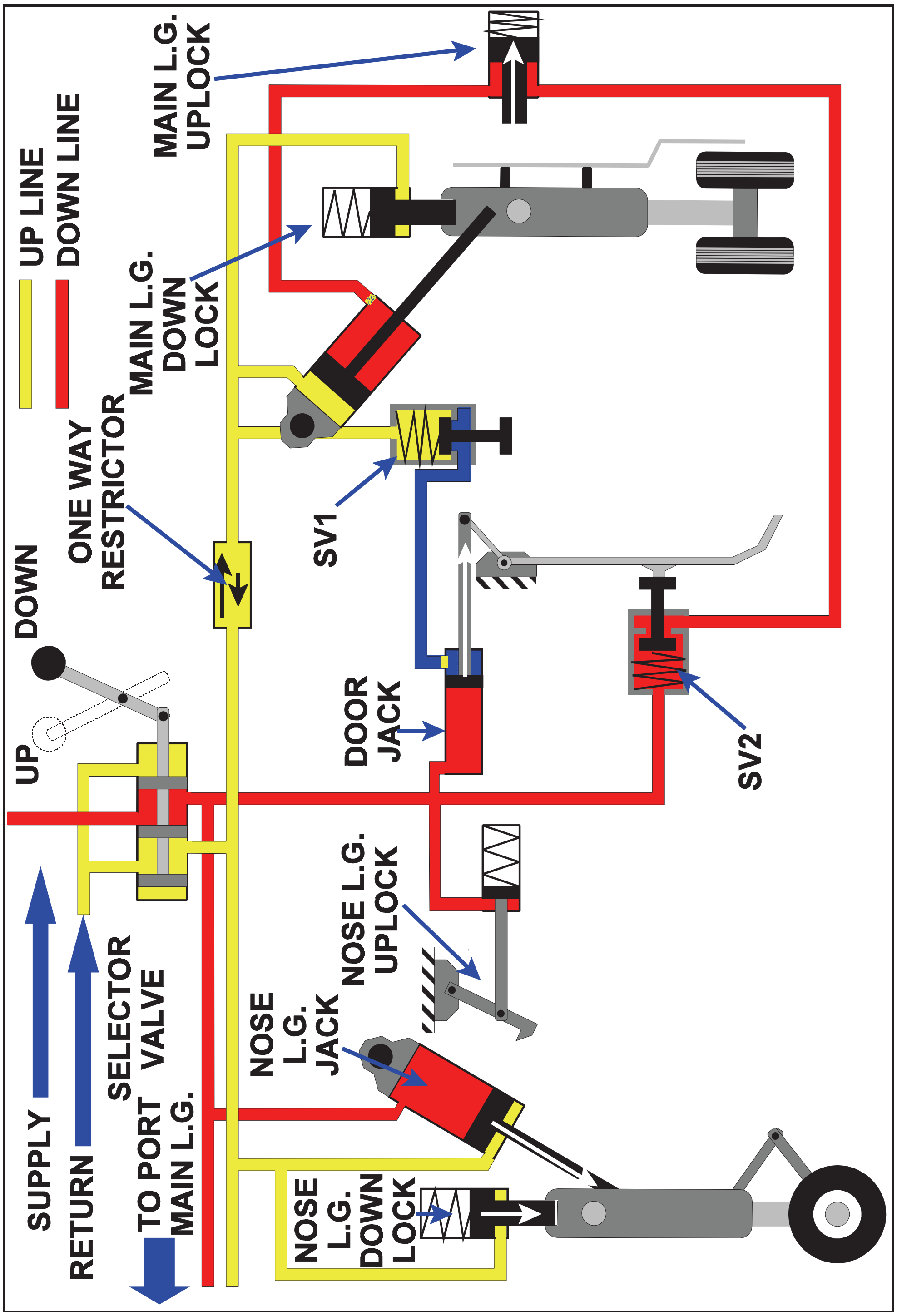


Figure 3.5d: The final movement of the gear being locked down.

When the door is fully open, it activates SV2 which allows fluid both to the MLG Up Lock, which releases, and to the MLG Jack, which retracts and pulls the MLG into the down position. Return fluid passes through the one way restrictor (Restricted Flow) the restriction acting as a damper to the rate of undercarriage travel thus preventing damage to the U/C mountings etc. Finally the MLG locks into place when it engages with the MLG Down Lock.

NOTE: Restrictor valves are normally fitted to limit the speed (rate) of lowering of the main undercarriage units, which are influenced in this direction by gravity. The nose undercarriage often lowers against the slipstream and does not need the protection of a restrictor valve.

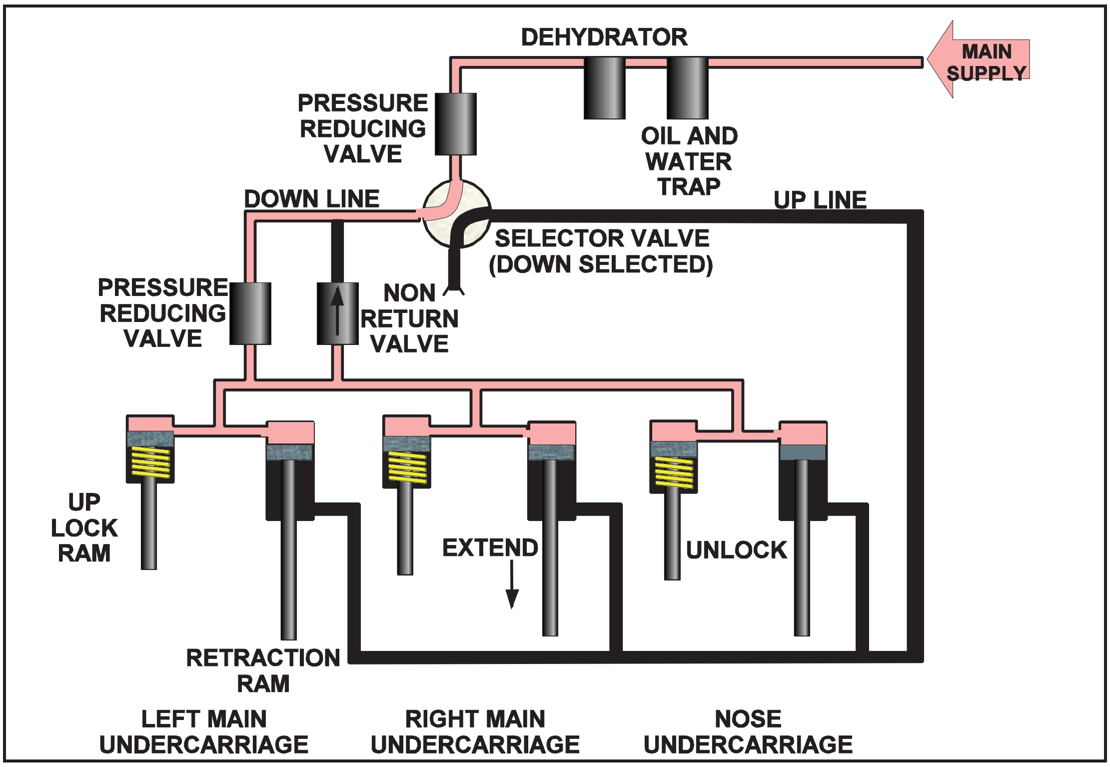


Figure 3.6: A simple pneumatic gear retraction system.

A PNEUMATIC RETRACTION SYSTEM

Operation of a pneumatic retraction system like the one shown in *Figure 3.6.*, is similar to that of a hydraulic system, except that pressure in the return lines is exhausted to atmosphere through the selector valve.

Pressure is built up in a main storage cylinder by engine driven air pumps, and passes through a pressure reducing valve to the landing gear selector valve. Operation of the selector valve to the 'UP' position directs pneumatic pressure through the 'up' lines to the retraction rams, and opens the down line to atmosphere.

Operation of the selector valve to the 'DOWN' position directs pneumatic pressure through a second pressure reducing valve and the down lines, to the up-lock rams and retraction rams.

NOTE: A low pressure is used for landing gear extension, for the same reason that restrictor valves are used in hydraulic systems, which is to prevent damage occurring through too rapid extension of the undercarriage units.

Retraction rams are usually damped to prevent violent movement. The hollow piston rod is filled with oil or grease, which is forced through the space between the inner surface of the piston rod and a stationary damper piston whenever the ram extends or retracts, thus slowing movement.

Up-locks and down-locks are similar to those used with hydraulic systems, the geometric down-locks being imposed by over-centering of the drag strut at the end of retraction ram stroke, and the up-locks by spring-ram operated locks.

Down-locks are released by initial movement of the retraction rams during retraction, and up- locks are released by pneumatic pressure in the spring-rams during extension.

Undercarriage doors are operated mechanically, by a linkage on the shock absorber housing.

AN ELECTRICAL GEAR RETRACTION SYSTEM

An electrical retraction system is often fitted to light aircraft which do not otherwise require the use of a high pressure fluid system.

The main and nose undercarriage units are similar to those used in fluid retraction systems, but push and pull forces on the retraction mechanism are obtained by an electric motor and suitable gearing. *Figure 3.7* illustrates a typical system, in which a single reversible electric motor provides the power to retract and extend the landing gear.

Operation. The motor operates a screw jack, which provides angular movement to a torque tube; a push-pull rod from the torque tube acts on the drag strut of the nose undercarriage, and cables and rods from the torque tube act on the main undercarriage sidestays, rubber cord being used to assist extension of the main undercarriage units.

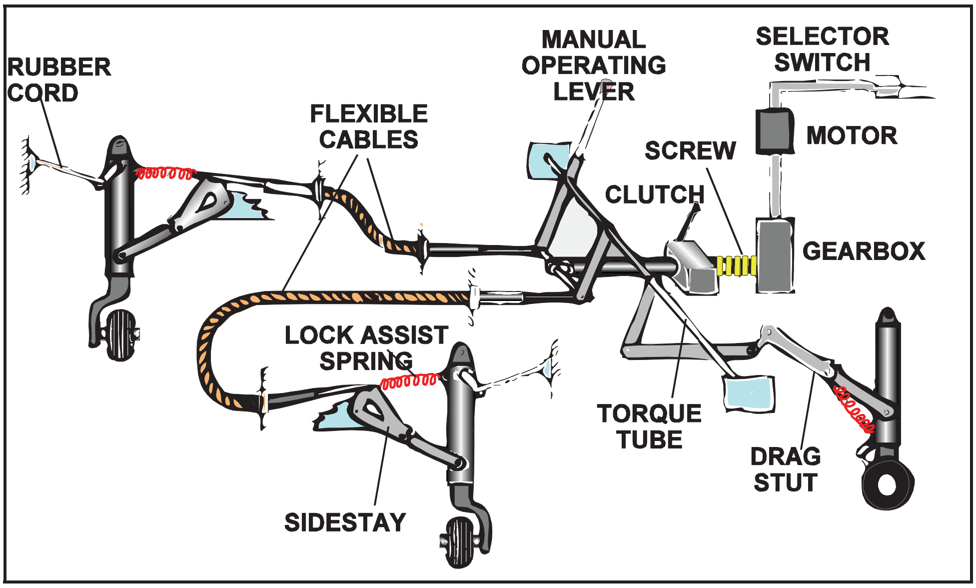


Figure 3.7: A simple electrical gear retraction system.

Down-locks are imposed by over-centering of the drag strut and sidestays during final movement of the operating mechanism, with the assistance of springs. Limit switches on the drag strut and sidestays cut off electrical power and brake the motor when the down-locks have engaged, while a limit switch on the torque tube stops and brakes the motor when the landing gear is fully retracted.

Undercarriage doors are operated by linkage to the shock absorber housings.

GEAR POSITION INDICATION

Although the landing gear, when selected down, may be visible from the crew compartment, it is not usually possible to be certain that each undercarriage is securely locked.

An electrical indicating system is used to provide a positive indication to the crew of the operation of the locks and of the position of the landing gear. The system usually consists of microswitches on the up-locks and down-locks, which make or break when the locks operate, and which are connected to a landing gear position indicator on the instrument panel.

A mechanical indicator may also be provided, to show that the landing gear is down and locked when the electrical system is inoperative.

On British manufactured aircraft, the electrical undercarriage system operates in such a manner that a green light is displayed when the undercarriage is locked down, a red light is displayed when the undercarriage is in transit, and no lights are visible when the undercarriage is locked up; bulbs are usually duplicated to avoid the possibility of false indications as a result of bulb failures.

On other aircraft, similar indications may be obtained by the use of magnetic indicators or lights, but on some light aircraft a single green light indicates that all undercarriages are locked down, and an amber light indicates that all undercarriages are locked up.

Many large aircraft also have main gear door lock indicators to confirm the doors are locked up when the gear is locked down.

The following diagrams show typical controls and indicators for an analogue and electronic displays.

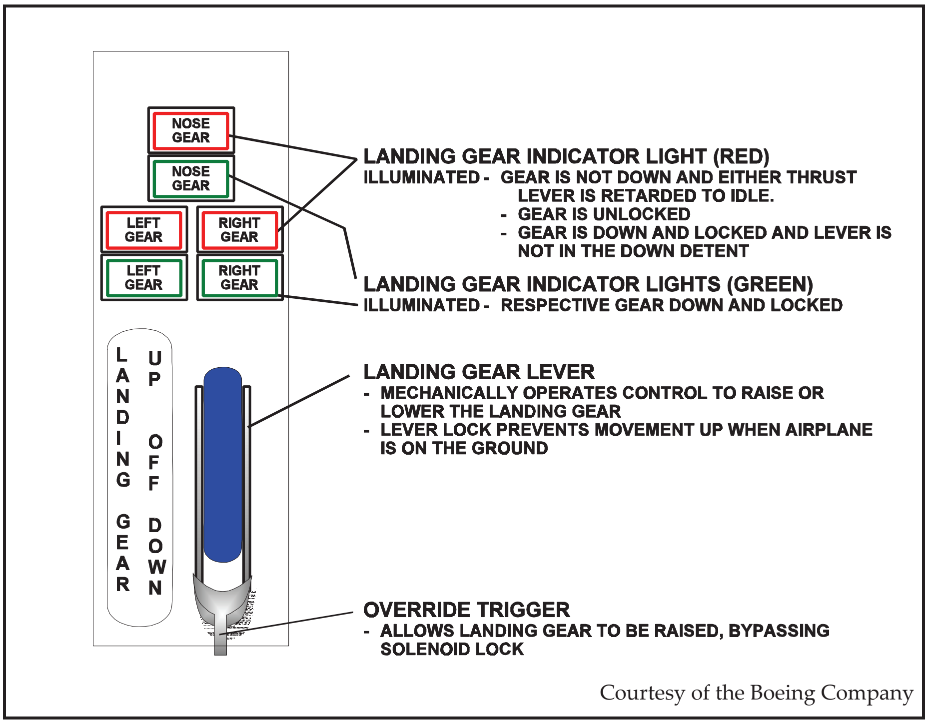
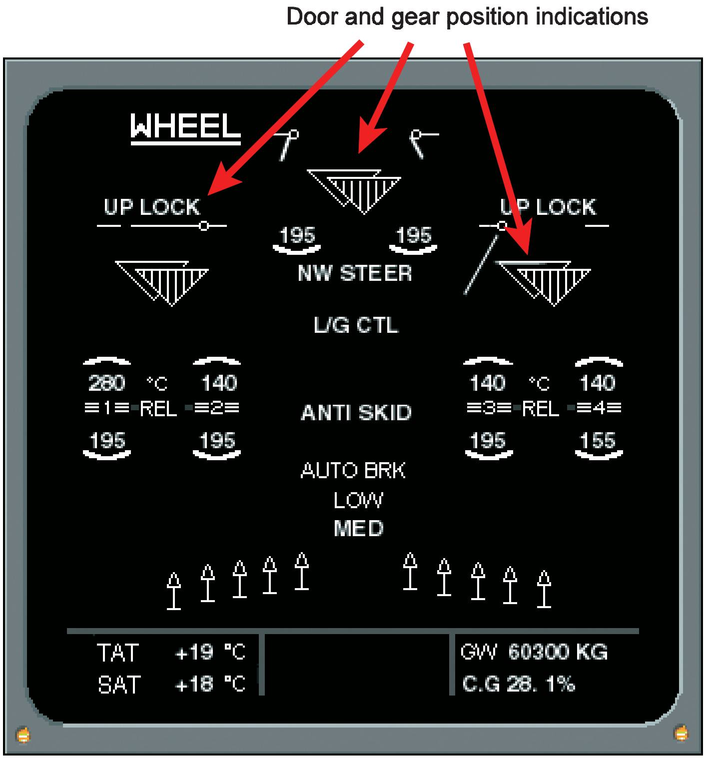


Figure 3.8: Landing gear selectors and indicators.



Courtesy of Airbus Industrie

Figure 3.9: An Airbus ECAM page.

GEAR SAFETY FEATURES

Since the correct operation of the landing gear is of the utmost importance, a number of safety features are included in the retraction system to ensure its correct operation under all conditions.

NOSE WHEEL CENTERING

To avoid damage to the airframe structure, the nose wheel must always be aligned in a fore (front) and aft (rear) direction during retraction, and a number of methods are used to ensure that this happens automatically. One method already discussed in *Paragraph 3.18*, is Hydraulic Nose Wheel Centering on aircraft with powered steering.

GEAR SELECTOR LOCK

To prevent inadvertent retraction of the landing gear when the aircraft is resting on its wheels, a safety device is incorporated which prevents movement of the selector lever. This safety device consists of a spring-loaded plunger which retains the selector in the down position and is released by the operation of a solenoid.

Electrical power to the solenoid is controlled by a switch mounted on the shock absorber strut (part of the air\ground logic circuits).

When the strut is compressed the switch is open, but as the strut extends after take-off, the switch contacts close and the electrical supply to the solenoid is completed, thus releasing the selector lever lock and allowing the landing gear to be selected up.

A means of overriding the lock, such as a separate gated switch to complete the circuit, or a mechanical means of avoiding the locking plunger, is provided for emergency use and for maintenance purposes. *See Figure 3.8*.

GROUND LOCKS

Ground locks or landing gear locking pins are a further safety feature which is intended to prevent inadvertent retraction of the gear when the aircraft is on the ground.

They will usually consist of pins or metal sleeves which interfere with the operation of the gear in such a way that it is impossible for the gear to move when they are in position.

They are fitted with **warning flags** which should prevent the crew from getting airborne with them still in position on the gear. This can be prevented by ensuring that the ground locks are removed before flight and stowed on board the aircraft and the flight crew are informed that they have been removed and stowed safely on the aircraft.

WARNING DEVICES

To guard against landing with the landing gear retracted or unlocked, a **warning horn** is incorporated in the system and connected to a throttle operated switch.

If one or more throttle levers are less than approximately one third open, as would be the case during approach to land, the horn sounds if the landing gear is in any position other than down and locked.

A **horn isolation switch** is often provided to allow certain flight exercises and ground servicing operations to be carried out without hindrance, but an **airspeed switch** is a definite advantage, since unlike an isolation switch, it cannot be first used, and then forgotten, with perhaps disastrous consequences. An airspeed switch can also be used to **prevent** the horn sounding during initial descent from high altitude.

GPWS - GROUND PROXIMITY WARNING SYSTEM

The GPWS will be inhibited below 500 ft **only** if the gear is locked down and the flaps are in the landing position.

For further information see the *Warnings and Recording section in Book 5.*

EMERGENCY LOWERING SYSTEMS

A means of extending the landing gear and locking it in the down position is provided to cater for the eventuality of main system failure.

On some aircraft the **up-locks are released mechanically or electrically by manual selection**. The landing gear '**free falls**' under its own weight (gravity) and the down locks are engaged mechanically.

If the gear has been lowered by the 'free fall' method, then it must be assumed that the main source of power to the gear has failed, if this is the case, then because there is no power to retract them after they have been released, **the doors will remain open**. The size of the doors can prove a problem on some aircraft, because there is a chance that they will contact the ground upon touchdown unless the landing is exceptionally gentle. Some aircraft have doors fitted with a frangible portion at their lowest extent so that replacement problems are minimised.

On other aircraft the landing gear is extended by an **emergency pressure system** which often uses alternative pipelines to the jacks. Pressure for the emergency system may be supplied by a hydraulic accumulator, a hand pump, a pneumatic storage cylinder, or an electrically powered pump.

A Mechanical Indicator will be provided to indicate gear locked down.

AIR/GROUND LOGIC SYSTEM

Inevitably there are systems of all types which need to be selected on or off in response to the criterion of whether the aircraft is airborne or not.

This effect can be obtained by merely placing micro switches or the main landing gear oleo's so that their position will be changed when the weight of the aircraft compresses the oleo, or alternatively, on take off, when the weight of the wheel and bogie assembly extends the oleo.

On more modern aircraft, the use of micro switches has been superseded by proximity sensing devices which work essentially in the same manner as the micro switches by deducing the extension or retraction of the oleo by capacitive or inductive sensing equipment fitted to the oleo.

Whichever system is used, a controlling signal will be sent to a relay or bank of relays, which in themselves are capable of switching the affected circuits on or off as required.

Some aircraft use sensors on just one main landing gear oleo, but it is common to find the sensors duplicated on both main oleos to provide a degree of redundancy in the system.

CHAPTER FOUR

AIRCRAFT WHEELS

Contents

INTRODUCTION

The wheels and tyres of an aircraft support it when on the ground and provide it with a means of mobility for take-off, landing and taxying.

The pneumatic tyres cushion the aircraft from shocks due to irregularities both in the ground surface and occasionally, lack of landing technique.

The main wheels, and in some cases nose wheels, house brake units which control the movement of the aircraft and provide a means of deceleration on landing.

AIRCRAFT WHEELS

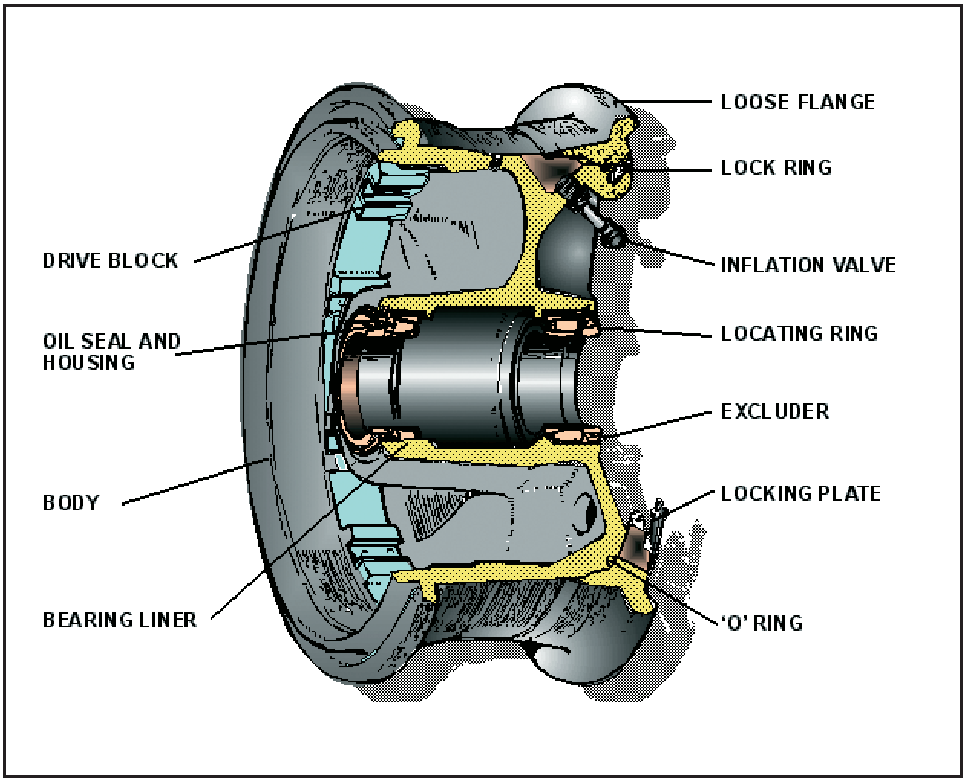


Figure 4.1: The loose flange wheel.

Aircraft wheels are so designed as to facilitate tyre replacement. Wheels are classified as follows:

- Loose and detachable flange.
- Divided.

LOOSE AND DETACHABLE FLANGE WHEEL

Wheels of this type, see *Figure 4.1,* are made with one flange integral with the wheel body, and the other loose and machined to fit over the wheel rim.

The difference between the loose flange type and the detachable flange type is the method by which the removable flange is secured, the loose flange is retained by a locking device on the wheel rim, and the detachable flange is secured to the wheel body by nuts and bolts.

A detachable flange may be a single piece, or two or three pieces bolted together.

THE DIVIDED WHEEL

The divided wheel consists of two half wheels, matched up and connected by bolts which pass through the two halves, the bolts are fitted with stiff nuts, or, if one half of the wheel is tapped, each bolt is locked with a locking plate.

In the wheel illustrated in *Figure 4.2,* the two halves are clamped together by bolts, nyloc nuts and washers.

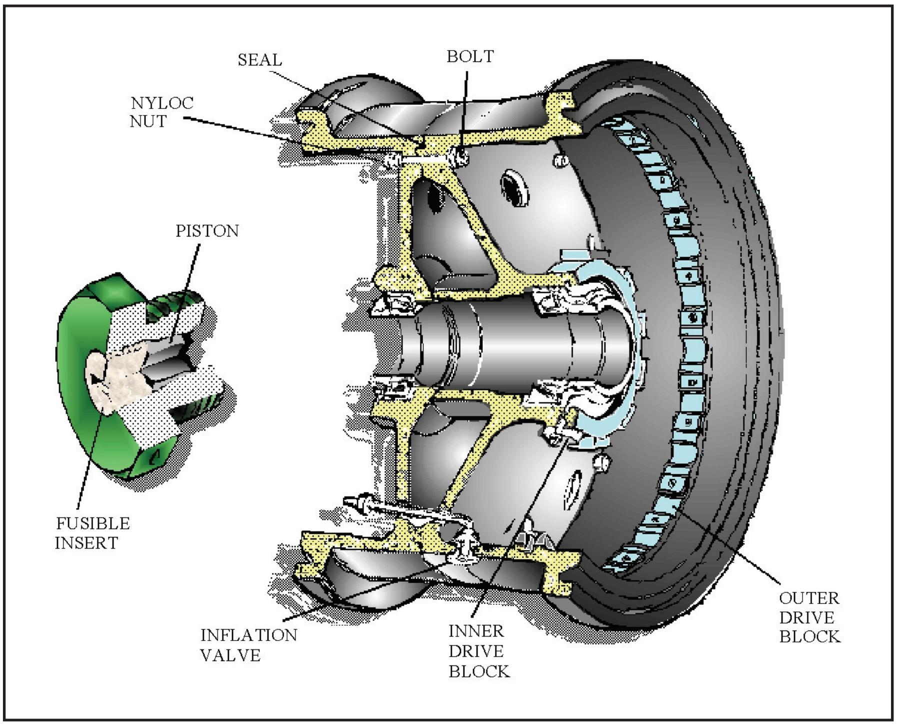


Figure 4.2: The divided wheel and a fusible plug.

This wheel is designed to be used with a tubeless tyre. A seal, incorporated at the joint, prevents abrasion between the two halves and provides an airtight joint.

When used with a conventional tyre, the wheel inflation valve is removed to enable the tube inflation valve to be fitted through the rim.

PREVENTION OF CREEP

When in service, the tyre has a tendency to rotate, creep (slippage) around the wheel (see Chapter 5 - Aircraft Tyres). This creep, if excessive, will tear out the inflation valve and cause the tyre to burst.

Creep is less likely to occur if the tyre air pressure is correctly maintained, but additional precautions may be incorporated in the design of the wheel.

Methods of counteracting creep are as follows:

- **Knurled Flange.** The inner face of the wheel flange is milled so that the side pressure of the tyre locks the beads to the flange.

- **Tapered Bead Seat.** The wheel is tapered so that the flange area is of greater diameter than at the centre of the rim. When the tyre is inflated, the side pressure forces the bead outwards to grip the rim.

- **Creep Marks.** Creep can be detected by misalignment of two matched white lines one painted on the wheel and one on the tyre.

WHEEL MATERIAL

Aircraft wheels are either cast or forged, then machined and ground to the required finish. They are made of:

- Aluminium alloy.

- Magnesium alloy - Electron.

After initial machining has been carried out, an anti-corrosive treatment is applied:

- Anodising for aluminium alloy wheels.

- Chromate treatment for magnesium alloy wheels.

- A final finish using cellulose or epoxy resin paint is applied to each wheel.

WHEELS FOR TUBELESS TYRES

Wheels for tubeless tyres are similar in construction to non-tubeless but are ground to a finer finish and impregnated with Bakelite to seal the material. 'O' ring seals are used between the parts of the wheel to prevent leakage.

Unlike tubed wheels, the **valve** is built into the wheel itself and is thus **not affected by creep.**

FUSIBLE PLUGS

Under extra hard braking conditions the heat generated in the wheel, tyre and brake assembly could be sufficient to cause a tyre blowout, with possible catastrophic effect to the aircraft.

To prevent a sudden blowout **fusible plugs** are fitted in some tubeless wheels. These plugs are held in position in the wheel hub by means of fusible alloy, which melts under excessive heat conditions and allows the plug to be blown out by the tyre air pressure.

This prevents excessive pressure build up in the tyre by allowing controlled deflation of the tyre. An example of a fusible plug is shown in *Figure 4.2*, they are made for 3 different temperatures, being colour coded for ease of identification:

- Red - 155 °C
- Green - 177 °C
- Amber - 199 °C

CHAPTER FIVE

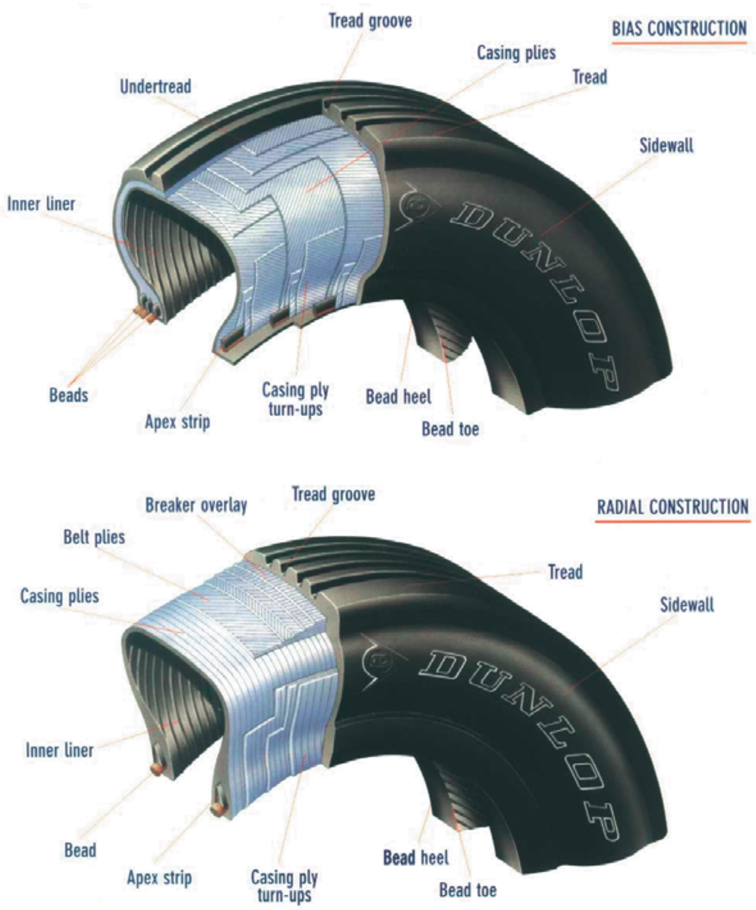
AIRCRAFT TYRES

Contents

TYRES INTRODUCTION

Aircraft wheels are fitted with pneumatic tyres which may be tubeless or have an inner tube. Tubes tend to be fitted to light and older aircraft.

Tyres are usually inflated with **nitrogen** which absorbs shock and supports the weight of the aircraft, while the cover restrains and protects the tube from damage, maintains the shape of the tyre, transmits braking and provides a wearing surface.



Reproduced by kind permission of Dunlop Aircraft Tyres Ltd

Figure 5.1: The make up of a tyre.

TYRE COVERS

The tyre cover consists of a casing made of rubber which is reinforced with **plies** of cotton, rayon or nylon **cords**. The cords are not woven, but arranged parallel in single layers and held together by a thin film of rubber which prevents cords of adjacent plies from cutting one another as the tyre flexes in use.

During the construction of the cover, the plies are fitted in pairs and set so that the cords of adjacent plies are at 90 degress to one another in the case of **bias** (**cross-ply**) tyres and from bead to bead at approximately 90 degrees to the centre line of the tyre in **radial** tyres.

To absorb and distribute load shocks, and protect the casing from concussion damage, two narrow plies embedded in thick layers of rubber are situated between the casing and the tread, these special plies are termed **breaker strips**.

The casing is retained on the rim of the wheel by interlocking the plies around inextensible steel wire coils to form ply overlaps, this portion of the cover is known as the **bead**.

The tyre manufacturers give each tyre **a ply rating**. This rating does not relate directly to the number of plies in the tyre, **but is the index of the strength of the tyre**.

For example, a 49 x 17 size tyre with a ply rating of 32 only has 18 plies.

The wire coils are made rigid by bonding all the wires together with rubber, to ensure a strong bond, each wire is copper plated. The bead coil is also reinforced by winding with strips of fabric before the apex and filler strips are applied. The apex strips, which are made of rubber and located by rubberised fabric filler strips, provide greater rigidity and less acute changes of section at the bead. They also provide a greater bonding area.

Finally, the bead portion is protected on the outside by chafer strips of rubberised fabric. *Figure 5.1* illustrates the above points.

THE REGIONS OF THE TYRE

To assist in describing the cover, it is divided into regions or sections as illustrated in *Figure 5.2.*

The **tread** of the tyre is situated in the **crown** and **shoulder** section, and it should be noted that the term 'tread' is applied irrespective of whether the rubber is plain and smooth, or moulded on a block pattern.

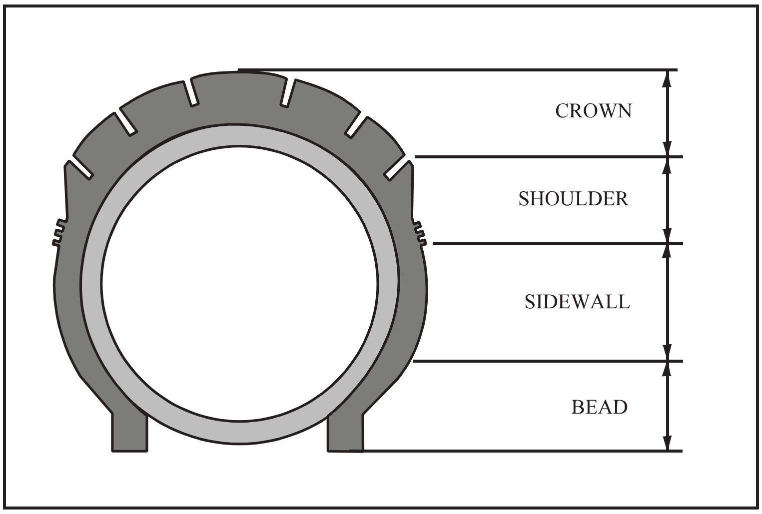


Figure 5.2: The regions of the tyre.

The most popular tread pattern is that termed **Ribbed**,which has circumferential grooves around the tyre to assist in water dispersion and to help prevent **aquaplaning (hydroplaning).** The grooves also help to improve traction and contact grip between the tread and the runway surface.

Not seen so frequently now, but still termed the **all weather pattern**, is the **Diamond tread** pattern.

Nose wheel tyres, particularly those fitted to aircraft with the engines mounted on the rear fuselage, may have a **chine** moulded onto the shoulder. This is to direct water away from the engine intakes and so prevent flameouts due to water ingestion.

A nose wheel tyre fitted to a single wheel installation will have a chine moulded onto both sides of the tyre.

INNER TUBES

An inner tube is manufactured by an extruding machine, which forces a compound of hot rubber through a circular die, thus producing a continuous length of tubing. The requisite length is cut off, the ends are then butt welded and a valve is fitted.

The tube is placed in a mould, inflated and vulcanised, so producing the finished tube to the required dimensions.

During braking, excessive heat is generated in some types of brake unit, which could cause damage to a standard base tube. Depending on the design of the wheel and the type of brake unit, the tube may have a standard, thickened, or cord reinforced base.

When renewing a tube it must be replaced by one of the same type.

THE INFLATION VALVE

The tube is inflated through an inflation valve, in which the stem is attached to the rubber base by direct vulcanisation, and the rubber is vulcanised to the tube, renewal of the inflation valve is not permitted.

Each inflation valve is fitted with a **Schrader valve** core which operates as a non-return valve. **The valve core is not considered to be a perfect seal**, therefore, **the inflation valve must always be fitted with a valve cap**, the valve cap also prevents dirt entering the valve. The older type of valve core has a spring made of brass, but the modern type is fitted with a stainless steel spring.

TUBELESS TYRES

These tyres are similar in construction to that of a conventional cover for use with a tube, but an extra rubber lining is vulcanised to the inner surface and the underside of the beads. This lining, which retains the gas pressure, forms an gastight seal on the wheel rim.

The gas seal depends on a wedge fit between the underside of the tyre bead and the taper of the wheel rim on which the beads are mounted. The inflation valve is of the usual type, but is fitted with a rubber gasket and situated in the wheel rim. The advantage of tubeless tyres over conventional tyres include the following:

- The gas pressure in the tyre is maintained over longer periods because the lining is unstretched.

- Penetration by a nail or similar sharp object will not cause rapid loss of pressure because the unstretched lining clings to the objects and prevents loss of nitrogen.
- The tyre is more resistant to impact blows and rough treatment because of the increased thickness of the casing, and the lining distributes the stresses and prevents them from causing local damage.
- Lack of an inner tube means an overall saving of approximately 7.5% in weight.
- Inflation valve damage by creep (slippage) is eliminated.

TYRE PRESSURES

The difference in landing speeds, loading, landing surfaces and landing gear construction of aircraft make it necessary to provide a wide range of tyre sizes, types of tyre construction and inflation pressures.

There are four main categories of tyre pressures, which are as follows:

- **Low Pressure**. Designed to operate at a pressure of 25 lb. to 35 lb. per sq.in, (1.73 - 2.42 bar), used on grass surfaces.
- **Medium Pressure**. Operates at a pressure of 35 lb. to 70 lb. per sq. in, (2.42 - 4.83 bar) and is used on grass surfaces or on medium firm surfaces without a consolidated base.
- **High Pressure**. Operates at a pressure of 70 lb. to 90 lb. per sq. in, (4.83 - 6.21 bar) and is suitable for concrete runways.
- **Extra High Pressure**. Operates at pressures of over 90 lb. per sq. in (some tyres of this type are inflated to 350 lb. per sq. in)(6.21 - 24.2 bar), the tyre is suitable for concrete runways.

TYRE MARKINGS

The letters ECTA or the symbol are used to indicate a tyre that has extra carbon added to the rubber compound to make it electrically conducting to provide earthing (grounding) between the aircraft and ground.

The size of a tyre is marked on its sidewall and includes the following information:

- The outside diameter in inches or millimetres.
- The nominal width in inches or millimetres.
- The inside diameter in inches.

The ply rating, the index of the tyre's strength, is also marked on the sidewall. Normally it is shown as an abbreviation, i.e. 16PR, but occasionally it is shown in full as "16 PLY RATING".

The speed rating of the tyre denotes the maximum rated ground speed in miles per hour to which the tyre has been tested and approved. This is embossed on the sidewall of the tyre. The rating takes account of pressure altitude, ambient temperature and wind component, enabling the maximum take off weight the tyres can sustain to be calculated.

Green or grey dots painted on the sidewall of the tyre indicate the position of the "awl" vents. Awl vents prevent pressure being trapped between the plies which would cause disruption of the tyre carcase if it was exposed to the low pressures experienced during high altitude flight.

A Red Dot or Triangle indicates the lightest part of the tyre. If this is placed opposite the valve during tyre fitting then it assists in balancing the wheel assembly.

The letters DRR printed in the code panel and the words "**REINFORCED TREAD**" printed on the sidewall are indicative of the fact that the tyre has a layer of fabric woven into the tread which may become visible during normal wear. This layer must not be confused with the casing **cords**.

TYRE CONTAMINATION

Tyres must be protected from excessive heat, dampness, bright sunlight, contact with oil, fuel, glycol and hydraulic fluid, all of these have a harmful effect on rubber. Oilskin covers should be placed over the tyres when the aircraft is to be parked for any length of time or during the periods when oil, fuel, cooling or hydraulic systems are being drained or replenished. Any fluid inadvertently spilt or allowed to drip on to a tyre must be wiped off immediately.

CREEP (SLIPPAGE)

When tyres are first fitted to a wheel they tend to move slightly around the rim. This phenomenon is called '**creep**' and at this stage it is considered normal. After the tyres settle down this movement should cease.

In service, the tyre may tend to continue to creep around the wheel. If this creep is excessive on a tyre fitted with an inner tube, it will tear out the inflation valve and cause the tyre to burst. Creep is less of a problem with tubeless tyres, as long as the tyre bead is undamaged and any pressure drop is within limits.

Creep is less likely to occur if the tyre air pressure is correctly maintained. To assist in this, tyre manufacturers specify a **RATED INFLATION PRESSURE** for each tyre. This figure applies to a **cold tyre not under load**, that is, a tyre not fitted to an aircraft. Distortion of the tyre cover when the weight of the aircraft is on it will cause the **tyre pressure to rise by 4%.** When checking the tyre pressure of a cold tyre fitted to an aircraft should mentally add 4% to the rated tyre pressure.

During use, that is during taxying, take off or landing, the tyres will become heated. This can cause up to **a further 10% rise in tyre pressure**.

CORRECT TYRE PRESSURES

Tyres in use must be kept inflated to the correct pressures using nitrogen or other inert gas (with a maximum 5% oxygen content) as under inflated tyres may move (creep) round the wheel, over inflated tyres will cause other types of failure. It is estimated that 90% of all tyre failures can be attributed to incorrect air pressure. Modern aircraft can even display tyre pressures on the electronic systems monitoring screen.

AQUAPLANING

Aquaplaning is a phenomenon caused by a wedge of water building up under the tread of the tyre and breaking its contact with the ground.

Aquaplaning speed, in **Nautical Miles per Hour**, the speed that the tyre loses contact can be found by applying the formula:

AQUAPLANING SPEED = $9\sqrt{P}$ (where P = the tyre pressure in PSI)

or:

AQUAPLANING SPEED = $34\sqrt{P}$ (where P = the tyre pressure in kg/cm2)

The possibility of aquaplaning increases as the depth of the tread is reduced, it is therefore important that the amount of tread remaining is accurately assessed. The coefficient of dynamic friction will reduce to very low values, typically 0, when aquaplaning.

MAT LIMITS

When calculating take off distance/obstacle clearance with increased V2 speeds it is important not to exceed the speed rating of the tyres fitted to the aircraft e.g. it may be necessary to reduce mass in order to satisfy MAT Limits.

TYRE DAMAGE

During servicing, tyre covers must be examined for cuts, bulges, embedded stones, metal or glass, signs of wear, creep, local sponginess, etc. The defects, which may make the cover unserviceable, should receive the following attention or treatment:

- **Cuts.** Cuts in the tyre cover penetrating to the cords render the tyre unserviceable and must be repaired.

- **Bulges**. These may indicate partial failure of the casing, if the casing has failed, i.e. the fabric is fractured, renew the cover.

- **Foreign Bodies**. Embedded Stones, Metal, Glass etc. These must be removed and the cuts probed with a blunt tool to ascertain their depth, repair or renewal of the cover is governed by the extent of the damage (see sub-para (a)).

- **Wear**. Pattern tread covers worn to the base of the **marker grooves** or **marker tie bars** for 25% of the tyre circumference, or plain tread covers worn to the casing fabric, must not be used. *See Figure 5.3*.

- **Creep**. Movement of the tyre round the wheel must not exceed 1 in for tyres of up to 24 in outside diameter and 1½ in for tyres over 24 in outside diameter. If these limits are exceeded, the tyre must be removed from the wheel and the tube examined for signs of tearing at the valve, also examine the valve stem for deformation. If the tube is serviceable, the tyre may be refitted and creep marks re-applied.

REDUCTION OF TYRE WEAR

With the increased size of modern airports, taxi distances also increase, thus increasing the amount of tyre wear and risk of damage. To minimise tyre wear therefore, it is recommended that a **speed of no more than 25 m.p.h (40 kph)** should be reached during the taxi run.

Over inflation will cause excessive wear to the crown of the tyres whilst under inflation is the cause of excessive shoulder wear.

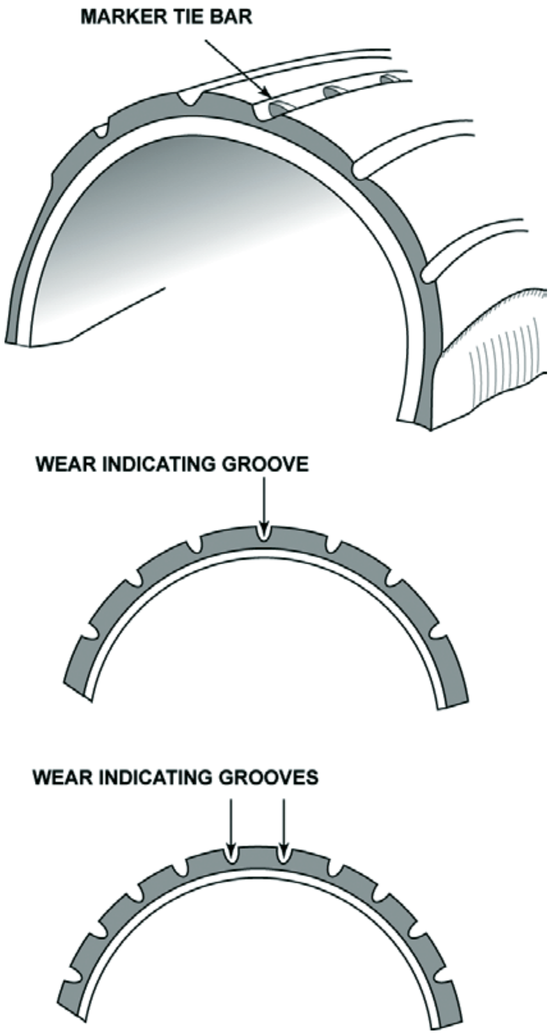


Figure 5.3: Wear markers and indicating grooves.

CHAPTER SIX

AIRCRAFT BRAKES

Contents

INTRODUCTION

In common with most braking systems, aircraft wheel brakes function by using friction between a fixed surface and a moving one to bring an aircraft to rest, converting kinetic energy into heat energy. The amount of heat generated in stopping a large modern aircraft, is enormous, the problem of dissipating this heat has been a challenge to aircraft designers and scientists for years. As progress has been made in this direction, so aircraft have got faster and heavier and the problem worse.

The ideal answer of course, would be to build runways of sufficient length, so that an aircraft would have no need to use its brakes at all, but the prohibitive cost of building runways 4 and 5 miles long makes it a non starter.

The advent of reverse pitch on propeller driven aircraft and reverse thrust on jet engines aircraft, has provided a partial answer to the problem, but even with these, the need for normal braking still exists.

PLATE OR DISC BRAKES

All modern aircraft now use **plate brakes** operated by hydraulic systems as their means of slowing down or stopping. This system uses a series of fixed friction pads, bearing on or gripping, one or more rotating plates, similar in principle to disc brakes on a car.

The number of friction pads and rotating plates that are used is a matter of design and wheel size, a **light aircraft** would be able to utilise a **single plate disc brake** whereas a typical arrangement on a **large aircraft** would be a **multi-plate unit** similar to the one illustrated in *Figure 6.1.*

In this unit, the physical size of the braking area has been increased by employing multiple brake plates sandwiched between layers or friction material. In this sort of construction the rotating plates (rotors) are keyed to revolve with the outer rim of the wheel and the stationary plates carrying the friction material (stators) are keyed to remain stationary with the hub of the wheel. When the brake is applied hydraulic pressure pushes the actuating pistons, housed in the torque plate, squeezing the rotors and stators between the pressure plate and the thrust plate. The harder the brake pedal is applied the grater the braking force applied to the pressure plate by the pistons. The torque generated by the brake unit is transmitted to the main landing gear leg by a torque rod or 'brake bar', (*illustrated in chapter 3, figure 3.2*)

The friction pads are made of an inorganic friction material and the plates of '**heavy' steel** with a specially **case hardened surface**. It is this surface which causes the **plates to explode** if covered **with liquid fire extinguishant** when they are red hot. In the unfortunate event of a wheel or brake fire, the **best extinguishant to use is dry powder.**

Recent technological advancements in heat dissipation, have resulted in the design of the brake plates being changed from a continuous rotating single plate, to a plate constructed of many interconnected individual segments with the heat dissipation properties greatly improved, thus increasing brake efficiency. Carbon is also used for manufacturing brake units because it has much better heat absorbing and dissipating properties. Carbon brakes are also much lighter than equivalent steel units. The disadvantage is their increased cost and shorter life, so they tend to be fitted only to aircraft where the weight saving is worth the extra cost, long haul aircraft, for example.

If the brakes become too hot, they will not be able to absorb any further energy and their ability to retard (slow down) the aircraft diminishes. This phenomenon is termed **Brake Fade.**

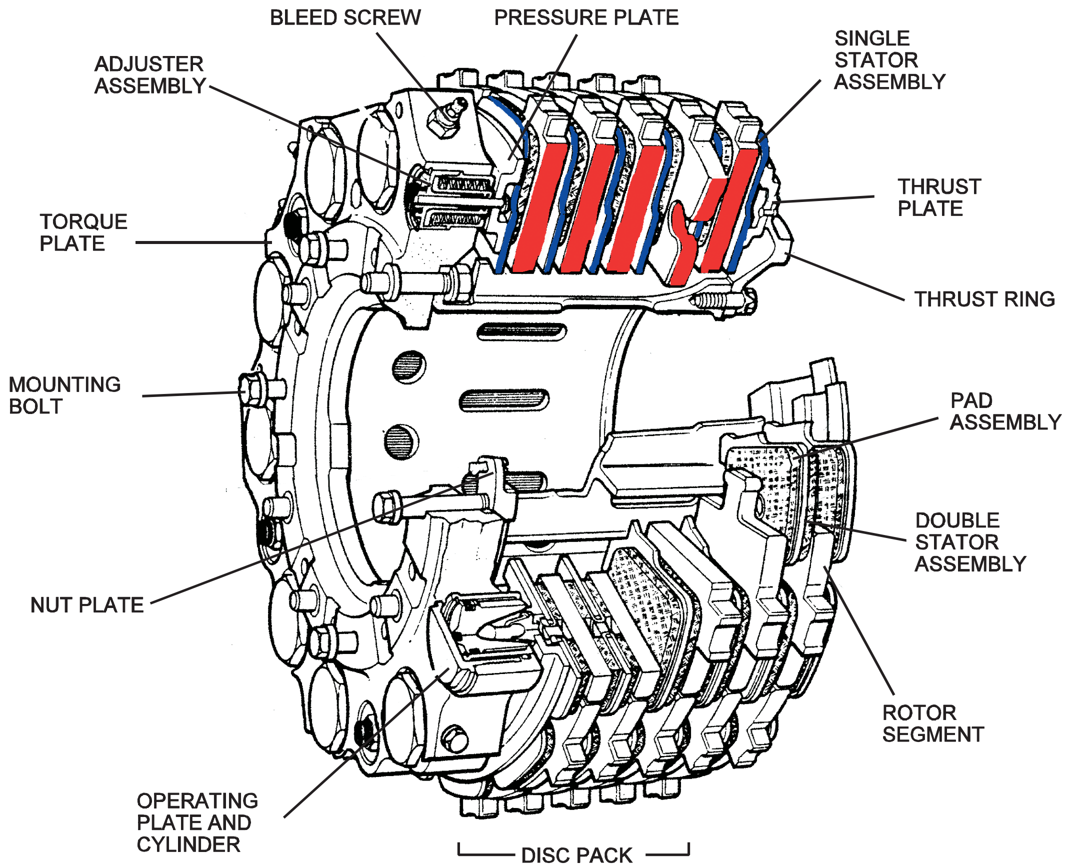


Figure 6.1: A typical multi-plate brake unit.

BRAKE RELEASE

When the pilot releases the pressure on the brake pedals, the **brake adjuster assemblies** will move the pressure plate away from the stators and rotor assemblies, thus allowing them to move slightly apart. The internal construction of the brake adjuster assemblies allows them to maintain a constant running clearance when the brake is off thereby **automatically compensating for brake wear**.

If the return spring inside the adjuster assembly ceases to function, or **if the unit is wrongly adjusted, then they could be the cause of a brake not releasing correctly. This is termed brake drag.**

Brake drag will generate a lot of heat and can be responsible for **Brake Fade** occurring sooner than it otherwise would. Air in the hydraulic system of the brake can also cause the brakes to drag.

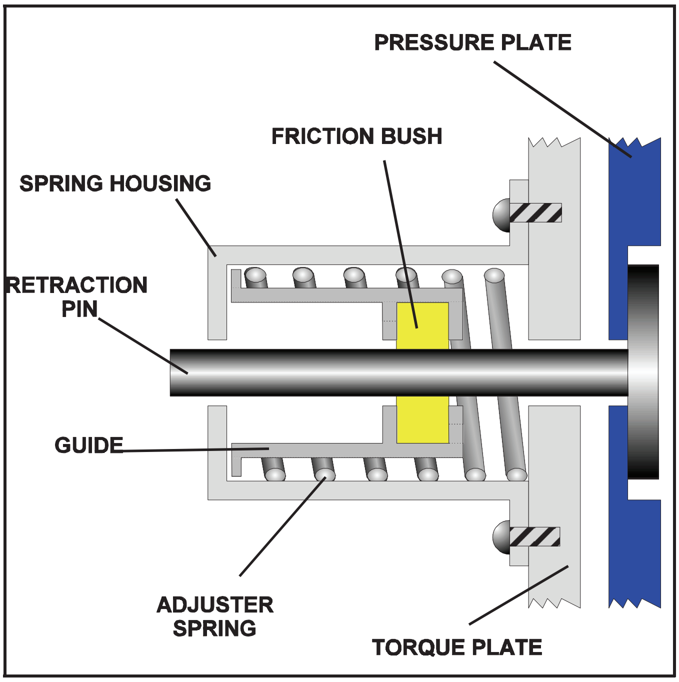


Figure 6.2: A brake adjuster assembly.

BRAKE WEAR

Aircraft brakes are designed to give good retardation, while at the same time avoiding excessive wear of the brake lining material.

It is important that the thickness of the brake lining material is carefully monitored.

Too little brake lining material remaining may mean that the disc of a single disc brake system may become excessively worn or grooved, or that on a multiple disc brake, the remaining material overheats and erodes extremely fast.

There are several methods of determining the amount of brake lining material which remains on the brake unit, the following are just some of those methods.

On **multiple disc brake** systems, the most popular method of gauging the depth of brake lining material remaining is by checking the amount that the **retraction pin** (or the indicator pin, as it is sometimes called) extends from (or intrudes within) the **spring housing** with the **brakes selected on.**

Figure 6.3 shows how a **wear gauge** can be used to check that the retraction pin has not moved too far within the spring housing.

An alternative method which can be used if no retraction pins are fitted to the system is that whereby the amount of clearance between the back of the pressure plate and the brake housing can be measured, once again with the brakes applied.

If the brake is a single disc unit, the amount of brake lining material remaining can be checked by once again applying the brakes and measuring the distance between the **disc** and the **brake housing** and ensuring that it is no less than a minimum value.

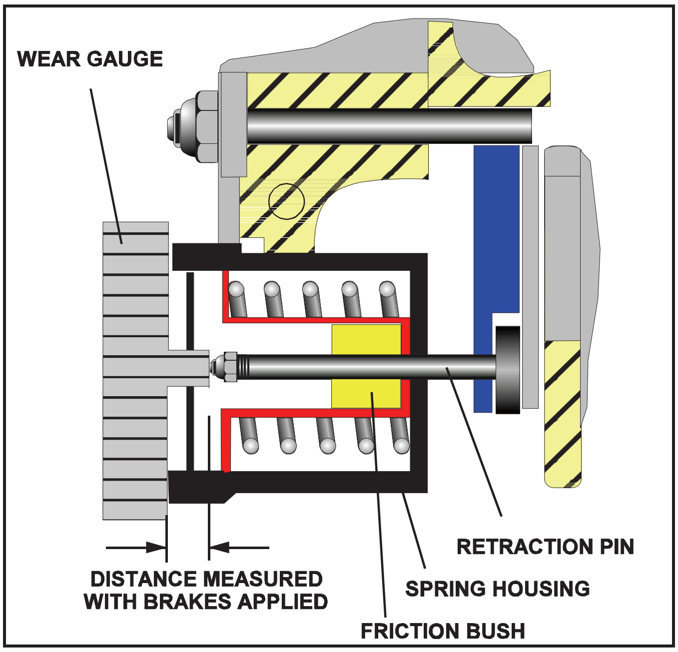


Figure 6.3: Measuring brake waer in a multiple disc brake system.

BRAKE SYSTEM OPERATION

Operation of the brake pedals on the flight deck, allows hydraulic fluid under pressure to move small pistons which, by moving the pressure plate, force the stator pads against the rotor plates, with the resultant friction slowing the plates down.

On a small aircraft the hydraulic pressure from the brake pedals may be enough to arrest its progress. On a large aircraft it is obvious that foot power alone will be insufficient, some other source of hydraulic power is required. This is supplied by the aircraft main hydraulic system.

BRAKE MODULATING SYSTEMS

Optimum braking is important in the operation of modern aircraft with their high landing speeds, low drag and high weight, particularly when coupled with operation from short runways in bad weather. The pilot is unable to sense when the wheels lock and so the first requirement off a brake modulating system is to provide anti-skid protection.

Whenever braking torque is developed there must be only a degree of slip between the wheel and the ground, a skidding wheel provides very little braking effect. In all brake modulating systems the deceleration of the individual wheels is taken as the controlling parameter of braking torque.

A datum figure for wheel deceleration is selected which is known to be greater than the maximum possible deceleration of the aircraft - of the order of 18 ft/s^2 ($6m/s^2$) - and when this datum figure is exceeded, brake pressure is automatically reduced or released.

The facility to "**hold off**" brake pressure in the event of a wheel bounce or to prevent brake operation before touchdown may also be built into the system.

Systems may be mechanical or electrical, mechanical systems have been in use since the early 1950s. Most aircraft use electrical or electronic systems.

MECHANICAL ANTI-SKID SYSTEMS

The basic principle of these systems is the use of the inertia of a **flywheel** as a sensor of wheel deceleration.

A wheel directly driven by the aircraft wheel is coupled to the flywheel by a spring. Any changes in aircraft wheel velocity cause a relative displacement between the flywheel and the driven wheel. This relative displacement is used as a control signal to operate a valve in the hydraulic braking system to release the brake pressure. The unit may be wheel rim or axle mounted.

ELECTRONIC ANTI-SKID SYSTEMS

The response rates of the flywheels used in mechanical systems are low when compared with electrical signalling and furthermore the modulation does not always conform to the true runway conditions.

It is also much easier to alter the response rates and system biases of electronic circuitry to suit different aircraft types, thus making it simpler to adapt the circuits to match the requirements of new aircraft types.

The electronic system gives approximately a 15% improvement over the mechanical unit with the advantage that it can be tested prior to use.

The electronic system comprises three main elements:

- A sensor which measures wheel speed.
- A control box to compute wheel speed information.
- A servo valve to modulate brake pressure.

The basic control loop described above offers few advantages over a mechanical system except that the cycling rate is much improved. A system refinement is that of the **Adaptive Pressure Bias Modulation Circuit.**

This ensures that the brake pressure applied immediately after a wheel is released after an Anti-Skid Unit (A.S.U.) operation, is lower than the pressure which was applied before the A.S.U. operation preventing an immediate return to the conditions that caused the ASU to release the pressure in the first place.

The ASU provides three important functions:

- **Touch down protection.**
  This will prevent the brakes being applied before touch down. The electronic anti-skid controller will monitor the wheel speed and air/ground logic. If no signal is received the brakes cannot be applied while the aircraft is airborne. On touch down the wheels 'spin up' and apply a signal to the controller which will now allow the brakes to be applied.

- **Skid prevention.**
  The anti skid controller will **reduce** the brake pressure to any wheel that it determines is approaching a skid by monitoring the deceleration rate of the individual wheels

- **Locked wheel protection**
  If a wheel locks because of a wet patch, or ice, the anti-skid controller will **release** the pressure to that wheel completely until the wheel spins up again and the pressure will be re-applied.

To enable the pilot to have full control of the brakes for taxying and manoeuvring, the anti-skid system is deactivated, either manually or automatically, when the aircraft has slowed down to **below approximately 20 m.p.h.**, it is assumed then that there is no further danger of skidding.

TYPICAL AIRCRAFT WHEEL BRAKE SYSTEM

The brakes are powered by one of the aircraft hydraulic power systems (system 1) with automatic switch over to an alternate system (system 2) in the event of low system 1 pressure. When normal and alternate brake hydraulic sources are lost, an accumulator is automatically selected to maintain parking brake pressure.

Antiskid Protection

The antiskid valves receive hydraulic pressure from the normal brake metering valves or the autobrake valves with the antiskid control unit providing electrical signals to the antiskid valves to control braking during skid conditions. Wheel speed transducers mounted in the axle transmit wheel speed inputs to the antiskid control unit. Each wheel is provided individually with antiskid protection when normal brakes are operative. When skidding is initially detected, the antiskid controller commands the respective antiskid valve to reduce brake pressure which protects the wheel from further skidding. Touchdown braking protection is provided by comparing wheel speed to IRS (inertial reference system) groundspeed. During alternate brake operation antiskid protection is provided to wheel pairs rather than individual wheels.

Torque Limiting

A brake torque sensor is provided at each wheel to detect excessive torque during braking to prevent damage to the landing gear (more a problem with CARBON brakes). When excessive torque stress is detected, a signal is sent to the antiskid valve and brake pressure to that wheel is released.

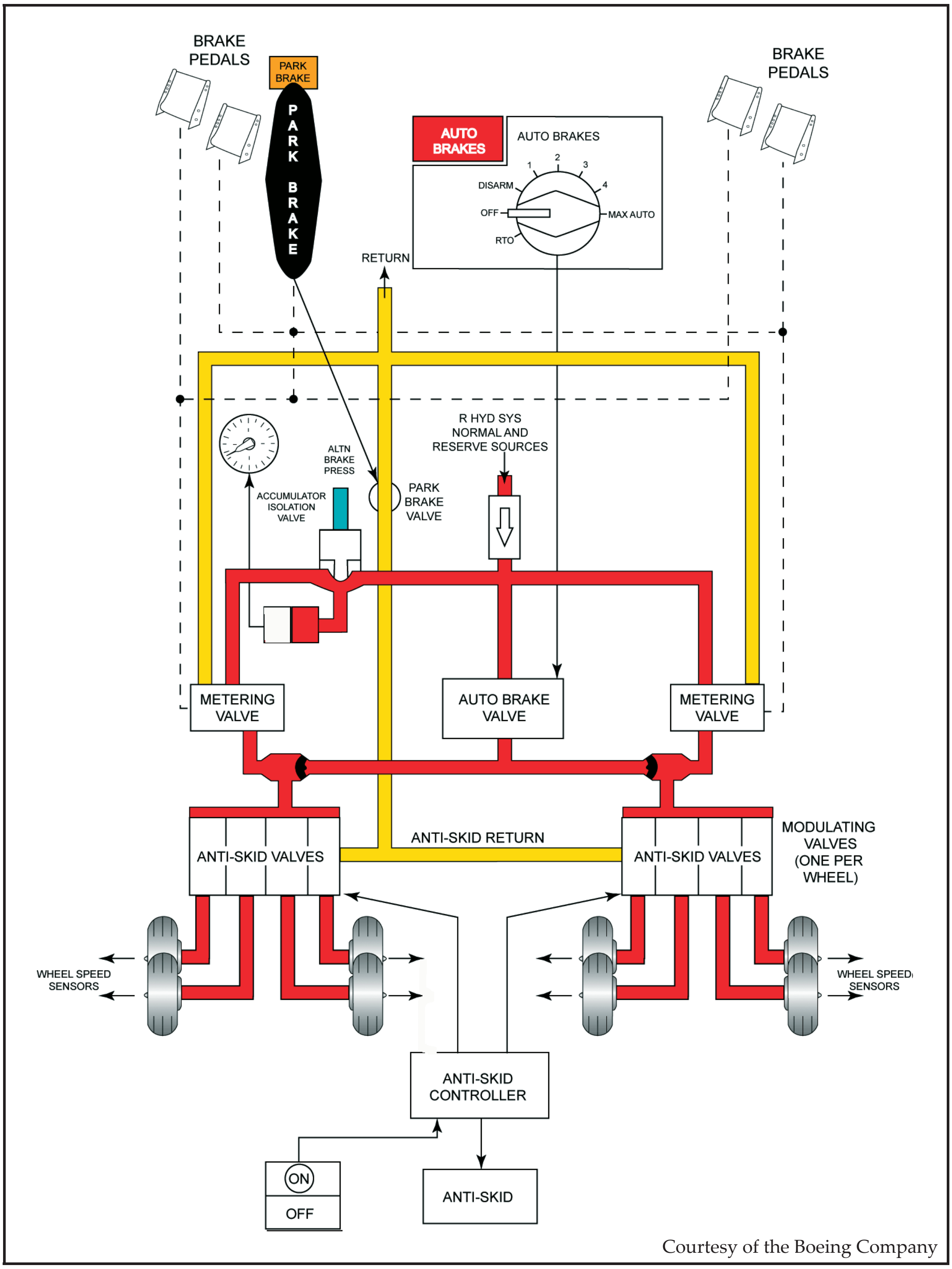


Figure 6.4: Typical brake and anti-skid system.

AUTOBRAKES

This system permits automatic braking when using the normal brake system during landing rollout or during a rejected takeoff. The autobrake system is not available when using the alternate brake system. Depending on the aircraft, three or five landing deceleration rates may be selected. The RTO (rejected takeoff) provides maximum braking. Antiskid protection is provided during autobrake operation. Landing autobrakes are armed by selecting one of the deceleration rates on the autobrake selector. On touchdown with ground mode and wheel spin up sensed the brakes will be automatically applied and will provide braking to a complete stop or until the autobrakes are disarmed. The deceleration rate may be changed during autobrake operation without disarming by rotating the selector.

With RTO selected, maximum brake pressure will be applied automatically when all thrust levers are closed at ground speeds above 85 knots. Below 85 knots autobrakes are not activated. The landing autobrakes system disarms immediately if an autobrake or normal antiskid system fault occurs. Disarming will also occur if any of the following crew actions are taken during autobrake operation:

Manual Braking.
Advancing any thrust lever after landing.

Moving the speed brake lever to the DN (down) detent after speed brakes have been deployed on the ground.

Moving the autobrake selector to Disarm or Off.

The autobrakes are normally disarmed by the non-handling pilot or flight engineer as the aircraft speed reduces to approximately 20 knots.

The parking brake handle operates a shut off valve in the return line to the reservoir from the antiskid valves. To apply the parking brake depress the foot pedals, apply the parking brake lever, then release the foot pedals. Hydraulic pressure is now trapped in the brakes because the return line from the anti-skid valves is closed. this will be capable of maintaining the brakes 'on' for overnight parking if required.

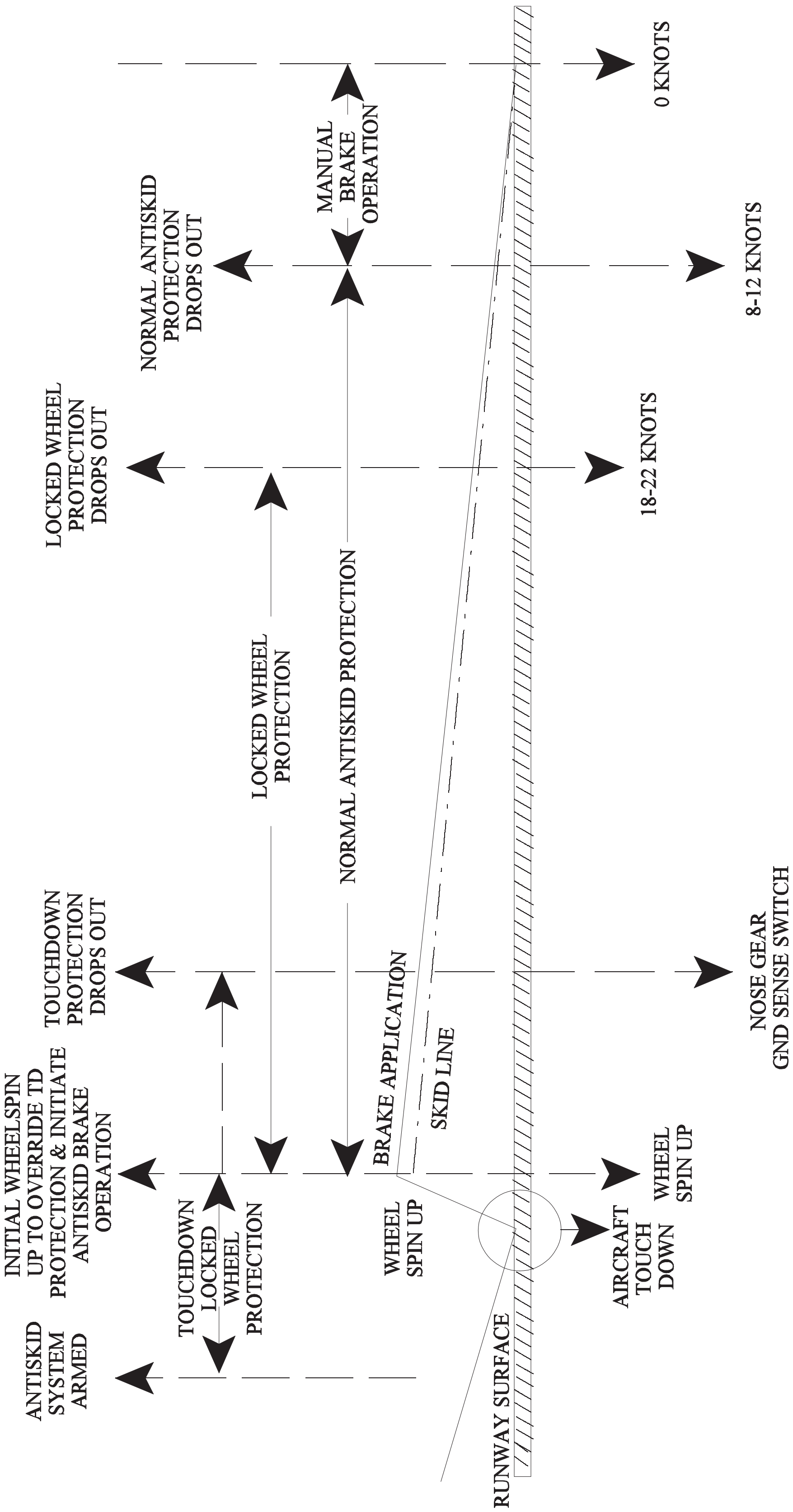

ANTISKID SYSTEM ARMED
INITIAL WHEELSPIN UP TO OVERRIDE TD PROTECTION & INITIATE ANTISKID BRAKE OPERATION
TOUCHDOWN PROTECTION DROPS OUT
LOCKED WHEEL PROTECTION DROPS OUT
NORMAL ANTISKID PROTECTION DROPS OUT
TOUCHDOWN LOCKED WHEEL PROTECTION
LOCKED WHEEL PROTECTION
NORMAL ANTISKID PROTECTION
MANUAL BRAKE OPERATION
WHEEL SPIN UP
BRAKE APPLICATION
SKID LINE
RUNWAY SURFACE
AIRCRAFT TOUCH DOWN
WHEEL SPIN UP
NOSE GEAR GND SENSE SWITCH
18-22 KNOTS
8-12 KNOTS
0 KNOTS

Figure 6.5

BRAKE KINETIC ENERGY GRAPH

During the application of brakes, a considerable amount of energy is absorbed. This energy is released in the form of heat which must be dissipated.

The brake packs, wheel assemblies and tyres are capable of absorbing so much heat and no more before they fail.

Some method of determining the amount of energy absorbed will facilitate decisions regarding precautions to be taken after an aborted take-off, a landing, or simply moving the aircraft around the airfield.

One such method is the **brake kinetic energy graph**, *Figure 6.6*. The graph is entered with an all up weight and a brake application speed and then factored for head or tailwind component, number of serviceable reversers and airfield altitude.

The end result is the amount of kinetic energy absorbed, but more importantly, three zones into which the situation has fallen, each of which will determine the course of action to be taken.

Figure 6.7. is a reproduction from an aircraft operations manual which outlines the three zones and the drills to be carried out in the event of the kinetic energy in the brakes being above a certain level.

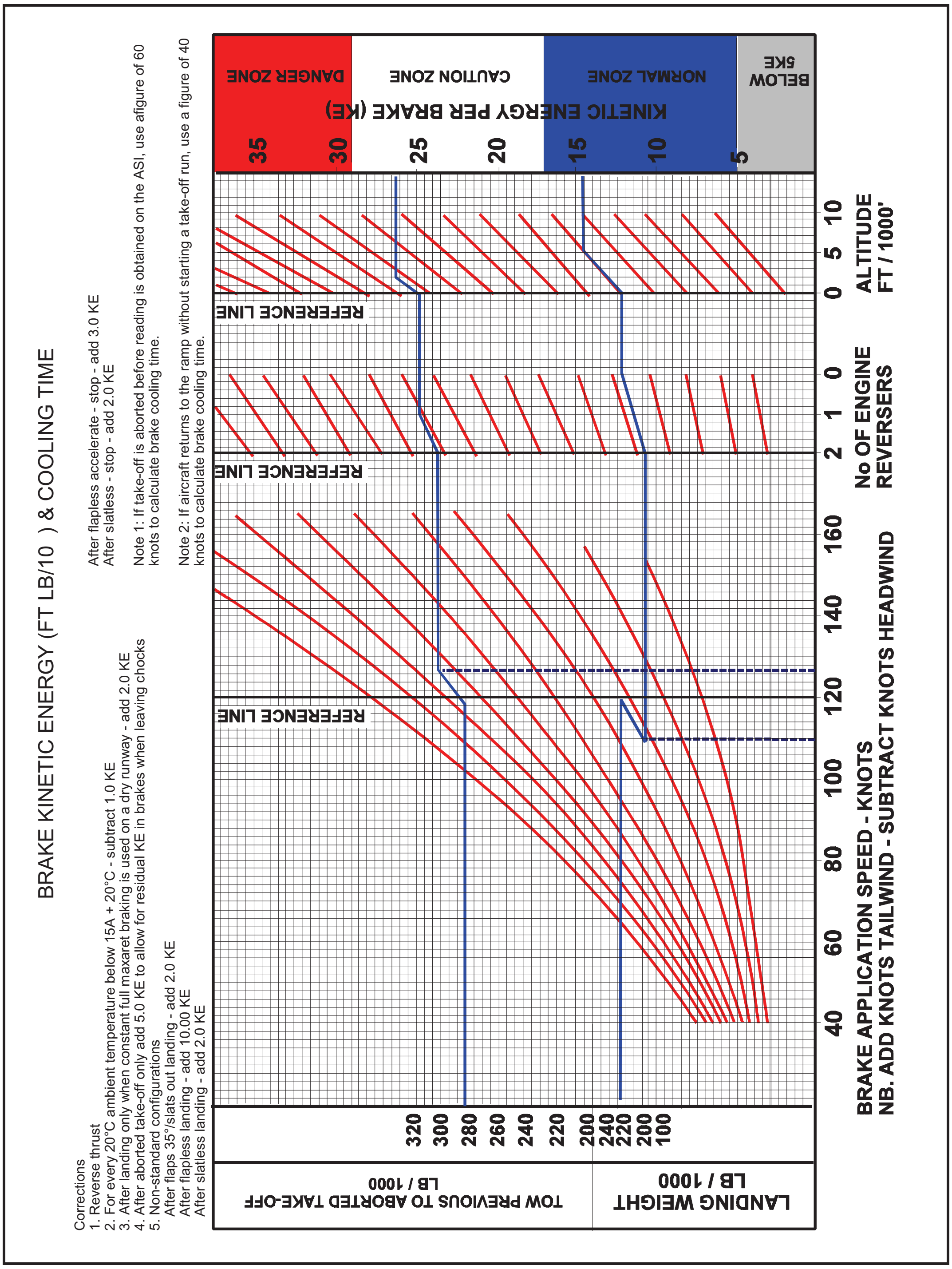


Figure 6.6: A brake kinetic energy graph.

ZONES

Danger Zone - (Above 29 KE)

1. Clear runway as soon as possible. Alert fire services.
2. Use minimum necessary footbrake pressure. Tyres will probably deflate.
3. Parking brake must not be used unless essential.
4. Shut down engines not required.
5. If tyres remain inflated, they must be approached with caution from front or rear.
6. Unless a brake/wheel assembly is in flames, allow brakes to cool without applying extinguishant.
7. If a brake/wheel assembly is on fire, apply dry powder extinguishant - and retire from the vicinity for at least 15 minutes.
8. Allow a cooling period of 2 to 3 hours, unless cooling air is used. Wheels and tyres must be changed.

Caution Zone - (17 to 29 KE)

1. Park the aircraft but do not apply parking brake.
2. Do not approach wheel assembly for at least 30 minutes.
3. Before take-off, check the brake wheel assembly for damage and apply brake pressure to check to brake seal leaks.
4. Operate the brakes and check that pressures are maintained.
5. Allow brake cooling time of 5 minutes for each 1.0 KE in excess of 5.0 KE.

Normal Zone - (5 to 17.0 KE)

1. Allow brake cooling time of 5 minutes for each 1.0 KE in excess of 5.0 KE.

Below 5 KE.

1. No brake cooling time necessary.
2. No special instructions.

Figure 6.7: The normal, caution and danger zones.

BRAKE TEMPERATURE INDICATORS

Larger aircraft types, (B747, B777, A340, A380 etc.) may be fitted with **Brake Temperature Indicators.**

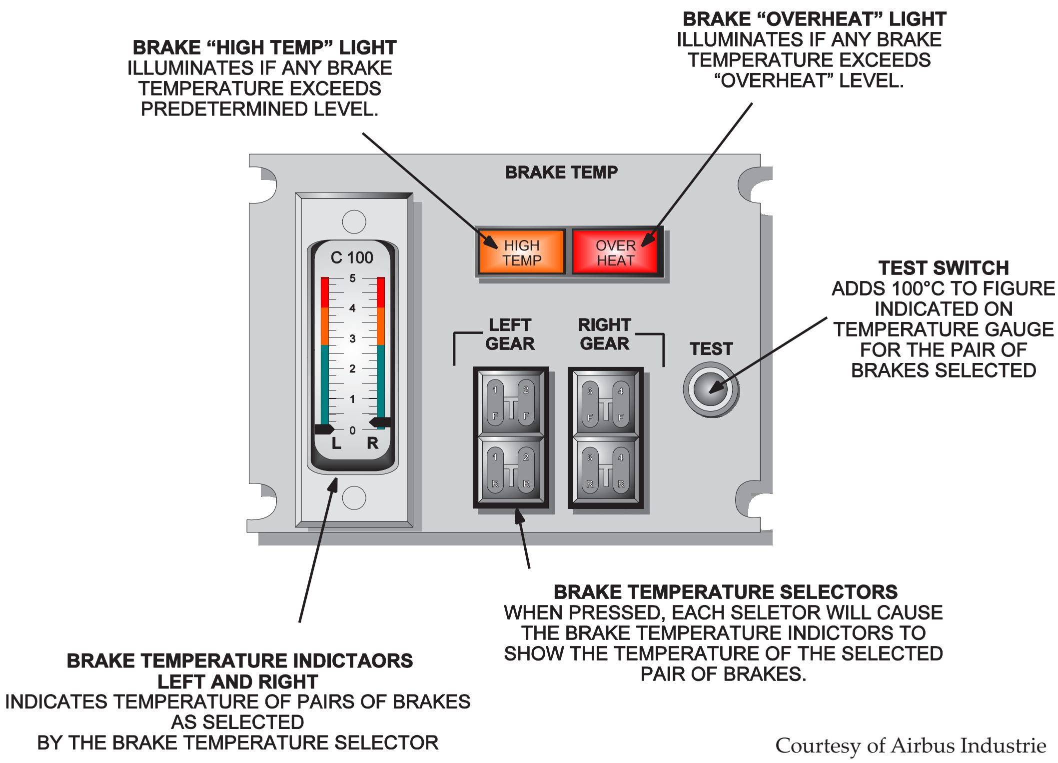
Sensors are arranged to **sample the temperature of the brakes of each individual wheel.**

An indicator can be used to **display the temperature of each pair of wheels** as selected on the system control panel.

The brake temperatures are constantly monitored by the system, if the temperature of any brake assembly rises above a predetermined level then a "**HIGH TEMP**" indicator light illuminates. Switch selection on the control panel will now enable the operator to locate the wheel brake or brakes which are triggering the alarm.

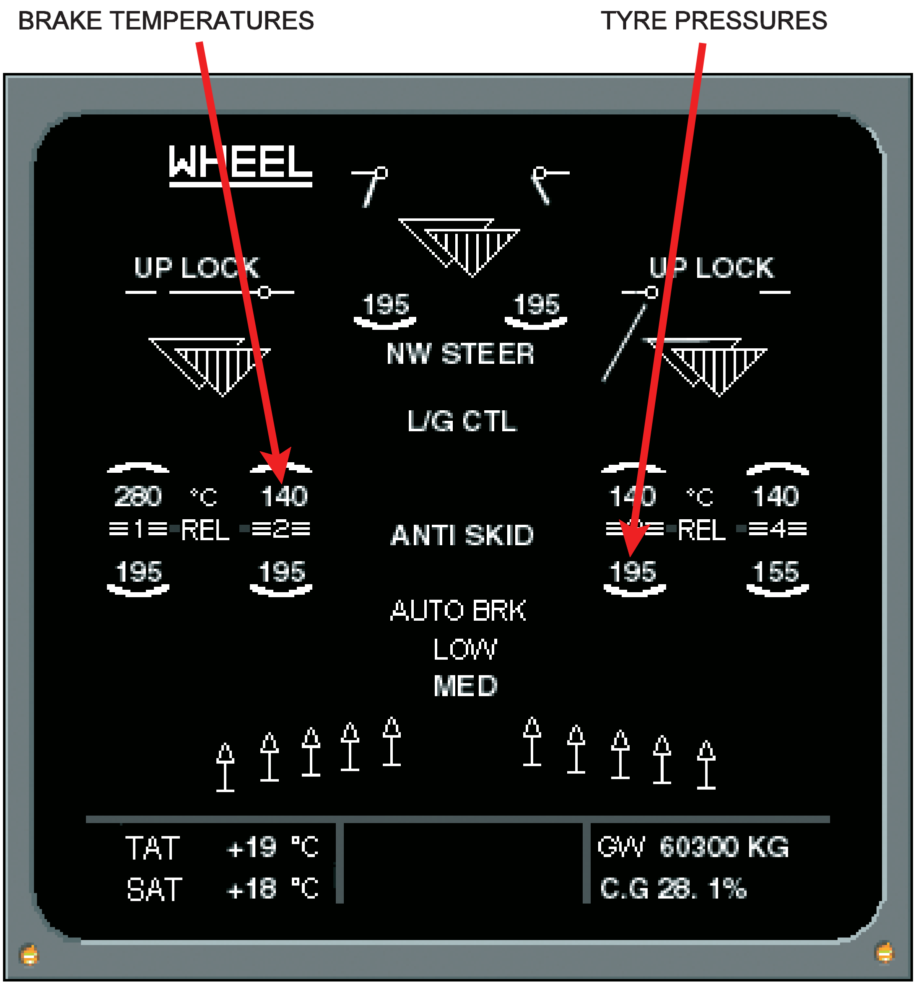
Should any brake temperature go above that level at which the High Temp warning light illuminates, then a brake "**OVERHEAT**" caption will come on.

This last event is duplicated on the Central Warning System. *Figure 6.8* illustrates a Brake Temperature Warning Panel.



Courtesy of Airbus Industrie

Figure 6.8: A brake temperature warning panel.



Courtesy of Airbus Industrie

Figure 6.9: A typical ECAM display.

WING GROWTH

Wing growth is a term used in relation to **swept wing aircraft only**. Because the centre of the turning circle of modern big jets is not the inboard oleo but a point further outboard, and also because of the swept wing planform, the circle which the outboard wing tip describes is larger than is first apparent. This may not be as great a problem with large aircraft with body gear steering. See *Figure 6.10*, where the wing growth area is shown in red.

Great caution should be exercised when manoeuvring large swept wing aircraft close to obstructions of any sort.

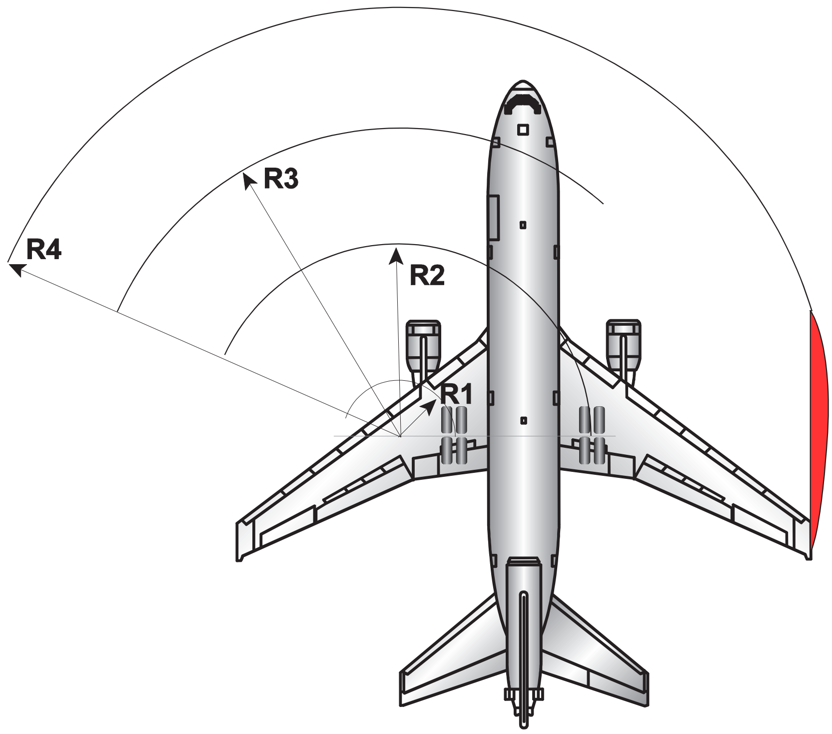


Figure 6.10: An illustration of wing growth.

QUESTIONS

1. Oil is used in an oleo strut to:

   a. support the weight of the aircraft.
   b. limit the speed of compression of the strut.
   c. lubricate the piston within the cylinder.
   d. limit the speed of extension and compression of the strut.

2. The nose wheel assembly must be centered before retraction because:

   a. there is limited space in the nose wheel bay.
   b. the aircraft may swerve on the next landing if the nose wheel is not straight.
   c. the tyres may be damaged on landing if the nose wheel is not straight.
   d. it will remove any slush or debris which may have accumulated on take-off.

3. The movement of the gear on lowering is normally damped to:

   a. prevent the fluid becoming aerated.
   b. counteract the force of gravity which would bring the gear down too fast.
   c. make the lowering time greater than the raising time.
   d. prevent the hydraulic fluid becoming overheated.

