Airframe & system

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At the first let me ask a question

Why did human want to fly?

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Design Concepts

Design philosophies: The manufacturer will attempt to design an aircraft taking into account all the loads that it may experience in flight. There are various guidelines, computer-aided design (CAD) programs, 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. Safe life for aircraft components may be recorded as:

- Flying hours
- Cycles of landing gear
- Aircraft pressurisations
- Calendar basis

Once the safe life event has been reached, the item is replaced or overhauled.

Fail-Safe (Multiple Load Paths)

Large modern aircraft are designed with a fail-safe structure This can be described as a structure in which a failure of a particular part is compensated by an alternative load path. This structure ensures that an adjacent part can carry the load for a limited time period, normally up to the next periodic inspection, without any catastrophic consequences. This is common practice and can be found in wing attachments, vertical stabiliser, and horizontal stabiliser attachment points.

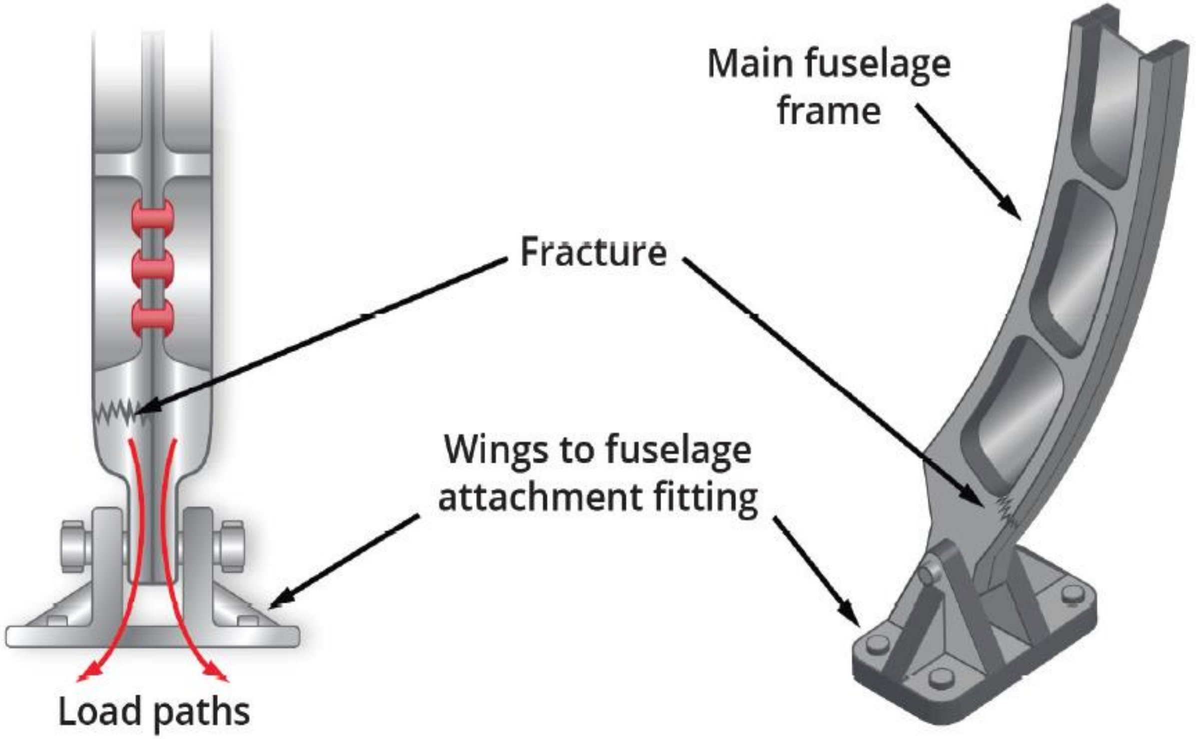


Figure 1.1 Multiple load paths

Damage-Tolerant

Fail-safe structures incur a weight penalty due to the extra structural members required to protect the integrity of the structure. A further development of the fail-safe design is the damage-tolerant method of construction.

A damage-tolerant structure eliminates the extra structural members by spreading the loading of a structure over a larger area. This means that the structure is designed so that the damage can be detected during the normal inspection cycles before a failure occurs.

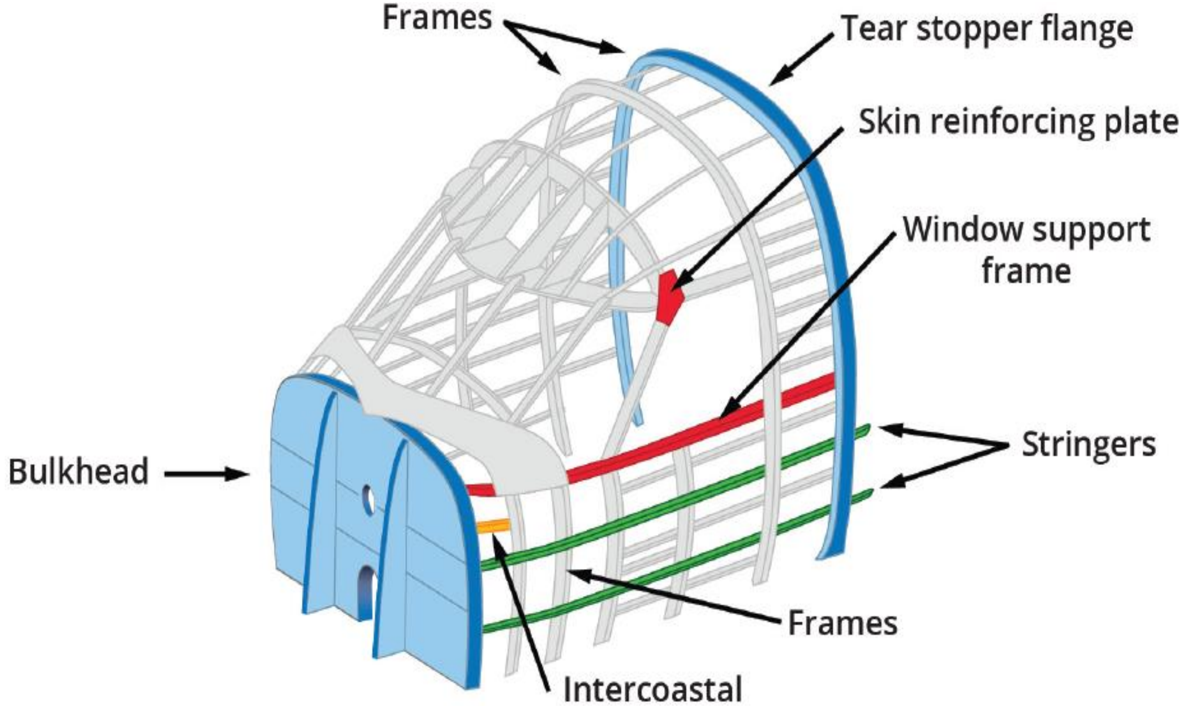


Figure 1.2 Damage tolerant structure

Levels of Certification

Safeguards in the form of duplication and triplication of essential systems are provided in large modern transport aircraft to eliminate the possibility of complete system failure. This is achieved by building in some form of redundancy into the system, which allows for the function of a component to be taken over by another component, in the event of failure.

Usual methods: Redundancy can be achieved by splitting the control surfaces into two or three sections, each powered by separate actuators and hydraulic systems. Control computer system redundancy is also provided in modern flyby-wire aircraft.

Requirement for Certification

Before a newly developed aircraft may enter operation, it must obtain a type certificate from the responsible aviation regulatory authority. EASA is responsible for the certification of aircraft in the European Union (EU) and for some European non-EU countries. This certificate testifies that the type of aircraft meets the safety requirements set by the EU. The certificate is issued after certification specifications (CS) are met.

Steps to certification: The certification process is made up of 4 steps: technical familiarisation, where the manufacture presents the project to EASA; establishment of the certification programme, where EASA and the manufacturer define and agree on the means to achieve compliance; compliance demonstration, where the manufacturer demonstrates compliance of its products with regulatory requirements; technical closure and issue of approval, where EASA closes the investigation and issues the certificate. This is a lengthy and expensive process.

Certification Specification

Different types of aeroplanes are certified to different EASA specifications:

- **CS-23** normal, utility, aerobatic, and commuter aeroplanes (smaller types)
- **CS-25** larger aeroplanes

Stress, Strains, and Loads

Forces Acting on the Aircraft Structure

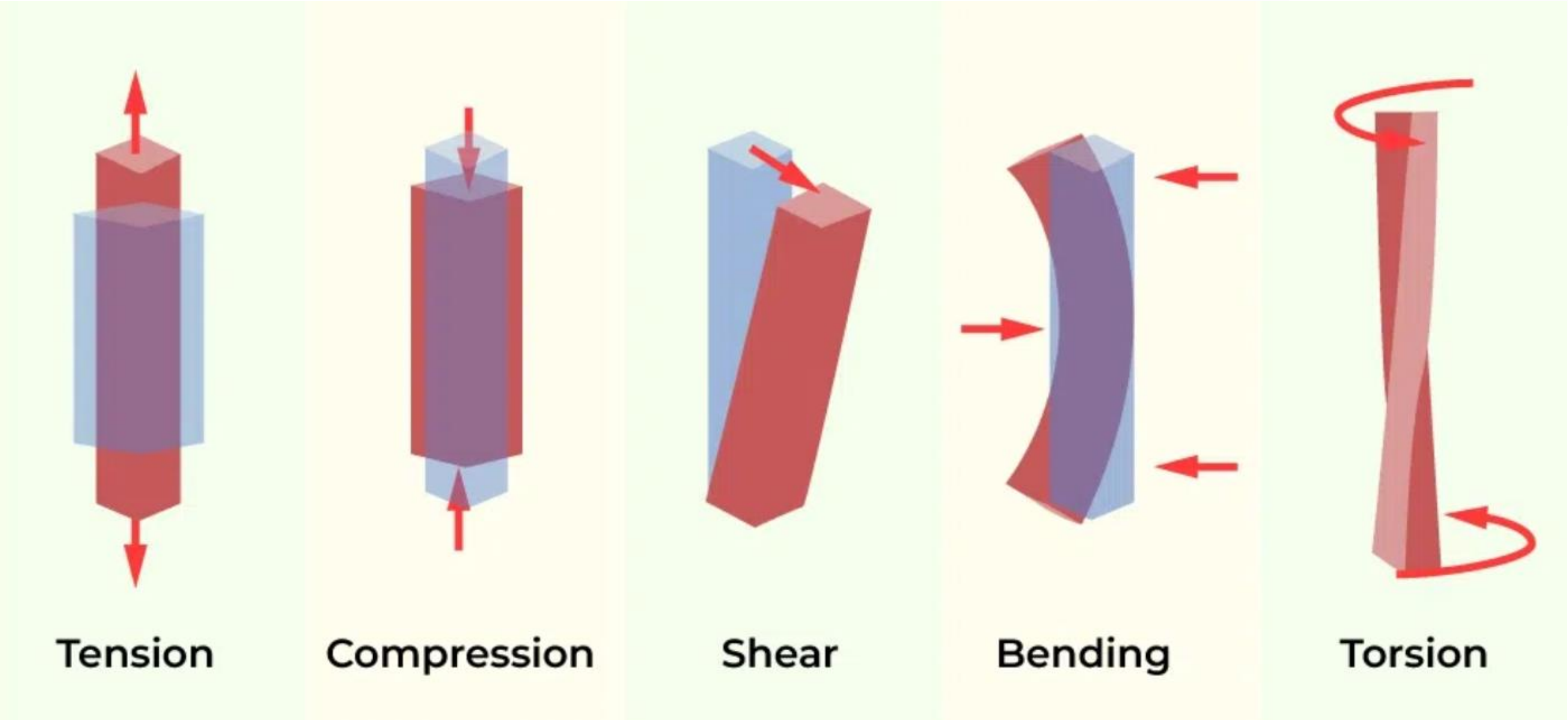
An aircraft is subject to various forces which act on the structure both in the ground and in the air, whether the aircraft is parked or manoeuvring. The four forces acting on an aircraft are:

- Weight - which is always present. The force of weight will vary as the force of gravity changes as the aircraft manoeuvres.
- Lift - is generated when taking off and when airborne, tending to bend the wings upwards.
- Drag - will act on components such as landing gear, bending them backwards.
- Thrust - produced on large transport aircraft will produce forwards loads on the airframe.

Stress and Strain

Stress is the internal force per unit area inside a structural part as a result of external loads. It can be further broken down into tensile (stretching) stress and compression stress.

Strain is the deformation caused by the action of stress on a material. This will only happen when the force reaches a certain magnitude.



Types of Loads

- Static loads
- Dynamic loads
- Cyclic loads

Static loads are generally constant and build slowly. An aircraft on the ground will experience static loads. Pilots should be careful not to exceed maximum operating weights for the aircraft.

Dynamic loads are those that build quickly due to changes in flight conditions. These loads are produced when an aircraft is manoeuvred and may induce other loads on other parts of the aircraft. Pilots should only manoeuvre the aircraft within the authorised load factor boundary calculated for that aircraft.

Cyclic loads occur repeatedly at regular or irregular intervals and can be of a static or dynamic nature. The safe life for components will determine the number of cycles that would lead to failure with a margin of safety. Pilots in conjunction with maintenance planners must ensure that load cycles are not exceeded.

Fatigue and Corrosion

Effects of Corrosion

Corrosion is one of the most persistent defects found in aircraft, and rectification of advanced corrosion has been known to take thousands of man hours. It is essential that corrosion is recognised at the earliest possible stage and effective preventative measures taken. Most metals are unstable, and 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. This change in state will reduce the ability of the material to withstand the forces applied in flight and can lead to earlier than planned structural failure.

Pilot Identification of Corrosion During Walk Round Check

It is difficult for the pilot to identify signs of corrosion during the walk around inspection because corrosion is very often hidden under layers of paint and can often only be detected during detailed maintenance inspections. It should be noted that the older the aircraft is, the more likely corrosion will be present. The presence of corrosion will also be affected by the aircraft operating environment. It is however possible for the pilot to detect signs of corrosion and should include Inspection of areas where water and pollutants are likely to get trapped. The pilot should look for:

- bumps or blister on paint.
- discoloration of paint.
- signs of grey/white powder on aluminium, reddish on ferrous material.
- cracking, which may be a result of corrosion.

Corrosion and Operating Environment

The rate of corrosion will be affected by the environment in which the aircraft is operated. Maintenance and inspection frequency will be adjusted accordingly, and special preventative maintenance procedures may be actioned. The table below shows the rate of corrosion in different atmospheres.

Rate of Corrosion	Type of Atmosphere		
High	Tropical	Industrial	Marine
Medium	Temperate	Suburban	Inland
Low	Arctic	Rural	

The effects of environmental factors can be minimised by use of the following procedures:

- Protecting the aircraft by keeping in hangarage
- Application of corrosion inhibitors/barrier fluids to aircraft surfaces
- Regular aircraft washing to remove pollutants and dirt
- Engine compressor washes
- Regular removal and application of paint to surface
- Increased maintenance inspections and early intervention when corrosion is detected

Aircraft Fluids and Corrosion Hazard

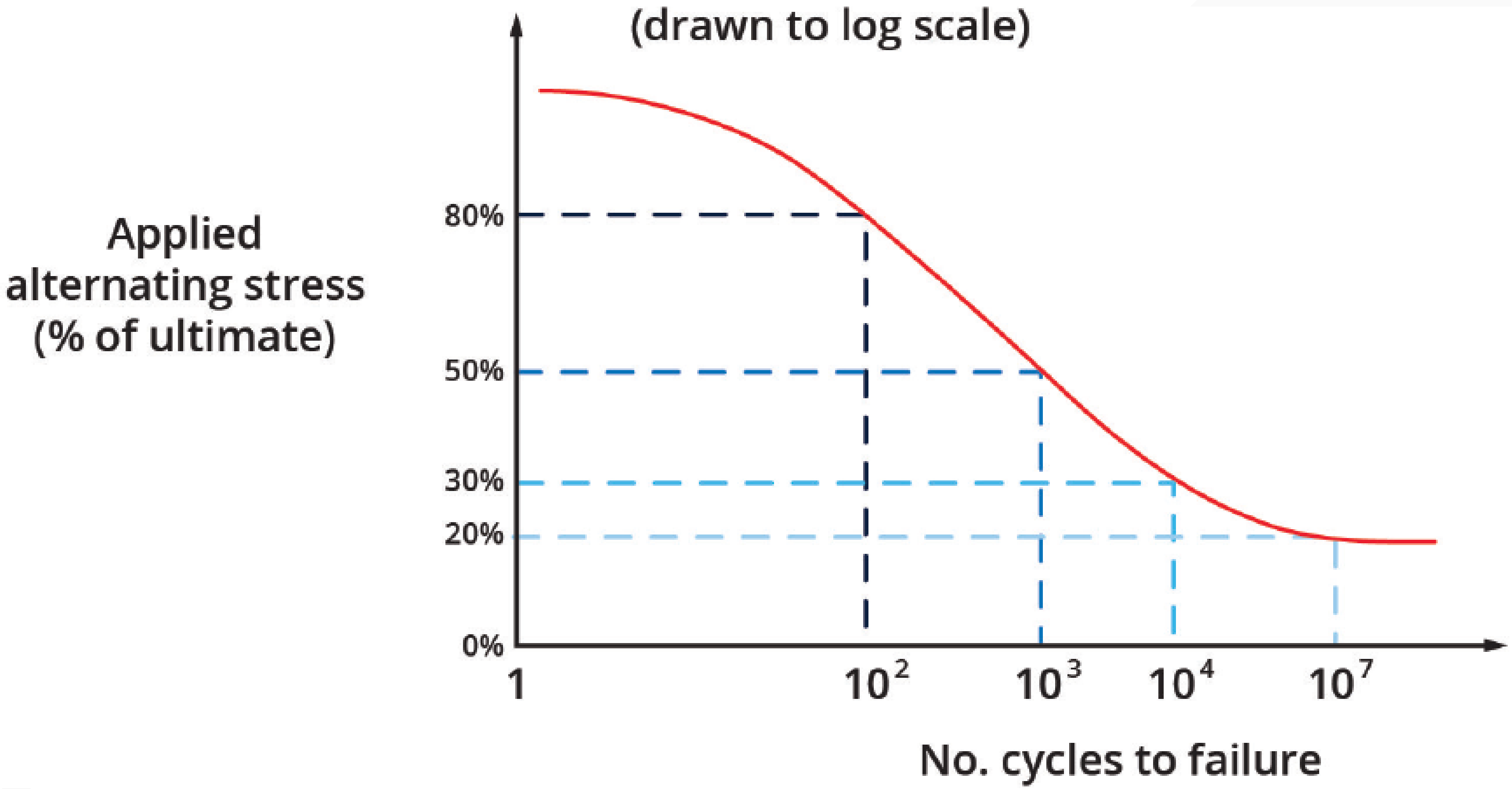
All aircraft use a number of different fluids in the aircraft systems that can potentially present a corrosion hazard, if spilt or leaked onto the aircraft structure. Some corrosive fluids are listed below:

- Hydraulic fluids
- Engine oils
- Chemical toilet fluids
- De-icing fluids
- Fluids carried as dangerous goods for transportation

If spilt or a leak is detected, the area around the spillage or leak must be cleaned and treated in accordance with the manufacturer material data safety sheet.