4. Inadvertent retraction of the landing gear on the ground is:

   a. not possible because the system is not powerful enough.
   b. prevented by the ground/air logic system.
   c. always a danger after the ground locks have been removed.
   d. the responsibility of the first officer when he is on the aircraft.

5. Creep (Slippage):

   a. is not a problem with tubeless tyres.
   b. refers to the movement of the aircraft against the brakes.
   c. can rip out the inflation valve on tubed tyres, and deflate the tyre.
   d. can be prevented by painting lines on the wheel and tyre.

6. Tyre wear when taxying can be reduced:

   a. restricting the use of brakes and using thrust reversers.
   b. taxying at less than 40 kph.
   c. staying on the smoothest parts of the taxiway.
   d. taxying at less than 25 knots.

7. To prevent scrubbing the tyres while taxying , you should:

   a. use tyres with fusible plugs.
   b. make sharp turns only if you have high speed tyres fitted.
   c. turn no sharper than the minimum specified radius.
   d. deflate the tyres to a minimum pressure.

8. The best extinguishant to use on a wheel or brake fire is:

a. CO_2.
b. dry powder.
c. freon.
d. water.

9. When inflating a tyre fitted to an aircraft, the tyre pressure reading on the gauge should be modified by:

a. 10psi.
b. 10%.
c. 4psi.
d. 4%.

10. The most likely cause of brake fade is:

a. oil or grease on the brake drums.
b. worn stators.
c. the pilot reducing the brake pressure.
d. the brake pads overheating.

11. The pressure needed to operate the wheel brakes on a large aircraft comes from:

a. the aircraft main hydraulic system.
b. the pilots brake pedals.
c. a self contained power pack.
d. the hydraulic reservoir.

12. Which of the following statements will produce the shortest landing run:

i. crossing the threshold at the correct height and speed
ii. applying full anti-skid braking as quickly as possible after touchdown
iii. using maximum pedal pressure but releasing the pressure as the wheels start to skid
iv. the use of cadence braking
v. use of minimum braking pressure early in the landing run and maximum pressure towards the end
vi. application of reverse thrust as early as possible in the landing run
vii. deployment of the lift dumpers/speed brakes as early as possible in the landing run

a. (i), (ii), (vi), (vii)
b. (i), (iii), (vi), (vii)
c. (i), (iv), (vi), (vii)
d. (i), (v), (vi), (vii)

13. The formula which gives the minimum speed (Vp) at which aquaplaning may occur is:

a. $Vp = 9 \times \sqrt{P}$ where P is kg/cm^2 and Vp is in knots.
b. $Vp = 9 \times \sqrt{P}$ where P is psi and Vp is in mph.
c. $Vp = 9 \times \sqrt{P}$ where P is psi and Vp is in knots.
d. $Vp = 34 \times \sqrt{P}$ where P is kg/cm^2 and Vp is in mph.

14. An aircraft has a tyre pressure of 225 psi, its minimum aquaplaning speed will be:

a. 135 mph.
b. 135 knots.
c. 145 knots.
d. 145 mph.

15. Landing gear ground locking pins are:

a. fitted before flight to ensure the landing gear locks are fully cocked.
b. removed prior to flight and returned to stores.
c. fitted after flight to maintain a hydraulic lock in the down lock jack.
d. removed prior to flight and stowed on the aircraft where they are visible to the crew.

16. The most likely cause of brake unit dragging is:

a. dirt between the rotor and stator assemblies.
b. grease on the rotor assembly.
c. the brake pressure being too high.
d. incorrect operation of the adjuster assemblies.

17. A likely cause of nose wheel shimmy is:

a. aircraft is overweight.
b. the tyre pressures are too high.
c. the aircraft is incorrectly loaded.
d. a torque link is worn or damaged.

18. Creep (slippage):

a. can damage the braking system.
b. can be measured by painting marks on the tyre and wheel rim.
c. may cause excess wear.
d. never occurs on new tyres.

19. The anti-skid system would be used:

a. on landing runs only.
b. on take off runs only.
c. for take off on icy runways.
d. for both take off and landing runs.

20. A hydraulic gear extension/retraction mechanism consists of sequence valves, uplocks and:

a. an anti-skid braking system.
b. downlocks.
c. torque links.
d. a shock absorber.

21. A nose wheel steering control system:

a. prevents the nosewheel from castering at all times.
b. allows the nosewheel to caster within preset limits about the neutral position.
c. allows the nosewheel to caster freely at all times.
d. prevents the nose gear from lowering if the nosewheels are not centralised.

22. At an aircraft taxying speed of 10mph the antiskid braking system is:

a. inoperative.
b. operative.
c. operative only on the nosewheel brakes.
d. operative only on the main wheel brakes.

23. The tyre pressures are checked after a long taxi to the ramp following landing. The pressures will have:

a. fallen by 15% from their rated value.
b. risen by 15% from their rated value.
c. remained constant.
d. risen by 10% of their original weight-on-wheels value.

24. The ply rating of a tyre:

a. always indicates the number of cords or plies in the tyre carcass.
b. never indicates the number of cords or plies in the tyre carcass.
c. indicates whether or not an inner tube should be fitted.
d. is the index of the tyre strength.

ANSWERS

1.	D	16.	D
2.	A	17.	D
3.	B	18.	B
4.	C	19.	D
5.	C	20.	B
6.	B	21.	B
7.	C	22.	A
8.	B	23.	D
9.	D	24.	D
10.	D		
11.	A		
12.	A		
13.	C		
14.	B		
15.	D		

CHAPTER SEVEN

FLIGHT CONTROL SYSTEMS

Contents

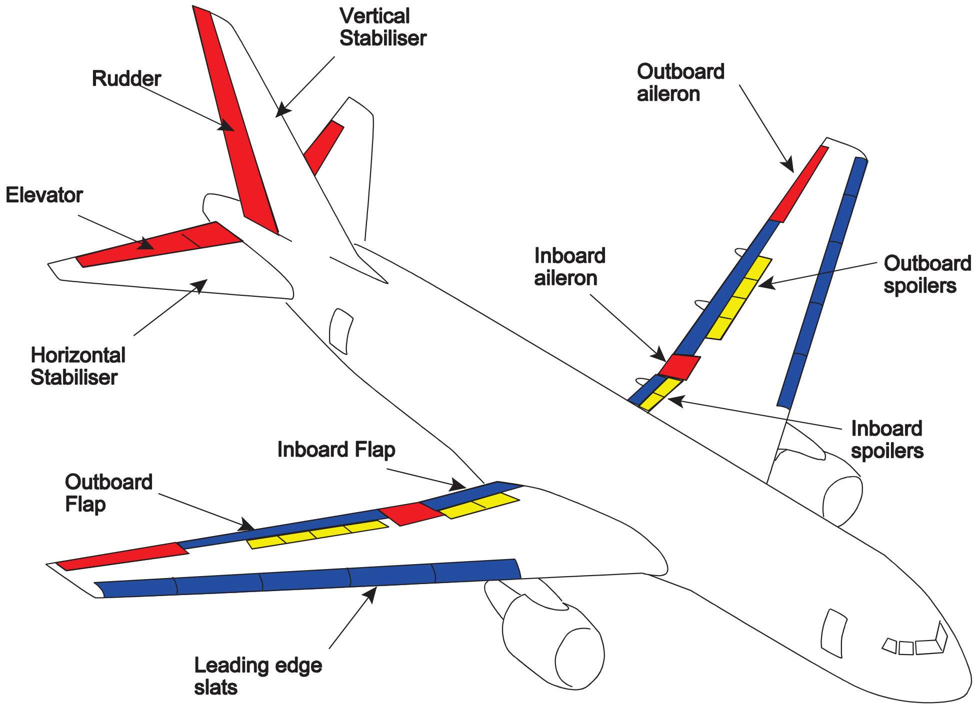


Figure 7.1: Aircraft controls - general arrangement.

INTRODUCTION

The movement of the flying control surfaces in response to the movement of the cockpit controls may be achieved:

- **Mechanically.** The control surfaces are connected directly to the cockpit controls by a system of cables, rods, levers and chains.
- **Hydraulically.** The control surfaces are moved by hydraulic power. The control valve may still be operated mechanically.
- **Electrically.** Movement of the cockpit control sends an electrical signal to the control surface. The movement of the control may be achieved hydraulically.

Figure. 7.2 shows a manually operated elevator control system for a light aircraft, showing the main components required.

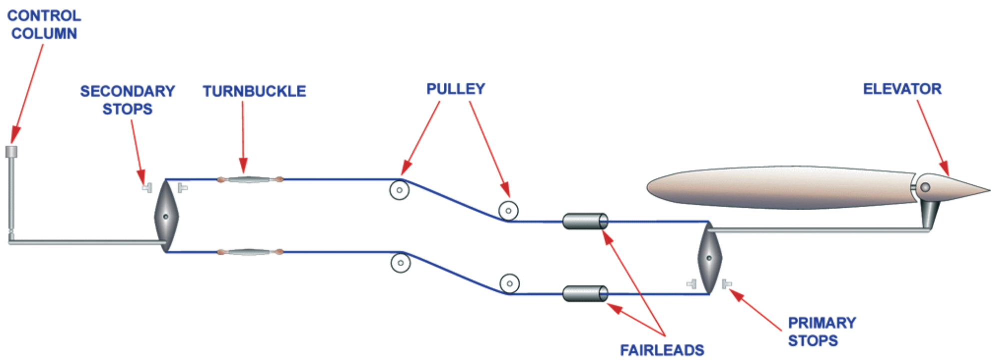


Figure 7.2: Elevator control system.

Rearward movement of the control column causes upward movement of the elevator, causing the aircraft to pitch nose upwards, and vice versa.

Control in roll is achieved by ailerons. Turning the control wheel to the right causes the right aileron to move up and the left aileron to move down, giving roll to the right.

Control in yaw is given by the rudder. Moving the right rudder pedal forward causes the rudder to move to the right and causes the aircraft to yaw to the right. These movements are obtained by similar arrangements of cables, push-pull rods and chains for the elevator.

The primary flying controls in a manually operated control system are reversible. That is, a force applied to the cockpit control will move the control surface, and also, a force applied to the control surface will cause the cockpit control to move. This means that the air pressure on the control surfaces is felt by the pilot through the cockpit controls. This is not the case if the controls are fully power operated. A power operated control is irreversible, that is, a load applied to the control surface cannot move the cockpit control, and the system has no natural feel.

NOTE: Power assisted controls still retain their natural feel and, if the loads at the surface are large enough, are reversible.

Because of this it is necessary to introduce feel to the system artificially. The artificial feel unit should increase the cockpit control load in proportion to the control deflection, and in proportion to the speed. [A manually operated trimming tab is irreversible, once its position has been set by the trim wheel, it cannot be moved from that position by a load on the trimming tab].

CONTROL SYSTEM CHECKS

During servicing, and after any adjustments to the flying control system, various checks are required on the system. In some situations it may be necessary for the pilot to perform part of these checks. The main checks required on the system are for:

- cable tension.
- safety and locking of controls.
- range of movement of controls (freedom and operation in the correct sense).
- friction in the system.
- backlash of the system.

CABLE TENSION

It is important to have the correct tension in the control cables. If the tension is too low, the cables will be loose, permitting excessive cable movement, and if the tension is too high, the controls will be too stiff to move. Cable tension is adjusted by means of turnbuckles, and measured with a tensiometer.

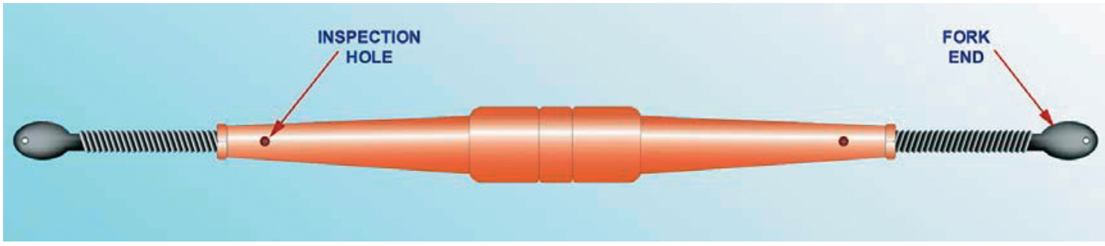


Figure 7.3: Barrel type turnbuckle.

Figure 7.3 illustrates a typical turnbuckle. It consists of a central barrel, and two end fittings, to which are attached the ends of the cable.

The tension of the cable is measured with a tensiometer. An illustration of a simple tensiometer is shown in *Figure 7.4.*

Figure 7.4: Simple tensionmeter.

TEMPERATURE COMPENSATION

When checking the tension of the cable, allowance should be made for the temperature, and the correct tension figure used appropriate to the ambient temperature. Changes of temperature will affect the length of the cables and also of the airframe structure, but as they are made of different materials the rate of expansion will be different. For a normal aluminium alloy airframe structure with steel control cables, an increase in Temperature will cause the aluminium alloy to expand more than the steel cables and so cause an increase in cable tension. On some aircraft a temperature compensator is fitted in the control system. This automatically maintains the correct tension if temperature changes.

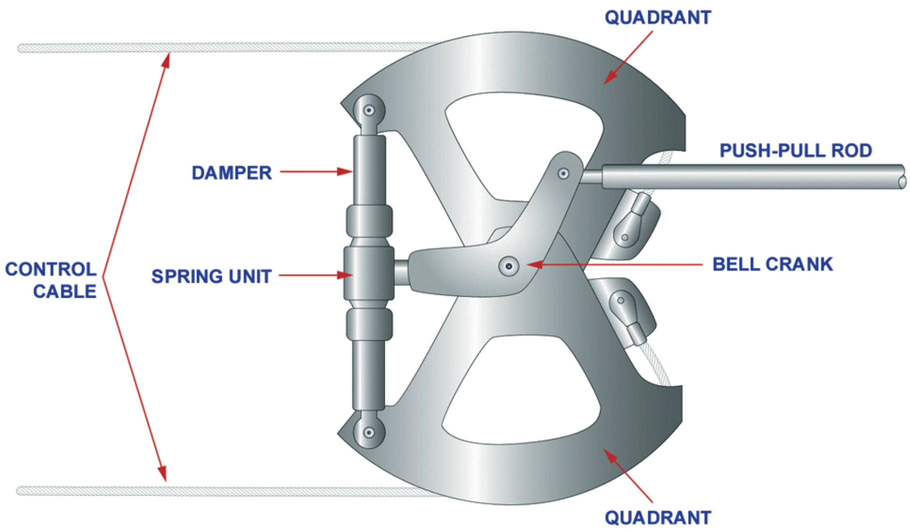


Figure 7.5: Temperature compensator.

SAFETY AND LOCKING

After the tension has been correctly set, the turnbuckle must be checked to safety. This means that sufficient thread must be engaged between the end fittings and the central portion of the turnbuckle to take the load which will be placed on the cable.

To enable this to be done, inspection holes are provided in the turnbuckle. To be 'in safety' the inspection hole must be completely blocked by the thread of the end fitting. This is verified by attempting to pass a hardened pin through the inspection hole.

Some types of turnbuckle are not provided with inspection holes, and these should be checked for safety by seeing that not more than three threads of the end fitting are visible outside the barrel.

When the tension has been correctly set and the turnbuckle is 'in safety' it must be locked to prevent any change of tension occurring during operation of the control system. Vibration could cause the barrel of the turnbuckle to rotate and allow the cable tension to decrease. The turnbuckle must be locked to prevent any rotation of the barrel relating to the end fittings.

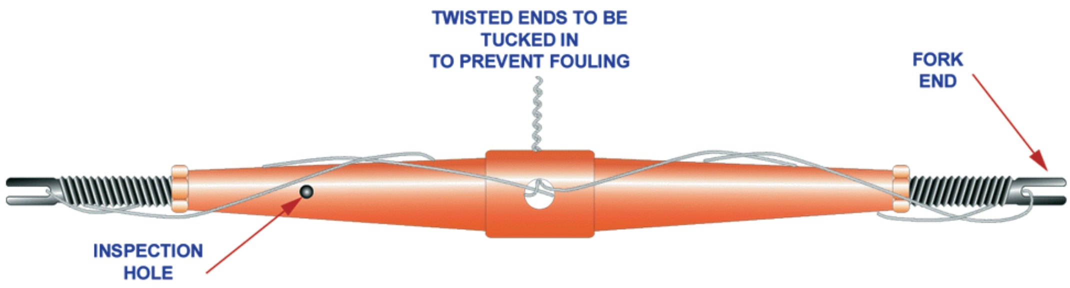


Figure 7.6: Wire locked turnbuckle.

The most commonly used method of locking is by locking wire, but many other approved systems of locking are in use, such as locking clips, locking plates etc.

RANGE OF CONTROL MOVEMENT

The movement of each control surface to either side of its neutral position, is laid down so that it can achieve the required control over the full range of operating conditions. The movement is not necessarily the same each side of neutral, for example, an elevator usually has a greater deflection upward than downward. The limit of movement of the control surface is determined by a mechanical stop. A stop which limits the movement of the control surface is called a primary stop.

A stop which limits the movement of the control column or rudder pedals is called a secondary stop; when the primary stop is closed there will be a small clearance at the secondary stop.

CONTROL SYSTEM FRICTION

The friction in the control system will determine the force required to move the controls when the aircraft is stationary. In flight the 'stick forces' will increase due to the air loads on the control surfaces. If the friction loads are too high, the feel of the controls with changing airspeed will be distorted. The friction in the control system is measured by attaching a spring balance to the control and moving it through its full travel. Excessive friction in the controls may be due to over-tensioned cables or lack of oil on the bearings.

BACKLASH

Control Systems should be free of backlash. Backlash is free or ineffective movement of the cockpit control when the direction of movement is reversed. It may indicate worn or incorrect components in the control system.

CONTROL LOCKS

When an aircraft is parked in the open, strong or gusty winds could blow the controls about against their stops with sufficient force to cause mechanical damage. To prevent this occurring, control locks are fitted. These may be external or internal and may be fitted to the control surface or to the cockpit control. If they are fitted to the cockpit control they may be arranged so that it is impossible to open the throttle until the control locks are removed.

It should be noted that with servo operated control surfaces, movement of the cockpit controls is possible with external control locks in position. Similarly with a spring tab assisted control, some movement of the cockpit control would be possible with external locks fitted, but the control would feel very stiff.

DUPLICATE INSPECTION OF CONTROLS

Because of the vital importance of the control system a procedure for duplication of inspection of the control system is laid down in the Regulations. (BCAR Section A). It requires that if the control system is disturbed in any way, the system shall be inspected separately by two qualified persons before the aircraft is permitted to fly. In some circumstances the second of these persons may be the pilot. An extract from BCAR's covering the duplicate inspection procedures is given at Appendix A. Note: BCAR Are the BRITISH CIVIL AIRWORTHINESS REQUIREMENTS and will continue to apply for the time being.

TAKE OFF CONFIGURATION WARNING

The take-off configuration warning is armed when the aircraft is on the ground and the forward thrust levers are advanced for take-off. An intermittent take-off warning sounds if some or all of the following conditions exist:

- The stabiliser trim is outside the safe range.
- The trailing edge flaps are not in the take-off position.
- Leading edge high lift devices are not in the take-off position.
- Speed brake lever not in the down position.
- All doors are not fully locked.
- Flight controls are not fully unlocked (aircraft fitted with internal control locks)

The warning indication is cancelled when the incorrect setting is corrected.

A steady warning horn alerts the pilots when the aircraft is in landing configuration and any landing gear is not down and locked. The landing gear warning horn is also activated by flap and thrust lever position.

HIGH LIFT DEVICES

Most jet transport aircraft are fitted with high lift devices on both leading and trailing edges which increase the lift coefficients to enable the aircraft to generate large amounts of lift at low speed for take-off and landing. Smaller aircraft are usually just fitted with trailing edge flaps.

TRAILING EDGE FLAPS

There are various types of flap design which all increase both lift and drag in varying amounts. The most popular type for light aircraft is the plain or camber flap with slotted Fowler flaps widely used on large transport aircraft. *See Figure 7.7* on the next page.

High Lift Devices	Increase of maximum lift	Angle of basic aerofoil at max lift	Remarks
 Basic Aerofoil		15°	Effects of all high lift devices depend on the basic shape of the aerofoil
 Plain or camber flap	50%	12°	Increase camber. Much drag when fully down. Nose down pitching moment
 Split Flap	60%	14°	Increase camber. Even more drag than plain flap. Nose down pitching moment
 Zap Flap	90%	13°	Increase camber and wing area. Much drag. Nose down pitching moment
 Slotted Flap	65%	16°	Control of boundary layer. Incresed camber. Stalling delayed. Not so much drag.
 Double Slotted Flap	70%	18°	Same as single slotted flap only more so. Treble slots sometimes used.
 Fowler Flap	90%	15°	Increased camber and wing area. Best flaps for lift. Complicated mechanism. Nose down pitching moment

Figure 7.7: Trailing edge flaps.

A typical trailing edge flap system is shown in *Figure 7.8*.

Operation of the flight deck selector produces an input to the Slat/flap computers (2off) which control, monitor and test the operation of the flaps. An electrically controlled hydro-mechanical power unit drives the transmission which moves the flaps. The position of the flaps is indicated on the cockpit display and the flaps are protected against asymmetric operation, runaway, uncommanded movement and overspeed. Torque limiting brakes are fitted to stop the operation if excess torque is sensed.

The flap Load Relief System (LRS) or load limiter retracts the flaps to the mid position if the airspeed exceeds a predetermined speed and automatically returns them to the fully extended position if the airspeed drops below its predetermined limit.

In the event of failure of the main control system, emergency operation of the flaps may be achieved by an alternate hydraulic supply or an electric motor which drives the trailing edge drive unit (gearbox) which then operates the same gear train.

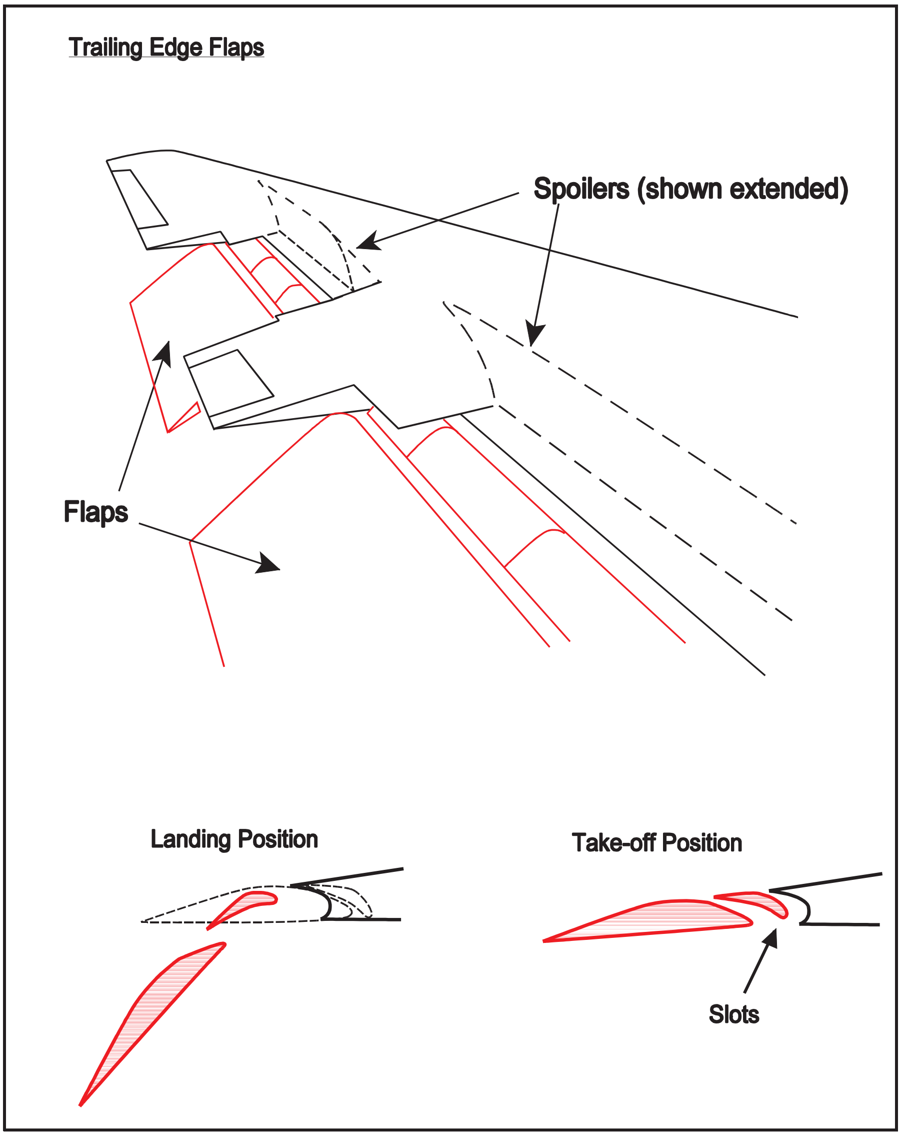


Figure 7.8: Trailing edge flaps.

LEADING EDGE DEVICES

These may consist of slats, Kreuger flaps or variable camber flaps or some combination as on the B747 which uses Kreuger flaps for the inboard section and variable camber for the outboard. Leading edge flaps and slats are operated by hydraulic power or by air turbine motors and controlled by operation of the flap lever. The three types of leading edge devices are shown in *Figure 7.10.*

Flaps are hinged surfaces that extend by rotating downward from the lower surface if the wing leading edge. Slats are sections of the wing leading edge that extend forward to form a sealed or slotted leading edge depending on the trailing edge flap setting.

The leading edge flaps and slats are retracted when the trailing edge flaps are retracted. The leading edge flaps extend fully and slats extend to the midway position (depending on aircraft type) when the trailing edge flaps move into the intermediate position, and when the trailing edge flaps are fully lowered, the slats extend fully. The sequence is reversed when the flaps are retracted.

Alternate hydraulic operation of the leading edge devices is a standby hydraulic system or, in the case of those powered by air turbine motors, an electrical standby system. The leading devices will then fully extend. **Depending on the aircraft type it may or may not be possible to retract the leading edge devices by the alternate system.**

An autoslat system may be incorporated that will automatically extend the slats from the intermediate position to the fully extend position. This system will operate if the aircraft approaches the stall angle of attack and the slats are not fully extended.

Typical indications for flap and slat/leading edge flap positions are shown below, on the left an electronic display and on the right an analogue display from an older aircraft.

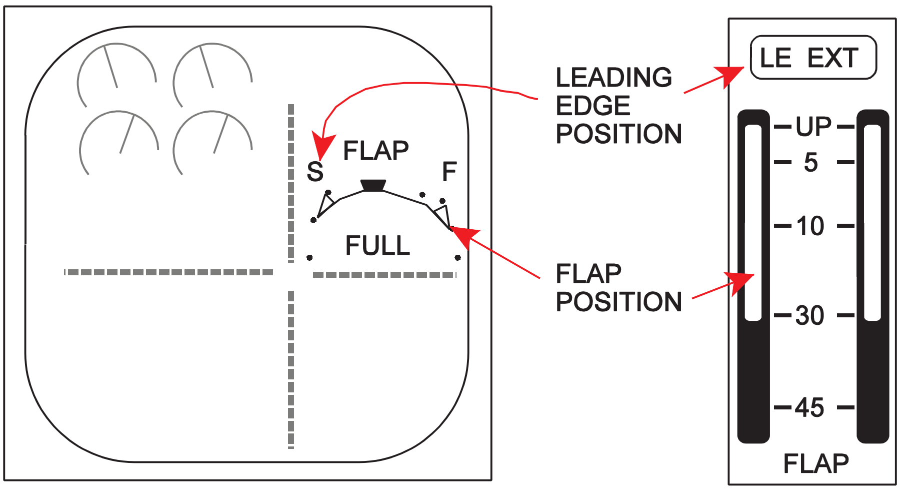


Figure 7.9: Typical electronic and analogue position indicators.

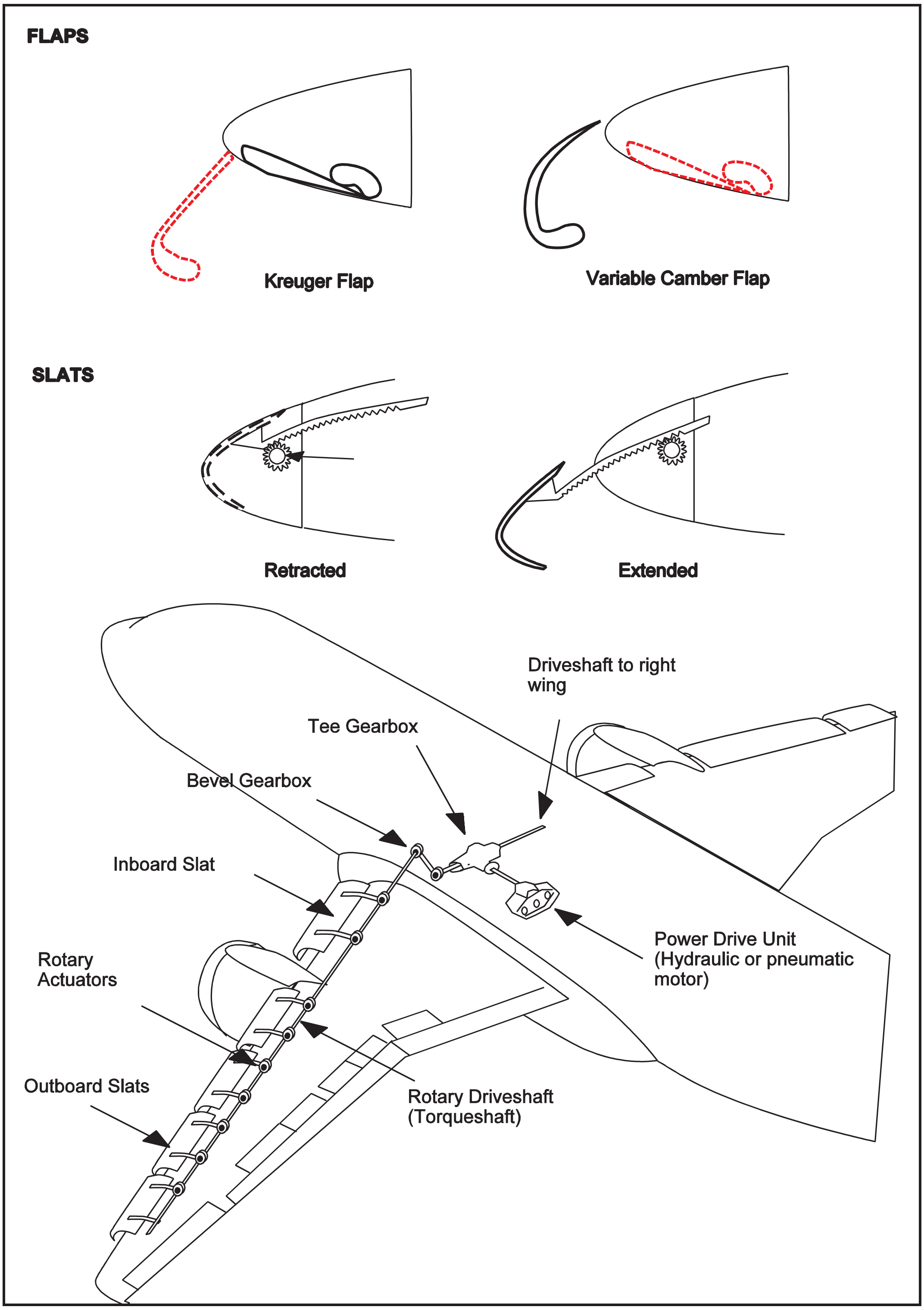


Figure 7.10: Leading edge flaps and slats.

SPEEDBRAKES

Speedbrakes consist of flight spoilers and ground spoilers. The speedbrake lever controls a spoiler mixer, which positions the flight spoiler control units, Power Control Units (PCU's), and a ground spoiler control valve. The surfaces are actuated by hydraulic power supplied to the PCU's or to actuators on each surface. Ground spoilers operate only on the ground, due to a ground spoiler shut-off valve which remains closed until the main landing gear operates a 'weight on' switch.

With lateral controls in neutral, application of the speed brakes will cause the flight spoilers to rise equally.

When speed brakes are applied on the ground, the ground spoilers will also rise. Moving the speedbrake control lever will provide an input to the spoiler mixer via a mechanical system.

The spoiler mixer conveys the speed brake signals to a ground spoiler control valve and to the flight spoiler actuators.

Ground spoiler shut off valve, fitted in the hydraulic system downstream of the spoiler control valve, is operated by a 'weight on' switch.

Speed brake control may also be applied by an electric speed brake lever actuator. When 'armed', the actuator will drive the speed brake lever to the 'full up ' position, raising the flight and ground spoilers when the landing gear wheels rotate on touchdown.

If the engine thrust levers are opened up again on the landing run, the actuator will sense the aborted landing and will lower the flight and ground spoilers.

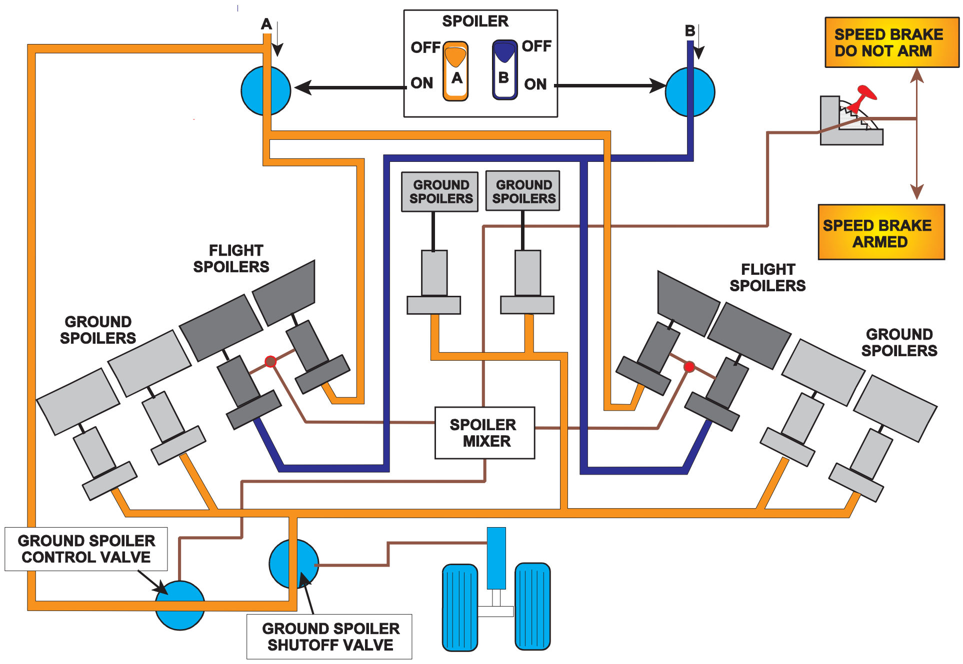
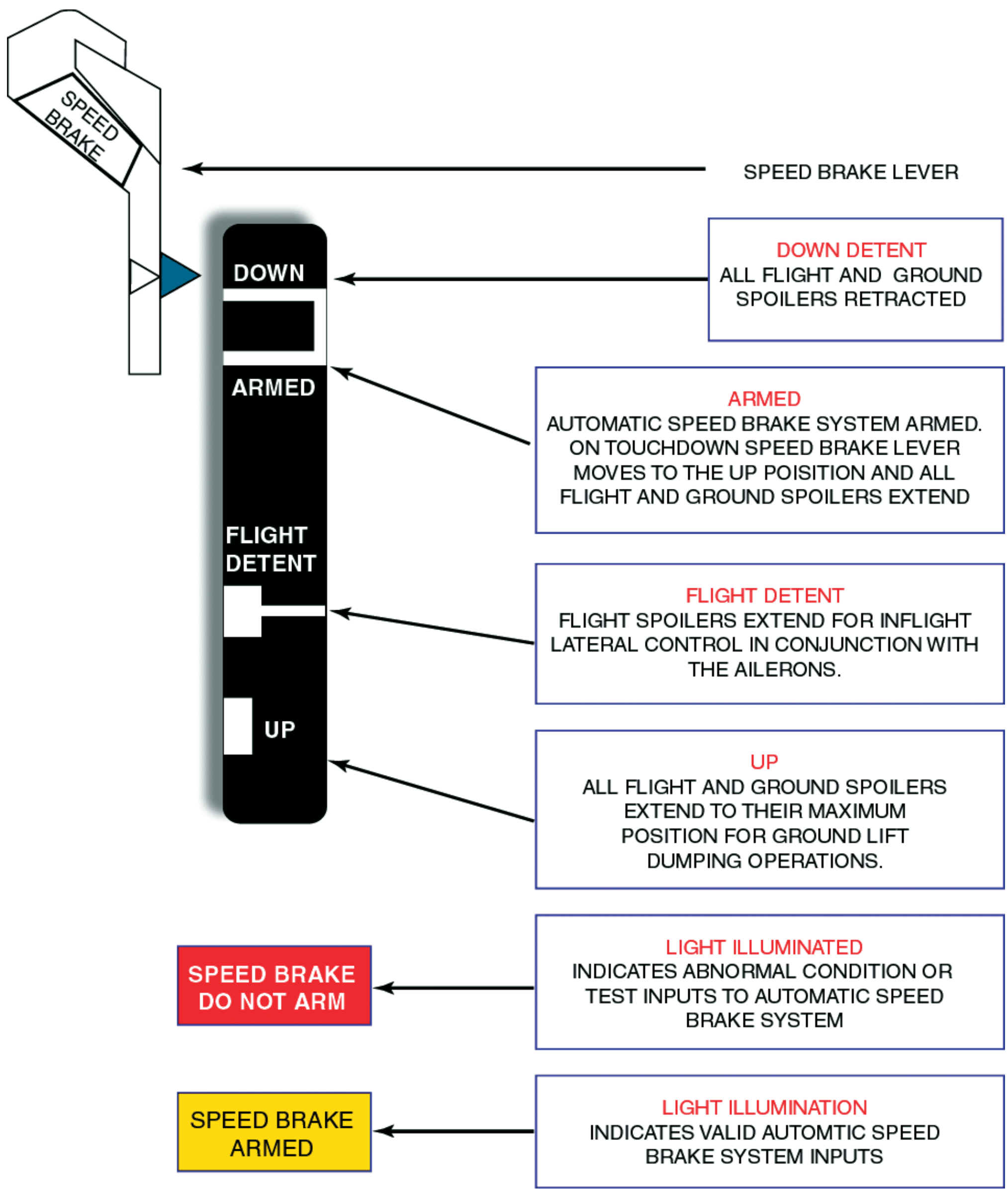


Figure 7.11: Typical speed brake/lift dumper systems.



Courtesy of the Boeing Company

Figure 7.12: Speed brake selector.

TYPICAL FLIGHT SPOILER SYSTEM

Two flight spoilers are located on the upper surfaces of each wing. The outboard spoilers are powered by one hydraulic system, whilst the inboard spoilers are powered by a second system. Hydraulic pressure shut off valves are controlled by the two flight spoiler switches.

The flight spoilers are hydraulically actuated in response to movement of the aileron controls. A spoiler mixer, connected to the aileron control system, controls the hydraulic PCUs on each spoiler panel to provide spoiler movement proportional to aileron movement. Flight spoilers rise on the wing with the 'up going' aileron and remain retracted on the wing with the 'down going' aileron.

SPOILER OPERATION

Aileron control wheel rotation transmits roll control signals to the aileron Power Flying Control Units through the captain's control cables.

Aileron Power Flying Control Unit movement actuates the ailerons and simultaneously sends a roll control signal to the spoiler mixer.

Rotation of the spoiler mixer output mechanism actuates the spoiler control valves to raise the spoilers on the down going wing (up going aileron).

Vertical rotation of the spoiler actuators provides the follow up to cancel the control valves input when the desired spoiler deflection has been achieved. This follow up allows the flight spoilers to be positioned at any intermediate angle between retracted and fully up. In this manner, the flight spoilers assist the ailerons in providing lateral control.

Flight spoiler hydraulic power is controlled by electric motor driven valves situated in the flight control power system, allowing the spoilers to be isolated if required. Two spoiler switches individually control these valves. The flight spoilers continue to provide lateral control when used as speedbrakes and will add any roll demand to the position already demanded by the speedbrake. ie. If the speedbrakes are deployed then if the aircraft is rolled to the right, the right spoilers will move further up, and the left spoiler will stay at the position demanded by the speedbrake.

AUTOMATIC GROUND SPEED BRAKE CONTROL OPERATION

Operation is a function of input signals from:

- **Speed brake lever selected to the armed position**. Arming the speed brake lever, places the flight and ground spoilers in the automatic lift dumping mode of operation.
- **Anti-skid (wheel spin up)** The anti-skid system will send electrical power signals to the wheel speed relays for each wheel. A combination of wheel spin up signals (on touchdown) through two parallel circuits will energise the speed brake actuator to drive the speed lever to the up position, so raising all spoilers.
- **Air/ground sensing**. If both anti-skid channels are inoperative on touchdown, the Air/Ground sensing circuits will actuate the system when the landing gear strut is compressed.
- **Thrust lever positions**. Retarding the thrust levers on touchdown, will operate the speed brake lever to raise all spoilers.
- **Thrust reverser operation.** The reverser system linkage mechanically raises the speed brake lever and energises a relay which supplies power to the speed brake system, raising all spoilers.
- **Excess IAS protection**. There will be an automatic protection system to prevent deployment at excess IAS.

The system has a 'Go - Round' capability whereby a wheel spin-up after slowing down or the opening of the thrust levers will retract all spoilers.

APPENDIX A

CIVIL AVIATION AUTHORITY

CONTROL SYSTEMS

1. INTRODUCTION. The purpose of this Leaflet is to provide general guidance and advice on the inspection procedures for control systems which are either manually operated, power assisted or power operated. The Leaflet should be read in conjunction with the relevant approved drawings and manuals for the aircraft concerned.

2. CONTROL SYSTEMS. A control system is defined as a system by which the flight attitude or the propulsive force of an aircraft is changed.

2.1 For the purpose of duplicate inspection *(see paragraph 2.2)*, the flight control system includes the main control surfaces, lift and drag devices and trim and feel systems, together with any flight control lock systems and the associated operating mechanisms and controls. On the case of rotorcraft, the flight control system includes the mechanisms used by the pilot to control collective pitch, cyclic pitch and yaw. The engine control system includes the primary engine controls and related control systems (eg throttle controls, fuel cock controls, oil-cooler controls) and the mechanisms used by the crew to operate them.

2.2 **Duplicate Inspection**. A duplicate inspection of a vital point/control system is defined as an inspection which is first made and certified by one qualified person and subsequently made and certified by a second qualified person.

NOTE: Vital Point. Any point on an aircraft at which single incorrect assembly could lead to catastrophe, ie result in loss of aircraft and/or in fatalities *(see BCAR Section A, Chapter A5-3)*.

2.2.1 Components, systems or vital points subject to duplicate inspection, must not be disturbed or re-adjusted between the first and second part of the inspection must, as nearly as possible, follow immediately after the first part.

2.2.2 In some circumstances, due to peculiarities of assembly or accessibility, it may be necessary for both parts of the inspection to be made simultaneously.

3. INSPECTION OF CONTROL SYSTEM COMPONENTS

3.1 Control system components, the part of which are concealed during bench assembly before installation, shall be inspected in duplicate on assembly during manufacture, overhaul or repair.

3.2 Both parts of the duplicate inspection and the results of any tests made during and after final assembly shall be certified on the Inspection Record for the part concerned.

4. DUPLICATE INSPECTION OF CONTROL SYSTEMS

4.1 A duplicate inspection of the control system in the aircraft shall be made (a) before the first flight of all aircraft after initial assembly, (b) before the first flight after the overhaul, replacement, repair adjustment or modification of the system. The two parts of the duplicate inspection shall be the final operations and as the purpose of the inspection is to establish the integrity of the system all work should have been completed. If after the duplicate inspection has been completed, the control system is disturbed in anyway before the first flight, that part of the system which has been disturbed shall be inspected in duplicate *(paragraph 2.2)* before the aircraft flies.

4.2 In some instances it may not be possible after complete assembly of the aircraft to inspect all parts of the system because some sections of the system may get progressively 'boxed in' and sealed during assembly operations. In such cases the condition and security of any section which is liable to be sealed must be established to the satisfaction of the persons named in paragraph 5 before the section is sealed and related Inspection Record endorsed accordingly.

4.3 Inspection Records should be carefully prepared to ensure that any duplicate inspection required at an early stage during assembly operations is clearly indicated, thus avoiding unnecessary dismantling at later stages.

4.4 The correct functioning of control systems is at all times of vital importance to airworthiness. It is also essential that suitably licensed aircraft engineers and members of approved inspection organisations responsible for the inspection or duplicate inspection should be thoroughly conversant with the systems concerned. The inspection must be carried out systematically to ensure that each and every part of the system is correctly assembled and is able to operate freely over the specified range of movement without the risk of fouling. Also that it is correctly and adequately locked, clean and correctly lubricated and is working in the correct sense in relation to the movement of the control by the crew.

5. PERSONS AUTHORISED TO CERTIFY DUPLICATE INSPECTIONS

5.1 Persons authorised to make the first and second parts of the duplicate inspection of the control systems in accordance with BCAR Section A Chapter A6-2 are as follows:

a) Aircraft engineers appropriately licensed in Categories A, B, C, and D.

b) Members of appropriately Approved Organisations who are considered by the Chief Inspector competent to make such inspections, in accordance with Airworthiness Notice No. 3.

For minor adjustments to control systems when the aircraft is away from base, the second part of the duplicate inspection may be performed by a pilot or flight engineer licensed for the type of aircraft concerned.

5.2 Certification. It is recommended that the certification of the duplicate inspection be in the following form:

Duplicate inspection performed in accordance with the requirements of BCAR, Section A Chapter A6-2.

1st Inspection	....	signature
	....	authority
2nd Inspection	....	signature
	....	authority
	Date	

CHAPTER EIGHT

FLIGHT CONTROLS

Contents

PURPOSE OF CONTROLS

For steady flight the aircraft must be in a state of balance (zero moments around the axes) and the controls enable this to be achieved for all possible configurations and C.G. positions. Secondly the controls will be required to manoeuvre the aircraft around its three axes.

MOMENTS AROUND THE AXES

- **Longitudinal axis**. Rotation around the longitudinal axis is rolling and is controlled by the ailerons, or for some aircraft, spoilers, or by a combination of the two.
- **Lateral Axis**. Rotation around the lateral axis is pitching and is controlled by the elevators, or by a moving tailplane.
- **Normal Axis**. Rotation around the normal axis is yawing and is controlled by the rudder.

On some of aircraft, rotation around two of the axes may be achieved with one control surface:

- The **elevon** (elevator and aileron) used on tail-less aircraft gives both pitching and rolling.
- The **ruddervator** (V tail) gives both pitching and yawing
- The **stabilator** a moveable tailplane combining the dual function of horizontal stabiliser and elevator i.e. gives both longitudinal stability and control.

The moment around an axis is produced by changing the aerodynamic force on the appropriate aerofoil (wing, tail or fin) and this may be done by:

- changing the camber of the aerofoil
- changing the angle of attack (incidence) of the aerofoil
- decreasing the aerodynamic force by "spoiling" the airflow

Increasing the camber of an aerofoil will increase its lift, and deflecting a control surface down effectively increases its camber.

This principle can be applied to control about each of the axes, the elevator for pitch, the aileron for roll, and the rudder for yaw.

Increasing the incidence and hence the angle of attack of an aerofoil will also increase its lift. The usual application of this system is for pitch control - the moving tail (stabilator). *Figure 8.1.*

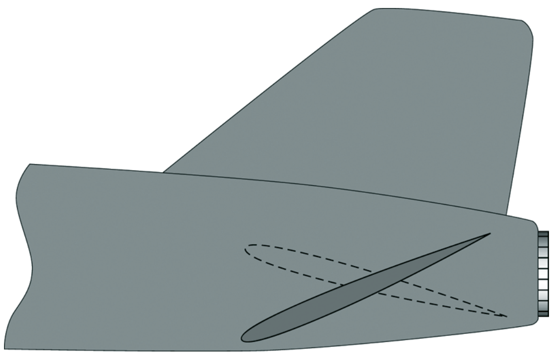


Figure 8.1

The spoiler is a device for reducing the lift of an aerofoil, by disturbing the airflow over the upper surface. It is used to give lateral control by reducing the lift on one wing but not on the other.

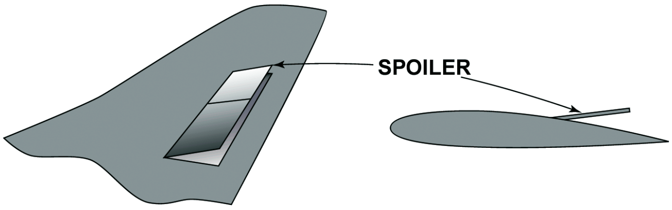


Figure 8.2

HINGE MOMENTS

If an aerodynamic force acts on a control surface, it will tend to rotate the control around its hinge, in the direction of the force. The moment will be the force multiplied by the distance from the hinge to the control surface centre of pressure. This is called the hinge moment. The force may be due to the angle of attack of the aerofoil or the deflection of the control surface.

It is assumed that the total hinge moment is the sum of the separate effects of angle of attack and control surface deflection. To maintain the control in its position the pilot has to balance the hinge moment by applying a load to the cockpit control. The cockpit control load will therefore depend on the size of the hinge moment.

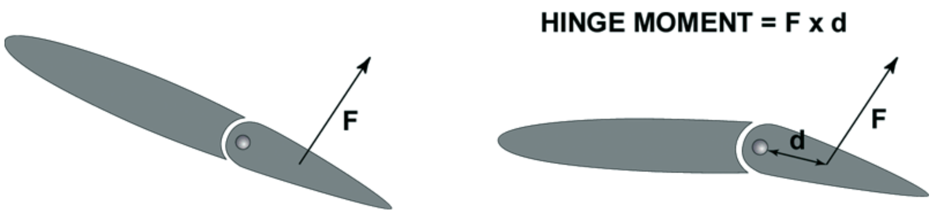


Figure 8.3

CONTROL BALANCING

The aerodynamic force on the control at a given deflection will depend on the size of the control surface, and the speed squared. For large and fast aircraft the resulting force could give hinge moments and stick forces which would be too high for easy operation of the controls.

The pilot will require assistance to move the controls in these conditions, and this can be done by using power operation, or by using aerodynamic balance.

AERODYNAMIC BALANCE

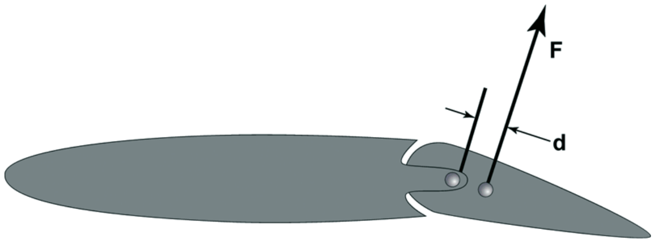


Figure 8.4

Aerodynamic balance involves using the aerodynamic forces on the control surface, to reduce the hinge moment, and may be done in several ways:

- **Set back hinge line.** The moment arm of the control surface force is the distance from the hinge to the centre of pressure on the control surface. If the hinge is moved back into the control surface, the arm and the hinge moment will be reduced.

  Setting the hinge back does not reduce the effectiveness of the control, only the hinge moment of the force is reduced, not the force itself.

- **Horn Balance**. The principle of the horn balance is similar to that of the set- back hinge, in that part of the surface is forward of the hinge line, and forces on this part of the surface give hinge moments which are in the opposite direction to the moments on the main part of the surface. The overall moment is therefore reduced, but not the control effectiveness.

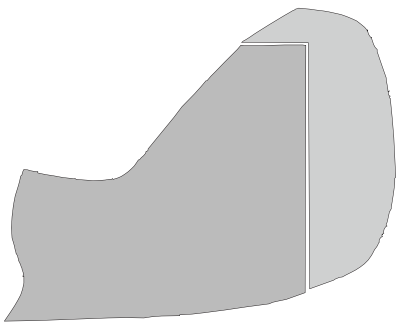


Figure 8.5

➢ **Internal Balance**. This balance works on the same principle as the set-back hinge, but the balancing area is inside the wing.

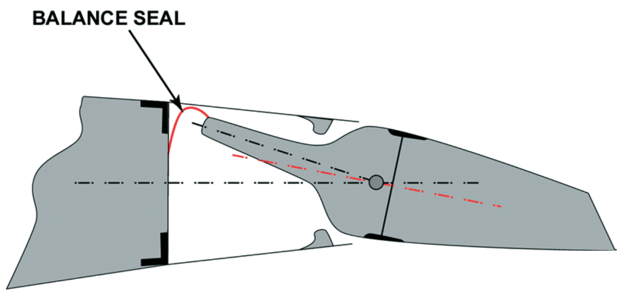


Figure 8.6

Movement of the control causes pressure changes on the aerofoil, and these pressure changes are felt on the balance area. For example, if the control surface is moved down, pressure above the aerofoil is reduced and pressure below it is increased. The reduced pressure is felt on the upper surface of the balance, and the increased pressure on the lower surface. The pressure difference on the balance therefore gives a hinge moment which is the opposite to the hinge moment on the main control surface, and the overall hinge moment is reduced.

➢ **Balance Tab.** All the types of balance considered above provide balance by causing some of the pressures on the control surface to act forward of the hinge line. The balance tab causes a force to act on the control surface trailing edge, which is opposite to the force on the main control surface. The tab is geared to move in the opposite direction to the control surface whenever the control surface is deflected.

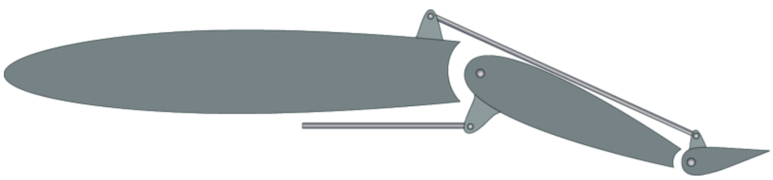


Figure 8.7

Unlike the previous types of balance, the balance tab will give some reduction in control effectiveness, as the tab force is opposite to the control force.

- **Anti-balance Tab.** The anti-balance tab is geared to move in the same direction as the control surface, and so will increase the control effectiveness, but of course will increase the hinge moment and give heavier stick forces.

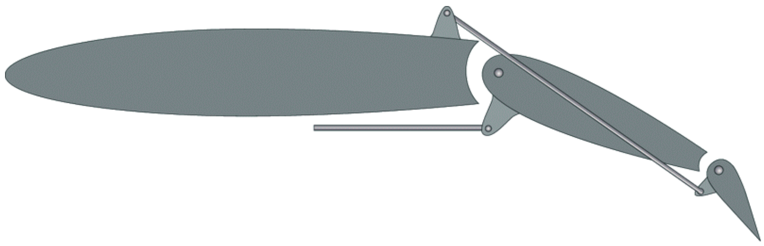


Figure 8.8

- **Spring Tab.** The spring tab is a modification of the balance tab, such that the tab movement is proportional to the applied stick force. Maximum assistance is therefore obtained when the stick forces are greatest. This is achieved by putting a spring in the linkage to the tab. The spring tab is used mainly to reduce control loads at high airspeeds.

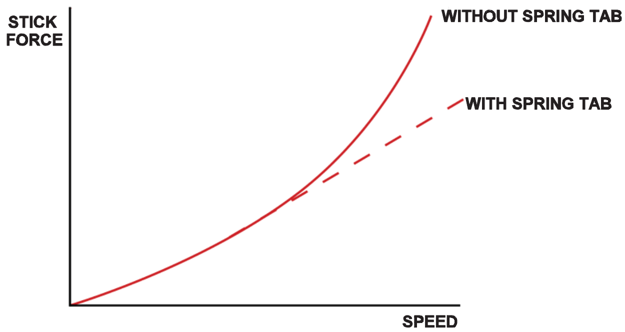


Figure 8.9

- **Servo Tab.** The purpose of the servo tab is to enable the pilot to move the control surface easily. In this system there is no direct movement of the control surface as a result of moving the cockpit control. The pilot's control input deflects the servo tab, and the force on the tab then deflects the control surface until an equilibrium position is reached. If the aircraft is stationary in the ground, movement of the cockpit control will give no movement of the control surface, only of the tab, and it should be noted that if external control locks are fitted to the control surface, the cockpit control will still be free to move.

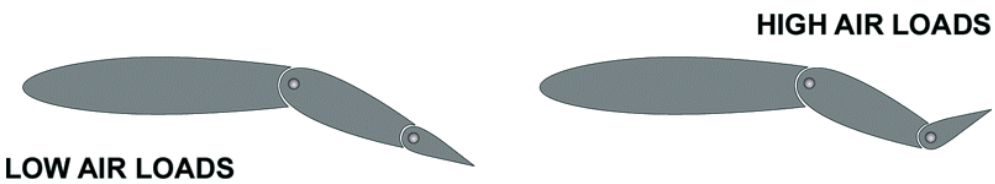


Figure 8.10

MASS BALANCE

Mass balance is a weight attached to the control surface forward of the hinge. Most control surfaces are mass balanced. The purpose of this is to prevent control surface flutter. Flutter is an oscillation of the control surface which can occur due to the bending and twisting of the structure under load. If the centre of gravity of the control surface is behind the hinge, its inertia causes it to oscillate about its hinge when the structure distorts. In certain circumstances the oscillations can be divergent, and cause failure of the structure.

Flutter may be prevented by adding weight to the control surface in front of the hinge line. This brings the centre of gravity of the control forward to a position which is normally close to, or slightly in front of the hinge, but always to the point required by the designers. This reduces the inertia moments about the hinge and prevents flutter developing. *Figure 8.11* illustrates some common methods of mass balancing.

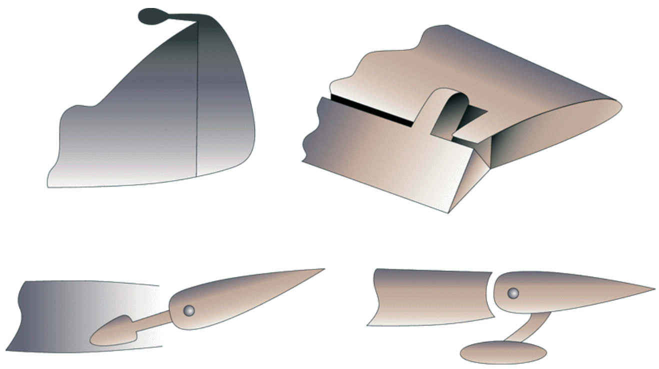


Figure 8.11

LONGITUDINAL CONTROL

Control in pitch is usually obtained by elevator or by a moving tailplane, and the controls must be adequate to balance the aircraft throughout its speed range, at all permitted C G positions and configurations and to give an adequate rate of pitch for manoeuvres.

LATERAL CONTROL

Lateral control is by the ailerons produce a rolling moment by increasing the lift on one wing and decreasing it on the other.

Adverse aileron yaw
The increased lift on the up-going wing gives an increase in the induced drag, whereas the reduced lift on the down going wing gives a decrease in induced drag. The difference in drag on the two wings produces a yawing moment which is opposite to the rolling moment, that is, a roll to the left produces a yawing moment to the right. This is known as adverse yaw.

Various methods have been adopted to reduce the adverse yaw, the main ones in use are:

- **Differential ailerons**. The aileron linkage causes the up-going aileron the move through a larger angle than the down-going aileron. This increases the drag on the up aileron, and reduces it on the down aileron, and so reduces the difference in drag between the two wings.

- **Frise ailerons**. The Frise aileron has an asymmetric leading edge, as illustrated in *Figure 8.12.*

  The leading edge of the up-going aileron protrudes below the lower surface of the wing, causing high drag. The leading edge of the down-going aileron remains shrouded and causes less drag.

Figure 8.12

- **Aileron-rudder coupling**. In this system the aileron and rudder systems are interconnected, so that when the ailerons are deflected the rudder automatically moves to counter the adverse yaw.

If roll spoilers are used to augment the roll rate obtained from the ailerons, they will reduce the adverse yaw, as the down-going wing will have an increase in drag due to the raised spoiler.

INBOARD AILERONS

The ailerons are normally situated at the wing tip, to give the greatest moment for the force produced. However this also means that they cause the maximum twisting and bending loads on the wing. This can cause a loss of effectiveness or even reversal of the aileron. To reduce these effects the ailerons can be mounted further inboard. Alternatively, two sets of ailerons may be fitted, one set at the wing tip for use at low speeds when the forces involved are low, and one set inboard for use at high speeds when the forces are greater and could cause greater structural distortion. In summary, only the inboard ailerons are used when the flaps are retracted.

FLAPERONS

The flaps and the ailerons both occupy part of the trailing edge of the wing. For good take-off and landing performance the flaps need to be as large as possible, and for a good rate of roll, the ailerons need to be as large as possible. However, the space available is limited, and one solution is to droop the ailerons symmetrically to augment the flap area. They then move differentially from the drooped position to give lateral control. Another system is to use the trailing edge moveable surfaces to perform the operation of both flaps and ailerons.

SPOILERS

Spoilers may be used to give lateral control, in addition to, or instead of ailerons. The spoiler consists of part of the upper surface of the wing which can be raised. It is illustrated in *Figure 2.3.* Raising the spoiler will disturb the airflow over the wing and reduce the lift. To function as a lateral control, the spoiler is raised on the wing which is required to move downwards, and remains in its retracted position on the other wing. Unlike the aileron the spoiler cannot give an increase of lift, and so a roll manoeuvre controlled by spoilers will always give a net loss of lift. However the spoiler has several advantages compared to the aileron:

- There is no adverse yaw. The raised spoiler increases the drag, and so the yaw is in the same direction as the roll.
- Wing twisting is reduced. The loss of lift is distributed across the chord rather than being concentrated at the trailing edge.
- At transonic speed its effectiveness is not reduced by shock induced separation.
- It cannot develop flutter.
- Spoilers do not occupy the trailing edge, which can then be utilised for flaps.

COMBINED AILERON AND SPOILER CONTROLS

On a few aircraft, lateral control is entirely by spoilers, but in the majority of applications the spoilers work in conjunction with the ailerons. Ailerons alone may be inadequate to achieve the required rate of roll at low speeds when the dynamic pressure is low, and at high speeds they may cause excessive wing twist, and begin to lose effectiveness if there is shock induced separation. Spoilers can be used to augment the rate of roll, but may not be required to operate over the whole speed range. On some aircraft the spoilers are only required at low speed, and this can be achieved by making them inoperative when the flaps are retracted. Movement of the cockpit control for lateral control is transmitted to a mixer unit which causes the spoiler to move up when the aileron moves up, but to remain retracted when the aileron moves down.

SPEED BRAKES

Speed brakes are devices to increase the drag of an aircraft when it is required to decelerate quickly or to descend rapidly. Rapid deceleration is required if turbulence is encountered at high speed, to reduce the speed to the Rough Air Speed as quickly as possible. A high rate of descent may be required to conform to Air Traffic Control instructions, and particularly if an emergency descent is required.

TYPES OF SPEED BRAKE

Ideally the speed brake should produce an increase in drag with no loss of lift or change in pitching moment. The fuselage mounted speed brake is best suited to meet these requirements. *(Figure 8.13)*

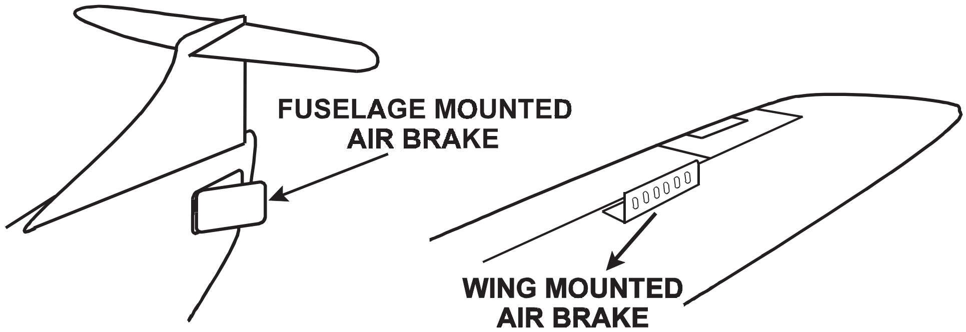


Figure 8.13

However, as the wing mounted spoiler gives an increase in drag, it is convenient to use the spoilers as speed brakes in addition to their lateral control function. To operate them as speed brakes they are controlled by a separate lever in the cockpit and move symmetrically. Speed brakes are normally cleared for operation up to VMO but may "blow back" from the fully extended position at high speeds. Spoilers will still function as a roll control whilst being used as speed brakes, by moving differentially from the selected brake position.

EFFECT OF SPEED BRAKES ON THE DRAG CURVE

The drag resulting from the operation of speed brakes is profile drag, and so will not only increase the total drag but will also decrease Vmd. This is advantageous at low speeds as the speed stability will be better than with the aircraft in the clean configuration.

GROUND SPOILERS (LIFT DUMPERS)

During the landing run the decelerating force is given by the aerodynamic drag and the drag of the wheel brakes. The wheel brake drag depends on the weight on the wheels, but this will be reduced by any lift that the wing is producing. The wing lift can be reduced by operating the wing spoilers. Both the brake drag and the aerodynamic drag are therefore increased, and the landing run reduced. On many aircraft types, additional spoilers are provided for use on the ground. These ground spoilers are made inoperative in flight by a switch on the undercarriage leg which is operated by the extension of the leg after take-off.

DIRECTIONAL CONTROL

Control in yaw is obtained by the rudder. The rudder is required to:

- maintain directional control with asymmetric power
- correct for crosswinds on take off and landing
- correct for adverse yaw
- recover from a spin
- correct for changes in propeller torque on single engined aircraft

RUDDER RATIO CHANGER

With a simple control system, full rudder pedal movement will provide full rudder deflection. With high speed aircraft, while it is necessary to have large rudder deflections available at low speed, when flying at high speed, full rudder deflection would cause excessive loads on the structure. To prevent this occurring a gear change system can be incorporated into the rudder control system. This may be a single gear change which gives a smaller rudder deflection for full pedal movement above a certain speed, or a progressive gear change which gives a decreasing rudder deflection with full pedal movement as speed increases.

TRIMMING

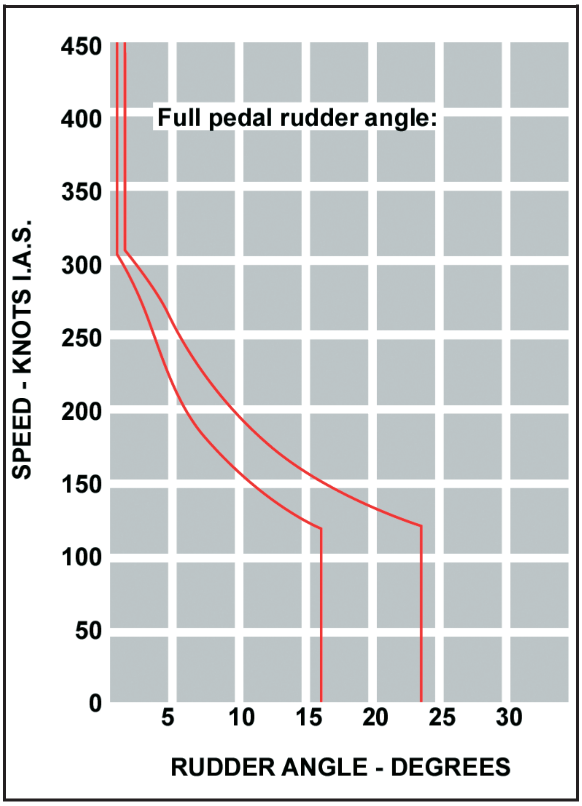


Figure 8.14

An aeroplane is trimmed when it will maintain its attitude and speed without the pilot having to apply any load to the cockpit controls. If it necessary for a control surface to be deflected to maintain balance of the aircraft, the pilot will need to apply a force to the cockpit control to hold the surface in its deflected position. This force may be reduced to zero by operation of the trim controls. The aircraft may need to be trimmed in pitch as a result of:

- changes of speed
- changes of power
- varying C.G. positions

Trimming in yaw will be needed:

- on a multi-engined aircraft if there is asymmetric power
- as a result of changes in propeller torque

Trimming in roll is less likely to be needed, but could be required if the configuration is asymmetric, or if there is a lateral displacement of the C.G.

METHODS OF TRIMMING

Various methods of trimming are in use, the main ones are:

- the trimming tab
- variable incidence tailplane
- spring bias
- C G adjustment
- adjustment of the artificial feel unit

TRIMMING TAB

The trimming tab is a small adjustable surface set into the trailing edge of a main control surface. Its deflection is controlled by a trim wheel or switch in the cockpit, usually arranged to operate in an instinctive sense. To maintain the primary control surface in its required position, the tab is moved in the opposite direction to the control surface, until the tab hinge moment balances the control surface hinge moment.

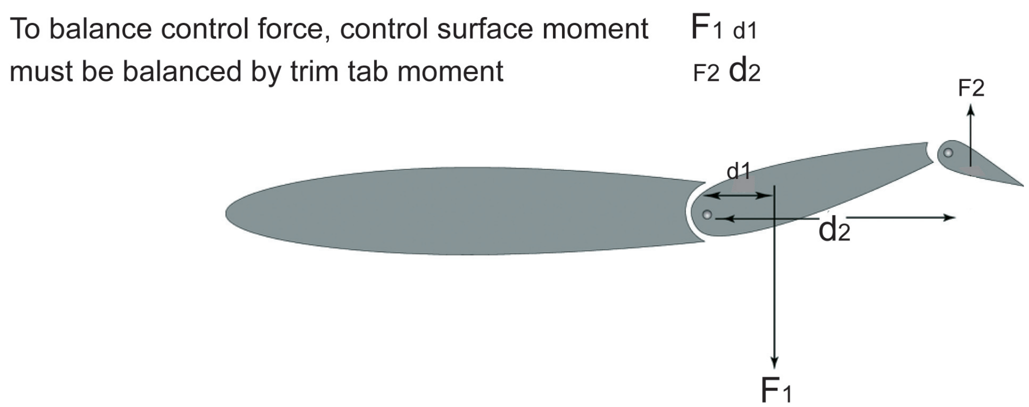


Figure 8.15

FIXED TABS

Some trimming tabs are not adjustable in flight, but can be adjusted on the ground, to correct a permanent out of trim condition. They are usually found on ailerons. They operate in the same manner as the adjustable tabs.

VARIABLE INCIDENCE TAILPLANE

This system of trimming may be used on manually operated and power operated tailplane-elevator controls. In the manual system the load on the elevator is felt on the control column, but the load on the tailplane is not. To trim, the tailplane incidence is adjusted by the trim wheel, until the total tailplane and elevator load with the elevator free, is equal to the balancing load required. As an alternative to the trim wheel the variable incidence tailplane may be operated by trim switches which operate in pairs. These are usually on the control wheel and there may be a pair of levers mounted on the centre console. One switch or lever controls the power, the other controls the direction of movement of the trimming device. Both must be moved simultaneously in order to trim the aircraft. This is to prevent inadvertent operation of the longitudinal trim system known as 'Trim-Runaway'.

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YOKES

Figure 8.16: FCVIT.

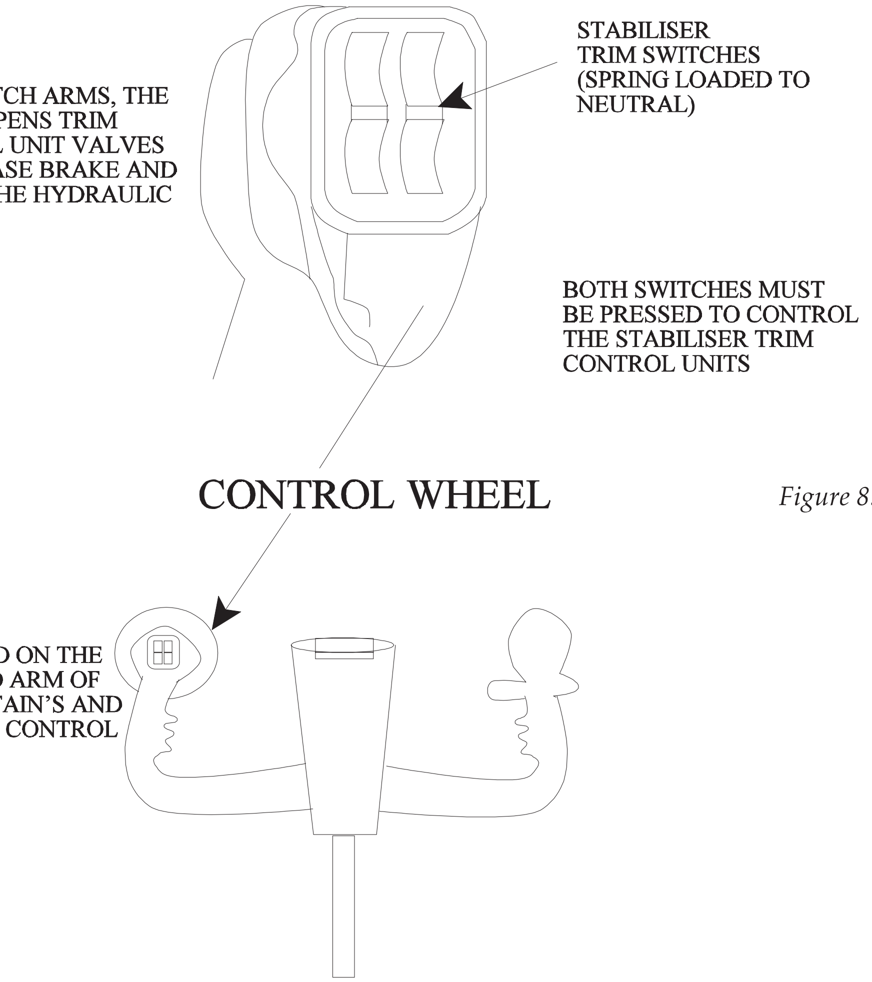
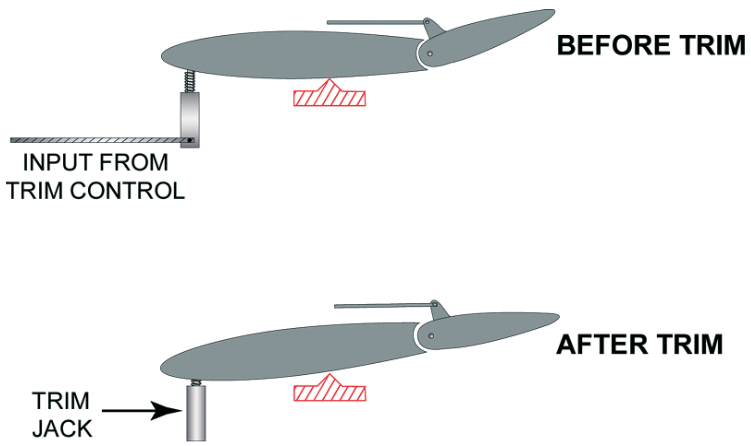


Figure 8.17



The main advantages of this system are:

- the drag is less in the trimmed state, as the aerofoil is more streamlined

- trimming does not reduce the range of pitch control, as the elevator is approximately neutral when the aircraft is trimmed.

In a power control system the load on the elevator is not felt on the cockpit control, but trimming by adjusting the tailplane incidence may still be used as the above advantages are still obtained. The amount of trim required will depend on the C.G. position, and recommended stabiliser settings will be given in the aircraft Flight Manual. It is important that these are correctly set before take-off, as incorrect settings could give either an excessive rate of pitch when the aircraft is rotated, leading to possible tail strikes, or very heavy stick forces on rotation, leading to increased take-off distances required.

SPRING BIAS

In the spring bias trim system, an adjustable spring force is used to replace the pilots holding load. No tab is required for this system.

C G ADJUSTMENT

If the flying controls are used for trimming, this results in an increase of drag due to the deflected surfaces. The out of balance pitching moment can be reduced by moving the CG nearer to the centre of pressure, thus reducing the balancing load required and therefore the drag associated with it. This will give an increase of cruise range. CG movement is usually achieved by transferring fuel between tanks at the nose and tail of the aircraft.

Figure 8.18: Mach trim by fuel transfer.

ARTIFICIAL FEEL TRIM

If the flying controls are power operated, there is no feedback of the load on the control surface to the cockpit control. The feel on the controls has to be created artificially. When a control surface is moved the artificial feel unit provides a force to resist the movement of cockpit control. To remove this force (i.e. to trim) the datum of the feel unit can be adjusted so that it no longer gives any load.

MACH TRIM

The wing centre of pressure moves rearward as aircraft approach high subsonic speed and this produces large nose down pitching moments known as "**tuck under**" It is essential that the aircraft is fitted with an automatic system of correcting this change in attitude. This system is known as "**mach trim"** and is designed so that it will operate whether or not the autopilot or some other method of automatic flight control is engaged. the system senses speed increases above a datum mach number and, through a servo system produces the appropriate movement of the horizontal stabiliser or a centre of gravity shift to maintain the trimmed flight position. See Figure 8.18 on the next page.

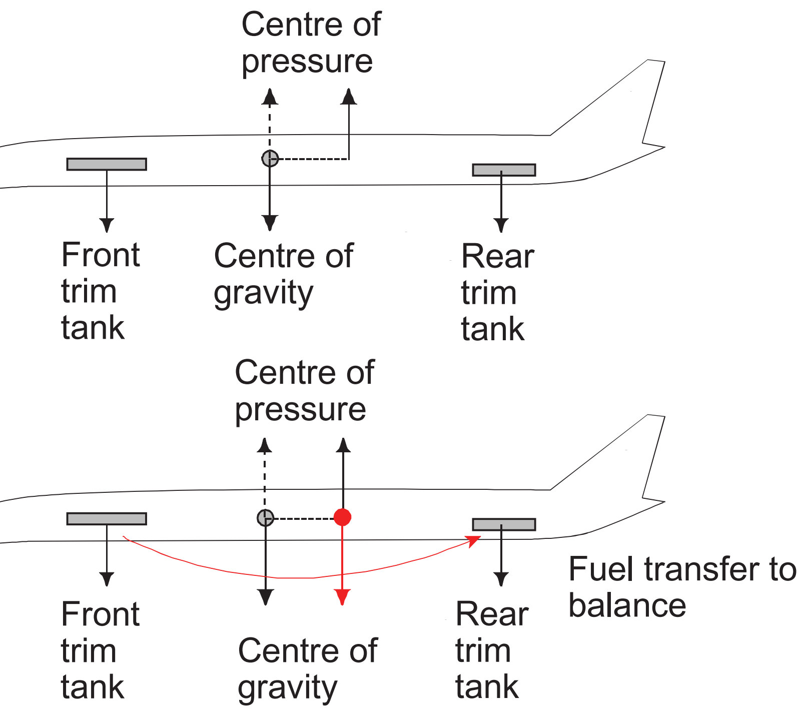


Figure 8.19: Controls for flap/slat, trim and speedbrake.

TRIM, FLAP and SPEED BRAKE SELECTORS

These controls are on the centre pedestal and usually consist of a large wheel for longitudinal trim and smaller wheels or switches for lateral and directional trim *(see Figure 8.19).*

Flap and speed brake selectors are also on the centre pedestal. The flap lever usually has a detent or gate between each flap position to prevent inadvertent operation and between three and five positions depending on the aircraft type. The speed brake selector is shown in *Chapter 7*.

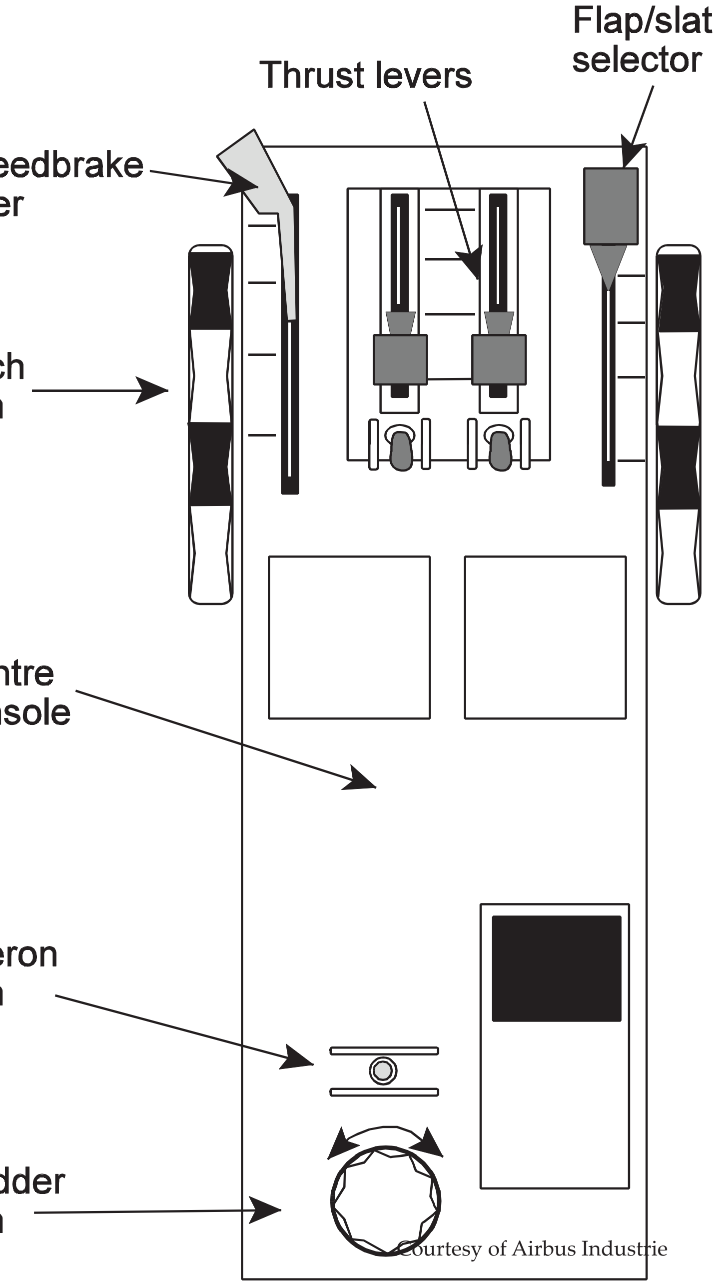


Figure 8.20: Electronic display.

CHAPTER NINE

POWERED FLYING CONTROLS

Contents

INTRODUCTION

On some modern aircraft, the flying controls are subjected to heavy loads due either to the movement of large control surfaces or by the operation of the controls at high speeds. The maximum control loads are specified in JAR-25.143 (c).

To reduce the stick forces created by these heavy air loads, hydraulic or electric power is used. The majority of powered flying controls are hydraulically operated and depending on the degree of assistance required, will depend on whether they are fully powered or power assisted.

POWER OPERATED CONTROLS

The essential components of a simple power operated control system are:

- A hydraulic actuator
- A servo or control valve
- An artificial feel unit

The above components must also incorporate some form of control **'follow up'** or **'feed back'** to ensure that the control surface movement is proportional to the amount of selection made and some form of feel which is proportional to the air loads on the control surfaces.

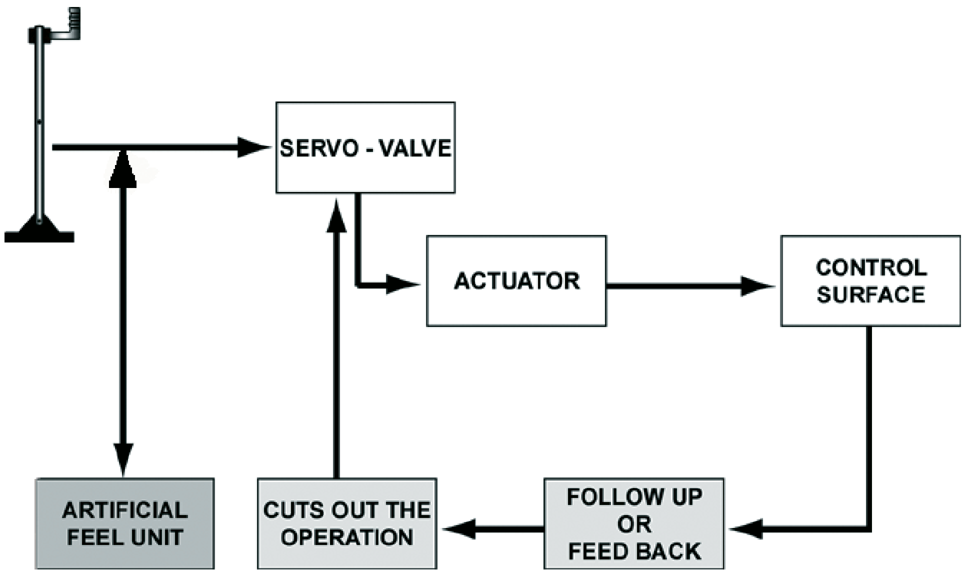


Figure 9.1: System requirements.

OPERATION

When the control column is pulled back, the control valve is selected over to the left via the control linkage. This action opens the left hand port of the actuator to hydraulic pressure whilst opening the right hand port to return. Hydraulic pressure will now move the actuator housing over to the left (since the piston is fixed to the aircraft), thus raising the elevator.

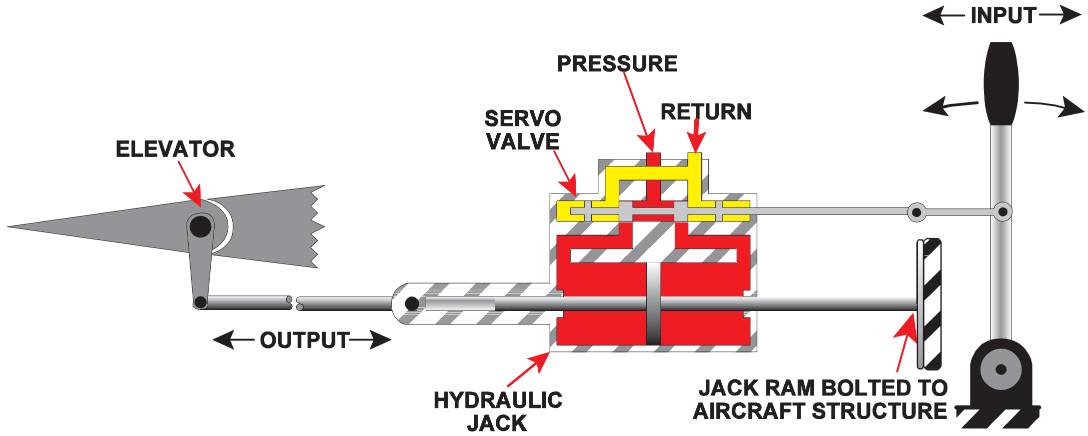


Figure 9.2: A fully powered flying control unit.

As the actuator housing moves, it gradually repositions the control valve pistons until they cover the actuator ports again, thereby cutting off further hydraulic supply and blocking off the return port. This creates a hydraulic lock in the actuator and prevents further control surface movement. Control surface movement is therefore proportional to the amount of selection made on the control valve and provides the necessary follow up system. This is a non-reversible system in that movement of the control surface cannot move the control column.

When the flying controls are power operated, some form of control unit duplication becomes necessary to guard against system failure. This is often accomplished by having power operated control units duplicated either in parallel or series. These units will have some form of power reversion like the one shown and will be operated by separate hydraulic systems. Should either system fail or be taken off line by the pilot, then the drop in hydraulic pressure will allow the spring loaded piston to open the bypass channel and so prevent a hydraulic lock from forming in the actuator. This then will permit the PFCU to follow the control movement of the backup unit.

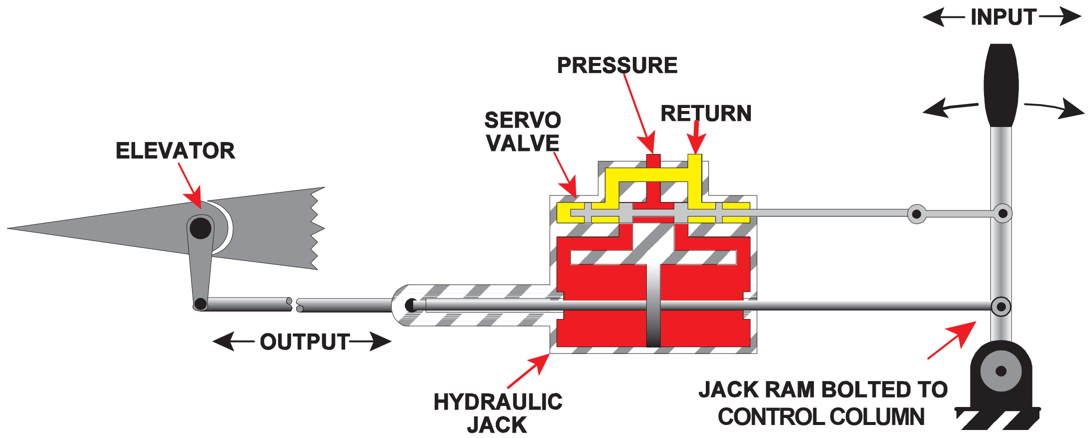


Figure 9.2a: A power assisted flying control unit.

ARTIFICIAL FEEL UNITS

When hydraulic actuators are used to operate the controls, hydraulic pressure moves the control surfaces thus removing from the pilot's control any control feel. Under these conditions the pilot would have no idea of the required amount of control surface movement to make and hence would be in danger of over controlling the aircraft.

To prevent this from happening, artificial feel units are fitted to these systems which are designed to give the pilot control feel which is proportional to the speed of the aircraft and to the amount of control surface movement made. These units vary from a simple spring box as shown in Figure 9.3. to a 'Q' pot operating system.

A fully powered flying control unit is irreversible, and requires an artificial feel system.

A Power assisted flying control unit is reversible, allowing feedback to the cockpit controls, and does not require an artificial feel system.

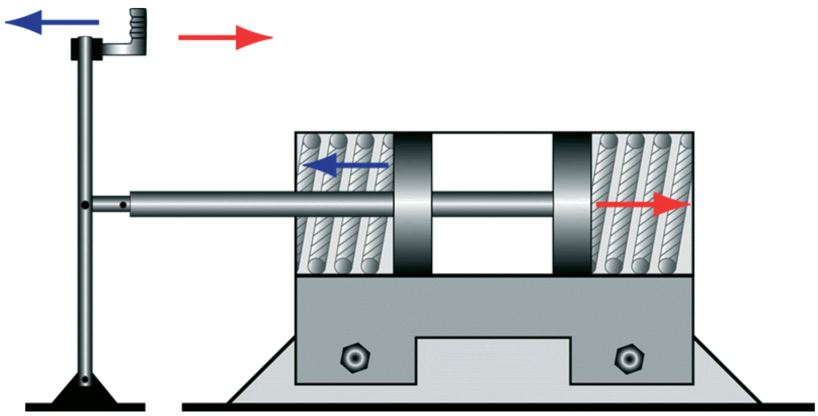


Figure 9.3

Movement of the control column in either direction will compress one or other of the springs. A simple 'Q' pot unit is shown Figure 9.4.. This unit contains a simple piston which is connected through a double linkage to the control column so that whichever way the control column moves, the piston will be pulled forward against pitot pressure which is admitted to the forward side of the pot. The rear side of the pot is open to static to enable the pressure on the front side of the piston to measure dynamic pressure which ensures that control feed is proportional to aircraft speed.

Pitot pressure - Static pressure = Dynamic pressure

$$P + \tfrac{1}{2}\rho V^2 \quad - \quad P \quad = \quad \tfrac{1}{2}\rho V^2$$

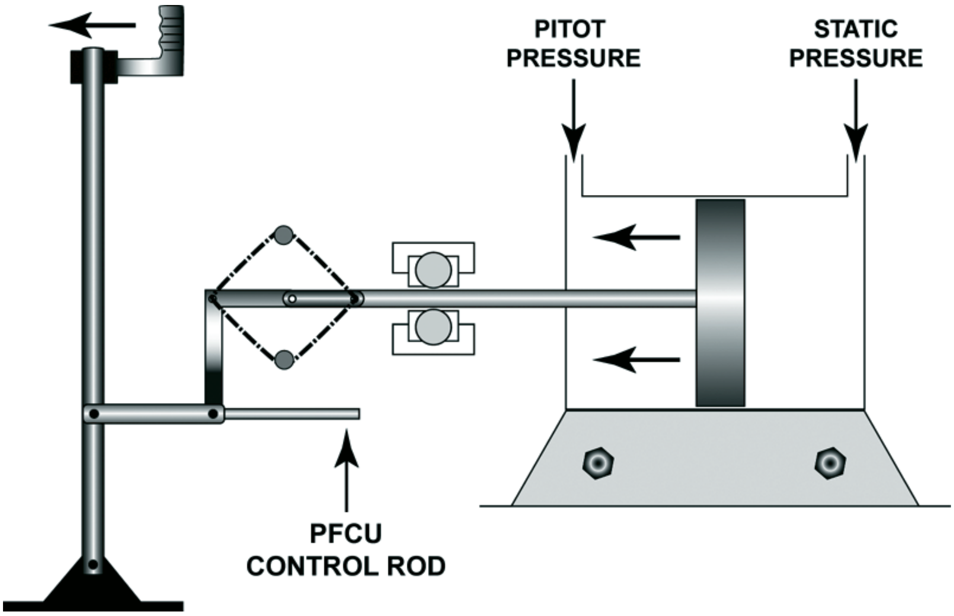


Figure 9.4

To be effective, these ‘Q’ pots would have to be very large and so nowadays these units are used in conjunction with a hydraulic spool valve selector which supplies hydraulic fluid to the piston. Figure 9.5. shows a simple ‘Q’ pot operated feel unit.

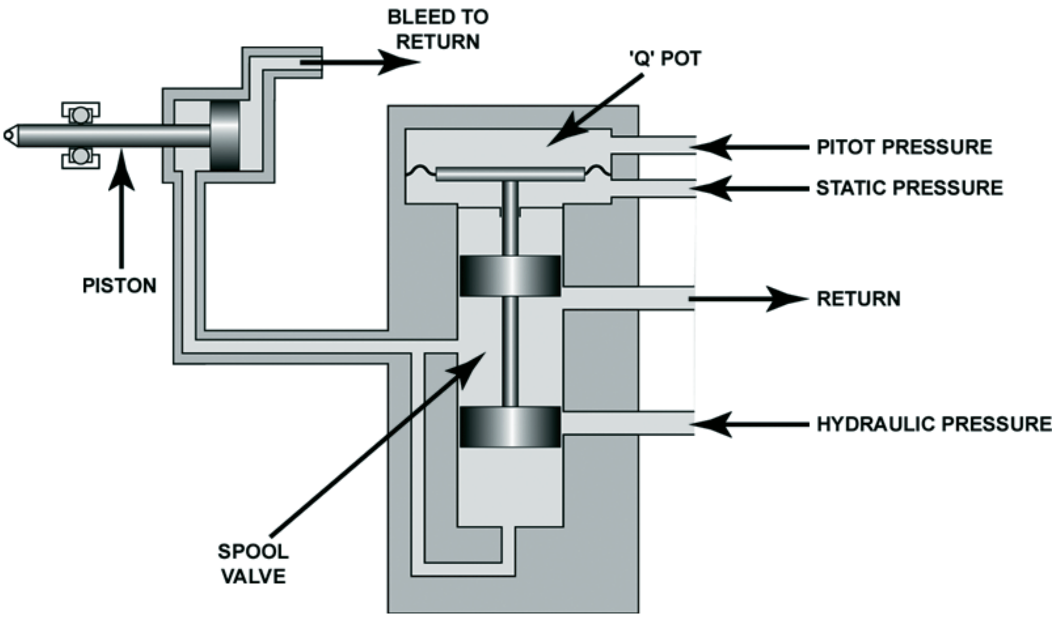


Figure 9.5

OPERATION

With the forward movement of the aircraft, pitot pressure is fed to the upper chamber of the 'Q' pot section of the unit, pushing down the diaphragm. The faster the aircraft flies, the greater will be the pressure on top of the diaphragm. The diaphragm is connected to a spool type selector valve so that the downward movement of the diaphragm opens the pressure port and partially closes off the return port. Hydraulic fluid admitted to the unit will then pass to the forward side of the piston and through a narrow channel to the underside of the spool valve to dampen its downward movement. The faster the aircraft flies therefore, the higher will be the pitot pressure pushing down on the diaphragm and the greater will be the opening of the pressure port in the selector which means that the pressure in front of the piston will increase thereby increasing the resistance to further control movement. The return port is never fully closed as this would otherwise cause a hydraulic lock to form in the system. Large control movement will have a similar effect on control feel as high speed flight does.

Figure 9.6 shows the two principal units in any fully-powered flying control system.

NOTE: The artificial feel unit is connected in parallel to the pilot's control column.

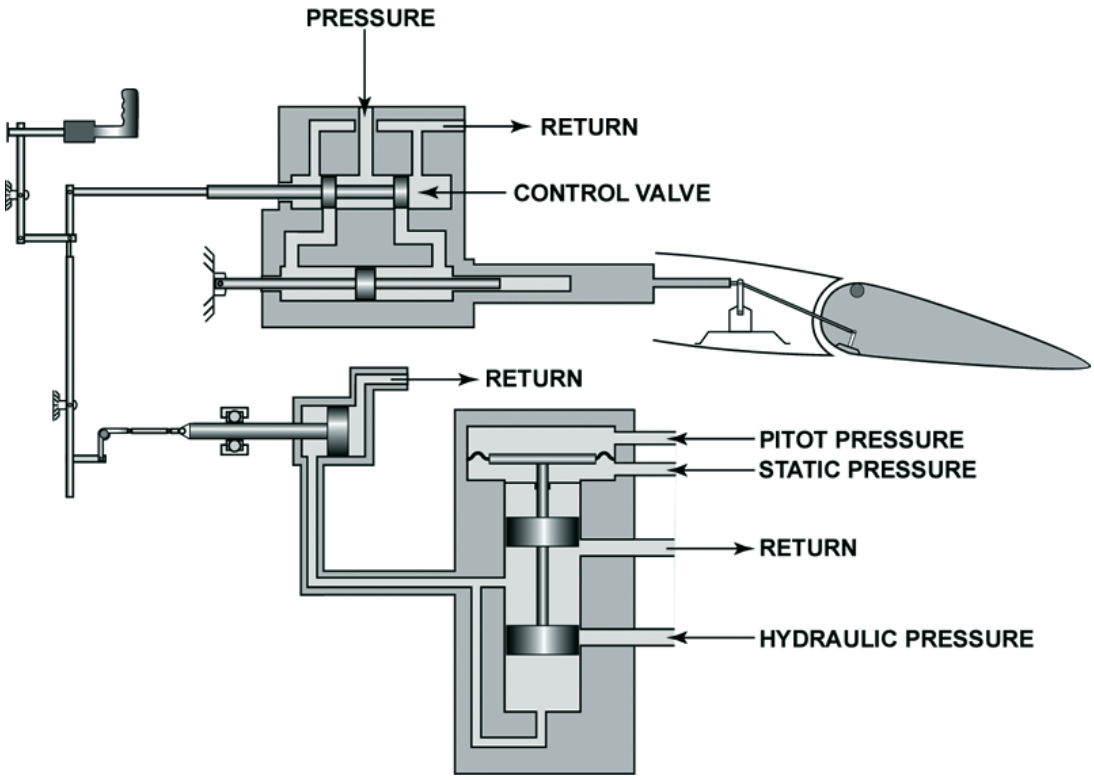


Figure 9.6

ARTIFICIAL FEEL SYSTEM

The artificial feel system shown in *Figure 9.7* uses both spring and hydraulic feel. Spring feel units may be adequate at low speeds, but at higher speeds, greater resistance to cockpit control movement is needed to prevent overstressing the aircraft structure.

The double cam on the aft elevator control quadrant illustrates the tendency of the artificial feel system to put the control column into the neutral position. If the pilot moves the control column he must compress the spring and overcome the force exerted on the hydraulic piston.

The feel computer provides the hydraulic feel. Pitot pressure is delivered to the top side of the airspeed diaphragm and static pressure is fed to the other side of the diaphragm. The diaphragm exerts a downward force on two sets of springs, one on top of the stabiliser position cam, the other above the metering valve and this force is proportional to the aircraft speed.

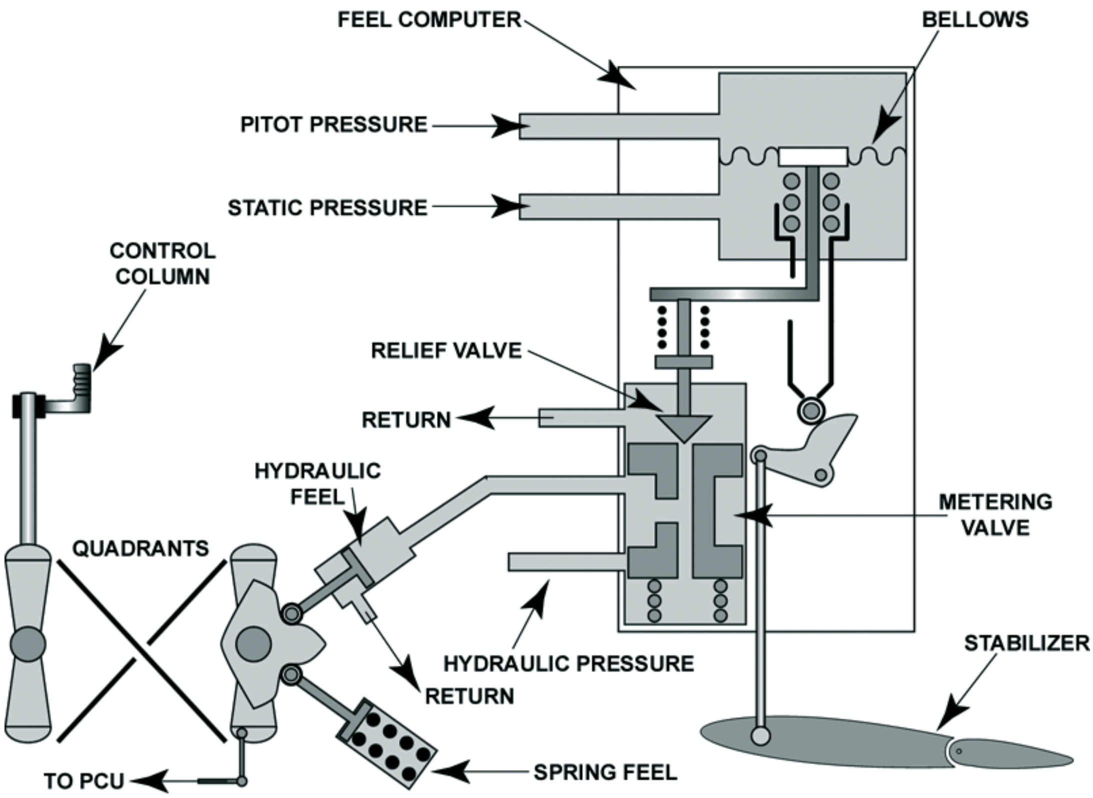


Figure 9.7

Metered pressure forces exerted against the internal horizontal surfaces of the metering valve balance each other and tend to hold it in the neutral position. If the metered pressure exerted against the relief valve at the top of the metering valve is enough to balance the downward force exerted on it by the diaphragm and the spring, then the pressure inlet port remains closed.

When the airspeed increases, the downward force on the metering valve increases and overcomes the metered pressure force and moves the metering valve down, opening its interior to the hydraulic pressure line until the metered pressure balances the downward force on the metering valve. The metering valve continually modulates to compensate for metered pressure bleed to return.

If the pilot moves the control column, he has to force the hydraulic feel piston up into the cylinder and in so doing overcome the hydraulic force acting on the piston. The force exerted by the pilot is transferred to the relief valve which opens slightly against pitot pressure acting downwards on it and allows hydraulic fluid to bleed to return.

The feel computer also incorporates a load relieving trim system connecting the horizontal stabiliser to the relief valve via the stabiliser position cam and the bellows. Operation of the elevators places a stick force on the pilot's controls which needs to be removed once control movement has been completed. To remove this stick force, the pilot trims the variable incidence stabiliser until the stick force is cancelled and the elevator returns to the neutral position.

FEEL TRIM SYSTEM

Figure 9.8 shows a basic sketch of a hydraulically operated artificial feel unit with feel trim included. Normal operation of the controls creates a stick force which requires trimming out. This is achieved by operation of the trim wheel which will relieve the downward pressure on the metering valve by allowing the bellows to expand downwards at the same time as it trims the tailplane or elevator to fly 'Hands Off'.

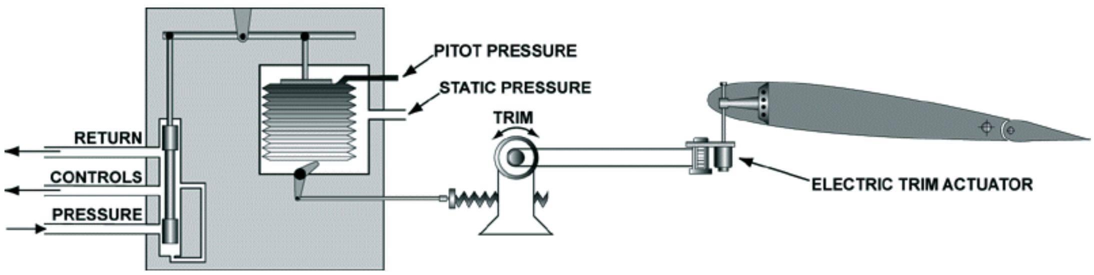


Figure 9.8

Figure 9.9 shows a simplified schematic sketch of a powered flying controls system to be found on a modern civil aircraft.

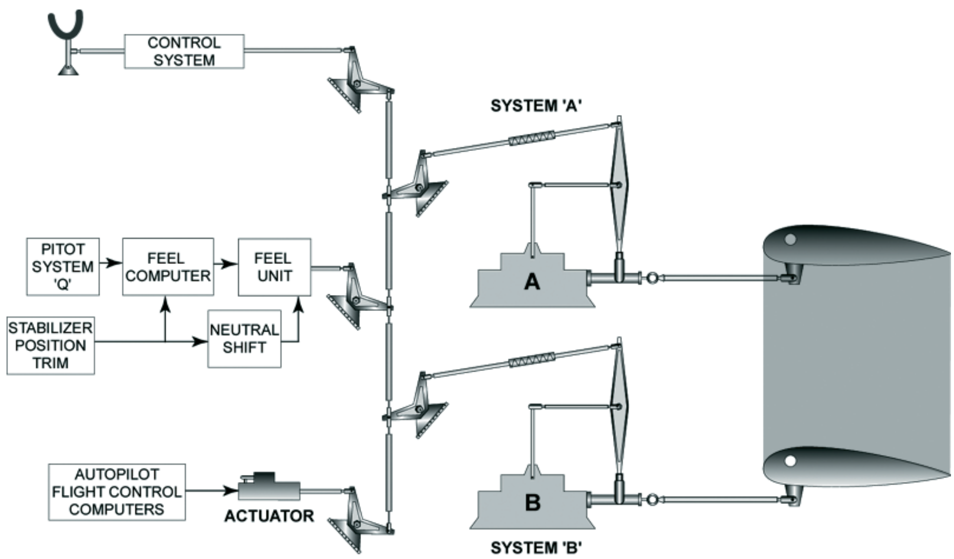


Figure 9.9

FLY BY WIRE (FBW) SYSTEMS

A powered flying control system that uses electronic inputs to a solenoid operated servo valve rather than the mechanical inputs on conventional power controls. The pilot operates the flight deck controls, which may be a side stick as with Airbus aircraft or a conventional control column and rudder pedals. This in turn operates transducers which convert the mechanical input into an electrical output which is amplified, processed by computers with the processed command signal providing the input to the servo valve which controls the movement of a hydraulic actuator. The A 320 is a typical example of an aircraft with a FBW system in which all surfaces are actuated hydraulically and are electrically or mechanically controlled. The main controls architecture is as follows.

Pitch Control
Elevator control electrica.l
Stabiliser control electrical for normal or alternate control. Mechanical for manual trim control.

Roll Control
Ailerons electrical.
Spoilers electrical.

Yaw Control
Rudder mechanical with electrical for yaw damping, turn co-ordination and trim.

Slats and Flaps electrical.

Speed Brakes electrical.

The flight deck controls consist of two side sticks, conventional rudder pedals and pedestal mounted controls and indicators.

Electrical control is by three types of computer:

- **ELAC** (**E**levator **A**ileron **C**omputer)
  There are two of these computers which control the ailerons, elevators and stabiliser.

- **SEC** (**S**poilers **E**levator **C**omputer)
  There are three of these computers which control the upper wing surfaces and the standby elevator and stabiliser.

- **FAC** (**F**light **A**ugmentation **C**omputer) Two computers for electrical rudder control.

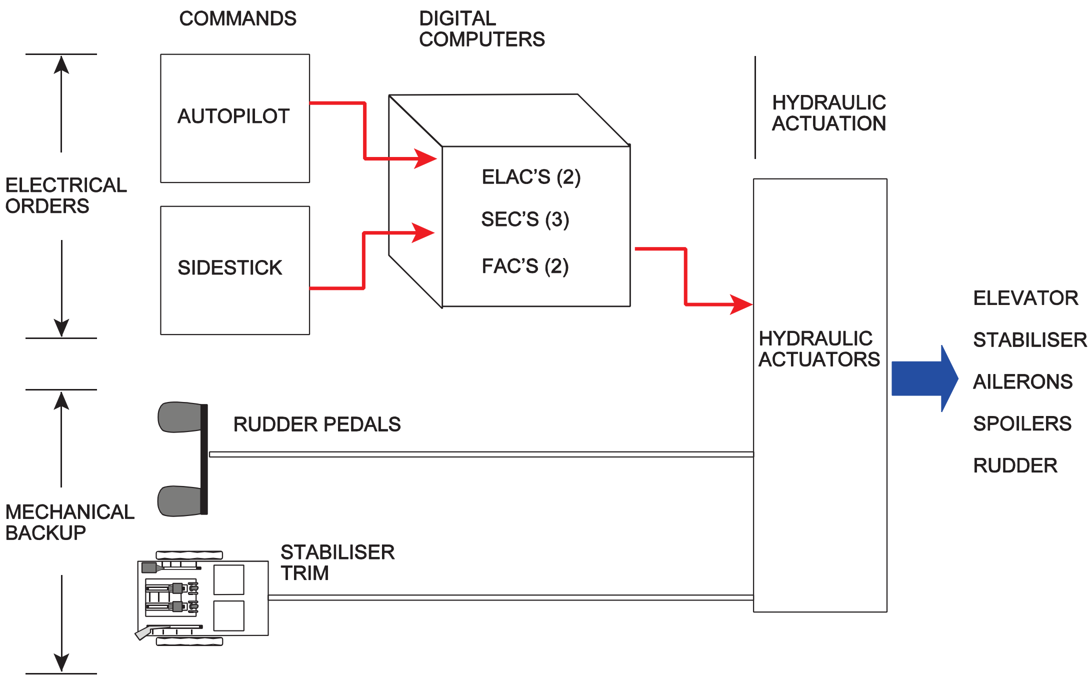


Figure 9.10: Fly by wire block diagram.

REDUNDANCY

Safeguards to eliminate the possibility of loss of control in the event of hydraulic or electrical failure must be provided on modern transport aircraft. This is generally achieved by building some form of redundancy into the control system. Splitting the control surfaces into two or three sections, each powered by separate actuators and hydraulic systems is the usual method. Computer system redundancy is also provided in the case of Airbus aircraft as shown in *Figure 9.11.*

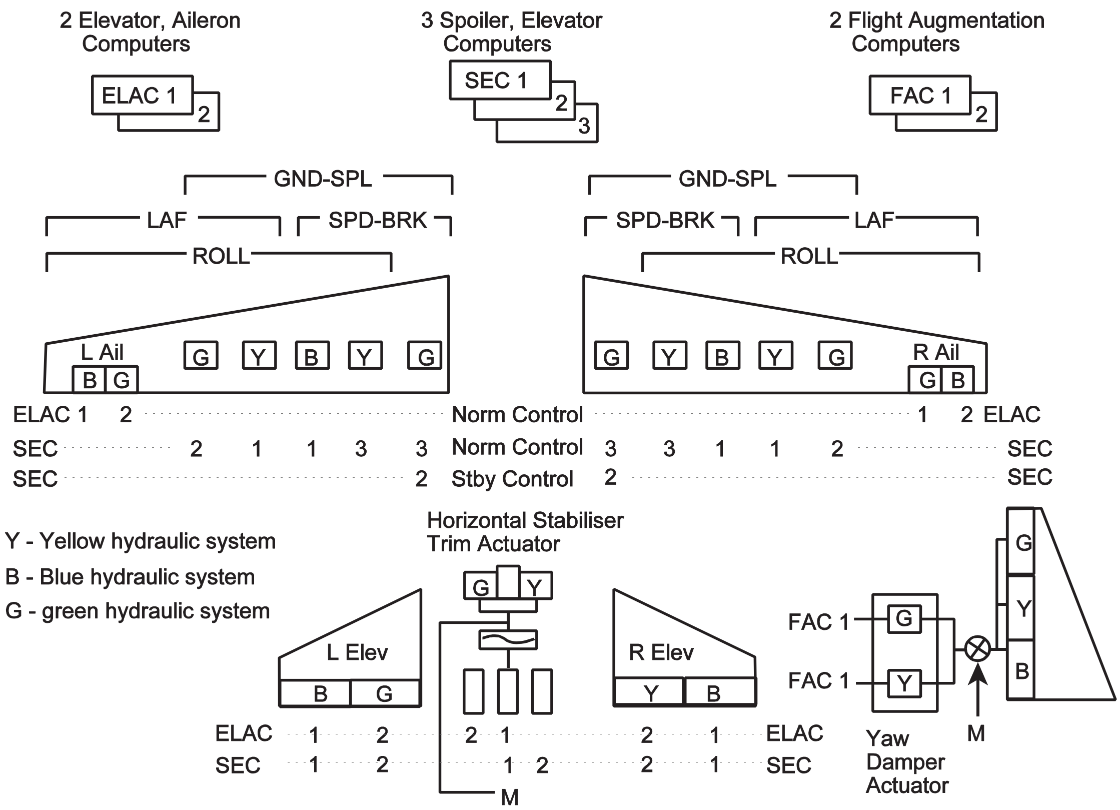


Figure 9.11: Flight control redundancy.

QUESTIONS

1. The purpose of pulley wheels in cable control systems is:

   a. to ensure the cable tensions are equal throughout the system.
   b. to change the direction of the control cable.
   c. to ensure smooth operation of the system.
   d. to prevent the cable from slackening.

2. The purpose of the primary stops in a control system is:

   a. to set the range of movement of the control surface.
   b. to enable the secondary stops to be correctly spaced.
   c. to limit control movement to one direction only.
   d. to set the control surface neutral position.

3. The purpose of the secondary stops in a control system is:

   a. to reduce the control loads on the primary stops.
   b. to limit control surface range in the event of primary stop failure.
   c. to limit the secondary control system from excessive movement.
   d. to remove the excess backlash in the controls.

4. The purpose of the fairleads in a cable control system is to:

   a. alter the angle of deflection of the cables.
   b. to guide the cables on to the pulley wheels.
   c. to attach the cables to chain drives.
   d. to keep the cable straight and clear of structure.

5. In a cable control system cables are tensioned to:

   1. remove backlash from the control linkage.
   2. provide tension on the turnbuckles.
   3. provide positive action in both directions.
   4. ensure the full range is achieved.
   5. compensate for temperature variations.

   a. 1, 3 and 5 only.
   b. 3 only.
   c. 4 only.
   d. all the above.

6. In a cable control system the cables are mounted in pairs to:

   1. remove backlash from the control linkage.
   2. provide tension on the turnbuckles.
   3. provide positive action in both directions.
   4. ensure the full range is achieved.
   5. compensate for temperature variations.

   a. 1, 3 and 5 only.
   b. 3 only.
   c. 4 only.
   d. all the above.

7. In a manual flying control system the control inputs to the primary control surfaces:

1. are reversible.
2. are irreversible.
3. are instinctive for the movement required.
4. are opposite for the movement required.
5. are limited in range by flight deck obstructions.

a. 1 and 4 only.
b. 2 and 4 only.
c. 1 and 3 only.
d. 1, 3 and 5 only.

8. To yaw the aircraft to the right:

a. the right rudder pedal is pushed forward and the rudder moves to the left.
b. the right rudder pedal is pushed forward and the rudder moves to the right.
c. the left rudder pedal is pushed forward and the rudder moves to the left.
d. the left rudder pedal is pushed forward and the rudder moves to the left.

9. To roll the aircraft to the right:

a. the rudder control is moved to the right, the right aileron moves up and the left down.
b. the aileron control is moved to the left and the right aileron moves up and the left down.
c. the aileron control is moved to the right and the right elevator goes up and the left one down.
d. the aileron control is moved to the right, the right aileron goes up and the left one down.

10. The advantages of a cable control are:

1. light, very good strength to weight ratio.
2. easy to route through the aircraft.
3. less prone to impact damage.
4. takes up less volume.
5. less bolted joints.

a. 1, 2 and 4 only.
b. 3 and 5 only.
c. 1, 2 and 5 only.
d. all the above.

ANSWERS

1. B
2. A
3. B
4. D
5. A
6. B
7. C
8. B
9. D
10. D

CHAPTER TEN

AIRCRAFT PNEUMATIC SYSTEMS

Contents

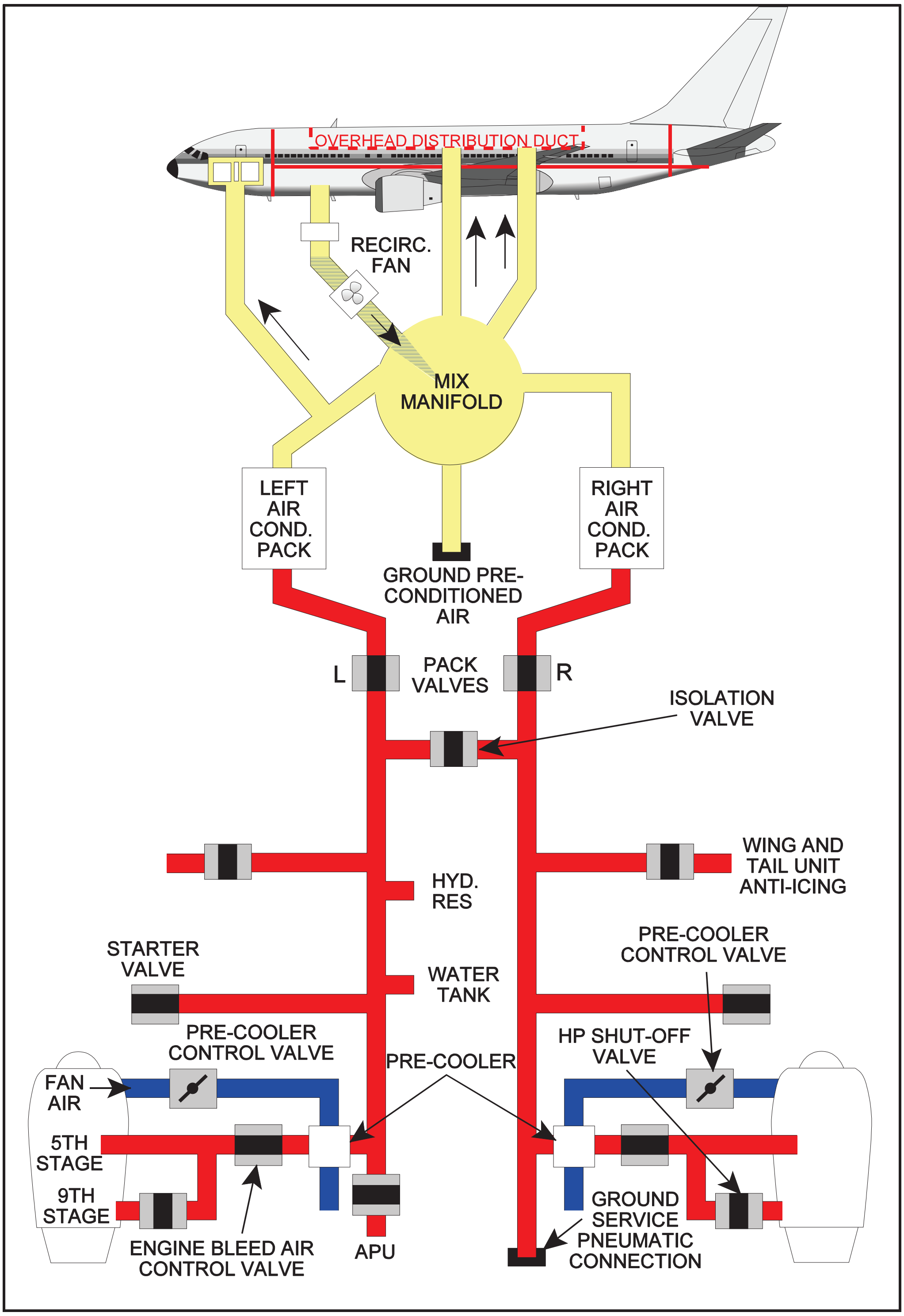


Figure 10.1a: Air sources and uses (schematic).

AIRCRAFT PNEUMATIC SYSTEMS

A pneumatic system is fitted in most modern aircraft to supply some or all of the following aircraft systems.

- Airconditioning
- Pressurisation
- Aerofoil and engine anti-icing
- Air turbine motors
    - Engine starting
    - Hydraulic power
    - Thrust reverse
    - Leading and trailing edge flap/slat operation
- Pneumatic rams, e.g. thrust reverser actuation
- Hydraulic reservoir and potable water tank pressurisation
- Cargo compartment heating

Most of these systems use high volume low pressure airflow bled from the compressor stages of a gas turbine engine, see *Figures 10.1a and 10.1b*. Other sources of supply are engine driven compressors or blowers, auxiliary power unit bleed air and ground power units.

Some older turbo-propeller and piston engined aircraft use high pressure pneumatic systems for the operation of landing gear, brakes, flaps etc. (Fokker F.27) but these aircraft are a minority and hydraulic power has become the normal method of operation for these systems.

ENGINE BLEED AIR SYSTEM

The engine bleed air system consists of the power source (the engine) and control devices for temperature and pressure regulation during operation. Because of the great variation of air output available from a gas turbine engine between idle and maximum rpm there is a need to maintain a reasonable supply of air during low rpm as well as restricting excessive pressure when the engine is at maximum rpm. It is usual to tap two pressure stages to maintain a reasonable pressure band at all engine speeds.

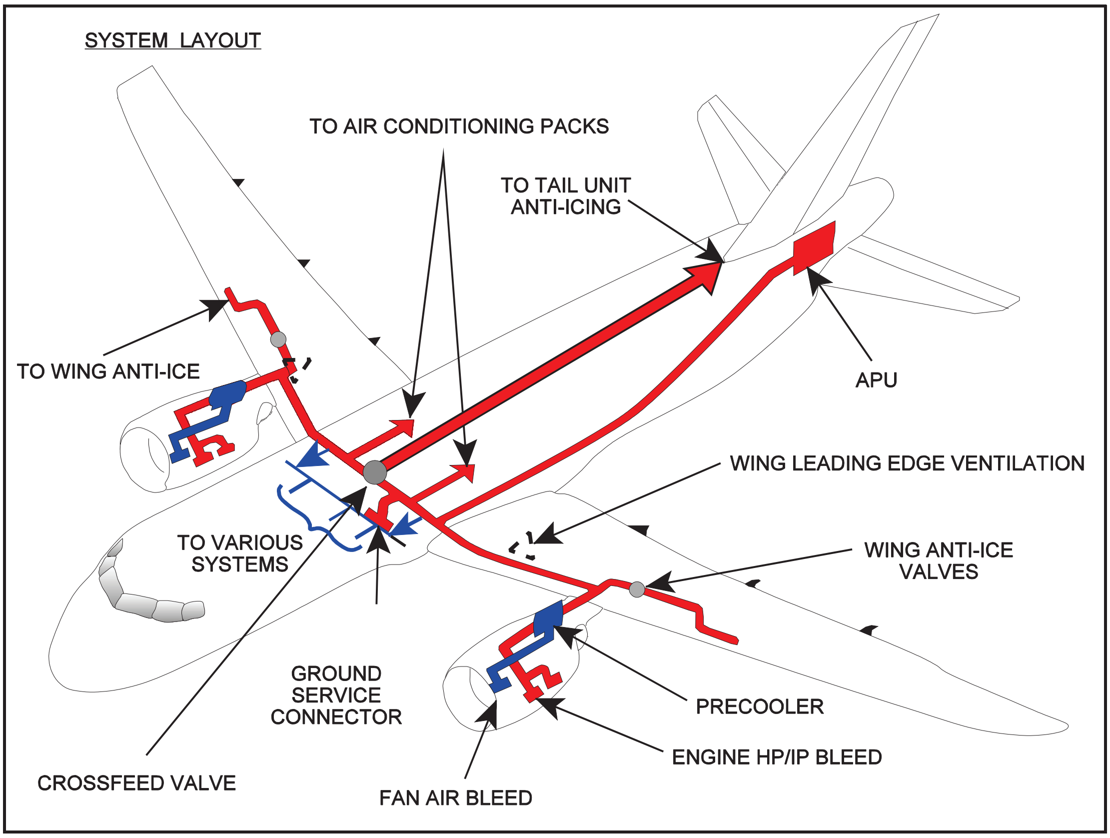


Figure 10.1b: Air sources and uses (pictorial).

Figure 10.1a shows a typical bleed air system with air being ducted from two stages of the compressor, a low pressure (LP) stage and a higher pressure (HP) stage. In this case the stages used are the 5th and 9th. The two sources are combined together at the High Pressure Shut-Off Valve (HPSOV). This valve is pressure sensitive and pneumatically operated and is open when there is insufficient air pressure from the LP system to maintain the required flow. As the engine speeds up the LP air pressure will increase until it closes the high pressure shut-off valve so that, in all normal stages of flight, bleed air will come from the LP stages. The high pressure shut-off valves are designed to open relatively slowly on engine start up or when airconditioning is selected to minimise the possibility of a surge of air pressure. They are also designed to close very quickly to prevent an ingress of fumes or fire to the cabin in the event of an engine fire.

The bleed air control valve is the separation point between the engine and the pneumatic system manifold and allows the bleed air to enter the pneumatic system and is controlled electrically from the flight deck. Non-return valves (NRV) are installed in the LP stage ducts to prevent HP air entering the LP stages of the engine when the high pressure shut-off valve is open.

Most multi-engined aircraft also keep the supplying engines or sides separate with each engine supplying its own user services. These are kept independent by **isolation valves** which are normally closed but which may be opened if an engine supply is lost to feed the other side's services.

The system will be fitted with a duct pressure gauge, valve position indicators and overheat sensors both inside and outside the supply ducts.

The system will also be fitted with safety devices to prevent damage to the supply ducting due to over pressure or overheat.

- **Over pressure**
  This is usually caused by failure of the high pressure shut-off valve and a pressure relief valve is fitted to the engine bleed air ducting. If the over pressure persists, a sensor bleeds high pressure shut-off valve opening pressure and forces the valve to close.

- **Overheat**
  An electrical temperature switch downstream of the bleed air control valve will close the valve if the temperature of the air reaches a predetermined level.

  Both overheat and over pressure conditions will be indicated to the pilots by warning lights. If an overheat occurrence took place, the bleed valve switch would be selected **'OFF'** and the isolation valve opened to restore the lost system.

AIR CONDITIONING SYSTEMS

The air conditioning or environmental control system is fitted to an aircraft to regulate the temperature, humidity, quantity and quality of the air supply to the passengers and crew. This conditioned air is also used, with additional components, for the pressurisation of the aircraft.

Modern aircraft are pressurised for the following reasons.

- The aircraft can fly at an altitude where it can operate efficiently, economically and avoid the worst of the weather conditions whilst maintaining cabin pressure at a comfortable level.

- Aircraft can achieve high rates of climb and descent with small corresponding rates of cabin pressure changes

The requirements of an air-conditioning system as laid down in BCAR's are described below.

Provision of fresh air
Fresh air must be provided at a rate of 1 lb per seat per minute in normal circumstances, or at not less than 0.5 lb following a failure of any part of the duplicated air-conditioning system (No JAR Figures quoted except for crew which is "not less than 10 cubic ft per minute per crew member")

Temperature
Cabin air temperature should be maintained within the range 65°F to 75°F, (18°C to 24°C).

Relative humidity
The relative humidity of the cabin air must be maintained at approximately 30% (at 40,000 ft the relative humidity is only 1 to 2%).

Contamination
Carbon monoxide contamination of the cabin air must not exceed 1 part in 20,000.

Ventilation
Adequate ventilation must be provided on the ground and during unpressurised phases of flight.

Duplication
The air-conditioning system must be duplicated to the extent that no single component failure will cause the provision of fresh air to fall to rate which is lower than 0.5 lb per seat per minute. An aircraft air conditioning system must be capable of maintaining an adequate supply of air for ventilation and pressurisation at a temperature and relative humidity which ensures comfortable conditions for both passengers and crew. These requirements are met as follows:

Adequate supply
The mass flow of air into the cabin is maintained at a constant value which must be sufficient to achieve cabin pressurisation when cruising at maximum operating altitude.

Temperature
The temperature of the air supply to the cabin is controlled by mixing hot and cold air in variable proportions to maintain the cabin air temperature within prescribed limits.

Humidity
Moisture is removed from, or added to, the cabin air supply to maintain a comfortable level of humidity. The method of conditioning will vary depending upon the type of aircraft, the power unit and the operating characteristics of the aircraft concerned.

RAM AIR SYSTEMS

In these systems, which are used in used in unpressurised piston engined aircraft, ambient atmospheric air is introduced to the cabin through forward facing air intakes. Some of this **ram air** can be heated by exhaust or combustion heaters and then mixed with the cold ambient air in varying proportions to give a comfortable cabin temperature. It is of extreme importance that the supply (ram) air does not come into contact with, or is contaminated by, the exhaust gases or the air used for combustion.

A typical system for a light aircraft is shown in *Figure 10.2* which also features hot windscreen demisters and a fresh air blower for use on the ground when there is no ram air. The heater muff or exhaust muff is a close fitting cowl around the exhaust pipe which allows ram air to come into close contact with the hot exhaust pipe to provide hot air for heating the cabin. Fresh cold air can be allowed into the cabin through the ram air inlets on the wing leading edge. After use the air is dumped overboard through a vent on the underside of the aircraft.

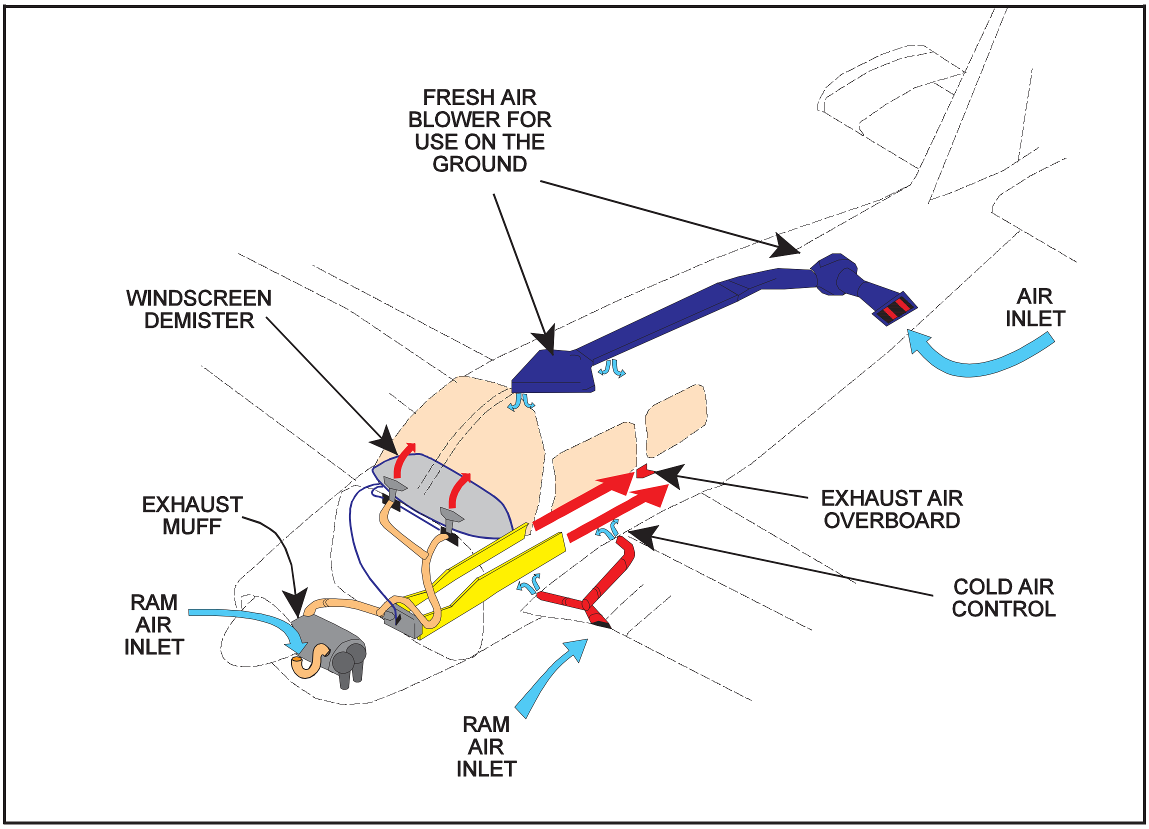


Figure 10.2: Light aircraft hot and cold air system.

COMBUSTION HEATER.

The fuel used in the heater is normally that which is used in the aircraft's engines and the heater works by burning a fuel/air mixture within the combustion chamber. Air for combustion is supplied by a fan or blower and the fuel is supplied via a solenoid operated fuel valve. The fuel valve is controlled by duct temperature sensors but can be manually overridden. The system is designed so that there is no possibility of leaks from inside the chamber contaminating the cabin air. In addition the system must be provided with a number of safety devices which must include:

- Automatic fuel shut-off in the event of any malfunction.
- Adequate fire protection in the event of failure of the structural integrity of the combustion chamber.
- Automatic shut-off if the outlet air temperature becomes too high.

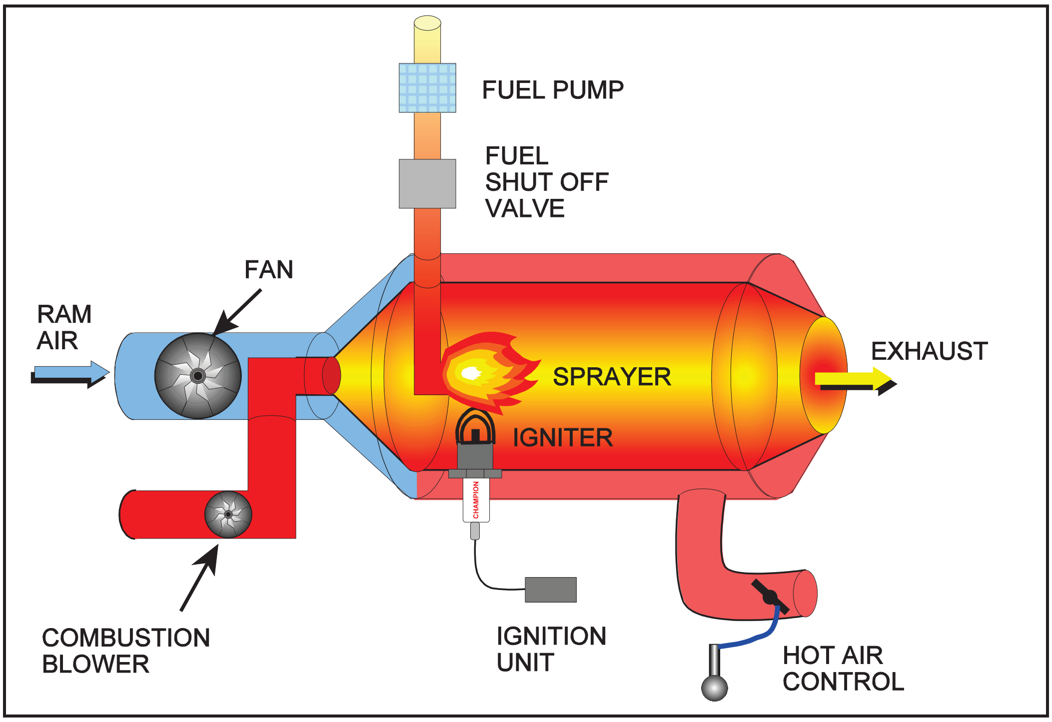


Figure 10.3: A combustion heater.

SYSTEMS USED FOR PRESSURISED FLIGHT

ENGINE DRIVEN CABIN SUPERCHARGER (BLOWER) SYSTEMS

When a supply of air from the compressor of a gas turbine engine for air conditioning or pressurisation is not available, cabin air supply may be provided by blowers driven through the accessory gearbox or by turbo compressors driven by bleed air. Such systems were necessary for piston engined and turbo-propeller aircraft and are used for some turbo-jet aircraft where the air supply from the compressor is considered to be too dirty (contaminated).These blowers may be of the centrifugal or positive displacement (Rootes) type.

The blower must be capable of supplying the required mass flow of air under all operating conditions which means that at sea level with the engine running at high speed too high a mass flow will be delivered, therefore in order to prevent over pressurisation of the supply ducts, a mass flow controller signals spill valves to vent the excess air flow to atmosphere. This method is wasteful and is avoided where possible by using variable speed drives.

In such a system, the mass flow produced by the engine is dependent on the rotational speed of the blower and the air density. This air can be heated by restricting the flow by means of a **choke valve** which can be progressively closed to increase the temperature and pressure of the air leaving the blower and opened to prevent excessive temperatures and pressures. The hot and cold air supplies are mixed in varying proportions to maintain the delivery temperature at a comfortable level for both passengers and crew. Selection and control may be automatic or manual.

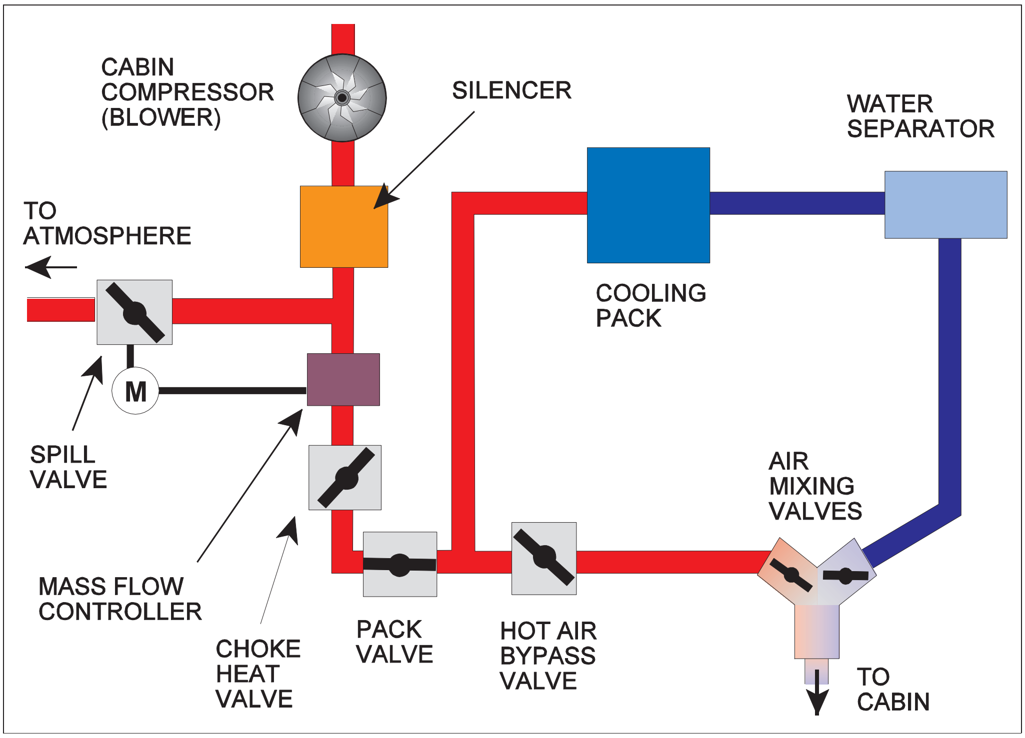


Figure 10.4

ENGINE BLEED AIR SYSTEMS

This the most widely used method of supplying charge air for the air conditioning systems of modern aircraft. Hot pressurised air is supplied to the bleed air duct from the LP/HP compressor. A tapping is then taken from the duct to supply the air-conditioning system. This air is passed through a mass flow controller or a modulated engine bleed air valve and since the bleed air supply is always at a higher temperature than that required for passenger comfort a means of cooling this air is accomplished by the air conditioning pack.

AIR CYCLE COOLING

This is the preferred system for most modern jet transport aircraft and uses the principles of energy conversion and surface heat exchange for it's operation. At the heart of the system is the **Cold Air Unit** (C.A.U.) of which there are three basic types, the turbo-compressor or bootstrap, the brake- turbine and the turbo-fan.

TURBO-COMPRESSOR (BOOTSTRAP)

This is the most popular air cycle system in current use being used where high pressure bleed air is not available or its use is undesirable as in the case of aircraft using high by-pass ratio or small turbo propeller engines. The low pressure bleed air (or air from a blower) is pre-cooled in the primary heat exchanger and then has its pressure boosted by the compressor. This is done in order to make the energy conversion (i.e heat and pressure to work) process across the turbine more efficient. Between the compressor and the turbine is the secondary heat exchanger which serves to remove any excess temperature rise across the compressor.

The point to note is the pressure rise across the compressor which allows the use of much lower initial tapping pressures while still being able to achieve a sufficiently high pressure drop across the turbine. In order to provide sufficient airflow across the cold air unit when the aircraft is on the ground or at low speed in the air a fan is provided to draw in air through the ram air or ground cooling air ducts. The ram air doors may be opened and closed according to flap position or modulated automatically by signals from the temperature control system. This fan may be electrically powered or be a third wheel of the cold air unit.

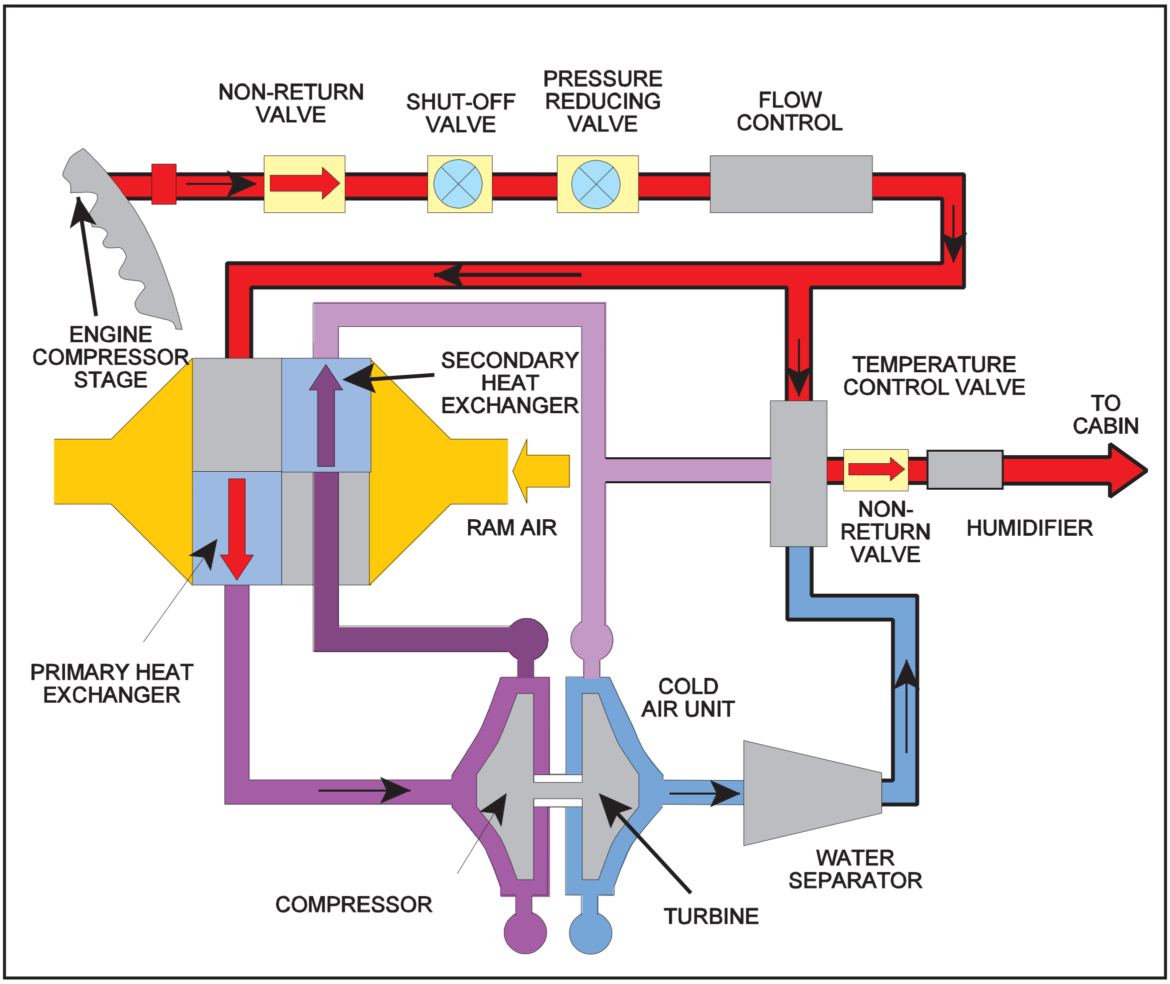


Figure 10.5: Typical bleed air ("bootstrap") system.

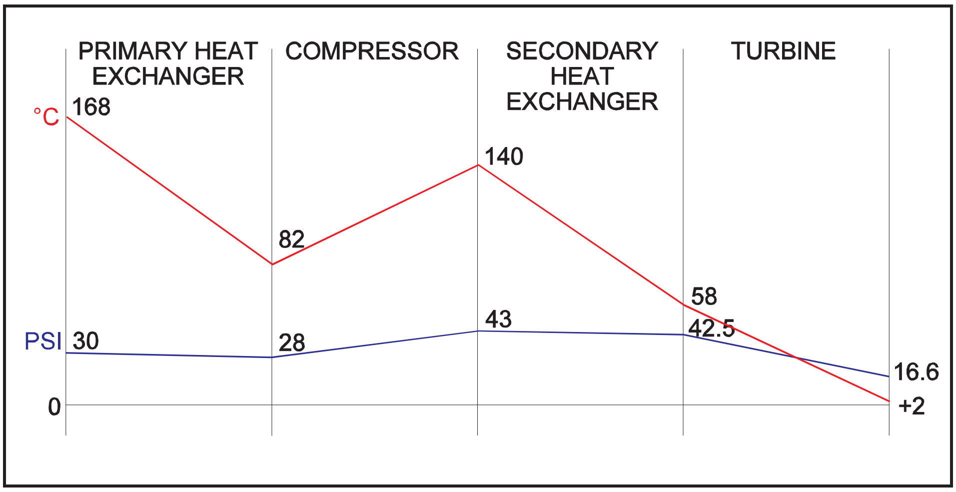


Figure 10.6: Typical performance of a bootstrap system.

BRAKE TURBINE

In this system the initial tapping pressure is higher and the charge air is supplied directly to the turbine via a heat exchanger. The turbine drives the compressor, which takes in low pressure ambient air and expels it through a restriction. This causes a back pressure on the compressor which puts a "brake" on the turbine (hence the name) and provides energy conversion which removes the heat from the charge air. Some installations feed the output from the compressor into the ducting downstream of the heat exchanger to increase the thermal efficiency of the heat exchanger by "jet pump" action. This system is lighter (only one heat exchanger) and the mass flow/weight ratio is better but, unless the "jet pump" installation is used, it cannot be used to cool the charge air when the aircraft is on the ground.

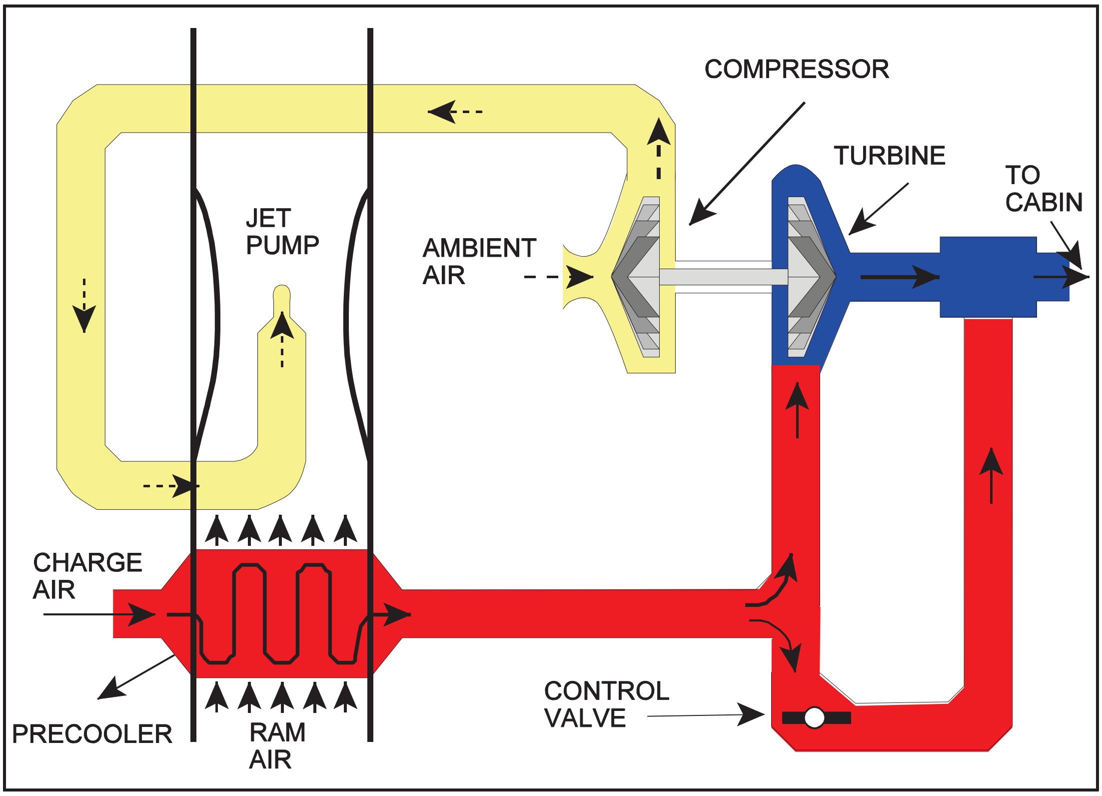


Figure 10.7: Schematic brake turbine unit.

FAN TURBINE (TURBO-FAN)

This is a refinement of the brake turbine unit, in which, instead of a compressor, the turbine is coupled to a fan of sufficient capacity to draw the required volume of cooling airflow through the primary heat exchanger so that the unit is not dependent on ram air for it's operation and can therefore be operated on the ground. The general design of the unit is such that it is extremely light and compact. The delivery pressure (and therefore temperature) is higher and the turbine speed must be higher to achieve the necessary pressure drop.

HEAT EXCHANGER

These components operate on the principle of surface heat exchange and normally use ram air as the cooling medium. They are designed to give a thermal efficiency of at least 80% of the difference between the charge air temperature and the ambient air temperature but can never reduce the charge air temperature below that of ambient hence the need for the cold air units. It should be noted that in the vapour cycle system both the evaporator and condenser are also heat exchangers but use a refrigerant for cooling the charge air and ram air for changing the vaporised refrigerant back to its liquid state.

GROUND COOLING FAN

The ground cooling fan, as its name implies, allows the air conditioning system to be used when the aircraft is on the ground by drawing (or pushing) air across the primary and, if necessary, the secondary heat exchangers. It may be electrically driven or be powered by a third wheel on the cold air unit.

WATER SEPARATOR

Located downstream of the turbine of the air cycle machine, the water separator removes the excess water which condenses during the cooling process. This is a problem at low altitude and when running the system on the ground during conditions of high humidity. A safety valve is provided to ensure that the flow of air to the cabin is safeguarded in the event of the water extractor icing up. In some installations a temperature sensor controls an anti-ice by-pass valve which allows hot air to pass directly into the airflow between the turbine and the water separator to prevent icing.

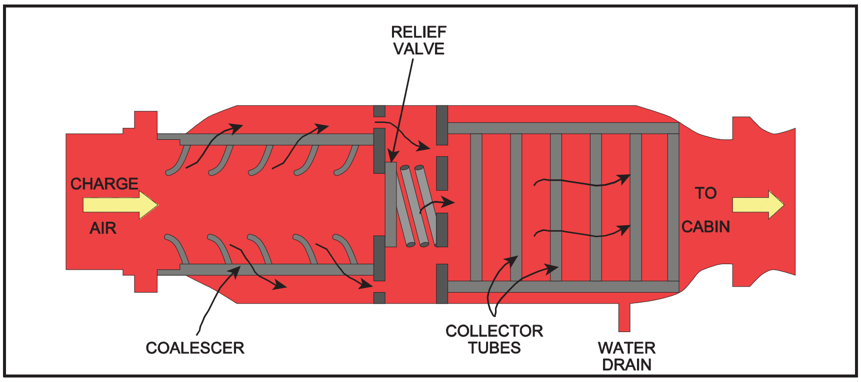


Figure 10.8: Water separator.

HUMIDIFIER

In aircraft operating at high altitudes for long periods of time it may be necessary to increase the moisture content of the conditioning air from the 1-2% relative humidity of the ambient air to a more comfortable level to prevent physical discomfort arising from low relative humidity. This is the function of the humidifier, a typical example of which is shown below. The aircraft's drinking water supply is used and the water is atomised by air from the air conditioning supply.

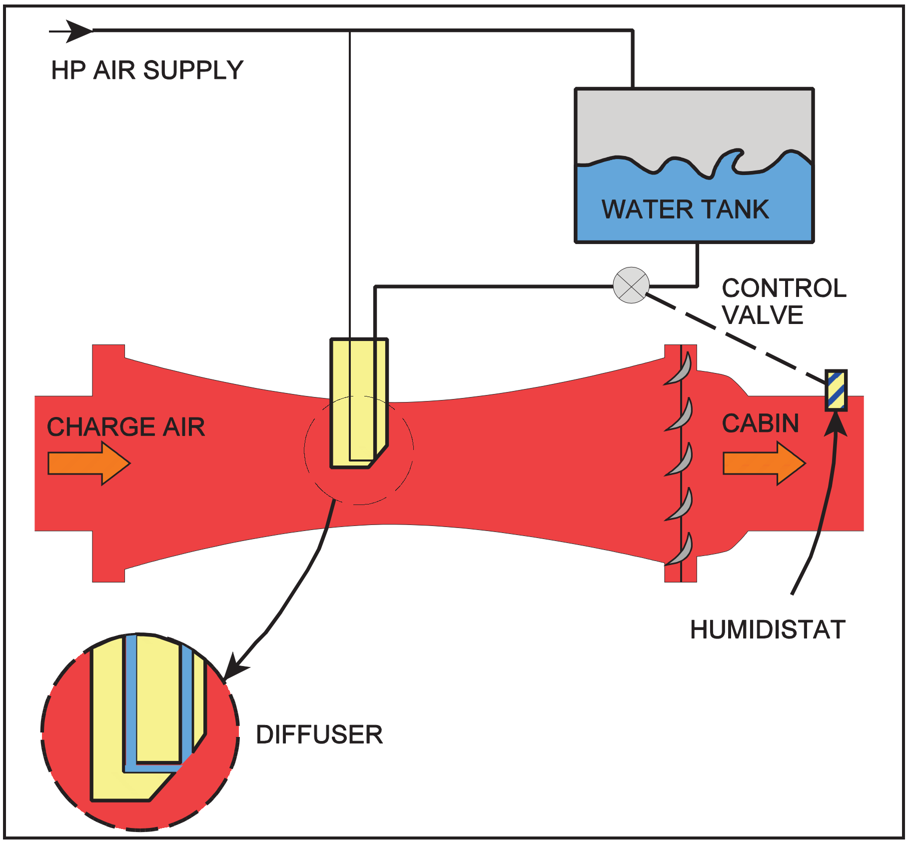


Figure 10.9: "Venturi humidifier" humidity control.

RAM AIR VALVES

The ram air valves (inlet and outlet doors) are opened and closed by the pack controller and regulate the amount of air entering the ram air duct. This is done automatically as part of the temperature control system and during landing and take-off in order to prevent ingestion of foreign matter.

MASS FLOW CONTROLLER

This component is fitted to ensure that a constant mass flow is supplied regardless of the engine rpm. The mass flow controller spills excess air to atmosphere when used with blower systems but the variable orifice valve fitted to bleed air systems is calibrated so that the total aerodynamic effect on its internal mechanism automatically adjusts the orifice so that the required mass flow passes to the system irrespective of changes in the value of the pressure upstream and downstream of the unit.

TEMPERATURE CONTROL

The temperature of the air entering the cabin is usually achieved by mixing hot air with cooled air. There are two basic methods of temperature control, mechanical and electro-mechanical. The simple non-automatic manual method consists of valves which are manually positioned to regulate the temperature by mixing hot and cold air prior to it entering the cabin. Automatic control of the cabin, flight deck, cargo holds etc. Temperature is achieved by comparing a pilot selected temperature with the temperature of the mixed air inlet to the cabin etc. Sensors in the cabin and the supply ducts are compared electronically with the selected value and any difference modulates the hot air by-pass valve to allow more or less air to pass through the cooling components to obtain the correct temperature at the point of mixing. In manual control the valves will move in response to hot/cold or increase/decrease selection.

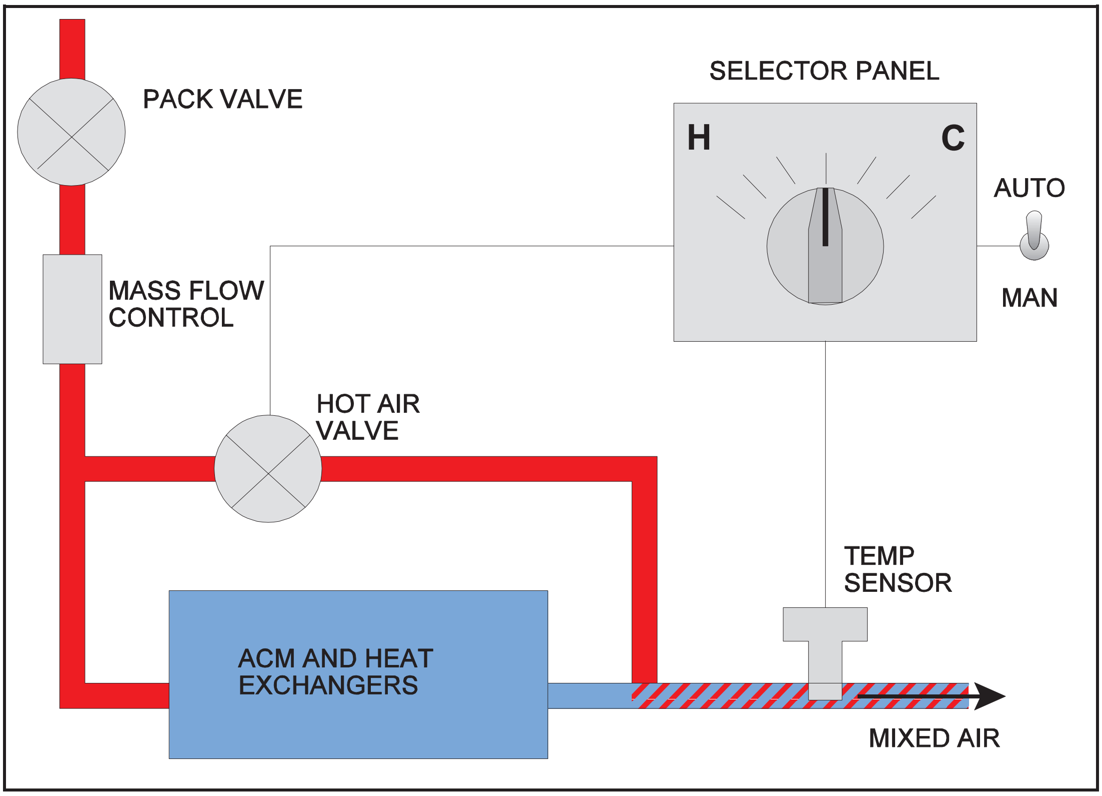


Figure 10.10

AIR DISTRIBUTION

Most passenger transport aircraft supply warm air to the cabin walls by means of floor and wall passages which maintains the interior surfaces at cabin temperature, reducing draughts, direct heat losses which in turn allows the entering air temperature to be closer to the cabin temperature. The ducting is in two distinct sections to provide for separate flows of cold and heated air. The cold (conditioned) air is supplied to the passengers through the gasper air system. Conditioned air is also supplied to the flight deck to the crew stations where it can be adjusted for flow direction and quantity. It is also supplied to the flight deck windows for de-misting purposes.

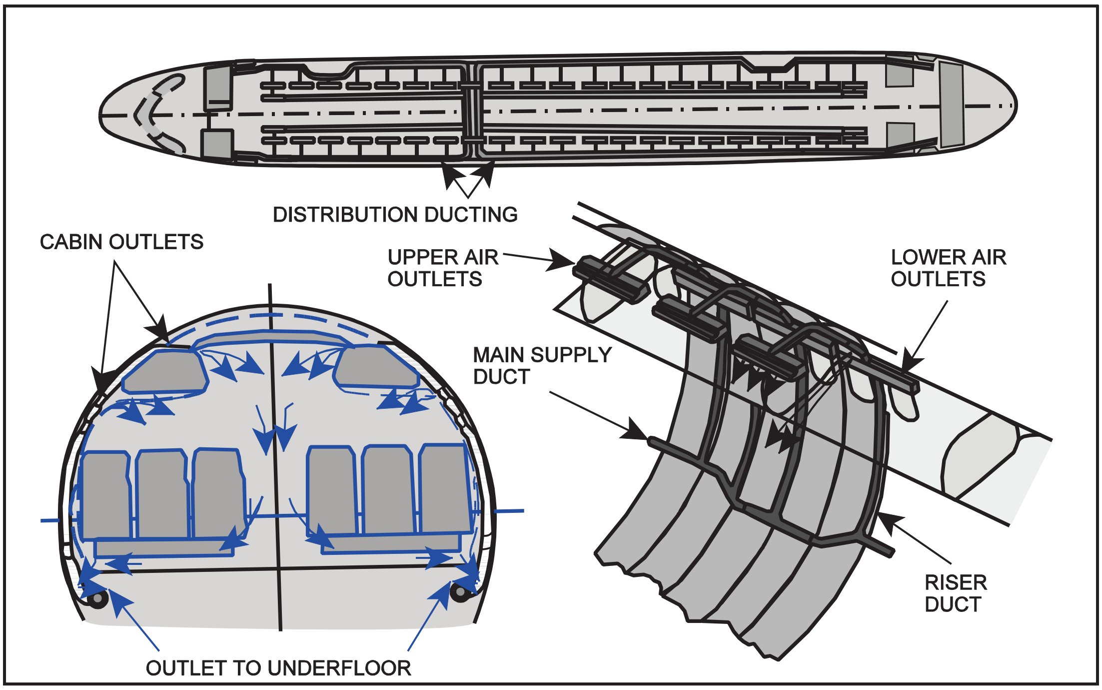


Figure 10.11: Cabin air distribution.

GASPER AIR

Gasper air is tapped from one of the zone supply ducts upstream of where trim air is added and the gasper fan provides a positive supply of conditioned air to all zones through individually controlled outlets (punkah louvres).

TRIM AIR

In order to avoid large temperature gradients between the extremities of the cabin it is often necessary to divide the cabin into sections and deal with each as a separate distribution problem (zone trim).

The temperature delivered by the packs is determined by the zone requiring the coolest air input. Individual zone requirements are satisfied by adding hot trim air to the output of the packs. The pressure and quantity of trim air is dependent on inputs from cockpit and cabin temperature control systems. The pressure of the trim air is controlled by pressure regulating valves.

RE-CIRCULATION FANS

These augment the air conditioning packs allowing the packs to be operated at a reduced rate during the cruise which decreases engine bleed requirements and maintains a constant ventilation rate throughout the cabin. The fans draw cabin air from the underfloor area through filters then reintroduce the air into the conditioned distribution system. Air from the region of toilets and galleys is not re-circulated but is vented directly overboard by the pressurisation discharge valves.

VAPOUR CYCLE (REFRIGERATION) SYSTEM

The vapour cycle air conditioning system is similar in operation to the domestic refrigerator or the galley cart cooling system used on some large aircraft. Its use for aircraft is now generally limited to small piston engined types.

A refrigerant is used to absorb heat from the charge air by changing its state from liquid to gas. The heat is carried by the refrigerant to a condenser where it is given up to the atmosphere and the refrigerant returns to its liquid state.

In the vapour cycle system the refrigerant alternates between the vapour and liquid phases. It is compressed, cooled, expanded and heated in that order. The refrigerant is a liquid which boils at approx 3.5°C (38°F) at sea level atmospheric pressure. At higher pressures the boiling point is increased and vice versa. Refrigerant at low pressure is drawn through the evaporator by the compressor (which may be electrically or air driven). As it passes through the evaporator the refrigerant changes state from liquid to gas absorbing heat from the cabin air supply and therefore cooling the air as it does so.

The compressor raises the pressure and therefore the boiling point of the refrigerant before it enters the condenser. The condenser is positioned so that cold ram air passes over it and the refrigerant changes back to its liquid state giving up latent heat to the ram air. The pressurised liquid then passes to the receiver which acts as a reservoir and then through an expansion valve which reduces its pressure and boiling point before entering the evaporator to repeat the cycle.

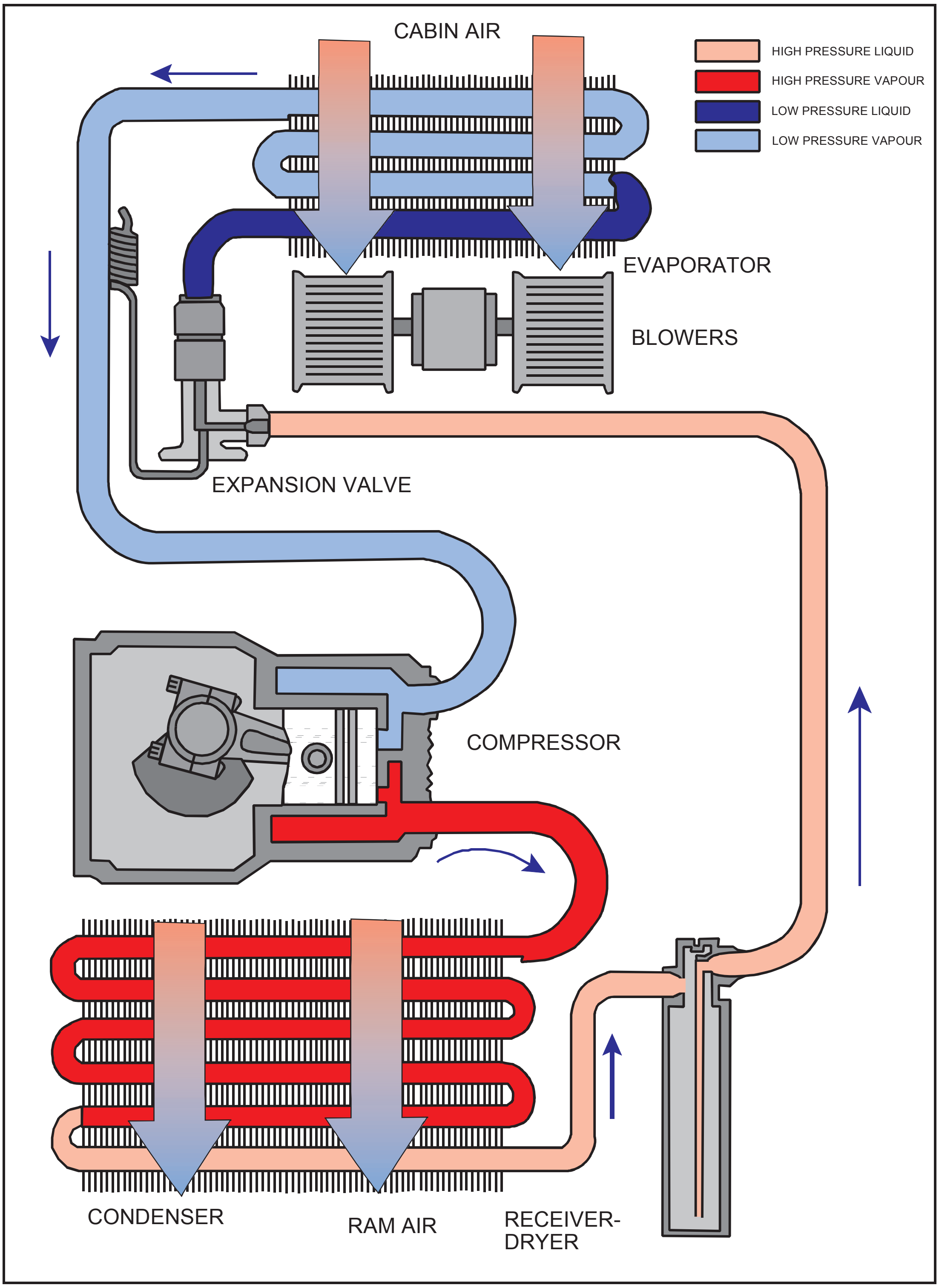


Figure 10.12: Vapour cycle (refrigeration system).

CHAPTER ELEVEN

PRESSURISATION SYSTEMS

Contents

PRESSURISATION

Modern aircraft operate more efficiently at high altitudes and have high rates of climb and descent.

In order to take advantage of these properties the interior of an aircraft flying at high altitude is pressurised to allow passengers and crew to function normally without the need for additional oxygen.

Insufficient oxygen or **hypoxia** will result in a reduction in the ability to concentrate, loss of consciousness and, finally death. (The effects etc are fully described in the Human Performance notes).

Up to an altitude of 10,000 ft (3.3km), the air pressure and consequently the amount of oxygen is sufficient for humans to operate without too many problems. However, lack of oxygen can become apparent at altitudes above this and cabin pressurisation systems are designed to produce conditions equivalent to those of approximately 8,000 ft (2.6km) or less. This means that there is no need for oxygen equipment except for emergency use by crew or passengers and the effect of low atmospheric pressure on passengers is negligible.

Once the cabin altitude **(the pressure altitude corresponding to the pressure inside the cabin)** reaches 10,000 ft the crew must be on oxygen, and at 14,000 ft cabin the passengers must be on emergency oxygen.

It also means that aircraft are able (when required) to achieve high rates of climb and descent while making correspondingly small rates of change of cabin pressure.

THE AIRCRAFT STRUCTURE

The airframe structure must, therefore, be strong enough to withstand the differential pressures generated without being too heavy and therefore uneconomic in operation.

The difference in pressure between the inside and outside of the pressurised areas of the aircraft or **differential pressure** produces **hoop stresses** which are applied cyclically every time the aircraft is pressurised and de-pressurised causing fatigue which can, ultimately, lead to structural failure.

Keeping the maximum differential pressure to its lowest practical value reduces the hoop stress. Pressurising the cabin to the 8,000 ft level reduces the stresses and therefore the fatigue on the airframe as well as reducing the required structural strength and keeping the weight of the aircraft down which increases the economy of operation and reduces the initial costs of the aircraft.

Typical maximum differential pressures for large jet transport aircraft are between 8 and 9 psi. (552-621hPa). The passenger cabin, flight deck and cargo compartments are normally pressurised with the undercarriage bays, tail and nose cones unpressurised.

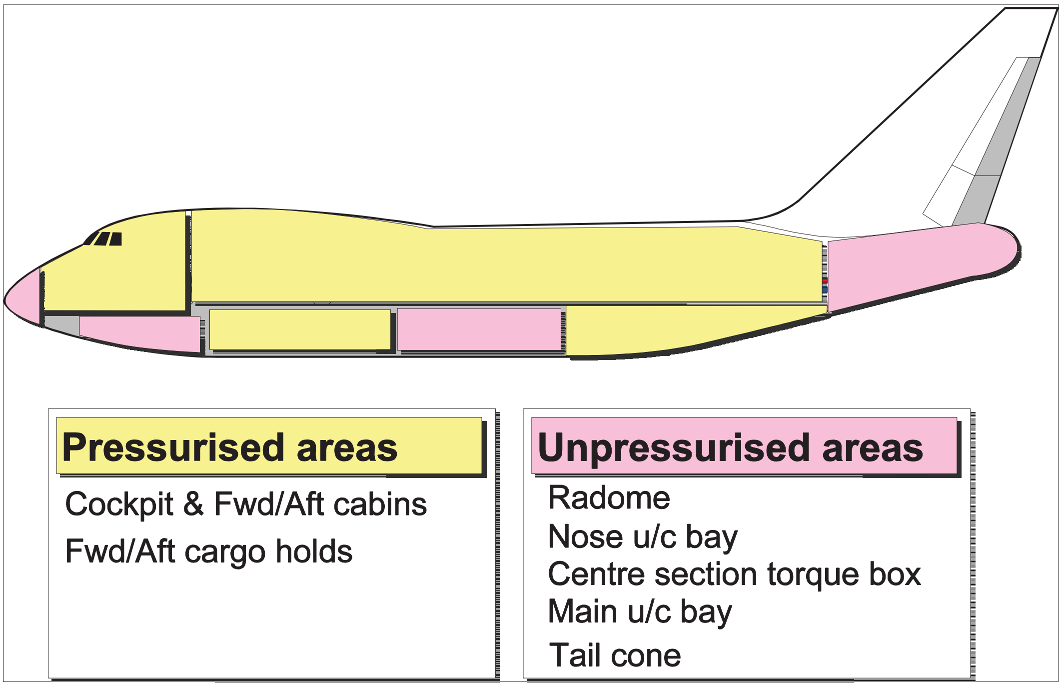


Figure 11.1: Pressurised and unpressurised areas.

SYSTEM CONTROL

Cabin pressurisation is controlled by having a constant mass flow of air entering the cabin and then varying the rate at which it is discharged to atmosphere. The constant mass flow of air is supplied by the air-conditioning system via the mass flow controller and is discharged to atmosphere by the discharge or outflow valves.

The operation of these valves is governed by the pressure controller when in automatic control and by the flight crew when in manual.

Closing the valve reduces the outflow and increases the pressure, opening the valve increases the outflow and reduces the pressure. During the cruise the outflow valves form a thrust recovery nozzle to regain lost thrust energy from the cabin exhaust air.

In addition to the outflow valves the following safety devices must be fitted to any cabin pressurisation system.

Safety valve. A simple mechanical outwards pressure relief valve fitted to relieve positive pressure in the cabin when the maximum pressure differential allowed for the aircraft type is exceeded i.e prevents the structural max. diff. being exceeded. This valve will open if the pressure rises to max. Diff. Plus 0.25psi.

Inwards relief (inwards vent) valve. A simple mechanical inwards relief valve is fitted to prevent excessive negative differential pressure which will open if the pressure outside the aircraft exceeds that inside the aircraft by 0.5 to 1.0 psi.