Material Fatigue

A structure may be subject to cyclic loads. This is where a structure experiences a continual reversal of loading and 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 where, 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. Pilots must be careful to operate the aircraft within the flight load limitation envelope. If the pilot believes they have exceeded a limiting load, perhaps due to abnormal manoeuvres or severe turbulence, it must be reported to maintenance either in the technical log or automatically through flight data monitoring (FDM) Maintenance procedures and maintenance planning are essential to the non-exceedance of fatigue limits.


(drawn to log scale)
Applied alternating stress (% of ultimate)
80%
50%
30%
20%
0%
1
10^2
10^3
10^4
10^7
No. cycles to failure

Maintenance

Aircraft maintenance can be divided into hard/fixed-time maintenance and on-condition maintenance.

Hard/Fixed-Time Maintenance

This is a procedure under which an item must be removed from service before its scheduled maintenance period for inspection or repair.

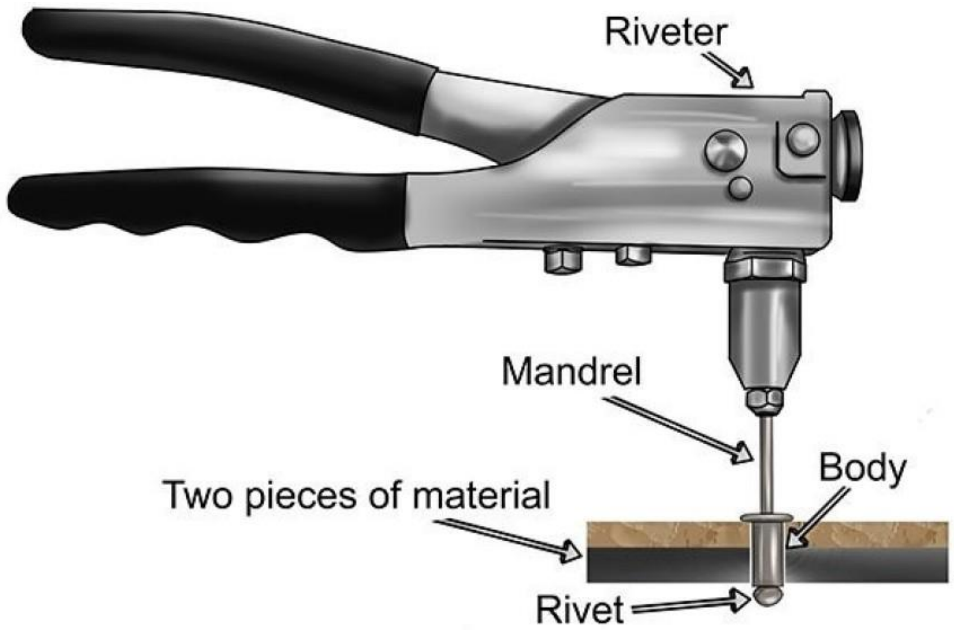
On-Condition Maintenance

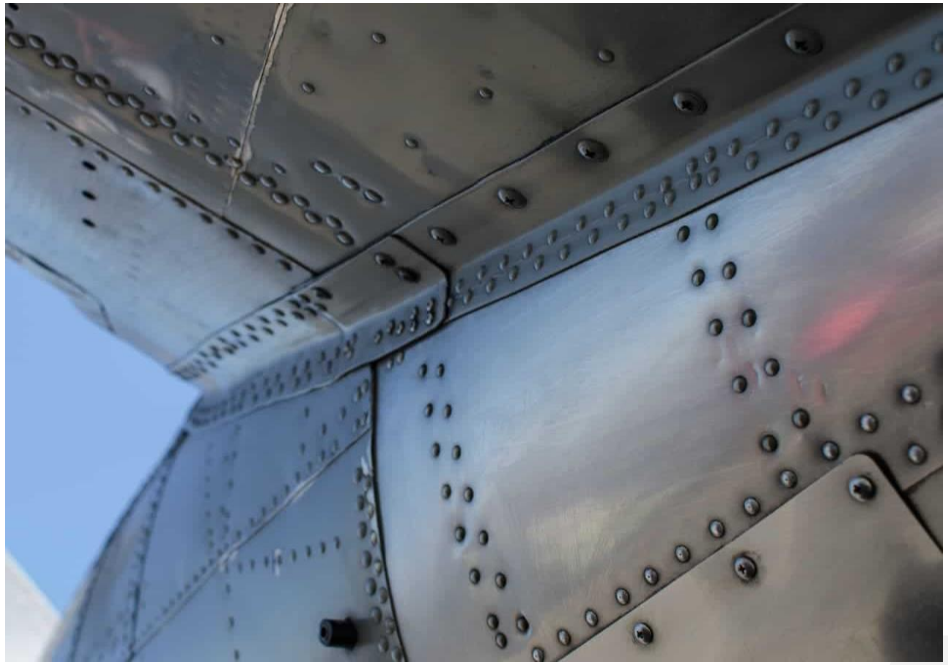
On-condition maintenance uses an inspection or functional check to determine an item's performance. This may result in the removal of an item before it fails in service. It is applied to items where their continued airworthiness can be determined by visual inspection, measurements, tests, or other means without disassembly inspection or overhaul. The condition of an item is monitored either continuously or at specified periods, and its performance is compared to an appropriate standard to determine if it can continue in service.

Attachment Methods

Riveting

This has been the most common way of joining materials and involves placing a rivet in a pre-drilled hole. The tail of the rivet is deformed, usually using a pneumatic rivet gun applied to the rivet head and a metallic block (known as a reaction block) on the tail of the rivet. This clamps the material together. There are times when access is limited to one side only, so there are a variety of blind (deformed from one side) rivets. During the pre-flight inspection, the pilot should look for missing or pulled (loose) rivets. If a rivet is loose, a dirt stain may trail on the skin from the failed rivet.





Welding

This is a process where two metals are fused to become one. Fusion welding uses a gas flame to heat the metal, and a filling material is used to fill the gaps. There are many other types of welding, including forge, electric arc, and spot welding, all of which have particular applications. Welds are not usually visible to the pilot on pre-flight inspection, visible signs of cracks across the weld may indicate failure.

Bolting

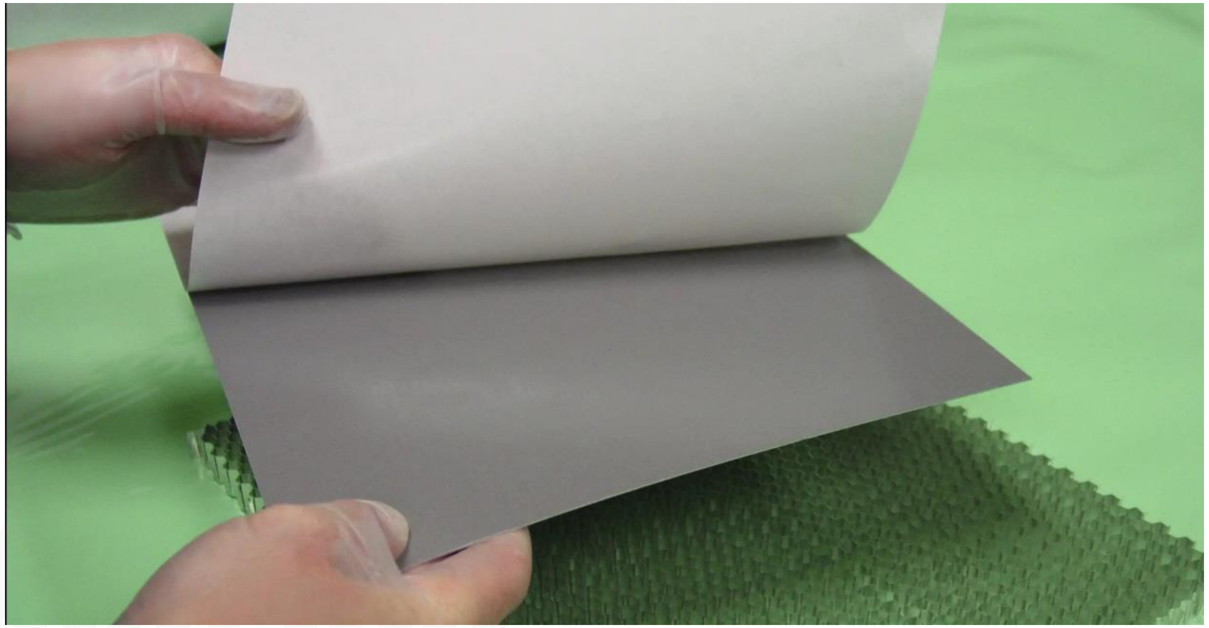
This is employed where high shear or tensile loads are experienced. Most applications use steel bolts. These must be locked to make sure that they do not loosen in service. This may involve the use of locking wire, split pins, or special nuts. During the pre-flight inspection, the pilot should look to ensure locking devices are in place and are not loose or broken.

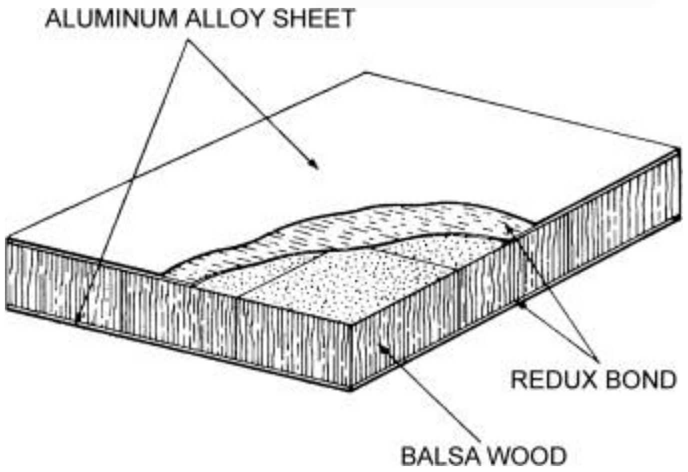
Pinning

As the name implies, this uses pins of various designs to hold the materials together.

Adhesive Bonding

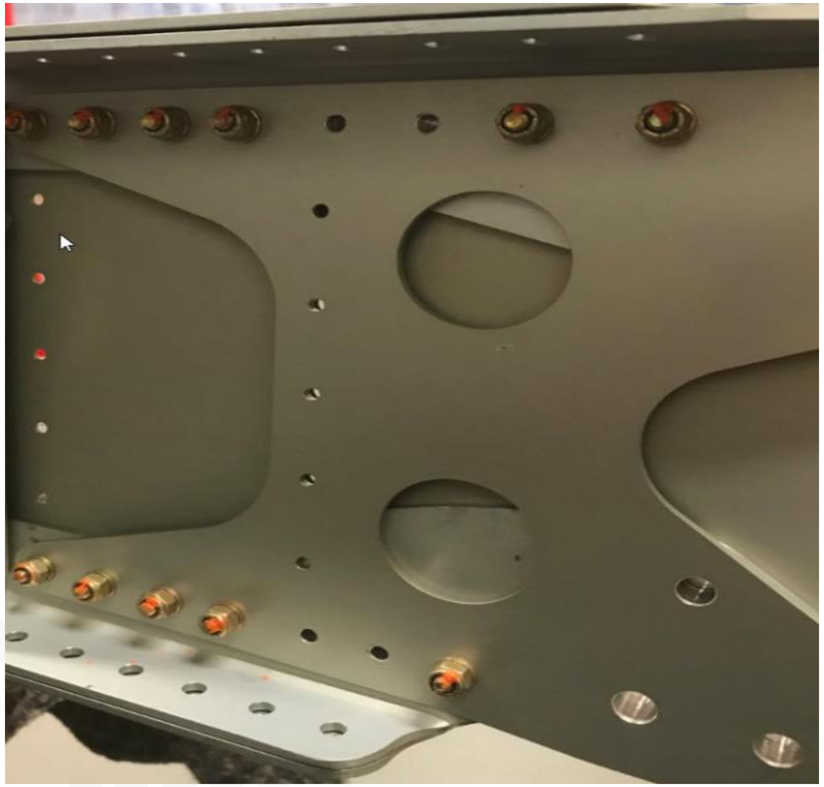
Redux bonding is one of the commonly used methods. A sheet of adhesive is placed between the two materials, and heat is then applied to cure the adhesive, which produces a strong bond. One advantage of this method is that, compared to riveted joints, it is easier to seal structures, making it particularly useful for fuel tanks. The pilot performing pre-flight inspection should look for signs of separation and delamination on bonded areas of skin.





Screwing

The use of screws is commonplace for securing panels that will be required to be removed for maintenance access. Special screwhead designs may be used to facilitate regular removal. Like rivets, the pilot should look for missing and loose screws during the pre-flight inspection. If a screw has become loose, a dirt stain may trail on the skin from the loose screw.



Materials

Principle of Composite Materials

Composite materials are made of at least two elements to produce a material with properties that are different to those of the original elements. Nearly all composites consist of a bulk material, which is called the matrix, and some form of reinforcement. This reinforcement is used mainly to increase the strength and stiffness of the matrix and is usually in a fibre form. The matrix can be produced using a variety of materials such as epoxies and polyester resins. These materials on their own have poor mechanical properties (compressive, tensile, flexibility, hardness, etc.), especially when compared to materials such as most metals. They do, however, have many desirable properties, the most important of which is their ability to be easily formed into complex shapes. When the matrix is combined with reinforcing fibres, exceptional properties can be obtained. The matrix will spread the load to the composite between each of the individual fibres and protects the fibres from damage. This could be caused by impact or abrasion.

Examples of Non-Metallic Composite Materials

- Carbon fibre
- Glass fibre
- Kevlar aramid
- Resin or filler

Airframe

Material propreties	Aluminium alloys	Composites
Strength to weight ratio	Good	Excellent
Adaptable strength direction	No	Yes
Stiffness	Good	Excellent
Electrical conductivity (Lightning strike)	Good	Low
Fatigue resistance	Moderate (Rapid loss)	Excellent (Gradual loss)
Corrosion resistance	Moderate	Excellent
Cost	Moderate	Expensive
Detection of damage	Good	Poor

Airframe

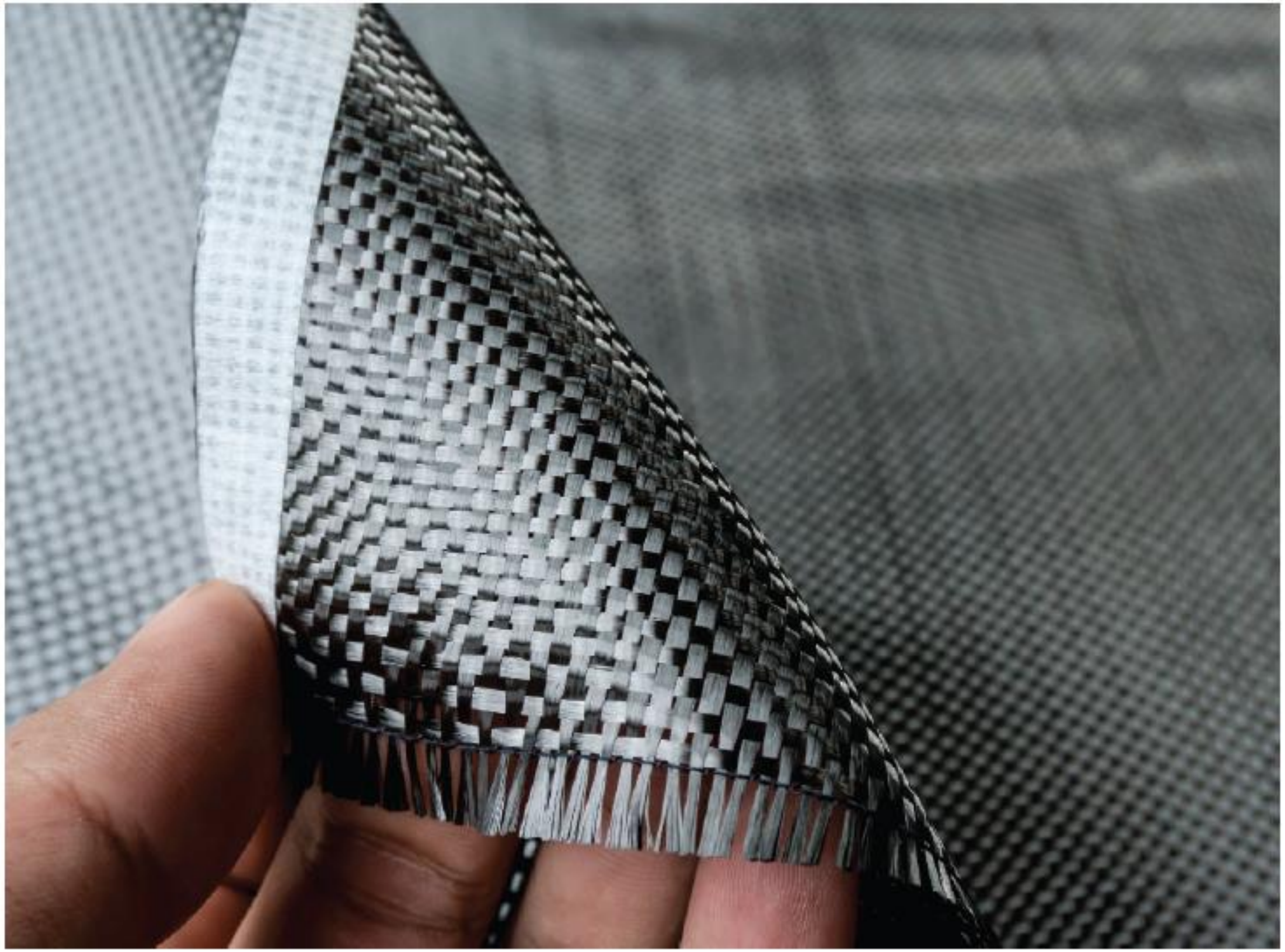


Figure 2.3 Composite materials

Selection of Materials in Aircraft Design

Different components in an aircraft may be required to display particular characteristics. Titanium has excellent heat resistance properties and is used in areas subjected to high heat such as engine bays. Composite materials can be easily formed into complex shapes, making them ideal for wingtip devices. Components that are required to carry large weight will be made of steel, which is very strong but also heavy. An aircraft will be made from several different materials. However, the use of composites continues to grow, due to their high specific strength, specific stiffness, and their ability to retain those properties at elevated temperatures. It is also possible to tailor strength to the direction of the load. There are cost factors involved in the use of composites in aircraft. The manufacturing costs are high, due to manufacture being a labour-intensive and complex process. These factors are outweighed by the reduced operating costs.

Airframe

Aircraft such as the Boeing Dreamliner are approximately 20% lighter, giving a large reduction in fuel consumption.

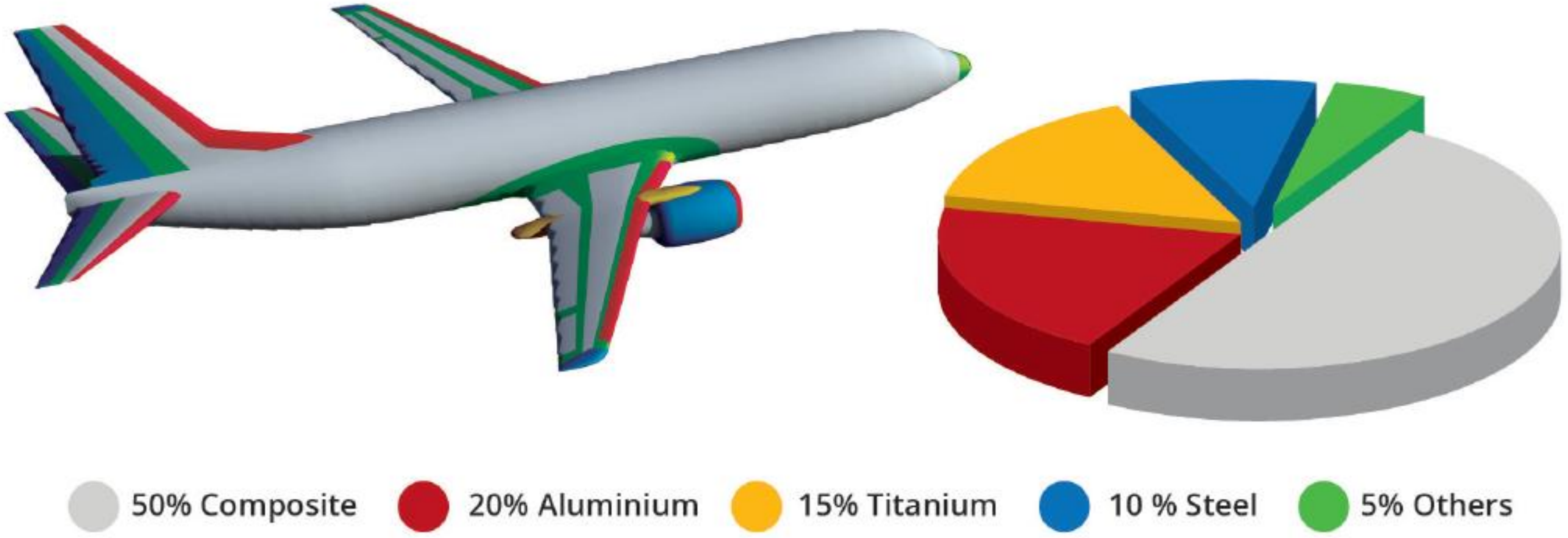


Figure 2.4 Materials used in modern aircraft construction

Aeroplane: Wings, Tail Surfaces and Control Surfaces

Wing Position

The positioning of the wing will depend on the anticipated role of the aircraft. For cargo-carrying aircraft, there is advantage of placing the wing on top of the fuselage. This will result in no narrowing of the fuselage cross section and will allow loads of larger dimensions to be accommodated. A high wing will also give more ground clearance, allowing the use of turbo-propeller engines. This position will affect the aircraft's inherent controllability and stability qualities. For flying in the transonic speed-range, a mid-positioned wing is more suitable, giving better high-speed characteristics. A lower wing may present ground clearance problems for engine design. A low wing aircraft is also more susceptible to ground effect.

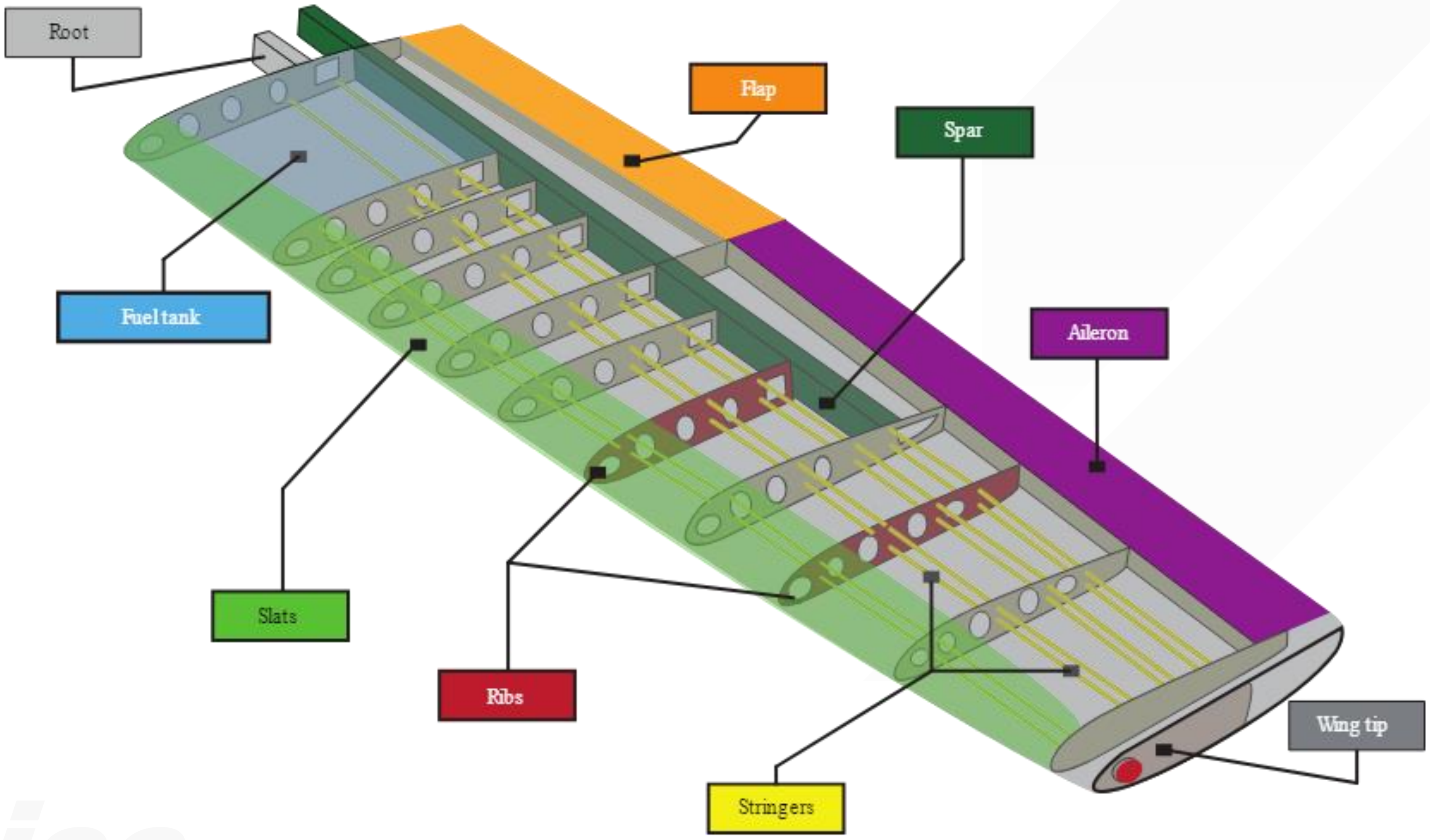
Tailplane Position

Like the positioning of the wing, the positioning of the tailplane will be depend on the anticipated role of the aircraft and desired engine positioning. A high T-tail will allow for the engines to be mounted on the vertical stabiliser. This engine position has a number of advantages of wing mounting with reduced asymmetric thrust in the event of engine failure and also removes ground clearance problems. The T-tail position may present problems if the aircraft stalls at a high angle of attack, as the elevators may be masked in turbulence from the wings, preventing stall recovery. Often a stick push device will be fitted to prevent the aircraft from entering the stall.

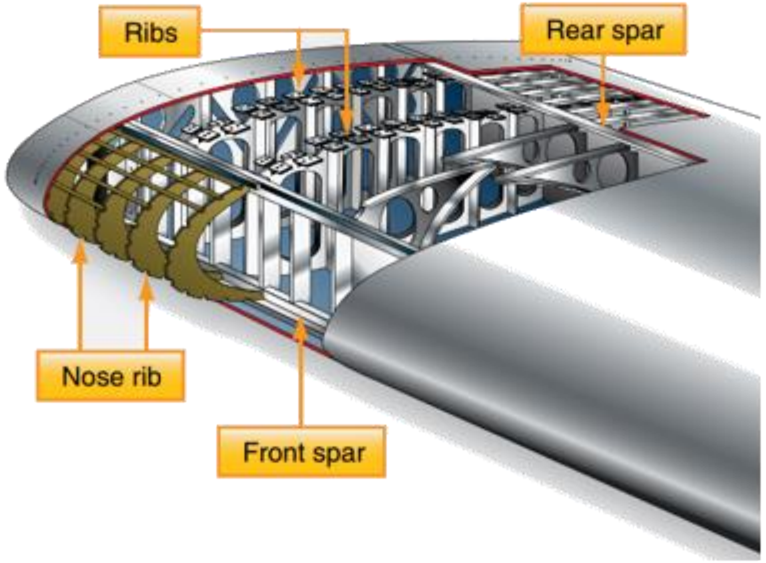
Wing Structural Components

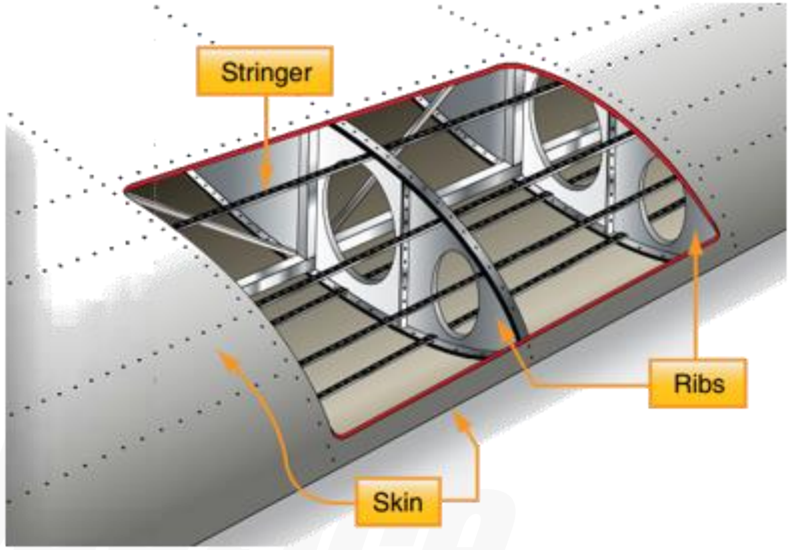
- Spars are the main structural load-bearing members of the wing and absorb the entire bending and torsional loads on the wing. They consist of vertical elements called webs or girders and horizontal elements called spar caps. The spar extends the entire length of wing.
- Ribs maintain the aerofoil shape 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.
- Stringers are spanwise members giving the wing rigidity by stiffening the skin in compression.
- Aircraft 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 spanwise direction as a response to bending moments and reacts against twisting (torsion).
- Torsion box is made from the following wing components the front and rear spar (which may be of single spar, twin spar, or multi-spar construction) the metal skin attached to the spar booms, the ribs, and the stringers.

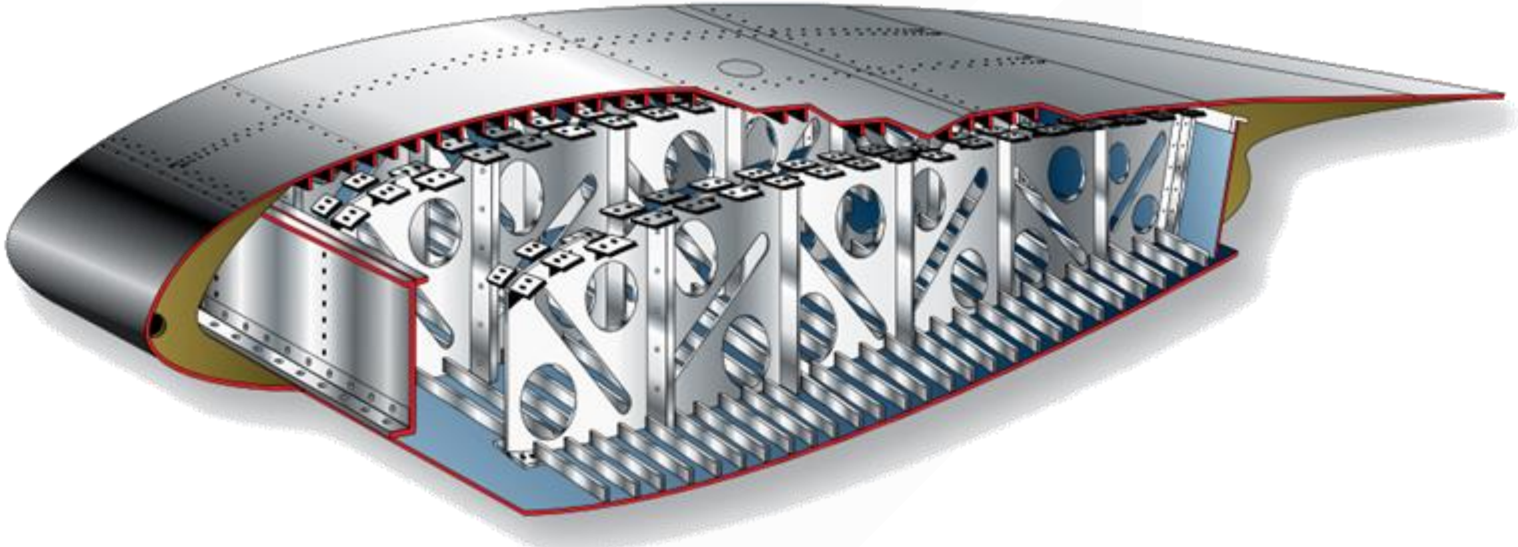
Airframe


Root
Flap
Spar
Fuel tank
Aileron
Slats
Ribs
Stringers
Wing tip

Airframe



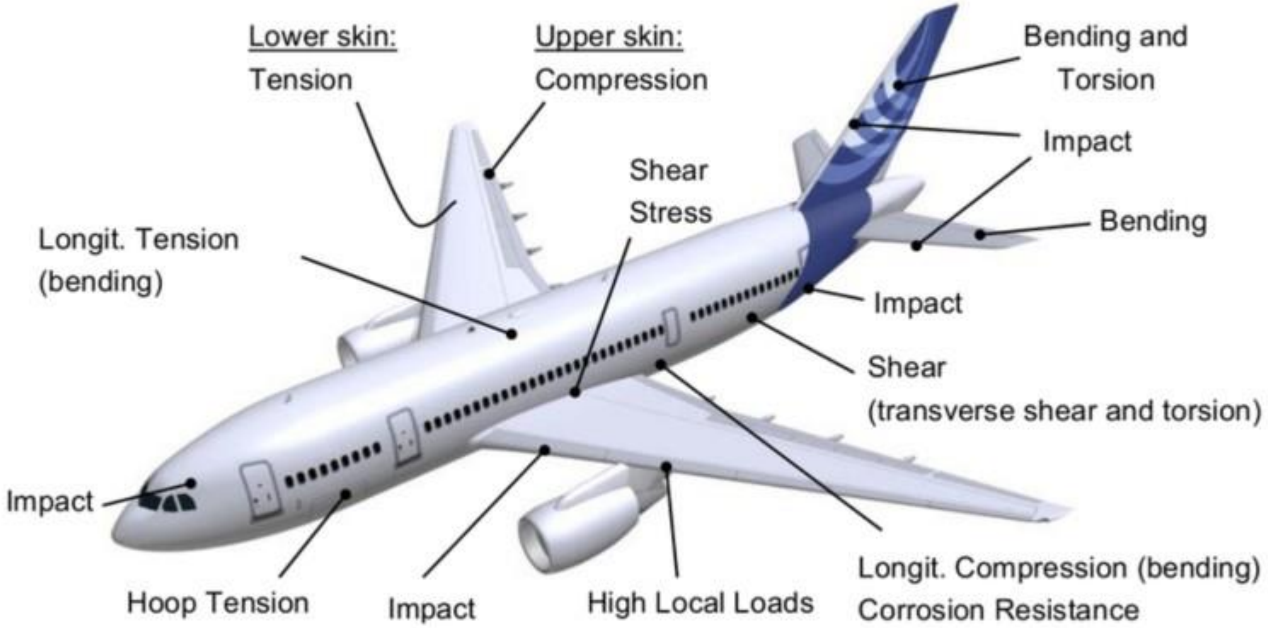


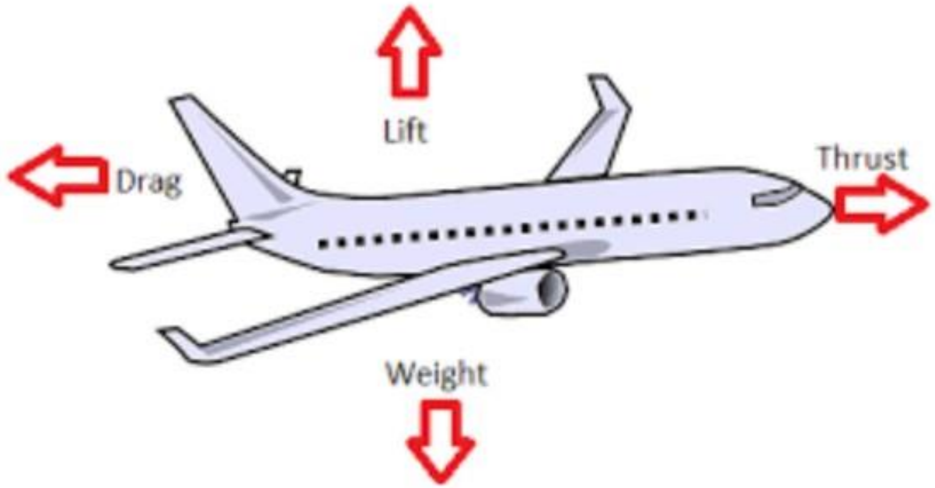


Loads on an Aircraft

An aircraft is subject to various forces, which act on the structure both on the ground and in flight. During flight, the wings produce lift, which tends to bend the wing upwards. As a result, there will be compression on the upper surface and tension on the lower. Lift also causes a torsional force, which twists the wing. Drag will also act on components such as the landing gear, bending them backwards whilst the mass of the aircraft will pull it downwards. An aircraft flying straight and level at a constant speed will be subject to 1g. Any change in attitude will change the g, which, in turn, alters the weight of the structure and the loads.