The inwards and outwards safety valves may be combined together in one unit or may be completely separate components and are positioned above the aircraft flotation line. **The outwards and inwards relief valves must be duplicated.**

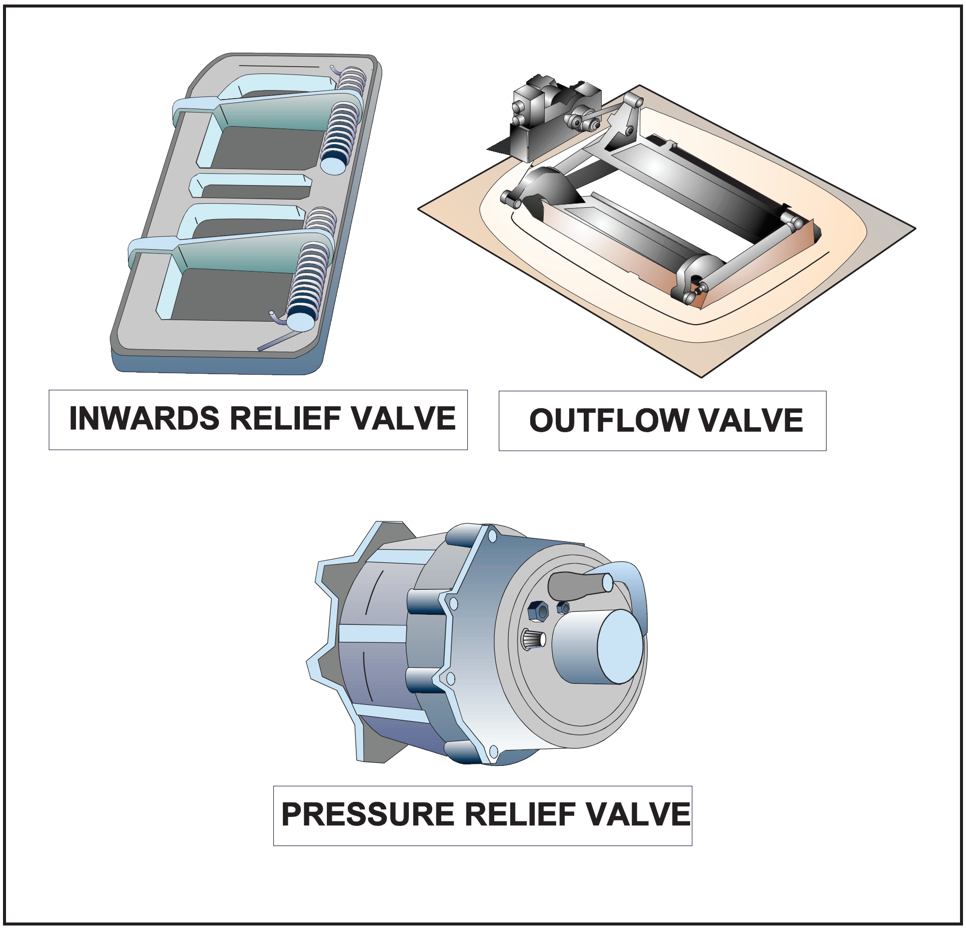


Figure 11.2: Air conditioning and pressurisation valves.

Dump Valve. A manually operated component, the Dump Valve, will enable the crew to reduce the cabin pressure to zero for emergency depressurisation. This valve may also be used as the air outlet during manual operation of the pressurisation system an aircraft fitted with pneumatic discharge valves.

Blow out panels are fitted between passenger and cargo compartments in order to prevent excessive differences in pressure occurring between these areas in the event of, for example, a cargo door opening in flight.

PRESSURISATION CONTROLLERS

Pressure controllers vary in construction and operation and may be pneumatic, electro-pneumatic or, as is the case with most modern aircraft, electronic. Pneumatic controllers comprise pressure sensing elements which are subject to both cabin and ambient pressures as well as metering valves and controls for selecting the required cabin altitude and rate of pressure change.

As the cabin pressure changes, the controller automatically transmits a signal to the outflow (discharge) valves.

The outflow valves are positioned to regulate the release of air from the cabin at the pre-selected rate to achieve the required differential pressure and eventual stabilisation at the required maximum differential pressure and are biased fully open when the aircraft is on the ground. In addition some pressure controllers are fitted with a ditching control which will close all the discharge valves to reduce the flow of water into the cabin in the event of a forced landing on water.

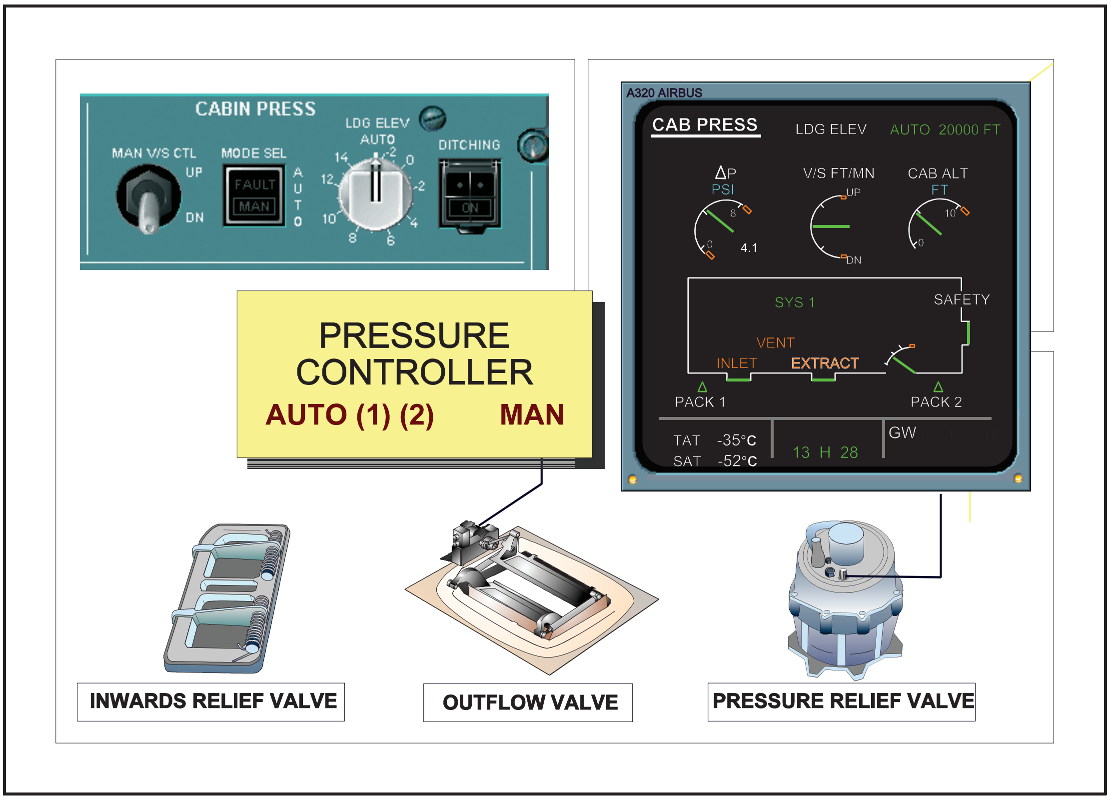


Figure 11.3: Electronic pressurisation control.

SYSTEM OPERATION

Figure 11.3 shows the schematic arrangement of the pressurisation control system of a modern passenger transport aircraft. The automatic controllers are duplicated and have inputs from the aircraft static pressure sensing system, the cabin pressure and air/ground logic system.

If pre-pressurisation is part of the schedule then inputs will be required from the thrust lever positions and the door warning system.

The cabin altitude control panel is remote from the controller and will generally be fitted to overhead panels on the flight deck.

There are two modes of operation, auto (1 & 2) and manual with the outflow valves being electrically operated by either of the two AC motors under the control of the automatic controllers or by the DC motor for emergency or manual operation.

Only one controller is in use at any one time, the other being on standby. The standby controller will automatically take over in the event of failure of the other controller.

Selection of manual will lock out all normal automatic functions and enable the outflow valve(s) to be positioned by the manual control switch via the DC motor. The pilot will set the controller to produce the required flight profile. (*see Figure 11.4*)

Taxi. When the aircraft begins to taxi the pressurisation GROUND/FLIGHT switch is selected to **FLIGHT** and the aircraft is pre-pressurised to a differential pressure (Δ) of 0.1 psi.

This ensures that the transition to pressurised flight will be gradual and that there will be no surges of pressure on rotation and ingress of fumes from engines etc.

Take off and climb. As the aircraft takes off, the 'ground / air' logic system will signal the controller to switch to **proportional control**. The controller will sense ambient and cabin pressure and position the outflow valves to control the rate of change of cabin altitude in proportion to the rate of climb of the aircraft (between 300 and 500 ft per minute).

Cruise. When cruise altitude is reached the controller will switch to **isobaric control** to maintain a constant differential pressure.

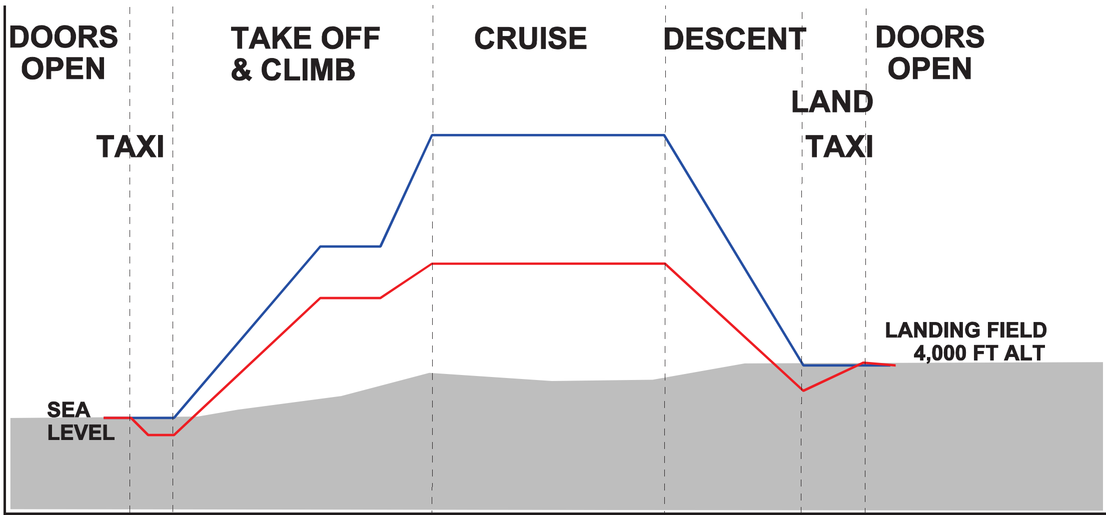
Once established in the cruise small changes in altitude (+/- 500 - 1,000 ft) will be accommodated without any change in cabin pressure, however if the cruise altitude has to be increased significantly, then the flight altitude selection will have to be reset.

If the maximum differential pressure has been reached the controller will not allow any further increase in differential pressure and the aircraft will now be in **Max. Diff. Control**.

Descent and landing. At commencement of the descent the controller will switch back to **proportional control** and will give a cabin rate of descent of 300 ft/minute to produce a diff. pressure of 0.1 psi on touchdown (airfield altitude -200 ft).

With the 'ground/air' logic system now in ground mode, changing the cabin pressure controller GROUND/FLIGHT switch to **GROUND** will drive the outflow valves to fully open to equalise cabin and ambient pressures.

NOTE: On older aircraft the controller will reduce the differential pressure to zero on touchdown. To summarise: if the differential pressure is increasing the discharge valves are closing, if the differential pressure is decreasing then the discharge valves are opening and if the differential pressure is constant then, since the mass flow in is constant, the discharge valve will not move.



0	300' min	500' min	0	300' min	500' min	0	CABIN VERT SPEED
0	0.1 psi	*Increases* according to	Up to a max of 8.06 psi (A320)	*Decreases* according to	0.1 psi	0	CABIN DIFF. PRESS
0	-120'	altitude	Up to a max 8,000 ft	altitude	4,000 ft	4,000 ft	CABIN ALTITUDE

Figure 11.4: Pressurisation profile.

With the system in manual control, the outflow valve position can be varied by means of the main outflow valve control and with reference to the cabin altitude gauge and the valve position indicator. The maximum permissible rate of change of cabin pressure is 0.16psi/min (approximately a rate of climb or descent of 1,500 ft/min).

Cabin rates of climb and descent should be carefully monitored and should not normally exceed 500 ft/min during the climb or 300 ft/ min in the descent in order not to cause too much discomfort for the passengers, particularly those with colds etc and to reduce the effect of rapid pressure changes in the ears.

Courtesy of Airbus Industrie

Figure 11.5: Example of system instrumentation (A320).

SYSTEM INSTRUMENTATION

The minimum indications required for a pressurisation system are:

- **Cabin Altimeter.** This gauge reads cabin pressure but is calibrated to read this in terms of the equivalent altitude of the cabin.
- **Cabin Vertical Speed Indicator.** This indicates the rate at which the aircraft cabin is climbing or descending.
- **Cabin Differential Pressure Gauge.** This indicates the difference in the absolute pressure between the inside and outside of the aircraft cabin and is generally calibrated in psi . In the event of a malfunction of the pressure controller or outflow valve , this instrument would indicate that the Safety Valves were controlling the cabin pressure at the Structural (emergency) maximum pressure differential.

In addition to the above there must both **AURAL** and **VISUAL** warnings when the cabin altitude exceeds 10,000 ft. These will take the form of a horn and red light on the Centralised Warning Panel or warning caption on the appropriate EICAS or ECAM display.

GROUND TESTING AND CHECKING

Pressurisation systems must be checked at periodic intervals in order to ensure that there are no serious leaks and that the pressure control components and safety devices are operating correctly. The occasions on which these tests are carried out are:

- Initial proof pressure test.
- When specified in the maintenance manual.
- After actual or suspected system malfunction.
- After repairs and modifications to the aircraft pressure hull.

The exact procedure to be followed when carrying out functioning and leak rate tests is specific to type and will be laid down in the aircraft maintenance manual but may be required to establish any or all of the following:

- General functioning and temperature control.
- Operation of pressurisation controller(s) and normal maximum differential control.
- Safety valve check (maximum structural differential pressure).
- Leak rate check.

Altitude (ft)	*Temperature (°C)*	*Pressure (hPa)*	*Pressure (psi)*	*Density (kg per m3)*	*Relative Density (%)*
0	+15.0	1013.25	14.7	1.225	100.0
5,000	+5.1	843.1	12.22	1.056	86.2
10,000	-4.8	696.8	10.11	0.905	73.8
15,000	-14.7	571.8	8.29	0.771	62.9
20,000	-24.6	465.6	6.75	0.653	53.3
25,000	-34.5	376.0	5.45	0.549	44.8
30,000	-44.4	300.9	4.36	0.458	37.4
35,000	-54.3	238.4	3.46	0.386	31.0
40,000	-56.5	187.6	2.72	0.302	24.6
45,000	-56.5	147.5	2.15	0.237	19.4
50,000	-56.5	116.0	1.68	0.186	15.2

ICAO Standard Atmosphere (Surface Density 1.225 kg per m^3)

QUESTIONS

1. Main and nose wheel bays are:

   a. pressurised.
   b. unpressurised.
   c. conditioned.
   d. different, with the mains being unpressurised and the nose pressurised.

2. Normal maximum negative differential pressure is:

   a. when atmospheric pressure exceeds cabin pressure by the amount permitted by the system controls.
   b. where the cabin pressure falls below aircraft altitude pressure at which time the inward relief valve opens.
   c. when the cabin pressure exceeds the atmospheric pressure by 0.5 PSI.
   d. the pressure at which the duct relief valve is set to operate.

3. When would the negative differential limit be reached/exceeded:

   a. rapid descent when AC descends below cabin altitude.
   b. during ground pressure testing.
   c. rapid ascent when aircraft climbs.
   d. when changing to manual operation.

4. A/C in level flight if cabin altitude increases does pressure diff:

   a. increase.
   b. decrease.
   c. remain the same.
   d. nil.

5. In level pressurised flight does the outflow valve:

   a. close.
   b. adjust to provide constant flow, and is normally partially open.
   c. open to increase air conditioning.
   d. adjust to provide constant flow, and is normally almost closed.

6. In a turbo cooler system is the cooling air:

   a. ram air.
   b. engine by pass air.
   c. cabin air.
   d. compressor air.

7. The rate of change of cabin pressure should be kept to the minimum. Is this more important:

   a. in descent.
   b. in climb.
   c. in periods when the dehumidifier is in use.
   d. in cruise.

8. Is a cabin humidifier:

   a. on the ground in conditions of low relative humidity.
   b. at high altitude.
   c. at low altitude.
   d. on the ground in high ambient temperatures.

9. Fatigue life of the fuselage is based on the:

   a. number of pressurisation cycles.
   b. number of explosive decompressions.
   c. number of landings only.
   d. number of cycles at maximum differential.

10. If the forward oil seal in an axial flow compressor fails, will air be:

   a. contaminated.
   b. unaffected.
   c. 'b' is only correct if synthetic oil is used.
   d. 'a' will be correct only if the aircraft is inverted.

11. Rate of change of cabin altitude is shown on a:

   a. special gauge.
   b. aircraft VSI.
   c. cabin pressure controller.
   d. gauge reading a percentage of Max Diff Pressure.

12. Cabin discharge valve (pneumatic. is supplied with:

   a. air data computer output information.
   b. cabin and static pressure.
   c. cabin pressure, static and air speed information.
   d. cabin pressure only.

13. On what principle does the vapour cycle cooling system work on:

   a. liquid into vapour.
   b. vapour into liquid.
   c. vapour into gas.
   d. cold gas into hot gas.

14. What is the purpose of the duct relief valve:

   a. to protect the undercarriage bay.
   b. to ensure the compressor pressure is regulated.
   c. to prevent damage to the ducts.
   d. to relieve excess pressure to compressor return line.

15. What system is installed to control the air conditioning:

   a. emulsifier and water extractor.
   b. impingement type dehydrator and humidifier.
   c. dehydrator only.
   d. humidifier only.

16. How is the (charge) air cooled in a bootstrap (turbo-compressor) system?

a. by expanding over turbine.
b. by expanding over turbine driving compressor.
c. via an air cooled radiator.
d. by passing it through the fuel heater.

17. At the max differential phase, is the discharge valve:

a. open.
b. closed.
c. under the control of the rate capsule.
d. partly open.

18. What is the purpose of inward relief valves:

a. to prevent negative differential.
b. to back up the duct relief valve.
c. to allow positive pressure to be bled off in an emergency.
d. to back up the outflow valve.

19. On a ground pressurisation test, if the cabin suffers a rapid de-pressurisation:

a. the temperature will rise suddenly.
b. water precipitation will occur.
c. damage to hull may occur.
d. duct relief valve may jam open
.

20. A heat exchanger functions by:

a. combining ram and charge air.
b. mixing the various vapours inside the heat exchanger.
c. passing charge air through ducts and cool air around ducts.
d. removing the static charge.

21. Maximum Differential pressure:

a. is the maximum authorised pressure difference between the inside of the fuselage and the atmospheric ambient pressure.
b. is the absolute pressure provided by the vacuum pump.
c. is the pressure loss over a given time limit.
d. is the absolute pressure the cabin pressure ducting is designed to carry.

22. A humidifier is fitted to:

a. extract the moisture content in the air.
b. filter the air.
c. increase the moisture content in the air when operating at high altitude.
d. to ensure the cabin air is saturated at high altitude.

23. If the discharge or outflow valve closes:

a. the duct relief valve will take control.
b. the inward relief valve would assume control.
c. the safety valve would limit the positive pressure difference.
d. the safety relief valve would limit the negative pressure difference.

24. Air for conditioning and pressurisation is taken from:

a. the engine compressor or cabin compressor.
b. the engine by pass duct or thrust reverse by pass duct.
c. the engine compressor or ram turbine.
d. the engine turbine or cabin compressor.

25. Safety valves are biased:

a. inwards.
b. outwards.
c. in the direction sensed by the SVC.
d. neither a nor b.

26. Cabin compressors:

a. increase their flow in cruise conditions.
b. decrease their flow in cruise conditions.
c. increase their flow in proportion to increases of altitude differential pressure and reduction in engine RPM in order to maintain the mass flow.
d. deliver minimum air at sea level via the cold air unit.

27. In a pressurisation circuit the sequence of operation is for the:

a. inward relief valve to open before the safety valve.
b. outflow valve to operate before the safety valve.
c. outflow valve to operate after the safety valve.
d. outflow valve to operate the same time as the safety valve.

28. With the QFE set on the cabin controller, against an altitude of zero:

a. the fuselage will be pressurised on landing.
b. a ground pressurisation will automatically take place.
c. the cabin will be unpressurised on landing.
d. the flight deck will be depressurised.

29. In the cruise at 30,000 ft the cabin altitude is adjusted from 4,000 ft to 6,000 ft:

a. cabin differential will increase.
b. cabin differential will not be affected.
c. cabin differential will decrease.
d. nil.

30. An aircraft climbs from sea level to 16,000 ft at 1,000 ft per min, the cabin pressurisation is set to climb at 500 ft per min to a cabin altitude of 8,000 ft. The time taken for the cabin to reach 8,000 ft is:

a. the same time as it takes the aircraft to reach 16,000 ft.
b. half the time it takes the aircraft to reach 16,000 ft.
c. twice the time it takes the aircraft to reach 16,000 ft.
d. three times the time it takes the aircraft to reach 16,000 ft.

31. The aircraft inhibiting switch connected to the A/C landing gear:

a. allows the aircraft to be pressurised on the ground.
b. stops pressurising on the ground and ensures that there is no pressure differential.
c. ensures that the discharge valve is closed.
d. cancels out the safety valve on the ground.

32. Negative differential is limited by:

a. dump valve.
b. inward relief valve.
c. outflow valve.
d. safety valve.

33. Sequence of air through a vapour cooling system is:

a. turbine then expansion valve.
b. tank then evaporator.
c. turbine then evaporator.
d. compressor then turbine.

34. To maintain a steady and constant airflow regardless of altitude or cabin pressure:

a. a duct relief valve is fitted.
b. a venturi device is fitted.
c. a mass flow controller is fitted.
d. a thermostatic relief valve is fitted.

35. The term "pressurisation cycle" means:

a. air introduced into a fuselage under pressure only.
b. air introduced into a fuselage under pressure until the time the air is released.
c. air discharged from the fuselage, above 15 psi.
d. the frequency in Hz the pressure cycles from the rootes blowers enter the fuselage.

36. Inward Relief Valves operate:

a. in conjunction with the cabin pressure controller when there is a negative diff.
b. in conjunction with the cabin altitude selector when there is negative diff.
c. when manually selected during the emergency descent procedure.
d. automatically when there is a negative diff.

37. Safety valves operate:

a. at higher diff than discharge valve.
b. as soon as initiation takes place.
c. at a lower diff than a discharge valve.
d. at a set value, which is selected.

38. Ditching Cocks are operated:

a. automatically when the soluble plugs disolve.
b. to shut all outflow valves.
c. to direct pressure into flotation bags.
d. for rapid depressurisation.

39. Duct Relief Valves operate when:

a. excessive pressure builds up in the air conditioning system supply ducts.
b. to keep cabin pressure close to ambient pressure.
c. to prevent the floor from collapsing should baggage door open.
d. the cooling modulator shutters reach the optimised position.

40. During a normal pressurised cruise, the discharge valve position is:

a. at a position pre-set before take off.
b. partially open.
c. open until selected altitude is reached.
d. closed until selected altitude is reached.

41. A dump valve:

a. automatically opens when fuel is dumped.
b. is controlled manually.
c. is opened automatically when the safety valve opens.
d. is controlled by the safety valve integrating line.

42. When air is pressurised the % of oxygen:

a. increases.
b. decreases.
c. remains the same.
d. nil.

43. If pressure is manually controlled:

a. an extra member is required to monitor system operation.
b. the climb rate would be maintained automatically.
c. climb rate could not be maintained.
d. care should be taken to ensure climb/descent rates are safe.

44. An aircraft is prevented from pressurising on the ground by:

a. the auto deflating valve on the main oleos.
b. inhibiting micro switches on the landing gear.
c. inhibiting micro switches on the throttles.
d. the pressure control master switch.

45. If the pressurisation air is passed over the cold air unit compressor does it:

a. increase the charge air temperature.
b. decrease the charge air temperature.
c. decrease the charge air pressure.
d. make no change to the charge air condition.

46. If the cabin pressure increases in level flight does the cabin VSI show:

a. rate of climb.
b. no change unless the aircraft climbs.
c. rate of descent.
d. nil.

47. Cabin altitude in pressured flight is:

a. the altitude corresponding to cabin pressure regardless of aircraft height.
b. is presented on a second needle on the aircraft altimeter.
c. altitude at which cabin pressure equals ambient pressure.
d. altitude corresponding to cabin pressure in relation to MSL ISA conditions.

48. The term pressure cabin is used to describe:

a. pressurisation of the flight deck only.
b. the ability to pressurise the aircraft to a higher than ambient pressure.
c. the passenger cabin on an airliner.
d. the ability to maintain a constant pressure differential at all altitudes.

49. A pressurisation system works by:

a. essentially constant input mass flow and variable output.
b. essentially constant output mas flow and variable input.
c. does not start until an altitude of 8,000 ft has been reached.
d. supplying hot gases from the engine exhaust unit to the mass flow control system.

50. When air is pressurised by an engine driven compressor, it is also:

a. moisturised.
b. heated.
c. cooled.
d. the temperature is not affected.

ANSWERS

1.	B	26.	C
2.	A	27.	B
3.	A	28.	C
4.	B	29.	C
5.	B	30.	A
6.	A	31.	B
7.	A	32.	B
8.	B	33.	A
9.	A	34.	C
10.	A	35.	B
11.	A	36.	D
12.	B	37.	A
13.	A	38.	B
14.	C	39.	A
15.	B	40.	B
16.	B	41.	B
17.	A	42.	C
18.	A	43.	D
19.	B	44.	B
20.	C	45.	A
21.	A	46.	C
22.	C	47.	A
23.	C	48.	B
24.	A	49.	A
25.	A	50.	B

CHAPTER TWELVE

ICE AND RAIN PROTECTION

Contents

INTRODUCTION AND THEORY

Without exception, the formation of ice or frost on the surfaces of an aircraft will cause a detrimental effect on aerodynamic performance. The ice or frost formation on the aircraft surfaces will alter the aerodynamic contours and affect the nature of the boundary layer. Of course, the most important surface of the aircraft is the wing and the formation of ice or frost can create significant changes in the aerodynamic characteristics.

Types of Ice:

- Hoar Frost
- Rime Ice
- Clear or Glaze Ice

A large formation of ice on the leading edge of the wing can produce large changes in the local contours and severe local pressure gradients. The extreme surface roughness common to some forms of ice will cause high surface friction and a considerable reduction of boundary layer energy. As a result of these effects, the ice formation can produce a considerable increase in drag and a large reduction in maximum lift coefficient. Thus, the ice formation will cause an increase in power required and stall speed. In addition, the added weight of the ice formation on the aircraft will provide an undesirable effect. Because of the detrimental effects of ice formation, recommended anti-icing procedures must be followed to preserve the aircraft performance.

The effect of frost is perhaps more subtle than the effect of ice formation on the aerodynamic characteristics of the wing. The accumulation of a hard coat of frost on the wing upper surface will provide a surface texture of considerable roughness. While the basic shape and aerodynamic contour is unchanged, the increase in surface roughness increases skin-friction and reduces the kinetic energy of the boundary layer. As a result, there will be an increase in drag but, of course, the magnitude of drag increase will not compare with the considerable increase due to a severe ice formation.

The reduction of boundary layer kinetic energy will cause incipient stalling of the wing, i.e. separation will occur at angles of attack and lift coefficients lower than for the clean, smooth wing. While the reduction in C_L max due to frost formation ordinarily is not as great as that due to ice formation, it is usually unexpected because it may be thought that large changes in the aerodynamic shape (such as due to ice) are necessary to reduce C_L max. However, the kinetic energy of the boundary layer is an important factor influencing separation of the airflow and this energy is reduced by an increase in surface roughness.

The effect of ice or frost on take-off and landing performance is of great importance. The effects are so detrimental to the landing and take-off that no effort should be spared to keep the aircraft as free as possible from any accumulation of ice or frost. If any ice remains on the aircraft as the landing phase approaches it must be appreciated that the ice formation will have reduced C_L max and incurred an increase in stall speed. Thus, the landing speed will be greater. When this effect is coupled with the possibility of poor braking action during the landing roll, a critical situation can exist. It is obvious that great effort must be made to prevent the accumulation of ice during flight.

In no circumstances should a formation of ice or frost be allowed to remain on the aircraft wing surfaces prior to take-off. The undesirable effects of ice are obvious but, as previously mentioned, the effects of frost are more subtle. If a heavy coat of hard frost exists on the wing upper surface, a typical reduction in C_L max would cause a 5 to 10 percent increase in the aircraft stall speed.

Because of this magnitude of effect, the effect of frost on take-off performance may not be realised until too late. The take-off speed of an aircraft is generally some 5 to 25 percent greater than the stall speed, hence the take-off lift coefficient will be a value from 90 to 65 percent of C_L max. Thus, it is possible that the aircraft with frost cannot become airborne at the specified take-off speed because of premature stalling. Even if the aircraft with frost were to become airborne at the specified take-off speed, it could have insufficient margin of airspeed above the stall. Turbulence, gusts and or turning flight could produce incipient or complete stalling of the aircraft.

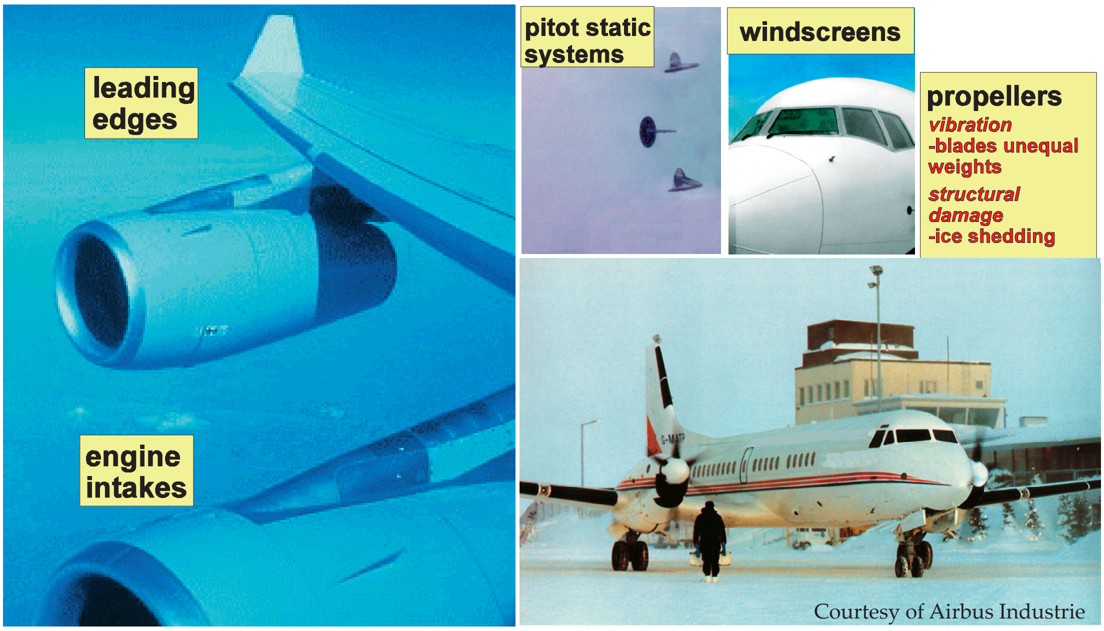


Figure 12.1: Areas most susceptible to ice formation.

The increase in drag during take-off roll due to frost or ice is not considerable and there will not be any significant effect on the initial acceleration during take-off. Thus, the effect of frost or ice will be most apparent during the later portions of take-off if the aircraft is unable to become airborne or if insufficient margin above the stall speed prevents successful initial climb. In no circumstances should a formation of ice or frost be allowed to remain on the aircraft wing surfaces prior to take-off.

Icing on aircraft in flight is caused primarily by the presence of super-cooled water droplets in the atmosphere. If the droplets impinge on the forward facing surfaces of an aircraft, they freeze and cause a build up of ice which may seriously alter the aerodynamic qualities. This applies particularly to small objects, which have a higher catch rate efficiency than large ones, as small amounts of ice will produce relatively bigger changes in shape. The actual amount and shape of the ice build up depends on the surface temperature. This results from an energy change caused by heat variations to the skin of the aircraft, e.g:

- kinetic air heating (Plus).
- kinetic heating by water droplets (Plus).
- latent heat of fusion, (caused by the water droplets changing from liquid to solid upon impact) (Plus).
- evaporation (Minus).
- convection (Minus).

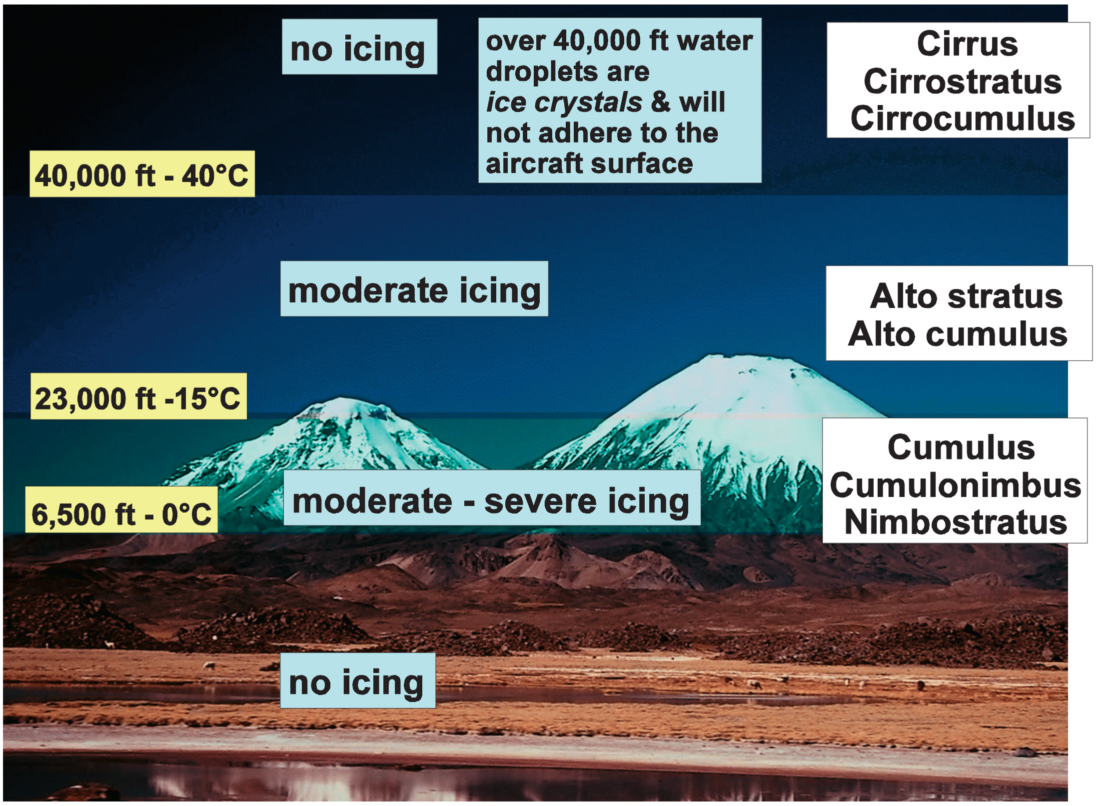


Figure 12.2: Where airframe icing occurs.

Three different situations arise, depending on whether the surface temperature is less than, equal to or greater than 0°C. When the temperature is less than 0°C, all the impinging water droplets are frozen, and when it is above 0°C none are frozen.

However, for a particular set of atmospheric conditions and altitudes it is found that there is quite a wide aircraft speed range over which the energy balance gives a skin temperature of 0°C. This energy balance occurs at one end of the speed range by all the droplets freezing and at the other by none freezing. The potential "catch rate" or "impingement rate" and the actual icing rate are thus not simply related in this region. The "no icing hazard" speed depends, therefore, upon the free water content of the atmosphere as well as the temperature and altitude.

For severe conditions it is about the maximum speed of subsonic aircraft. The final influencing factor of note is that icing does not occur above about 12,000 m (40,000 ft) since the droplets are all frozen and in the form of ice crystals and will not adhere to the aircraft's surface.

REQUIREMENTS AND STANDARDS OF PROTECTION

The aircraft must be cleared of ice, frost and snow prior to dispatch, and CS-OPS requires that public transport aircraft shall be provided with certain protective equipment for flights in which the weather reports available at the time of departure indicate the probability that conditions predisposing to ice formation will be encountered.

Certain basic standards have to be met by all aircraft whether or not they are required to be protected by the requirements of CS-OPS, and these are intended to provide a reasonable protection if the aircraft is flown unintentionally for short periods in icing conditions. The requirements specified in CS-OPS cover such considerations as the stability and control balance characteristics, jamming of controls and the ability of the engine to continue to function in icing conditions.

Two different approaches are generally used:

- 'De-icing' where ice is allowed to accumulate prior to being removed.

- 'Anti-icing' where the object is to prevent any ice accumulation.

There are a number of avenues which need exploring and these include detection and warning systems and the methods used to protect the aircraft, which can be any or all of the following:

- **Pneumatic** Expanding rubber boots - mechanical.

- **Thermal** Electrically heated.
  Oil heated.
  Air heated.

- **Liquid** Freezing point depressant fluids. (FPD)

- **Ice detection** Is provided automatically by the provision of ice detectors which relay a warning to the flight crew.

- **Anti-Icing** Is the application of continuous heat or fluid.

- **De-Icing** Is the intermittent application of fluid, heat or mechanical effort.

These aspects will all be dealt with in detail later.

DETECTION DEVICES AND WARNINGS

There are three main types of ice detector in current use:

- the ice detector head. (Accretion principle)
- the mechanical ice detector. (Accretion principle)
- the element ice sensing unit. (Inferential Principle)

Ice Detector Heads

Teddington Ice Detector. This detector consists of an aerofoil shaped mast protruding into the airflow and visible from the cockpit.

The mast incorporates a heater element and a light to illuminate the mast at night *(Figure 12.3)*. When icing conditions are encountered in flight, with the heater power supply switched off, ice accumulates on the mast and gives a direct visual indication of ice accretion. The heater may be switched on to dissipate accumulated ice.

Smiths Ice Detector. The Smiths ice detector consists of a hollow tube, attached to the aircraft by one end and has holes drilled in the leading and trailing faces; there are four holes in the leading edge and two in the trailing edge *(Figure 12.4)*.

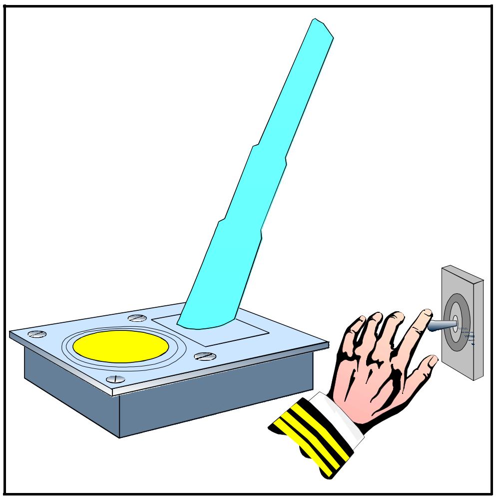


Figure 12.3: Teddington ice detector.

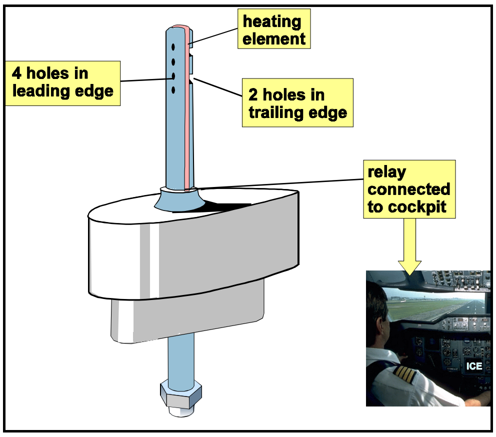


Figure 12.4: Smiths' ice detector.

In flight under normal conditions, there is a pressure build up in the probe which is sensed by a relay unit at the open base of the tube. In icing conditions, the leading edge holes become blocked by ice and a negative pressure is created in the hollow tube, causing the relay unit to give a warning. A heater element is fitted around the tube to dissipate accumulated ice.

MECHANICAL ICE DETECTORS

English Electric (Napier) Ice Detector. In the Napier ice detector a serrated rotor shaft is continuously driven by an electric motor. The shaft rotates adjacent to a fixed knife-edge cutter *(see Figure 12.5)*, with a clearance between them of less than 0.002 inches. The unit is mounted on the aircraft fuselage with the rotor axis at right angles to the airflow and with the cutter in the lee of the shaft. Under normal conditions, little torque is required to drive the rotor. In icing conditions, ice builds up on the rotor and is shaved off by the cutter. This requires greater rotational torque and causes the motor to rotate slightly in its flexible mountings. This movement operates a micro-switch which gives an ice warning, or automatically initiates the anti-icing sequence. The warning remains as long as ice continues to foul the cutter blade.

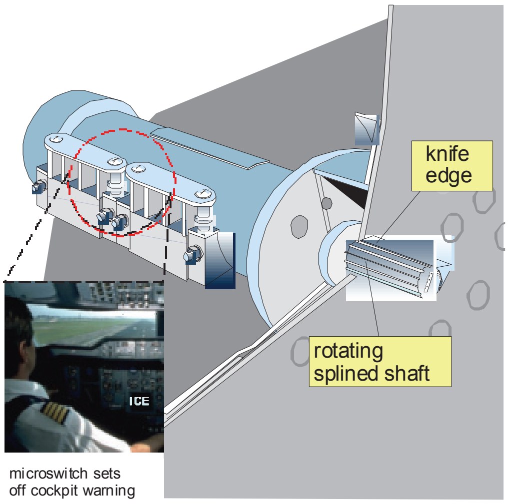


Figure 12.5: English electric (Napier) ice detector.

Rosemount Ice Detector. This detector consists of a short cylindrical probe mounted on a vibrator housing which vibrates the probe axially at about 35 kHz *(see Figure 12.6)*. If ice builds up on the probe, the added mass reduces the resonant frequencies. When the frequency falls to a predetermined level, an ice warning is given. The warning signal also operates a built in heater element in the probe to shed accumulated ice. After six seconds, the heater switches off and the icing cycle recommences. The frequency of the cycle may be measured to give an indication of the ice accretion rate.

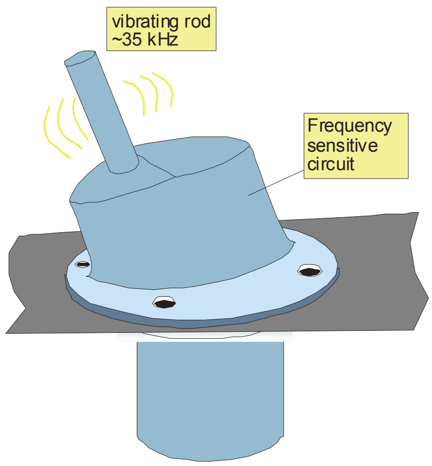


Figure 12.6: Rosemount ice detector.

ELEMENT ICE SENSING UNIT

Sangamo Weston Ice Detector. Ice can only be formed when there is a combination of moisture and freezing temperatures. In the Sangamo Weston ice detector, these two conditions are detected separately and, therefore, icing conditions are detected rather than actual ice formation. The system comprises three main components *(see Figure 12.7)*.

- **Moisture Detector Controller.** The **Sangamo Weston Ice Detector** is an example of an **Inferential** method of ice detection. All other ice detectors use the principle of **Ice Accretion.** This controller is situated in the base of the unit and senses the temperature difference between the "wet" and "dry" sensing bulbs. When the temperature difference reaches a predetermined value, and provided that the thermal switch is made, relays operate a ice warning or initiate the anti-icing or de-icing cycles.

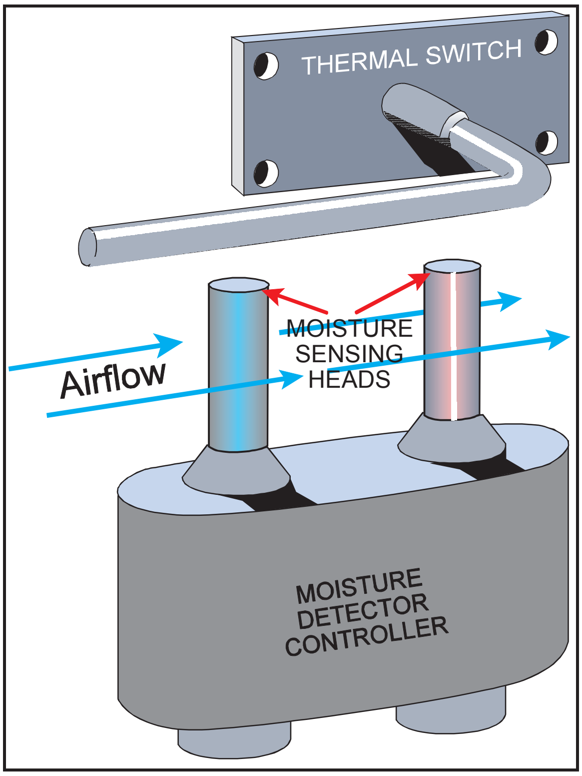


Figure 12.7: Sangamo weston ice detector.

- **Moisture Sensing Head.** This consists of two heated metal resistance bulbs situated in the airflow and arranged so that the leading bulb screens the rear one so that no moisture impinges upon it. When the detector encounters free water in the airflow, the shielded rear bulb remains dry and cools at a slower rate than the wet leading bulb.

- **Thermal Switch.** This is a contact operating thermometer which is housed in a bulb and is exposed to ambient temperature. When the temperature is above freezing, the thermal switch prevents the moisture detector from sending an ice warning signal, even though the latter unit is sensing the presence of water in the airflow. With a temperature below freezing, the thermal switch allows the warning signal to be sent.

BETA PARTICLE ICE DETECTION PROBE

Two probes, mounted perpendicularly from the forward fuselage, plus a relay and the flight deck warning constitute the basic system.

Under nil ice conditions the forward probe, an emitter, will emit Beta particles which are detected by the rear probe, a detector. Beta particles are absorbed by ice so that, in icing conditions, less particles are sensed by the detector.

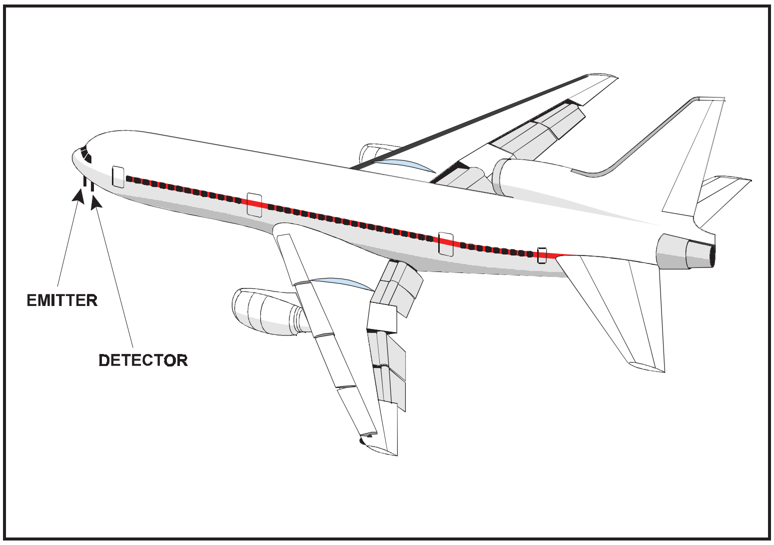


Figure 12.8: Beta particle ice detection probe.

At a certain Beta particle count rate, corresponding to 0.4 mm of ice, a relay in the detector probe will operate causing a warning on the flight deck. This may take the form of an ECAM system display and a single chime. A system test gives the same indications as above.

Ice Formation Spot Light. Many aircraft have two ice formation spot lights mounted one each side of the fuselage, in such a position as to light up the leading edges of the mainplanes, when required, to allow visual examination for ice formation.

NOTE: In some aircraft, this may be the only aid to ice detection at night.

An awareness of the in flight conditions with regard to temperature and moisture is essential for all aircrew, and a general rule for engine protection is to apply it when the IOAT is +10°C or below, and the air contains visible moisture. Airframe protection is generally applied at the onset of indicated icing. This may be from visual indications of leading edges, aerials, windscreen wipers etc or from the ice detector systems. Ice warnings usually take the form of an amber caution light and can in some systems initiate the de-icing or anti-icing systems if they have been pre selected to 'auto'. However mechanical de-icing by the 'Boots' method must not be initiated until a specific depth of ice has built up.

The following list is not exhaustive, but should give an indication of the variety of systems and components which are protected against the effects of ice and rain.

- Engine - Intakes - IGVs - Struts or Webs
- Oil cooler intakes, fuel system filters.
- Ram air intakes for generator cooling or Engine bay ventilation. Aerofoils - Wing and tail leading edges. Slats - Propellers.
- Airframe - Aerials - Waste water outlet horns, Large fences and bullets. Instrument Systems - Pitot heads and probes.
- Cockpit windows.

MECHANICAL 'DE-ICING'

Pneumatic de-icing systems are employed in certain types of piston engined aircraft and twin turbo-propeller aircraft. The number of components comprising a system vary, together with the method of applying the operating principle. The arrangement of a typical system is illustrated schematically in Figure 12.9.

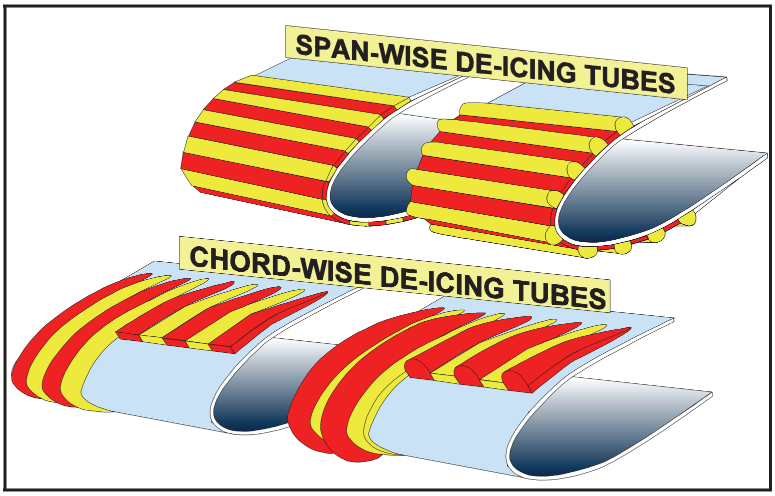


Figure 12.9: De-icer boots.

De-icer Boots. The de-icer boots, or overshoes, consist of layers of natural rubber and rubberised fabric between which are disposed flat inflatable tubes closed at the ends. The tubes are made of rubberised fabric and are vulcanised inside the rubber layers. In some boots the tubes are so arranged that when the boots are in position on a wing or tailplane leading edge the tubes run parallel to the span; in others they run parallel to the chord. The tubes are connected to the air supply pipelines from the distribution valves system by short lengths of flexible hose secured to connectors on the boots and to the pipelines by hose clips. The external surfaces of the boots are coated with a film of conductive material to bleed off accumulations of static electricity. Depending on the type specified, a boot may be attached to a leading edge either by screw fasteners (rivnuts) or by cementing them directly to the leading edge.

Air Supplies and Distribution. The tubes in the boot sections are inflated by air from the pressure side of an engine-driven vacuum pump, from a high-pressure reservoir or in the case of some types of turbo-propeller aircraft, from a tapping at an engine compressor stage.

At the end of an inflation stage of the operating sequence, and whenever the system is switched off, the boots are deflated by vacuum derived from the vacuum pump or, in systems utilising an engine compressor tapping, from the Venturi section of an ejector nozzle.

The method of distributing air supplies to the boots depends on the de-icing systems required for a particular type of aircraft but, in general, three methods are in use. One method employs shuttle valves which are controlled by a separate solenoid valve; in the second method air is distributed to each boot by individual solenoid-controlled valves; in the third method distribution is effected by a motor-driven valve.

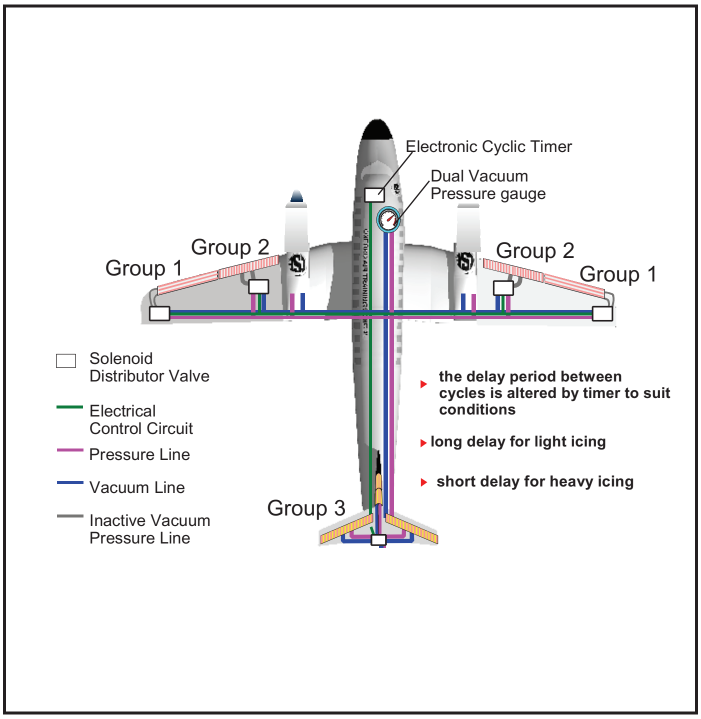


Figure 12.10: Schematic diagram of a pneumatic de-icing system.

Controls and Indicators. The controls and indicators required for the operation of a de-icing system depend on the type of aircraft and on the particular arrangement of its de-icing system. In the basic arrangement, a main on-off switch, pressure and vacuum gauges or indicating lights form part of the controlling section. Pressure and vacuum is applied to the boots in an alternating timed sequence and the methods adopted usually vary with the methods of air distribution referred to above. In most installations, however, timing control is effected by means of an electronic device. Reference should always be made to the relevant aircraft Maintenance Manual for details of the appropriate controlling system and time cycles.

Operation. When the system is switched on, pressure is admitted to the boot sections to inflate the tubes. The inflation weakens the bond between ice and the boot surfaces, causing the ice to break away. At the end of the inflation stage of the operating sequence, the air in the tubes is dumped to atmosphere through automatic opening valves and the tubes are fully deflated by the vacuum supply. This inflation and deflation cycle is repeated during the period the system is in operation. When the system is switched off vacuum is supplied continually to all tubes of the boot **sections to hold the sections flat against the wing and tail leading edges thus minimising aerodynamic drag.**

The de-icer boots are pulsated in a set cycle, the frequency of which can be varied by the frequency selector to cater for light or heavy icing conditions. For cycling purposes, the boots are usually divided into three groups as follows:

Group 1 - Port and Starboard mainplane inboard boots.
Group 2 - Port and Starboard mainplane outboard boots.
Group 3 - Fin and tailplane boots.

The cycle takes 34 seconds, irrespective of the selection made on the cyclic frequency selector. The selector merely alters the delay period between cycles, e.g. 206 seconds for light icing and 26 seconds for heavy icing.

THERMAL 'ANTI-ICING' AND 'DE-ICING'

Hot air systems on modern aircraft are generally engine bleed air and are said to be 'anti-icing'. Other methods of obtaining the hot air will be described, and depending on the duration of application and the temperature applied, they may be either de-icing or anti-icing systems.

In systems of this type, the leading edge sections of wings including leading edge slats but not leading edge flaps, and tail units are usually provided with a second, inner skin positioned to form a small gap between it and the inside of the leading edge section. Heated air is ducted to the wings and tail units and passes into the gap, providing sufficient heat in the outer skin of the leading edge to melt ice already formed and prevent further ice formation. The air is exhausted to atmosphere through outlets in the skin surfaces and also, in some cases, in the tips of wings and tail units. The temperature of the air within the ducting and leading edge sections is controlled by a shutter or butterfly type valve system, the operation of which depends on the type of heating system employed.

A gas turbine engine presents a critical icing problem, and therefore requires protection against ice formation particularly at the air intake, nose bullet or fairing and inlet guide vanes. Icing of these regions can considerably restrict the airflow causing a loss in performance and, furthermore, cause damage to the compressor as a result of ice breaking away and being ingested by the compressor.

There are two thermal systems in use for air intake de/anti-icing; a hot air bleed system and an electrical resistance heating system, and although the latter is usually chosen for turbo-propeller engines to provide protection for the propeller, there are some examples where both systems are used in combination.

Air Supplies. There are several methods by which the heated air can be supplied and these include bleeding of air from a turbine engine compressor, heating of ram air by passing it through a heat exchanger located in an engine exhaust gas system, and combustion heating **of ram air.**

In a compressor bleed system the hot air is tapped directly from a compressor stage, and after mixing with a supply of cool air in a mixing chamber it passes into the main ducting. In some systems, equipment, e.g. safety shut-off valves, is provided to ensure that an air mass flow sufficient for all de-icing requirements is supplied within pressure limits acceptable to duct and structural limitations.

The heat exchanger method of supplying warm air is employed in some types of aircraft powered by turbo-propeller engines. The heat exchanger unit is positioned so that exhaust gases can be diverted to pass between tubes through which outside air enters the main supply ducts. The supply of exhaust gases is usually regulated by a device such as a thermostatically controlled flap fitted in the ducting between the exhaust unit and the heat exchanger.

In a combustion heating system ram air is passed through a cylindrical jacket enclosing a sealed chamber in which a fuel/air mixture is burned, and is heated by contact with the chamber walls. Air for combustion is derived from a separate air intake and is supplied to the chamber by means of a blower.

Temperature Control. The control of the air temperature within ducting and leading edge sections is an important aspect of thermal de-icing system operation and the methods adopted depend on the type of system.

In a typical compressor bleed system, control is effected by temperature sensing units which are located at various points in the leading edge ducting and by valves in the main air supply ducting. The sensing units and valves are electrically interconnected so that the valves are automatically positioned to regulate the flow of heated air to the system, thus maintaining the temperature within a predetermined range. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights. On some aircraft the electrical supplies to the valves are interrupted by landing gear controlled relays when the aircraft is on the ground. Under these conditions, valve operation is accomplished by holding the system control switch to a 'TEST' position.

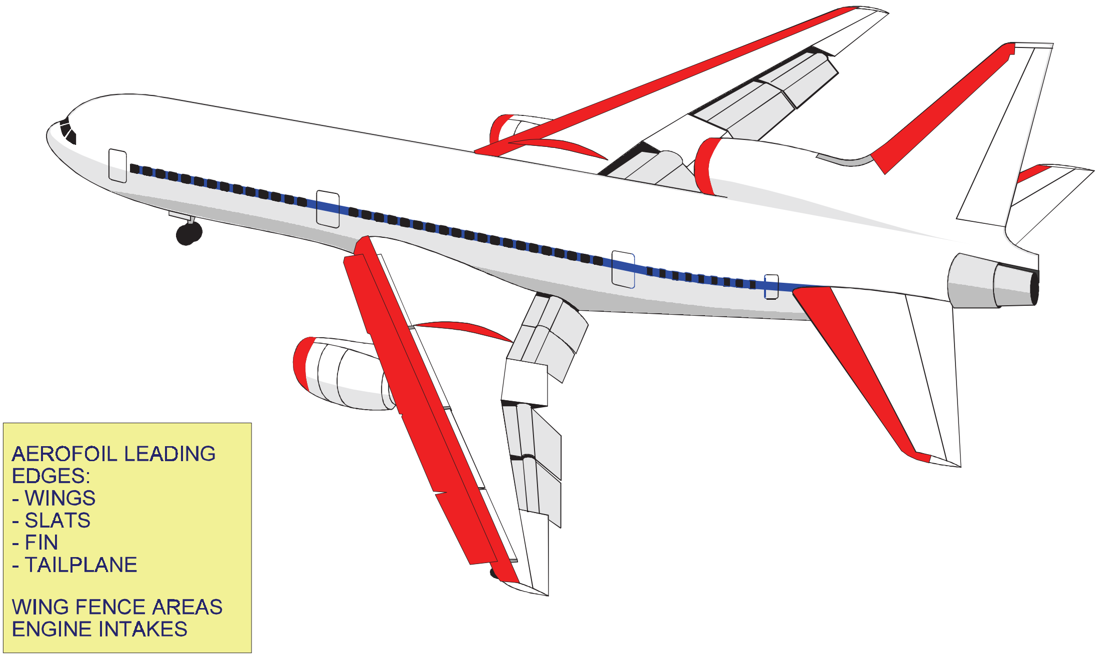


Figure 12.11: Areas heated by 'anti-icing' air.

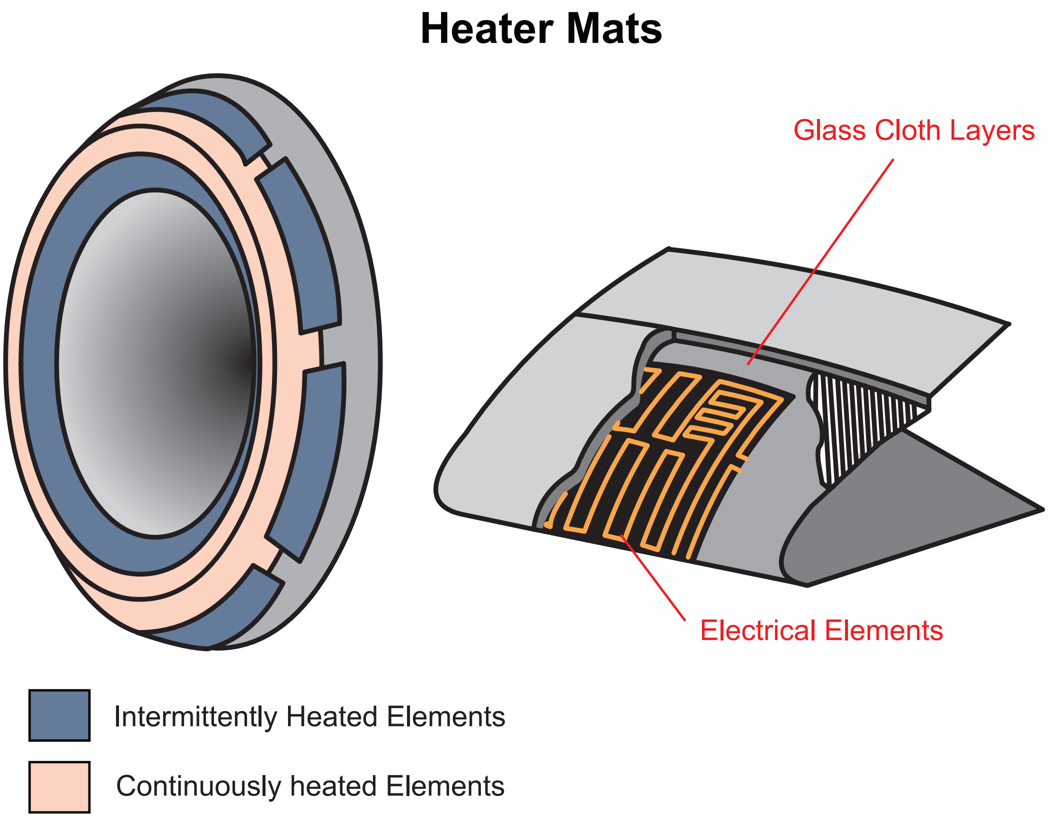


Figure 12.12: Heater Mats.

When heat exchangers are employed, temperature control is usually obtained by the use of adjustable flaps and valves to decrease or increase the supply of heating and cooling air passed across the exchangers.

The method of controlling the flaps and valves varies with different aircraft, but a typical system incorporates an electric actuator, which is operated automatically by an inching device controlled by a temperature sensing element fitted in the duct on the warm air outlet side of the heat exchanger. In some systems, actuators are directly controlled by thermal switches, so that the flaps or valves are automatically closed when a predetermined temperature is reached. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights.

In systems incorporating combustion heaters, the temperature is usually controlled by thermal cyclic switches located in the heater outlet ducts, so that when the temperature reaches a predetermined maximum the fuel supply to the heaters is automatically switched off.

In an engine hot air system the air is bled from the compressor and is fed via ducting into the air intake nose cowl, through the inlet guide vanes of the engine and also, in some engines, through the nose bullet. After circulating the intake cowl and guide vanes, the air is exhausted either to atmosphere or into the engine air intake. The flow of hot air is regulated by electrically operated control valves which are actuated by control switches on a cockpit panel. An air temperature control system is not usually provided in a hot air system.

Electrical Heating System. In an electrical heating system, heating elements either of resistance wire or sprayed metal, are bonded to the air intake structure. The power supply required for heating is normally three-phase alternating current. The arrangement adopted in a widely used turbo-propeller engine is illustrated in *Figure 12.12* as an example. The elements are of the resistance wire type and are formed into an overshoe which is bonded around the leading edge of the air intake cowl and also around the oil cooler air intake.

Both anti-icing and de-icing techniques are employed by using continuously heated and intermittently heated elements respectively. The elements are sandwiched between layers of glass cloth impregnated with resin. In some systems the elements may be sandwiched between layers of rubber. The outer surfaces are, in all cases, suitably protected against erosion by rain, and the effect of oils, greases, etc. The power supply is fed directly to the continuously heated elements, and via a cyclic time switch unit to the intermittently heated elements and to the propeller blade elements. The cyclic time switch units control the application of current in selected time sequences compatible with prevailing outside air temperature conditions and severity of icing. The time sequences which may be selected vary between systems.

For the system shown in *Figure 12.12* the sequences are 'Fast', giving one complete cycle (heat on/heat off) of 2 minutes at outside air temperatures between -6°C and +10°C, and 'Slow', giving one complete cycle of 6 minutes at outside air temperatures below -6°C. An indicator light and, in some cases, an ammeter, is provided on the appropriate cockpit control panel to indicate correct functioning of the time switch circuit.

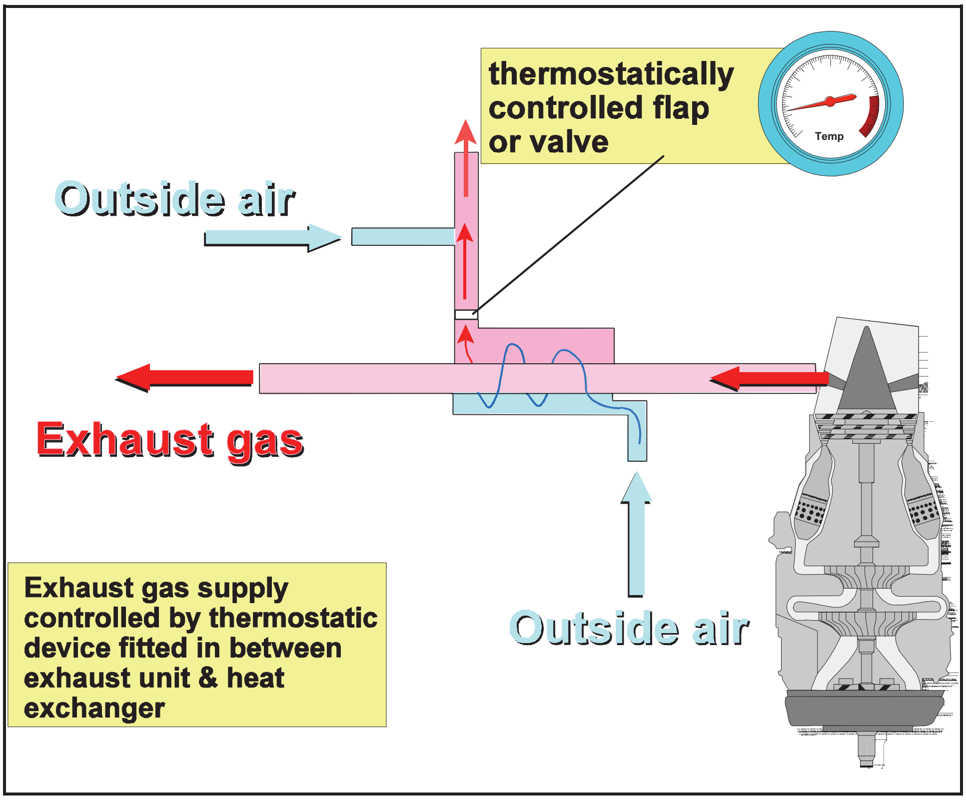


Figure 12.13: A heat exchange system.

FLUID SYSTEMS

This system prevents the adhesion of ice on surfaces by pumping freezing point depressant fluid (FPD) to panels in the leading edge of the aerofoil, and allowing the fluid to be carried over the surface by air movement.

The fluid is supplied from the storage tank to the pump through an integral filter. The pump has a single inlet and a number of delivery outlets to feed the distributors on the aerofoil leading edges. A diagrammatic layout is shown in *Figure 12.14.* The pump consists of a main casting which incorporates a pump body, a filter chamber, and a gear casing. When the pump is incorporated in a system, the pump body and the filter chamber are flooded with de-icing fluid which acts as a lubricant.

To protect the pump and the system from damage due to pipe blockage etc, the pump incorporates a safety device which relieves abnormal pressure by reducing the flow. There are two types of distributor for use with the system, i.e. strip and panel.

The panel distributors cover a large area of the aerofoil leading edge, and are more economical and efficient than strip distributors. They have the disadvantage of not being suitable for surfaces with double curvature, e.g. fins where the strip distributor has to be used. The panel distributor is fitted over, or let into the leading edges of the mainplanes and tailplane. It consists of a porous outer panel, a micro porous sheet, and a back plate. The porous panel extends beyond the edges of the porous sheet, and screws passing through the panel secure the distributor to the aerofoil surface. An entry connector, which accommodates a metering tube, passes through the backplate to which it is bolted. A sectional view of a panel distributor is shown inset in *Figure 12.14.*

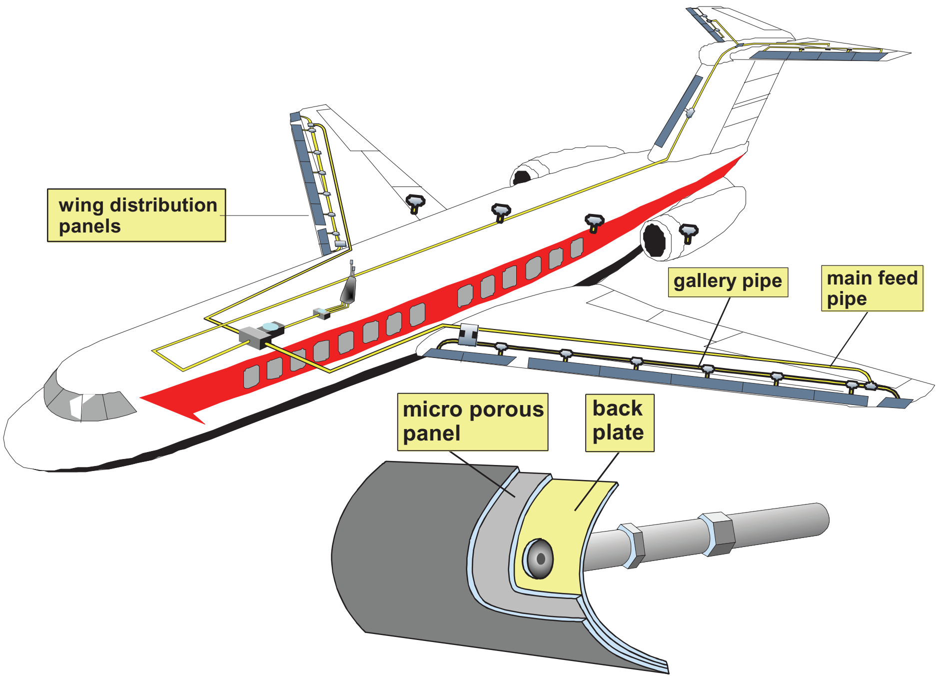


Figure 12.14: Fluid systems.

The fluid enters the connector from the main supply pipe, passes through the metering tube, and enters the cavity between the backplate and the porous sheet. The fluid then seeps through the porous sheet of the distributor, and is distributed over the aerofoil surfaces by the air stream. The strip distributors are inserted in the leading edge of the aerofoil, and are connected, in series to the main supply pipe.

The fluid fills the primary feed channel and passes through the flow control tubes into the secondary feed channel. The fluid in the secondary feed channel filters through the porous metal side and onto the leading edge of the aerofoil.

WINDSCREEN PROTECTION

Windscreen protection is provided by fluid sprays, electrical heating, and cabin air may be provided for de misting. Electrical heating may be within the main windscreen, or added as an optional extra by means of a small heated glass panel fitted in front of the windscreen. Wipers are also provided on some aircraft and these may be assisted by the use of rain repellent systems.

Windshield or Windscreen Wipers. Independent two speed wipers are usually provided for both pilots. They may be electrically or hydraulically powered, with two operating speeds and some systems have a parking facility. They should not be operated on a dry windscreen.

Windscreen Washers. This system sprays washer fluid into the windscreen panels, and is used in conjunction with the wipers to clean the windscreens; a typical control panel is shown in *Figure 12.15*, where a single washer control button controls the fluid for both screens. Typically the reservoir would contain about one gallon, located in one of the underfloor bays and have a slight gauge visible for replenishment. Fluid being routed from the pump to four spray nozzles, with manually operated flow distribution and control valves located on the flight deck to provide selective flow to the windshields.

Windscreen Rain Repellent System. The rain repellent system consists of four valve/timer nozzles, two for each screen and a manifold which stores and distributes the fluid to the nozzles. It is charged with repellent fluid from an aerosol type disposable container which screws into the manifold. A sight gauge displays a refill float when the fluid is low, and a pressure gauge with green and red areas to indicate a go/no go condition. If the float is visible or the pressure gauge indication is in the red area the container fluid is depleted.

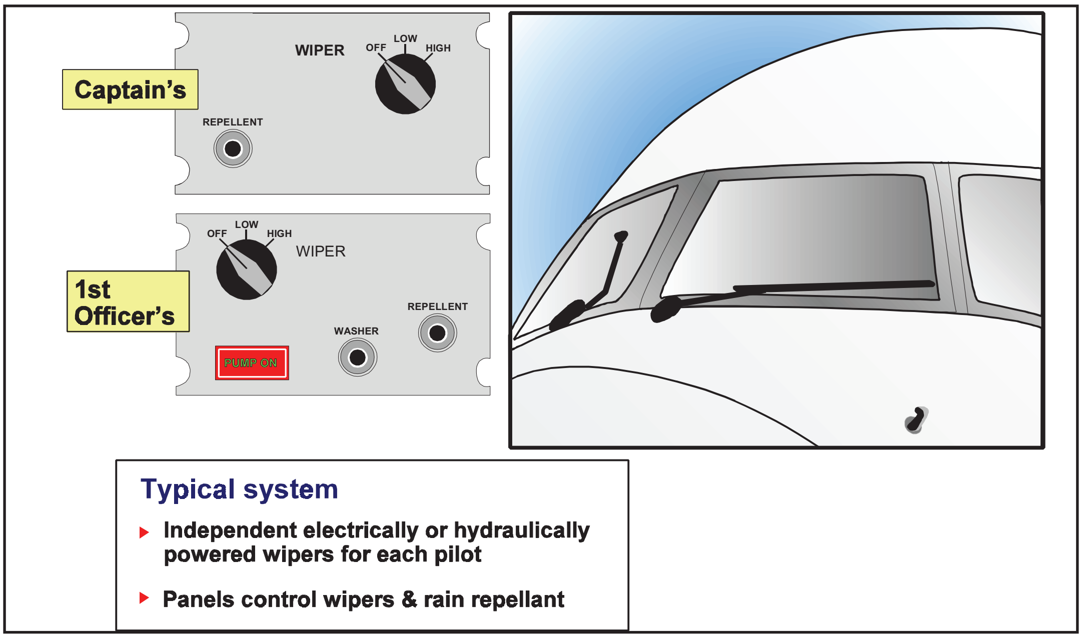


Figure 12.15: Typical Washer, Wiper and Repellent Controls

The rain repellent system is used with the wipers to improve visibility during heavy rain. Rain repellent fluid is sprayed onto the respective windshield by momentarily pressing the rain repellent button switch on the captain's or first officer's wiper control panel. Each actuation of the switch opens the container valve for approximately one third of a second regardless of how long the switch is held in. Depending on airspeed and rain intensity, each actuation should be adequate for 2 to 5 minutes. A fully charged container holds about 75 applications, and repellent applied to a dry windscreen will reduce visibility. The use of both systems simultaneously should be avoided. *See Figure 12.15*.

Fluid De-icing System. The method employed in this system is to spray the windscreen panel with a methyl-alcohol based fluid. The principal components of the system are a fluid storage tank, a pump which may be a hand-operated or electrically operated type, supply pipe lines and spray tube unit. *Figure 12.16* illustrates the interconnection of components based on a typical aircraft system in which fluid is supplied to the spray tubes by two electrically operated pumps. The system may be operated using either of the pumps or both, according to the severity of icing.

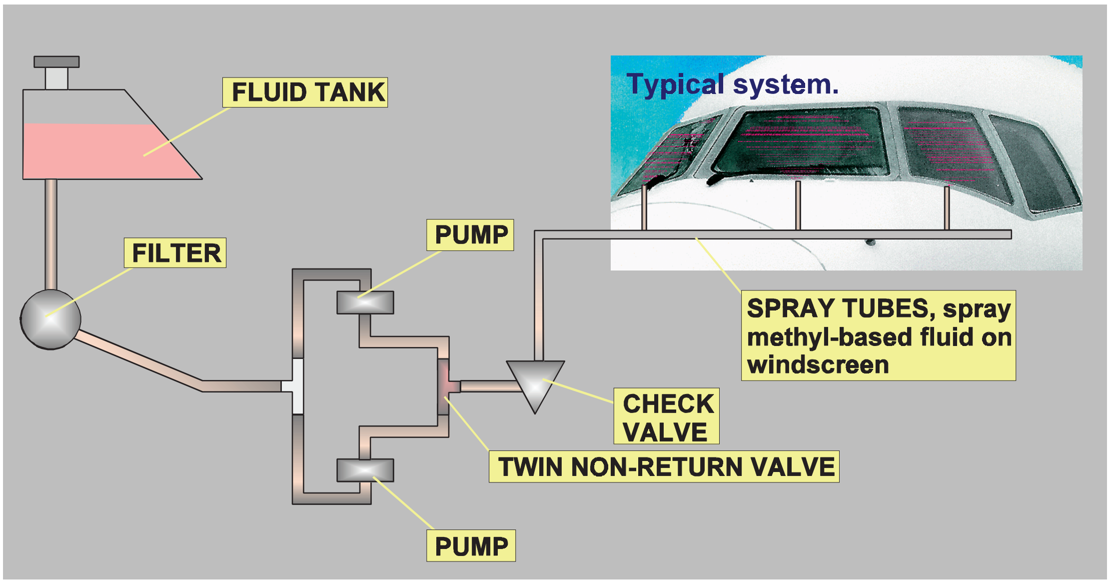


Figure 12.16: Typical windscreen fluid de-icing system.

Electrical Anti-icing System. This system employs a windscreen of special laminated construction heated electrically to prevent, not only the formation of ice and mist, but also to improve the impact resistance of the windscreen at low temperatures.

The film-type resistance element is heated by alternating current supplied from the aircraft's electrical system. The power required for heating varies according to the size of the panel and the heat required to suit the operating conditions. The circuit embodies a controlling device, the function of which is to maintain a constant temperature at the windscreen and also to prevent overheating of the vinyl interlayer which would cause such permanent damage as vinyl 'bubbling' and discolouration.

In a typical anti-icing system, shown schematically in *Figure 12.17*, overleaf, the controlling device is connected to two temperature sensing elements laminated into the windscreen. The elements are usually in the form of a fine wire grid, the electrical resistance of which varies directly with the windscreen temperature. One sensing element is used for controlling the temperature at a normal setting and the other is used for overheat protection.

A system of warning lights and, in some cases, magnetic indicators, also forms part of the control circuit and provides visual indications of circuit operating conditions, e.g. 'normal', 'off' or 'overheat'.

When the power is applied via the system control switch and power relay, the resistance element heats the glass. When it attains a temperature pre-determined for normal operation the change in resistance of the control element causes the control device or circuit to isolate, or in some cases, to reduce the power supply to the heater element. When the glass has cooled through a certain range of temperature, power is again applied and the cycle is repeated. In the event of a failure of the controller, the glass temperature will rise until the setting of the overheat sensing element is attained.

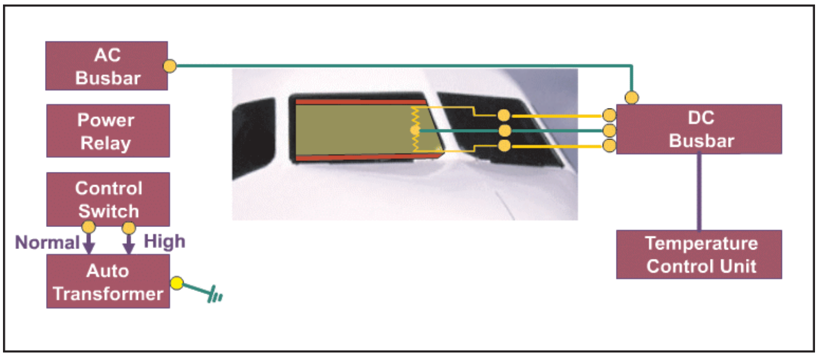


Figure 12.17

At this setting an overheat control circuit cuts off the heating power supply and illuminates a warning light. The power is restored and the warning light extinguished when the glass has cooled through a specific temperature range. In some systems a lock-out circuit may be incorporated, in which case the warning light will remain illuminated and power will only be re-applied by cycling the system control switch to 'OFF' and back to 'ON'.

- In addition to the normal temperature control circuit it is usual to incorporate a circuit which supplies more heating power under severe icing conditions when heat losses are high. When the high power setting is selected, the supply is switched to higher voltage output tappings of an auto transformer which also forms part of an anti-icing system circuit thus maintaining the normal operating temperature. The temperature is controlled in a manner similar to that of the normal control temperature circuit.

- For ground testing purposes, the heating power supply circuit may also be controlled by landing gear shock-strut micro-switches in such a way that the voltage applied to the resistance elements is lower than that normally available in flight.

PROPELLER PROTECTION SYSTEMS

Ice formation on a propeller blade produces distortion to the aerofoil section, causing a loss in efficiency, possible unbalance and destructive vibration. The build up of ice must be prevented and there are two systems in use.

Protection is provided either by an Anti-Icing fluid system, or by an electrically powered thermal De-Icing system.

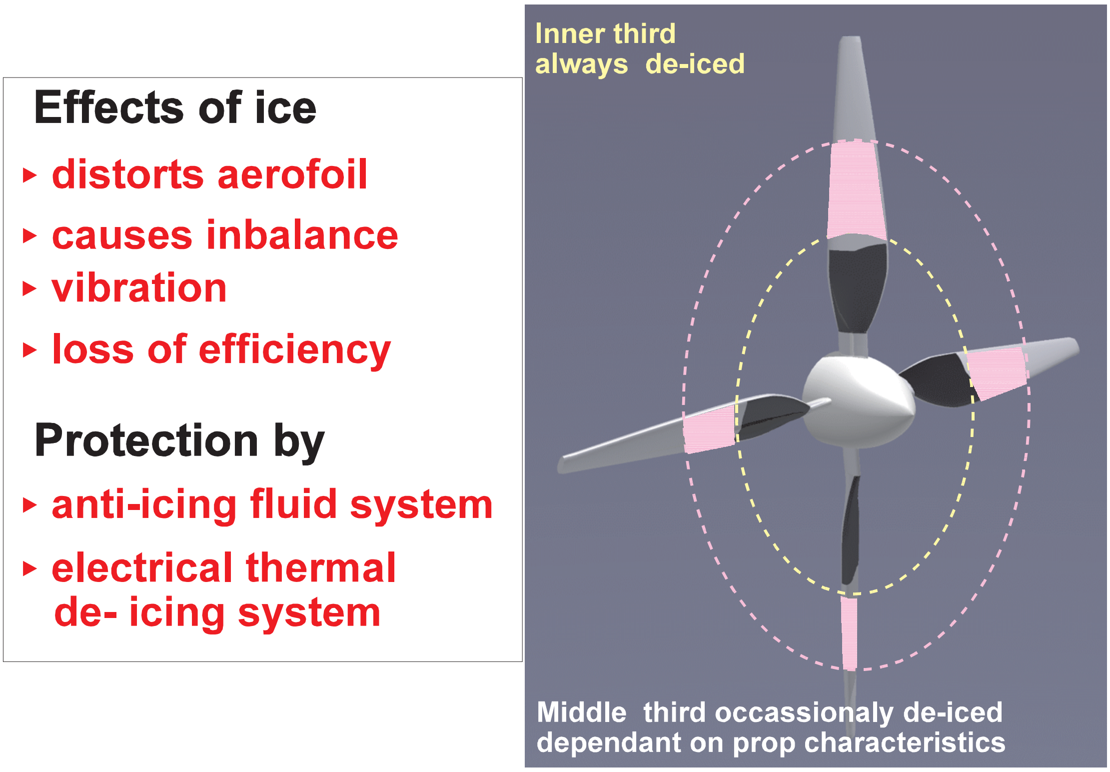


Figure 12.18: Propeller de-icing system.

The fluid system provides a film of freezing point depressant fluid to the propeller blade surfaces during flight which mixes with the water or ice and reduces the freezing point of the mixture. Fluid is distributed to each propeller blade from a slinger ring which is mounted on the back of the propeller hub. The fluid is pumped into this ring through a delivery pipe from a supply tank. Some propellers have rubber overshoes fitted to the blades to assist the distribution of the fluid.

On this type of installation fluid is fed from the slinger ring to a small trough, which is part of the overshoe, and is then forced by centrifugal action along longitudinal grooves in the overshoes. On propellers which are not fitted with overshoes, fluid is fed from the slinger ring through a pipe to the root of the blade and is then distributed by centrifugal action. The fluid may be pumped to the slinger ring from the supply tank by an independent electrically driven pump but air pressure is sometimes used. The electric pump may be controlled by a switch and, in some installations, the pump speed may be varied by means of a rheostat. Check valves are sometimes provided to prevent loss of fluid when the pump is not operating, the supply pressure is typically 10 PSI. Where air pressure is used to supply fluid, a relief valve is usually fitted to the air supply line and a control valve provided to regulate the fluid flow.