Airframe


Lower skin:
Tension
Upper skin:
Compression
Bending and
Torsion
Impact
Shear
Stress
Bending
Longit. Tension
(bending)
Impact
Shear
(transverse shear and torsion)
Impact
Hoop Tension
Impact
High Local Loads
Longit. Compression (bending)
Corrosion Resistance


Lift
Drag
Thrust
Weight

Types of Fuselage Construction

There are two main types of construction in use:

Monocoque construction is generally used for light aircraft. 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. Extra strength needs to be built in around holes in the structure for windows, doors, or undercarriages, as these will weaken the structure. This type of construction is only suitable for smaller aircraft.

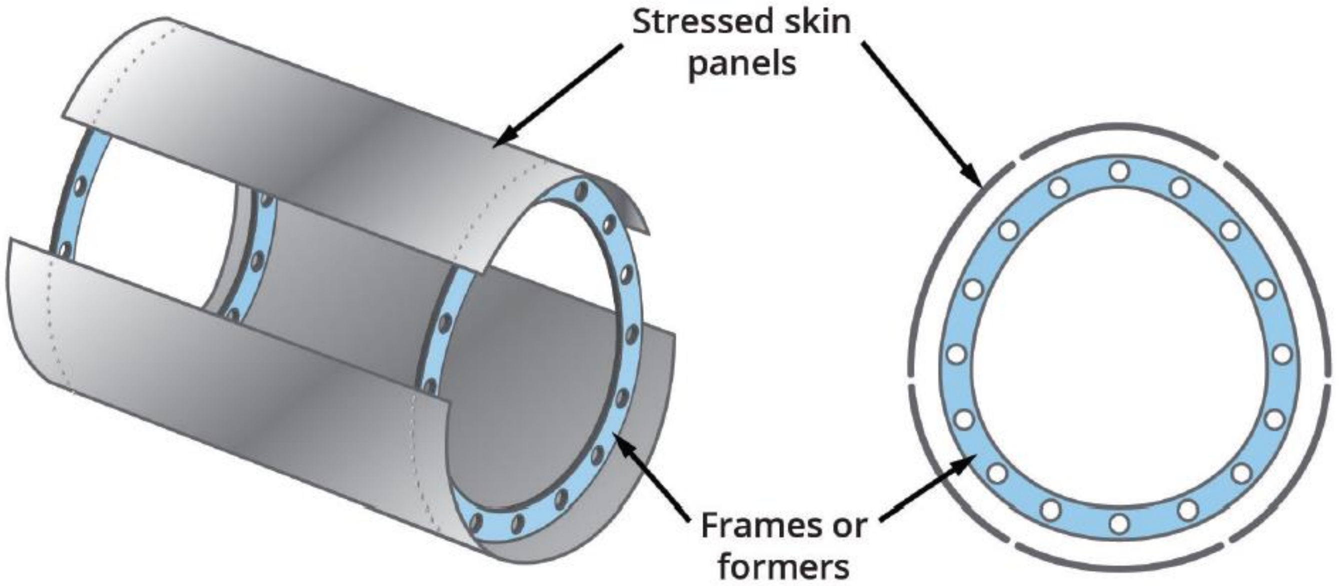


Figure 2.5 Monocoque construction

Airframe

Semi-monocoque is widely used on most other aircraft. This type of structure can be referred to as ‘stressed skin’. 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 riveting or adhesive bonding. Stringers stiffen the skin and assist the sheet materials to carry loads along their length.

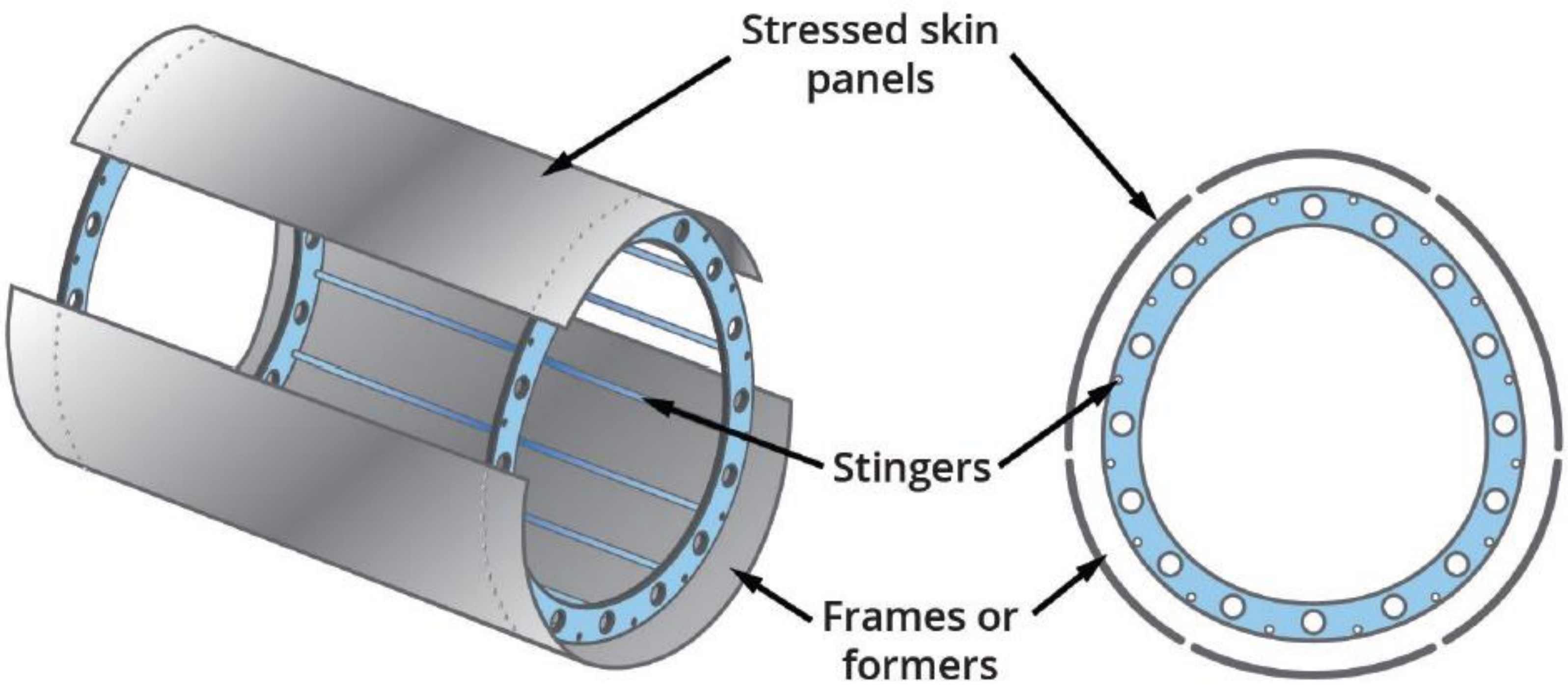


Figure 2.6 Semi-monocoque construction

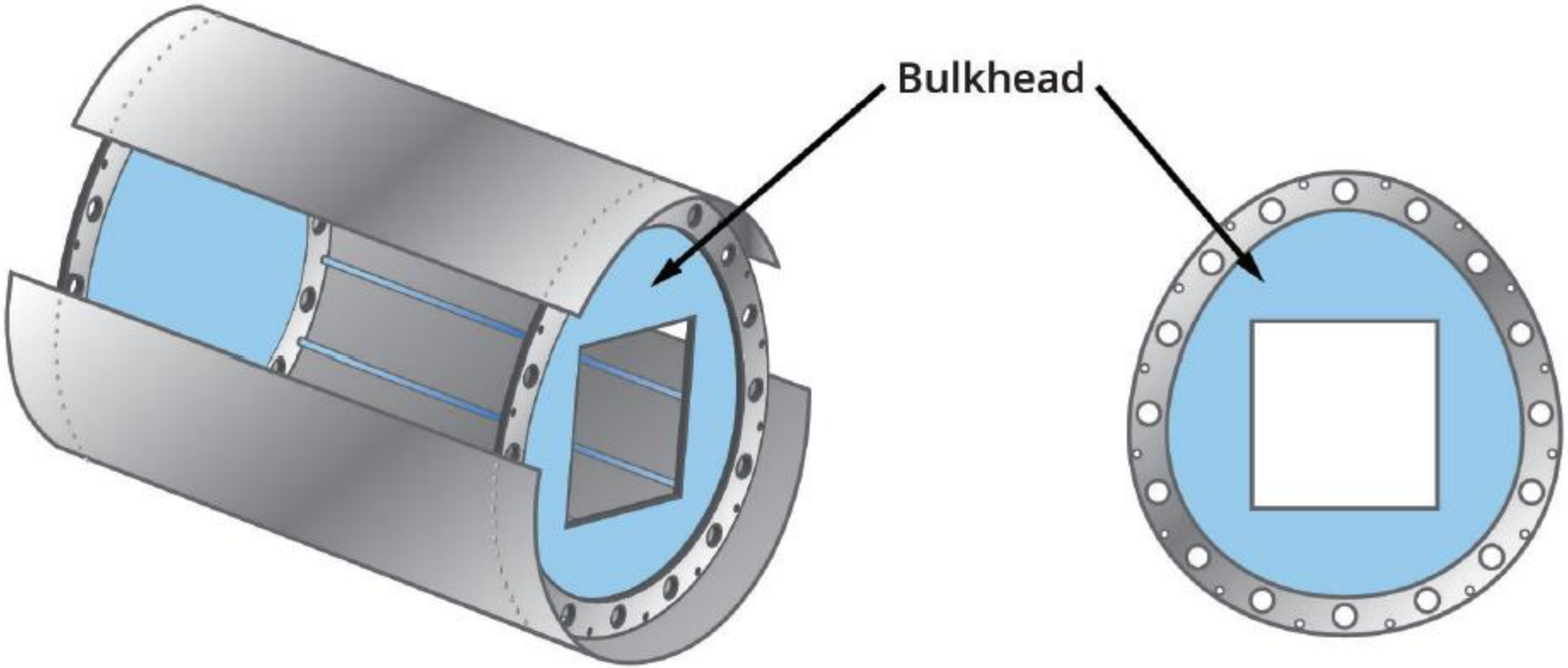
Fuselage Components

- Frames are vertical structures that are open in their centre. They are designed to take the major loads and give the aircraft its shape.

Figure 2.7 Semi monocoque fuselage

Airframe

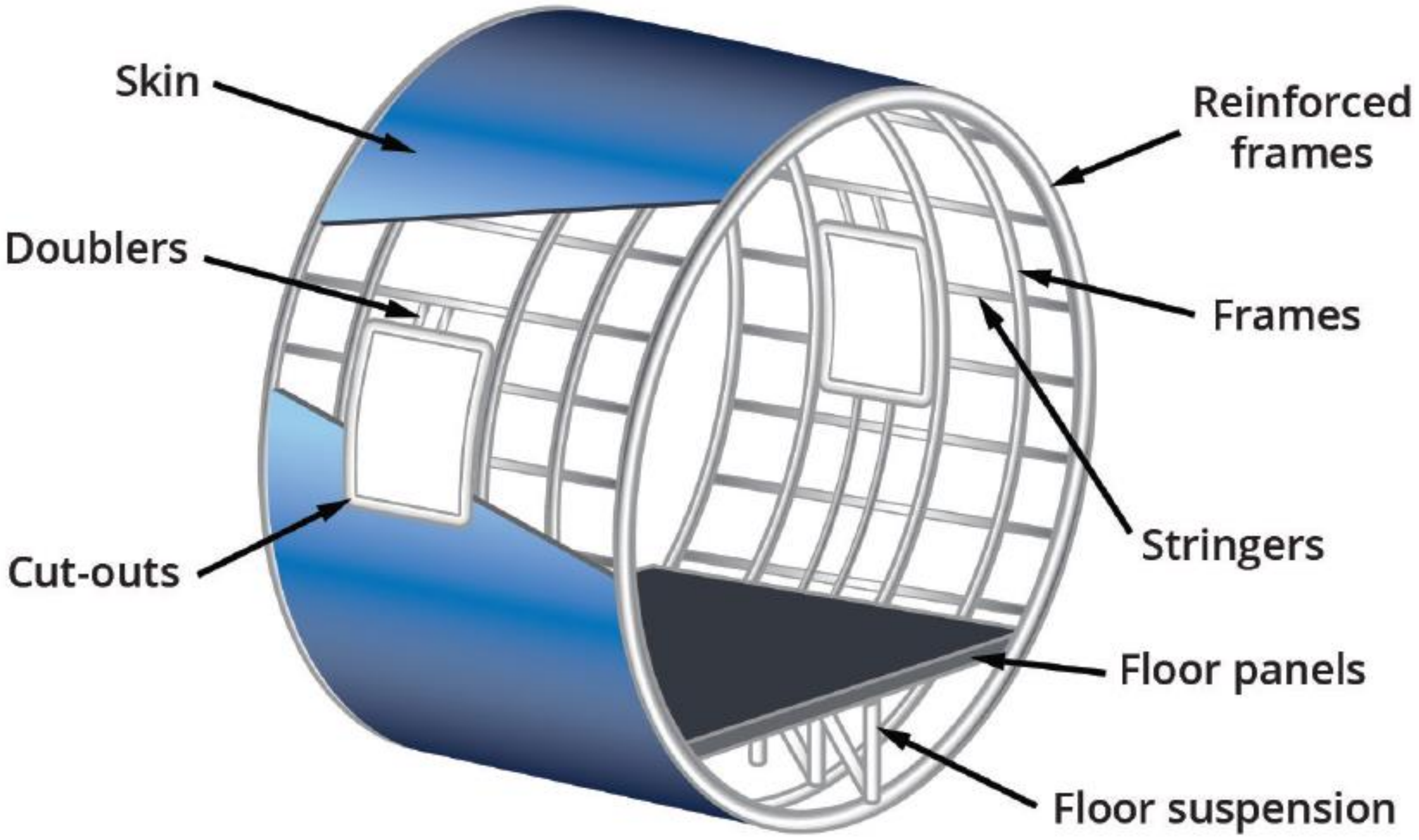
- Bulkheads are similar to frames but are usually solid and may have access doors. They are also designed to give the fuselage its shape and take some of the main loads. Two of the major bulkheads in a transport aircraft are the front and rear bulkheads, which separate the pressurised and unpressurised areas.



Airframe

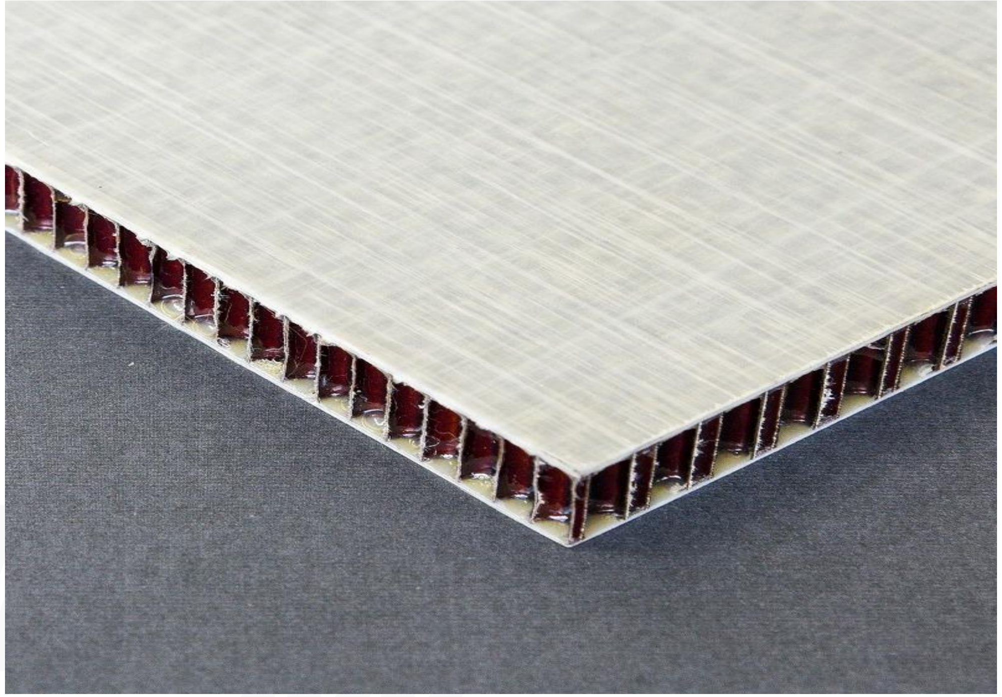
- Stringers (Stiffeners) stiffen the skin and assist the sheet materials to carry loads along their length.
- Longerons are beams in the fuselage that are fitted longitudinally from nose to tail. They are often placed below the floor and take the main bending loads of the aircraft.
- Skin is a lightweight aluminium alloy or fabric covering of the framework, which gives an enclosed, aerodynamically efficient load-carrying compartment.
- Doublers are reinforcements or backing plates. They are required around cut-outs in the skin such as passenger windows, access panels, or when repairs are required to damaged areas. 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.
- Floor suspension (crossbeams) are used to add strength to the aircraft and support the passenger or cargo floor. Modern aircraft use sandwich or honeycomb materials for the floor panels.