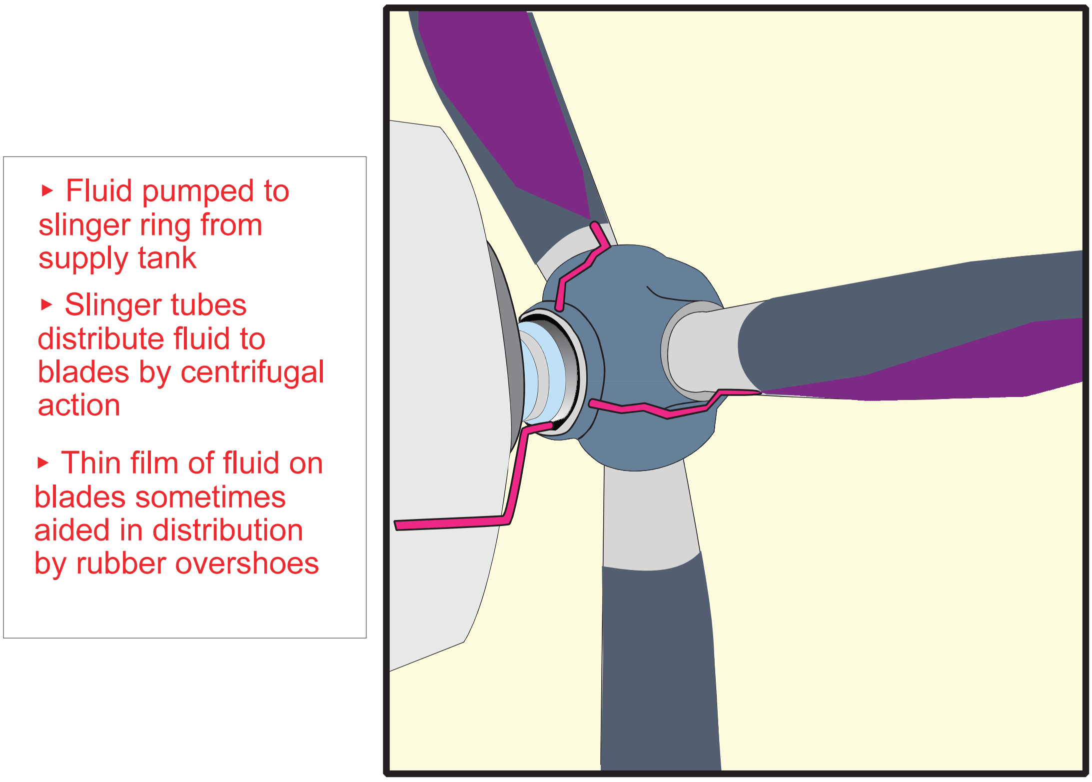


Figure 12.19

In electrical systems, the basis for effective de-icing is formed by resistance wire heating elements bonded to the leading edges of the propeller blades; in the case of turbine engine propellers, wire woven or sprayed elements are also bonded to the front shell of the spinner. Depending on the type of aircraft, the power for heating the elements is either direct current or alternating current and is applied in a controlled sequence by a cyclic timer unit. In turbo-propeller engine installations, the propeller heating circuit forms part of a power unit de-icing and anti-icing system, and the cyclic control is integrated with the engine air intake heating circuit.

Construction. The construction of the elements, or overshoes as they are sometimes called, varies between propeller types. In one commonly used propeller, the heating element wires are interwoven with glass threads which form a glass cloth base, this in turn, being cemented between sheets of rubber. A protective guard of wire gauze is cemented beneath the outer rubber covering. The overshoe is shaped to fit around the blade leading edge and is cemented to it. In some cases, the overshoe is cemented in a rebate machined in the leading edge, so that it lies flush with the blade surfaces.

Power Supplies. The power required for heating is conveyed to the elements via cables, slip rings and by brushes contained within a brush block housing. The slip rings are normally mounted at the rear of the propeller hub or on a starter ring gear, and the brush housing on the engine front casing, but in some systems the method of mounting may be the reverse way round. The cables are of sufficient length and are positioned so as to allow for movement of the blades throughout their designed pitch range.

Heating Control. Efficient operation of these systems necessitates a relatively high consumption of electrical power. This is, however, controlled by employing a cyclic de-icing technique whereby a short unheated period allows a thin film of ice to build up on the leading edges of the propeller blades. Before this film builds up sufficiently to interfere appreciably with the aerodynamic characteristics of the blades, the cyclic control applies heating power. The ice already deposited then acts as thermal insulation, and as the ice in contact with the blade surfaces melts, the main ice catch is carried away under the action of centrifugal and aerodynamic forces.

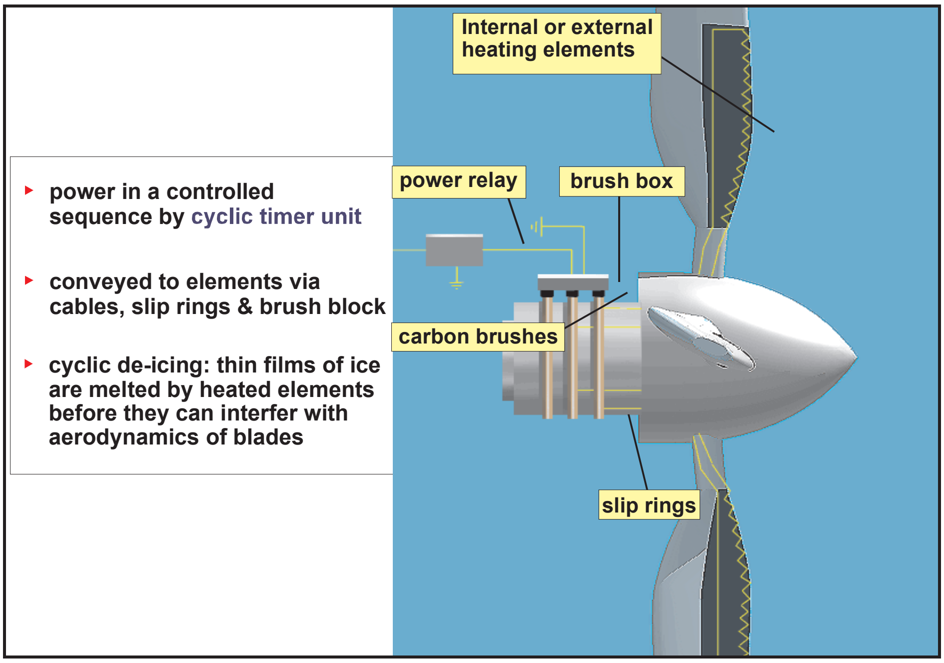


Figure 12.20: Propeller schematic circuit.

MISCELLANEOUS ITEMS

In addition to the major items already covered there is the possibility that heating may be required on any or all of the following items:

- Pitot Heads or Probes.
- Alpha Probes.
- Q Feel Probes.
- P1 Probes.
- Waste Water Drain Horn.
- Total Air Temp Heads.
- Aerials.
- Water Pipes "In Line" Heaters.

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CHAPTER THIRTEEN

ICE AND SNOW - RECOMMENDED PRACTICES

Contents

GENERAL

The presence of frozen deposits on an aircraft may be the result of direct precipitation(rain, snow, frost etc.) or accretion of frost or ice on external surfaces of integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear and forward surfaces or undersurfaces following taxying through snow or slush.

Any deposits of ice, snow or frost on the external surfaces of an aircraft may drastically affect its performance. This can be due to reduced aerodynamic lift and increase aerodynamic drag resulting from the disturbed airflow over the aerofoil surfaces or due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges and microswitches, or by the ingestion of ice into the engine. Furthermore, since the in- flight de-icing system may not become effective until the aircraft is established in the climb out , the measures taken to remove frozen deposits on the ground must also be such as to provide adequate protection during the initial stages of flight.

Neither the use of currently available Freezing Point Depressant (FPD) types of de- icing/anti-icing compounds, nor the use of manual techniques of de-icing with such compounds should be though of as producing reliable anti-icing qualities for a definable period of time, because the number of variables involved make it impractical to estimate that time. Only in the sense that under certain conditions FPD anti-icing compounds are known to be effective in retarding the formation of frost, snow or ice, may they be considered to have anti-icing qualities for a period of time, thus making the process of de-icing simpler and in many case obviating the need for further de-icing or treatment during that period. It is emphasised, however, that the need for a close inspection of an aircraft prior to take-off still remains.

The aircraft de-icing systems are designed to remove or prevent the accretion of ice on a specific area of the wings, tail and engine nacelles in flight and would not normally be effective in removing deposits which have accumulated while the aircraft is stationary. Their use on the ground may, in some instance, also cause a different type of unsatisfactory situation by melting parts of the deposit which would then freeze elsewhere. The use of cabin heating to remove deposits from the fuselage is also not recommended for the same reason.

When aircraft are moved so as to be under cover during inclement weather, any melted snow or ice may freeze again when the aircraft is subsequently moved into sub-zero temperatures. Complete protection could be provided by placing aircraft in heated hangars, but due to the size of modern transport aircraft and the need to meet schedules, involving quick turn round times this is not often practicable. Removal of frost, ice and snow from aircraft is therefore often necessary and maintenance crews need to be familiar with the methods of ground de-icing in current use.

- Aircraft may be de-iced by FPD fluids and heated water
- De-icing & anti-icing can be performed as one stage or several depending on -
  - prevailing conditions
  - fluid concentration
  - methods used
  - facilities available

Figure 13.1

Commonly used to maximise protection times.

- Spray entering the engines or APU intakes could cause toxic fumes to enter cabin and affect crew or passengers
- Therefore APU & engine bleeds should be *closed* during such operations to minimise the risk of cabin contamination

Figure 13.2

There are three main types of de-icing/anti-icing fluids:

- **ISO Type I fluids (unthickened)** (SAE AMS 1424A). These fluids have a high glycol content and a low viscosity. The de-icing performance is good; however, they provide only limited protection against re-freezing. Type I fluids are usually clear.

- **ISO Type II fluids (thickened)** (SAE AMS 1428A). These fluids have a minimum glycol content of approximately 50% and due to the thickening agent have special properties which enable the fluid to remain on the aircraft surfaces until take-off. The de-icing performance is good and, in addition, protection is provided against re-freezing and/or build-up of further accretions, when exposed to freezing precipitation. Type II fluids are usually straw coloured.

- **ISO Type IV fluids (thickened)** (SAE AMS 1428A) This fluid is simlilar in both composition and operation to Type II fluids. however, through the use of advanced thickening systems it is able to provide longer holdover time than Type II fluids, when used in concentrated form. As with Type II fluids the holdover time can be extended by increasing the concentration of fluid in the fluid/water mix. Type IV fluids are usually coloured green.

PRE-FLIGHT PREPARATION

The whole aircraft should be inspected to ensure that it is free from deposits of frost, ice and snow. When necessary, a de-icing fluid should be used. The objectives of using such fluids are to achieve effective removal of any frost or ice and to provide a measure of protection against further formation. Only fluids approved for the purpose should be used.

- The ability of the fluid to achieve the above objectives under varying atmospheric conditions id dependent upon the correct mixture strength and methods of application, both of which should be strictly in accordance with recommended procedures. For example, while fluid diluted with water may effectively remove ice, its ability to prevent further formation will be significantly reduced, and under certain conditions the fact that the aircraft surfaces are wetted may actually enhance the accumulation of wet snow.

- Where adequate advice on approved fluids, mixture strength and method of application is not given in the relevant aircraft Maintenance Manuals, guidance should always be sought from the aircraft manufacturer and from the suppliers of the fluid. The following information is only intended as general information and should not be used to override that which is contained in the aircraft Maintenance Manuals.

NOTES: (1) *Under extreme cold conditions it may be necessary to heat the neat fluid (60°C max) to give it sprayability*

(2) *No significant increase in holdover time is achieved by strengthening the mix of type I (AEA) fluids.*

(3) *Stations using Kilfrost will normally provide a mix of 50/50 or 60/40. It may be difficult to get stronger mixes at short notice unless the temperature conditions at the stations involved are below limits for that mix.*

Advances in the composition of de-icing fluids have led to the production of a dual purpose anti-icing (DID 900/4907) which is capable of removing ice and snow and delaying deposits re-forming. When used as a de-icing agent, this should be mixed with the required volume of water and applied at a temperature of approximately 70°C by the method described earlier.

It is however, strongly recommended that refractometer readings be taken so that the precise concentration of the solution can be determined.

NOTE: Pocket refractometers are available which permit on site measurement of fluid concentration as a refractive index which can be converted to fluid/water proportions accurately by means of a chart.

Table 1 gives a guide to some typical maximum times during which the residual film of fluid may be effective in providing protection from re-freezing. It must be appreciated, however, that the period of protection will vary dramatically, depending upon the severity of the particular condition. Visual checks of the aircraft external surfaces are therefore always required to confirm the actual condition of the aircraft in extreme conditions of snow and freezing rain.

FROST DEPOSITS AND METHODS OF TREATMENT

A deposit of frost is best removed by the use of a frost remover, or in severe conditions, a de-icing-icing fluid (e.g. Kilfrost ABC or similar proprietary fluids). These fluids normally contain either ethylene glycol and isopropyl alcohol or diethylene glycol (or propylene glycol) and isopropyl alcohol, and may be applied by spray or by hand. The process is not lengthy, as one application is usually sufficient, provided that it is applied within the two hours prior to flight.

NOTES: (1) De-icing fluids may adversely affect glazed panels or the exterior finish of aircraft, particularly when the paint is new. Only the type of fluid recommended by the aircraft manufacturer should therefore be used and any instructions relating to its use should be strictly observed.

(2) De-icing fluids, particularly those with an alcohol base, may cause dilution or complete washing out of oils and greases from control surface bearings, etc., allowing the entry of water which could subsequently freeze, jamming controls. Spray nozzles should not, therefore, be direct at lubrication pints or sealed bearings and an inspection of areas where fluid may be trapped is usually necessary. The Maintenance Schedule may specify relubrication in these areas whenever de-icing fluids are used.

Frost may also be removed from aircraft surfaces using a mobile unit capable of supplying large quantities of hot air through a delivery hose and nozzle. The air is blow on to the wings, fuselage and tail surfaces and either blows away or melts any frost deposits. Operators using this equipment should ensure that any melted frost is dried up and not allowed to accumulate in hinges, microswitches, etc. where re-freezing could occur.

ICE AND SNOW DEPOSITS AND METHODS OF TREATMENT

Probably the most difficult deposit to deal with is deep wet snow when ambient temperatures are slightly above freezing point. This deposit should be removed with a brush or squeegee, care being taken not to damage aerials, vents, stall warning vanes, Pitot probes, vortex generators, etc., which may be concealed by the snow. Light dry snow in sub-zero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a de-icing fluid, which may be successfully applied to any aircraft by spraying; in severe conditions it may be necessary to spray a final application immediately before flight. The aircraft nose and cockpit canopy should normally be left dry to ensure that the windscreen does not become contaminated with fluid which could cause smearing and reduced vision. Windscreens should not be cleared by wiping with an alcohol-soaked cloth or by use of the windscreen anti-icing system.

NOTES: *(1) No attempt should be made to remove ice deposits or break an ice bond by force.*

(2) It is essential that removal of deposits proceeds symmetrically.

COLD FLUID SPRAY. A cold fluid spray is the simplest method of applying de-icing fluid, but suffers from several disadvantages which must be considered in relation to the particular circumstances.

- In very severe conditions one sprayed application of cold fluid may be sufficient to remove all the ice and snow; brushing or rubbing thickly iced areas is usually necessary, followed by a second or even third application of fluid. As the ice and snow melts, the fluid is diluted, becomes less effective and is prone to freezing again quite quickly. This may have serious consequences if the diluted fluid is allowed to run into control surface and landing gear mechanisms. Under these conditions the cold spray method may be both prolonged and expensive.

HOT FLUID SPRAY. Many airline operators have dispensed with the use of cold spraying techniques except at small airports and in an emergency. They have adopted a hot fluid spraying system which was developed specifically to reduce turnaround times and to inhibit the bonding of ice and snow to aircraft surfaces for a period of time. The equipment used consists of a static unit, in which quantities of both water and de-icing fluid are heated, and a mobile unit which houses an insulated tank, a pump, an hydraulically-operated boom-mounted platform and several spray lances.

- In this system, hot fluid is pumped from static unit to the insulated tank on the mobile unit, the proportions of water and de-icing fluid being adjusted to suit prevailing weather conditions. The mobile unit is then driven to the site of operations, the optimum number and disposition of units being found by experience on a particular aircraft type.

- The fluid is normally sprayed on at a temperature of 70°C and a pressure of 700 kN/m2 (100 lbf in2), holding the nozzle close to the aircraft skin to prevent heat losses. Heat is transferred to the aircraft skin, thus breaking the ice bond, and large areas of ice may be flushed away by turning the nozzle sideways. In this way, time is saved and the dilution of fluid with ice and snow reduced to a minimum. The film of fluid left on the aircraft skin, being only slightly further diluted, is effective in preventing ice re-forming.

NOTE: *Overheating in the de-icing rig, of most de-icing fluids will result in a gelled formation being deposited on the aircraft which will not shear off on take-off and may, therefore, have an adverse aerodynamic effect.*

HOT WATER DE-ICING. Hot water de-icing **should not** be carried out at temperatures below -7 C, and the second step must be performed within three minutes of the beginning of step 1, if necessary area by area.

- **Step 1**. Snow and ice is initially removed with a jet of hot water at a maximum temperature of 95°C

- **Step 2**. A light coating of de-icing fluid is then immediately applied to the aircraft to prevent re-freezing.

HIGH PRESSURE SPRAYS

- High pressure sprays used for de-icing are capable of causing damage to Pitot- static probes and other sensing devices. A carelessly directed spray could also result in the ingress of a considerable quantity of fluid into engine intakes, drains or vents, possibly resulting in cabin smoke or malfunction of an associated aircraft system. Where covers or bungs are provided they should be fitted during de-icing operations. Where this is not possible care must be taken to prevent direct impingement of the spray on any vents or probes.

- High pressure sprays can also cause erosion of the aircraft skins and some aircraft manufacturers recommend a maximum impingement pressure which is quoted in the appropriate Maintenance Manual and should not be exceeded.

DE-ICING OF AIRCRAFT WITH ENGINES OPERATING

- Aircraft 'taxi-through' de-icing facilities are presently being used which de-ice aircraft with the engines operating. Winter environmental conditions and the manner of application create potentially unsafe conditions if an incorrect de-icer solution is inadvertently sprayed into the engine/APU inlets or contacts the exhausts when the engines or APU are operating. APU and engine bleeds should be closed during such operations to minimise the risk of contamination of the cabin environment.

- De-icing fluid have a flashpoint of 139°C to 156°C in their undiluted state which is within the engine/APU operating range. The numerous de-icing fluids available also include some which have toxic characteristics that could affect personnel or passengers if ingested by the air-conditioning system.

- Some aircraft manufacturers issue instructions which contain precautions concerning fluids and techniques for de-icing aircraft with engines operating. A safety hazard could exist if the manufacturer's instructions are not followed.

- Safeguards should include procedures which ensure that de-icing fluids are diluted below critical flashpoints and that such fluid are prevented from entering air ducts, air-conditioning systems, and engines/APU inlets or exhaust.

- Fire and emergency equipment should also be readily available at all times.

ANTI-ICING MEASURES

When used as an anti-icing agent, the FPD fluid should be sprayed onto the aircraft cold and undiluted, either before the onset of icing conditions or after hot de-icing has been carried out. This will leave a film of fluid approximately 0.5 mm (0.020 in) thick on the surfaces sprayed and give protection overnight in all but the most severe weather conditions. The fluid prevents ice and snow from sticking to the aircraft skin and given time will melt any fresh precipitation. Newly fallen snow may be quickly removed by blowing, and heavy ice deposits, such as those produced by freezing rain may be removed by a light and economical spray of hot fluid. Excess fluid will shear off during the take-off run.

***NOTE**: FPD compound should not be applied to windscreens or essential glazed panels as it will severely restrict vision.*

On some aircraft not equipped with an aerofoil de-icing system, the use of a De-Icing paste may be specified. This paste is intended to prevent the accumulation of frozen deposits which may result from inadvertent flight into icing conditions. When spread smoothly by hand over the leading edges of the wings and tail unit the paste presents a chemically active surface, on which ice may form but may not bond. Any ice which does form may ultimately be blown off in the airstream.

- The paste should be reactivated before each flight in accordance with the manufacturer's instructions.

WARNING: It is important to note that de-icing pastes do not constitute an approved method of de-icing otherwise unprotected aircraft for intended flights into known or forecast icing conditions.

INSPECTION AFTER DE-ICING OPERATIONS

It is important to carry out an inspection of an aircraft after completion of de-icing operations. The aircraft should also be continually monitored between de-icing and departure to ensure no further ice build-up has occurred. The presence of ice in certain areas may not be obvious to personnel handling the de-icing equipment.

***NOTE:** The effective duration of anti-icing fluids depends on concentration/temperature of application, volume of snow and ice, etc. Subsequent ambient temperature and time.*

All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control surface gaps and hinges. This is especially important where control surfaces are sealed by 'curtains' of the Westland-Irvine type. Drainage or pressure sensing holes and radiator honeycombs should be checked to ensure that they are not blocked. Where it has been necessary to physically remove a layer of snow all protrusions and vents should be examined for signs of damage.

Where possible, control surfaces should be moved by hand to ascertain that they have full and free movement. Where this is not possible the pilot's controls should be gently operated, bearing in mind that power operated controls exert considerable force on the control surface and could cause damage if any part of circuit is frozen. If any restriction is found, the control cables, pulleys, fairleads, hinges etc. should be examined and any frozen deposits treated with de-icing fluid until smooth control operation is achieved.

The landing gear mechanism, doors, bays and wheel brakes should be inspected for snow or ice deposits, and the operation of uplocks and microswitches checked. In very severe conditions it is possible for the tyres to become frozen to the ground; they may be freed by the application of warm air to the ice (not the tyre) and the aircraft should then be moved to a dry area.

Snow or rain can enter jet engine intakes after flight and freeze in the compressor when the engine has cooled. If compressors cannot be turned by hand for this reason, the engine should be blown through with hot air immediately before starting, until the rotating parts are free.

The low temperatures associated with icing conditions may also introduce problems apart from those associated with the clearance of precipitation.

- Contraction of metal parts and seals can lead to fluid leakage and particular attention should be given to landing gear shock absorber struts and hydraulic jacks.

- Tyre and shock absorber strut pressures reduce with temperature and may require adjustment in accordance with the loading requirements.

Technical Logs. An entry should be made in the Technical Log as required by British Civil Airworthiness Requirements, Section A, Chapter A6-8, unless an alternative company procedure has been agreed by the CAA.

AIRCRAFT DE-ICING AND ANTI-ICING

An aeroplane may be de-iced by any FPD fluids and heated water. In respect of rotocraft, manufacturers have not formally approved the used of FPD fluids and should, therefore, be consulted being using such fluids. Heated water, FPD fluids or aqueous solutions of FPD fluids are more effective in the de-icing process. The de-icing and anti-icing processes may be performed as one stage or multiple stage processes as desired depending upon prevailing conditions, concentration of FPD fluid utilised, facilities available and de-icing methods. Unheated FPD fluids or aqueous solutions are more effective in the anti-icing process than heated fluids.

In conditions of freezing precipitation or high humidity when aircraft surface temperatures are near or below freezing, it should not be assumed that snow or other ice crystal accumulations will blow off during initial stages of take-off. Surfaces should therefore be anti-iced to retard the formation of ice prior to take-off.

FPD freeze point and/or mixture strength can be determined using refractive index techniques FPD fluid manufacturers can suggest or supply suitable equipment.

Critical surface temperatures under many circumstances are found in the vicinity of integral wing fuel tanks. When fuel temperatures are higher than ambient, critical surface temperatures will occur at other locations. These temperatures can be determined by direct measurement or by estimating fuel temperature.

In conditions of non-precipitation an anti-iced aircraft should be closely inspected prior to flight to ensure that no ice crystals have formed in the residual fluid film. If freezing is in evidence the holdover time will have been exceeded and a de-icing process must be carried out. This is especially important when relative humidity is high.

Underwing frost should be removed and, where practical, the surface anti-iced to delay re-formation of frost. See Appendix for additional information on this subject.

PRE-FLIGHT INSPECTION

Pre-flight inspection should be performed immediately prior to departure, following the ground de-icing and anti-icing process. Areas to be inspected depend upon the aircraft design and should be identified in an inspection checklist. The inspection checklist should include all items recommended by the aircraft manufacturer (for rotorcraft see paragraph 7.1) and may be supplemented, as necessary, to include special operational considerations, but this checklist should include the following general items:-

- Wing leading edges, upper surfaces, and lower surfaces.
- Stabilising device leading edges, upper surfaces, lower surfaces, and side panels.
- High lift devices such as leading edge slats and leading or trailing edge flaps.
- Wing lift spoilers

- All control surfaces and control balance bays
- Propellers
- Rotor blades, rotor heads and controls
- Critical rotor system devices such as droop stops
- Engine inlets, particle separators and screens
- Windscreens and other transparencies necessary for visibility
- Antennae
- Fuselage sections forward of stabilising, control and lifting surfaces, propellers, rotors, or engine air inlets.
- Exposed instrumentation devices such as angle-of-attack vanes, pitot-static pressure probes, total air temperature probes and static vents.
- Fuel tank and fuel cap vents
- Cooling and APU air intakes/inlets/exhaust
- Landing gear
- Technical Log, which should be checked for the relevant entry.

Once it has been determined through pre-fight inspection that the aircraft is clean and adequately protected, the aircraft should be released for take-off as soon as possible. This is especially important in conditions of precipitation of high relative humidity.

PRE-TAKE OFF INSPECTION

FIXED WING AIRCRAFT

- Just prior to taking the active runway for take-off or just prior to initiating take- off roll, a visual pre-take-off inspection should be made. The components to be inspected depend upon aircraft design. In some aircraft, the entire wing and portions of the empennage are visible from the cockpit or the cabin. In other aircraft, these surfaces are so remote that only portions of the upper surface of the wings are in view. Undersurfaces of wings and landing gear are not viewable in any but high-wing type aircraft. A practice in use by some operators is to perform close visual inspection of wing surfaces, leading edges, engine inlets, and other components of the aircraft that are in view either from the cockpit or cabin (whichever provides maximum view). If surfaces have not been treated with FPD fluid , evidence of melting snow and possible freezing is sought. Also evidence of any ice formation that may have been induced by taxi operations is sought. If the aircraft has been treated with FPD fluids, evidence of a glossy smooth and wet surface is sought. If, as a result of these inspections, evidence of ice, snow, or frost accretions is observed, the aircraft should be returned to a maintenance areas for additional de-icing.

- The fact that is impractical for an aircraft crew member to disembark at the end of a runway and perform pre-take-off inspections means that the crew member should perform that inspection from the best vantage point available from within the aircraft. The crew member may elect to open windows, doors, or hatches to improve the view, but in many aircraft even this is impractical. At night the crew member must rely upon wing and engine ice inspection lights which may not always provide sufficient reflection to make all the appropriate visual observations.

- The crew member may, where practical, call upon the assistance of qualified ground personnel. If under any circumstances, the pilot in command cannot ascertain that the aircraft is clean, take-off should not be attempted.

- Conducting pre take-off inspection in the manner described relies upon: the pilot in command being knowledgeable of ground de-icing procedures; the ground de-icing process having been conducted in a thorough and uniform manner; and critical surfaces or components not in view during pre-take-off inspection also being clean. The decision to take off following pre take-off inspection remains the responsibility of the pilot in command.

ROTORCRAFT

- Pre-take-off inspection of rotor systems should be conducted just prior to starting rotors turning. Rotor systems should not be started unless blade surfaces and other critical components are free of ice, frost or adhering snow.

- Not all rotorcraft are certificated for flight in falling, blowing or recirculating snow. Flight Manual limitations prohibiting such operations must be observed.

- Rotorcraft manufacturers have not formally approved the use of FPD fluids and should, therefore, be consulted being using such fluids.

COMMON PRACTICES

SUGGESTED PRACTICES FOR SAFE COLD WEATHER OPERATIONS

COMPANY QUALITY ASSURANCE PROCEDURES

Establish quality assurance programmes to ensure that FPD fluids being purchased and used are of the proper characteristics and that:

- storage limitations are being observed.

- proper ground de-icing and anti-icing procedures are utilised. c) all critical areas are being inspected.

- all critical components of the aircraft are clean prior to departure.

Perform thorough planning of ground de-icing activities to ensure that proper supplies and equipment are available for forecast weather conditions and those responsibilities are specifically assigned and understood. This should also include maintenance service contracts at line stations to ensure that the ground facilities and procedures used provide assurance in matters which the pilot cannot check and so enable the crew to be satisfied that the aircraft can safely take-off.

Monitor weather conditions very closely to ensure that planning information remains valid during the ground de-icing or anti-icing processes and subsequent aircraft operations. FPD fluids, de-icing or anti-icing procedures and departure plans should be altered accordingly.

Use FPD concentrations which will provide adequate holdover times under the prevailing conditions.

De-ice or anti-ice areas which may be viewed by the pilot (from inside the aircraft) first so that during pre-take-off inspection he may have some assurance that other areas of the aircraft are clean, since areas de-iced or anti-iced first will generally freeze first.

Use the two-stage de-icing process where ice deposits are first removed, and then coat all critical components of the aircraft with an appropriate mixture of FPD fluid (anti-icing) to prolong effectiveness.

Ensure thorough co-ordination of the ground de-icing and anti-icing processes so that final treatments are provided just prior to take-off.

Where feasible, use remote sites near the take-off position for de-icing or anti-icing to reduce the time between de-icing and take-off, or to provide additional FPD fluid to prolong anti-icing effectiveness.

Use multiple aircraft de-icing or anti-icing units for faster and more uniform treatment during precipitation.

Use FPD fluids that are approved for use by the aircraft manufacturer. Some fluids may not be compatible with aircraft materials and finishes some may have characteristics that impair aircraft performance and flight characteristics or cause control surface instabilities.

Do not use substances which are approved for use on pneumatic boots (to improve de-icing performance) for other purposes unless such uses are approved by the aircraft manufacturer.

PERSONNEL TRAINING

Establish training programmes to continually update pilots on the hazards of winter operations, adverse effects of ice accretions on aircraft performance and flight characteristics, proper use of ice protection equipment, ground de-icing and pre-take-off inspection procedures following ground de-icing or anti-icing, and operations in conditions conducive to aircraft icing.

Establish training programmes for maintenance or other personnel who perform aircraft de-icing to ensure thorough knowledge of the adverse effects of ice accretion on aircraft performance and flight characteristics, critical components and specific ground de-icing and anti-icing procedures for each aircraft type, and the use of ground de-icing and anti-icing including detection of abnormal operational conditions.

SUGGESTED PRACTICES TO ENSURE THE CLEAN AIRCRAFT CONCEPT

Be knowledgeable of the adverse effects of surface roughness on aircraft performance and flight characteristics.

Be knowledgeable of ground de-icing and anti-icing practices and procedures being used on your aircraft whether this service is being performed by your own company, a service organisation, or operator.

Do not allow de-icing or anti-icing unless you are satisfied with the ground de-icing practices and quality control procedures of the service organisation.

Be knowledgeable of critical areas of your aircraft and ensure these areas are properly de-iced and anti-iced, that proper precautions are being taken during the de-icing process to avoid damage to aircraft components, and that proper pre-flight inspections are performed, even though this is also the responsibility of other organisations or personnel.

Be knowledgeable of aircraft ice protection system function, capabilities, limitations, and operation.

Perform additional pre-flight inspections related to de-icing or anti-icing as may be required.

Be aware that no one can accurately determine the time of effectiveness of an FPD de-icing or anti-icing treatment because of the many variables that can influence this time. Be knowledgeable of the variables that can reduce time of effectiveness and their general effects.

Ensure that de-icing or the anti-icing treatment is performed at the latest possible time prior to taxying to the take-off position.

Do not start engines until it has been ascertained that all ice deposits are removed. Ice particles shed from rotating components such as propellers or rotor blades, under centrifugal and aerodynamic forces can be lethal.

Be aware that certain operations may produce recirculation of ice crystals, snow or moisture.

Be aware that operations in close proximity to other aircraft can induce snow, other ice particles, or moisture to be blown onto critical aircraft components, or allow dry snow to melt and re-freeze.

Do not take off if snow or slush is observed splashing onto critical areas of the aircraft, such as wing leading edges, during taxi. It should be remembered that mud and water splashed, during taxying or take-off, on to a cold soaked airframe may stick and freeze to the under (lifting) side of the tailplane, especially if it is already dirty.

Always perform pre-take-off inspections just prior to take-off.

Do not take off if positive evidence of a clean aircraft cannot be ascertained.

APPENDIX - GENERAL INFORMATION RELATING TO GROUND AND FLIGHT OPERATIONS IN CONDITIONS CONDUCIVE TO AIRCRAFT ICING

INTRODUCTION

This Appendix provides additional general information necessary for the overall understanding of hazards following ground de-icing and ground operations in conditions conducive to aircraft icing. It also includes causes and effects of ice accretions (induced on the ground or in flight) as well as ground related issues such as: methods of ground de-icing, capabilities and limitations of freezing point depressant (FPD) ground de-icing fluids, and discussions of variables that can influence the effectiveness of ground de-icing fluids.

CONDITIONS CONDUCIVE TO AIRCRAFT ICING

- Aircraft on the ground or in flight are susceptible to accumulation of ice accretions under various atmospheric and operational conditions. Aircraft in flight can encounter a variety of atmospheric conditions which will individually or in combination produce ice accretions on various components of the aircraft. These conditions included:

  - **Supercooled Clouds**. Clouds containing water droplets (below 0°C) that have remained in the liquid state. Supercooled water droplets will freeze upon impact with another object. Water droplets can remain in the liquid state at ambient temperatures as low as -40°C. The rate of ice accretion on an aircraft component is dependent upon many factors such as droplet size, cloud liquid water content, ambient temperature, and component size, shape, and velocity.

  - **Ice Crystal Clouds** Clouds existing usually at very cold temperatures where moisture has frozen to the solid or crystal state.

  - **Mixed Conditions** Clouds at ambient temperatures below 0°C containing a mixture of ice crystals and supercooled water droplets.

  - **Freezing Rain and Drizzle** Precipitation existing within clouds or below clouds at ambient temperatures below 0°C where rain droplets remain in the supercooled liquid state.

FROZEN PRECIPITATION SUCH AS SNOW, SLEET OR HAIL

Aircraft on the ground, during ground storage or ground operations, are susceptible to many of the conditions that can be encountered in flight in addition to conditions peculiar to ground operations. These include:

- Supercooled ground fog and ice clouds.

- Operation on ramps, taxiways and runways containing moisture, slush or snow.

- Blown snow from snow drifts, other aircraft, or ground support equipment.

- Snow blown by ambient winds, other aircraft, or ground support equipment.

- Re-circulated snow made airborne by engine, propeller or rotor wash. Operation of jet engines in reverse thrust, reverse pitch propellers and helicopter rotor blades are common causes of snow re-circulation.

- Conditions of high relative humidity that may produce frost accretions on aircraft surfaces having a temperature at or below the frost point. Frost accumulations are common during overnight ground storage and after landing where aircraft surface temperatures remain cold following descent from higher altitudes. This is a common occurrence on lower wing surfaces in the vicinity of fuel cells. Frost accretions can also occur on upper wing surfaces in contact with cold fuel.

THE EFFECTS OF ICE, SNOW, AND FROST ACCRETIONS ON AIRCRAFT PERFORMANCE AND FLIGHT CHARACTERISTICS

GENERAL. During flight operations ice will form on leading edges of various components, within forward-acting air intakes (eg. engine inlets) and frontal areas of the airframe. During ground storage or operations, ice will form on other portions of aircraft components such as upper surfaces of wings, fuselages, engine nacelles, horizontal stabiliser surfaces, and control surfaces. The effects that in-flight or ground ice accretions will have on aircraft performance and flight characteristics are many, varied and highly dependent upon aircraft design, ice surface roughness, ice shape, and areas covered. These effects will generally be reflected in the form of decreased thrust, decreased lift, increased drag, increased stall speed, trim changes, and altered stall characteristics and handling qualities. Slight weight increases will also occur, however, the effect of weight increase (with the exception of heavy snow and freezing rain deposits) is usually insignificant in comparison to aerodynamic degradation.

AIRCRAFT CERTIFICATION FOR FLIGHT IN ICING CONDITIONS

- Before an aircraft is certificated to fly in atmospheric conditions conducive to icing, that capability must be demonstrated to the CAA. This is accomplished through extensive analyses and flight testing. If an aircraft is not so certificated, it should be not intentionally flown in atmospheric icing conditions. Aircraft which are certificated for flight in icing conditions are equipped with ice protection systems to reduce the adverse effect of ice formations, either by preventing the formation of ice (anti-icing) or by periodically removing ice (de- icing). Some components of some aircraft certificated for flight in icing conditions do not require ice protection equipment. Aircraft so certificated have been demonstrated to be capable of safe flight with ice of certain shapes adhering to critical areas. Aircraft certificated for flight in icing conditions are capable of sustained operations in supercooled cloud conditions. Their engines and engine inlets are capable of operation without serious performance degradations in supercooled clouds.

  Some aircraft may have limited capability of flight in freezing rain and drizzle, in mixed conditions of pure ice crystal clouds, however, ice protection systems are certified only for operation under the supercooled cloud conditions noted in paragraph 2.a) i) above. Small aircraft are generally less tolerant to freezing rain conditions than large aircraft.

- Aircraft which are certificated for flight in icing conditions are not certified for take-off or flight with ice formed as a result of ground storage or operations. Such formations must be removed and the aircraft sustained in a clean configuration prior to initiation of take off and throughout the take-off roll.

- No commercial helicopters are currently fully certificated in the U.K. for flight in unrestricted icing conditions. A small number of types are approved for flight in conditions of light or moderated icing, but none of these types may take off when icing conditions are actually present, or are likely to be encountered below 500 ft above the take-off surface. Some helicopters are certificated for flight in falling or blowing snow and may take off in those conditions.

- Many aircraft in service today (generally small aeroplanes) have ice protection equipment installed, but are not certificated for flight in icing conditions. Aircraft of this type have only been required to demonstrate that the equipment is non-hazardous for flight in non-icing conditions with the equipment installed. Aircrews should be aware of these limitations and be cautious because this type of equipment may not provide safe flight during icing encounters.

- Many aircraft in service today (generally large aircraft) are permitted by Maintenance Manuals to be dispatched for flight with slight amounts of frost on fuselage surfaces and adhering to fuel tank areas of wing undersurfaces. Maintenance Manuals of such aircraft specify limits of frost thickness (generally between 3 and 9 mm) depending upon the aircraft characteristics. It is emphasised that this practice is based upon operational experience only and no CAA certification or other test data has verified the accuracy of these limits. Operational experience as well as research experiments indicated that fuselage and underwing frost formations do not generally influence aircraft performance and flight characteristics as severely as leading edge and upper wing frost; however, some wing designs may be more sensitive to underwing frost than others.

EFFECTS OF ICE ACCRETIONS

- Wind tunnel and flight testing conducted in the past under research, development, and certification efforts, as well as operational experience, has shown that ice accretions on various aircraft components can have very significant and sometimes devastating effects on aircraft equipment operation, aircraft performance, and flight characteristics. Components of an aircraft normally affected by ice accretions are highly dependent upon aircraft design; however, they generally fall into the following categories lifting devices; stabilising devices; control surfaces; engine inlets; engines; propellers; rotor blades; anti-torque devices; windscreens and other transparent structures; cooling air inlets; fuselage sections; antennae; landing gear devices; fuel cap vents; and fuel tank vents.

- The effects of ice accretions on some of these components and the contribution to degradation of aircraft performance and flight characteristics are itemised in the following list:

  - Slight surface roughness can have significant effects on stall speed, stall behaviour and power required to achieve or to sustain flight.

  - Increased surface roughness due to ice accretion, on wing leading and trailing edges will produce additional drag and further reduce lift. Leading edge surface roughness is more significant on most aerofoils.

  - Due to increased stall speed, manoeuvres should be more gentle and airspeed margin during approach should be increased.

- Stall angle-of-attack will decrease and in some aircraft stall will occur prior to activation of stall warning or stall protection devices.

- Stall characteristics will change and, depending upon aircraft design, the nature of ice accretions can cause either violent stall or a slower progression of stall. In some aircraft, pitch-up tendencies may be greater and roll-off tendencies can be exaggerated.

- Controllability may be reduced requiring more stick deflection for manoeuvres or stall recovery.

- Power available may be reduced due to ice accretions on propellers or jet engines inlets.

- Ice or excessive quantities of FPD fluid have been known to cause control surface flutter.

- Trim effectiveness can deteriorate with the accumulation of ice on unprotected surfaces.

- Power failures may occur due to intake duct icing, carburetor icing, ingestion of ice particles into jet engines or clogging of fuel tank vents and fuel caps.

- Severe vibrations may occur due to asymmetric shedding of ice from propellers or rotor blades. Helicopter autorotation capability can be significantly changed or lost.

- Control surfaces such as ailerons, elevators, and wing spoilers can freeze in place if water deposits, snow, and FPD fluids are not properly cleaned or drained from critical areas.

- Movement of flying and trim control cables, rods or jacks can be impaired by freezing moisture in un-pressurised areas, making control surfaces immovable. Attention to sealing and the use of anti-freeze lubricants can ensure protection.

- Wing flaps may be damaged if retracted with ice accretions adhering to critical areas.

- Landing gear mechanisms may be damaged or frozen in place if not properly cleared of ice accretions.

- Forward visibility may be lost or significantly reduced if windscreen anti-icing systems are not available or are not properly utilised.

- Radio, radar, and other communication and navigation antennae may be damaged or efficiency reduced due to ice accretions.

- Ventilation, air conditioning, and other air inlets can be blocked or flow restricted.

- Ice dislodged from fuselage or wing sections, antennae and other components forward of engine inlets and other critical components can produce damage.

- Ice accretions, under certain conditions, may not have noticeable effects on aircraft performance and flight characteristics, however, these effects may become quite apparent in the event of engine failure or other emergencies.

- Flight, engine, and other instruments are subject to error if ice accretions exist on external probes, in pressure lines, or on areas forward or adjacent to external probes. Operational experience indicates that typical sources of error are icing of pitot-static probes used for airspeed, altitude and engine pressure ratio measurements.

- Automatic systems that utilise signal sources from external sensors such as Automatic Flight Control Systems, autothrottle speed command systems, or stability augmentation systems may be adversely affected by ice accretions on or in the vicinity of the sensors.

- Residual moisture on door and cargo hatch seals may freeze under certain conditions causing leaks or seal damage, and the inability to open doors in an emergency.

METHODS OF DE-ICING OR CLEARING ICE FROM AIRCRAFT SURFACES

Ground de-icing procedures have been under development, practically speaking, since the time of the invention of the aircraft. Early methods employed the use of hangars to avoid exposure to the elements or use of wing covers and covers for other critical components such as windscreens, engine air intakes, pitot probes, etc. But these devices were useful only to lessen the extent of work required to remove frost, snow or other ice accretions from the aircraft. Various devices such as brooms, brushes, ropes squeegees, fire hoses, or other devices were used to remove dry snow accumulations but caution had to be exercised to preclude damage to aircraft skins and other critical components. Common sense prevailed. Many of these manual methods are still used today for both small and large aircraft. As larger aircraft were introduced and the numbers of air carrier fleets and scheduled flights increased, more expeditious and less costly procedures were developed. Thus, FPD fluids were introduced to prevent or retard the formation of frost during overnight storage, to assist in melting and removal of frost, snow, or other ice accretions such as would develop as a result of freezing rain or drizzle or for assisting in the removal of ice or frost formations accumulated during a previous flight.

Various methods of applying FPD fluids were utilised, such as mopping the fluid on the surface requiring treatment from a bucket, use of hand pumps attached to a supply tank and spreading the solution with a mop, brush or other suitable devices to, in time, melt the ice to the extent that is could be removed by using manual means.

These manual methods of de-icing provided a capability, in clear weather, to clean an aircraft adequately to allow a safe take-off and flight. In inclement cold weather conditions, however, the only alternative was to place the aircraft in a protected area such as a hangar to perform the cleaning process by whatever means were available. In freezing precipitation conditions, take-off had to initiated almost immediately following removal from the protected area. A common practice developed was to clean the aircraft in the hangar and provide a protective coating of anti-icing fluid to protect the aircraft from ice or snow accumulation prior to take-off.

Many of these techniques remain in use today, depending upon the local facilities and services that exist. However, most modern airports have traffic conditions and limitations of hangar space that, for the most part, preclude indoor ground de-icing. These airports usually have one or more operators who have the equipment, capability, and experience to clean the aircraft and provide brief protection to allow safe take-off to be performed. Many airlines have pre positioned ground de-icing equipment for ramp de-icing at major airports where icing conditions are prevalent in the United States, Canada and European countries. Several manufacturers of various types of aircraft ground de-icing equipment exist today to meet the ground support equipment demands of the aviation community.

These ground support equipments vary in types from simple trailers hauling a 55 gallon drum of FPD fluid with a wobble pump and mop, to exotic equipment capable of heating and dispensing large quantities of water and de-icing fluid and capable of elevating de-icing personnel to heights necessary to have access to any area of the largest of today's aircraft. This technology exists and it is believed that any demand for aircraft ground de-icing can be readily met by the ground support equipment industry.

Although modern and sophisticated ground support equipment exists, cost considerations sometimes dictate combination of ice removal methods. For example, heavy accumulations of snow may be more cost effectively removed using brooms, brushes, ropes, fire hoses, and other techniques followed by final cleaning with aqueous solutions of FPD fluid. Again, common sense, experience and planning prevail to make the aircraft ground de-icing process a cost effect and safe operation. With the rising cost of petroleum products, the primary base of most commonly used aircraft de-icing fluids, the expense of FPD fluid de-icing has become a very significant parameter in the final decision process. An answer to this problem has been developed in recent years employing use of very hot water (see paragraph 4.2 (c) of para 1). Some manufacturers of such equipment have conducted extensive testing and evaluation to develop and perfect the procedures, precautions and recommended aqueous FPD fluid mixtures necessary for cost-effective, but safe, de-icing. However, an understanding of the equipment, the characteristics, and limitations regarding use of FPD fluids is essential to ensure safe winter operations.

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NATS Limited
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RECOMMENDATIONS FOR DE-ICING/ANTI-ICING OF AIRCRAFT ON THE GROUND

1 Introduction

1.1 This Circular is issued to advise operators of the minimum requirements for ground based aircraft de-icing/anti-icing methods with fluids and procedures to facilitate the safe operation of transport aircraft during icing conditions. This Circular does not specify requirements for particular aircraft types. The recommended holdover times with respect to ground de-icing are regularly revised and can be found in the AEA (Association of European Airlines, www.aea.be) booklet entitled, 'Recommendations for De-icing/Anti-icing of Aircraft on the Ground'. This Circular incorporates revised definitions together with additional de-icing information.

1.2 This Circular has therefore been published to:

(a) Advise operators of sources of information on holdover times for Type I, Type II, Type III and Type IV fluids;

(b) provide additional and revised definitions, notes and precautions;

(c) advise operators of the JAA Administrative and Guidance leaflet on de-icing;

(d) advise operators of experience from incidents;

(e) introduce information concerning infra-red and forced air technology;

(f) provide information on off-gate de-icing.

2 Sources of Further Guidance Material

2.1 It should be noted that there are other sources of guidance material associated with de-icing, over and above the information published by aircraft manufacturers and manufacturers of de-icing fluids. Aircraft type design organisations (manufacturers) normally publish de-icing procedures in the relevant aircraft Maintenance Manuals. They may also publish service bulletins, service letters or letters to operators to inform operators and engineering organisations of additional information, such as lists of approved fluids, feedback from other operators, de-icing techniques, etc.

Other sources of guidance material include:

(a) ICAO Doc 9640-AN/940 'Manual of Aircraft Ground De-icing/Anti-icing Operations';

(b) The Association of European Airlines (AEA) publish ' Recommendations for De-icing/Anti-Icing of Aircraft on the Ground'. This document is published annually and is available on the Internet at www.aea.be;

(c) SAE International report number ARP 4737 'Aircraft De-Icing/Anti-Icing Methods with Fluids'. Available on the Internet at www.sae.org;

(d) CAA Winter Operations website: www.caa.co.uk/winteroperations;

(e) Ground Icing Training: http://aircrafticing.grc.nasa.gov/courses.html.

3 Information

3.1 Holdover protection is achieved by a layer of anti-icing fluid remaining on and protecting aircraft surfaces for a period of time. With a one-step de-icing/anti-icing procedure, the holdover time begins at the commencement of the application of de-icing/anti-icing fluid. With a two-step procedure, the holdover time begins at the commencement of the second (anti-icing) step. Should frozen deposits form/accumulate on an aircraft surface, the holdover time will have, in effect, run out.

3.2 The published holdover time is only a guideline because other variables can reduce or enhance the effectiveness of the fluid. These include high winds, jet blast, wet snow, heavy precipitation, aircraft skin temperature lower than outside air temperature and direct sunlight. The time of protection may be shortened and may reduce holdover times below the lowest time stated in the tables. Therefore, the indicated times should be used only in conjunction with a pre-take-off check.

3.3 Operators should include de-icing/anti-icing processes in their Quality Audit Programme to satisfy themselves that the service provided by contracted organisations is acceptable. The same applies for operators who have their own in-house de-ice/anti-ice services. The AEA booklet contains an example audit proforma, checklist and report.

6 Operational Considerations

6.1 The application of de-icing/anti-icing fluids must be in accordance with the aircraft manufacturer's practices and procedures.

6.2 The operator should comply with any operational requirements such as an aircraft mass decrease and/or an increased take-off speed when operating with a particular fluid applied to the aircraft. Thickened fluids are known to have caused loss of aerodynamic lift on, particularly, turbo-prop aircraft with rotation speeds of less than 100 kts. Turbo-jet aircraft have been similarly affected.

6.3 The operator should take into account any changes to flight handling procedures, stick force, rotation speed and rate, take-off speed, aircraft attitude etc, stipulated by the aircraft manufacturers associated with a particular fluid applied to the aircraft.

6.4 The limitations or handling procedures resulting from paragraphs 6.2 and 6.3 should be included in the flight crew pre-take-off briefing.

6.5 Operators of aircraft equipped with turbo-prop or low bypass engines should implement procedures to address the hazards associated with accumulation of snow/slush in engine intakes whilst parked. Procedures should address the need for fitment/removal of intake blanks and visual checks.

6.6 Operators should take account of the practicalities of pre-flight inspection of intakes. Operators should consider the need to carry steps for this purpose.

6.7 Repetitive application of thickened fluids (SAE AMS 1428/ISO 11078) may lead to a build-up of residues in aerodynamically quiet areas such as balance bays, and on wing and stabiliser trailing edges and rear spars. This residue may rehydrate, and increase in volume to many times its original size during flight and freeze under conditions of certain temperature, high humidity and/or rain causing moving parts such as elevators, ailerons, and flap actuating mechanisms to stiffen or jam in flight. It may also form on exterior surfaces which can reduce lift and increase drag and stall speed, block or impede critical flight control systems, and cause aerials to malfunction.

6.8 Residues may also collect in hidden areas, around flight control hinges, pulleys on cables and in gaps, and inside flight control surfaces affecting water drainage and control balance.

6.9 Additional inspections may therefore be required to ensure that no build-up of residues has occurred in critical areas not visible from the ground. The operator should request guidance/instructions from the aeroplane manufacturer in order to establish satisfactory procedures to prevent, detect and remove residues of dried fluid with the potential to cause any of the problems as described above. Appropriate inspection intervals should be established.

6.10 Operators should consider defining a policy on the use of two-step de-icing/anti-icing procedures preferably using hot water or unthickened fluids in the first step. Fluid selection should be based on dry-out and rehydration data supplied by manufacturers. Appropriate operational and maintenance/handling procedures should be established.

6.11 Information and training should be provided for in-house and contractors' staff. This should include appropriate flight safety information.

7 Subcontracting (see also JAR-OPS 1 AMC-OPS 1.035 Sections 4 and 5)

7.1 The operator should ensure that the ground handling agency or de-icing subcontractor is aware of the de-icing/anti-icing requirements for a particular aircraft type. Such subcontracting is normally determined in accordance with the IATA Airport Handling Manual, Standard Ground Handling Agreement AHM810 Annex A Section 7 Aircraft Servicing paragraph 6.

7.2 The contract should address the:

(a) Provision of the fluid to be used (it must include the proprietary or brand name which must be one specified by the aircraft manufacturer);

(b) specific aircraft type requirements which will include the application of fluids to an aircraft, details of no spray areas, techniques, aircraft configuration, inspections etc;

(c) concentration, viscosity and degradation checks of fluids prior to use;

(d) supervision of the completion and performance of the de-icing/anti-icing operation;

(e) performance of a final inspection of the aircraft after the de-icing/anti-icing operation and informing the flight crew of the result.

8 Communications

8.1 Before the aircraft is to be treated with the flight crew on board, the ground crew should confirm with the flight crew, the type of fluid to be used, the extent of treatment and any aircraft type-specific procedures to be used.

8.2 The operator's procedure should include an anti-icing code, which indicates the process which has been applied to the aircraft. The code provides flight crew with the minimum details necessary to assess holdover time and confirms that the aircraft is clear of ice.

9 The Technical Log

9.1 An entry must be made in the aircraft technical log to record the process, even in the case of an interrupted or failed application (see AMC-OPS 1.915 paragraph 2, section 3 vi). JAR-OPS requires the time the de-icing commences, in the case of a one step process or the time at which the anti-icing process is commenced in a two step process, to be recorded in the aircraft technical log.

De-Icing/Anti-Icing Combination of the two procedures described above. It may be performed in either one or two steps.

Holdover Time Estimated time for which an anti-icing fluid will prevent the formation of frost or ice and the accumulation of snow on the protected surfaces of an aircraft, under specified weather conditions.

Check An examination of an aircraft against the relevant standard by a trained and qualified person.

Freezing Conditions Conditions in which the outside air temperature is below +3°C (37.4°F) and visible moisture in any form (such as fog with visibility below 1.5 km, rain, snow, sleet or ice crystals) or standing water, slush, ice or snow is present on the runway.

Frost/Hoar Frost Ice crystals that form from ice saturated air temperatures below 0°C (32°F) by direct sublimation on the ground or other exposed objects.

Active Frost Active frost is a condition when frost is forming. Active frost occurs when aircraft surface temperature is at or below 0°C (32°F), and at or below the dew point.

Freezing Fog A suspension of numerous minute water droplets that freeze upon impact with ground or other exposed objects, generally reducing the horizontal visibility at the earth's surface to less than 1 km (5/8 mile).

Snow Precipitation of ice crystals, most of which are branched, star-shaped or mixed with unbranched crystals. At temperatures higher than -5°C (23°F), the crystals are generally agglomerated into snowflakes.

Freezing Drizzle Fairly uniform precipitation composed exclusively of fine drops (diameter less than 0.5 mm (0.02 ins)) very close together which freezes upon impact with the ground or other exposed objects.

Light Freezing Rain Precipitation of liquid water particles which freeze upon impact with the ground or other exposed objects, either in the form of drops of more than 0.5 mm (0.02 ins) or smaller drops which in contrast to drizzle, are widely separated. Measured intensity of liquid water particles is up to 2.5 mm per hour (0.10 ins per hour) or 25 gms/dm2/hour with a maximum of 0.25 mm (0.01 ins) in 6 minutes.

Moderate and Heavy Freezing Rain Precipitation of liquid water particles which freeze upon impact with the ground or other exposed objects, either in the form of drops of more than 0.5 mm (0.02 ins) or smaller drops which in contrast to drizzle, are widely separated. Measured intensity of liquid water particles is up to 2.5 mm per hour (0.10 ins per hour) or 25 gms/dm2/hour.

Cold-Soak Effect The wings of an aircraft are said to be 'cold-soaked' when they contain very cold fuel as a result of having just landed after a flight at high altitude or from having been refuelled with very cold fuel. Whenever precipitation falls on a cold-soaked aircraft on the ground clear ice may form. The following factors contribute to cold-soaking: temperature and quantity of fuel in fuel cells, type and location of fuel cells, length of time at high altitude, temperature of refuelled fuel and time since refuelling.

Rain or High Humidity Water forming ice or frost on the wing surface, when the temperature of the aircraft (on cold-soaked wing) wing surface is at or below 0°C (32°F).

Rain and Snow (Sleet) Precipitation in the form of a mixture of rain and snow. For operation in light rain and snow (sleet) treat as light freezing rain.

Slush Snow or ice that has been reduced to a soft watery mixture by rain, warm temperatures and/or chemical treatment.

Ice Crystals/Diamond Dust A fall of unbranched ice crystals (snow crystals are branched) in the form of needles, columns or plates.

Ice Pellets Precipitation of transparent (grains of ice), or translucent (small hail) pellets of ice, which are spherical or irregular, and which have a diameter of 5 mm (0.2 ins) or less. The pellets of ice usually bounce when hitting hard ground.

Snow Pellets Precipitation of white and opaque grains of ice. These grains are spherical or sometimes conical; their diameter is about 2-5 mm (0.1-0.2 ins). Grains are brittle, easily crushed; they bounce and break on hard ground.

Snow Grains Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is less than 1 mm (0.04 ins). When the grains hit hard ground they do not bounce or shatter. Treat as snow for holdover time purposes.

Hail Precipitation of small balls or pieces of ice with a diameter ranging from 5 to > 50 mm (0.2-2 ins) falling either separately or agglomerated.

6 Operational Considerations

6.1 The application of de-icing/anti-icing fluids must be in accordance with the aircraft manufacturer's practices and procedures.

6.2 The operator should comply with any operational requirements such as an aircraft mass decrease and/or an increased take-off speed when operating with a particular fluid applied to the aircraft. Thickened fluids are known to have caused loss of aerodynamic lift on, particularly, turbo-prop aircraft with rotation speeds of less than 100 kts. Turbo-jet aircraft have been similarly affected.

6.3 The operator should take into account any changes to flight handling procedures, stick force, rotation speed and rate, take-off speed, aircraft attitude etc, stipulated by the aircraft manufacturers associated with a particular fluid applied to the aircraft.

6.4 The limitations or handling procedures resulting from paragraphs 6.2 and 6.3 should be included in the flight crew pre-take-off briefing.

6.5 Operators of aircraft equipped with turbo-prop or low bypass engines should implement procedures to address the hazards associated with accumulation of snow/slush in engine intakes whilst parked. Procedures should address the need for fitment/removal of intake blanks and visual checks.

6.6 Operators should take account of the practicalities of pre-flight inspection of intakes. Operators should consider the need to carry steps for this purpose.

6.7 Repetitive application of thickened fluids (SAE AMS 1428/ISO 11078) may lead to a build-up of residues in aerodynamically quiet areas such as balance bays, and on wing and stabiliser trailing edges and rear spars. This residue may rehydrate, and increase in volume to many times its original size during flight and freeze under conditions of certain temperature, high humidity and/or rain causing moving parts such as elevators, ailerons, and flap actuating mechanisms to stiffen or jam in flight. It may also form on exterior surfaces which can reduce lift and increase drag and stall speed, block or impede critical flight control systems, and cause aerials to malfunction.

6.8 Residues may also collect in hidden areas, around flight control hinges, pulleys on cables and in gaps, and inside flight control surfaces affecting water drainage and control balance.

6.9 Additional inspections may therefore be required to ensure that no build-up of residues has occurred in critical areas not visible from the ground. The operator should request guidance/instructions from the aeroplane manufacturer in order to establish satisfactory procedures to prevent, detect and remove residues of dried fluid with the potential to cause any of the problems as described above. Appropriate inspection intervals should be established.

6.10 Operators should consider defining a policy on the use of two-step de-icing/anti-icing procedures preferably using hot water or unthickened fluids in the first step. Fluid selection should be based on dry-out and rehydration data supplied by manufacturers. Appropriate operational and maintenance/handling procedures should be established.

6.11 Information and training should be provided for in-house and contractors' staff. This should include appropriate flight safety information.

7 Subcontracting (see also JAR-OPS 1 AMC-OPS 1.035 Sections 4 and 5)

7.1 The operator should ensure that the ground handling agency or de-icing subcontractor is aware of the de-icing/anti-icing requirements for a particular aircraft type. Such subcontracting is normally determined in accordance with the IATA Airport Handling Manual, Standard Ground Handling Agreement AHM810 Annex A Section 7 Aircraft Servicing paragraph 6.

7.2 The contract should address the:

(a) Provision of the fluid to be used (it must include the proprietary or brand name which must be one specified by the aircraft manufacturer);

(b) specific aircraft type requirements which will include the application of fluids to an aircraft, details of no spray areas, techniques, aircraft configuration, inspections etc;

(c) concentration, viscosity and degradation checks of fluids prior to use;

(d) supervision of the completion and performance of the de-icing/anti-icing operation;

(e) performance of a final inspection of the aircraft after the de-icing/anti-icing operation and informing the flight crew of the result.

8 Communications

8.1 Before the aircraft is to be treated with the flight crew on board, the ground crew should confirm with the flight crew, the type of fluid to be used, the extent of treatment and any aircraft type-specific procedures to be used.

8.2 The operator's procedure should include an anti-icing code, which indicates the process which has been applied to the aircraft. The code provides flight crew with the minimum details necessary to assess holdover time and confirms that the aircraft is clear of ice.

9 The Technical Log

9.1 An entry must be made in the aircraft technical log to record the process, even in the case of an interrupted or failed application (see AMC-OPS 1.915 paragraph 2, section 3 vi). JAR-OPS requires the time the de-icing commences, in the case of a one step process or the time at which the anti-icing process is commenced in a two step process, to be recorded in the aircraft technical log.

10 Pre-Take-Off Check

10.1 The commander should continually monitor the environmental situation after the performed de-icing/anti-icing treatment. Prior to take-off the commander should assess whether the applied holdover time is still appropriate and inspect the aircraft, to the extent possible, to ensure critical surfaces are clear of frozen contamination, especially any surfaces that have been de-iced/anti-iced. This check is normally done from inside the aircraft.

11 Pre-Take-off Contamination Check

11.1 This check is normally conducted from outside the aircraft by visual and tactile inspection of the critical surfaces. This check shall be performed when the condition of the critical surfaces cannot be effectively assessed by a pre-take-off check. This may be due to the aircraft configuration, the prevailing visibility and lighting and the reliability of the viewable area as an indicator of the condition of non-viewable areas particularly when the holdover time has been exceeded.

11.2 The alternate means of compliance to a pre-take-off contamination check is a complete de-icing/anti-icing re-treatment of the aircraft.

12 Procedures

12.1 The operator should provide procedures for ground handling agencies, engineering personnel and flight crew, detailing processes, duties, and responsibilities for ground de-icing/anti-icing and associated ground handling tasks, such as intake blanking. De-icing/anti-icing techniques for intakes and undercarriage should be detailed. Those tasks contracted to ground handling agencies should be subject to regular quality reviews.

12.2 In the case of off-gate de-icing/anti-icing, the key elements to be considered are communication, inspection and records. The following should be considered for inclusion in procedures as applicable:

(a) The responsibility for determining the need for de-icing/anti-icing on the gate, and the means of communication to the commander;

(b) establishment of two-way communication with de-icing/anti-icing ground staff;

(c) key staff responsibilities, including post-treatment inspection;

(d) the procedure for ensuring deactivation of aircraft systems;

(e) the format and passing of de-icing/anti-icing codes;

(f) ground and flight deck record requirements.

13 Training Requirements

13.1 The operator should establish and provide appropriate initial and recurrent de-icing/anti-icing training for both flight and ground crew personnel. When de-icing/anti-icing is contracted out to ground handling agencies, the operator should ensure that their staff have also been suitably trained. In addition, training should address other procedures associated with winter operations, such as intake blanking and inspection methods.

14 Quality

14.1 The operator's Quality System should ensure that de-icing/anti-icing, and winter ground handling activities are carried out in accordance with the operator's procedures at all stations where de-icing/anti-icing is carried out.

15 Application Limits

15.1 Under no circumstances may an aircraft that has been anti-iced receive a further coating of anti-icing fluid directly on top of the contaminated film. If an additional treatment is required before flight, a complete de-icing/anti-icing process must be performed to ensure that any residues from the previous treatment have been removed. In these circumstances anti-icing only is not permitted.

16 De-Icing/Anti-Icing Holdover Times

16.1 Refer to AEA document 'Recommendations for De-Icing/Anti-Icing of Aircraft on the Ground' which provides generic holdover time information (Latest edition available on the AEA Web site: www.aea.be). Fluid manufacturers provide brand specific holdover time information. It is the operator's responsibility to ensure fluid holdover times have been measured/derived per the appropriate SAE or ISO specification as referred to in paragraph 4 of this Circular.

17 Experience from Incidents

17.1 The CAA Safety Data Department has records of a number of MORs associated with difficulties following aircraft ground de-icing. A review of those records highlights a number of trends of which operators should be aware.

Examples include:

- De-icing crews being called back to the aircraft following flight crew and engineering inspection.
- Problems following de-ice fluids being sprayed into no-spray areas.
- Cabin crews advising flight crew of ice on upper surfaces of the wings.
- Differences between operator and contracted de-icing ground crews on the definition of a clean wing.
- Inadequate de-icing procedures and communication between de-icing crews and flight deck.
- Failures of de-icing equipment.
- Turbo-prop engine flameout during taxi and take-off due to snow accumulation in intakes.
- Inadequate ground support equipment available for pre-flight inspection of intakes.
- Problems associated with fluid residue rehydration.
- Incorrect or no fluid used in the de-icing rig.

17.1.1 It is therefore recommended that consideration is given to the foregoing when operations and maintenance procedures are reviewed.

18 Infra-red and Forced Air De-icing Methods

18.1 These de-icing methods involve the removal of snow and ice using thermal methods, and require the subsequent application of anti-icing fluid. A disadvantage of this method is the loss of the first step removal of thickened (sleet) fluid residues (see paragraph 6). This Circular does not contain detailed requirements for these two techniques, therefore further information may be obtained from the sources detailed below.

18.2 Operators intending to utilise infra-red or forced air de-icing methods must comply with the aeroplane manufacturer's recommendations, and must establish appropriate procedures for use by flight crew and ground personnel. The operator's assigned Flight Operations Inspector should be informed of the intent to utilise these methods.

18.3 For infra-red de-icing, refer to SAE ARP 4737 section 6.2 for minimum requirements and cautions.

This Circular is issued for information, guidance and necessary action.

QUESTIONS - PAPER 1

1. The electrical supply to the propeller blades for de-icing purposes:

   a. is controlled to give an intermittent supply.
   b. must be taken directly from the APU generator.
   c. must only be selected on for short periods.
   d. is continuous to all blades.

2. Propeller blade heating elements are:

   a. fitted only to the thin outer sections where maximum ice accretion occurs.
   b. fitted only to the thick inner section where minimum ice accretion occurs.
   c. usually fitted to the thick section but sometimes a second element is fitted to a mid section.
   d. fitted to the complete leading edge.

3. When an aircraft is de-iced prior to departure, if the temperature is 0 C in precipitation, which type of fluid and application method will provide the longest holdover period:

   a. Type I fluid at 100% cold spray application.
   b. Type II fluid diluted to 50% hot spray application.
   c. Type I fluid diluted to 50% hot spray application.
   d. Type II fluid at 100% cold spray application.

4. The effect of frost on an aircraft:

   a. is to cause an increase in boundary layer energy and so delay the onset of the stall.
   b. can be generally ignored.
   c. has no significant effect on the aerodynamic contour or CL max.
   d. is to cause an increase in the surface roughness which in turn increases skin friction and reduces the kinetic energy of the boundary layer.

5. In flight airframe icing does not occur:

   a. above 25,000 ft.
   b. above 40,000 ft.
   c. above 35,000 ft.
   d. above 30,000 ft.

6. The methods used to provide de-icing in flight can be:

   a. mechanical or pneumatic or fluid.
   b. pneumatic or thermal or fluid.
   c. electrically heated or air heated or oil heated.
   d. centrifugally forced or ram air heated.

7. Ice detectors are used primarily to warn the crew:

   a. that they are approaching airframe icing conditions.
   b. that they are approaching engine icing conditions.
   c. that engine icing conditions now warrant the initiation of the engine system.
   d. that airframe icing conditions exist.

8. Fluid is delivered to a propeller by:

   a. a centrifugal slipper ring and pipes.
   b. integral passages within the propeller dome.
   c. a small reservoir contained within the spinner.
   d. a slinger ring and pipes.

9. If an aircraft is to be de-iced prior to departure:

   a. the aircraft can be de-iced with the engines running.
   b. the aircraft can be de-iced with the APU running.
   c. the aircraft can be de-iced with the APU running and the bleed air off.
   d. neither the APU or main engines can be running during the procedure.

10. With a gas turbine engine, should engine anti-icing be selected "ON":

   a. whenever the igniters are on.
   b. whenever the IOAT is +10 C or below and the air contains visible moisture.
   c. whenever the TOAT is +10 C or below and it is raining.
   d. whenever the ice detector system warning light comes on.

QUESTIONS - PAPER 2

1. In a pneumatic de-icing system:

   a. the boots remain inflated while the system operates.
   b. the boots are inflated and deflated repeatedly.
   c. vacuum inflates the boots and pressure deflates them repeatedly.
   d. when the boots are fully inflated the pressure is released and they collapse due to their elasticity.

2. When the pneumatic de-icer system is switched off:

   a. the relief valves admit ram air to the boots.
   b. a small flow of hot air continuously flows through the boots.
   c. the dynamic pressure on the leading edge ensures that the boots lie flat.
   d. vacuum deflates the boots to minimise drag.

3. Propeller electrical de-icing systems:

   a. use only continuous loads to the elements.
   b. use a cyclic timer.
   c. convert electrical energy to mechanical energy.
   d. transfer power to the elements via a commutator in DC systems.

4. To prevent propeller elements overheating:

   a. use only when all other services are switched off.
   b. carry out a load check before starting engines.
   c. use only when the propellers are rotating.
   d. use only when in flight.

5. A thermal wing de-icing system:

   a. feeds hot air along the complete upper wing surface.
   b. feeds the engine exhaust through the leading edge ducts only.
   c. can use air taken from the engine compressor.
   d. relies on heat generated by the kinetic heating effect of the airflow.

6. Pilots cockpit windows are heated:

   a. only to prevent condensation occurring.
   b. by agitating the window molecules with an AC current.
   c. with a reflective inner coating that prevents fogging.
   d. by passing current across an inner conductive electrical coating.

7. For maximum strength against impact damage pilots windows are:

   a. normally kept to a minimum size.
   b. specially treated during construction.
   c. heated internally to increase their elasticity.
   d. only heated when the IOAT falls below 0 C in precipitation.

8. Pilots cockpit windows are:

   a. only heated by air from the de-misting fan.
   b. constructed by heat treating the outer surface to reduce glare.
   c. made of sandwich construction with an electrical conductive coating.
   d. made of polarised glass.

9. If an aircraft is to be de-iced prior to departure:

   a. the aircraft can be de-iced with engines running.
   b. the aircraft can be de-iced with the APU running.
   c. the aircraft can be de-iced with APU running and bleed air selected off.
   d. neither APU or engines can be running.

10. An aircraft is to be de-iced and then enter the line up for departure. Which de-ice fluid will have the best holdover time at 0 C with precipitation:

   a. type I fluid at 100% cold spray.
   b. a 50%/50% solution of type II fluid hot spray.
   c. a 50%/50% solution of type I fluid hot spray.
   d. type II fluid at 100% cold spray.

ANSWERS - PAPER 1

1. A
2. C
3. D
4. D
5. B
6. B
7. D
8. D
9. C
10. B

ANSWERS - PAPER 2

1. B
2. D
3. B
4. C
5. C
6. D
7. C
8. C
9. C
10. D

CHAPTER FOURTEEN

EMERGENCY EQUIPMENT

Contents

INTRODUCTION

The provision, fitting, marking and use of safety equipment is governed by many requirements and regulations listed in JAR's. These notes have the general aim of giving an overall view of the positioning and use of this variety of emergency/safety equipment. The notes and diagrams in this publication may be type specific of various aircraft. However, reference should always be made to the specific Flight/Operations Manual.

The Emergency/Safety equipment described in this section is laid out in the order it may be used during an envisaged ditching/crash landing situation.

All equipment must be readily accessible for emergency use. The location of the equipment must be obvious, directly accessible and protected from inadvertent damage.

PUBLIC ADDRESS

When required at least one microphone to be available for use by the Flight Attendant (Cabin Staff) at each floor level exit in the passenger compartment. It is ususal for all Flight Crew members to be able to use the public address either through a hand microphone or their normal headset communications.

EMERGENCY LIGHTING

All Aircraft with a passenger seating capacity of more than 9 must have an emergency lighting system with a power supply independent of the main lighting system.

The design of the system must be such that it is:

Operable form the Flight Station or passenger compartment.

- Capable of providing the Flight Crew with a warning if not armed.
- The Flight crew compartment must have a three-position switch marked ON-OFF-ARMED and a means must be provided to prevent inadvertent operation (guarded). The Cabin Staff will also have a means of control but this switch will have positions of NORMAL and ON only.
- Capable of providing illumination to the areas on the wing and ground where an evacuee is likely to make his first step or contact.
- The capacity of the emergency batteries which are of the NiCad type with a charging, monitoring and voltage regulator circuit must be such that they are capable of providing emergency lighting for a minimum period of at least 10 minutes but usually last for approximately 30 minutes

For Aircraft with an approved seating capacity of more than 9, but less than 20 seats, the following requirements apply:

- General illumination must be provided along the centre-line of the main passage aisles to the emergency exits.
- Internal lighting in the emergency exit areas (**Post JAR-23 or 25).**

- Exit location signs must have red letters on a white electrically illuminated or self illuminated background. **(Post JAR-23 or 25).**

For aircraft with an approved passenger seating capacity of more that 19, the following additional requirements apply:

- General illumination must be provided along the centre-line of the main passage aisles to the emergency exits.
- Internal lighting in floor level emergency exit areas.
- Exit location signs must have red letters on a white electrically illuminated or self illuminated background.
- Floor proximity emergency escape-path illumination must be provided when other means of illumination are more than 4 feet above the cabin aisle floor to enable passengers to leave their seats, visually identify escape routes and exits. The floor lights are normally in the form of green arrows or white light which turn red near the exit areas.

Operation: The system is normally controlled by a switch in the Flight Deck. The Flight Deck switch has three positions, **OFF, ARMED** and **ON** and is guarded to the **ARMED** position. The Passenger cabin switch has two positions **NORMAL** and **ON**, and is usually in the **NORMAL** position. With the Flight Deck switch in the **ARMED** position and the Cabin switch in the **NORMAL** position, the emergency lights will normally be extinguished. If electrical power to **28 volt DC** bus No.1 fails or if **AC** power has been turned off, the emergency lights will **illuminate automatically**.

Alternatively the emergency lighting system may be switched on from the Cabin Supervisors control panel by selecting from NORMAL to ON. This operation of the Cabin Switch will **override the Flight deck switch in any event**. The selection of emergency lights from the passenger cabin will illuminate the 'Unarmed' caption in the Flight Deck switch and thereby inform the Flight crew that the emergency lights have been initiated from the passenger cabin.

Passenger carrying Aircraft with less than 10 seats and flying by night.
Passenger carrying Aircraft with less than 10 passenger seats which are used for night flying have to have provision for general Cabin illumination for evacuation purposes which is self-sustaining after the Aircraft battery has been switched off. The type of illumination used is normally by means of **'Dome-Lights'**.

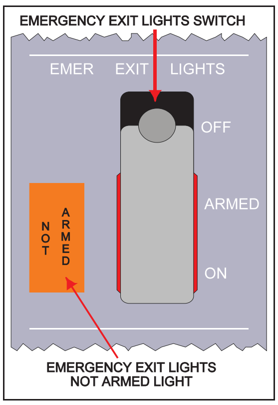


Figure 14.1: Flight deck emergency lights switch

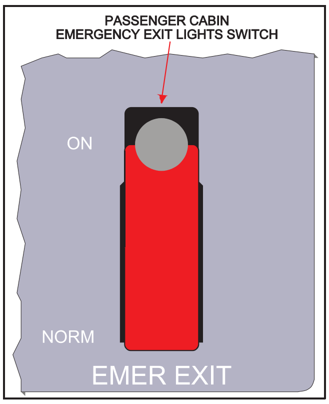


Figure 14.2: Cabin crew emergency lights switch

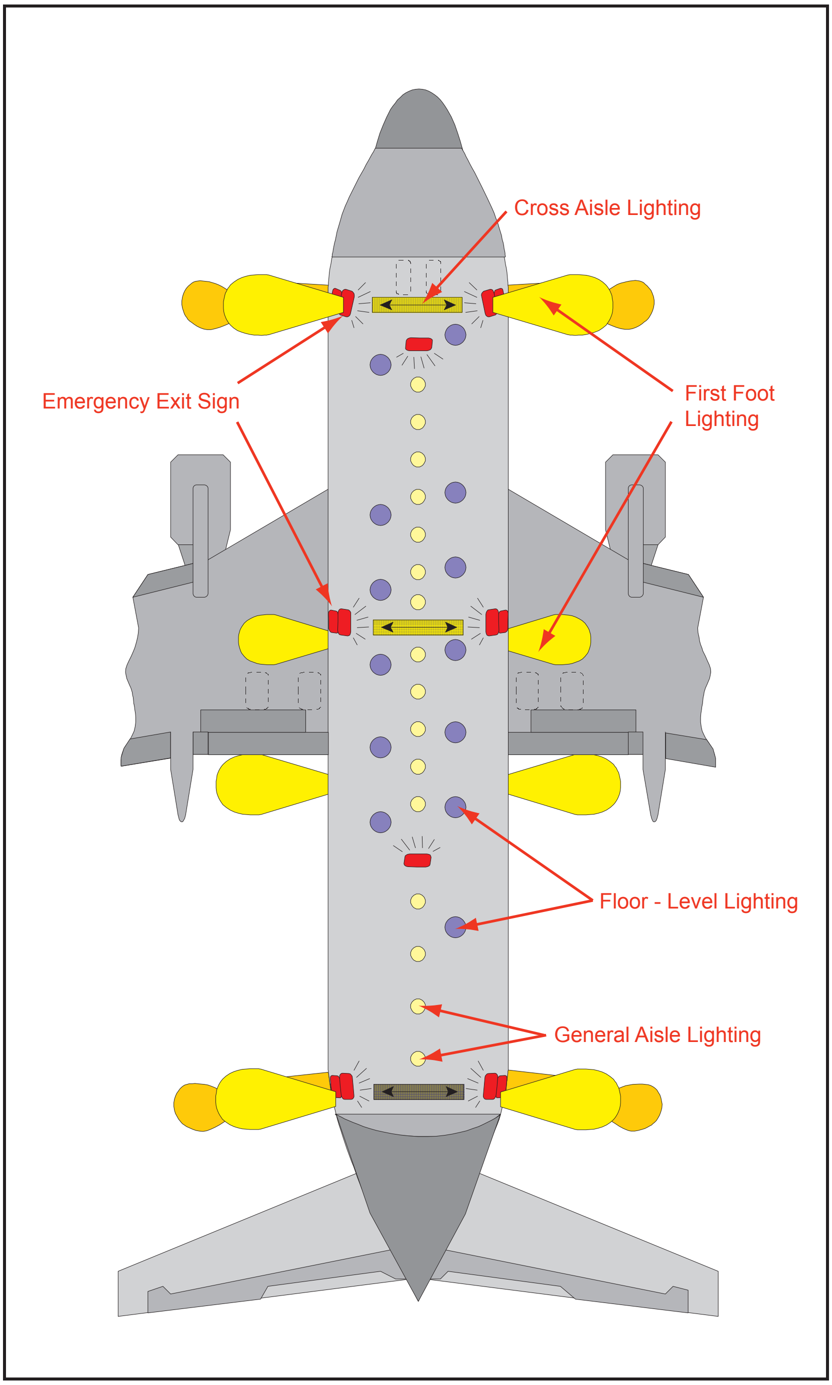


Figure 14.3: Emergency lights installation.

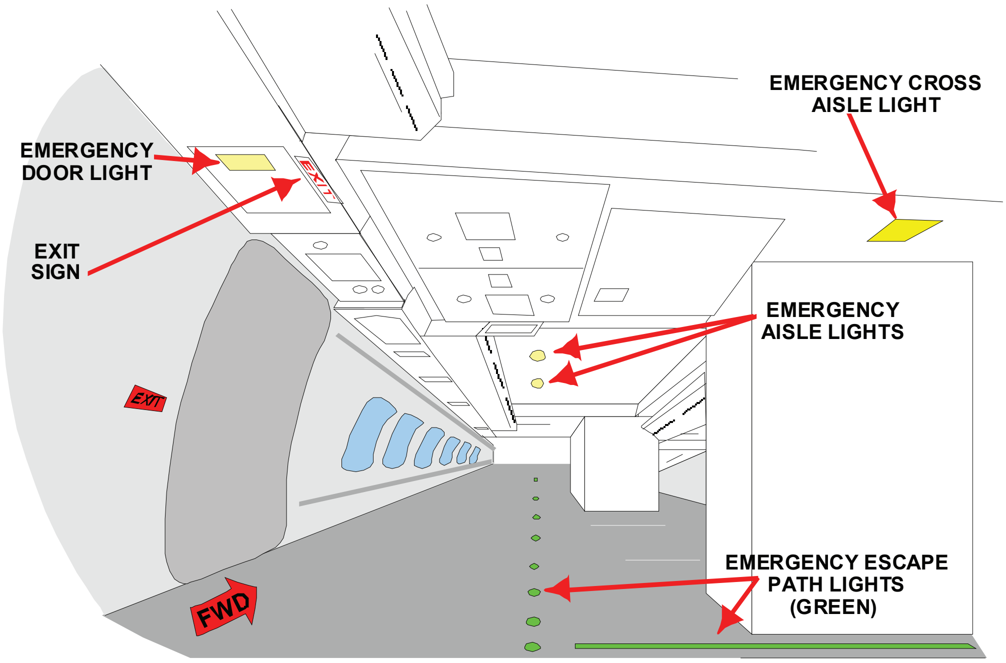


Figure 14.4: Emergency lights in cabin.

Interior emergency exit lights are located:

- In the bullnose of the stowage bins to illuminate the aisle.
- Over the entry/service and overwing emergency hatches to indicate the door and hatch exits.
- In the ceiling to locate the exits and provide general illumination in the area of the exits. Self-illuminating exit locator signs are installed at the forward, the middle and the aft end of the passenger cabin.

Floor proximity emergency escape path lighting consists of locator lights spaced at approximately
40 inch intervals down the aisles. Lighted arrows point to overwing exits and a lighted “EXIT” indicator is near the floor by each door and overwing exit. Escape path markings are provided for visual guidance for emergency cabin evacuation when all sources of cabin lighting more than four feet above the aisle floor ate totally obscured by smoke.

Exterior emergency lights illuminate the escape slides. The fuselage installed escape slide lights are adjacent to the forward and aft service entry doors. Two lights are also installed on the fuselage to illuminate the overwing escape routes and ground contact area.

NOTE: Whenever these switches are ON the Emergency Exit Lights are being powered by their own individual Nicad batteries and last approximately 20 minutes, in this particular installation.

MEGAPHONES

These are located at strategic points in the cabin e.g. front and rear, upper and lower decks and are for use by the cabin staff. Their purpose is for passenger information in the event of normal aircraft power failure i.e. nil Public Address system available. They are battery powered and must be checked prior to flight. This is carried out by pressing the transmit switch and listening for an audible "click" or the illumination of a green neon light on the megaphone body.

Megaphones are fitted as per scale below for each passenger deck:

Passenger seats available	Number of megaphones
61 - 99	1
100 or more	2

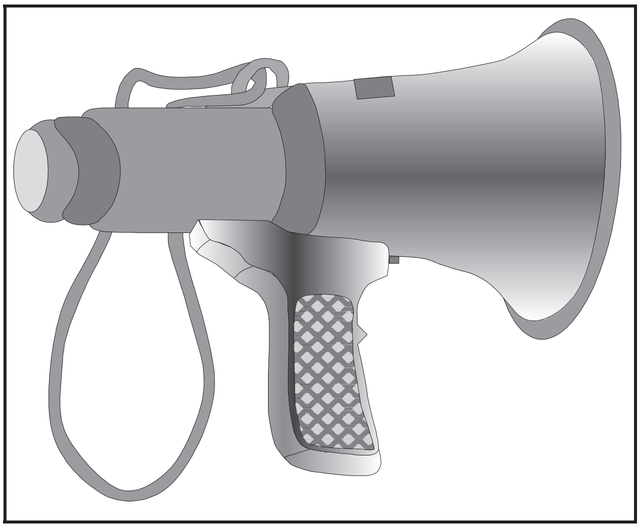


Figure 14.5: Megaphone.

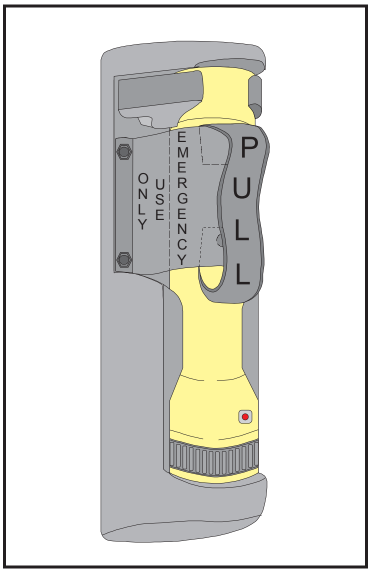


Figure 14.6: Emergency torch.

TORCHES

It is a legal requirement that torches are carried on public transport aircraft. These are positioned at each crew station including the flight deck and adjacent to each floor level exit which is intended for normal or emergency disembarkation.

Torches are affixed by each intended exit by a velcro strap and are not able to be re-charged from the aircraft electrical supply. Indication of serviceability is by a flashing red neon light situated on the body of the torch.

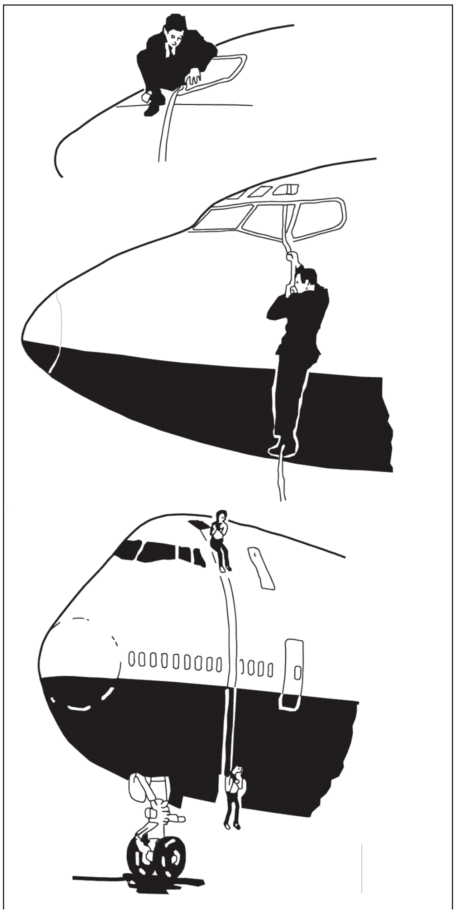
EMERGENCY EXIT DESCENT DEVICES

Varying equipment must be provided with the evacuation process. These could include any of the following:- A simple rope, a slide, an inertial reel or a tape. It is possible to find fully inflatable escape slides which are rigid and double as slide rafts, apron slides which need human effort to keep them taut, this would be provided by the first two escapees, who would probably descended down a rope or by using the slide as a rope.

CREW ESCAPE METHODS

An inflatable slide may double for use as a life raft. Such slides are usually stored inside the door and as such have to be engaged (set to ENGAGE) for emergency deployment/door operation, or selected to disengaged (DETACH) for normal door operation. Instructions for setting the door controls are often issued by the flight crew over the Public Address System. Flotation equipment requirements are promulgated in the JAR OPS 1. Briefly if the aircraft will be operating more than 120 minutes flight time or 400 miles from land then rafts and jackets are required to be carried. (See JAR sub-part K 1.830) If the aircraft takes off or lands over water then life jackets would need to be carried on that account.

Crew escape methods still include simple rope systems and extend to Inertial reel systems on some larger aircraft when the crew member has to hang onto a handle and slide over the side when they will be lowered at a controlled rate to the ground providing of course that they are capable of hanging onto the handle!



Courtesy of the Boeing Company

Figure 14.7

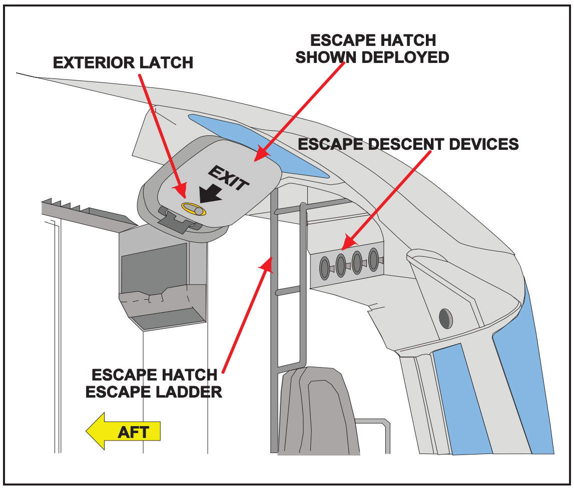


Figure 14.8: Crew wide bodied escape device.

CUT IN AREAS

In the event that the nominated emergency exits are blocked or are unable to be opened, a supplementary escape route, which can be broken from outside the aircraft, must be available. These will take the form of Cut In Areas and are mandatory on public transport aircraft over 3,600 kgs a.u.w. They are rectangular in shape, marked by right angled corners and red or yellow in colour and outlined in white if a contrast is required. Cut In Areas are not weak points on the fuselage structure, but areas under which no control runs, electrical looms or multi stringers exist.

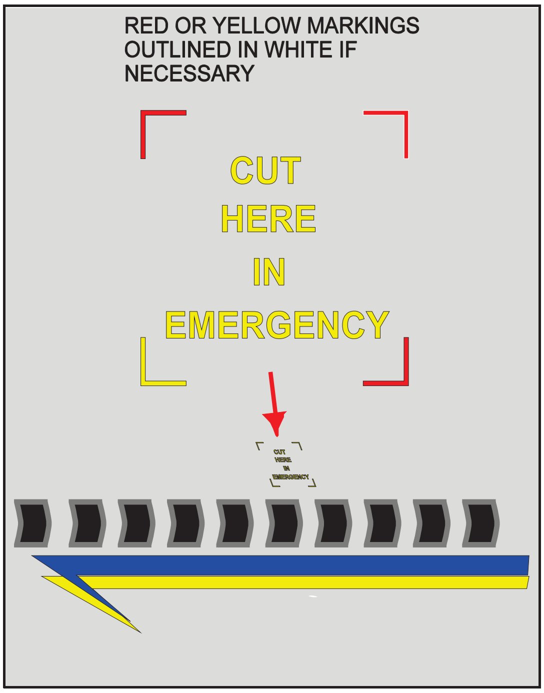


Figure 14.9: Cut-in-area.

OVERWING ESCAPE HATCHES

Escape straps are installed above each emergency escape hatch frame. The overwing escape hatches must be removed to expose the straps. One end of the strap is attached to the hatch frame. The remainder of the strap is stowed in a tube extending into the cabin ceiling.

The escape strap can be used as a hand hold in a ditching emergency for passengers to walk out on to the wing and step into a life raft.

Escape hatches are located in the passenger cabin over the wings. These are plug-type hatches and are held in place by mechanical locks and aeroplane cabin pressure. The hatches can be opened from the inside or from the outside of an aeroplane by a spring-loaded handle at the top of the hatch. A seat-back blocking an exit may be pushed forward by applying force to the top of the seat-back. For safety reasons, hatches should not be removed in flight.

On some aircraft, hatch removal illuminates the overwing emergency exit lights on the same side, provided the cockpit emergency Exit Light Switch is in the ARMED position.

Warning Do not remove hatches in flight preparation for passenger evacuation. For emergency evacuation on the ground or in water, remove hatch and place so as not to obstruct egress. The hatch may be thrown out onto the wing, placed on the seat armrests, or placed in any other suitable location as indicated by the conditions at the time of aeroplane evacuation.

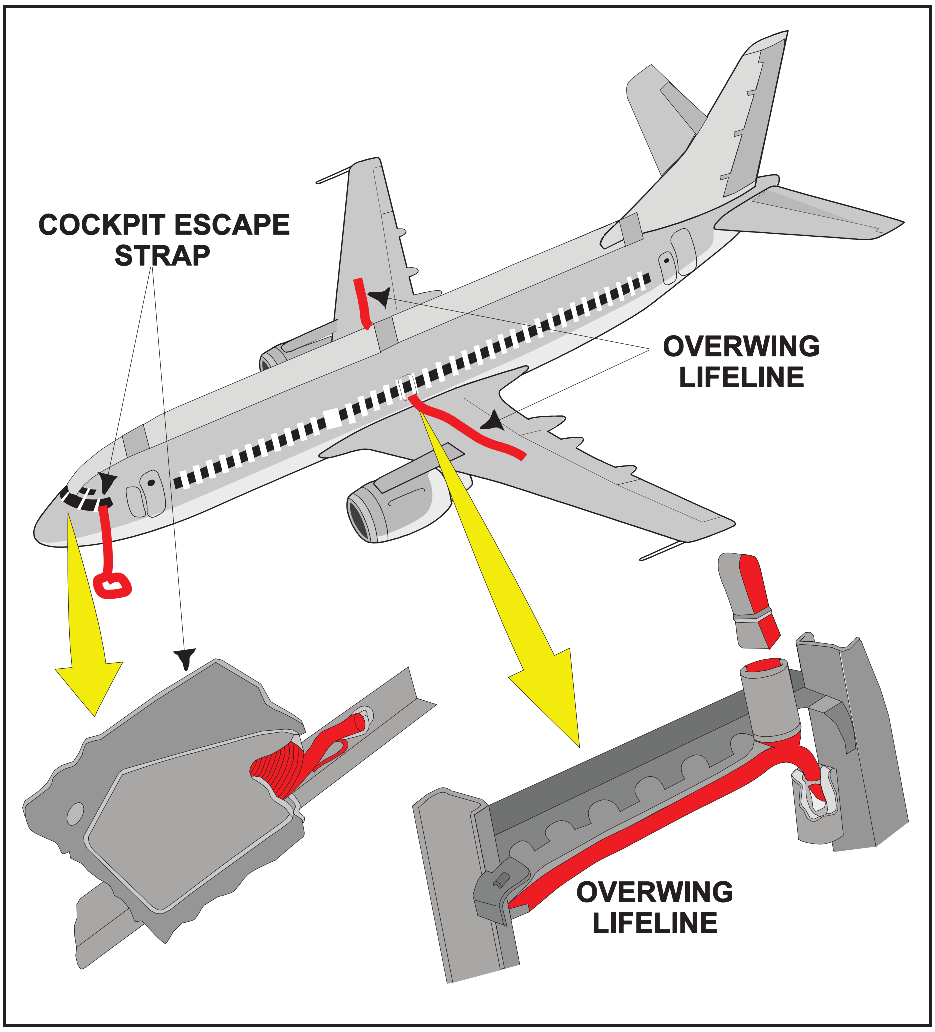


Figure 14.10: Overwing escape hatch.

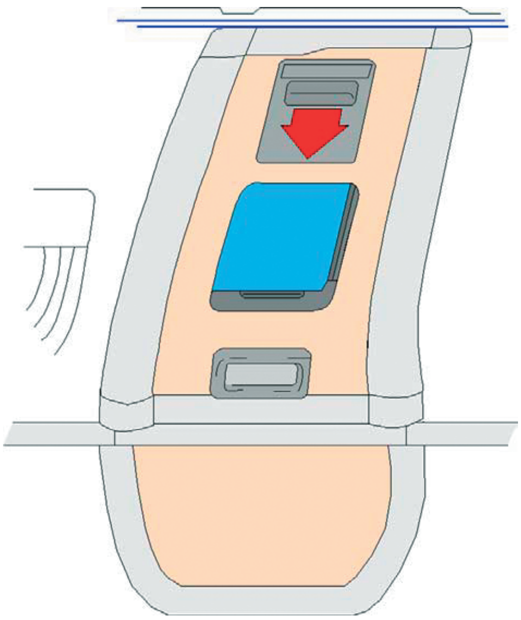


Figure 14.11: Overwing lifeline

DOORS / EMERGENCY EXITS

Aircraft doors, depending on the size of the aircraft, may be electrically or manually operated. In the case of the former there must be a manual override system in the event of electrical failure e.g. crash/ditching. Apart from the obvious purpose of entry to an aircraft, doors may act as emergency exits. However, if this is the case they must be outlined externally by a 5cm band in a contrasting colour. This requirement applies to any opening designated as an emergency exit. There are many requirements laid down in respect of doors the main ones are listed below:

- If a lockable door is fitted to the flight crew compartment, then suitable emergency exits must be provided so that neither passengers or crew members need to use the door in order to reach their designated emergency exits.

- There must be a means to lock and safeguard each door against opening in flight. Each door must be operable from both inside and outside.

- The means of operation must be simple and obvious and so arranged that it can be located and operated in darkness.

- All doors must be fitted with warning lights in order to alert the crew when it is not fully closed and locked.

- Interlocks may be fitted between the door locks and the aircraft's pressurisation system.

- If the aircraft capacity is over 20 seats then there must be one exit and one top hatch in the flight crew area.

- Emergency exits located at points other than above the wing more then 1.83 mtrs above the ground with the aircraft standing on its landing gear must have an approved means to assist the occupants in descending to the ground (i.e. a self supporting slide).

- All exits must be clearly marked with details of method of access and operation and also be recognisable from a distance equal to the width of the cabin.

- A means must be provided to assist the occupants in locating the exits in conditions of dense fog, smoke or darkness (Emergency Lighting).

- Each passenger emergency exit must be indicated by a sign visible to the occupants approaching along the main aisle or aisles.

- All doors and emergency exits must be kept clear of any obstruction during flight.

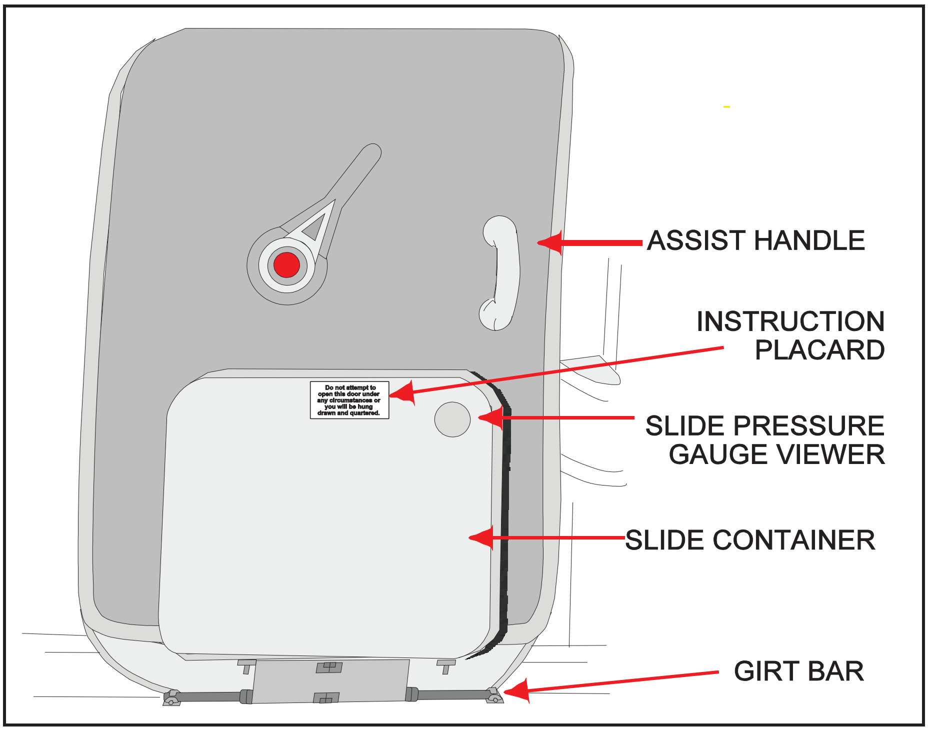


Figure 14.12: Manual door/semi-automatic slide.

ESCAPE SLIDES

When an emergency dictates rapid evacuation of the aircraft i.e. crash/ditching will be necessary. To this end actuation of the emergency escape slides will take place. The slides are inflatable rubber/nylon units which are stowed in compartments on the bottom inner face of entrance and service doors.

The slides incorporate a retainer (girt) bar which is normally stowed in stowage hooks on the compartment cover. Escape slides are of two types:- fully automatic and semi-automatic. Fully automatic slides have a Detach/Engage lever on the inner face of the passenger/service door. When selected to Engage the door close circuit (electrical) is armed on the ground. The girt bar floor is armed on the ground. The girt bar floor fittings are raised to connect the bar to the floor when the door is closed. On selecting Detach the door open circuit is armed and the girt bar Floor Fittings are raised to detach the bar when the door is opened. On semi-automatic installations the girt bar is attached and detached to the Floor Fittings manually. In either case, fully or semi automatic, with the girt bar engaged in the floor fittings, opening the door for emergency evacuation will deploy the escape slide and automatically inflate it, normally with CO_2. Should auto-inflation fail a red manual inflation handle is provided.

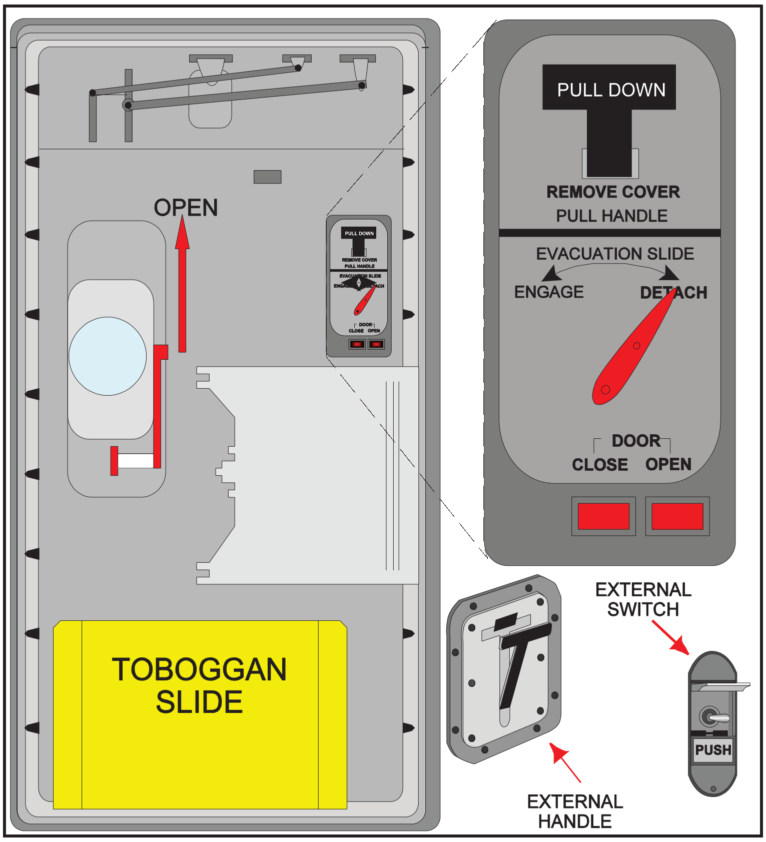


Figure 14.13: Electrically operated door/automatic slide.

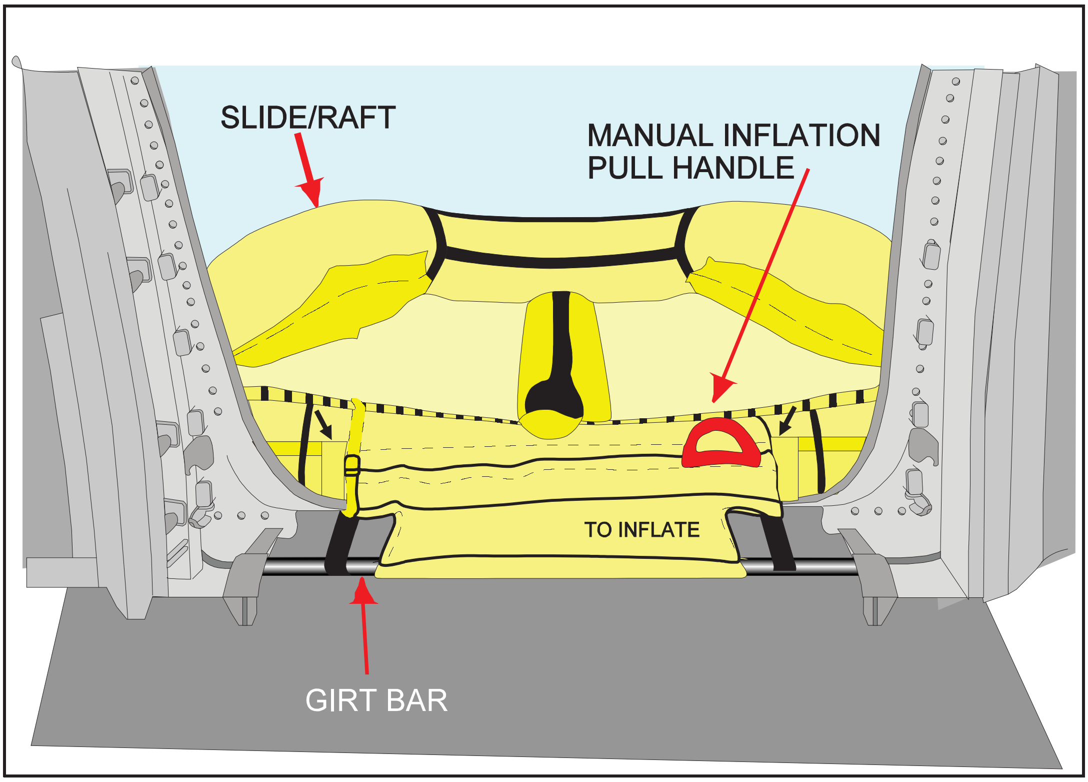


Figure 14.14: Electrically operated door/automatic slide.

RAFTS/DINGHIES

Many large aircraft utilise the escape slide as a survival raft with accommodation for up to 60 persons, B747. When the slide has been released from the aircraft, by detaching the girt bar, it can be used in this mode. The raft has a secondary floor which drops onto the primary floor and can be inflated to provide buoyancy. A centre mast and protective canopy can also be rigged. Typical survival equipment may be carried in the raft may include repair kits, flares, sea markers, compass and torches. Emergency rations and water sachets can also be included in the equipment.Aircraft dinghies can be internally or externally stowed. In the case of the latter their inflation is automatic, normally via internal release levers. Their capacities are dependent on design, 30 being a representative figure. The equipment provided in dinghies can vary but it is similar to that found in rafts. Sufficient life rafts must be carried to accommodate all the occupants of the aircraft if the largest capacity raft/dinghy is lost.

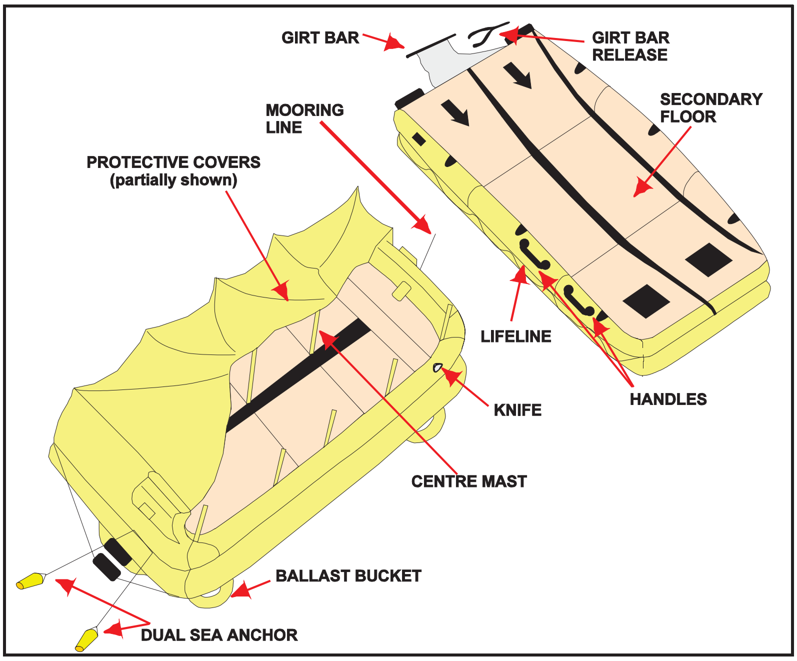


Figure 14.15: Escape slide.

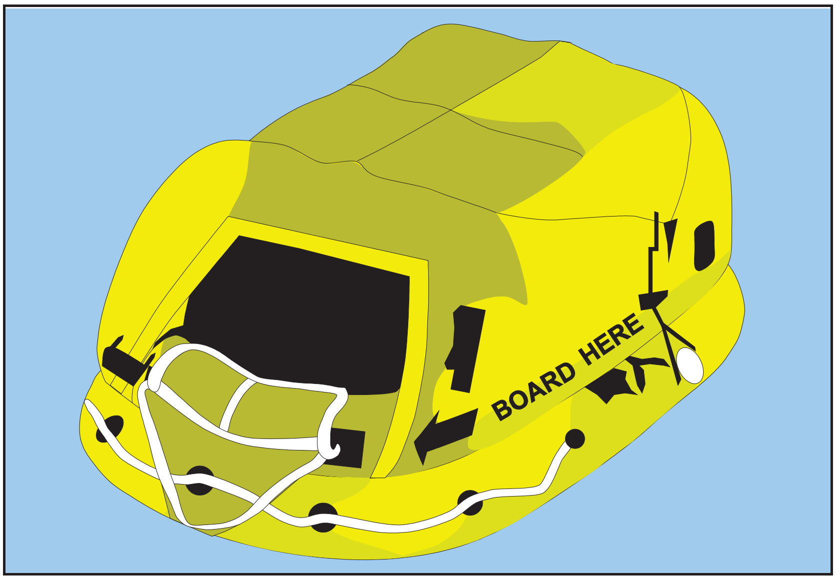


Figure 14.16: Dinghy.

PERSONAL FLOTATION EQUIPMENT

The personal equipment is the **Lifejacket** or **Life Preserver**, there are numerous types of jacket and the information contained here is of a general nature and does not apply to any particular make, model or type.

They will be designed as lightweight items of equipment and should be treated with care at all times avoiding dropping or the placement of heavy loads on them. They are normally stowed in special packs or containers for ease of handling and protection, stowage in this manner will ensure that the jacket is maintained correctly folded to ensure easy and rapid fitting if required for use. If there is any evidence of mishandling or immersion in sea water they should be rejected for operational use.

Instruction for fitting are printed on the container and or jacket and included on the safety leaflet which all are asked to read prior to take off. The normal stowage is under the seat for passengers and in any easily reached stowage for the crew. The stowages will be inspected for damage, cleanliness, security and ease of release on a regular basis. Jackets used for demonstration purposes are usually marked **Demo Only** or **Dummy** and should not be kept in normal stowages. If real jackets are used for demonstrations they must be returned for servicing prior to being returned for operational use.

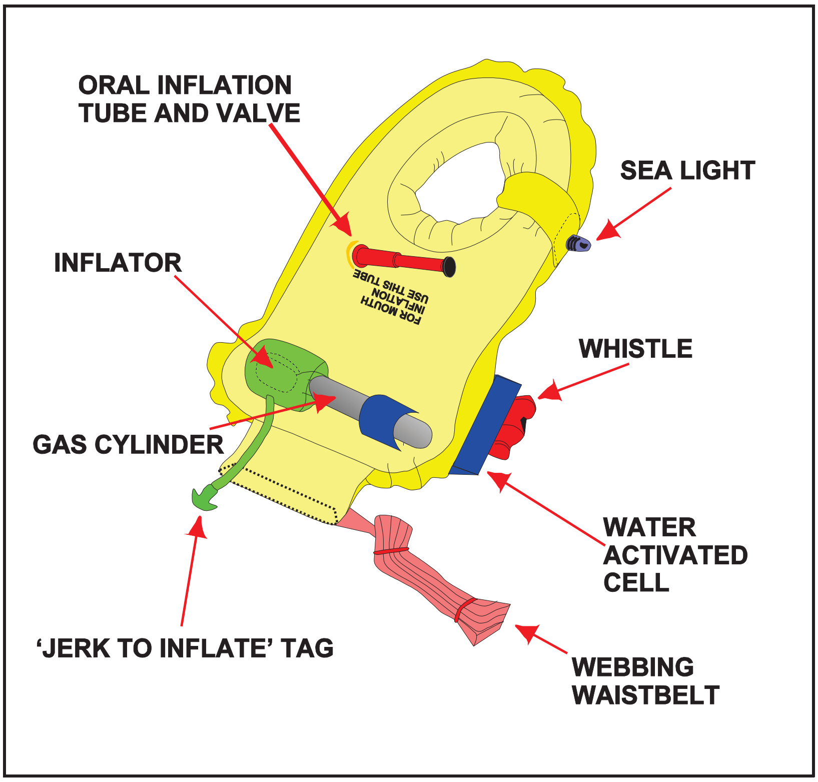


Figure 14.17: Lifejacket.

All the jackets are basically similar in design. Buoyancy is achieved by inflating the jacket with (CO_2) Carbon Dioxide Gas which is stored under pressure in a small bottle or cylinder and released manually by the operation of a red toggle or lever. Once operated the gas will pass through a NRV into the jacket and cannot be stopped. A standby or top up method of inflation by mouth (Oral) is available and this manual inflation tube usually contains a valve which can be operated by a key if it is desired to lower or release the pressure in the jacket. They are coloured either brilliant yellow or Flame red as an aid to identification and may contain any or all of the following equipment. Crew life jackets must be checked for serviceability prior to flight.

- A whistle
- A lifeline
- A sea water activated light
- A Heliograph (mirror)
- Sea water dye
- Shark repellant

A crew jacket may contain communications equipment or a Search and Rescue Beacon also known as **PLB** or **SARBE**.

Global - Positioning - System (GPS) search and rescue beacon for civil and military air crew. Called the SARBE-GPS, the system offers rescuing aircraft two locating options, a satellite-generated latitude and longitude position or a conventional swept-tone signal on the VHF/UHF frequencies. The SARBE-GPS weighs 0.8kg and is compatible with current life- preservers. It has a five-year battery shelf life and is water-proofed to 10m.

The lifejacket is usually constructed of rubberised fabric and contains a single air chamber which covers the chest and extends round either side of the neck to form a cushion at the back of the neck. The jacket is secured by tapes which are tied around the body prior to inflation. For children the tapes should be tied over the jacket and it is possible to have special jackets for children under three, when the regulations allow the jacket to be without a whistle! Flotation cots for infants may be provided on certain services and these will provide protection from the elements to keep the child dry. Adult jackets should only be slightly inflated by mouth prior to leaving the aircraft or the bulk of a fully inflated by mouth prior to leaving the aircraft or the bulk of a fully inflated jacket on an adult may cause a problem when leaving the aircraft through an escape hatch. When correctly fitted and fully inflated the jacket will turn an unconscious person on to their back and support them at about 45° with their face clear of the water.

LOCATOR BEACONS

The locator beacon is a self buoyant, dual frequency, 243.0 or 121.5 Mhz, radio distress beacon transmitter with an 80 mile range. It provides at least 48 hours continuous transmission on the Civil and Military International aviation distress frequencies. The beacon can be operated on land, or it can be thrown into the sea.

The beacon is operated by pulling on the red toggle, which in turn releases the "Velcro" straps holding the aerial. Release of the aerial will lift the aerial from its position parallel to the cylinder switches on the radio transmitter. The aerial will lift to the vertical position, a neon lamp on top of the beacon will continuously pulsate indicating the beacon is transmitting. The volume, weight and shape of the cylinder are such as to provide sufficient buoyancy to maintain the aerial in a vertical position above the water.

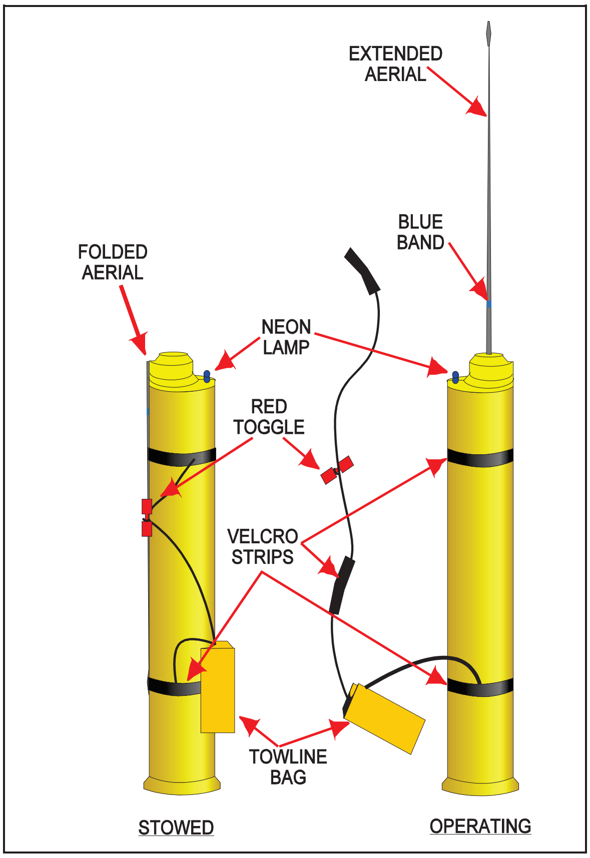


Figure 14.18: Locator beacon.

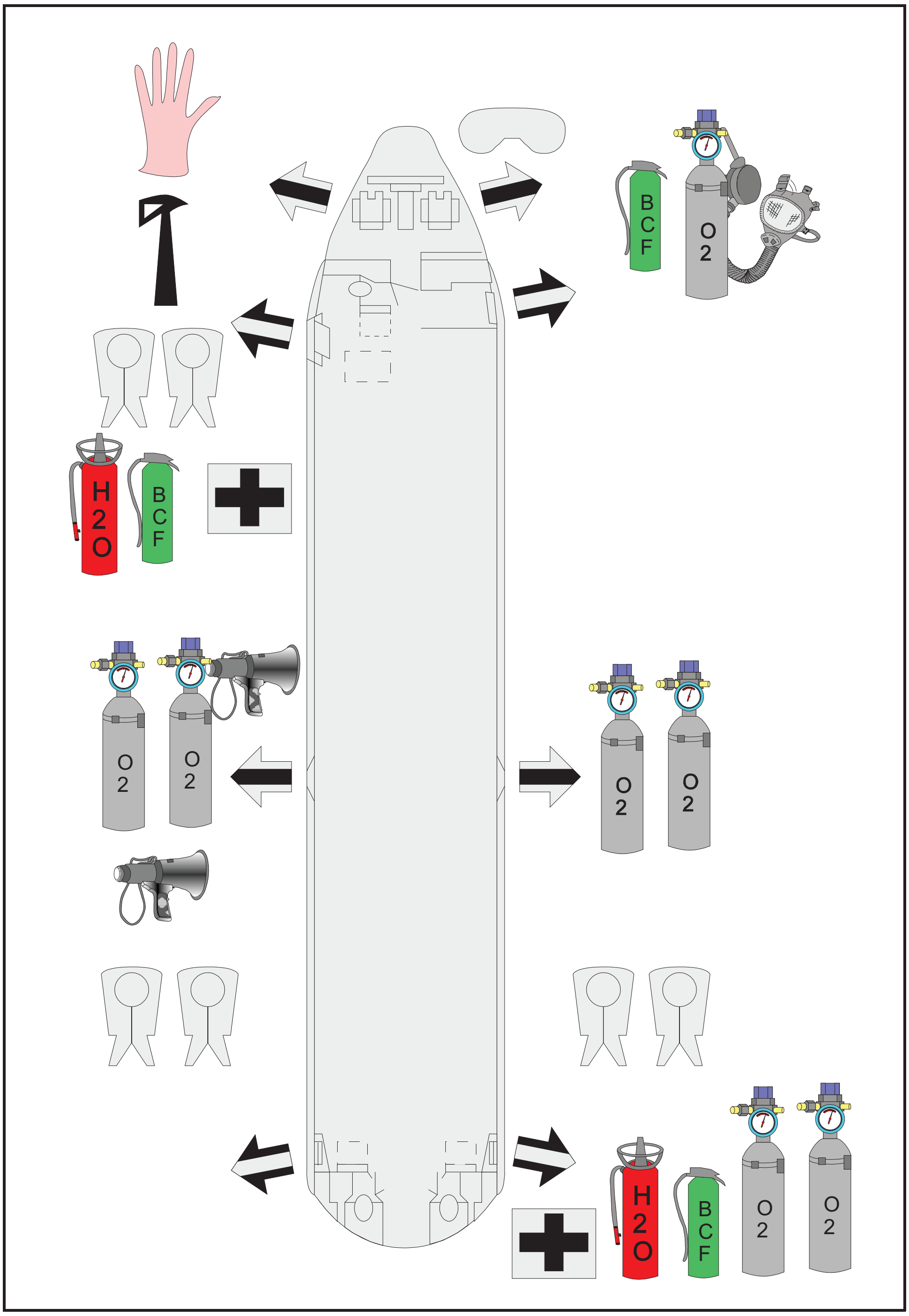


Figure 14.19: Emergency equipment location.

FIRST AID EQUIPMENT

Three types of First Aid Kit are normally carried in larger aircraft:

- **First Aid Holdalls**
  These are not sealed and are designed for use by cabin crew for the treatment of minor emergencies and ailments. Information, contents list and Survival booklets are inside.

- **Slide/Raft Kits**
  This First Aid Kit is situated in the survival pack of the slide/raft and includes a survival booklet.

- **Emergency First Aid Kits**
  The kit is split into two parts, one for cabin crew use and the other half for use by qualified doctors only. The half for use by cabin may contain various tablets such as Ventolin, Arret and Isordil. The part available for use by qualified personnel contains sophisticated medical equipment and controlled drugs and must be provided for aircraft with more than 30 seats if any part of the planned route is more than 60 minutes flying time at normal cruising speed from an aerodrome at which qualified medical assistance could be expected to be available. These can only be used with the authority of the captain and must be checked prior to flight for serviceability.

ANCILLARY EQUIPMENT

Fire-proof gloves
A pair of Fire-proof gloves are usually stowed on the flight deck for use in handling overheated equipment. They are normally made of Nomex with silver heat resistance coating.

Fire Axe or Jemmy
One fire axe or jemmy will be stowed on the flight deck whilst one or more may be stowed in a secure place in the cabin out of view of the passengers. These are used for levering and lifting hot panels or access doors to fight a fire beneath with a hand held extinguisher. Fire axes are generally being phased out in favour of the jemmy.

EXTRACT FROM JAR-OPS SUBPART K

The following information in JAR OPS 1 Subpart K is the JAR requirement for the carriage of safety equipment and the requirement for emergency oxygen is recommended reading for all students.

Note: The information contained in the following extract was correct at the time of going to print but it should be remembered that JAR OPS is subject to regular amendment.

SUBPART K – INSTRUMENTS AND EQUIPMENT

JAR-OPS 1.630 General introduction
(See IEM OPS 1.630)

(a) An operator shall ensure that a flight does not commence unless the instruments and equipment required under this Subpart are:

(1) Approved, except as specified in sub-paragraph (c), and installed in accordance with the requirements applicable to them, including the minimum performance standard and the operational and airworthiness requirements; and

(2) In operable condition for the kind of operation being conducted except as provided in the MEL (JAR-OPS 1.030 refers).

(b) Instruments and equipment minimum performance standards are those prescribed in the applicable Joint Technical Standard Orders (JTSO) as listed in JAR-TSO, unless different performance standards are prescribed in the operational or airworthiness codes. Instruments and equipment complying with design and performance specifications other than JTSO on the date of JAR-OPS implementation may remain in service, or be installed, unless additional requirements are prescribed in this Subpart. Instruments and equipment that have already been approved do not need to comply with a revised JTSO or a revised specification, other than JTSO, unless a retroactive requirement is prescribed.

(c) The following items shall not be required to have an equipment approval:

(1) Fuses referred to in JAR-OPS 1.635;

(2) Electric torches referred to in JAR-OPS 1.640(a)(4);

(3) An accurate time piece referred to in JAR-OPS 1.650(b) & 1.652(b);

(4) Chart holder referred to in JAR-OPS 1.652(n).

(5) First-aid kits referred to in JAR-OPS 1.745;

(6) Emergency medical kit referred to in JAR-OPS 1.755;

(7) Megaphones referred to in JAR-OPS 1.810;

(8) Survival and pyrotechnic signalling equipment referred to in JAR-OPS 1.835(a) and (c); and

(9) Sea anchors and equipment for mooring, anchoring or manoeuvring seaplanes and amphibians on water referred to in JAR-OPS 1.840.

JAR-OPS 1.630(c) (continued)

[(10) Child restraint devices referred to in JAR-OPS 1.730(a)(3).**]**

(d) If equipment is to be used by one flight crew member at his station during flight, it must be readily operable from his station. When a single item of equipment is required to be operated by more than one flight crew member it must be installed so that the equipment is readily operable from any station at which the equipment is required to be operated.

(e) Those instruments that are used by any one flight crew member shall be so arranged as to permit the flight crew member to see the indications readily from his station, with the minimum practicable deviation from the position and line of vision which he normally assumes when looking forward along the flight path. Whenever a single instrument is required in an aeroplane operated by more than 1 flight crew member it must be installed so that the instrument is visible from each applicable flight crew station.

[Ch. 1, 01.03.98 ; Amdt. 9, 01.09.05]

JAR–OPS 1.635 Circuit protection devices

An operator shall not operate an aeroplane in which fuses are used unless there are spare fuses available for use in flight equal to at least 10% of the number of fuses of each rating or three of each rating whichever is the greater.

JAR–OPS 1.640 Aeroplane operating lights

An operator shall not operate an aeroplane unless it is equipped with:

(a) For flight by day:

(1) Anti-collision light system;

(2) Lighting supplied from the aeroplane's electrical system to provide adequate illumination for all instruments and equipment essential to the safe operation of the aeroplane;

(3) Lighting supplied from the aeroplane's electrical system to provide illumination in all passenger compartments; and

(4) An electric torch for each required crew member readily accessible to crew members when seated at their designated station.

(b) For flight by night, in addition to equipment specified in paragraph (a) above:

(1) Navigation/position lights; and

JAR-OPS 1.652 IFR or night operations – Flight and navigational instruments and associated equipment
(See AMC OPS 1.650/1.652)
(See IEM OPS 1.650/1.652)

An operator shall not operate an aeroplane in accordance with Instrument Flight Rules (IFR) or by night in accordance with Visual Flight Rules (VFR) unless it is equipped with the flight and navigational instruments and associated equipment and, where applicable, under the conditions stated in the following sub-paragraphs:

(a) A magnetic compass;

(b) An accurate time-piece showing the time in hours, minutes and seconds;

(c) Two sensitive pressure altimeters calibrated in feet with sub-scale settings, calibrated in hectopascals/millibars, adjustable for any barometric pressure likely to be set during flight. Not later than 1 April 2002 these altimeters must have counter drum-pointer or equivalent presentation.

(d) An airspeed indicating system with heated pitot tube or equivalent means for preventing malfunctioning due to either condensation or icing including a warning indication of pitot heater failure. The pitot heater failure warning indication requirement does not apply to those aeroplanes with a maximum approved passenger seating configuration of 9 or less or a maximum certificated take-off mass of 5 700 kg or less and issued with an individual Certificate of Airworthiness prior to 1 April 1998 (See AMC OPS 1.652(d) & (k)(2));

Note: Applicability Date 1 April 1999 (for the pitot heater failure warning indication).

(e) A vertical speed indicator;

(f) A turn and slip indicator;

(g) An attitude indicator;

(h) A stabilised direction indicator;

(i) A means of indicating in the flight crew compartment the outside air temperature calibrated in degrees Celsius (See AMC OPS 1.650(i) & 1.652(i)); and

(j) Two independent static pressure systems, except that for propeller driven aeroplanes with maximum certificated take-off mass of 5 700 kg or less, one static pressure system and one alternate source of static pressure is allowed.

(k) Whenever two pilots are required the second pilot's station shall have separate instruments as follows:

JAR-OPS 1.652 (continued)

(1) A sensitive pressure altimeter calibrated in feet with a sub-scale setting, calibrated in hectopascals/millibars, adjustable for any barometric pressure likely to be set during flight and which may be one of the 2 altimeters required by sub-paragraph (c) above. Not later than 1 April 2002 these altimeters must have counter drum-pointer or equivalent presentation.

(2) An airspeed indicating system with heated pitot tube or equivalent means for preventing malfunctioning due to either condensation or icing including a warning indication of pitot heater failure. The pitot heater failure warning indication requirement does not apply to those aeroplanes with a maximum approved passenger seating configuration of 9 or less or a maximum certificated take-off mass of 5 700 kg or less and issued with an individual Certificate of Airworthiness prior to 1 April 1998 (See AMC OPS 1.652(d) & (k)(2));

Note: Applicability Date 1 April 1999 (for the pitot heater failure warning indication).

(3) A vertical speed indicator;

(4) A turn and slip indicator;

(5) An attitude indicator; and

(6) A stabilised direction indicator.

(l) Those aeroplanes with a maximum certificated take-off mass in excess of 5 700 kg or having a maximum approved passenger seating configuration of more than 9 seats must be equipped with an additional, standby, attitude indicator (artificial horizon), capable of being used from either pilot's station, that:

(1) Is powered continuously during normal operation and, after a total failure of the normal electrical generating system is powered from a source independent of the normal electrical generating system;

(2) Provides reliable operation for a minimum of 30 minutes after total failure of the normal electrical generating system, taking into account other loads on the emergency power supply and operational procedures;

(3) Operates independently of any other attitude indicating system;

(4) Is operative automatically after total failure of the normal electrical generating system; and

(5) Is appropriately illuminated during all phases of operation, except for aeroplanes with a maximum certificated take-off mass of 5 700 kg or less, already registered in a JAA Member State

JAR-OPS 1.652 IFR or night operations – Flight and navigational instruments and associated equipment
(See AMC OPS 1.650/1.652)
(See IEM OPS 1.650/1.652)

An operator shall not operate an aeroplane in accordance with Instrument Flight Rules (IFR) or by night in accordance with Visual Flight Rules (VFR) unless it is equipped with the flight and navigational instruments and associated equipment and, where applicable, under the conditions stated in the following sub-paragraphs:

(a) A magnetic compass;

(b) An accurate time-piece showing the time in hours, minutes and seconds;

(c) Two sensitive pressure altimeters calibrated in feet with sub-scale settings, calibrated in hectopascals/millibars, adjustable for any barometric pressure likely to be set during flight. Not later than 1 April 2002 these altimeters must have counter drum-pointer or equivalent presentation.

(d) An airspeed indicating system with heated pitot tube or equivalent means for preventing malfunctioning due to either condensation or icing including a warning indication of pitot heater failure. The pitot heater failure warning indication requirement does not apply to those aeroplanes with a maximum approved passenger seating configuration of 9 or less or a maximum certificated take-off mass of 5 700 kg or less and issued with an individual Certificate of Airworthiness prior to 1 April 1998 (See AMC OPS 1.652(d) & (k)(2));

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(e) A vertical speed indicator;

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(g) An attitude indicator;

(h) A stabilised direction indicator;

(i) A means of indicating in the flight crew compartment the outside air temperature calibrated in degrees Celsius (See AMC OPS 1.650(i) & 1.652(i)); and

(j) Two independent static pressure systems, except that for propeller driven aeroplanes with maximum certificated take-off mass of 5 700 kg or less, one static pressure system and one alternate source of static pressure is allowed.

(k) Whenever two pilots are required the second pilot's station shall have separate instruments as follows:

JAR-OPS 1.652 (continued)

(1) A sensitive pressure altimeter calibrated in feet with a sub-scale setting, calibrated in hectopascals/millibars, adjustable for any barometric pressure likely to be set during flight and which may be one of the 2 altimeters required by sub-paragraph (c) above. Not later than 1 April 2002 these altimeters must have counter drum-pointer or equivalent presentation.

(2) An airspeed indicating system with heated pitot tube or equivalent means for preventing malfunctioning due to either condensation or icing including a warning indication of pitot heater failure. The pitot heater failure warning indication requirement does not apply to those aeroplanes with a maximum approved passenger seating configuration of 9 or less or a maximum certificated take-off mass of 5 700 kg or less and issued with an individual Certificate of Airworthiness prior to 1 April 1998 (See AMC OPS 1.652(d) & (k)(2));

Note: Applicability Date 1 April 1999 (for the pitot heater failure warning indication).

(3) A vertical speed indicator;

(4) A turn and slip indicator;

(5) An attitude indicator; and

(6) A stabilised direction indicator.

(l) Those aeroplanes with a maximum certificated take-off mass in excess of 5 700 kg or having a maximum approved passenger seating configuration of more than 9 seats must be equipped with an additional, standby, attitude indicator (artificial horizon), capable of being used from either pilot's station, that:

(1) Is powered continuously during normal operation and, after a total failure of the normal electrical generating system is powered from a source independent of the normal electrical generating system;

(2) Provides reliable operation for a minimum of 30 minutes after total failure of the normal electrical generating system, taking into account other loads on the emergency power supply and operational procedures;

(3) Operates independently of any other attitude indicating system;

(4) Is operative automatically after total failure of the normal electrical generating system; and

(5) Is appropriately illuminated during all phases of operation, except for aeroplanes with a maximum certificated take-off mass of 5 700 kg or less, already registered in a JAA Member State

JAR-OPS 1.652(l)(5) (continued)

on 1 April 1995, equipped with a standby attitude indicator in the left-hand instrument panel.

(m) In complying with sub-paragraph (l) above, it must be clearly evident to the flight crew when the standby attitude indicator, required by that sub-paragraph, is being operated by emergency power. Where the standby attitude indicator has its own dedicated power supply there shall be an associated indication, either on the instrument or on the instrument panel, when this supply is in use. This requirement must be complied with no later than 1 April 2000.

(n) A chart holder in an easily readable position which can be illuminated for night operations.

(o) If the standby attitude instrument system is certificated according to JAR 25.1303(b)(4) or equivalent, the turn and slip indicators may be replaced by slip indicators.

(p) Whenever duplicate instruments are required, the requirement embraces separate displays for each pilot and separate selectors or other associated equipment where appropriate;

(q) All aeroplanes must be equipped with means for indicating when power is not adequately supplied to the required flight instruments; and

(r) All aeroplanes with compressibility limitations not otherwise indicated by the required airspeed indicators shall be equipped with a Mach number indicator at each pilot's station.

(s) An operator shall not conduct IFR or night operations unless the aeroplane is equipped with a headset with boom microphone or equivalent for each flight crew member on flight deck duty and a transmit button on the control wheel for each required pilot. (See IEM OPS 1.650(p)/1.652(s).)

[Ch. 1, 01.03.98; Amdt. 3, 01.12.01]

JAR-OPS 1.655 Additional equipment for single pilot operation under IFR

An operator shall not conduct single pilot IFR operations unless the aeroplane is equipped with an autopilot with at least altitude hold and heading mode.

[Ch. 1, 01.03.98]

JAR-OPS 1.660 Altitude alerting system

(a) An operator shall not operate a turbine propeller powered aeroplane with a maximum certificated take-off mass in excess of 5 700 kg or

JAR-OPS 1.660(a) (continued)

having a maximum approved passenger seating configuration of more than 9 seats or a turbojet powered aeroplane unless it is equipped with an altitude alerting system capable of:

(1) Alerting the flight crew upon approaching a preselected altitude; and

(2) Alerting the flight crew by at least an aural signal, when deviating from a preselected altitude,

except for aeroplanes with a maximum certificated take-off mass of 5 700 kg or less having a maximum approved passenger seating configuration of more than 9 and first issued with an individual certificate of airworthiness in a JAA Member State before 1 April 1972 and already registered in a JAA Member State on 1 April 1995.

[Amdt. 7, 01.09.04]

JAR-OPS 1.665 Ground proximity warning system and terrain awareness warning system

(a) An operator shall not operate a turbine powered aeroplane having a maximum certificated take-off mass in excess of 5 700 kg or a maximum approved passenger seating configuration of more than 9 unless it is equipped with a ground proximity warning system,

(b) The ground proximity warning system must automatically provide, by means of aural signals, which may be supplemented by visual signals, timely and distinctive warning to the flight crew of sink rate, ground proximity, altitude loss after take-off or go-around, incorrect landing configuration and downward glide-slope deviation.

(c) An operator shall not operate a turbine powered aeroplane having a maximum certificated take-off mass in excess of 15 000 kg or having a maximum approved passenger seating configuration of more than 30 on or after;

(1) 1 October 2001 for aeroplanes first issued with a Certificate of Airworthiness on or after this date; or

(2) 1 January 2005 for aeroplanes first issued with a Certificate of Airworthiness before 1 October 2001;

unless it is equipped with a ground proximity warning system that includes a predictive terrain hazard warning function (Terrain Awareness and Warning System – TAWS).

(d) An operator shall not operate a turbine powered aeroplane having a maximum certificated

JAR-OPS 1.665(d) (continued)

take-off mass in excess of 5 700 kg but not more than 15 000 kg or a maximum approved passenger seating configuration of more than 9 but not more than 30 on or after:

(1) 1 January 2003 for aeroplanes first issued with a Certificate of Airworthiness on or after 1 January 2003; or

(2) 1 January 2007 for aeroplanes first issued with a certificate of Airworthiness before 1 January 2003;

unless it is equipped with a ground proximity warning system that includes a predictive terrain hazard warning function (Terrain Awareness and Warning System – TAWS).

(e) The terrain awareness and warning system must automatically provide the flight crew, by means of visual and aural signals and a Terrain Awareness Display, with sufficient alerting time to prevent controlled flight into terrain events, and provide a forward looking capability and terrain clearance floor.

[Ch. 1, 01.03.98; Amdt. 3, 01.12.01; Amdt. 7, 01.09.04]

JAR-OPS 1.668 Airborne Collision Avoidance System
(See IEM OPS 1.668)

(a) An operator shall not operate a turbine powered aeroplane:

(1) Having a maximum certificated take-off mass in excess of 15 000 kg or a maximum approved passenger seating configuration of more than 30 after 1 January 2000; or

(2) Having a maximum certificated take-off mass in excess of 5 700 kg, but not more than 15 000 kg, or a maximum approved passenger seating configuration of more than 19, but not more than 30, after 1 January 2005,

unless it is equipped with an airborne collision avoidance system with a minimum performance level of at least ACAS II.

[Ch. 1, 01.03.98]

JAR-OPS 1.670 Airborne weather radar equipment

(a) An operator shall not operate:

(1) A pressurised aeroplane; or

(2) An unpressurised aeroplane which has a maximum certificated take-off mass of more than 5 700 kg; or

JAR-OPS 1.670(a) (continued)

(3) An unpressurised aeroplane having a maximum approved passenger seating configuration of more than 9 seats after 1 April 1999,

unless it is equipped with airborne weather radar equipment whenever such an aeroplane is being operated at night or in instrument meteorological conditions in areas where thunderstorms or other potentially hazardous weather conditions, regarded as detectable with airborne weather radar, may be expected to exist along the route.

(b) For propeller driven pressurised aeroplanes having a maximum certificated take-off mass not exceeding 5 700 kg with a maximum approved passenger seating configuration not exceeding 9 seats the airborne weather radar equipment may be replaced by other equipment capable of detecting thunderstorms and other potentially hazardous weather conditions, regarded as detectable with airborne weather radar equipment, subject to approval by the Authority.

JAR-OPS 1.675 Equipment for operations in icing conditions

(a) An operator shall not operate an aeroplane in expected or actual icing conditions unless it is certificated and equipped to operate in icing conditions.

(b) An operator shall not operate an aeroplane in expected or actual icing conditions at night unless it is equipped with a means to illuminate or detect the formation of ice. Any illumination that is used must be of a type that will not cause glare or reflection that would handicap crew members in the performance of their duties.

JAR-OPS 1.680 Cosmic radiation detection equipment

(a) An operator shall not operate an aeroplane above 15 000 m (49 000 ft) unless:

(1) It is equipped with an instrument to measure and indicate continuously the dose rate of total cosmic radiation being received (i.e. the total of ionizing and neutron radiation of galactic and solar origin) and the cumulative dose on each flight, or

(2) A system of on-board quarterly radiation sampling acceptable to the authority is established (See ACJ OPS 1.680(a)(2)).

[Amdt. 3, 01.12.01]

JAR-OPS 1.685 Flight crew interphone system

An operator shall not operate an aeroplane on which a flight crew of more than one is required unless it is equipped with a flight crew interphone system, including headsets and microphones, not of a handheld type, for use by all members of the flight crew. For aeroplanes already registered in a JAA member State on 1 April 1995 and first issued with an individual certificate of airworthiness in a JAA member State or elsewhere before 1 April 1975, this requirement will not be applicable until 1 April 2002.

JAR-OPS 1.690 Crew member interphone system

(a) An operator shall not operate an aeroplane with a maximum certificated take-off mass exceeding 15 000 kg or having a maximum approved passenger seating configuration of more than 19 unless it is equipped with a crew member interphone system except for aeroplanes first issued with an individual certificate of airworthiness in a JAA member State or elsewhere before 1 April 1965 and already registered in a JAA member State on 1 April 1995.

(b) The crew member interphone system required by this paragraph must:

(1) Operate independently of the public address system except for handsets, headsets, microphones, selector switches and signalling devices;

(2) Provide a means of two-way communication between the flight crew compartment and:

(i) Each passenger compartment;

(ii) Each galley located other than on a passenger deck level; and

(iii) Each remote crew compartment that is not on the passenger deck and is not easily accessible from a passenger compartment;

(3) Be readily accessible for use from each of the required flight crew stations in the flight crew compartment;

(4) Be readily accessible for use at required cabin crew member stations close to each separate or pair of floor level emergency exits;

(5) Have an alerting system incorporating aural or visual signals for use by flight crew members to alert the cabin crew and for use by cabin crew members to alert the flight crew;

JAR-OPS 1.690(b) (continued)

(6) Have a means for the recipient of a call to determine whether it is a normal call or an emergency call (See AMC OPS 1.690(b)(6)); and

(7) Provide on the ground a means of two-way communication between ground personnel and at least two flight crew members. (See IEM OPS 1.690(b)(7).)

JAR-OPS 1.695 Public address system

(a) An operator shall not operate an aeroplane with a maximum approved passenger seating configuration of more than 19 unless a public address system is installed.

(b) The public address system required by this paragraph must:

(1) Operate independently of the interphone systems except for handsets, headsets, microphones, selector switches and signalling devices;

(2) Be readily accessible for immediate use from each required flight crew member station;

(3) For each required floor level passenger emergency exit which has an adjacent cabin crew seat, have a microphone which is readily accessible to the seated cabin crew member, except that one microphone may serve more than one exit, provided the proximity of the exits allows unassisted verbal communication between seated cabin crew members;

(4) Be capable of operation within 10 seconds by a cabin crew member at each of those stations in the compartment from which its use is accessible; and

(5) Be audible and intelligible at all passenger seats, toilets and cabin crew seats and work stations.

JAR-OPS 1.700 Cockpit voice recorders–1 (See ACJ OPS 1.700)

(a) An operator shall not operate an aeroplane first issued with an individual Certificate of Airworthiness on or after 1 April 1998, which:

(1) Is multi-engine turbine powered and has a maximum approved passenger seating configuration of more than 9; or

(2) Has a maximum certificated take-off mass over 5 700 kg,

JAR-OPS 1.700(a)(2) (continued)

unless it is equipped with a cockpit voice recorder which, with reference to a time scale, records:

(i) Voice communications transmitted from or received on the flight deck by radio;

(ii) The aural environment of the flight deck, including without interruption, the audio signals received from each boom and mask microphone in use;

(iii) Voice communications of flight crew members on the flight deck using the aeroplane's interphone system;

(iv) Voice or audio signals identifying navigation or approach aids introduced into a headset or speaker; and

(v) Voice communications of flight crew members on the flight deck using the public address system, if installed.

(b) The cockpit voice recorder shall be capable of retaining information recorded during at least the last 2 hours of its operation except that, for those aeroplanes with a maximum certificated take-off mass of 5 700 kg or less, this period may be reduced to 30 minutes.

(c) The cockpit voice recorder must start automatically to record prior to the aeroplane moving under its own power and continue to record until the termination of the flight when the aeroplane is no longer capable of moving under its own power. In addition, depending on the availability of electrical power, the cockpit voice recorder must start to record as early as possible during the cockpit checks prior to engine start at the beginning of the flight until the cockpit checks immediately following engine shutdown at the end of the flight.

(d) The cockpit voice recorder must have a device to assist in locating that recorder in water.

[Amdt. 4, 01.07.02]

JAR-OPS 1.705 Cockpit voice recorders–2
(See ACJ OPS 1.705/1.710)

(a) After 1 April 2000 an operator shall not operate any multi-engined turbine aeroplane first issued with an individual Certificate of Airworthiness on or after 1 January 1990 up to and including 31 March 1998 which has a maximum certificated take-off mass of 5 700 kg or less and a maximum approved passenger seating configuration of more than 9, unless it is equipped with a cockpit voice recorder which records:

JAR-OPS 1.705(a) (continued)

(1) Voice communications transmitted from or received on the flight deck by radio;

(2) The aural environment of the flight deck, including where practicable, without interruption, the audio signals received from each boom and mask microphone in use;

(3) Voice communications of flight crew members on the flight deck using the aeroplane's interphone system;

(4) Voice or audio signals identifying navigation or approach aids introduced into a headset or speaker; and

(5) Voice communications of flight crew members on the flight deck using the public address system, if installed.

(b) The cockpit voice recorder shall be capable of retaining information recorded during at least the last 30 minutes of its operation.

(c) The cockpit voice recorder must start to record prior to the aeroplane moving under its own power and continue to record until the termination of the flight when the aeroplane is no longer capable of moving under its own power. In addition, depending on the availability of electrical power, the cockpit voice recorder must start to record as early as possible during the cockpit checks, prior to the flight until the cockpit checks immediately following engine shutdown at the end of the flight.

(d) The cockpit voice recorder must have a device to assist in locating that recorder in water.

[Amdt. 4, 01.07.02]

JAR-OPS 1.710 Cockpit voice recorders–3
(See ACJ OPS 1.705/1.710)

(a) An operator shall not operate any aeroplane with a maximum certificated take-off mass over 5 700 kg first issued with an individual certificate of airworthiness, before 1 April 1998 unless it is equipped with a cockpit voice recorder which records:

(1) Voice communications transmitted from or received on the flight deck by radio;

(2) The aural environment of the flight deck;

(3) Voice communications of flight crew members on the flight deck using the aeroplane's interphone system;

(4) Voice or audio signals identifying navigation or approach aids introduced into a headset or speaker; and

JAR-OPS 1.710(a) (continued)

(5) Voice communications of flight crew members on the flight deck using the public address system, if installed.

(b) The cockpit voice recorder shall be capable of retaining information recorded during at least the last 30 minutes of its operation.

(c) The cockpit voice recorder must start to record prior to the aeroplane moving under its own power and continue to record until the termination of the flight when the aeroplane is no longer capable of moving under its own power.

(d) The cockpit voice recorder must have a device to assist in locating that recorder in water.

[Amdt. 4, 01.07.02]

JAR–OPS 1.715 Flight data recorders–1
(See Appendix 1 to JAR-OPS 1.715)
(See ACJ OPS 1.715)

(a) An operator shall not operate any aeroplane first issued with an individual Certificate of Airworthiness on or after 1 April 1998 which:

(1) Is multi-engine turbine powered and has a maximum approved passenger seating configuration of more than 9; or

(2) Has a maximum certificated take-off mass over 5 700 kg,

unless it is equipped with a flight data recorder that uses a digital method of recording and storing data and a method of readily retrieving that data from the storage medium is available.

(b) The flight data recorder shall be capable of retaining the data recorded during at least the last 25 hours of its operation except that, for those aeroplanes with a maximum certificated take-off mass of 5 700 kg or less, this period may be reduced to 10 hours.

(c) The flight data recorder must, with reference to a timescale, record:

(1) The parameters listed in Tables A1 or A2 of Appendix 1 to JAR-OPS 1.715 as applicable;

(2) For those aeroplanes with a maximum certificated take-off mass over 27 000 kg, the additional parameters listed in Table B of Appendix 1 to JAR-OPS 1.715;

(3) For aeroplanes specified in (a) above, the flight data recorder must record any dedicated parameters relating to novel or unique design or operational characteristics of the aeroplane as

JAR-OPS 1.715(c)(3) (continued)

determined by the Authority during type or supplemental type certification; and

(4) For aeroplanes equipped with electronic display system the parameters listed in Table C of Appendix 1 to JAR-OPS 1.715, except that , for aeroplanes first issued with an individual Certificate of Airworthiness before 20 August 2002 those parameters for which:

(i) The sensor is not available; or

(ii) The aeroplane system or equipment generating the data needs to be modified; or

(iii) The signals are incompatible with the recording system;

do not need to be recorded if acceptable to the Authority.

(d) Data must be obtained from aeroplane sources which enable accurate correlation with information displayed to the flight crew.

(e) The flight data recorder must start automatically to record the data prior to the aeroplane being capable of moving under its own power and must stop automatically after the aeroplane is incapable of moving under its own power.

(f) The flight data recorder must have a device to assist in locating that recorder in water.

(g) Aeroplanes first issued with an individual Certificate of Airworthiness on or after 1 April 1998, but not later than 1 April 2001 may not be required to comply with JAR-OPS 1.715(c) if approved by the Authority, provided that:

(1) Compliance with JAR-OPS 1.715(c) cannot be achieved without extensive modification (See ACJ-OPS 1.715(g)) to the aeroplane systems and equipment other than the flight data recorder system; and

(2) The aeroplane complies with JAR-OPS 1.720(c) except that parameter 15b in Table A of Appendix 1 to JAR-OPS 1.720 need not to be recorded.

[Amdt. 4, 01.07.02]

JAR-OPS 1.720 Flight data recorders–2
(See Appendix 1 to JAR-OPS 1.720)
(See ACJ OPS 1.720/1.725)

(a) An operator shall not operate any aeroplane first issued with an individual certificate of airworthiness on or after 1 June 1990 up to and including 31 March 1998 which has a maximum certificated take-off mass over 5 700 kg unless it is equipped with a flight data recorder that uses a digital method of recording and storing data and a method of readily retrieving that data from the storage medium is available.

(b) The flight data recorder shall be capable of retaining the data recorded during at least the last 25 hours of its operation.

(c) The flight data recorder must, with reference to a timescale, record:

(1) The parameters listed in Table A of Appendix 1 to JAR-OPS 1.720; and

(2) For those aeroplanes with a maximum certificated take-off mass over 27 000 kg the additional parameters listed in Table B of Appendix 1 to JAR-OPS 1.720.

(d) For those aeroplanes having a maximum certificated take-off mass of 27 000 kg or below, if acceptable to the Authority, parameters 14 and 15b of Table A of Appendix 1 to JAR-OPS 1.720 need not be recorded, when any of the following conditions are met:

(1) The sensor is not readily available,

(2) Sufficient capacity is not available in the flight recorder system,

(3) A change is required in the equipment that generates the data.

(e) For those aeroplanes having a maximum certificated take-off mass over 27 000 kg, if acceptable to the Authority, the following parameters need not be recorded: 15b of Table A of Appendix 1 to JAR-OPS 1.720, and 23, 24, 25, 26, 27, 28, 29, 30 and 31 of Table B of Appendix 1, if any of the following conditions are met:

(1) The sensor is not readily available,

(2) Sufficient capacity is not available in the flight data recorder system,

(3) A change is required in the equipment that generates the data,

(4) For navigational data (NAV frequency selection, DME distance, latitude, longitude, ground speed and drift) the signals are not available in digital form.

JAR-OPS 1.720 (continued)

(f) Individual parameters that can be derived by calculation from the other recorded parameters, need not to be recorded if acceptable to the Authority.

(g) Data must be obtained from aeroplane sources which enable accurate correlation with information displayed to the flight crew.

(h) The flight data recorder must start to record the data prior to the aeroplane being capable of moving under its own power and must stop after the aeroplane is incapable of moving under its own power.

(i) The flight data recorder must have a device to assist in locating that recorder in water.

[Amdt. 4, 01.07.02]

JAR-OPS 1.725 Flight data recorders–3
(See Appendix 1 to JAR-OPS 1.725)
(See ACJ OPS 1.720/1.725)

(a) An operator shall not operate any turbine-engined aeroplane first issued with an individual Certificate of Airworthiness, before 1 June 1990 which has a maximum certificated take-off mass over 5 700 kg unless it is equipped with a flight data recorder that uses a digital method of recording and storing data and a method of readily retrieving that data from the storage medium is available .

(b) The flight data recorder shall be capable of retaining the data recorded during at least the last 25 hours of its operation.

(c) The flight data recorder must, with reference to a timescale, record:

(1) The parameters listed in Table A of Appendix 1 to JAR-OPS 1.725.

(2) For those aeroplanes with a maximum certificated take-off mass over 27 000 kg that are of a type first type certificated after 30 September 1969, the additional parameters from 6 to 15b of Table B of Appendix 1 to JAR-OPS 1.725 of this paragraph. The following parameters need not be recorded, if acceptable to the Authority: 13, 14 and 15b in Table B of Appendix 1 to JAR-OPS 1.725 when any of the following conditions are met:

(i) The sensor is not readily available,

(ii) Sufficient capacity is not available in the flight recorder system,

(iii) A change is required in the equipment that generates the data and

JAR-OPS 1.725(c) (continued)

(3) When sufficient capacity is available on a flight recorder system, the sensor is readily available and a change is not required in the equipment that generates the data:

(i) For aeroplanes first issued with an individual Certificate of Airworthiness on or after 1 January 1989, with a maximum certificated take off mass of over 5 700 kg but not more than 27 000 kg, parameters 6 to 15b of Table B of Appendix 1 to JAR-OPS 1.725 ; and

(ii) For aeroplanes first issued with an individual Certificate of Airworthiness on or after 1 January 1987, with a maximum certificated take off mass of over 27 000 kg the remaining parameters of Table B of Appendix 1 to JAR-OPS 1.725.

(d) Individual parameters that can be derived by calculation from the other recorded parameters, need not to be recorded if acceptable to the Authority.

(e) Data must be obtained from aircraft sources which enable accurate correlation with information displayed to the flight crew.

(f) The flight data recorder must start to record the data prior to the aeroplane being capable of moving under its own power and must stop after the aeroplane is incapable of moving under its own power.

(g) The flight data recorder must have a device to assist in locating that recorder in water.

[Amdt. 4, 01.07.02]

JAR-OPS 1.727 Combination Recorder
(See ACJ-OPS 1.727)

(a) Compliance with Cockpit Voice recorder and flight data recorder requirements may be achieved by:

(1) One combination recorder if the aeroplane has to be equipped with a cockpit voice recorder or with a flight data recorder only; or

(2) One combination recorder if the aeroplane with a maximum certificated take-off mass of 5 700 kg or less has to be equipped with a cockpit voice recorder and a flight data recorder; or

(3) Two combination recorders if the aeroplane with a maximum take-off mass over 5 700 kg has to be equipped with a cockpit voice recorder and a flight data recorder.

JAR-OPS 1.727(a) (continued)

(b) A combination recorder is a flight recorder that records:

(1) all voice communications and aural environment required by the relevant cockpit voice recorder paragraph; and

(2) all parameters required by the relevant flight data recorder paragraph, with the same specifications required by those paragraphs.

[Amdt. 4, 01.07.02]

JAR–OPS 1.730 Seats, seat safety belts, harnesses and child restraint devices

(a) An operator shall not operate an aeroplane unless it is equipped with:

(1) A seat or berth for each person who is aged two years or more;

(2) A safety belt, with or without a diagonal shoulder strap, or a safety harness for use in each passenger seat for each passenger aged 2 years or more;

(3) A **[**child**]** restraint device, **[**acceptable to the Authority,**]** for each infant **[**(See ACJ OPS 1.730(a)(3);**]**

(4) Except as provided in sub-paragraph (b) below, a safety belt with shoulder harness for each flight crew seat and for any seat alongside a pilot's seat incorporating a device which will automatically restrain the occupant's torso in the event of rapid deceleration;

(5) Except as provided in sub-paragraph (b) below, a safety belt with shoulder harness for each cabin crew seat and observer's seats. However, this requirement does not preclude use of passenger seats by cabin crew members carried in excess of the required cabin crew complement; and

(6) Seats for cabin crew members located near required floor level emergency exits except that, if the emergency evacuation of passengers would be enhanced by seating cabin crew members elsewhere, other locations are acceptable. The seats shall be forward or rearward facing within 15° of the longitudinal axis of the aeroplane.

(b) All safety belts with shoulder harness must have a single point release.

JAR-OPS 1.730 (continued)

(c) A safety belt with a diagonal shoulder strap for aeroplanes with a maximum certificated take-off mass not exceeding 5 700 kg or a safety belt for aeroplanes with a maximum certificated take-off mass not exceeding 2 730 kg may be permitted in place of a safety belt with shoulder harness if it is not reasonably practicable to fit the latter.

[Ch. 1, 01.03.98; Amdt. 9, 01.09.05]

JAR-OPS 1.731 Fasten Seat belt and No Smoking signs

An operator shall not operate an aeroplane in which all passenger seats are not visible from the flight deck, unless it is equipped with a means of indicating to all passengers and cabin crew when seat belts shall be fastened and when smoking is not allowed.

[Ch. 1, 01.03.98]

JAR-OPS 1.735 Internal doors and curtains

An operator shall not operate an aeroplane unless the following equipment is installed:

(a) In an aeroplane with a maximum approved passenger seating configuration of more than 19 passengers, a door between the passenger compartment and the flight deck compartment with a placard 'crew only' and a locking means to prevent passengers from opening it without the permission of a member of the flight crew;

(b) A means for opening each door that separates a passenger compartment from another compartment that has emergency exit provisions. The means for opening must be readily accessible;

(c) If it is necessary to pass through a doorway or curtain separating the passenger cabin from other areas to reach any required emergency exit from any passenger seat, the door or curtain must have a means to secure it in the open position;

(d) A placard on each internal door or adjacent to a curtain that is the means of access to a passenger emergency exit, to indicate that it must be secured open during take off and landing; and

(e) A means for any member of the crew to unlock any door that is normally accessible to passengers and that can be locked by passengers.

JAR-OPS 1.740 Intentionally blank

JAR-OPS 1.745 First-Aid Kits
(See AMC OPS 1.745)

(a) An operator shall not operate an aeroplane unless it is equipped with first-aid kits, readily accessible for use, to the following scale:

Number of passenger seats installed	Number of First-Aid Kits required
0 to 99	1
100 to 199	2
200 to 299	3
300 and more	4

(b) An operator shall ensure that first-aid kits are:

(1) Inspected periodically to confirm, to the extent possible, that contents are maintained in the condition necessary for their intended use; and

(2) Replenished at regular intervals, in accordance with instructions contained on their labels, or as circumstances warrant.

JAR-OPS 1.750 Intentionally blank

JAR-OPS 1.755 Emergency Medical Kit
(See AMC OPS 1.755)

(a) An operator shall not operate an aeroplane with a maximum approved passenger seating configuration of more than 30 seats unless it is equipped with an emergency medical kit if any point on the planned route is more than 60 minutes flying time (at normal cruising speed) from an aerodrome at which qualified medical assistance could be expected to be available.

(b) The commander shall ensure that drugs are not administered except by qualified doctors, nurses or similarly qualified personnel.

(c) Conditions for carriage

(1) The emergency medical kit must be dust and moisture proof and shall be carried under security conditions, where practicable, on the flight deck; and

(2) An operator shall ensure that emergency medical kits are:

(i) Inspected periodically to confirm, to the extent possible, that the contents are maintained in the condition necessary for their intended use; and

JAR-OPS 1.755(c)(2) (continued)

(ii) Replenished at regular intervals, in accordance with instructions contained on their labels, or as circumstances warrant.

JAR-OPS 1.760 First-Aid oxygen
(See IEM OPS 1.760)

(a) An operator shall not operate a pressurised aeroplane, above 25 000 ft, when a cabin crew member is required to be carried, unless it is equipped with a supply of undiluted oxygen for passengers who, for physiological reasons, might require oxygen following a cabin depressurisation. The amount of oxygen shall be calculated using an average flow rate of at least 3 litres Standard Temperature Pressure Dry (STPD)/minute/person and shall be sufficient for the remainder of the flight after cabin depressurisation when the cabin altitude exceeds 8 000 ft but does not exceed 15 000 ft, for at least 2% of the passengers carried, but in no case for less than one person. There shall be a sufficient number of dispensing units, but in no case less than two, with a means for cabin crew to use the supply. The dispensing units may be of a portable type.

(b) The amount of first-aid oxygen required for a particular operation shall be determined on the basis of cabin pressure altitudes and flight duration, consistent with the operating procedures established for each operation and route.

(c) The oxygen equipment provided shall be capable of generating a mass flow to each user of at least four litres per minute, STPD. Means may be provided to decrease the flow to not less than two litres per minute, STPD, at any altitude.

[Amdt. 3, 01.12.01]

JAR-OPS 1.765 Intentionally blank

JAR-OPS 1.770 Supplemental oxygen – pressurised aeroplanes
(See Appendix 1 to JAR-OPS 1.770)
(See AMC OPS 1.770)

(a) General

(1) An operator shall not operate a pressurised aeroplane at pressure altitudes above 10 000 ft unless supplemental oxygen equipment, capable of storing and dispensing the oxygen supplies required by this paragraph, is provided.

(2) The amount of supplemental oxygen required shall be determined on the basis of cabin

JAR-OPS 1.770(a)(2) (continued)

pressure altitude, flight duration and the assumption that a cabin pressurisation failure will occur at the pressure altitude or point of flight that is most critical from the standpoint of oxygen need, and that, after the failure, the aeroplane will descend in accordance with emergency procedures specified in the Aeroplane Flight Manual to a safe altitude for the route to be flown that will allow continued safe flight and landing.

(3) Following a cabin pressurisation failure, the cabin pressure altitude shall be considered the same as the aeroplane pressure altitude, unless it is demonstrated to the Authority that no probable failure of the cabin or pressurisation system will result in a cabin pressure altitude equal to the aeroplane pressure altitude. Under these circumstances, the demonstrated maximum cabin pressure altitude may be used as a basis for determination of oxygen supply.

(b) Oxygen equipment and supply requirements

(1) Flight crew members

(i) Each member of the flight crew on flight deck duty shall be supplied with supplemental oxygen in accordance with Appendix 1. If all occupants of flight deck seats are supplied from the flight crew source of oxygen supply then they shall be considered as flight crew members on flight deck duty for the purpose of oxygen supply. Flight deck seat occupants, not supplied by the flight crew source, are to be considered as passengers for the purpose of oxygen supply.

(ii) Flight crew members, not covered by sub-paragraph (b)(1)(i) above, are to be considered as passengers for the purpose of oxygen supply.

(iii) Oxygen masks shall be located so as to be within the immediate reach of flight crew members whilst at their assigned duty station.

(iv) Oxygen masks for use by flight crew members in pressurised aeroplanes operating at pressure altitudes above 25 000 ft, shall be a quick donning type of mask.

(2) Cabin crew members, additional crew members and passengers

(i) Cabin crew members and passengers shall be supplied with supplemental oxygen in accordance with Appendix 1, except when sub-paragraph (v) below applies. Cabin crew members carried in addition to the minimum number of cabin

JAR-OPS 1.770(b)(2)(i) (continued)

crew members required, and additional crew members, shall be considered as passengers for the purpose of oxygen supply.

(ii) Aeroplanes intended to be operated at pressure altitudes above 25 000 ft shall be provided sufficient spare outlets and masks and/or sufficient portable oxygen units with masks for use by all required cabin crew members. The spare outlets and/or portable oxygen units are to be distributed evenly throughout the cabin to ensure immediate availability of oxygen to each required cabin crew member regardless of his location at the time of cabin pressurisation failure.

(iii) Aeroplanes intended to be operated at pressure altitudes above 25 000 ft shall be provided an oxygen dispensing unit connected to oxygen supply terminals immediately available to each occupant, wherever seated. The total number of dispensing units and outlets shall exceed the number of seats by at least 10%. The extra units are to be evenly distributed throughout the cabin.

(iv) Aeroplanes intended to be operated at pressure altitudes above 25 000 ft or which, if operated at or below 25 000 ft, cannot descend safely within 4 minutes to 13 000 ft, and for which the individual certificate of airworthiness was first issued by a JAA Member State or elsewhere on or after 9 November 1998, shall be provided with automatically deployable oxygen equipment immediately available to each occupant, wherever seated. The total number of dispensing units and outlets shall exceed the number of seats by at least 10%. The extra units are to be evenly distributed throughout the cabin.

(v) The oxygen supply requirements, as specified in Appendix 1, for aeroplanes not certificated to fly above 25 000 ft, may be reduced to the entire flight time between 10 000 ft and 13 000 ft cabin pressure altitudes for all required cabin crew members and for at least 10% of the passengers if, at all points along the route to be flown, the aeroplane is able to descend safely within 4 minutes to a cabin pressure altitude of 13 000 ft.

[Ch. 1, 01.03.98]

JAR-OPS 1.775 Supplemental oxygen – Non-pressurised aeroplanes
(See Appendix 1 to JAR–OPS 1.775)

(a) General

(1) An operator shall not operate a non-pressurised aeroplane at altitudes above 10 000 ft unless supplemental oxygen equipment, capable of storing and dispensing the oxygen supplies required, is provided.

(2) The amount of supplemental oxygen for sustenance required for a particular operation shall be determined on the basis of flight altitudes and flight duration, consistent with the operating procedures established for each operation in the Operations Manual and with the routes to be flown, and with the emergency procedures specified in the Operations Manual.

(3) An aeroplane intended to be operated at pressure altitudes above 10 000 ft shall be provided with equipment capable of storing and dispensing the oxygen supplies required.

(b) Oxygen supply requirements

(1) *Flight crew members.* Each member of the flight crew on flight deck duty shall be supplied with supplemental oxygen in accordance with Appendix 1. If all occupants of flight deck seats are supplied from the flight crew source of oxygen supply then they shall be considered as flight crew members on flight deck duty for the purpose of oxygen supply.

(2) *Cabin crew members, additional crew members and passengers.* Cabin crew members and passengers shall be supplied with oxygen in accordance with Appendix 1. Cabin crew members carried in addition to the minimum number of cabin crew members required, and additional crew members, shall be considered as passengers for the purpose of oxygen supply.

JAR-OPS 1.780 Crew Protective Breathing Equipment

(a) An operator shall not operate a pressurised aeroplane or, after 1 April 2000, an unpressurised aeroplane with a maximum certificated take-off mass exceeding 5 700 kg or having a maximum approved seating configuration of more than 19 seats unless:

(1) It has equipment to protect the eyes, nose and mouth of each flight crew member while on flight deck duty and to provide oxygen for a period of not less than 15 minutes. The supply for

JAR-OPS 1.780(a)(1) (continued)

Protective Breathing Equipment (PBE) may be provided by the supplemental oxygen required by JAR-OPS 1.770(b)(1) or JAR-OPS 1.775(b)(1). In addition, when the flight crew is more than one and a cabin crew member is not carried, portable PBE must be carried to protect the eyes, nose and mouth of one member of the flight crew and to provide breathing gas for a period of not less than 15 minutes; and

(2) It has sufficient portable PBE to protect the eyes, nose and mouth of all required cabin crew members and to provide breathing gas for a period of not less than 15 minutes.

(b) PBE intended for flight crew use must be conveniently located on the flight deck and be easily accessible for immediate use by each required flight crew member at their assigned duty station.

(c) PBE intended for cabin crew use must be installed adjacent to each required cabin crew member duty station.

(d) An additional, easily accessible portable PBE must be provided and located at or adjacent to the hand fire extinguishers required by JAR-OPS 1.790(c) and (d) except that, where the fire extinguisher is located inside a cargo compartment, the PBE must be stowed outside but adjacent to the entrance to that compartment.

(e) PBE while in use must not prevent communication where required by JAR-OPS 1.685, JAR-OPS 1.690, JAR-OPS 1.810 and JAR-OPS 1.850.

JAR-OPS 1.785 Intentionally blank

JAR-OPS 1.790 Hand fire extinguishers
(See AMC OPS 1.790)

An operator shall not operate an aeroplane unless hand fire extinguishers are provided for use in crew, passenger and, as applicable, cargo compartments and galleys in accordance with the following:

(a) The type and quantity of extinguishing agent must be suitable for the kinds of fires likely to occur in the compartment where the extinguisher is intended to be used and, for personnel compartments, must minimise the hazard of toxic gas concentration;

(b) At least one hand fire extinguisher, containing Halon 1211 (bromochlorodifluoro-methane, $CBrClF_2$), or equivalent as the extinguishing agent, must be conveniently located on the flight deck for use by the flight crew;

JAR-OPS 1.790 (continued)

(c) At least one hand fire extinguisher must be located in, or readily accessible for use in, each galley not located on the main passenger deck;

(d) At least one readily accessible hand fire extinguisher must be available for use in each Class A or Class B cargo or baggage compartment and in each Class E cargo compartment that is accessible to crew members in flight; and

(e) At least the following number of hand fire extinguishers must be conveniently located in the passenger compartment(s):

Maximum approved passenger seating configuration	Number of Extinguishers
7 to 30	1
31 to 60	2
61 to 200	3
201 to 300	4
301 to 400	5
401 to 500	6
501 to 600	7
601 or more	8

When two or more extinguishers are required, they must be evenly distributed in the passenger compartment.

(f) At least one of the required fire extinguishers located in the passenger compartment of an aeroplane with a maximum approved passenger seating configuration of at least 31, and not more than 60, and at least two of the fire extinguishers located in the passenger compartment of an aeroplane with a maximum approved passenger seating configuration of 61 or more must contain Halon 1211 (bromochlorodi-fluoromethane, $CBrClF_2$), or equivalent as the extinguishing agent.

JAR-OPS 1.795 Crash axes and crowbars

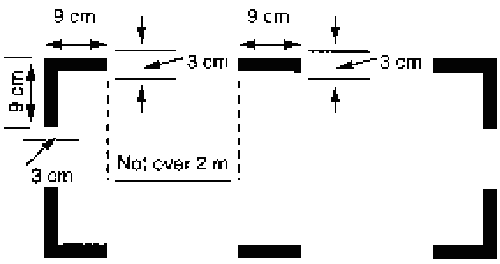
(a) An operator shall not operate an aeroplane with a maximum certificated take-off mass exceeding 5 700 kg or having a maximum approved passenger seating configuration of more than 9 seats unless it is equipped with at least one crash axe or crowbar located on the flight deck. If the maximum approved passenger seating configuration is more than 200 an additional crash axe or crowbar must be carried and located in or near the most rearward galley area.

JAR-OPS 1.795 (continued)

(b) Crash axes and crowbars located in the passenger compartment must not be visible to passengers.

JAR-OPS 1.800 Marking of break-in points

An operator shall ensure that, if areas of the fuselage suitable for break-in by rescue crews in emergency are marked on an aeroplane, such areas shall be marked as shown below. The colour of the markings shall be red or yellow, and if necessary they shall be outlined in white to contrast with the background. If the corner markings are more than 2 metres apart, intermediate lines 9 cm x 3 cm shall be inserted so that there is no more than 2 metres between adjacent marks.



[Amdt. 3, 01.12.01]

JAR-OPS 1.805 Means for emergency evacuation

(a) An operator shall not operate an aeroplane with passenger emergency exit sill heights:

(1) Which are more than 1·83 metres (6 feet) above the ground with the aeroplane on the ground and the landing gear extended; or

(2) Which would be more than 1·83 metres (6 feet) above the ground after the collapse of, or failure to extend of, one or more legs of the landing gear and for which a Type Certificate was first applied for on or after 1 April 2000, unless it has equipment or devices available at each exit, where sub-paragraphs (1) or (2) apply, to enable passengers and crew to reach the ground safely in an emergency.

(b) Such equipment or devices need not be provided at overwing exits if the designated place on the aeroplane structure at which the escape route terminates is less than 1·83 metres (6 feet) from the ground with the aeroplane on the ground, the landing gear extended, and the flaps in the take off or landing position, whichever flap position is higher from the ground.

JAR-OPS 1.805 (continued)

(c) In aeroplanes required to have a separate emergency exit for the flight crew and:

(1) For which the lowest point of the emergency exit is more than 1·83 metres (6 feet) above the ground with the landing gear extended; or,

(2) For which a Type Certificate was first applied for on or after 1 April 2000, would be more than 1·83 metres (6 ft) above the ground after the collapse of, or failure to extend of, one or more legs of the landing gear, there must be a device to assist all members of the flight crew in descending to reach the ground safely in an emergency.

JAR-OPS 1.810 Megaphones
(See AMC OPS 1.810)

(a) An operator shall not operate an aeroplane with a maximum approved passenger seating configuration of more than 60 and carrying one or more passengers unless it is equipped with portable battery-powered megaphones readily accessible for use by crew members during an emergency evacuation, to the following scales:

(1) For each passenger deck:

Passenger seating configuration	Number of Megaphones Required
61 to 99	1
100 or more	2

(2) For aeroplanes with more than one passenger deck, in all cases when the total passenger seating configuration is more than 60, at least 1 megaphone is required.

JAR-OPS 1.815 Emergency lighting

(a) An operator shall not operate a passenger carrying aeroplane which has a maximum approved passenger seating configuration of more than 9 unless it is provided with an emergency lighting system having an independent power supply to facilitate the evacuation of the aeroplane. The emergency lighting system must include:

(1) For aeroplanes which have a maximum approved passenger seating configuration of more than 19:

(i) Sources of general cabin illumination;

JAR-OPS 1.815(a)(1) (continued)

(ii) Internal lighting in floor level emergency exit areas; and

(iii) Illuminated emergency exit marking and locating signs.

(iv) For aeroplanes for which the application for the type certificate or equivalent was filed in a JAA Member State before 1 May 1972, and when flying by night, exterior emergency lighting at all overwing exits, and at exits where descent assist means are required.

(v) For aeroplanes for which the application for the type certificate or equivalent was filed in a JAA Member State on or after 1 May 1972, and when flying by night, exterior emergency lighting at all passenger emergency exits.

(vi) For aeroplanes for which the type certificate was first issued in a JAA Member State on or after 1 January 1958, floor proximity emergency escape path marking system in the passenger compartment(s).

(2) For aeroplanes which have a maximum approved passenger seating configuration of 19 or less and are certificated to JAR-23 or JAR-25:

(i) Sources of general cabin illumination;

(ii) Internal lighting in emergency exit areas; and

(iii) Illuminated emergency exit marking and locating signs.

(3) For aeroplanes which have a maximum approved passenger seating configuration of 19 or less and are not certificated to JAR-23 or JAR-25, sources of general cabin illumination.

(b) After 1 April 1998 an operator shall not, by night, operate a passenger carrying aeroplane which has a maximum approved passenger seating configuration of 9 or less unless it is provided with a source of general cabin illumination to facilitate the evacuation of the aeroplane. The system may use dome lights or other sources of illumination already fitted on the aeroplane and which are capable of remaining operative after the aeroplane's battery has been switched off.

[Amdt. 7, 01.09.04]

JAR-OPS 1.820 Emergency Locator Transmitter
(See [ACJ] OPS 1.820)

(a) An operator shall not operate an aeroplane first issued with an individual certificate of airworthiness on or after 1 January 2002 unless it is equipped with an automatic Emergency Locator Transmitter (ELT) capable of transmitting on 121·5 MHz and 406 MHz.

(b) An operator shall not operate on or after 1 January 2002 an aeroplane first issued with an individual Certificate of Airworthiness before 1 January 2002 unless it is equipped with any type of ELT capable of transmitting on 121·5 MHz and 406 MHz, except that aeroplanes equipped on or before 1 April 2000 with an automatic ELT transmitting on 121·5 MHz but not on 406 MHz may continue in service until 31 December 2004.

(c) An operator shall ensure that all ELTs that are capable of transmitting on 406 MHz shall be coded in accordance with ICAO Annex 10 and registered with the national agency responsible for initiating Search and Rescue or another nominated agency.

[Amdt. 2, 01.07.00; Amdt. 9, 01.09.05]

JAR-OPS 1.825 Life Jackets
(See IEM OPS 1.825)

(a) *Land aeroplanes*. An operator shall not operate a land aeroplane:

(1) When flying over water and at a distance of more than 50 nautical miles from the shore; or

(2) When taking off or landing at an aerodrome where the take-off or approach path is so disposed over water that in the event of a mishap there would be a likelihood of a ditching,

unless it is equipped with life jackets equipped with a survivor locator light, for each person on board. Each life jacket must be stowed in a position easily accessible from the seat or berth of the person for whose use it is provided. Life jackets for infants may be substituted by other approved flotation devices equipped with a survivor locator light.