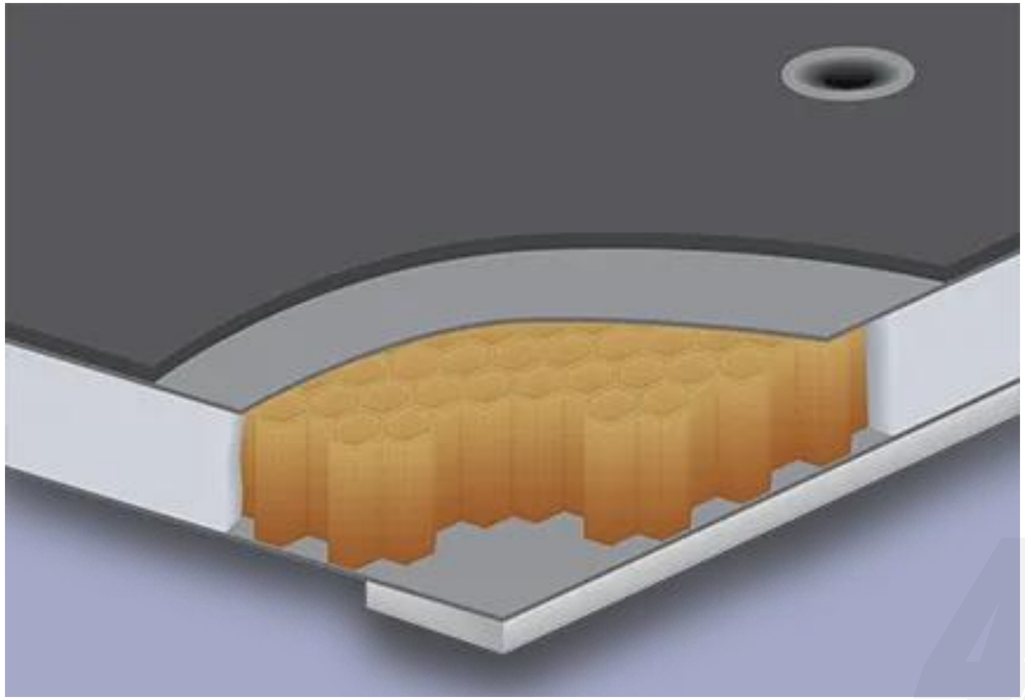
Airframe


Skin
Doublers
Cut-outs
Reinforced frames
Frames
Stringers
Floor panels
Floor suspension

Airframe

- **Floor panels** separate the cabin from the underfloor areas such as cargo holds and service bays. Modern aircraft use sandwich or honeycomb materials for floor panels.
- **Firewalls** are means of separating the flight deck and cabin from the engine. The firewall is required to protect the flight crew and passengers in the event of an engine fire. These are constructed using heat resistant stainless steel or titanium alloy. These materials are able to withstand moderate temperatures for prolonged periods whilst also being able to withstand high temperatures for a short time.





Airframe

Titanium can be exposed to up to 3,000°C for short periods.

Figure 2.10 Example of firewall bulkhead

Pressurisation Loads

Structures must also be capable of supporting the axial and hoop stresses imposed by the pressurisation forces.

- Axial stress or longitudinal stress is set up in the fuselage of aircraft when pressurised and tends to elongate the fuselage.
- Hoop stress or radial stress is set up in addition to axial stress and tends to expand fuselage cross-section area. The internal pressures that set up these stresses can be as high as 9.5 psi.

Airframe

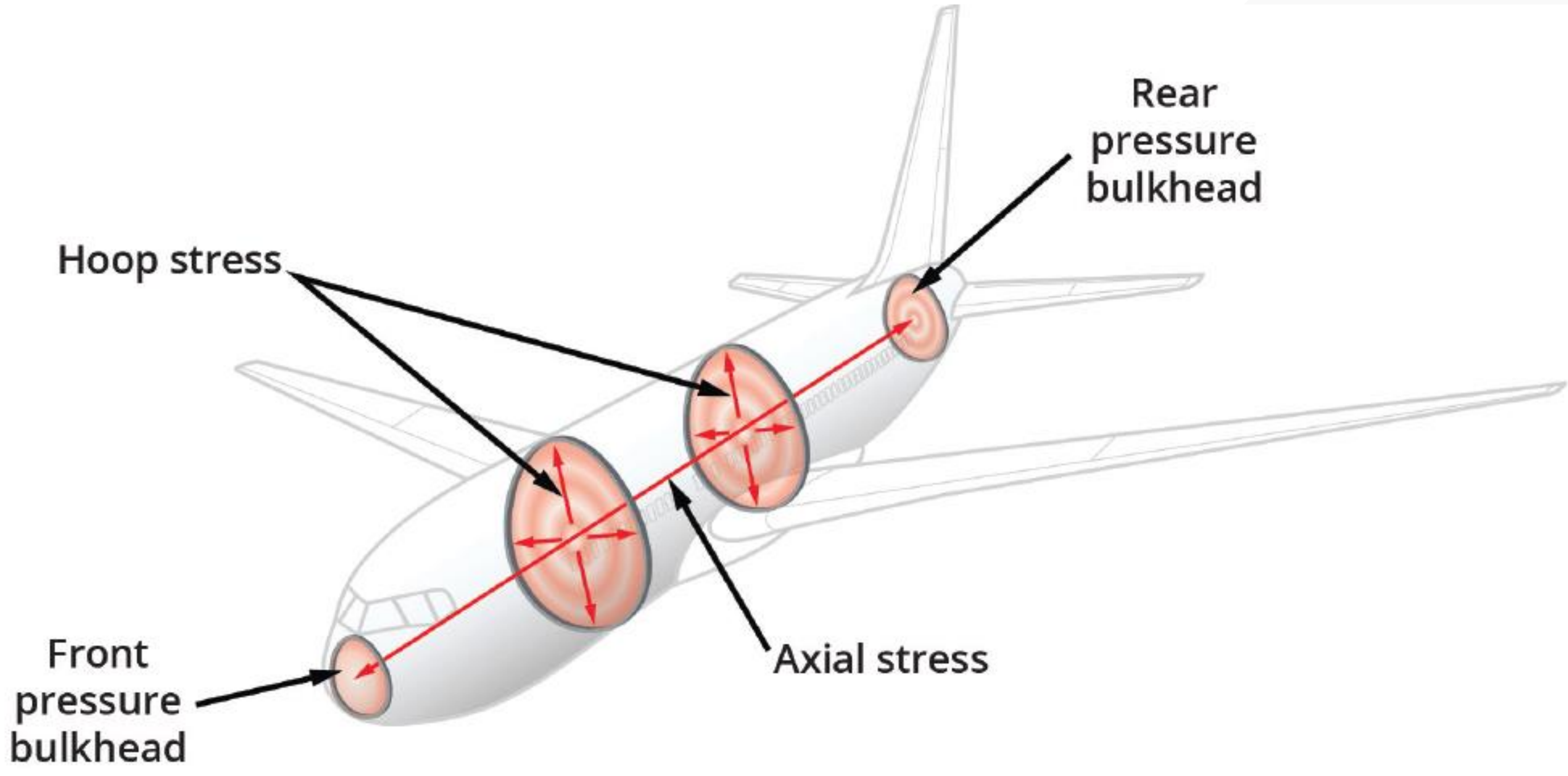


Figure 1.52 Hot to cold, don't be bold

Landing Gear Loads

04 Describe the following loads on a main landing gear: touch-down loads (vertical and horizontal); taxi loads on bogie gear (turns).

- Touchdown loads (vertical and horizontal) –compressive loads during touchdown, side loads during crosswind, and rearward bending during braking.
- Taxi loads – forward loads during push back and side loads during turning.
- Bogie gear loads (turns) – torsional (twisting) loads during turns.

Danger of Nose Wheel First Landing

05 Describe the structural danger of a nose-wheel landing with respect to fuselage loads; nose-wheel strut loads.

There is a danger of structural damage with a nose wheel landing. This will usually affect the front pressure bulkhead in the fuselage and the nose wheel strut. In addition to defects in the strut, there may also be damage to the drag link. There is also a possibility of nose wheel collapse.

Figure 2.12 Danger of nose wheel landing

Danger of Tail Strike

There is a higher risk of a tail strike on an approach and landing flown below Vref. Over rotation at take-off and at the landing flare can also lead to tail strike. This may lead to structural damage to the tail plane and the rear pressure bulkhead in the fuselage, damaging the structural integrity of the aircraft.

Figure 2.13 Tail strike

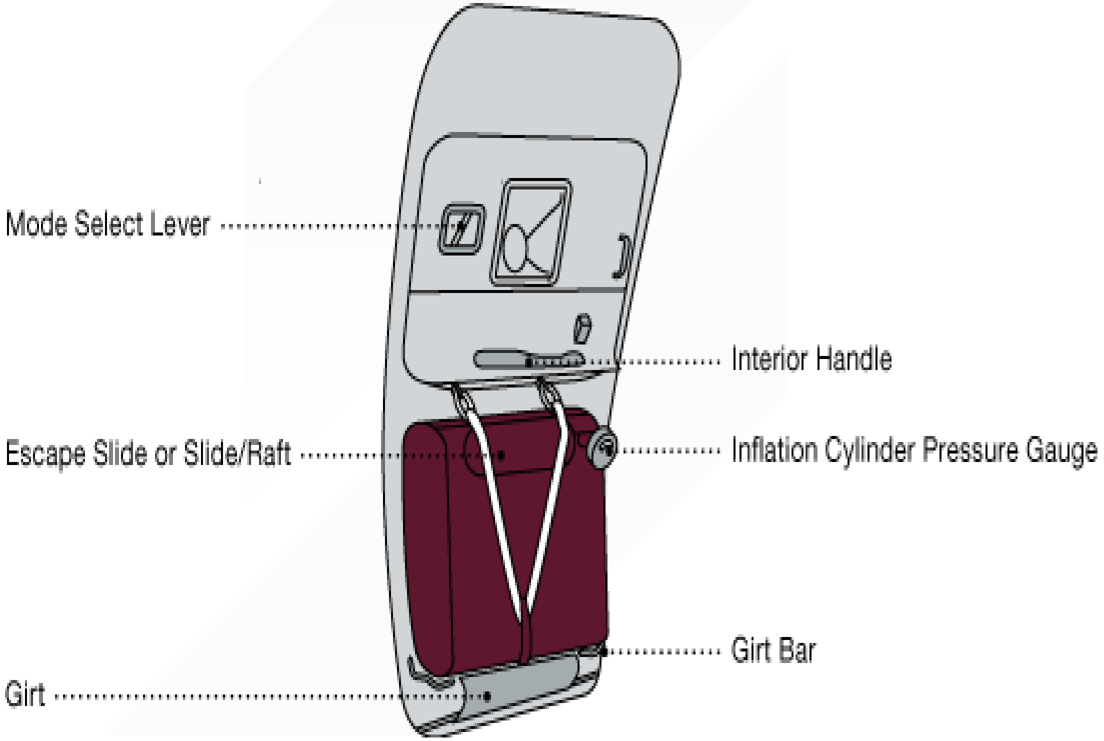
Door and Hatch Construction

07 Describe the door and hatch construction for pressurised and unpressurised aeroplanes including door and frame (plug type); hinge location; locking mechanism.

Aircraft doors may be side or top opening. All passenger doors on pressurised aircraft are now of the plug type. When closed, the internal pressure holds the door shut, and locking pins engage with the frame structure to ensure that it cannot open in flight. To open a plug type door, it is pulled inwards and rotated sideways. Some open outwards for better access. They must be able to withstand the pressure loads, if the aircraft is pressurised, and they have to have a means of preventing the aircraft being pressurised with the door unlocked. They must be easy to open in an emergency and usually have escape slides built into the construction of the door. A visual inspection panel is also required. Unpressurised aircraft have doors of a lighter construction. Some aircraft have freight doors in the side of the fuselage. These usually hinge upwards and open by means of an electric motor or hydraulic power pack. The loads go through the hinges.

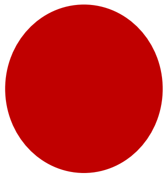
Airframe


EXIT
THIS SIDE DOWN

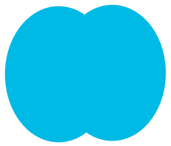

Mode Select Lever
Interior Handle
Escape Slide or Slide/Raft
Inflation Cylinder Pressure Gauge
Girt Bar
Girt

Fuselage Design

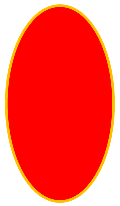
The fuselage can be built in a number of cross-sectional shapes.



- **Circular** – This is an ideal shape for pressurised aircraft, as the hoop stresses are spread evenly throughout the structure and is a relatively easy build. Sometimes considerable amounts of space are wasted when certain passenger/cargo configurations have to be accommodated.



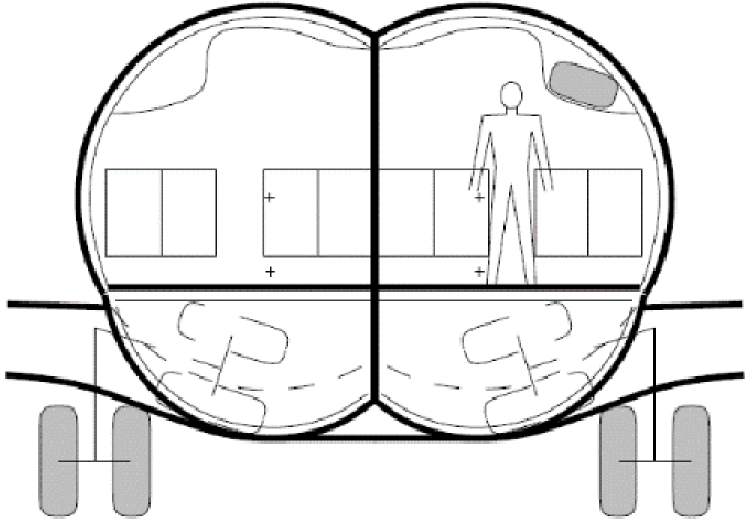
- **Double bubble** – These are similar to a figure eight. They provide effective use of space for both passengers and cargo whilst not having the increased drag of a large circular fuselage, and they are cost-effective. Recent designs favour a side-by-side bubble. These allow for larger number of passengers for a given structural weight and are said to be very efficient due to reduced drag. Engines would be rear-mounted.

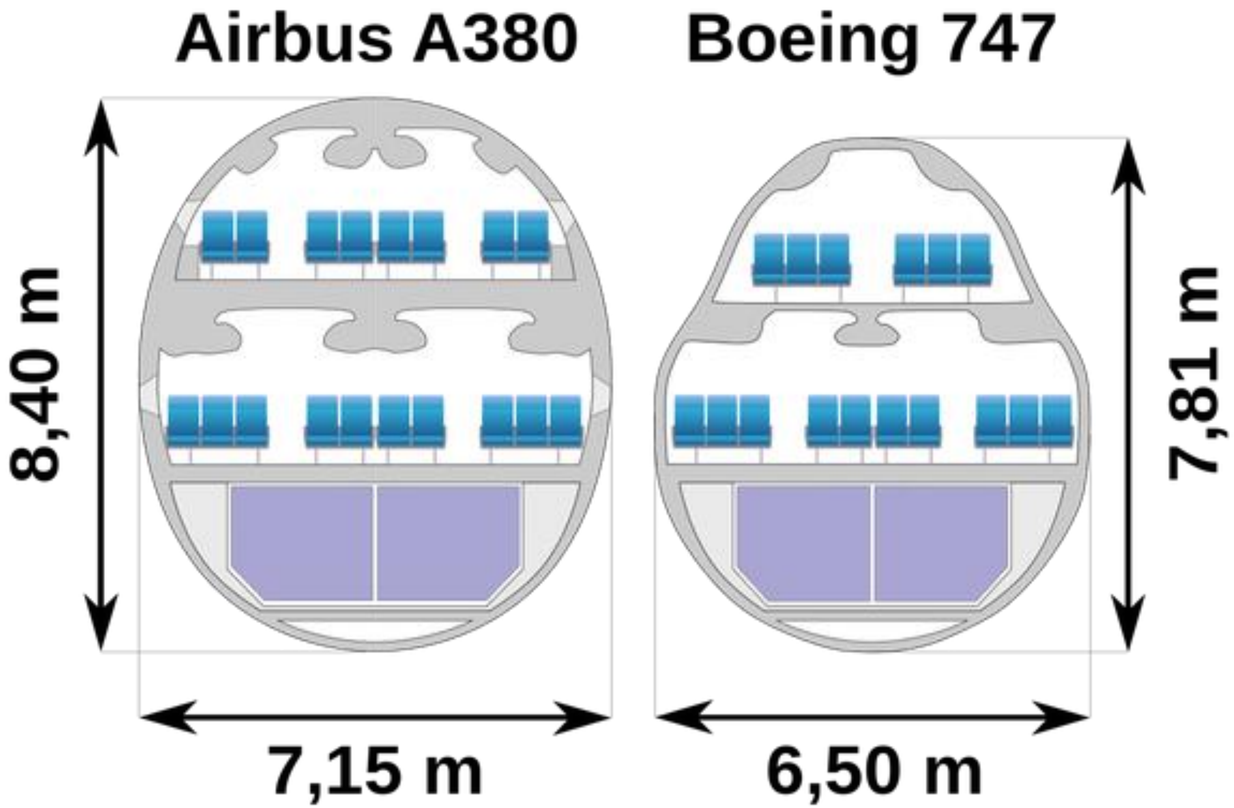


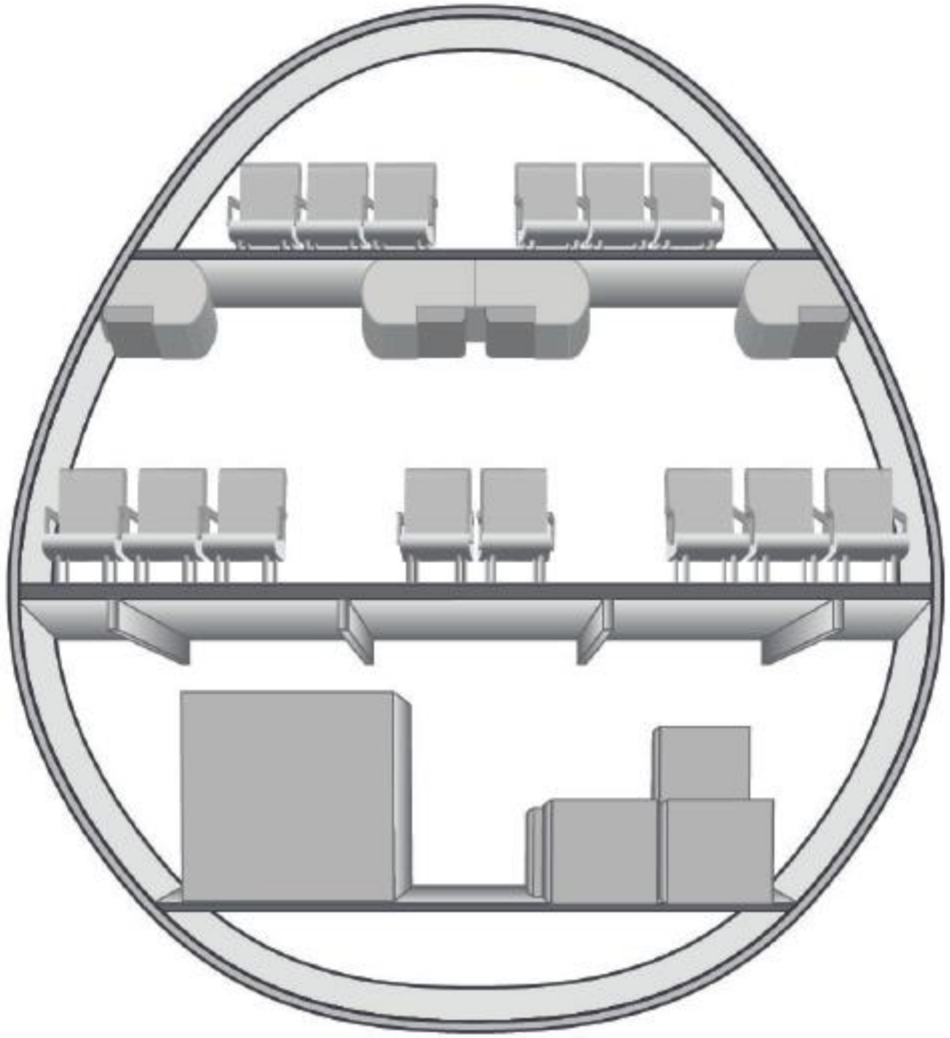
- **Oval** – An oval is less efficient than a circular shape but is frequently used to complete pressure hull construction behind the rear bulkhead.

- **Rectangular** – Many non-pressurised aircraft use this shape due to cost constraints. They are easier to construct but do have a high weight-to-strength ratio.

The “double bubble” D8 Series future aircraft design concept comes from the research team led by the Massachusetts Institute of Technology.
Based on a modified tube and wing with a very wide fuselage to provide extra lift, its low sweep wing reduces drag and weight; the embedded engines sit aft of the wings. The D8 series aircraft would be used for domestic flights and is designed to fly at Mach 0.74 carrying 180 passengers




Airbus A380
Boeing 747
8,40 m
7,81 m
7,15 m
6,50 m



Flight Deck Windows

The flight deck windows fitted to pressurised aircraft must withstand both the loads of pressurisation and impact loads from bird strikes. They are constructed from toughened glass panels attached to each side of a clear vinyl interlayer. The shock loading of a bird strike 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 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.

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

An opening window, normally referred to as a direct vision (DV) window, must be provided to enable the pilot to land the aircraft safely should forward vision be restricted. DV windows slide open on a track that first lets the aft end of the window tilt in, then it slides along a track until it is opened.

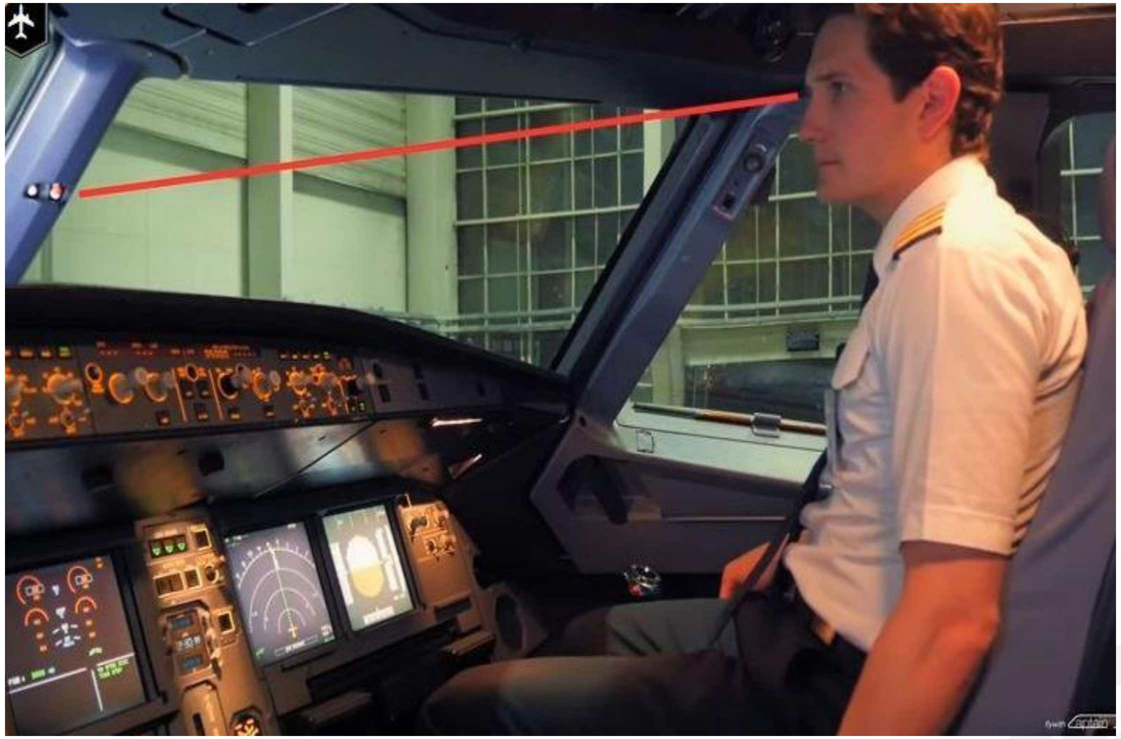
The DV window:

- can be used in the event of a failure of the demisting system.
- can be opened in flight, if the aircraft is depressurised.
- may also be used as an emergency exit, depending on size.


Captain Bob Hayes, OON

Eye Reference Position

Fixed markers or other guides are installed at each pilot station to enable the pilots to position themselves in their seats for optimum combination of outside visibility and instrument scan. The eye reference position standardises the pilots' visual attitude, especially on approach and landing. Specific eye reference systems are used for head-up displays (HUD).



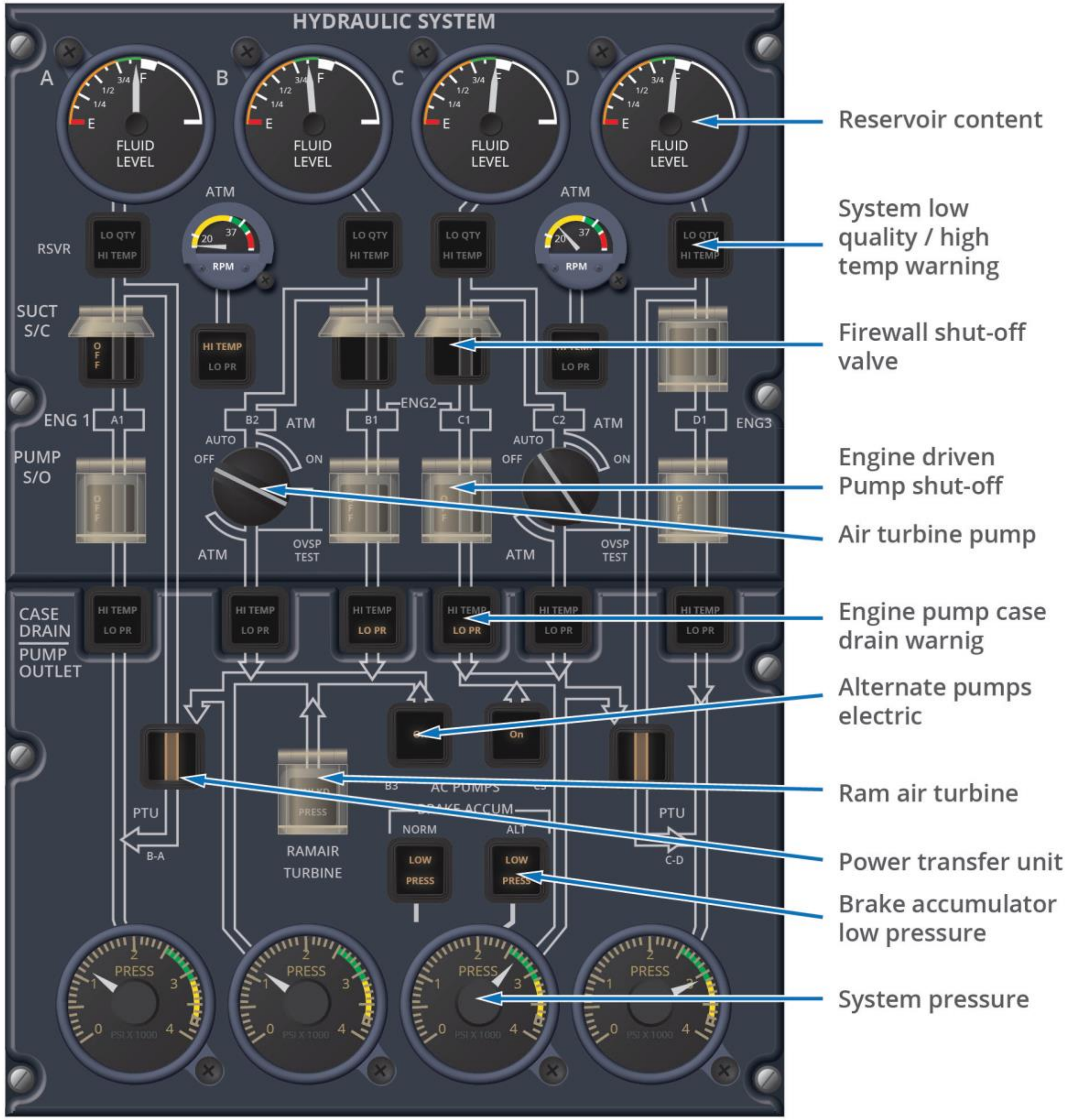
Structural Limitations

- Maximum structural taxi mass is sometimes referred to as maximum ramp mass, and it is the structural limitation of the aeroplane mass at commencement of taxi (at departure from the loading gate). The aeroplane would then burn fuel down to take-off mass (TOM).
- Maximum takeoff mass (MTOM) is the maximum permissible mass of the aeroplane, including everything and everyone contained in it at the start of the take-off run.
- Maximum structural landing mass (MSLM) is the maximum permissible total aeroplane mass on landing in normal circumstances.
- Maximum zero fuel mass (MZFM) is defined as the maximum permissible mass of an aeroplane with no usable fuel.

Airframe Life

Metal fatigue is normally the limiting factor of an aircraft's lifespan. Fatigue cracks build up every flight (at start and landing), called a cycle. The design life of an aircraft is typically given in cycles. An aircraft's lifespan is measured not in years but in pressurisation cycles. Each time an aircraft is pressurised during flight, its fuselage and wings are stressed.

HYDRAULICS



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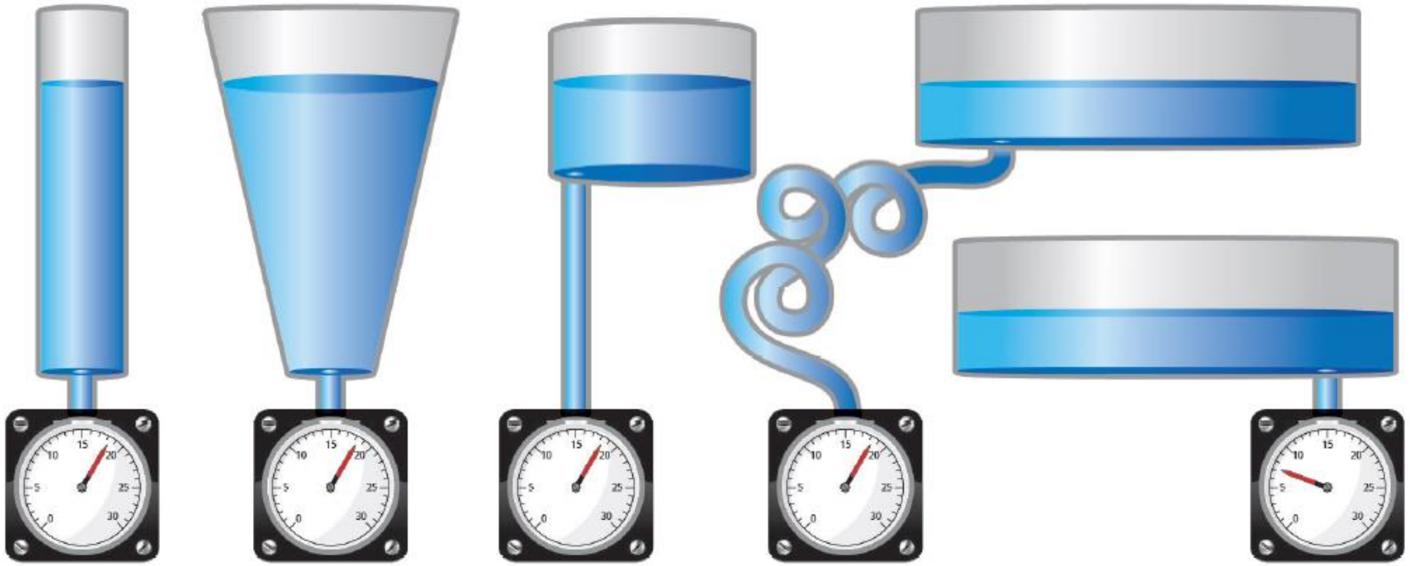
Hydromechanics: Basic Principles

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.

A stationary fluid has hydrostatic pressure due to the force of gravity. For an open container, the pressure exerted by the fluid is dependent only on the height of fluid. Hence, varying containers of different sizes will give the same pressure, if they contain the same height of fluid.

Hydrostatic Pressure



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".

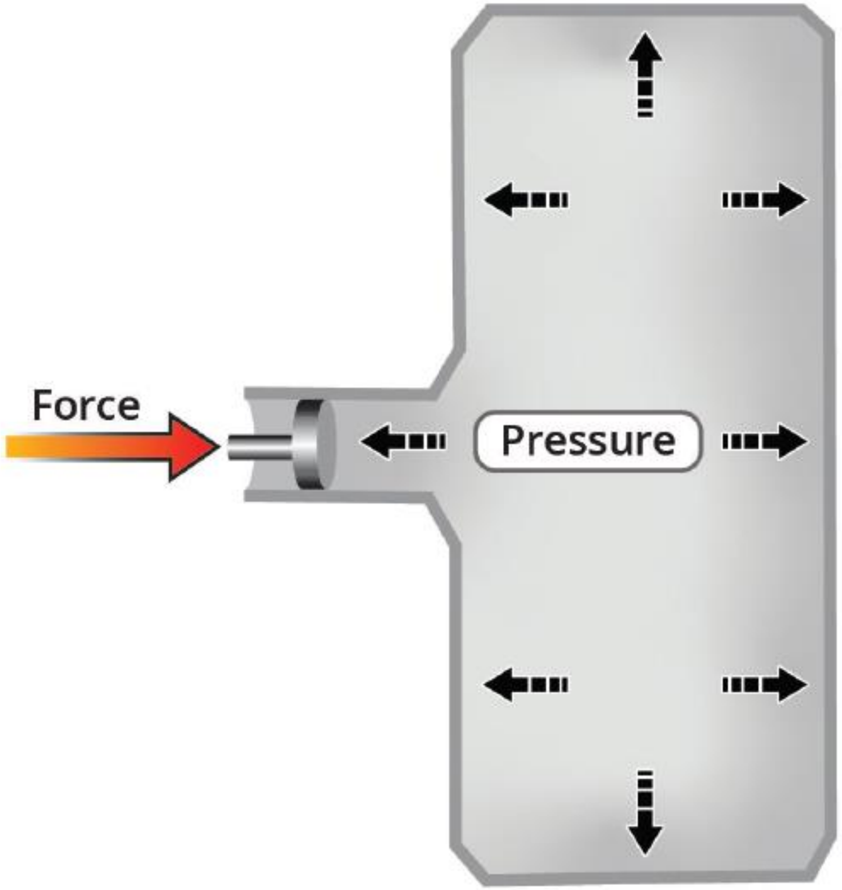


Figure 3.2 Pascal's law

The force employed when a hydraulic system is operated is caused by "pressure". This force is not delivered by the hydraulic pump; the pump provides fluid flow. 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.