(b) *Seaplanes and amphibians*. An operator shall not operate a seaplane or an amphibian on water unless it is equipped with life jackets equipped with a survivor locator light, for each person on board. Each life jacket must be stowed in a position easily accessible from the seat or berth of the person for whose use it is provided. Life jackets for infants may be substituted by other approved flotation devices equipped with a survivor locator light.

JAR-OPS 1.830 Life - rafts and survival ELTs for extended overwater flights

(a) On overwater flights, an operator shall not operate an aeroplane at a distance away from land, which is suitable for making an emergency landing, greater than that corresponding to:

(1) 120 minutes at cruising speed or 400 nautical miles, whichever is the lesser, for aeroplanes capable of continuing the flight to an aerodrome with the critical power unit(s) becoming inoperative at any point along the route or planned diversions; or

(2) 30 minutes at cruising speed or 100 nautical miles, whichever is the lesser, for all other aeroplanes,

unless the equipment specified in sub-paragraphs (b) and (c) below is carried.

(b) Sufficient life-rafts to carry all persons on board. Unless excess rafts of enough capacity are provided, the buoyancy and seating capacity beyond the rated capacity of the rafts must accommodate all occupants of the aeroplane in the event of a loss of one raft of the largest rated capacity. The life-rafts shall be equipped with:

(1) A survivor locator light; and

(2) Life saving equipment including means of sustaining life as appropriate to the flight to be undertaken (see AMC OPS 1.830(b)(2)); and

(c) At least two survival Emergency Locator Transmitters (ELT(S)) capable of transmitting on the distress frequencies prescribed in ICAO Annex 10, Volume V, Chapter 2. (See [ACJ OPS 1.820]).

[Ch. 1, 01.03.98; Amdt. 9, 01.09.05]

JAR-OPS 1.835 Survival equipment (See IEM OPS 1.835)

An operator shall not operate an aeroplane across areas in which search and rescue would be especially difficult unless it is equipped with the following:

(a) Signalling equipment to make the pyrotechnical distress signals described in ICAO Annex 2;

(b) At least one ELT(S) capable of transmitting on the distress frequencies prescribed in ICAO Annex 10, Volume V, Chapter 2 (See [ACJ OPS 1.820]); and

(c) Additional survival equipment for the route to be flown taking account of the number of persons

JAR-OPS 1.835(c) (continued)

on board (See AMC OPS 1.835(c)), except that the equipment specified in sub-paragraph (c) need not be carried when the aeroplane either:

(1) Remains within a distance from an area where search and rescue is not especially difficult corresponding to:

(i) 120 minutes at the one engine inoperative cruising speed for aeroplanes capable of continuing the flight to an aerodrome with the critical power unit(s) becoming inoperative at any point along the route or planned diversions; or

(ii) 30 minutes at cruising speed for all other aeroplanes,

or,

(2) For aeroplanes certificated to JAR-25 or equivalent, no greater distance than that corresponding to 90 minutes at cruising speed from an area suitable for making an emergency landing.

[Ch. 1, 01.03.98; Amdt. 9, 01.09.05]

JAR-OPS 1.840 Seaplanes and amphibians – Miscellaneous equipment

(a) An operator shall not operate a seaplane or an amphibian on water unless it is equipped with:

(1) A sea anchor and other equipment necessary to facilitate mooring, anchoring or manoeuvring the aircraft on water, appropriate to its size, weight and handling characteristics; and

(2) Equipment for making the sound signals prescribed in the International Regulations for preventing collisions at sea, where applicable.

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Appendix 1 to JAR-OPS 1.715
Flight data recorders - 1 - List of parameters to be recorded

Table A1 - Aeroplanes with a maximum certificated take-off mass of over 5 700 kg

Note: The number in the left hand column reflect the Serial Numbers depicted in EUROCAE document ED55

No.	Parameter
1	Time or relative time count
2	Pressure altitude
3	Indicated airspeed
4	Heading
5	Normal acceleration
6	Pitch attitude
7	Roll attitude
8	Manual radio transmission keying
9	Propulsive thrust/ power on each engine and cockpit thrust/power lever position if applicable
10	Trailing edge flap or cockpit control selection
11	Leading edge flap or cockpit control selection
12	Thrust reverse status
13	Ground spoiler position and/or speed brake selection
14	Total or outside air temperature
15	Autopilot, autothrottle and AFCS mode and engagement status
16	Longitudinal acceleration (Body axis)
17	Lateral acceleration

Table A2 - Aeroplanes with a maximum certificated take-off mass of 5 700 kg or below

Note: The number in the left hand column reflect the Serial Numbers depicted in EUROCAE document ED55

No.	Parameter
1	Time or relative time count
2	Pressure altitude
3	Indicated airspeed
4	Heading
5	Normal acceleration
6	Pitch attitude
7	Roll attitude
8	Manual radio transmission keying
9	Propulsive thrust/ power on each engine and cockpit thrust/power lever position if applicable

Appendix 1 to JAR-OPS 1.715 (continued)

10	Trailing edge flap or cockpit control selection
11	Leading edge flap or cockpit control selection
12	Thrust reverse status
13	Ground spoiler position and/or speed brake selection
14	Total or outside air temperature.
15	Autopilot/autothrottle engagement status
16	Angle of attack (if a suitable sensor is available)
17	Longitudinal acceleration (Body axis)

Table B - Additional parameters for aeroplanes with a maximum certificated take-off mass of over 27 000 kg

Note: The number in the left hand column reflect the Serial Numbers depicted in EUROCAE document ED55

No.	Parameter
18	Primary flight controls - Control surface position and/or pilot input (pitch, roll, yaw)
19	Pitch trim position
20	Radio altitude
21	Vertical beam deviation (ILS Glide path or MLS Elevation)
22	Horizontal beam deviation (ILS Localiser or MLS Azimuth)
23	Marker Beacon Passage
24	Warnings
25	Reserved (Navigation receiver frequency selection is recommended)
26	Reserved (DME distance is recommended)
27	Landing gear squat switch status or air/ground status
28	Ground Proximity Warning System
29	Angle of attack
30	Low pressure warning (hydraulic and pneumatic power)
31	Groundspeed
32	Landing gear or gear selector position

Table C - Aeroplanes equipped with electronic display systems

Note: The number in the centre column reflect the Serial Numbers depicted in EUROCAE document ED55 table A1.5

No.	No.	Parameter
33	6	Selected barometric setting (Each pilot station)
34	7	Selected altitude

Appendix 1 to JAR-OPS 1.715 (continued)

35	8	Selected speed
36	9	Selected mach
37	10	Selected vertical speed
38	11	Selected heading
39	12	Selected flight path
40	13	Selected decision height
41	14	EFIS display format
42	15	Multi function /Engine / Alerts display format

[Amdt. 4, 01.07.02]

Appendix 1 to JAR-OPS 1.720
Flight data recorders - 2 - List of parameters to be recorded

Table A - Aeroplanes with a maximum certificated take-off mass of over 5 700 Kg

No	Parameter
1	Time or relative time count
2	Pressure altitude
3	Indicated Airspeed
4	Heading
5	Normal Acceleration
6	Pitch attitude
7	Roll attitude
8	Manual radio transmission keying unless an alternate means to synchronise FDR and CVR recordings is provided
9	Power on each engine
10	Trailing edge flap or cockpit control selection
11	Leading edge flap or cockpit control selection
12	Thrust reverse position (for turbojet aeroplanes only)
13	Ground spoiler position and/or speed brake selection
14	Outside air temperature or Total Air Temperature
15a 15b	Autopilot engagement status Autopilot operating modes, autothrottle and AFCS systems engagement status and operating modes.

Table B - Additional parameters for aeroplanes with a maximum certificated take-off mass over 27 000 kg

No	Parameter
16	Longitudinal acceleration
17	Lateral acceleration
18	Primary flight controls - Control surface position and/or pilot input (pitch, roll and yaw)
19	Pitch trim position
20	Radio altitude
21	Glide path deviation
22	Localiser deviation
23	Marker beacon passage
24	Master warning
25	NAV 1 and NAV 2 frequency selection
26	DME 1 and DME 2 distance

Appendix 1 to JAR-OPS 1.720 (continued)

27	Landing gear squat switch status
28	Ground proximity warning system
29	Angle of attack
30	Hydraulics, each system (low pressure)
31	Navigation data
32	Landing gear or gear selector position

[Amdt 4, 01.07.02]

Appendix 1 to JAR-OPS 1.725
Flight data recorders - 3 - List of parameters to be recorded

Table A - Aeroplanes with a maximum certificated take-off mass of over 5 700 Kg

No	Parameter
1	Time or relative time count
2	Pressure altitude
3	Indicated Airspeed
4	Heading
5	Normal Acceleration

Table B – Additional parameters for aeroplanes with a maximum certificated take-off mass of over 27 000 kg

No	Parameter
6	Pitch attitude
7	Roll attitude
8	Manual radio transmission keying unless an alternate means to synchronise the FDR and CVR recordings is provided
9	Power on each engine
10	Trailing edge flap or cockpit control selection
11	Leading edge flap or cockpit control selection
12	Thrust reverse position (for turbojet aeroplanes only)
13	Ground spoiler position and/or speed brake selection
14	Outside air temperature or Total air temperature
15a 15b	Autopilot engagement status Autopilot operating modes, autothrottle and AFCS, systems engagement status and operating modes.
16	Longitudinal acceleration
17	Lateral acceleration
18	Primary flight controls – Control surface position and/or pilot input (pitch, roll and yaw)
19	Pitch trim position
20	Radio altitude
21	Glide path deviation
22	Localiser deviation
23	Marker beacon passage
24	Master warning
25	NAV 1 and NAV 2 frequency selection
26	DME 1 and DME 2 distance

Appendix 1 to JAR-OPS 1.725 (continued)

27	Landing gear squat switch status
28	Ground proximity warning system
29	Angle of attack
30	Hydraulics, each system (low pressure)
31	Navigation data (latitude, longitude, ground speed and drift angle)
32	Landing gear or gear selector position

[Amdt 4, 01.07.02]

Appendix 1 to JAR–OPS 1.770
Oxygen – Minimum Requirements for Supplemental Oxygen for Pressurised Aeroplanes (Note 1)

(a) SUPPLY FOR:	(b) DURATION AND CABIN PRESSURE ALTITUDE
1. All occupants of flight deck seats on flight deck duty	Entire flight time when the cabin pressure altitude exceeds 13 000 ft and entire flight time when the cabin pressure altitude exceeds 10 000 ft but does not exceed 13 000 ft after the first 30 minutes at those altitudes, but in no case less than: (i) 30 minutes for aeroplanes certificated to fly at altitudes not exceeding 25 000 ft (Note 2) (ii) 2 hours for aeroplanes certificated to fly at altitudes more than 25 000 ft (Note 3).
2. All required cabin crew members	Entire flight time when cabin pressure altitude exceeds 13 000 ft but not less than 30 minutes (Note 2), and entire flight time when cabin pressure altitude is greater than 10 000 ft but does not exceed 13 000 ft after the first 30 minutes at these altitudes.
3. 100% of passengers (Note 5)	Entire flight time when the cabin pressure altitude exceeds 15 000 ft but in no case less than 10 minutes.(Note 4)
4. 30% of passengers (Note 5)	Entire flight time when the cabin pressure altitude exceeds 14 000 ft but does not exceed 15 000 ft.
5. 10% of passengers (Note 5)	Entire flight time when the cabin pressure altitude exceeds 10 000 ft but does not exceed 14 000 ft after the first 30 minutes at these altitudes.

Note 1: The supply provided must take account of the cabin pressure altitude and descent profile for the routes concerned.

Note 2: The required minimum supply is that quantity of oxygen necessary for a constant rate of descent from the aeroplane's maximum certificated operating altitude to 10 000 ft in 10 minutes and followed by 20 minutes at 10 000 ft.

Note 3: The required minimum supply is that quantity of oxygen necessary for a constant rate of descent from the aeroplane's maximum certificated operating altitude to 10 000 ft in 10 minutes and followed by 110 minutes at 10 000 ft. The oxygen required in JAR–OPS 1.780(a)(1) may be included in determining the supply required.

Note 4: The required minimum supply is that quantity of oxygen necessary for a constant rate of descent from the aeroplane's maximum certificated operating altitude to 15 000 ft in 10 minutes.

Note 5: For the purpose of this table 'passengers' means passengers actually carried and includes infants.

Appendix 1 to JAR–OPS 1.775
Supplemental Oxygen for non-pressurised Aeroplanes

Table 1

(a) SUPPLY FOR:		(b) DURATION AND PRESSURE ALTITUDE
1.	All occupants of flight deck seats on flight deck duty	Entire flight time at pressure altitudes above 10 000 ft
2.	All required cabin crew members	Entire flight time at pressure altitudes above 13 000 ft and for any period exceeding 30 minutes at pressure altitudes above 10 000 ft but not exceeding 13 000 ft
3.	100% of passengers (See Note)	Entire flight time at pressure altitudes above 13 000 ft.
4.	10% of passengers (See Note)	Entire flight time after 30 minutes at pressure altitudes greater than 10 000 ft but not exceeding 13 000 ft.

Note: For the purpose of this table 'passengers' means passengers actually carried and includes infants under the age of 2.

CHAPTER FIFTEEN

AIRCRAFT OXYGEN EQUIPMENT

Contents

INTRODUCTION

In order for the body to function satisfactorily it requires oxygen which it extracts from oxygenated blood provided by the lungs.

Insufficient oxygen is known as **Hypoxia**. **The importance of aircrew being able to recognise Hypoxia cannot be overstated**.

Knowledge of the signs and symptoms and early identification of the problem will allow the correct drills to be carried out before anyone is placed in jeopardy but it is important that these drills are well learnt and easily accomplished.

The drills to overcome this can be summarised as:

- Provide Oxygen.
- Descend to a level where atmospheric oxygen is present in sufficient quantities to meet the body's needs.

Aircrew **must** familiarise themselves with the appropriate oxygen drills for the aircraft they are flying before venturing above an altitude at which Hypoxia can occur i.e. above 10,000 ft.

The symptoms of hypoxia can be summarised as follows:

- Apparent Personality Change
- Impaired Judgement
- Muscular Impairment
- Memory Impairment
- Sensory Loss

Impairment of Consciousness i.e. confusion, semi-consciousness, unconsciousness and finally **DEATH.**

TIME OF USEFUL CONSCIOUSNESS

This is the time available for a pilot/flight engineer to recognise the development of Hypoxia and do something about it. It is not the time to unconsciousness but the shorter time from a reduction in adequate oxygen until a specific degree of impairment, generally taken to be the point when the individual can no longer take steps to help him/herself.

Time of Useful Consciousness	
Altitude	Time
18,000 ft	30 minutes approx.
25,000 ft	5 to 3 minutes
30,000 ft	90 to 45 seconds
35,000 ft	45 to 30 seconds
45,000 ft	About 12 seconds

A more detailed study of Hypoxia can be found in Book 8 - Human Performance and Limitations.

Pressurised aircraft are therefore fitted with oxygen systems to provide the crew with oxygen:

- if the cabin pressure altitude exceeds 13,000 ft, or more than 30 minutes at cabin pressure altitudes of between 10,000 ft and 13,000 ft

- if hazardous fumes enter the flight deck, and

- if the cabin pressure altitude exceeds 15,000 ft, to provide all the passengers with oxygen, above 14,000 ft 30% of passengers and above 10,000 ft 10% of passengers. **See JAR OPS 1 sub part K appendix 1 to JAR-OPS 1.770 and appendix 1 to JAR-OPS 1.775.**

AVAILABLE SYSTEMS
(JAR - OPS 1 Subpart K)

Portable oxygen sets are provided in addition for therapeutic use by passengers and for use by cabin staff during emergencies. Special smoke sets may also be provided for crew use.

In unpressurised aircraft, oxygen equipment will be installed for the use of passengers and crew if the aircraft is to fly above 10,000 ft with portable oxygen sets being provided if no fixed installation exists.

Crew oxygen is stored in High Pressure gaseous form whilst passenger supplies may be of HP gas or be chemically generated. Gaseous oxygen systems are generally of the **diluter demand** type for crew use and the **continuous flow** type for passenger use, although some smaller aircraft may have the continuous flow type for crew use as well. In both systems the gas is stored in cylinders at 1800psi, the pressure being reduced to a suitable level for use.

Quantity (pressure) indication is provided by a gauge on the flight compartment. In the event of an over-pressure the cylinder is vented to atmosphere through a safety (bursting) disc. Indication of this fact is given by a discharge indicator located on the outer skin of the aircraft adjacent to the oxygen storage bottle(s). The cylinders are fitted with “shut-off valves” to enable them to be removed from the aircraft for maintenance purposes.

CONTINUOUS FLOW OXYGEN SYSTEM

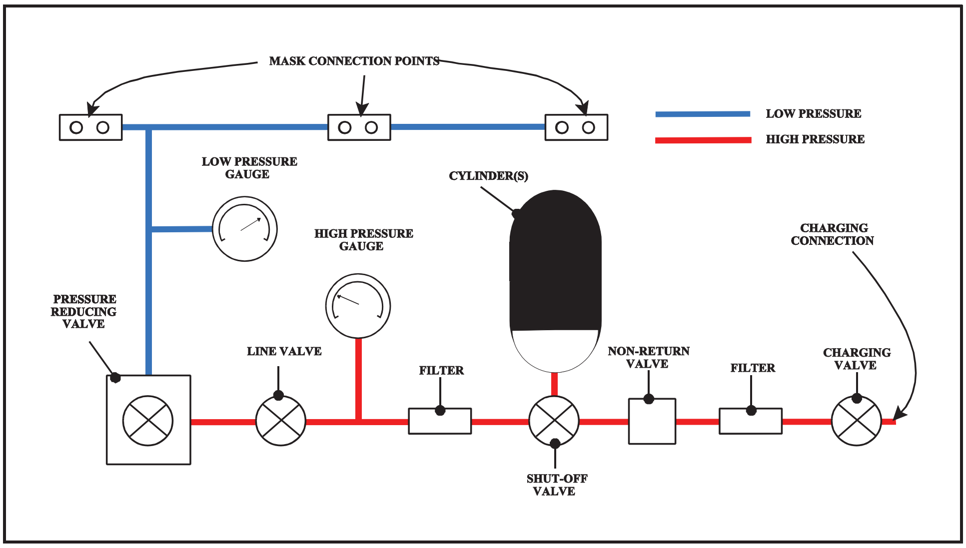


Figure 15.1: Continuous flow oxygen system.

When the shut-off valve and line valve are turned on, high pressure oxygen will flow from the charged cylinder to the Pressure Reducing Valve (PRV).

At the PRV the pressure is reduced to 80-100 psi for supply to the mask connection points, where the pressure is further reduced by the fitting of a calibrated orifice. This ensures that oxygen is supplied at the correct pressure for breathing at a continuous rate when required.

The mask connection points may be of the normal plug-in type or of the drop out type where, in the case of pressurisation failure, the masks are presented automatically and oxygen flow will commence when the passenger puts on the mask.

Continuous flow regulators of the hand adjustable and automatic type may be installed for crew and passenger oxygen supply respectively.

The hand adjustable regulator delivers a continuous stream of oxygen at a rate that can be controlled. The system usually has a pressure gauge, a flow indicator and a manual control knob used to regulate the flow according to the cabin altitude. The gauge indicates the pressure in the cylinder in psi. and the flow indicator is calibrated in terms of cabin altitude.

The user adjusts the manual control knob until the altitude of the flow indicator corresponds to the cabin altimeter setting. Most flow indicators, however, just show that oxygen is flowing through the regulator. They do not show how much is flowing or if the user is being supplied with sufficient oxygen.

DILUTER DEMAND SYSTEM

This type of system is provided in most aircraft for flight crew use and is separate and additional to the passenger system. The system is shown in *Figure 15.2.* Oxygen is diluted with air and supplied as demanded by the users respiration cycle and the oxygen regulator. There is a mask connection point for each crew member and the supernumary crew position.
A typical regulator operates as follows:-

- With the oxygen supply '**ON**' and '**NORMAL**' oxygen selected, diluted oxygen will be supplied to the crew members mask as he/she inhales. As the cabin altitude increases and cabin air pressure decreases the percentage oxygen increases until, at 32,000 ft cabin altitude, 100% oxygen is supplied.
- 100% oxygen will be supplied, regardless of altitude, if the crew member selects 100% O2 on the regulator control panel.
- Selecting '**EMERGENCY**' on the regulator will provide protection against the inhalation of smoke and harmful gases by supplying 100% O2 at a positive pressure.
- When '**TEST**' is selected, oxygen at a high positive pressure is supplied to check masks for fit and other equipment for leakage.

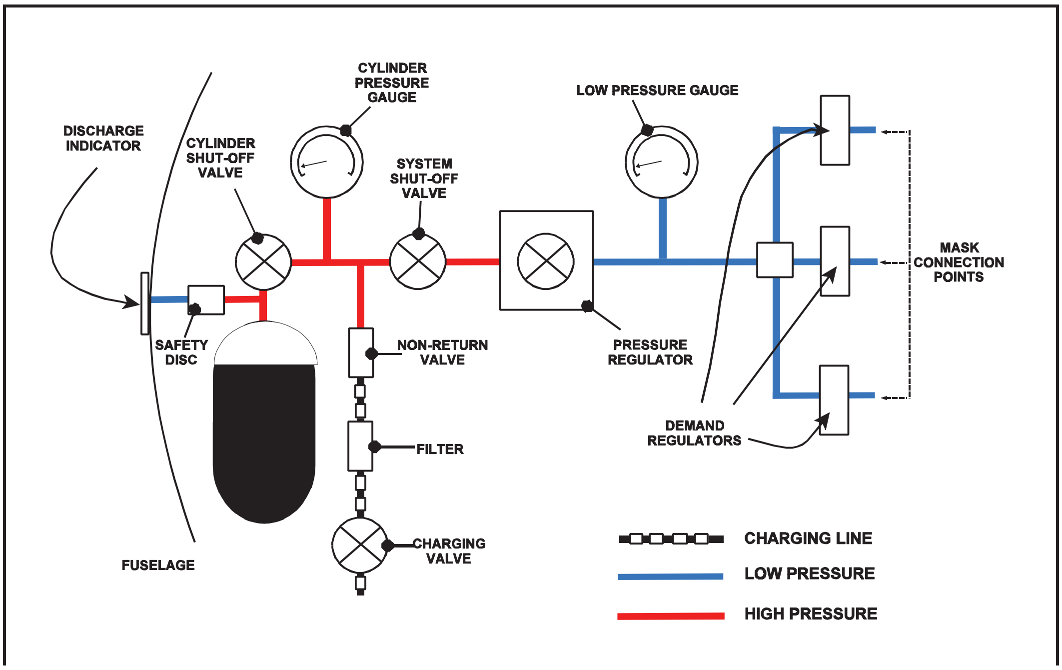


Figure 15.2

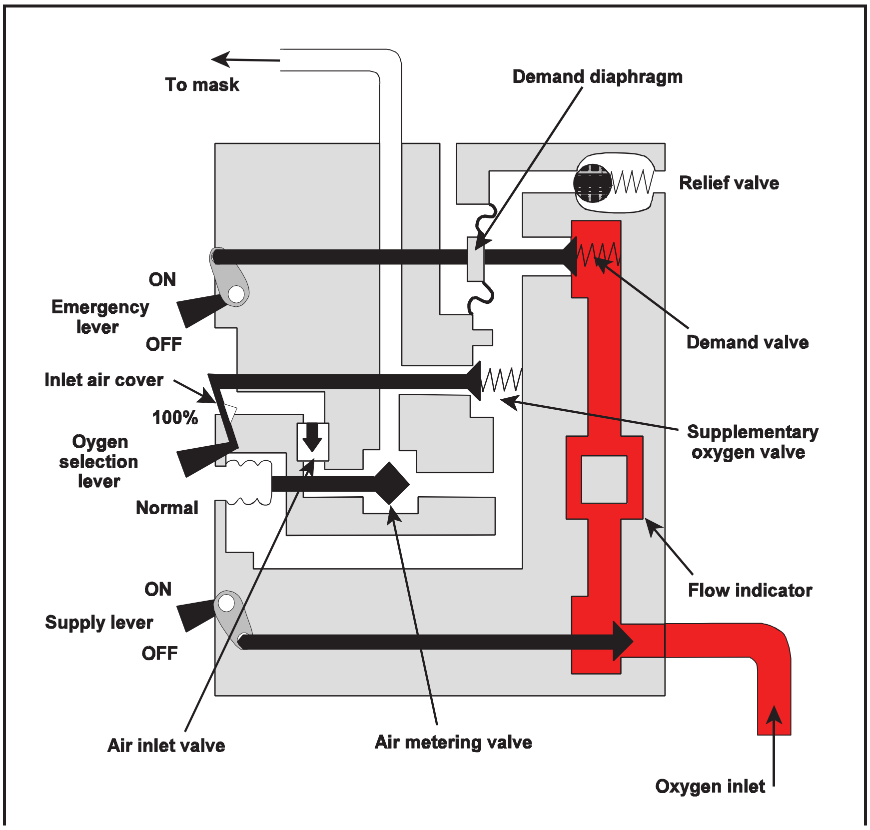


Figure 15.3

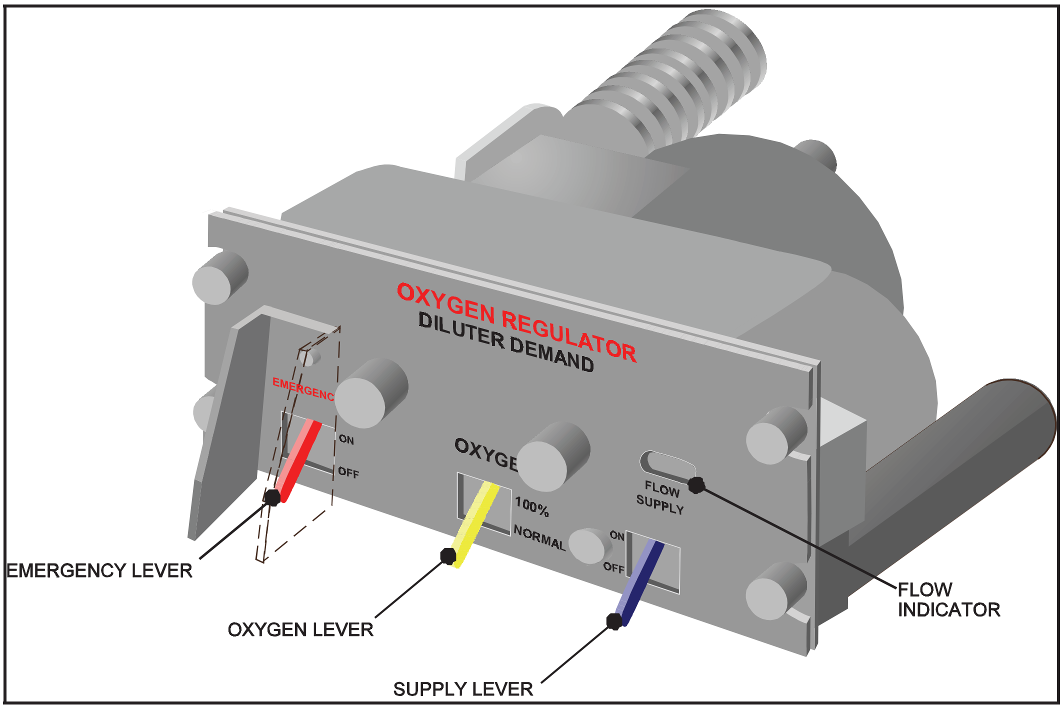


Figure 15.4

NARROW PANEL SYSTEM, NORMAL OPERATION

For normal operation the supply lever is set to "on", the oxygen selection lever to "normal" and the emergency lever is in the "off" position. When the user inhales a differential pressure is created across the demand diaphragm, causing the demand valve to open supplying oxygen to the mask. This pressure differential exists during the user's inhalation cycle. After passing through the demand valve , the oxygen is mixed with air that enters through the air inlet port. The mixture ratio is determined by an aneroid controlled air metering valve which provides a high air ratio at low altitudes and a high oxygen ratio at high altitudes. Airflow begins at the same time as oxygen flow through the air inlet valve.

Moving the oxygen selector lever to 100% cuts off the air supply through the inlet port from the flight compartment. This prevents fumes etc. from entering the mask.

Selecting the emergency lever to the "on" position mechanically loads the demand diaphragm to provide positive pressure.

EMERGENCY REGULATING OXYGEN SYSTEM (EROS) CREW OXYGEN MASKS

These are combined masks and regulators fitted at each crew station to provide the flight crew with diluted or 100% oxygen. They are stowed in a panel mounted box in such a way that the regulator controls and the feed hose protrude through apertures in the stowage doors. When the mask/regulator is stowed and the box doors closed, oxygen flow to the mask is prevented by a shut-off valve inside the box, this valve being held closed by the Reset-Test Lever on the left door. The flow indicator is visible with the doors open or closed. The pneumatic harness that holds the mask to the face is deflated when stowed . The harness fits all head sizes. It is a requirement(JAR OPS 1 sub part K) that these quick donning masks must be provided for the flight deck crew on all aircraft that have a maximum operating altitude above 25,000 ft.

CONTROL

The control for normal or 100% oxygen flow is on the front of the regulator, marked **N** and **100% PUSH**. 100% oxygen is obtained by pushing in on the end of the of the control marked 100% push.

The **EMERGENCY** control knob changes the flow from diluter demand to steady flow if it is rotated to the emergency setting.

OPERATION

The mask is withdrawn by grasping the red release grips between thumb and forefinger. This action initiates inflation of the harness, the inflated condition assisting its rapid donning. Subsequent release of the grips bleeds pressure from the harness, which will now form fit the head. The masks include R/T communication facilities and can be modified to include a mask ventilation feature which, when selected, will provide ventilation to the smoke goggles in order to overcome misting problems.

TESTING

The emergency knob is also marked **PRESS TO TEST**. When pressed together with the **RESET-TEST** lever, it allows oxygen to flow into the mask. Flow is checked on the flow indicator.

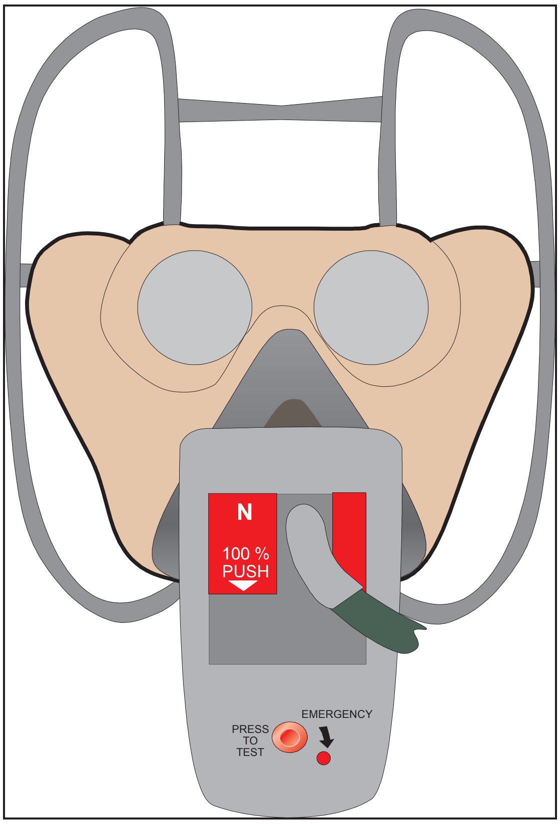


Figure 15.5: EROS oxygen mask.

PASSENGER OXYGEN SYSTEM

Provides an emergency oxygen supply to the passengers and cabin attendants and isof the continuous flow type supplied either by a high presssure gaseous system or a chemical generator system. The masks are stowed in the passenger service units (PSU), the doors of which will open automatically by a barometrically controlled release mechanism if the cabin altitude reaches 14,000 ft or by manual selection from the flight by the crew at any altitude below this. The release mechanism is actuated electrically for the chemical generator system and pneumatically for the gaseous system.

When the PSU doors open the masks drop to the "half-hung" position. Pulling the mask towards the face initiates the oxygen flow by opening a check valve on the gas supplied system or operating the electrical or percussion cap firing mechanism on the chemical generator. The masks are now ready for use.

CHEMICAL OXYGEN GENERATORS

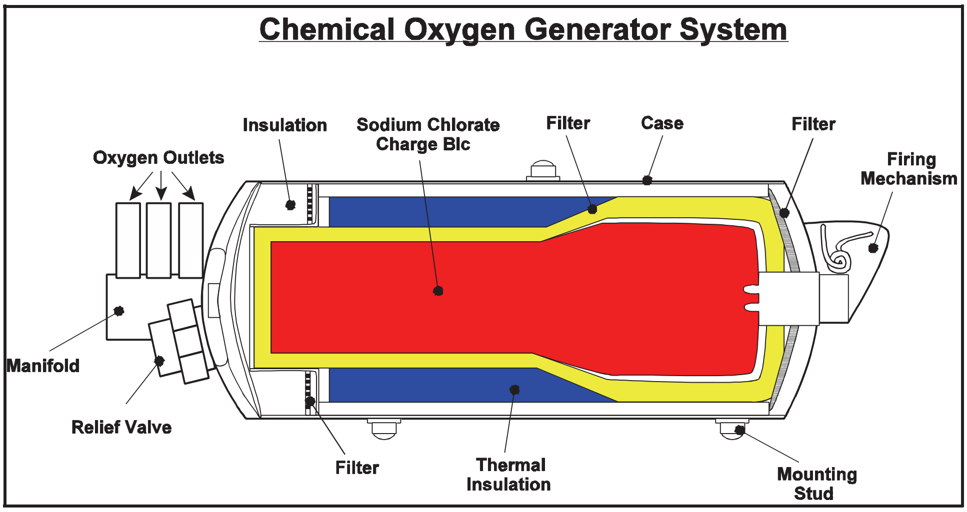


Figure 15.6

The generators are relatively light self-contained devices and are located in each passenger, cabin attendants and lavatory service units. Oxygen is generated by the chemical reaction of sodium chlorate ($NaClO_3$) and iron (Fe). The complete reaction is $NaClO_3$ + FeNaCl + FeO + $\mathbf{O_2}$. The sodium chlorate and iron core is shaped to provide maximum oxygen flow at starting.

A filter in the generator removes any contaminates and cools the oxygen to a temperature not exceeding 10°C above cabin ambient temperature. A relief valve prevents the internal pressure in the generator exceeding 50psi.the normal flow pressure is 10psi. Sufficient oxygen is supplied from the generator to meet the requirements of descent in emergency conditions (min of 15 mins). There has now been developed a Chemical Generator which lasts for a period of 22 minutes

Caution. Once the chemical reaction has started, it cannot be stopped. Surface temperatures of the generator can reach 232°C (450°F). A strip of heat sensitive tape or paint changes colour, usually to black, when the generator is used and provides visual indication that the generator is expended. Chemical generators have a shelf/installed life of ten years.

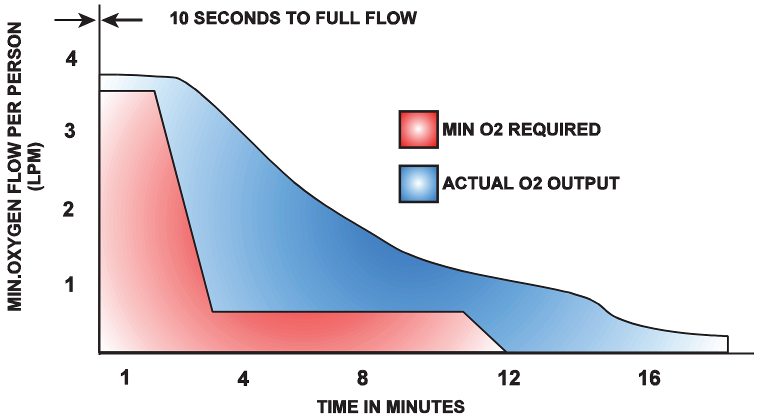


Figure 15.7: Oxygen flow profile for a chemical oxygen generator.

PORTABLE OXYGEN SYSTEMS

First aid and sustaining portable oxygen cylinders are installed at suitable locations in the passenger cabin. They consist of a cylinder containing normally 120 litres of oxygen at a pressure of 1800psi in a carrying bag with straps. It is usually possible to set one of two flow rates depending on requirement. These are Normal and High which correspond to flow rates of 2 and 4 litres per minute. At these rates a 120 litre bottle would last 60 or 30 minutes respectively. 310 litre bottles with four way manifolds for multiple supplies are available with high or medium rates as above.

CREW PORTABLE OXYGEN SYSTEMS AND SMOKE HOODS

Standard portable oxygen bottles can be used by the crew to enable them to move about the cabin during reduced cabin pressure situations but for use when harsh env ironm en tal conditions exist portable sets with a full face smoke mask will be used. They may be standard cylinders or may be special smoke sets with built in generators which can produce oxygen for 15 minutes once initiated. Special training is required prior to use and they are not suitable for passengers.

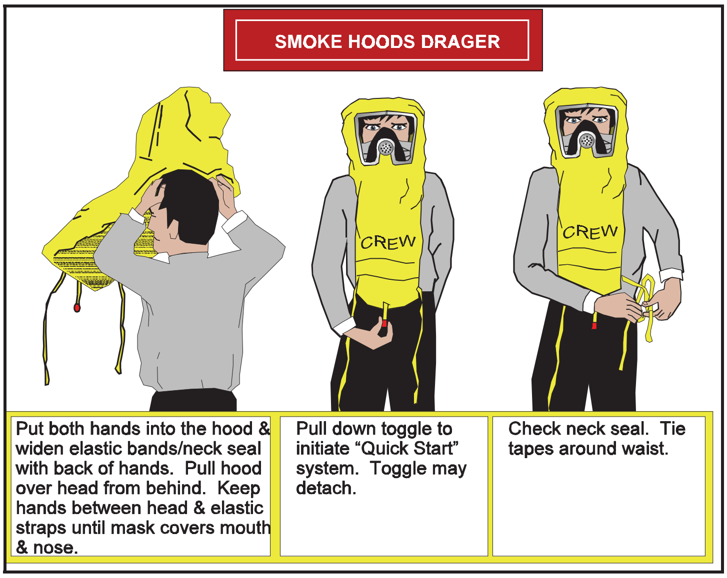


Figure 15.8: Smoke hoods (Drager).

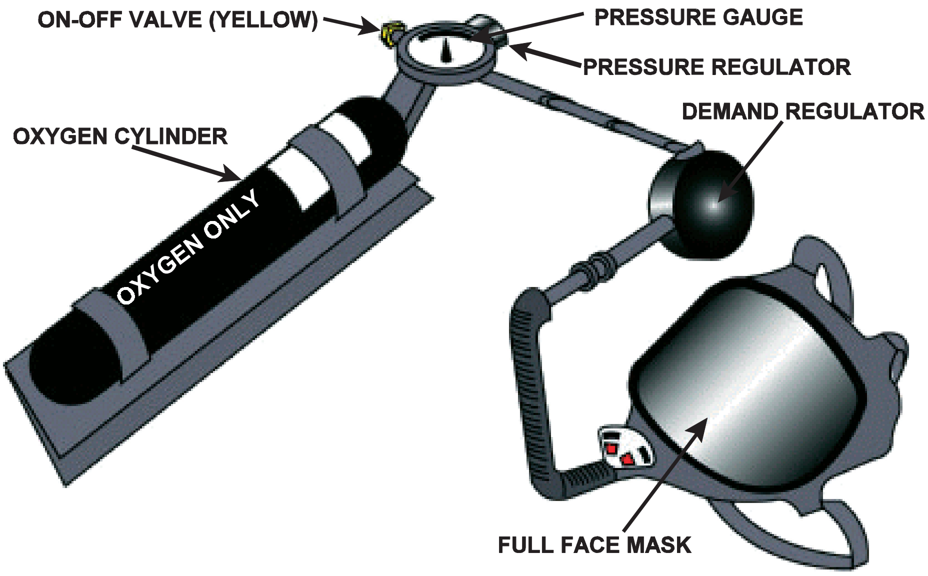


Figure 15.9: Crew portable oxygen.

SAFETY PRECAUTIONS

The following general safety precautions apply to all oxygen systems. Specific precautions for individual aircraft types are contained in the appropriate aircraft manual and flight crew should familiarise themselves with the safety precautions for the type.

- Oxygen is a non flammable heavier than air gas which **supports** combustion as well as life. Any flammable material will burn more fiercely in the presence of oxygen than in air. Smoking is therefore banned in oxygen rich atmospheres and all combustible materials should be removed from the area of oxygen recharging operations.

- No oil or grease should be allowed to come into contact with oxygen as there is the possibility of a severe chemical reaction and spontaneous combustion. This means that tools, protective clothing, etc. must be free from oil and grease.

- Any moisture present will react with gaseous oxygen and can cause corrosion and the possibility of valves freezing. The oxygen will probably smell “bad” when used. It is therefore essential that aircraft are replenished only with oxygen approved for aviation use.

- During replenishment or maintenance of oxygen systems the surrounding area must be adequately ventilated. Remember that oxygen is heavier than air and will fill low lying areas such as servicing pits, aircraft bilges, etc.

- Only lubricants specified in the maintenance manuals may be used. e.g. graphite.

CHAPTER SIXTEEN

SMOKE DETECTION

Contents

SMOKE DETECTION

Smoke detection systems are employed where it is not possible to keep a bay or compartment (for example cargo or electrical equipment bays) under constant physical surveillance. As a general rule a system of detectors are employed in each compartment/bay which can give remote warnings of smoke, can be tested from the flight deck, and can be re-set when a warning is received in order to verify it.

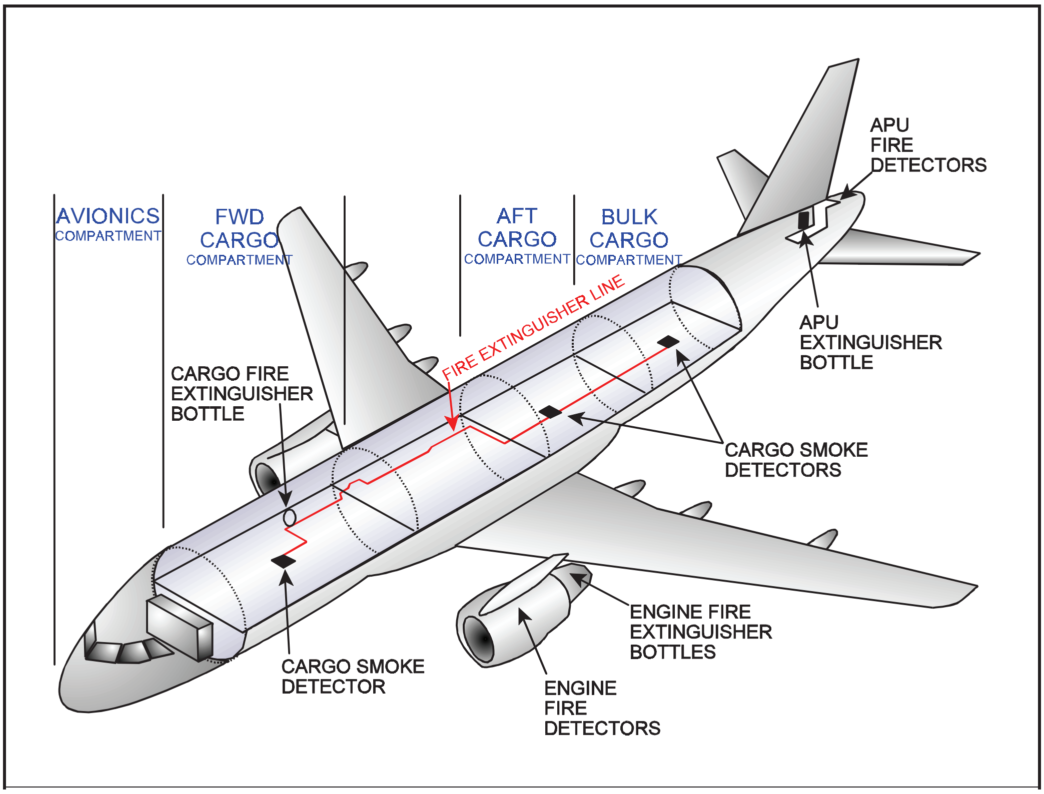


Figure 16.1: Location of smoke detectors.

Smoke and flame detectors operate according to several different principles, for example:

- Light detection
- Light refraction
- Ionisation
- Change in resistance of semiconductor

Light detection system - designed to respond to a change in visible light or a change in infrared radiation. Uses a photoelectric cell positioned so that it can monitor the surrounding area producing a change in current to activate a warning circuit when a change of light or infrared radiation striking the cell occurs. Activated by an open flame.

Light refraction system - shown in *Figure 16.2* uses a photoelectric cell which is shielded from direct light from a projection lamp directed into a detection chamber. Air from the compartment is drawn through the chamber. When smoke is introduced into the chamber light is reflected from the smoke particles and falls on the photoelectric cell. The change of current flow caused by the change in conductivity of the cell activates a visual and aural warning. The test lamp illuminates when the test is selected from the flight deck and activates the smoke detector.

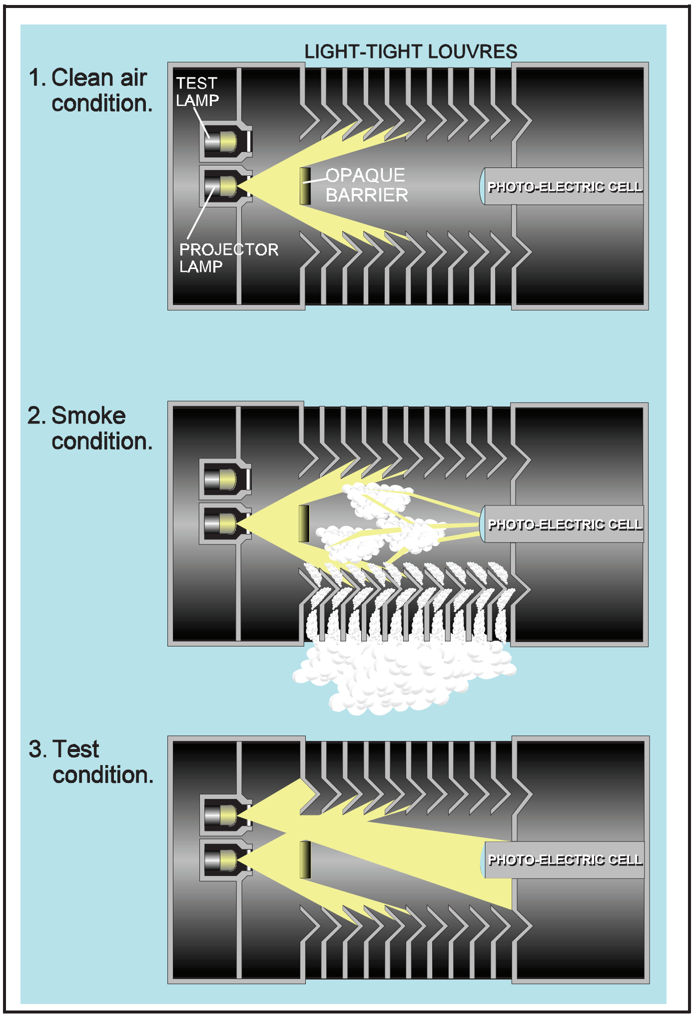


Figure 16.2: Light refraction smoke detector.

Ionisation - uses a small piece of radioactive material to bombard the oxygen and nitrogen molecules in the air inside a detection chamber. Ionisation takes place causing a small current to flow across the chamber and through an external circuit. When smoke is introduced to the chamber the smoke particles attach themselves to the oxygen and nitrogen ions and reduce the current flow which is detected by the external circuit and activates the aural and visual warning.

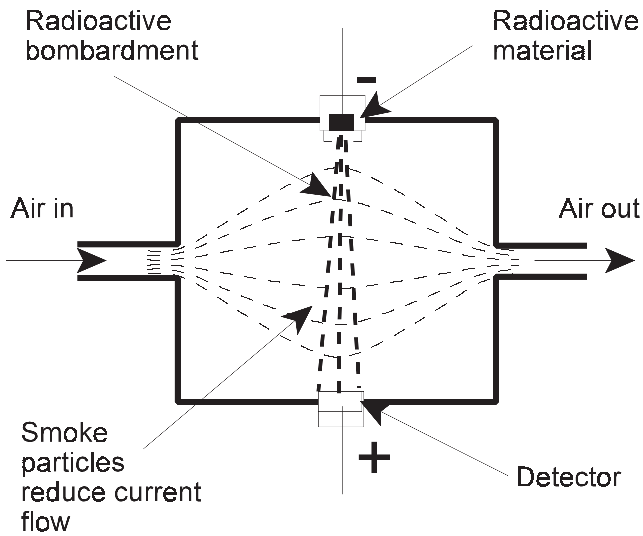


Figure 16.3: Ionisation type smoke detector.

Change in resistance of semiconductor material - uses two heated solid state detecting elements. Each element is enclosed in a coating of semiconductor material. The material will absorb ions of carbon monoxide or nitrous oxide thereby changing the conductivity of the material. The elements are positioned so that one samples air in the cabin and the other samples ambient air. The electrical output of the two elements is compared and if the sensor that is sampling the cabin air absorbs toxic gases due to exposure to smoke or toxic gas then the output of the two sensors is different and the warning will be activated.

Note. *Smoke detectors can give false warnings due to dust, dirt , gaseous emissions such as the discharge from rotting fruit or condensation.*

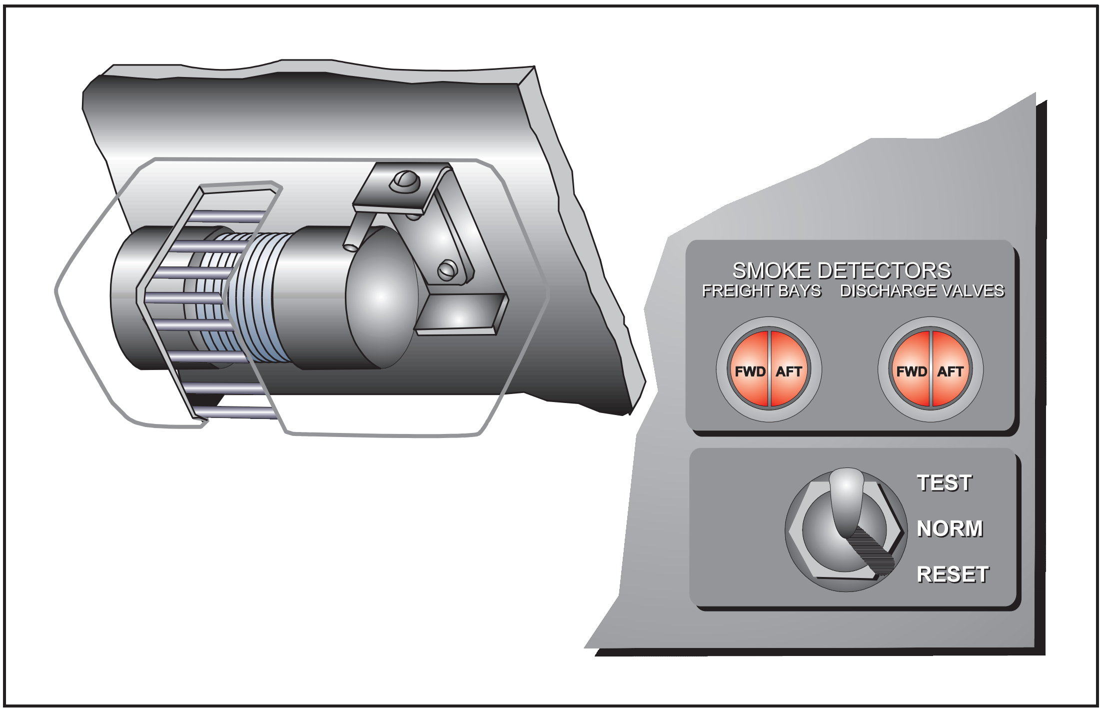


Figure 16.4: Smoke detector and indicator.

CARGO SMOKE DETECTION

Detectors situated in cargo bays, whilst operating on the same principle as previously described, will, on modern aircraft, give a flight deck warning of **FIRE** and a suitable fire protection system will be installed.

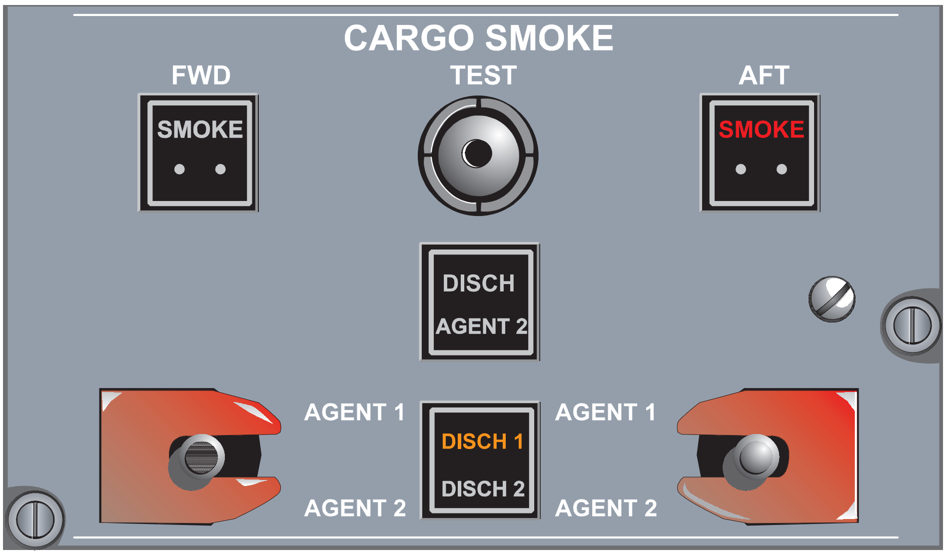


Figure 16.5: Cargo smoke detection (Airbus).

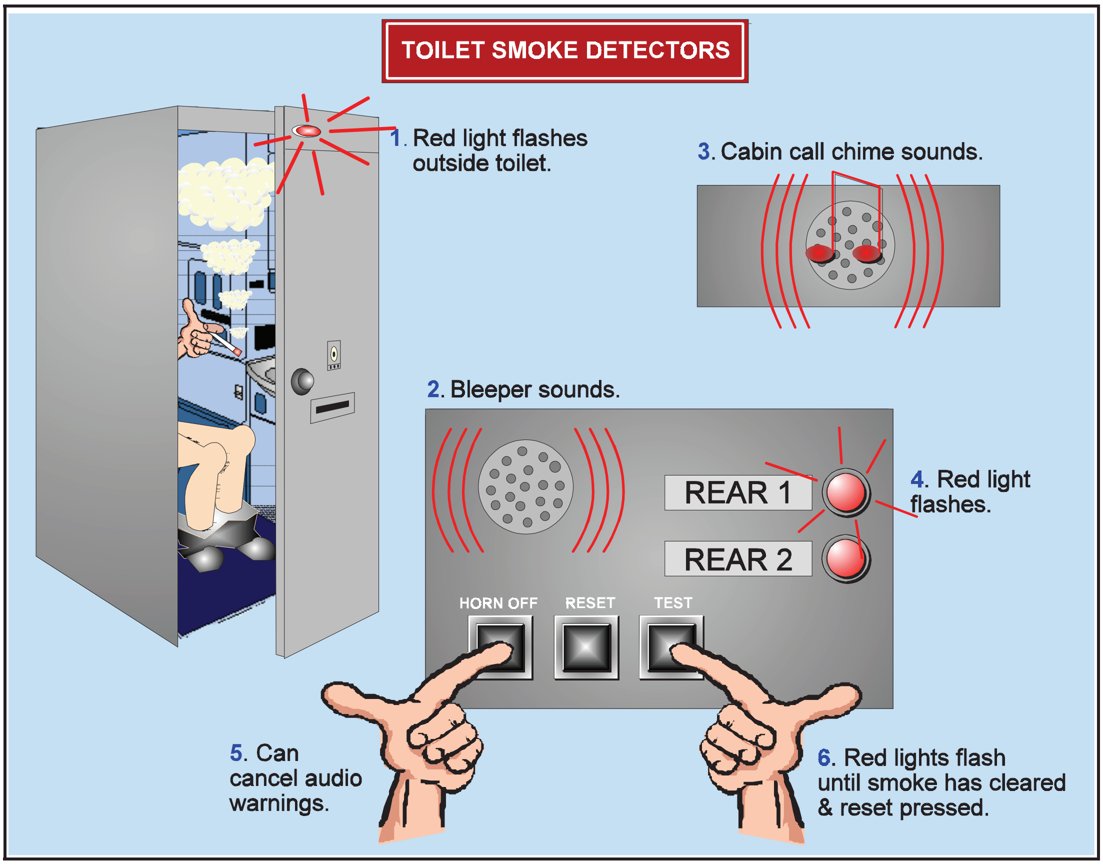


Figure 16.6: Toilet smoke detector.

SMOKE HOODS

Smoke hoods are a fairly recent innovation to emergency equipment. Owing to the training required to use a smoke hood it is only worn by flight and cabin crews.

The basic unit provides protection against all forms of smoke generated in a ground or flight emergency. A rubber neck seal ensures complete insulation for the wearer whilst oxygen is supplied via a self contained system, the during being a minimum of 15 minutes. Oxygen expiry may be indicated by a resistance to breathing. Smoke hoods will be stowed at flight crew stations and at cabin crew positions.

There are two types of smoke hood in airline use:

- Cabox. Stowed at the appropriate crew station in a sealed container, this unit has a chemical oxygen generator installed. Care should be taken to ensure the quickstart cord is intact before use.

- Drager. Like the above unit it is stowed in a sealed container. No pre-flight check is required. It has a self generating oxygen system actuated by a start cord.

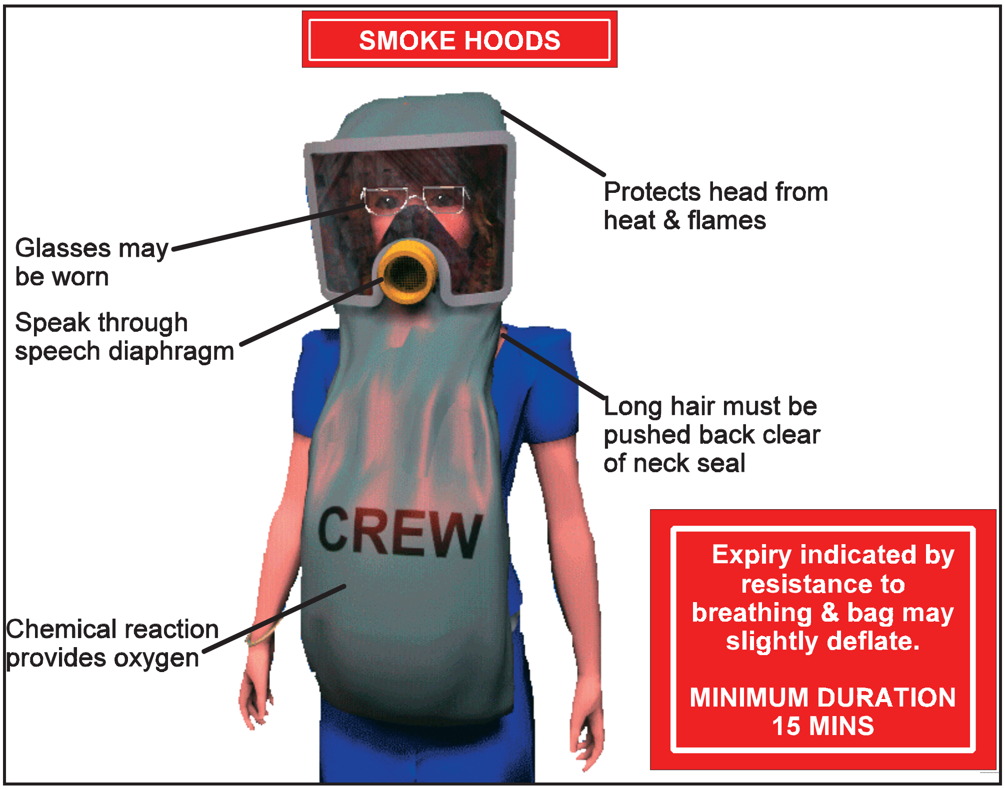


Figure 16.7: Smoke hoods.

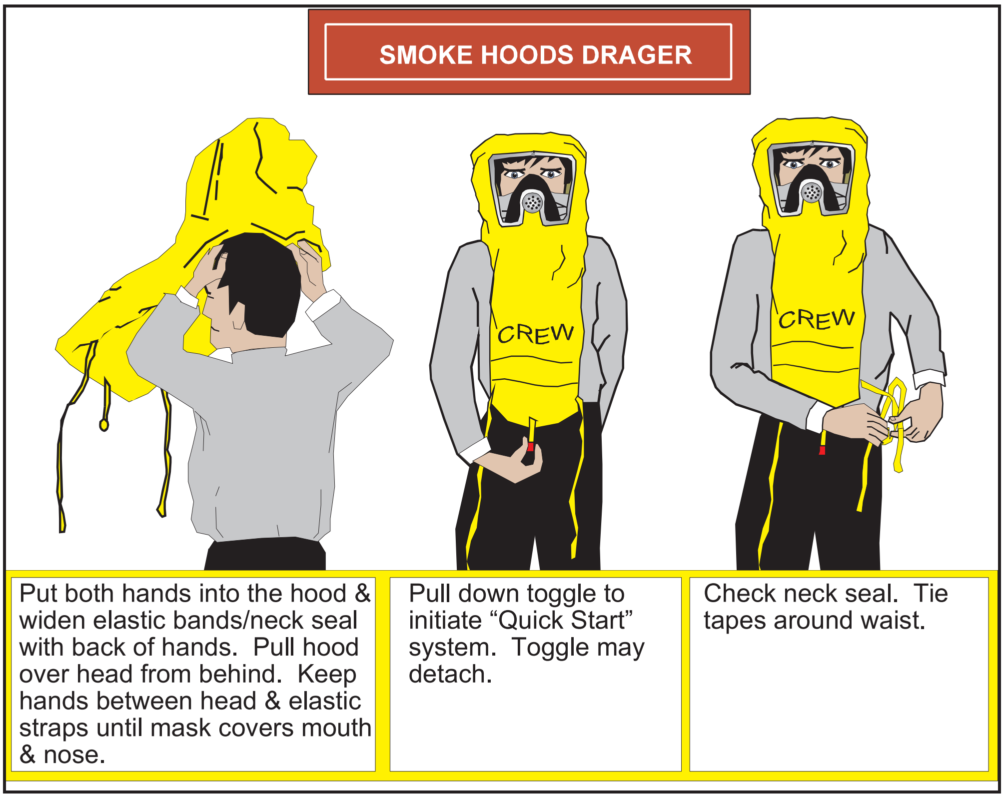


Figure 16.8: Smoke hoods Drager.

CHAPTER SEVENTEEN

FIRE DETECTION AND PROTECTION

Contents

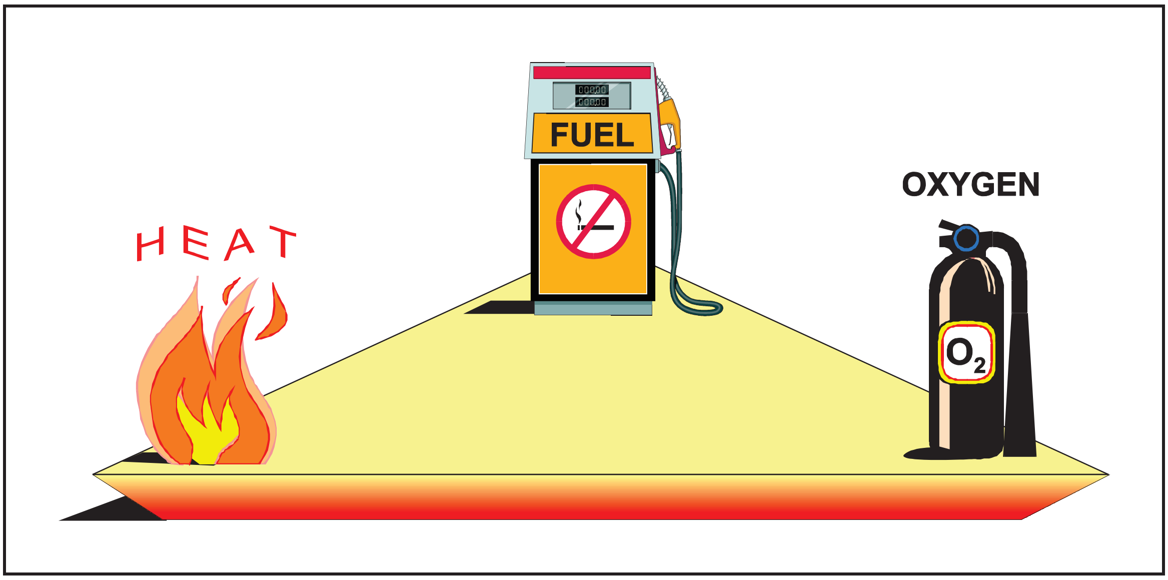


Figure 17.1: Triangle of fire.

INTRODUCTION

By design aircraft are intrinsically safe. However, it is an essential requirement that a "worse case scenario" must be catered for. To this end a Fire Detection/Protection system must be fitted in engines, APU's and main wheel wells.

Such areas are defined as Designated Fire Zones and may be described as:

"Areas where a potential fire risk may exist following failure or leakage of any component or associated equipment".

In order to avoid the spread of fire in engines or APU's, fire zones are established ie a series of fire proof bulkheads.

A fire detection system must be capable of providing rapid detection of a localised fire or overheat condition, however it must not automatically operate the fire extinguishers.

FIRE DETECTION SYSTEMS

Detection methods can vary according to the position of the equipment. Four methods of detection can be described as follows:

- **Melting Link Detectors**. These are found in older aircraft and consist of a pair of contacts held apart by a fusible plug. At a pre-determined temperature the fusible plug melts allowing the contacts to close and a fire warning circuit is made. A major drawback with this detector is that the contacts will not open after the fire has been extinguished thus giving a permanent fire warning.

- **Differential Expansion Detectors**. This type of detector operates on the principle of the differential rate of expansion of dissimilar materials. They consist of a pair of contacts mounted on a spring bow assembly, fitted within an expansion tube mounted on a base. When heat is applied the tube expands at a greater rate then the bow, drawing the contacts together, so providing power to the Fire Warning Circuit. A subsequent drop in temperature will cause the tube to shorten, the contact will open and the warning cancel. This type of unit is often used as a monitor on Engine Cooling Air Outlets to provide Internal Engine Overheat (I.E.O.H.) warning. This type of detector usually incorporates a short time delay before the warning is activated to prevent false warnings due to vibration.

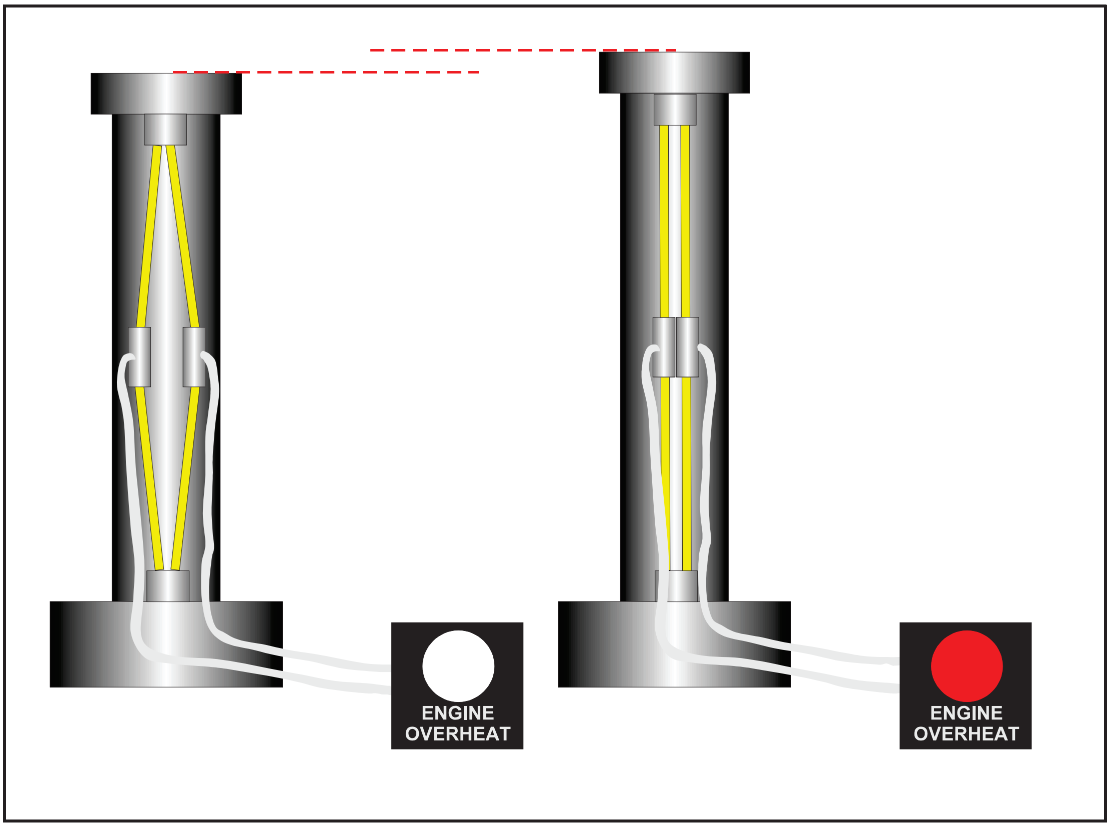


Figure 17.2: Differential expansion detectors.

- **Continuous Fire Detectors**. These detectors are commonly known as Fire Wire and operate on the principle of their elements having either a negative coefficient of resistance or a positive coefficient of capacitance.(one system has both) An element consists of a stainless steel tube, with a central electrode insulated from the tube by a temperature sensitive material.

- The resistance of insulating material in the resistive type will decrease with increase of temperature and current flow (leakage) between the central electrode and the outer tube will increase until, at a predetermined level , sufficient current will flow and the warning system will operate. If the temperature drops below a preset value the system will automatically reset. In the case of the capacitance type an increase in temperature causes an increase in capacitance. The element is polarised by the application of half wave rectified a.c. from a control unit which it stores and then discharges as a feedback current which, once it has reached a predetermined level, activates the aural and visual fire warnings. This system will reset itself once the temperature drops below a preset level and has the advantage over the resistive type that a short circuit grounding the element or system does not result in a false warning.

  Fire Wires are positioned around engine fire zones in a continuous double loop, both loops having to detect a fire to initiate the warning. The system is AC supplied and has the ability to continue functioning with a single wire break. Warning of this malfunction maybe displayed on the fire detection panel or electronic system display unit.

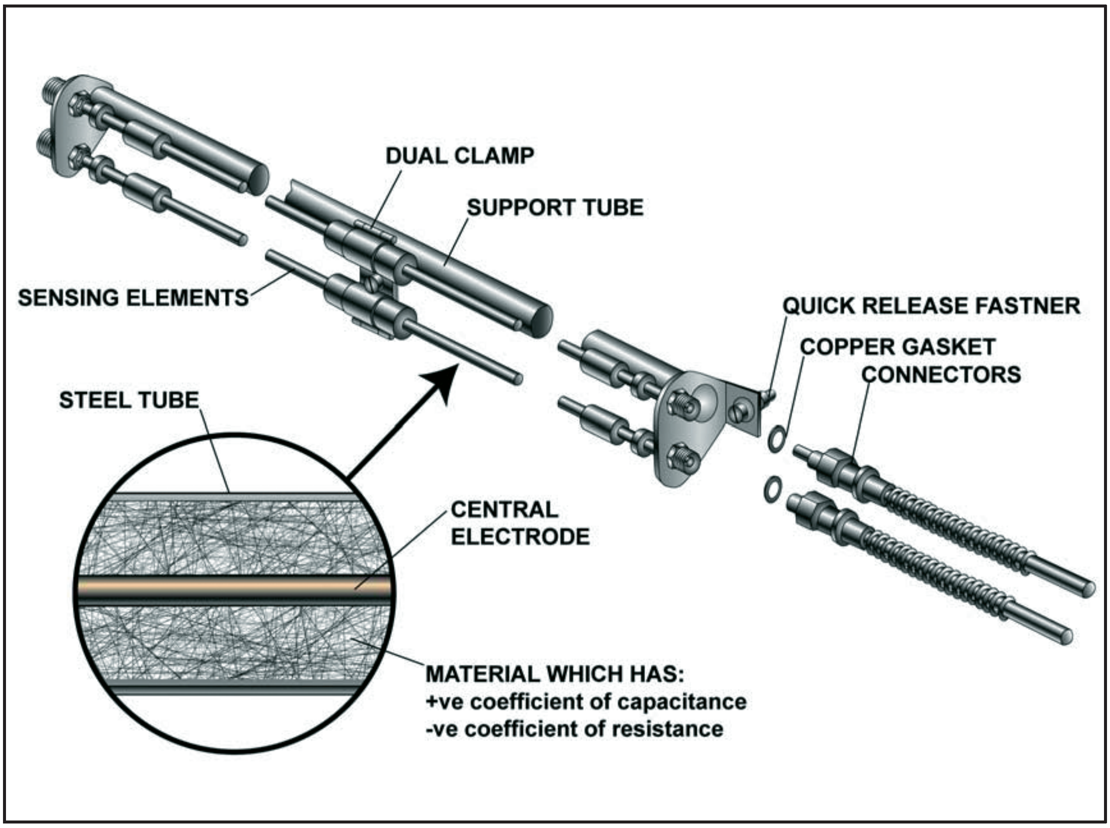


Figure 17.3: Continuous wire (fire wire) detector.

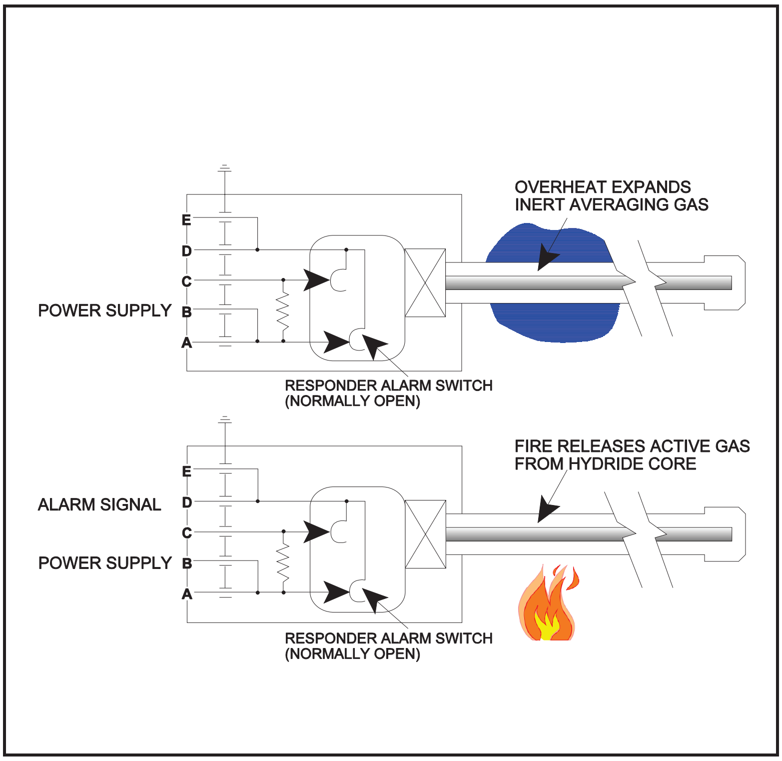


Figure 17.4: Overheat and fire warning.

- **Gas Filled Detectors**. This system consists of a continuous stainless steel tube containing a core gas absorbent material. The tube is positioned strategically around the engine wherever a fire is likely to occur. Gas is forced into the tube under pressure and partially absorbed by the core before the tube is sealed. When the tube is heated the absorbed gas is released from the core material and the pressure in the tube builds up rapidly. This increase of pressure sensed by a pressure switch at the end of the tube and a signal, via a system control box, will initiate a fire warning on the flight deck. This system also has the ability to detect an overheat within the Fire Zones possibly caused by a hot gas leak from a bleed supply.

  Like the fire wire this system is positioned around the fire zones in a double loop, once again both loops being required to detect a fire to give a warning.

  Should the integrity of the tube be breached and the gas released from the core, the same pressure switch that sensed the pressure rise due to increased temperature will sense the drop in pressure and signal a Loop Fault on the control panel or electronic systems display.

Note: *Any fault within a fire detection system which may give rise to a false fire warning* ***must be treated as a real fire.***

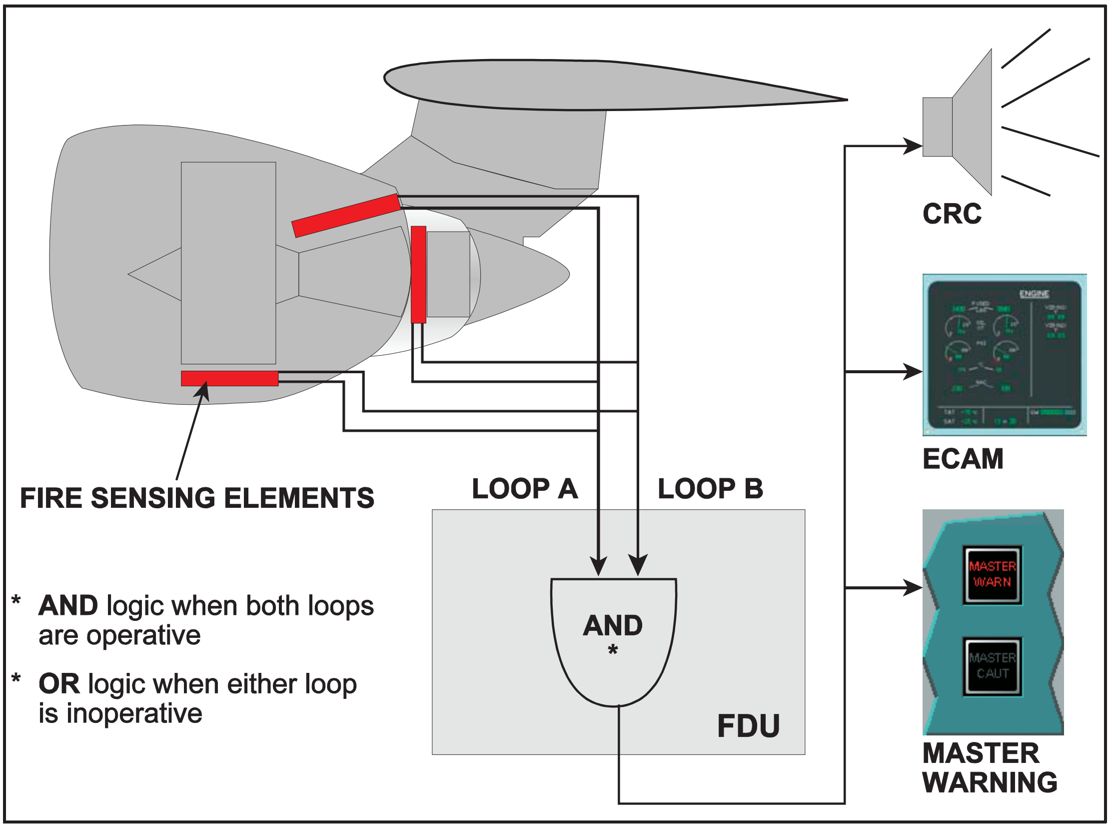
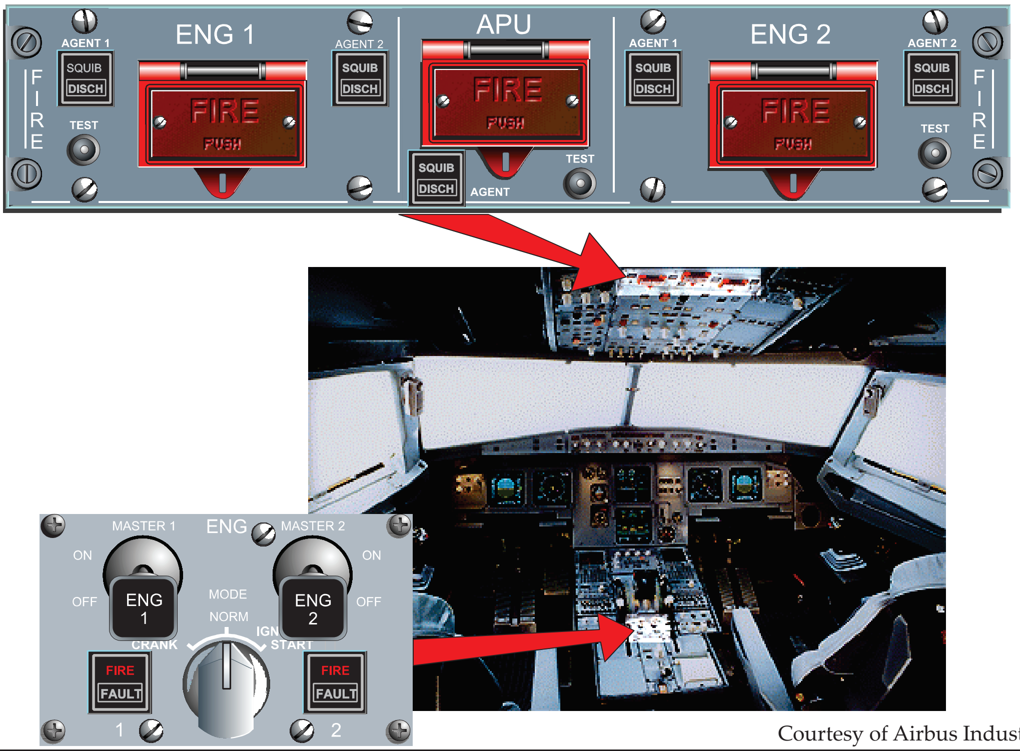


Figure 17.5: Fire detection loops.

FIRE TEST

Before flight a means must be available to test the fire circuit. A fire test selector is therefore provided on the flight deck. On selection the indications identical to a real fire warning will be displayed on all engines. This has tested circuit continuity. Should a break occur in a Fire Warning System no fire test will be given for that particular engine. Likewise a leakage in the gas filled system will negate a warning. It maybe designed that a warning is given to notify crews that a single fire loop has failed, the system now operating on a single loop. Depending on aircraft type limited leg operations maybe permitted in the single loop mode.

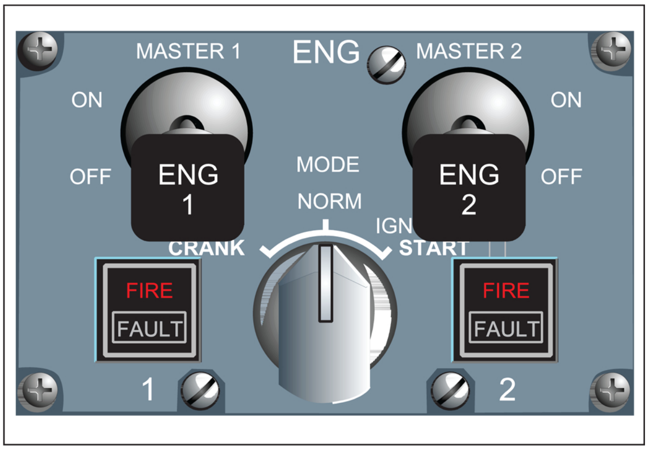


Courtesy of Airbus Industrie

Figure 17.6: Typical fire warning indicators.

Courtesy of Airbus Industrie

Figure 17.6a: Cockpit overhead engine fire panel.



Courtesy of Airbus Industrie

Figure 17.6b: Pedestal engine and fire control panel.

FIRE WARNING INDICATIONS/DRILLS

Flight deck indications of a fire warning must be attention getting rather than startling. To that end the format for such a warning may take the form of:

- a klaxon or bell or continuous repetitive chime sounding
- a master warning caption (No 1 engine fire)
- a steady red fire warning light in the appropriate engine display channel

On receipt of a fire warning the drill must be carried out in strict order. The following drill being representative:

- a means of cancelling the aural warning
- a sequence to shut off fuel, bleed air, electrics and hydraulics to the engine
- a means of discharging the fire bottles into the engine fire zones.

Note: The above drill is a generalisation and the appropriate aircraft emergency check list must be consulted.

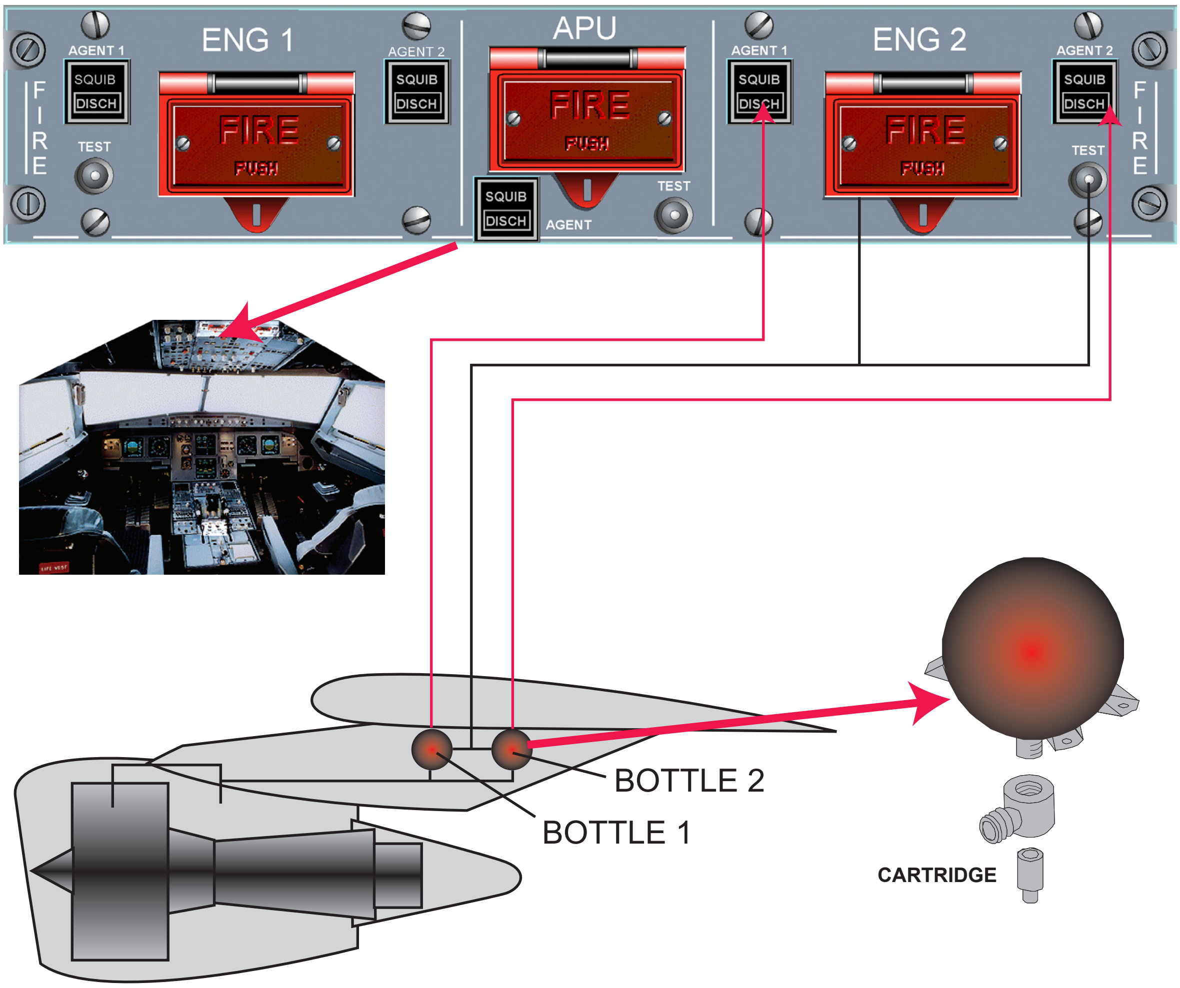


Figure 17.6c: Engine fire protection.

FIRE PROTECTION

Having adhered to the correct drill for shutting down an engine and isolating all services to it, fire protection ie a fire extinguishant, can now be sprayed into the fire zones. This system normally comprises of fire bottles, usually two per engine, connected via piping to the fire zones. At the zones the piping forms a spray ring from which the extinguishant is directed around the area.

A means of discharging the fire bottle is provided on the flight deck and its operation may follow the following sequence:

- engine shut down drill completed
- an electrical cartridge, situated between the base of the fire bottle and the piping, is armed (**SQUIB** illuminates an engine fire panel).
- pressing the **AGENT** selector fires the cartridge allowing fire extinguishant, under pressure, to enter the spray rings in the engine
- pressurised extinguishant operates a low pressure electrical switch which illuminates the **DISCH** caption on the **AGENT** selector.

In the event that a single fire bottle does not extinguish the fire a second is usually fitted, activation and indication being the same as previously described.

Older aircraft may have varying flight deck indications of a bottle having been fired. For example an indicator fuse (a clear small bulb which turns red on bottle firing).

Physical indications that a bottle has been fired may include:

- an indicator pin on the bottle head
- a bottle pressure gauge

NOTE: these may not be visible externally and panel access may be required.

In the event that a fire bottle has been subject to excess temperature/pressure a thermal discharge may take place. Indications that the bottle contents have discharged overboard can be:

- bottle pressure gauge reading zero
- an external green disc being ejected under which a red disc will show

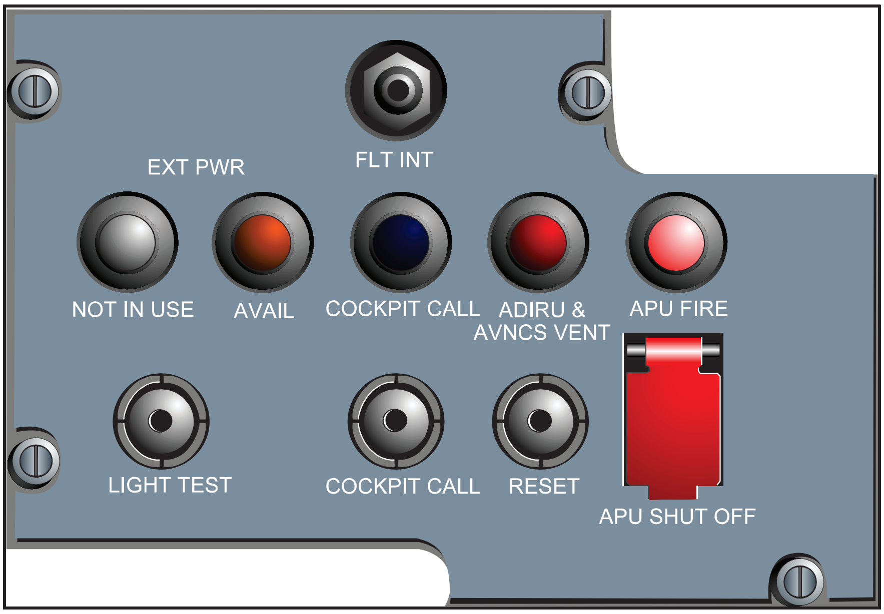
AUXILIARY POWER UNIT PROTECTION

APU's are constant speed self contained gas turbines, which derive their fuel supply from the aircraft system. Their services may include, bleed air, hydraulic power, electrical power. They can when certified be available for airborne use.

APU's are self monitoring and will auto shut down in the event of:

- fire (plus auto firing of the fire bottle)
- oil pressure failure
- over-speed
- over-heat

Note: *Although APU's auto shut down a manual control panel is normally included.*



Courtesy of Airbus Industrie

Figure 17.7: External APU fire control panel (Airbus).

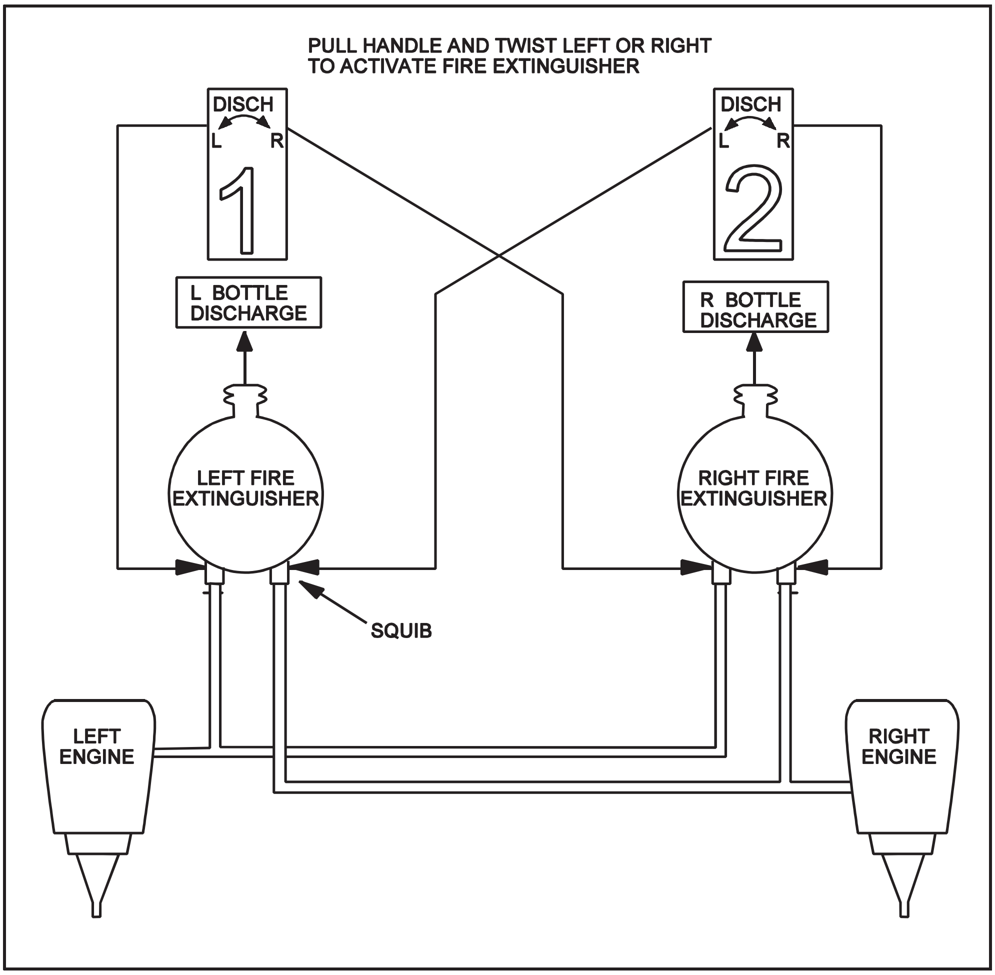


Figure 17.8: Typical fire protection system layout.

Reference *Figure 17.10* above.

On receipt of left engine fire warning:

1. **CLOSE LEFT THRUST LEVER**

2. **LEFT ENGINE H.P. OR ENGINE START LEVER CLOSE**

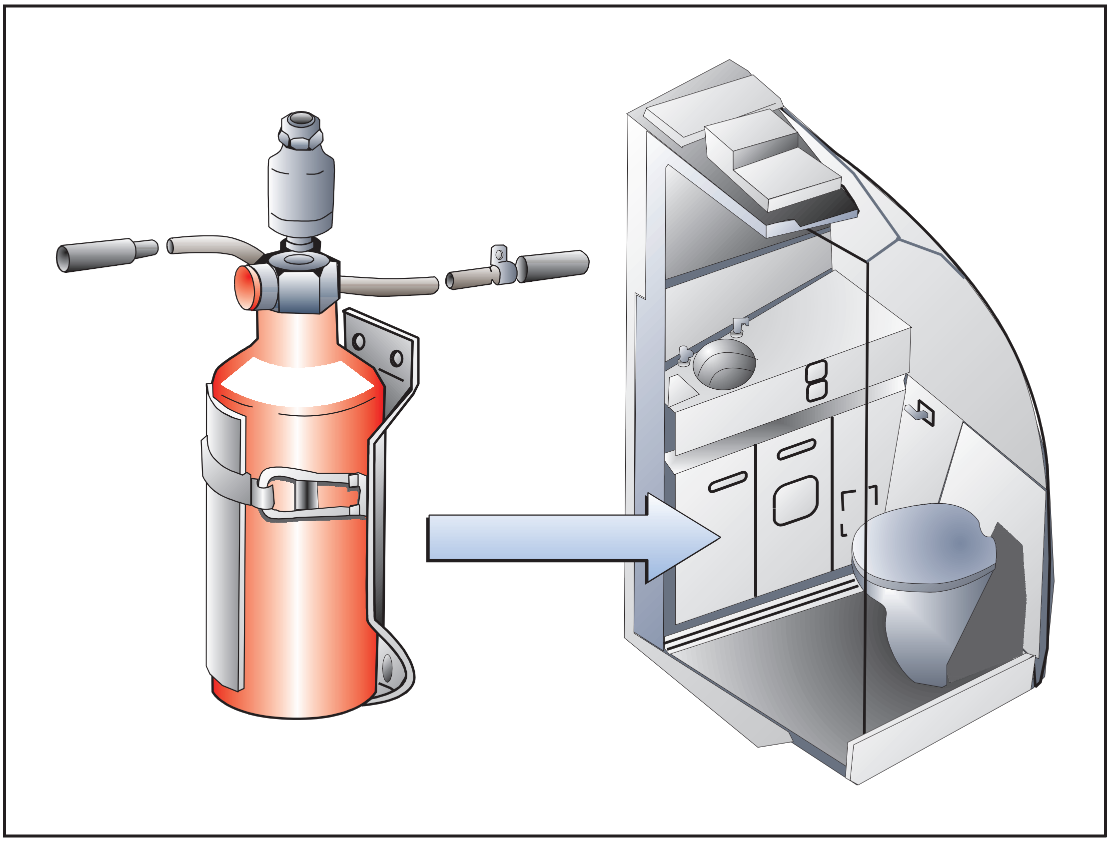
3. **PULL NO 1 FIRE HANDLE**

4. **NUMBER 1 ENGINE FIRE HANDLE ROTATE LEFT TO MECHANICAL LIMIT AND HOLD FOR AT LEAST 1 SECOND. THIS WILL DISCHARGE THE LEFT BOTTLE INTO THE LEFT ENGINE**

5. **IF AFTER 30 SECONDS FIRE WARNING REMAINS ILLUMINATED ROTATE No. 1 FIRE HANDLE RIGHT TO ITS MECHANICAL LIMIT AND HOLD FOR AT LEAST 1 SECOND. THIS WILL DISCHARGE THE RIGHT BOTTLE INTO THE LEFT ENGINE.**

6. **LAND AS SOON AS POSSIBLE**

This is an example and individual aircraft check lists must be consulted for the correct procedure to be followed.



Courtesy of Airbus Industrie

Figure 17.9: Automatic toilet fire extinguishers.

TOILET FIRE SYSTEM

These are fitted around each disposal receptacle for towels, paper or waste paper containers and consist of a fire bottle, fusible plug and spray ring and are a requirement for all aircraft with a passenger capacity of 20 or more. In the event of a fire the fusible plug will melt discharging fire extinguishant into the spray ring. The toilets must also be fitted with a smoke detector system. *(See chapter 16).*

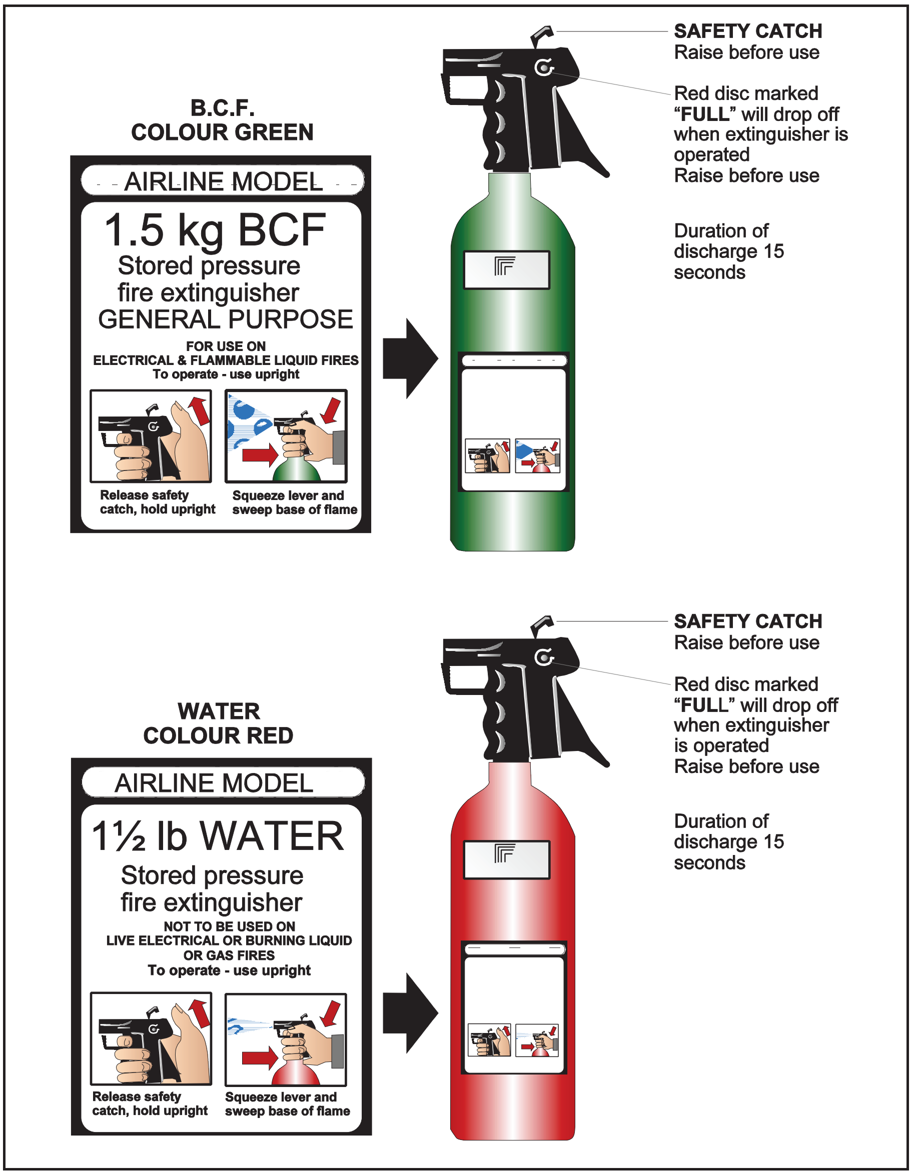


Figure 17.10: Extinguishers.

FIRE EXTINGUISHANTS

Fire extinguishants must be suitable for various on-board aircraft fires. The list below gives types and uses:-

BROMOCHLORODIFLUROMETHANE (BCF)

This is stored in **signal red, purple, brown or green** containers. This agent is very effective against electrical and flammable liquid fires. It is only slightly toxic, is colourless, non-corrosive and evaporates rapidly leaving no residue. It does not freeze or cause cold burns and will not harm fabrics, metals or other materials it contacts. It is also known as Halon 1211. It acts rapidly on fires by producing a heavy blanketing mist which eliminates air from the fire source but more importantly it interferes chemically with the combustion process. It has outstanding properties in preventing re-flash after the fire has been extinguished. Along with Halon 1301 it is widely used in HRD (High Rate Discharge) fire extinguishing systems fitted to some gas turbine power plants.

BROMOTRIFLUROMETHANE (BTM)
Stored in **grey** containers and used in fixed systems it is known as Halon 1301 and has a very low toxicity. It is used for the protection of APU's, power plants and cargo compartments. It has similar characteristics to Halon 1211 except that it has a vapour spray and is more difficult to direct.

NOTE: BCF & BTM are part of a group of Halogenated Hydrocarbons commonly called FREON. Others in the group have long names and are also Halon 1011, 104 & 1201. 104 is no longer used as it is toxic and the other two are not recommended for use in aircraft.

WATER or WATER GLYCOL
This is stored in red containers and used for hand held portable appliances. It can be used in passenger cabins for combatting fires involving domestic materials. **It must not be used on fires which involve electrical equipment or liquids**, the glycol is an antifreeze agent which permit operation of the extinguishers at temperatures as low as -20°C.

DRY CHEMICAL (DRY POWDER)
This is stored in a blue or red container with a blue label and occasionally called 'Dry Powder'. The use of this agent in crew compartments or passenger cabins of pressurised aircraft is not permitted (JAR25). However some light aircraft may have these and their use should be avoided if at all possible as visibility would be restricted and it can render inoperative otherwise serviceable electrical equipment. The agent is a non toxic powder ie Potassium Bicarbonate, similar to talcum powder. It is very effective against fires involving flammable liquids, wood, fabric and paper. It should not be used on electrical fires, and is best known for its application against wheel and brake fires. As a powder it has no cooling effect and this reduces the danger of wheel explosions or the distortion of the brakes or wheels.

GROUND USE EXTINGUISHERS.
In addition to the dry powder extinguisher, foam (cream or red with a cream label), water (red), Carbon dioxide, BCF and sand are available for ground use.

CARBON DIOXIDE (CO_2)
Stored in black or red containers with a black label. It is non-corrosive and extinguishes the flame by dissipating the oxygen in the immediate area. From a standpoint of toxicity and corrosion it is the safest agent to use and for many years was the most widely used. If handled improperly it can cause mental confusion and suffocation. It requires a stronger container than most other agents due to its variation in vapour pressure with changes of temperature. The use of this agent in aircraft is not permitted . Carbon dioxide may be used against most fires and is particularly useful against engine fires as it will extinguish the fire without damaging the engine. This agent may be used as a substitute for Dry Chemical against wheel and brake fires but it should not be sprayed directly on to the wheel but alongside to blanket the wheel with a CO_2 cloud.

FOAM
The principal extinguishant for use on flammable liquid fires, it blankets the flames by excluding oxygen.

WATER.
Used on combustible material fires, it extinguishes by cooling. It must not be used on electrical, fuel or brake fires.

SAND
Useful for containing metal fires such as magnesium or titanium where liquids will make matters worse.

HAND HELD EXTINGUISHERS

The regulations state that the number of hand held extinguishers required will be governed by the passenger capacity as follows : 7 to 30 = 1. 31 to 60 = 2. 61 to 200 = 3. 201 to 300 = 4. 301 to 400 = 5. 401 to 500 = 6. 501 to 600 = 7. 601 to 700 = 8.

At least two of the extinguishers in the passenger compartment of an aircraft with a maximum seating configuration of 61 seats or more must be BCF. There must be at least one additional BCF hand extinguisher conveniently located in the flight deck.

FIRE SYSTEMS AND COMPARTMENTS

There are three types of system in general aircraft use:

- **Fixed System**. This consists of containers holding the extinguishing agent fixed to the structure and a system of distribution pipes and controls provided for the protection of power plants and where applicable the auxiliary power units.

NOTE: *On large aircraft, fixed systems may also be provided for the protection of landing gear bays and baggage compartments.*

- **Portable System.** This refers to the several types of hand operated fire extinguishers provided to combat any outbreak of fire in flight crew compartments or passenger cabins.

- **Mixed Systems**. An arrangement used in some aircraft for the protection of baggage and service departments, it consists of a system of distribution pipes and spray rings which are mounted in the appropriate compartment, complemented by hand held or mounted fire extinguishers discharged through special adapter points.

FIRE COMPARTMENTS (JAR 25)

The cockpit and passenger cabin are designated Class A compartments, meaning that a fire may be visually detected, reached and combatted by a crew member. The engines are Class C compartments, and fire detection and warning is provided. There are five types of cargo compartments; Class A to E. Class A and B crew members may reach and combat a source of fire; Class C or D which crew members cannot reach the source of fire. A class E cargo compartment is one on aeroplanes only used for the carriage of cargo.

Class A Compartments comply with the following:

- They provide for visual detection of smoke

- They are accessible in flight

- There is a fire extinguisher available.

The Cargo and baggage compartments are classified **'B'** when complying with the following:

- Sufficient access provided while in flight to enable a member of the crew to move by hand all of the contents; and to reach effectively all parts of the compartment with a hand held extinguisher.
- When the access provisions are being used, no hazardous quantity of smoke, flames or extinguishing agent will enter any compartment occupied by the crew or passengers.
- Each compartment shall be equipped with a separate system of an approved type of Smoke or Fire Detector to give a warning at the pilots station.
- Hand fire extinguishers shall be readily available for use in all compartments of this category.

Class C compartments comply with the following:

- There is a separate Smoke or Fire Detector system to give warning at the pilot or flight engineer station.
- There is an approved built in Fire Extinguishing System controlled from the pilot or flight engineer station.
- Means provided to exclude hazardous quantities of smoke, flames, or other noxious gases from entering into any compartment occupied by the crew or passengers.
- Ventilation and draughts controlled within each compartment so that the extinguishing agent used can control any fire likely to occur in the compartment.

Class D compartments must be so designed and constructed that a fire occurring therein will be completely confined without endangering the safety of the aircraft or the occupants. Compliance is required with the following:

- Means provided to exclude hazardous quantities of smoke, flames, or other noxious gases from entering into any compartment occupied by the crew or passengers.
- Ventilation and draughts controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits.
- Compartment completely lined with fire resistant material.

Class E compartments

- Equipped with a separate system of an approved type of smoke or fire detector.
- Means provided to shut off the ventilating air flow to or within the compartment. Controls for such means shall be accessible to the flight crew from within the cockpit.
- Means provided to exclude hazardous quantities of smoke, flames, or noxious gases from entering the cockpit.
- Required crew emergency exits accessible under all cargo loading conditions.

QUESTIONS - OXYGEN

1. Without added oxygen the time of useful consciousness at 25,000 ft is approximately:

   a. twenty seconds.
   b. eighty seconds.
   c. three minutes.
   d. six minutes.

2. With out added oxygen the time of useful consciousness at 40,000 ft is approximately:

   a. twenty seconds.
   b. three minutes.
   c. eighty seconds.
   d. six minutes.

3. The maximum altitude without oxygen at which flying efficiency is not seriously impaired is:

   a. 10,000 ft.
   b. 17,500 ft.
   c. 25,000 ft.
   d. 30,000 ft.

4. In a pressure demand oxygen system:

   a. each member of the crew has a regulator.
   b. each member of the crew has a continuous oxygen supply.
   c. oxygen is supplied with a continuous pressure flow.
   d. oxygen demand will cause the pressure to rise.

5. In a continuous flow oxygen system, oxygen is supplied:

   a. only when the mask is plugged into the socket connection.
   b. only on passenger inhalation through the mask.
   c. only when the cabin altitude is above 18,000 ft.
   d. only when the supply has been regulated by the pilot.

6 In a diluter demand system, selection of emergency on this regulator will result in:

   a. air mix supplied at emergency pressure.
   b. 100% oxygen supply as called for by the user.
   c. 100% oxygen at positive pressure.
   d. 100% oxygen continuous flow at positive pressure.

7. If the aircraft suffers a decompression passenger oxygen masks:

   a. are released by the passengers.
   b. automatically drop to a half hung (ready position).
   c. are handed out by the cabin staff.
   d. must be removed from the life jacket storage.

8. Oxygen cylinders are normally charged to:

   a. 1,000 psi.
   b. 1,200 psi.
   c. 1,800 psi.
   d. 2,000 psi.

9. Rate of flow of oxygen is given in:

   a. litres/minute.
   b. pounds/minute.
   c. litres/second.
   d. kilos/hour.

10. The colour of American oxygen cylinders is:

   a. red.
   b. blue.
   c. green.
   d. brown.

11. The colour of British oxygen cylinders is:

   a. white with black lettering.
   b. grey with silver lettering.
   c. black with white neck.
   d. blue with white lettering.

12. Dangerous pressure rise in oxygen cylinders:

   a. is relieved by a thermostat.
   b. is relieved by under pressurising the bottle.
   c. is relieved by a bursting disc.
   d. is controlled by a thermal relief valve.

13. To leak test an oxygen system use:

   a. fairy liquid and de-ionised water.
   b. thin oil.
   c. acid free soap and distilled water.
   d. acid free soap and water.

14. Lubrication of an oxygen component thread is by:

   a. soap water.
   b. grease.
   c. oil.
   d. graphite.

15. Satisfactory operation of the oxygen system is indicated by:

   a. flow indicators.
   b. lack of anoxia.
   c. aural reassurance.
   d. pressure indicators.

16. If the pressurisation system fails and the cabin starts to climb, then at 14,000 ft oxygen will be available to the passengers by:

    a. the stewardess who will hand out masks.
    b. the passengers grabbing a mask from the overhead lockers.
    c. portable oxygen bottles located in the seat backs.
    d. masks automatically ejected to a ½ hung position.

17. When air is pressurised the % of oxygen:

    a. increases.
    b. decreases.
    c. remains the same.
    d. nil.

18 In an emergency chemically produced oxygen is supplied for a given period by:

    a. sodium chlorate, iron power, an electrical firing system and a filter.
    b. potassium chlorate, iron powder, an electrical firing system and a filter.
    c. sodium chlorate, iron powder which is chemically activated by air and then filtered.
    d. sodium chlorate and an electrical firing system.

19. Passenger oxygen masks will present:

    a. only when the cabin altitude reaches 14,000.
    b. only if selected by the crew.
    c. only if selected by the cabin staff:
    d. if selected manually / electrically / barometrically.

20. The charged pressure of a portable oxygen cylinder is normally:

    a. 500 psi.
    b. 1,200 psi.
    c. 1,800 psi.
    d. 3,000 psi.

21. With the control knob set to **high**, a 120 litre portable bottle will provide oxygen for a period of:

    a. 60 mins.
    b. 30 mins.
    c. 12 mins.
    d. 3 mins.

22. At what altitude will the diluter-demand oxygen regulator provide 100% pure oxygen:

    a. 10,000 ft.
    b. 14,000 ft.
    c. 24,000 ft.
    d. 34,000 ft.

23. A Flow Indicator fitted to an Oxygen regulator indicates:

a. that exactly the correct amount of oxygen is being used by the crew member.
b. that oxygen is flowing through the regulator.
c. that the crew member is correctly connected to the regulator.
d. that the system pressure reducing valve is supplying the correct pressure to the regulator.

24. what is the approximate time of useful conciousness when hypoxia develops at the specified altitudes.

	18,000 ft	30,000 ft
a.	2-3 min	10-15 sec
b.	10 min	2 min
c.	30 min	90-45 secs
d.	40 min	5 min

25. What is the effect on cabin temperature of a rapid de-compression at 30,000 ft:

a. sudden and extreme drop.
b. insignificant change over the first 2 minutes.
c. a gradual decrease to ambient over a period of about 10 minutes if the cabin heating ceases.
d. a gradual decrease to ambient temperature over a period of about 30 minutes if cabin heating continues.

26. Susceptibility to hypoxia is increased by:

a. heat.
b. noise.
c. smoking.
d. under-breathing.

27. What is the approximate cabin altitude above which you must breath 100% oxygen if you are to maintain an alveolar partial pressure equal to that at sea level:

a. 26,000 ft.
b. 30,000 ft.
c. 34,000 ft.
d. 38,000 ft.

QUESTIONS - EMERGENCY EQUIPMENT

1. A flight deck indication that a fixed fire extinguisher has been fired is:

   a. a green coloured bursting disc.
   b. a protruding indicator pin at the discharge head.
   c. low pressure warning lamp.
   d. thermal discharge indicator.

2. One type of extinguishing agent you would expect to find in an aircraft installed engine fire protection system is:

   a. carbon dioxide.
   b. argon.
   c. helium.
   d. freon.

3. A wheel brake fire should be fought with a:

   a. water/gas fire extinguisher.
   b. dry powder extinguisher.
   c. Carbon dioxide extinguisher.
   d. foam fire extinguisher.

4. An engine fire extinguisher has discharged due to an over temperature condition occurring in its vicinity. This will be indicated by:

   a. a bursting disc in the discharge nozzle.
   b. an externally mounted warning lamp.
   c. an externally mounted discharge indicator showing red.
   d. an audible warning.

5. On a multi engined aircraft, an engine fire warning system consists of:

   a. flashing red lights for each engine and a warning horn.
   b. steady red light for each engine and a common warning bell.
   c. flashing red light for each engine and a common warning bell.
   d. steady red light and bell for each engine.

6. Smoke detectors are fitted in:

   a. passenger cabins, cargo bays, electrical equipment bays.
   b. cargo bays, APU compartment, toilets.
   c. toilets, electrical equipment bays, APU compartments.
   d. cargo bays, electrical equipment bays, toilets.

7. A short circuit in a resistive "fire wire" detector will:

   a. fire the squib in the fire bottle discharge head.
   b. cause a spurious fire warning to be received.
   c. cause the blow out disc to be ruptured.
   d. disable the test circuit.

8. On receipt of an engine fire warning on the flight deck the correct procedure should be:

   a. fight the fire with the flight deck BCF fire extinguisher.
   b. pull the fire handle, fire the fire extinguisher, shut down the engine.
   c. shut down the affected engine, pull the fire handle, fire the first extinguisher.
   d. fire the first extinguisher, pull the fire handle, shut down the engine.

9. Fire detection systems:

   a. automatically fire the engine extinguishers.
   b. can only use AC electricity.
   c. are connected to the Vital bus bar.
   d. can be tested from the flight deck.

10. A toilet fire extinguisher is activated:

   a. by high temperature in its vicinity.
   b. by remote control from the flight deck.
   c. by a switch at the nearest flight attendant station.
   d. by a smoke detector.

11. Emergency exits:

   a. can only be opened from the inside.
   b. must have an escape slide fitted to them.
   c. are painted yellow.
   d. must be outlined externally by a 2 inch band of contrasting colour.

12. Regulations governing the fitting, marking and use of safety equipment is contained in:

   a. British Civil Airworthiness Requirements.
   b. Navigation Regulations.
   c. Joint Airworthiness Requirements.
   d. Operations Manual.

13. An automatic escape slide:

   a. can be armed from the inside of the aircraft only.
   b. can only be activated from the flight deck.
   c. automatically inflates when the crash switches are activated.
   d. inflates when the recovery team open the door from the outside of the aircraft.

14. Emergency lighting must be capable of remaining illuminated for a minimum of:

   a. 5 mins.
   b. 7 mins.
   c. 10 mins.
   d. 15 mins.

15. The LED indicator light on the emergency torch is flashing at 4 second intervals. This indicates:

    a. the battery is charging.
    b. the torch is serviceable.
    c. the battery needs replacing.
    d. the filament is broken.

16. Nomex gloves are provided on the flight deck to:

    a. protect hands during cold weather refuelling operations.
    b. remove hot meal containers from the oven.
    c. protect hands from hot materials during firefighting.
    d. to allow turn around checks to be carried out on a hot gas turbine engine.

17. If the emergency lighting system is powered from the aircraft electrical system, it takes is power supply from:

    a. AC essential bus-bar.
    b. DC essential bus-bar.
    c. Vital DC bus-bar.
    d. The inverter.

18. Lifejackets are inflated with compressed:

    a. helium.
    b. nitrogen.
    c. freon.
    d. carbon dioxide.

19. Emergency lighting:

    a. can be switched on from the flight deck only.
    b. must illuminate the inside of the passenger cabin only.
    c. comprises flight deck lighting, cabin internal and external lighting.
    d. once activated cannot be switched off.

20. A cut-in area:

    a. always has a crash axe located next to it.
    b. is designated as a weaker fuselage area.
    c. is lit internally by the emergency lighting system.
    d. is delineated by external markings having right angled corners.

ANSWERS - OXYGEN

1.	C	11.	C	21.	B
2.	A	12.	C	22.	D
3.	A	13.	C	23.	B
4.	A	14.	D	24.	C
5.	A	15.	A	25.	A
6.	D	16.	D	26.	C
7.	B	17.	C	27.	C
8.	C	18.	A		
9.	A	19.	D		
10.	C	20.	C		

ANSWERS - EMERGENCY EQUIPMENT

1.	C	11.	D
2.	D	12.	C
3.	B	13.	A
4.	C	14.	C
5.	B	15.	B
6.	D	16.	C
7.	B	17.	C
8.	C	18.	D
9.	D	19.	C
10.	A	20.	D

CHAPTER EIGHTEEN

AIRCRAFT FUEL SYSTEMS

Contents

INTRODUCTION

The specification of an ideal fuel for either a gas turbine engine or a piston engine would include the following main requirements:

- Ease of flow under all operating conditions.
- Complete combustion under all conditions.
- High calorific value.
- Non-corrosive.
- No damage to the engine from combustion by-products.
- Low fire hazard.
- Ease of engine starting.
- Lubricity.

These requirements can be met and the methods of doing so are discussed later. In practice the cost of satisfying all of them is prohibitive and therefore compromises have to be made.

PISTON ENGINE FUELS

Piston engined aircraft use gasoline fuels grouped under the title AVGAS (aviation gasoline). So that aviation gasoline will fulfill the above requirements, it is manufactured to conform with exacting **'specifications'** that are issued by the Directorate of Engine Research and Development (D.E.R.D.). The specification number for gasoline is D.E.R.D. 2485. The octane rating of the fuel is specified with the grade. ie. AVGAS 100 is a 100 octane fuel. Higher octane fuels are used with high performance engines having high compression ratios.

The most popular grades of AVGAS readily available today are:

Grade	Performance No	Colour	Specific Gravity (Density)	
AVGAS 100 LL	100/130	Blue	0.72	Low Lead
AVGAS 100	100/130	Green	0.72	High Lead
AVGAS 115	115/145		0.72	

NOTE: although AVGAS 100 and AVGAS 100LL have the same 100 / 130 performance No. they are however easily distinguished by their colour.

AVGAS 100 is **green**, while AVGAS 100LL is **blue.**

AIRCRAFT FUEL SYSTEMS

MOGAS (motor gasoline) can sometimes be used in certain airframe engine combinations, but only under the conditions specified in Airworthiness Notices number 98 and 98a because of its low octane rating.

Because of its higher volatility carburettor icing and vapour locking is much more likely. Information on the use of MOGAS can also be found in CAA Safety Sense leaflet no 4a.

GAS TURBINE FUELS

Gas turbine engined aircraft use kerosene fuels. The two main types of gas turbine fuel in common use in civilian aircraft are shown below, together with their characteristic properties:

AVTUR (Aviation turbine fuel).

- **JET A1.** This is a kerosene type fuel with a nominal SG of 0.8 at 15°C.
- **JET A** is a similar type of fuel, but it has a waxing point of -40°C. This fuel is normally only available in the U.S.A.

AVTAG (Aviation turbine gasoline)

- **JET B.** This is a wide-cut gasoline/kerosene mix type fuel with a nominal S.G. of 0.77 at 15°C, it has a low flash point, a wider boiling range than JET A1, and a waxing point of -60°C.

JET B can be used as an alternative to JET A1 but it has a wider range of flammability and is not generally used in civilian aircraft.

FUEL COLOUR

Turbine fuels are not dyed for identification, they retain their natural colour which can range between a straw yellow to completely colourless.

CLOUDY FUEL

If a fuel sample appears cloudy or hazy then there could be a number of reasons. If the cloudiness appears to rise quite rapidly towards the top of the sample then air is present, if the cloud falls quite slowly towards the bottom of the sample then water is present in the fuel. A cloudy appearance usually indicates the presence of water.

JET FUEL ADDITIVES

A number of additives may be blended into the fuel either at the refinery or at the airfield to improve the operating ability of the fuel. The most popular are listed below.

- **FSII** (Fuel System Icing Inhibitor). A certain amount of water is present in all fuel. FSII contains an icing inhibitor and fungal suppressant to combat the following problems:
  - **Icing.** As an aircraft climbs to altitude the fuel is cooled and the amount of dissolved water it can hold is reduced. Water droplets form and as the temperature is further reduced they turn to ice crystals which can block fuel system components.
  - **Fungal Growth and Corrosion.** A microbiological fungus called Cladasporium Resinae is present in all turbine fuels. This fungus grows rapidly in the presence of water to form long green filaments which can block fuel system components. The waste products of the fungus are corrosive, especially to fuel tank sealing substances. The inclusion of FSII in the fuel will help to overcome these problems.

- **HITEC** (Lubricity Agent). A lubricity agent is added to the fuel to reduce wear in the fuel system components. (pumps, fuel control unit etc.)

- **Static dissipater** additives partially eliminate the hazards of static electricity generated by the movement of fuel through modern high flow rate fuel transfer systems, particularly during refueling and defueling.

- **Corrosion inhibitors** protect ferrous metals in fuel handling systems, such as pipelines and storage tanks, from corrosion. Certain of these corrosion inhibitors appear to improve the lubricating qualities (lubricity) of some gas turbine fuels.

- Metal de-activators suppress the catalytic effect which some metals, particularly copper, have on fuel oxidation.

WATER IN THE FUEL

Water is always present in fuel, the amount will vary according to the efficiency of the manufacturer's quality control and the preventive measures taken during storage and transfer. Further measures can be taken to minimise water accretion once the fuel has been transferred to the aircraft tanks:

- **Water Drains.** If the fuel can be allowed to settle after replenishment then the water droplets, being heavier than the fuel, will fall to the bottom of the tank and can then be drained off through the water drain valve.

- **Fuel Heater.** A fuel heater is provided in turbine engine aircraft fuel systems to prevent water in the fuel freezing and blocking fuel filters.
  In gas turbine engine systems the fuel is passed through a heat exchanger utilising hot compressor delivery air, to remove any ice crystals which may have formed while the fuel was exposed to the very low temperatures experienced at high altitudes. Some systems also utilise a fuel cooled oil cooler, this uses the hot engine oil to warm the fuel and in doing so it also cools the oil..

- **Atmosphere Exclusion.** Once the fuel is in the aircraft fuel tanks, the main source of water contamination is the atmosphere that remains within the tank. If the tanks are topped up to full then the atmosphere is excluded together with the moisture it contains, thus minimising the likelihood that the fuel will be contaminated. Caution is required here, filling up the tanks may prove an embarrassment the next day if the ambient temperature rises as the volume of the fuel in the tank will increase and there is the danger that it may spill out of the vent system. Filling the fuel tanks may also incur a performance penalty as the aircraft may be too heavy to take off with the required traffic load and some defueling may be required.

WAXING

Waxing is the depositing of heavy hydrocarbons from the fuel at low temperatures. The deposits take the form of paraffin wax crystals which can clog the fuel filter and interfere with the operation of the fuel control unit. The effects of waxing can be minimised by:

- the refinery keeping the levels of heavy hydrocarbons low
- the inclusion of a fuel heater in the engine fuel system

BOILING

The temperature at which a fuel boils will vary with the pressure on its surface. As an aircraft climbs, the pressure on the surface of the fuel reduces and with that reduction comes an increased likelihood that the fuel will boil and form vapour in the pipelines. The vapour locks that this effect cause will effectively cut off the fuel supply to the engine with the inevitable result that the engine will stop.

Fuel booster pumps fitted inside the tanks can overcome this problem by pressurising the fuel in the pipelines from the tank to the engine, pushing fuel towards the engine rather than engine driven pumps sucking fuel from the tanks.

THE EFFECTS OF S.G.

The specific gravity of a liquid varies inversely with its temperature. On modern aircraft this usually makes little difference unless full tanks are required, because only the mass of the fuel load is taken into account. The fuel quantity measuring system is compensates for changes in fuel specific gravity, however, the maximum R.P.M. governor fitted to some gas turbine engines is sensitive to changes in specific gravity and so would require some adjustment if a different specific gravity fuel was uplifted.

FUEL SYSTEMS

The Aircraft Storage System

The fuel is carried in (or on) the aircraft within tanks which can be **integral, rigid or flexible.**

- Integral tanks - where the inside of the wings and, depending on type, the centre sectiontorsion box and horizontal stabiliser, are sealed during manufacture to provide large volume fuel storage. The advantage of this type of tank is that there is little extra weight added to the aircraft as the tank structure is formed by the structure already required; all modern large passenger aircraft will have this type of tank.

- Rigid tanks - a sealed metal container mounted in the aircraft wing or fuselage. Simple but does add extra weight and requires mounting structure. Most popular on light aircraft. This type of tank may be fitted externally, on the wing tip for example, made of metal or a composite construction.

- Flexible tanks - bags made of sealed rubberised fabric, sometimes referred to as a fuel bladders or bag tanks. This type of tank requires structure inside the aircraft to attach and support it. They are typically mounted inside the wing or fuselage, more popular on military aircraft as they can be effectively 'self sealing' in the event of battle damage occurring.

Baffles are fitted within the tank to minimise the large inertial forces generated when the fuel surges during aircraft manoeuvres, acceleration, deceleration or sideslip for example. Some large aircraft may be fitted with baffle check valves which allow the fuel to flow inboard but not outboard towards the wingtips during manoeuvres. Fuel tanks also incorporate vents, water drains, feed pipes, gauging system and filler caps. In larger aircraft the tanks will also have booster pumps, high and low level float switches, pressure refueling valves and filters.

The aircraft fuel system is designed to store and deliver fuel to the engine fuel system. It must be capable of delivering more fuel than the engine can possibly use in its most critical phase of flight so that the engine is never starved of fuel.

A simple, light aircraft fuel system is shown below. The fuel tanks are rigid tanks fitted in the wings and filled by the overwing method (open line through a filler cap in the top of the tank). The fuel is drawn from the tanks by a mechanical or electrical fuel pump through a tank selector and filter before being delivered to the carburetor. Engine priming is achieved by use of a priming pump which takes fuel from the filter housing and delivers it to the inlet manifold. The fuel system is monitored for contents and pressure and the fuel drains allow any water to be removed before flight.

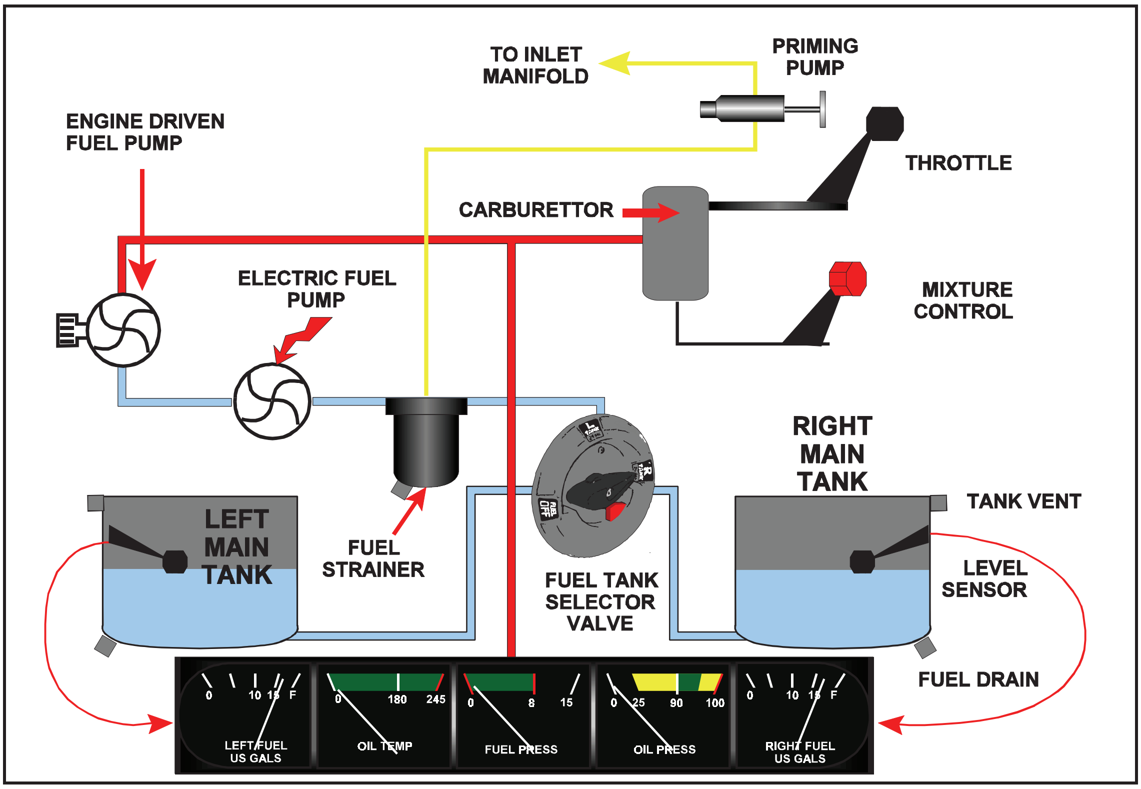


Figure 18.1: Single engine light aircraft fuel system.

Multi engine aircraft have more complex fuel systems to cope with the extra requirements for altitude and engine configuration. The fuel tanks are invariably integral tanks and are in the wings. Most modern aircraft may also have a 'centre tank', a tank in the centre section torque box between the wings. There are also aircraft fuel systems which include fuel tanks in the empennage (fin or stabilizer) which as well as being used to increase the fuel capacity may also be used to affect the aircraft centre of gravity.
The system will include the following.

- **Vent system** - may include vent valves and vent surge tank. Allows the air pressure above the fuel in the tank to equalise with the ambient pressure and may also provide for ram air to be introduced to partially pressurise the tanks in flight to assist the fuel flow and help to reduce fuel boiling at altitude. Any fuel overflowing into the vent system is collected by the vent/surge tank and recycled back to the main tanks. The vent space in each fuel tank as required by JAR 23 and JAR 25 is 2% of the tank volume.

- **Filters (screens)** - are used to prevent any debris in the tank being drawn into the booster pumps.

- **Booster pumps** - normally fitted in pairs in each tank to pump fuel from the tank to the engine. They are a necessity in high altitude aircraft to prevent cavitation of the engine driven pump. Booster pumps are typically centrifugal pumps driven by AC induction motors providing low pressure (20 - 40 psi) and high flow. In the event of a double booster pump failure in one main tank the aircraft Minimum Equipment List will invariably limit the aircraft to a maximum operating altitude to prevent fuel starvation.

- **Collector Tank (Feeder Box)** - The booster pumps are fitted in a collector tank or feeder box which always holds a measured quantity of fuel (typically 500 Kg) to allow the pumps to be continually submerged in fuel thereby preventing pump cavitation due to attitude changes of the aircraft which could cause the pumps to be uncovered. The collector tank may also have the facility to enable the pumps to be replaced without draining all the fuel from the tank

- **Cross-feed and shut off valves** - to enable fuel to be fed from any tank to any engine and isolated in the event of a fault or emergency.

- **High and Low level float switches or level sensors** - High level switches are used to automatically close the refuel valve when the tank is full (automatic top off) during refueling and the low level switches are used to maintain a required minimum fuel in the main tanks during fuel jettison or dumping.

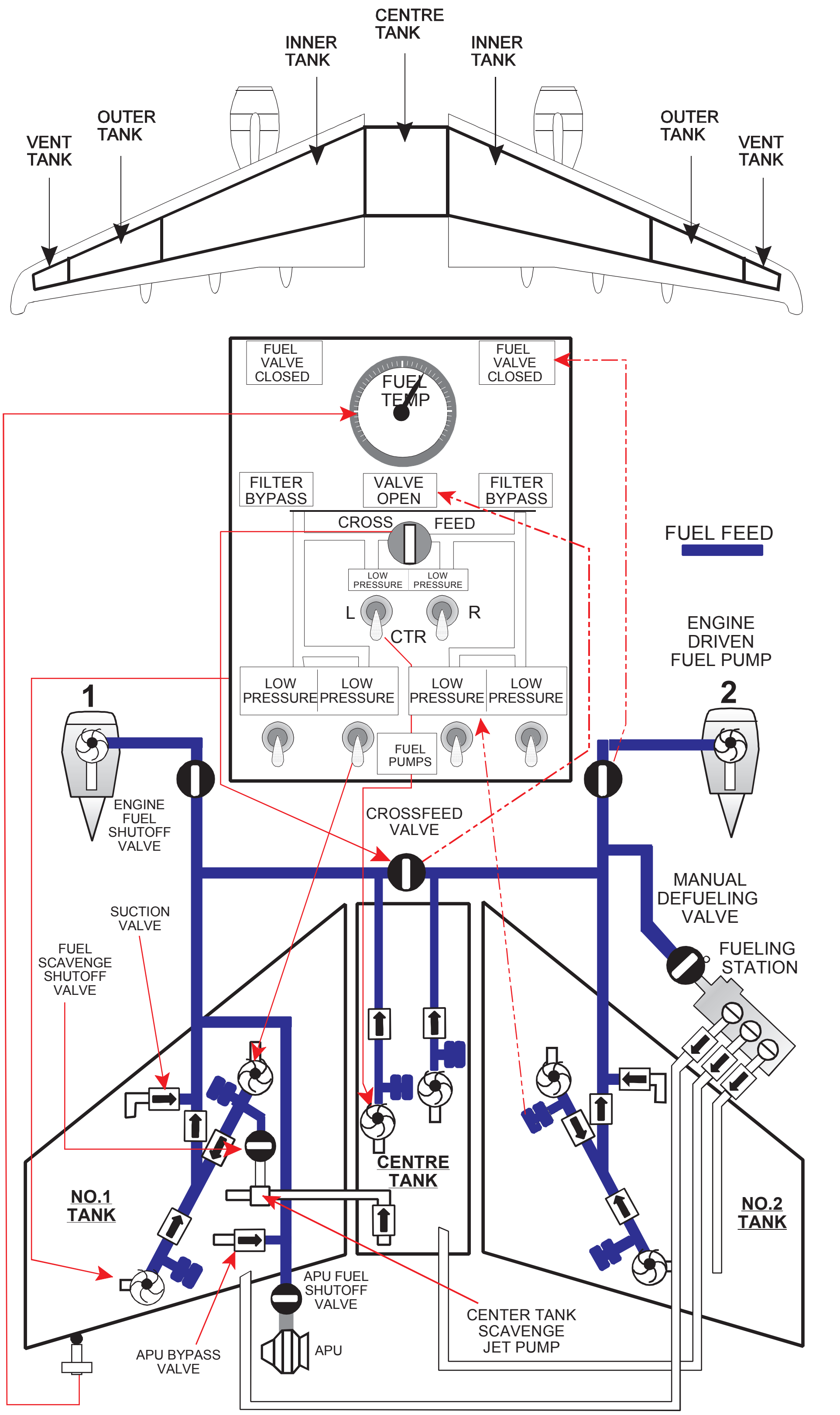
- **Fuel drains** - as in a light aircraft each fuel tank will have a fuel drain at the lowest point in the tank to allow water to be drained from the tank.

- **Baffles** - are fitted in the tanks to dampen rapid movement of fuel (surging or sloshing) during manoeuvring.

- **Overpressure relief valve** - In the event of the fuel tank being over pressurised due to a malfunction a relief valve may be incorporated to prevent structural damage to the tank.

The following diagram, *Figure 18.2*, shows a typical two engine jet aircraft system schematic layout with controls and indications.

NOTE: The wing tanks are split into two elements, outer and inner sections which are sometimes incorporated to allow a certain amount of fuel to remain in the outer section until the inner has reached a pre-determined level. Keeping fuel outboard in this manner helps to reduce wing bending stress and relieve flutter.



Courtesy of the Boeing Company

Figure 18.2: Fuel schematic.

AIRCRAFT FUEL SYSTEMS (TWIN ENGINES)

The normal sequence of fuel usage after take off would be to use the centre tank fuel first followed by the wing tank fuel. This sequence helps to relieve the wing bending stress. When the booster pumps can no longer pump fuel from the centre tank the residual fuel can be removed to the No.1 tank by use of the centre tank scavenge system.

The cross feed valve allows both engines to be fed from one side or one engine to be fed from both sides. Suction valves in the tanks allow the engine to be fed by gravity or suction by the engine driven pump in the event of both booster pumps failing in one tank.

The control panel shows selector switches for each pump accompanied by low pressure warning lights to show pump failure or low fuel level. There is also a control switch and indicator light for the cross feed valve. There is a temperature sensor in the No.1 tank which will transmit the fuel tank temperature to an indicator on the control panel.

The engine fuel shut off valve is closed by the operation of the fire handle for that particular engine, in some aircraft it is also operated by the selection of the fuel switch during the normal start or shut down procedure.

The APU takes its fuel from the No.1 tank from a bypass valve if there are no booster pumps operating, but could be fed from any tank if a booster pump in that tank was selected on. The APU shut off valve is typically operated by the automatic start or stop sequence.

Fuel imbalance in flight between the No.1 and No.2 tank can be corrected by selective switching of the booster pumps and cross feed valve (open the cross feed and switch off the pumps in the tank with less fuel until the correct balance is achieved by supplying both engines from the tank with more fuel). When the correct balance is achieved switch on the booster pumps previously switched off and close the cross feed valve. This will restore the ‘tank to engine’ configuration (No.1 tank feeding No.1 engine and No.2 tank feeding No.2 engine)

The control panel also has indicators to show low pressure fuel filter bypass valve open (filter blockage). This filter is the low pressure filter in the engine fuel system downstream of the fuel heater.

AIRCRAFT FUEL SYSTEMS (MULTI - ENGINES)

Fuel Jettison or Dump

The diagram of the right hand wing of an older four engine aircraft below shows similar components to the twin engine system. The aircraft has a stabiliser tank which feeds fuel into the transfer gallery or into the centre tank.

Where fuel pipes are routed through the pressurised rear fuselage they are double skinned to prevent fuel fumes entering the cabin in the event of a leaking pipe.

This type of aircraft also has a jettison system. This would be required if the maximum landing mass of the aircraft is significantly less than the maximum take off mass and landing at the higher mass would compromise the structural integrity of the aircraft or if the aircraft could not satisfy the climb requirements of CS25 and the discontinued approach requirements of. CS25. In an emergency therefore fuel can be dumped to reduce the mass to its maximum landing mass.

Fuel dumping is accomplished by pumping fuel out of a dump master valve, typically one on each wing at the trailing edge, well outboard to enable the fuel to be dumped safely with no danger of it entering the aircraft or any of its systems.

Fuel dumping is controlled from the pilot's or flight engineer's fuel control panel. The amount of fuel to be dumped (or the amount of fuel to remain) can often be selected and automatically controlled. The fuel dumping process will be automatically stopped when this level has been reached.

It would be clearly undesirable to dump all of the fuel in the aircraft and safeguards must be in place to allow a minimum amount of fuel to remain. **The minimum amount is stipulated in CS25 which states that the fuel remaining after jettisoning must be sufficient to enable the aircraft to climb to 10,000 ft and thereafter allow 45 minutes cruise at a speed for maximum range.**

Management of this type of fuel system may be manual (flight engineer) or in more modern two pilot aircraft, (747-400), can be almost fully automatic only requiring the minimum of input from the pilot. The majority of the monitoring and switching actions are accomplished by a fuel management computer. The stabilizer and centre tank fuel would be used first either by transferring to the main tanks, as in our old system, or by selective fuel feed, as in the modern aircraft. For the same reason as in the twin, fuel would be kept in the outboard section of the wings as long as possible.

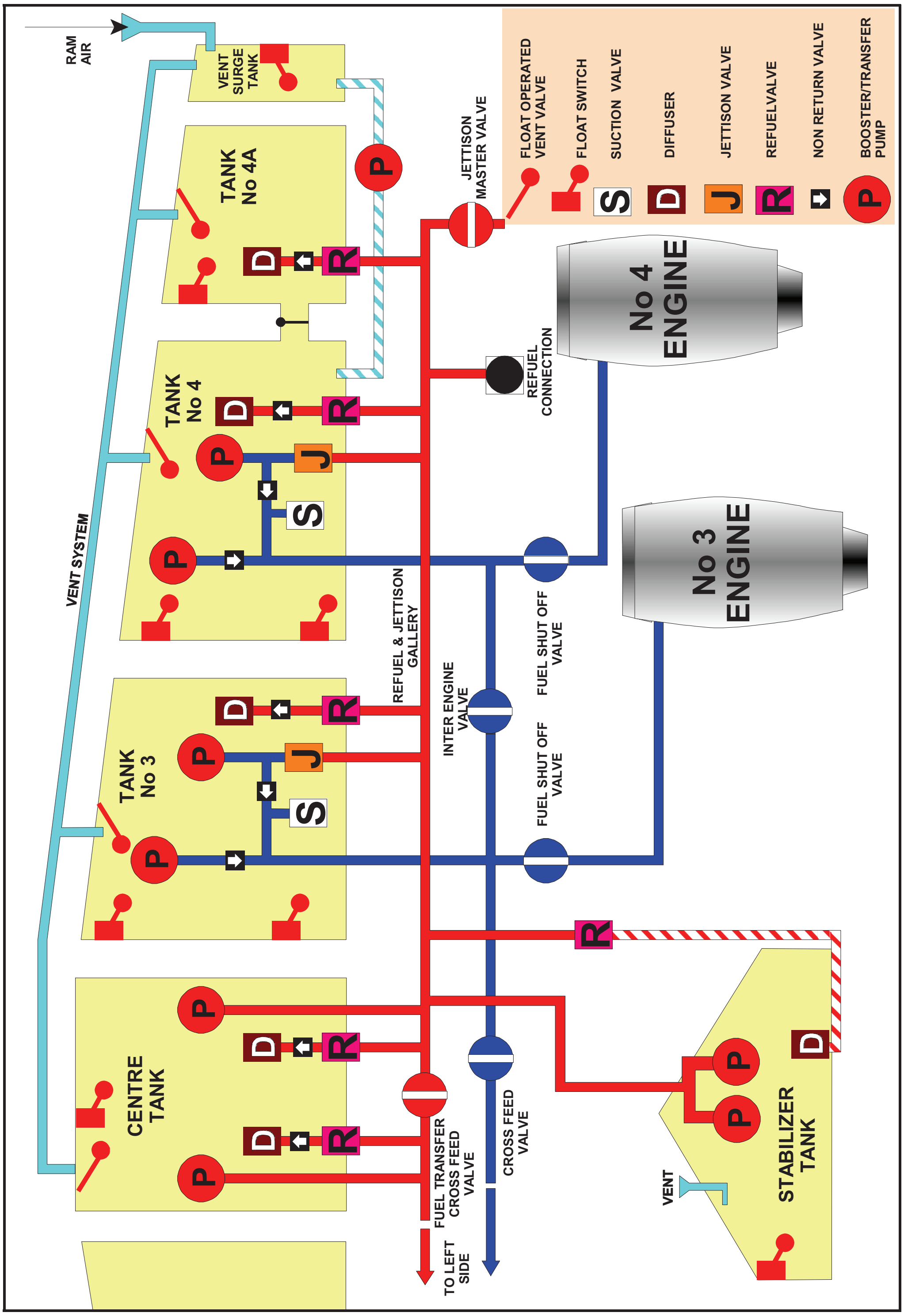


Figure 18.3: A representative jet aircraft engine fuel system.

FUEL QUANTITY MEASUREMENT.

There are two methods of measuring fuel quantity.

- Measuring volume by varying a resistance by a float - normally restricted to light aircraft, is subject to manoeuvring error and cannot compensate for variations of density.
- Measuring weight or mass by varying capacitance - essential on modern passenger aircraft - does not suffer from manoeuvring error and can compensate for variations of density.

The capacitive method works by supplying the two plates of a capacitor with A.C. The current that flows in the circuit now depends on four factors, the level of voltage applied, the frequency of the supply, the size of the plates and the dielectric constant of the material separating the plates. In our circuit three of these factors are fixed and the fourth, the dielectric constant, is variable because the dielectric consists of fuel and air. The higher the level of fuel in the tank the more fuel and less air will be in the capacitor probe, and vice-versa.

The amount of current flowing in the circuit therefore depends on the amount of fuel/air between the plates and in measuring this current we can have an accurate indication of the mass of fuel in our tanks.

The system can be made sensitive to the specific gravity (density) of the fuel so that although the volume of a quantity of fuel may increase with a temperature rise, the resulting decrease in the specific gravity will ensure that the indicated mass (weight) remains the same.

To compensate for change in aircraft attitude the capacitive system may have many capacitor probes in the tank connected in parallel to 'average' the measurement of the fuel in the tank. This enables the system to give an accurate indication irrespective of the aircraft attitude.

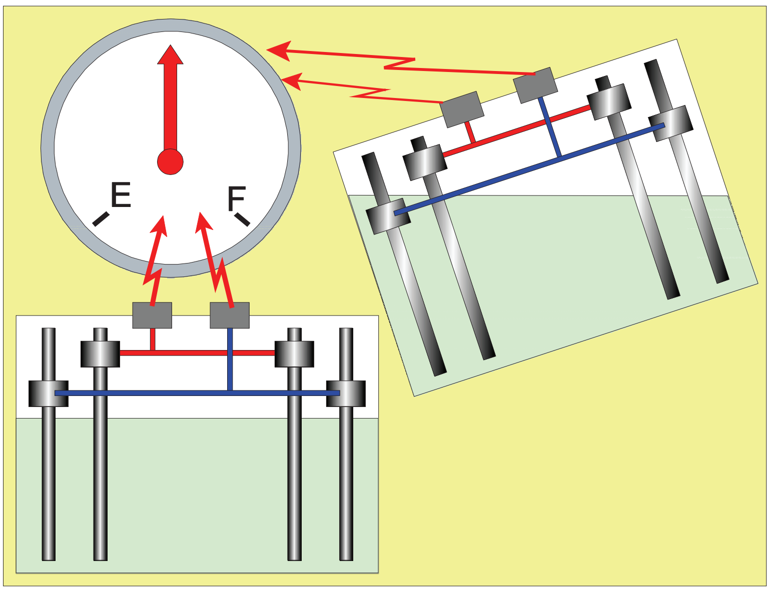


Figure 18.4: Attitude compensation.

SYSTEM FUNCTION

If a capacitive gauging system fails, it does so in a manner to draw the attention of the user, a fail safe circuit is incorporated which drives the gauge pointer slowly towards the empty position in order to prevent the indicator showing that there is more fuel in the tank than there actually is. Some systems also incorporate a test switch utilising the fail safe circuit, when the test switch is operated, the indication moves towards empty and when the switch is released the pointer should move back to its original position.

SIMPLE QUANTITY MEASURING SYSTEMS

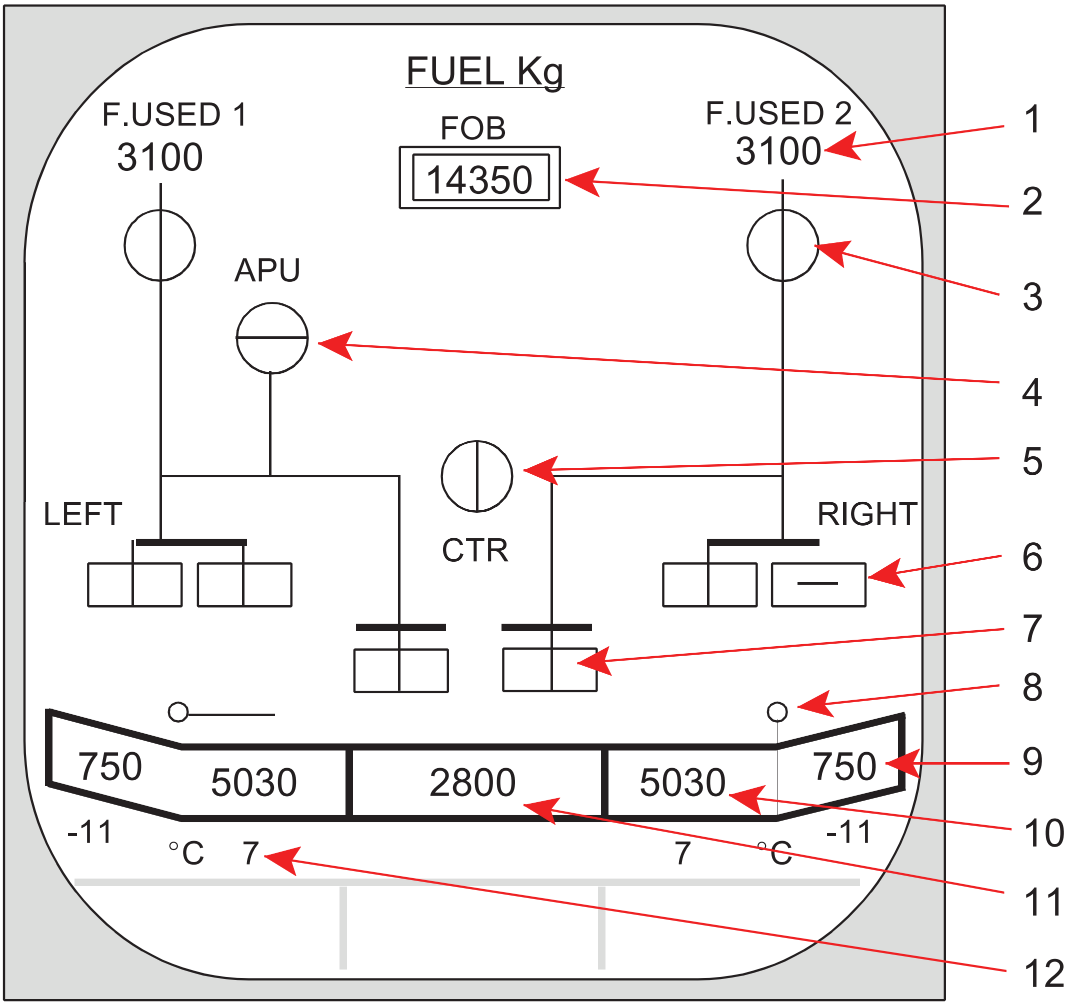
In the event that the electronic measuring system does fail, we must be able to determine the quantity of fuel in the aircraft. A dipstick can be used from the top of the tank but of course it exposes the user to the dangers inherent in walking on high slippery surfaces.

Another method is the '**dripstick**', a calibrated hollow tube which is withdrawn from the under surface of the tank through a fuel proof aperture. When the top of the tube becomes lower than the fuel level, the fuel will drip through the tube, hence the name 'dripstick'. The volume of the fuel in the tank can be established by reference to the calibrations on the tube. The disadvantage of this system is that the user's armpit soon becomes saturated with the fuel dripping from the pipe.

A more user friendly version of this system is the '**dropstick**' or Magnetic **Level Indicator (MLI)**. The previously mentioned tube now becomes a rod, calibrated to show the level of fuel in the tank. The rod is fitted within a fuel proof tube in the tank and around the tube is a magnet supported on a float. The tip of the rod is also fitted with a magnet and when it is lowered through the tube the fields of the two magnets interact. The length of rod protruding from the underside of the wing indicates the level of fuel in the tank. By reference to the aircraft manual and using the density of the fuel the mass of fuel in the tanks can be established.

FUEL SYSTEM INSTRUMENTATION

The fuel system instrumentation on a light aircraft will consist of contents and pressure gauges as shown in Figure 18.1, but on large aircraft it is necessary to provide information regarding not only the quantity and pressure but also fuel used, position of valves such as cross feed, inter engine and firewall shut off valve. Other indications include pumps on or off and fuel temperature. These indications are usually in the form of "mimic" diagrams with 'dolls eyes' and lights on the flight engineers panel or electronically presented schematic displays. The diagram below shows a typical Airbus Electronic Centralised Aircraft Monitoring (ECAM) system display. A Boeing Engine Indicating and Crew Alerting System (EICAS) would be a similar display.



Courstey of Airbus Industrie

Figure 18.5: Electronic fuel system display (Airbus).

1. Fuel used, each engine
2. Total fuel on Board
3. Engine fuel shut-off valve
4. APU fuel shut-off valve
5. Cross-feed valve
6. Wing tank booster pump indication (Shown switched off)
7. Centre tank booster pump indication
8. Transfer valve indication
9. Fuel quantity, right wing outboard
10. Fuel quantity, right wing inboard
11. Fuel quantity, centre tank
12. Tank fuel temperature

AIRCRAFT REFUELLING

Before fuelling an aircraft, fuelling zones should be established. These zones will extend at least 6m (20 feet) radially from the filling and venting points on the aircraft and the fuelling equipment.

Within these zones the following restrictions apply:

- There should be no smoking.
- If the exhaust of an A.P.U. which is required during the fuelling operation discharges into the zone, then it must be started before filler caps are removed or fuelling connections made.
- If the A.P.U. stops for any reason during fuelling, it should not be started again until fuelling has ceased and there is no danger of igniting the fuel vapors.
- Ground power units, (G.P.U.'s) should be located as far away as practical from the fuelling zones and not be connected or disconnected while fuelling is in progress.
- Fire extinguishers should be located so as to be readily accessible.

Light aircraft are refueled by the over wing method with the quantity issued vehicle in litres or gallons indicated on the delivery vehicle.

Large aircraft are pressure refueled from hydrants or bowsers through underwing refuel/defuel coupling points and controlled by quantity, tank and valve selection from a conveniently situated refuelling control panel. The quantity required in each tank can be preselected and the refuel valve to that tank will close when this level has been reached. The system will prevent any tank being overfilled. An example of an external refuel control panel is shown in *Figure 18.6.*

PRECAUTIONS BEFORE FUELLING

Before fuelling commences, the following procedures should be carried out:

- The aircraft should be bonded (grounded) to the fuelling equipment using dedicated wires and clips. Reliance must **not** be placed upon conductive hoses for effective bonding.
- When overwing refuelling, the hose nozzle should be bonded (grounded) to the aircraft structure before removing the tank filler cap. Similarly, even funnels, filters and cans should be bonded to the aircraft. Plastic funnels or pipes should **never** be used.
- When underwing pressure refuelling, the mechanical metal to metal contact between the aircraft fitting and the nozzle end eliminates the need for a separate hose-end bonding cable.

NOTE: The sequence of refuelling the aircraft tanks can adversely affect the CG position particularly if some of the tanks are only to be partially filled and/or the aircraft has a vertical or horizontal stabiliser tank. If in doubt consult the aircraft manual.

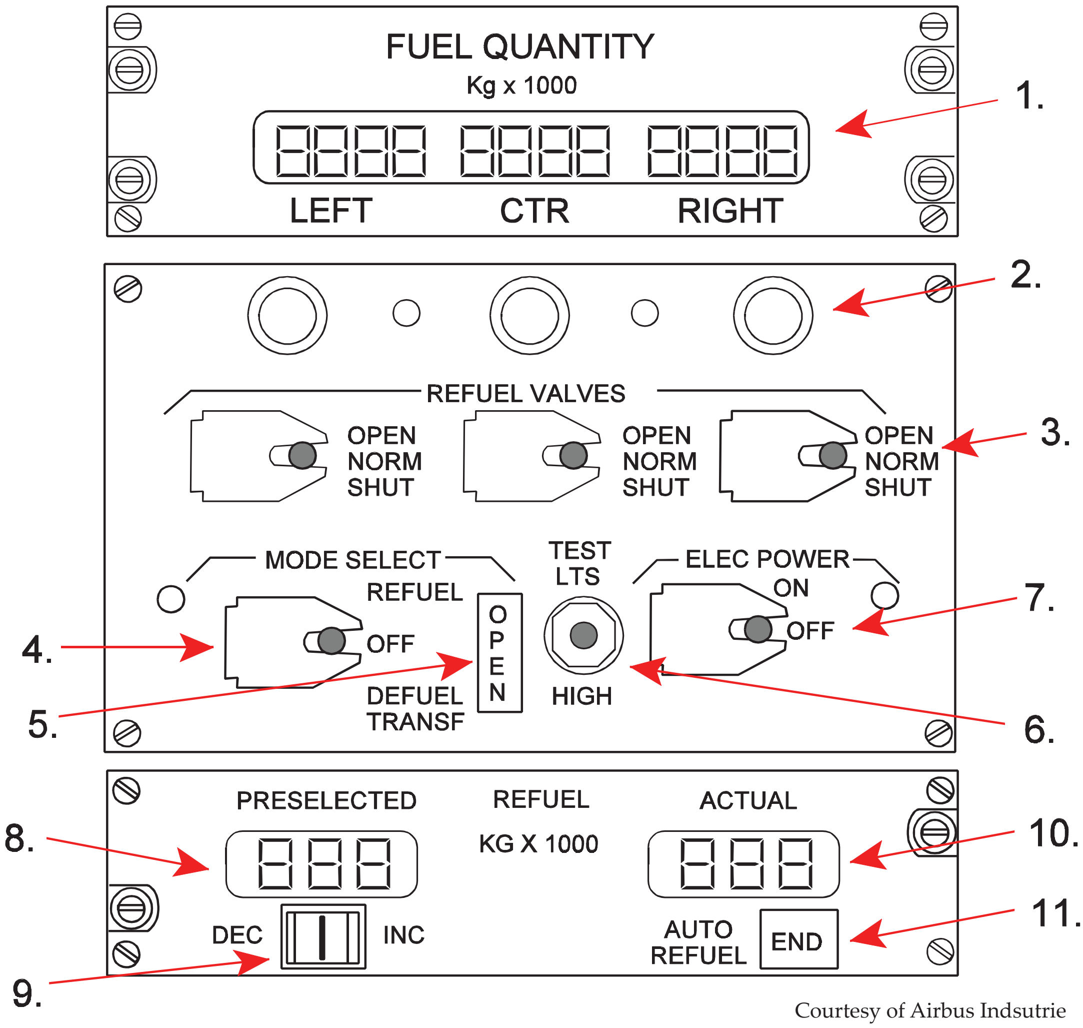
PRECAUTIONS DURING FUELLING

When passengers are embarking or disembarking during fuelling operations, they should do so under the supervision of an airline official and their route should avoid the fuelling zones.

WORK ON AIRCRAFT DURING REFUELLING

The precautions to be taken during refuelling which appertain to work being carried out on the aircraft are many and various, some if the most pertinent are listed below:

- In case the aircraft settles on the landing gear, all steps, trestles, jacks etc. should be moved clear.
- The main engines should not be operated.
- Strobe lighting should not be used.
- All torches and lamps used within the fuelling zones should be either certified flame proof or of the 'intrinsically safe' type.
- Only authorised personnel and vehicles should be allowed within the fuelling zone and their number should be kept to a minimum.



Courtesy of Airbus Indsutrie

Figure 18.6: An external refueling control panel.

Key to *Figure 18.6*

1. FUEL QTY. Shows fuel quantity by tank.

2. HIGH LEVEL LIGHTS. These come on BLUE when high level is sensed and the corresponding refuel valve will close automatically.

3. REFUEL VALVES SELECTOR (guarded in NORM)
NORM. Refuelling valves are controlled by automatic refueling logic.
OPEN. Valves open when the MODE SELECT switch is set to REFUEL or DEFUEL position. In REFUEL each refuel/ defuel valve will close when high level is detected in the associated tank.
SHUT. Valves close.

4. MODE SELECT switch (guarded at OFF)
OFF. Refuel system is de-energised and the refuel valves are closed.
REFUEL. Refuel valves operate in automatic or in manual mode depending on the position of the refuel valve switches.
DEFUEL. Refuel valves and transfer valve open.

5. TRF (transfer) light. Comes on AMBER when the transfer valve is open.

6. TEST switch.
HIGH. Illuminate if the high level sensors and associated circuits are serviceable. LTS. Lights on panel and all **8**'s on fuel quantity indicator illuminate.

7. ELEC POWER. Refueling or defueling can be powered by GPU, APU or BATTERY 1.

8. PRESELECTED DISPLAY. Displays the preselected total fuel quantity in kg. x 1000

9. PRESELECTOR ROCKER SWITCH. Pressing either side of the switch increases or decreases the preselected quantity.

10. ACTUAL . Displays the TOTAL fuel on board.

11. AUTO REFUEL LIGHT. Comes on GREEN (END) when automatic refueling is completed.

REFUELLING WITH PASSENGERS ON BOARD - JAR- OPS 1.305

To reduce turnaround time, and for security reasons, airline operators of fixed wing aircraft may allow passengers to **embark**, **disembark** or **remain on board** during fuelling operations, provided the following safety procedures are followed:

- **It is not permissible** to refuel fixed wing aircraft with less than 20 seats while passengers remain on board.
- **Passengers should disembark** if wide cut fuels (e.g. Jet B) are being used.
- **Passengers should disembark** whenever **AVGAS** is involved.
- One qualified person must remain at a specified location during fuelling operations with passengers on board. This qualified person must be capable of handling emergency procedures concerning fire protection and fire fighting, handling communications and initiating and directing an evacuation.
- Crew, staff and passengers must be warned that re/refueling is about to take place.
- Seat Belt signs must be off.
- NO SMOKING signs must be on together with interior lighting to enable emergency exits to be identified.
- Passengers must be instructed to unfasten their seat belts and refrain from smoking.
- Sufficient qualified personnel must be on board and be prepared for an immediate evacuation.
- If the presence of fuel vapour is detected inside the aircraft, or any other hazard arises during re/refueling , fuelling must be stopped immediately.
- The ground area beneath the exits intended for emergency evacuation and slide deployment areas must be kept clear.

- Provision must be made for a safe and rapid evacuation.
- Provision should be made, via at least **two main passenger doors** (or the main passenger door plus one emergency exit when only one main door is available) and preferably **at opposite ends of the aircraft,** for the safe evacuation of the aircraft in the event of an emergency.
- Ground servicing and work within the aircraft such as catering and cleaning, should be carried out in such a way that they do not create a hazard or obstruct exits.

ADDITIONAL INSTRUCTIONS FOR WIDE BODIED AIRCRAFT WITH AUTOMATIC INFLATABLE CHUTES

- When a loading bridge is in use, no additional sets of steps need be provided. However, either the left or right rear door should be manned constantly by a cabin attendant and should be prepared for immediate use as an emergency route using the automatic inflatable chute. Where slide action requires manual fitting of an attachment to the aircraft (e.g. girt bar) the slide should be engaged throughout the fuelling process.
- As a precautionary measure when a loading bridge is **not** available for use, one set of passenger steps should be positioned at the opened main passenger door which is normally used for the embarkation and / or disembarkation of passengers.

ADDITIONAL INSTRUCTIONS FOR AIRCRAFT WITHOUT AUTOMATIC INFLATABLE CHUTES

- When a loading bridge is in use, one set of aircraft steps should be positioned at another opened passenger door, preferably at the opposite end of the aircraft.
- When a loading bridge is **not** in use, aircraft steps should be positioned at two of the main passenger doors (i.e. preferably one forward and one aft) which are to be open.
- Where aircraft are fitted with integral stairways and these are deployed, each may count as one means of exit.

PRECAUTIONS AFTER FUELING

When fuelling is complete, bonding wires (grounding wires) should not be removed until either:

- filler caps have been refitted, or
- the pressure refueling hose has been disconnected.

SPECIAL HAZARDS

There are certain situations which pose a particular danger while fuelling is being carried out, following is a (not exhaustive) list which covers some of the rules to be observed in those certain situations:

- Aircraft should not be fuelled within 30 m (100 ft) of radar equipment either under test or in use in either aircraft or ground installations.

- If the landing gear is overheated, the aerodrome Fire Service should be called and no fuelling carried out until the heat has dissipated.

- Extreme caution should be exercised during electrical storms. Fuelling operations should be suspended during severe electrical disturbances in the vicinity of the airfield.

- The use of photographic flash bulbs or electronic flash equipment within 6 m (20 ft) of fuelling or vent points should not be permitted.

MARKING OF FUELLING EQUIPMENT

All fuelling vehicles, hydrant dispensers and their components should conform to the relevant standards.

Fuelling vehicles and hydrants dispensing AVTUR will be identified by prominently placed labels with the word **"AVTUR"** and/or **JET A , JET B** depending on grade printed in **white on a black background.**

Fuelling vehicles dispensing AVGAS will be identified by prominently placed labels with the word **"AVGAS"** and the grade e.g. 100/130, 100LL etc. printed in **white on a red background.**

QUESTION PAPER 1

1. Baffles are fitted in aircraft fuel tanks:

   a. to assist in correct fuel distribution.
   b. to prevent fuel surging during aircraft manoeuvres.
   c. to prevent the static build up in the tank during refueling.
   d. to channel fuel to the vent valve.

2. A power failure to a capacitive fuel contents system would cause the gauge to:

   a. show full scale deflection high.
   b. fluctuate between high and low readings.
   c. remain fixed on the last contents noted before failure.
   d. show full scale deflection low.

3. A fuel booster pump, besides pumping fuel to the engine, can also be utilised to:

   a. jettison and transfer fuel.
   b. jettison and heat the fuel.
   c. transfer and heat the fuel.
   d. transfer and recycle the fuel.

4. During fuel jettison, the aircraft is protected against running out of fuel by:

   a. high level float switches.
   b. preset jettison quantity switches.
   c. the crew remaining alert.
   d. low level float switches.

5. To indicate that a refueling bowser carries JET A1 aviation kerosene:

   a. yellow and black stripes are marked on the refueling hose.
   b. JET A1 would be painted in 30cm high symbols on the side of the container.
   c. JET A1 is printed in white on a black background label positioned prominently on the vehicle.
   d. the driver wears a straw yellow water and fuel proof jacket.

6. Adjustments may have to made to an aircraft's engine fuel system if it has been refueled with JET B instead of its normal JET A1 fuel, these adjustments are to cater for:

   a. the change in the specific gravity of the fuel.
   b. the change in the calorific value of the fuel.
   c. the change in the viscosity of the fuel.
   d. the lack of HITEC lubricant in the fuel.

7. The differences between AVGAS 100 and AVGAS 100LL are:

	Colour	Anti-knock value
a.	Same	Same
b.	Same	Different
c.	Different	Same
d.	Different	Different

8. The aircraft cannot be refueled while:

   a. a ground power unit is operating on the ramp.
   b. passengers are walking through the refueling zones.
   c. passengers are boarding.
   d. the A.P.U. is running.

9. The disadvantage of refueling the aircraft to “tanks full” the night before a departure in the heat of the day is that:

   a. the change in the specific gravity may cause the aircraft to be overweight.
   b. the change in the volume of the fuel may cause it to spill through the vent system.
   c. the change in calorific value may reduce engine power to below sufficient.
   d. the R.P.M. governor will be rendered inoperative.

10. An aircraft using MOGAS:

   a. is likely to be affected by detonation at cruise power.
   b. must have booster pumps fitted in the fuel tanks.
   c. is more likely to be affected by vapour locking and carburetor icing.
   d. will suffer from a loss of power during take off.

QUESTION PAPER 2

1. If a fuel sample appears cloudy or hazy, the most probable cause is:

   a. water contamination.
   b. anti-microbiological additives.
   c. mixing different fuel grades.
   d. oil in the fuel.

2. On an aircraft equipped with a compensated capacitance type fuel quantity indication system graduated to read in kg, the temperature increases just after the tanks are half filled with fuel. If the fuel expands by 10%, the gauges will show:

   a. an increase of 10%.
   b. a decrease of 10% of the volume factored by the new specific gravity.
   c. a decrease.
   d. the same amount.

3. The exhaust gases from the A.P.U. go into the refueling zone. The A.P.U:

   a. must be switched OFF throughout the refueling operation.
   b. can be started while refueling is carried out.
   c. must be started before fuelling is carried out, and can be run throughout the refueling operation.
   d. can be started only after the refueling operation has been terminated.

4. De-fuelled fuel:

   a. can only be used in domestic heating systems.
   b. can only be used by aircraft from the same operators fleet.
   c. must be put back into storage.
   d. cannot be re-used until its quality has been verified.

5. The background colour scheme for fuelling system pipelines carrying the following fuels is:

	JET A1	AVGAS
a.	Red	Black
b.	Black	Red
c.	Red	Yellow
d.	Yellow	Red

6. AVGAS:

   a. is coloured red for identification purposes.
   b. is coloured green if it is a leaded fuel and blue if it is a low lead fuel.
   c. has no artificial colouring and appears either clear or a straw yellow colour.
   d. can only be used in piston engines if oil is added to improve its anti-knock properties.

7. Information relating to the use of MOGAS can be found in:

   a. C.A.A. General Aviation Safety Sense Leaflets.
   b. Advisory Information Circulars.
   c. Notams.
   d. C.A.A. Airworthiness Publications.

8. The fuel cross feed valves are fitted in order to facilitate:

a. the use of fuel from any tank to any engine.
b. refueling when only one bowser is in use.
c. isolation of the engine from the fuel system in the case of an engine fire.
d. transfer of fuel between the main fuel tanks.

9. Refueling with passengers on board is not permissible:

a. on a fixed wing aircraft.
b. if AVGAS is being used.
c. if the aircraft has more than twenty seats and the ratio of cabin attendants to passengers is greater than 1:50 and it is a wide bodied jet.
d. in any of the above cases.

10. While refueling with passengers on board, when a loading bridge is in use:

a. two sets of extra steps must be provided, one of which must be at the rear of the aircraft.
b. the rear left or right door must be manned constantly by a cabin attendant ready for use as an emergency exit using the inflatable escape slide.
c. ground servicing must not be carried out.
d. catering and cleaning must not be carried out.

QUESTION PAPER 3

1. A “wide-cut” fuel is:

   a. more flammable than a kerosene type fuel.
   b. less volatile than a kerosene type fuel.
   c. coloured red for identification purposes.
   d. commonly used in civilian transport aircraft.

2. The purpose of fitting baffles in fuel tanks is to:

   a. prevent longitudinal movement of the fuel during acceleration.
   b. allow the booster pump to remain covered by fuel irrespective of the aircraft attitude.
   c. dampen lateral movement of the fuel in the wing tanks during a sideslip.
   d. maintain a pre-determined quantity of fuel in the outboard section of the wing tank.s

3. Fuel is heated:

   a. to stop cavitation in the High Pressure Fuel Pump.
   b. to maintain a constant viscosity.
   c. to prevent water contamination.
   d. to stop ice blocking the Low Pressure fuel filter.

4. What is the function of a collector tank (feeder box):

   a. prevent detonation during take off.
   b. prevent cavitation of the booster pumps.
   c. prevent fuel surge due to extreme aircraft attitude.
   d. allow suction feeding of the engine pump.

5. Fuel tank booster pumps are:

   a. centrifugal, low pressure.
   b. centrifugal, high pressure
   c. gear type, low pressure
   d. gear type, high pressure

6. The advantage of a capacitor type fuel contents gauging system is that the circuit:

   a. responds to changes in specific gravity.
   b. compensates for high altitude flight.
   c. responds automatically to extremely low temperatures.
   d. compensates for aircraft attitude changes.

7. The Low Pressure engine driven pump:

   a. backs up in case the engine High Pressure Pump fails.
   b. backs up in case of a double booster pump failure.
   c. assists in the refueling operation if only low pressure refueling systems are available.
   d. pressurises the fuel tanks to assist flow to the booster pumps.

8. The purpose of the fuel cooled oil cooler is to:

   a. heat the oil and cool the fuel.
   b. heat the fuel and cool the oil.
   c. cool the oil.
   d. heat the fuel.

9. If a fuel tank with a capacitive quantity system was filled with water instead of fuel, the gauge would indicate:

   a. full scale low (zero).
   b. it would indicate the same as if it were filled with fuel c. full scale high (max).
   c. it would freeze at the last known indication.

10. AVTUR or JET A1:

   a. varies in colour between clear and straw yellow.
   b. is a wide cut fuel which is not normally used in civilian transport aircraft.
   c. is a gasoline type fuel with a high flash point.
   d. is a 97 octane fuel which prevents detonation in gas turbine engines.

ANSWERS

PAPER 1		PAPER 2		PAPER 3	
1.	B	1.	A	1.	A
2.	D	2.	D	2.	C
3.	A	3.	C	3.	D
4.	D	4.	D	4.	B
5.	C	5.	B	5.	A
6.	A	6.	B	6.	D
7.	C	7.	A	7.	B
8.	B	8.	A	8.	B
9.	B	9.	B	9.	C
10.	C	10.	B	10.	A