The Relationship Between Pressure, Force and Area

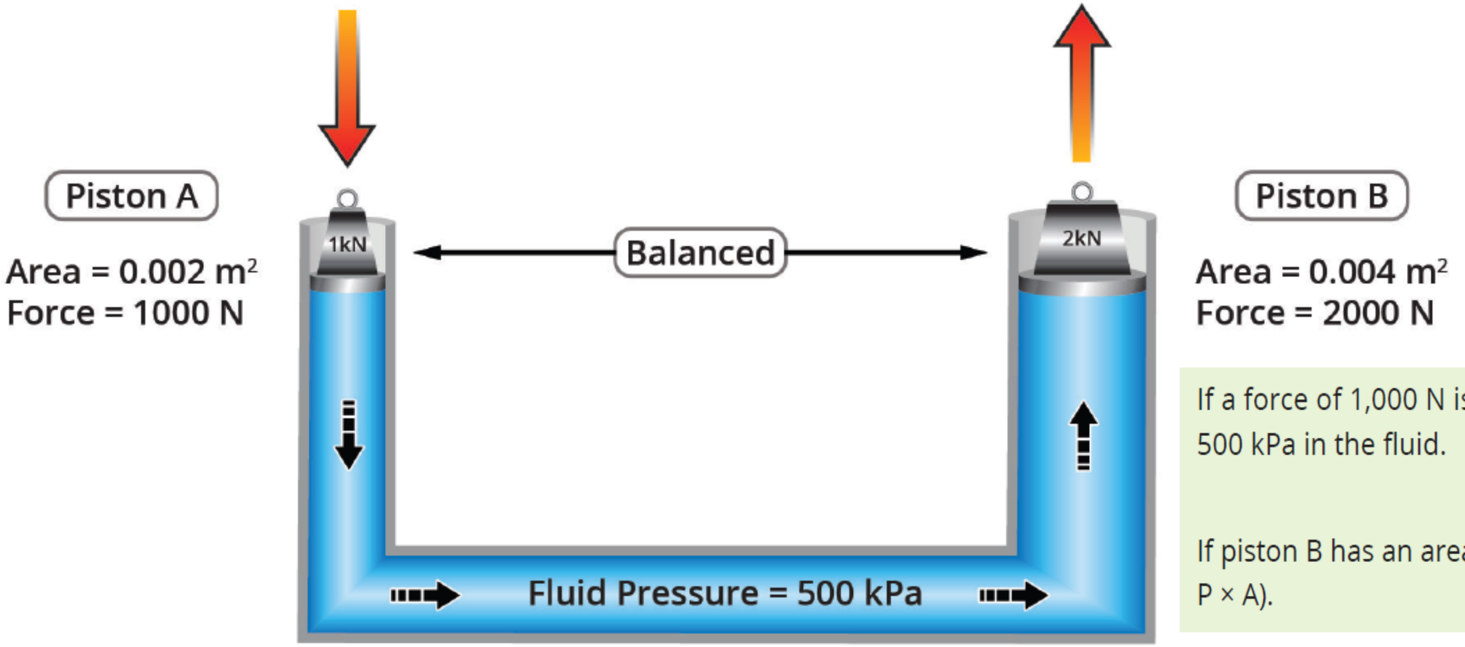
Without some form of restriction, there can be no pressure.

FORCE	=	PRESSURE × AREA
PRESSURE	=	FORCE PER UNIT AREA
FORCE	=	TOTAL LOAD AVAILABLE

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.



If a force of 1,000 N is applied to piston A, whose area is 0.002 m², it will produce a pressure of 500 kPa in the fluid.

If piston B has an area of 0.004 m², it will support a load of 0.004 m2 × 500 kPa = 2,000 N (i.e. F = P × A).

Figure 3.3 Balanced pressure

Hydraulic Systems

Hydraulic Fluids: Types, Characteristics and Limitations

Hydraulic fluids should have the following properties:

- relatively incompressible
- adequate lubricating properties for metal and rubber
- high viscosity (flow properties)
- high boiling point
- low freezing point
- flash point above 100°C
- non-flammable
- chemically inert
- low volatility (resistance to vaporisation)
- free from sludging and foaming
- acceptable storage properties
- non-corrosive
- reasonably priced and readily available

Hydraulic Fluid Hazards

Hydraulic fluids should be handled with care, as they are considered to be a skin and eye irritant. The fluids also have a detrimental effect on paintwork, sealing compounds, rubber materials, Perspex, etc.

Hydraulic Fluid Hazards

Hydraulic fluids should be handled with care, as they are considered to be a skin and eye irritant. The fluids also have a detrimental effect on paintwork, sealing compounds, rubber materials, Perspex, etc.

Compressibility

The efficiency of a hydraulic system is governed by the resistance to motion encountered by the fluid, and, therefore, incompressibility is considered the most important quality of a hydraulic fluid. For all practical purposes, hydraulic fluids are considered to be incompressible except at very high pressures.

Types of Hydraulic Fluid

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:

- Mineral - An example of this type of fluid is DTD 585 - a refined mineral-based oil (petroleum). Colour - red.
- Synthetic - An example of this type of fluid is SKYDROL - a phosphate ester-based oil. Colour - Type 500A & B - purple, Type 700 - green). It is fire-resistant and less prone to cavitation because of its higher boiling point.

Different types of hydraulic fluid should never be mixed due to their different chemical composition.

Principle of Operation of a Hydraulic System

Hydraulic systems provide a means of 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. 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.

Constant Pressure and Demand Type Hydraulic Systems

- Constant pressure system - In this type of system, pressure is constant due to a pressure pump that can build up and maintain pressure even when there is no demand on the hydraulic system. These systems have high pressure applied all the time but have fast reaction time when hydraulic services are selected.
- Demand system - In this type of system, the hydraulic pressure is built up on demand by a pump when hydraulic services are selected. Reaction time is much slower, but the components are not subject to constant pressure and, therefore, last longer.

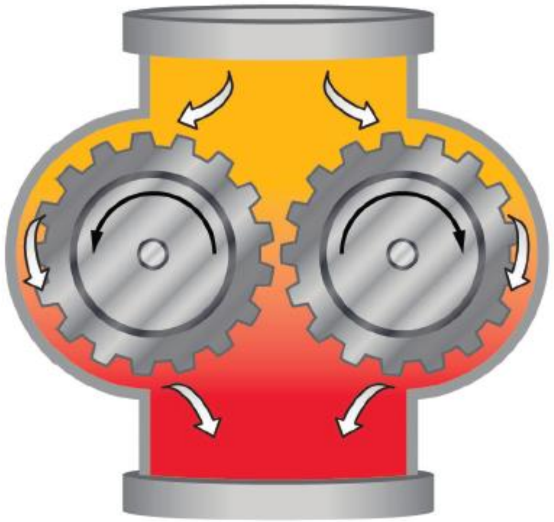


Figure 3.9 Constant delivery pressure pump

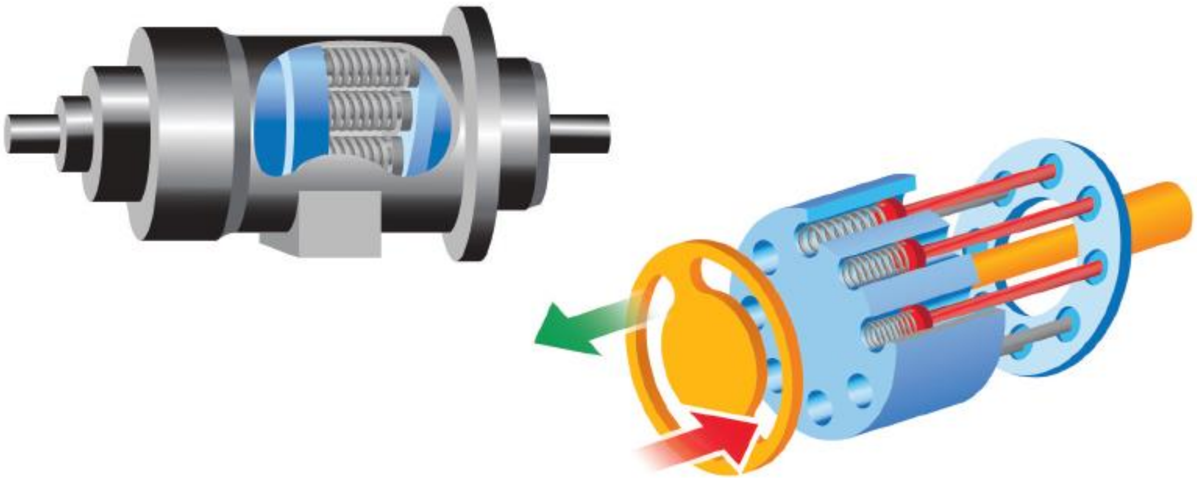


Figure 3.10 Constant pressure pump

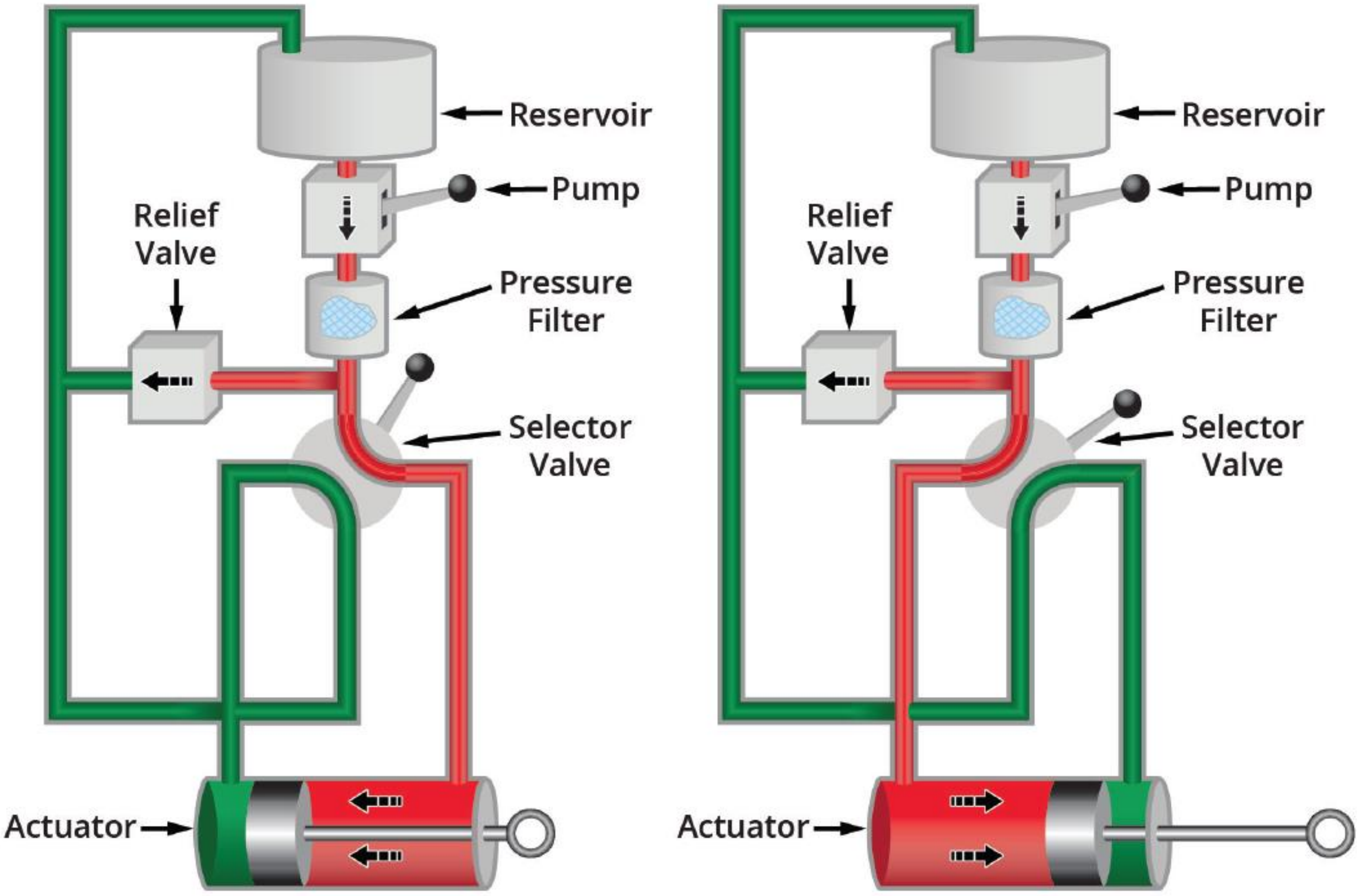
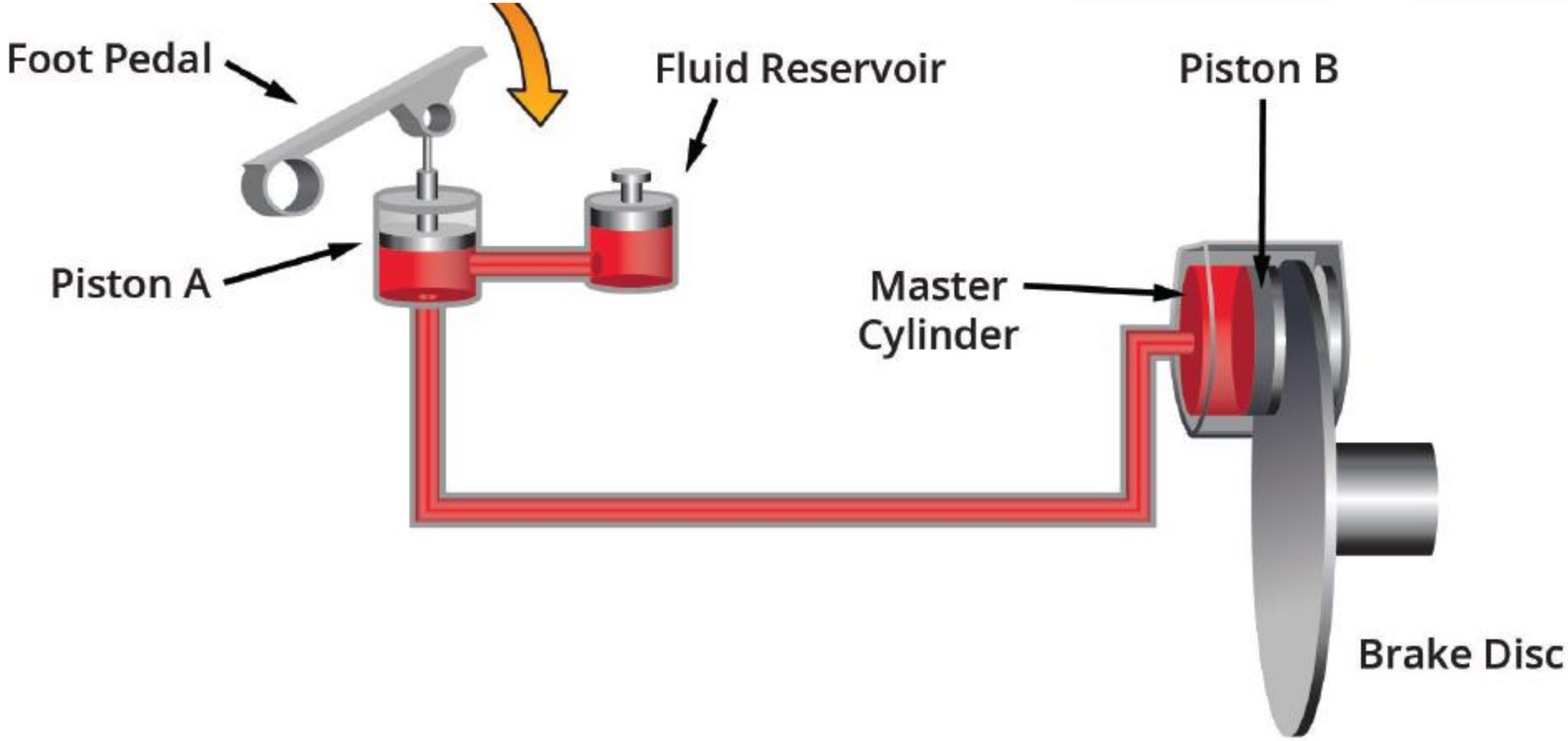


Figure 3.4 Hydraulic system

Passive Hydraulic Systems

A passive hydraulic system is one in which there is no pump, and pressure is only produced when a force is applied to a piston. 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.



Active Hydraulic Systems

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, nose wheel 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.

Active hydraulic systems are generally classified as low or high pressure: low pressure up to 2,000 psi and high pressure above that, with working system pressures averaging 3,000 psi. The main advantage of a high-pressure system is that the size of the actuators can be reduced, since these need less fluids, and the pipes can be made smaller.

Properties	High Pressure	Low Pressure
Weight (similar size aircraft)	Lighter due to smaller actuators	Higher
Force	Able to apply extremely large forces	Unable to apply larger forces
Construction	Complex	Simple
Pressure	Yes	No

Properties	Hydraulic	Mechanical
Weight	Higher (Components have to withstand high power)	Lower
Force	Able to apply extremely large forces	Applied force limited due to human input
Construction	Fewer moving parts	More moving parts
Motion options (Rotary and Linear)	Rotary and linear	Rotary more difficult
Efficiency	Very efficient	Not as efficient (mechanical losses)
Power transmission	Efficient	Not as effecient
Operation	Smooth	Not as smooth
Cost	More expensive	Cheaper, less complex
Leakage	Failure possible if leakage, damage to aircraft	Not affected
Hazard to personnel	Fluid present a hazard	No hazard
Accuracy	Very accurate	Not as accurate due to backlash in system
Load feel	Needs artificial load feel if required	Load feel inherent

Sources of Hydraulic Pressure

These 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-driven air turbine motor (ATM)
- Ram air turbine (RAT), (or HYDRAT)
- Hydraulically-driven (hydraulic motor driving a hydraulic pump), known as a power transfer unit (PTU)

In most cases, the ATM, RAT, or PTU is used to provide an alternate hydraulic supply as part of the redundancy provision for the safe operation of the aircraft. These pumps may not provide the same flow as an EDP, and simultaneous multiple system operation should be avoided when operating independently.

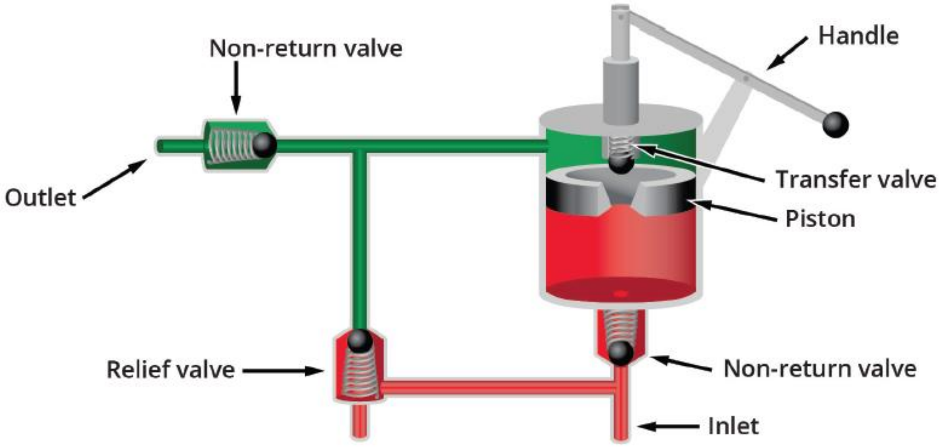
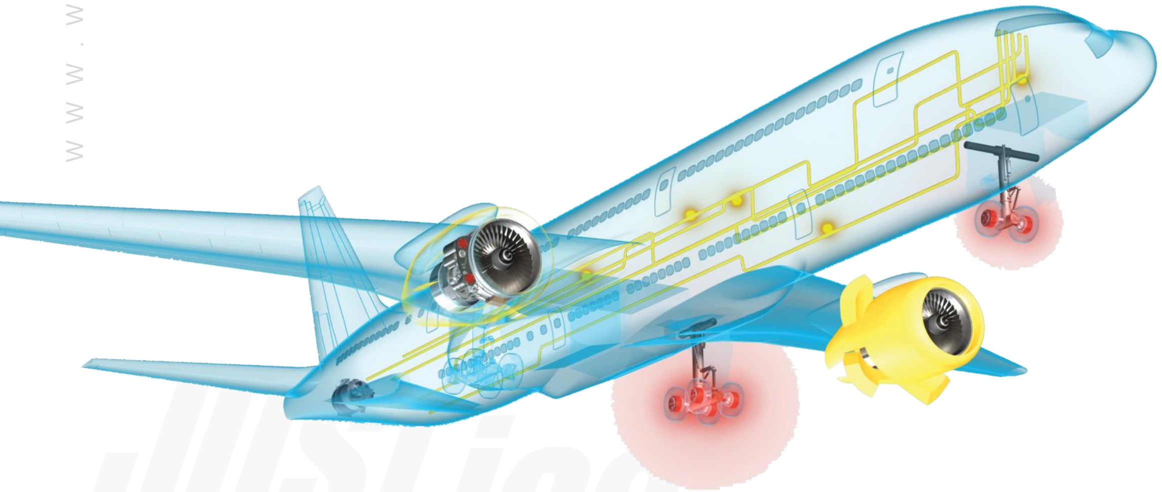


Figure 3.14 Hand pump



Hydraulic System Components

Reservoirs

A reservoir provides storage space for the system fluid, supplying a head of fluid for the pump and compensating for small leaks. It also provides 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.

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.

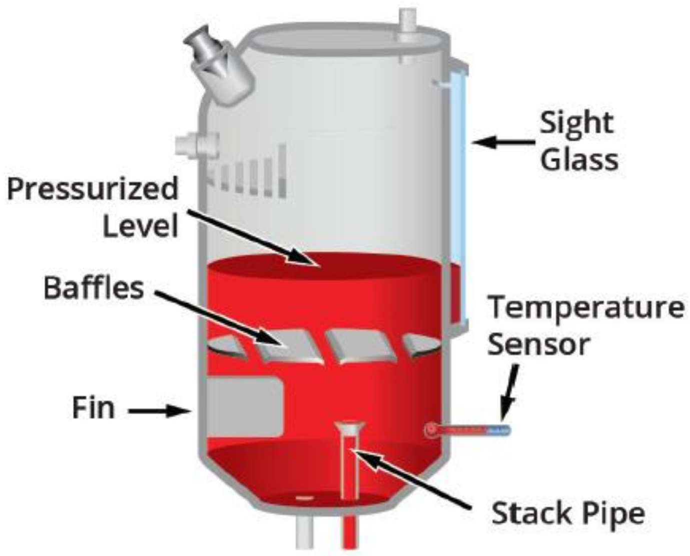


Figure 3.15 Reservoir A

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.
- to provide the initial fluid when a selection is made, and the pump is cut-out.

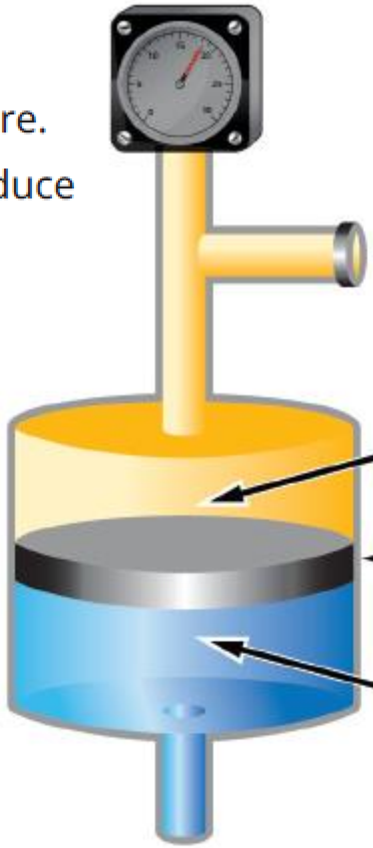


Figure 3.16 Hydraulic accumulator

Hydraulic Jacks (Actuators)

An actuator's purpose is to convert fluid flow into linear or rotary motion.

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.

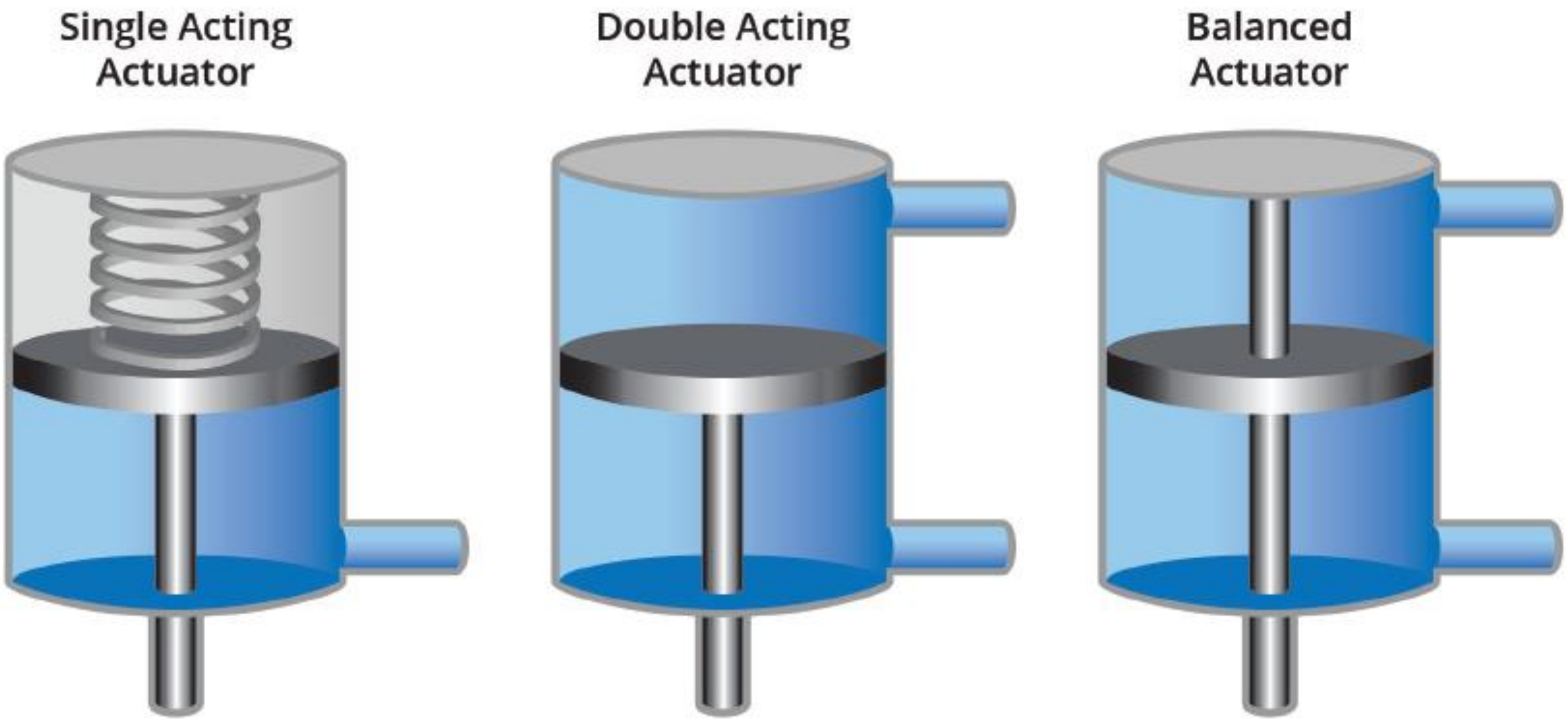


Figure 3.17 Hydraulic jacks

Filters

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 filte
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

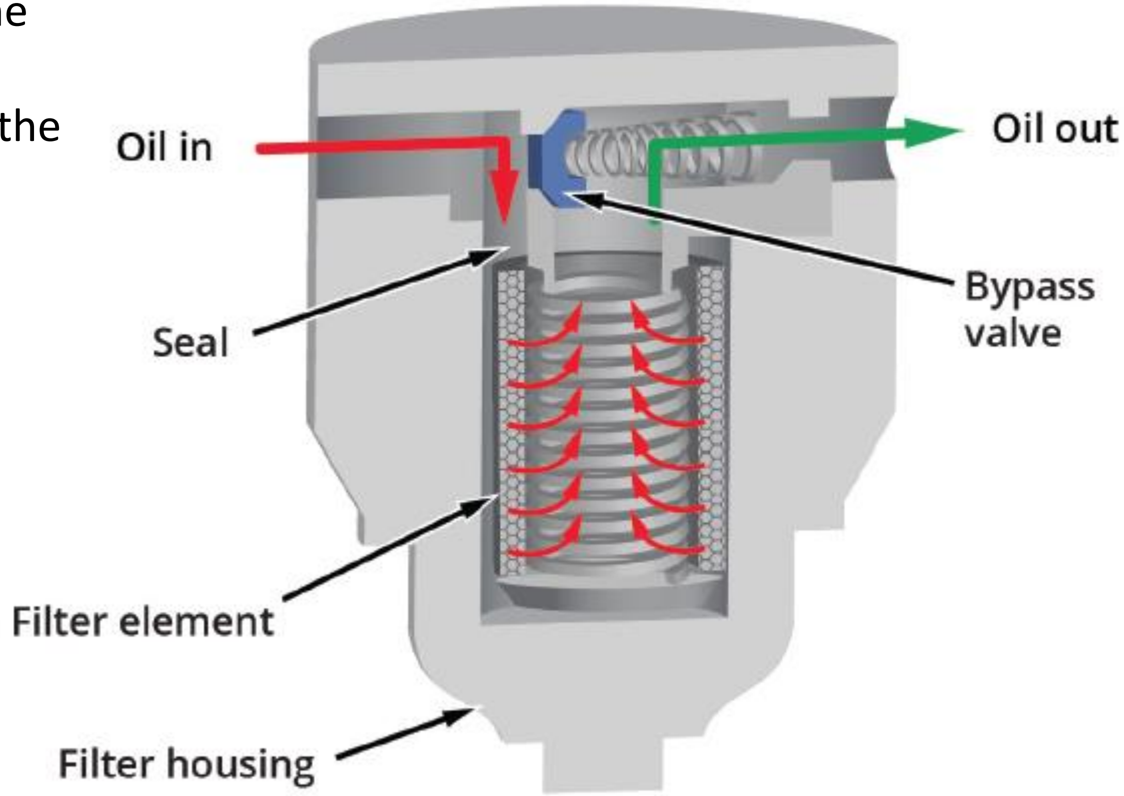


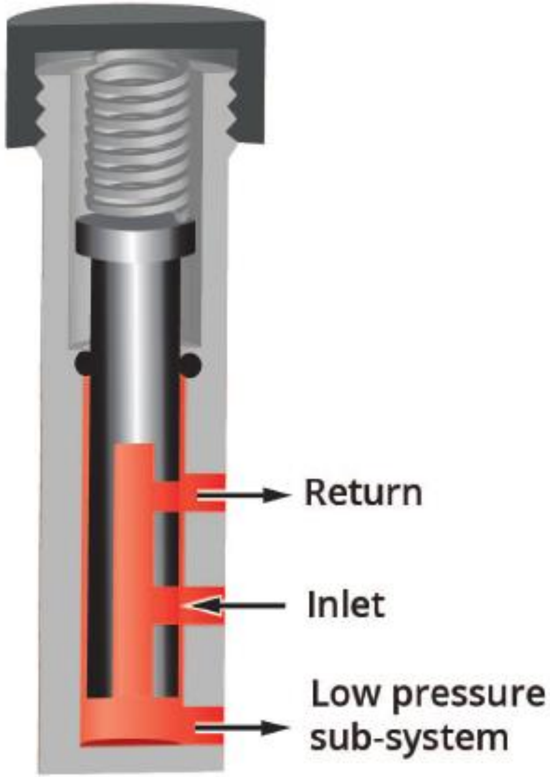
Figure 3.18 Oil filter

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:

Relief valves are used for:

- Expansion (thermal relief)
- Ultimate system protection (full flow relief)
- Mechanical overload protection (flap relief)



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 the figure below. 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.

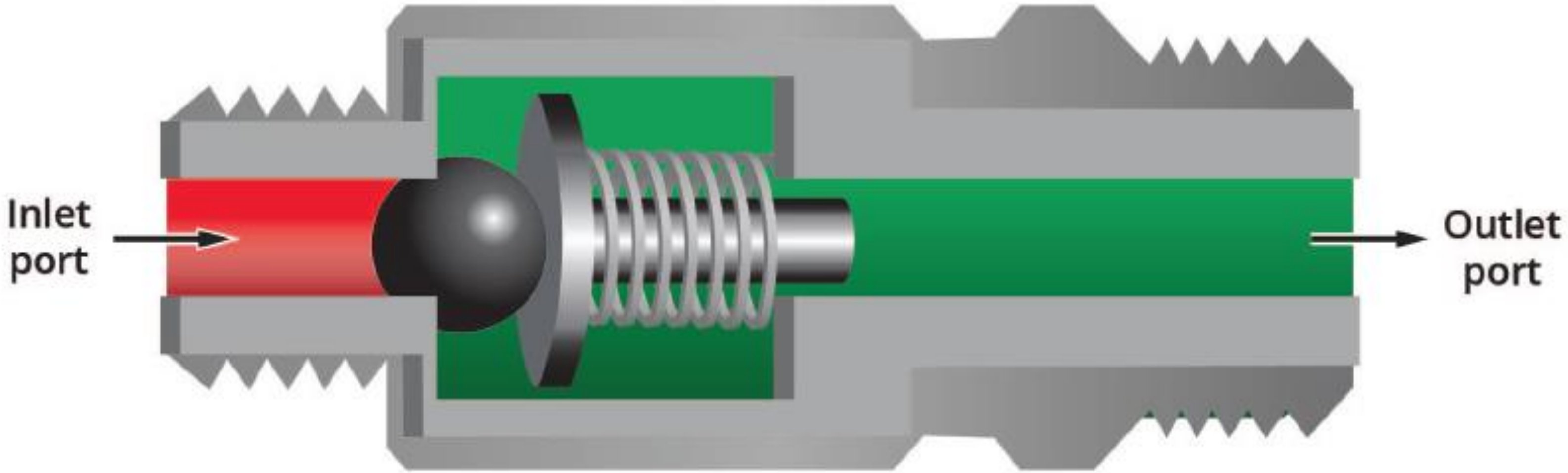
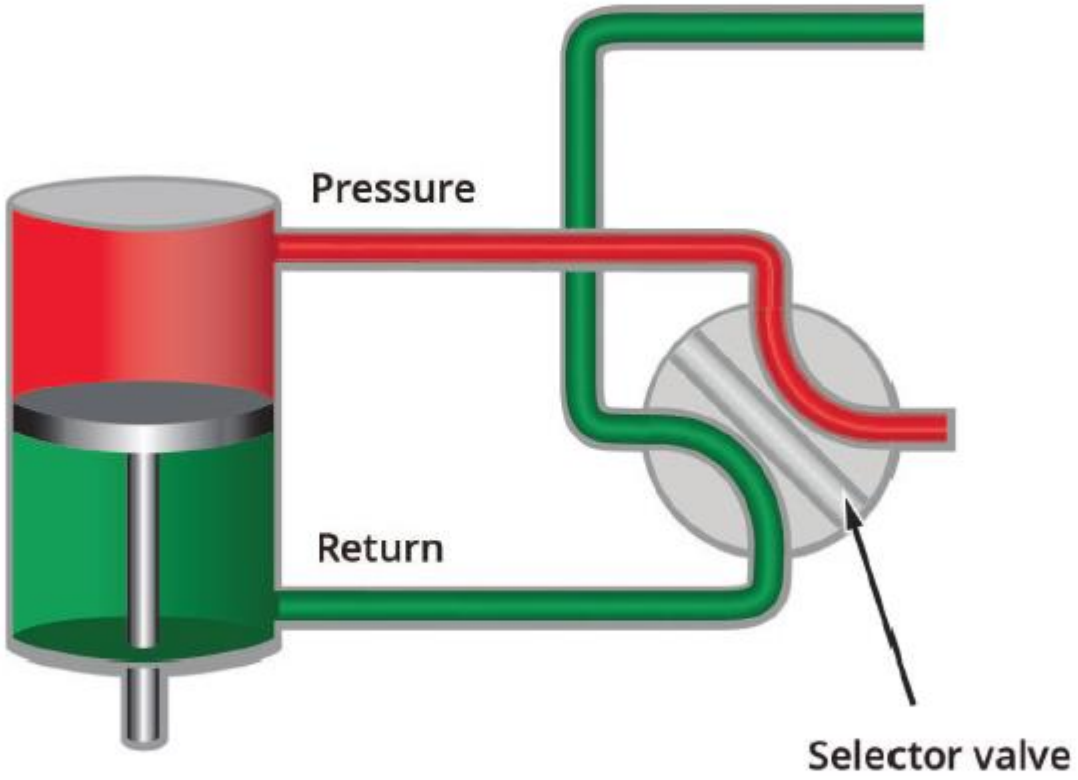


Figure 3.22 Non-return valve

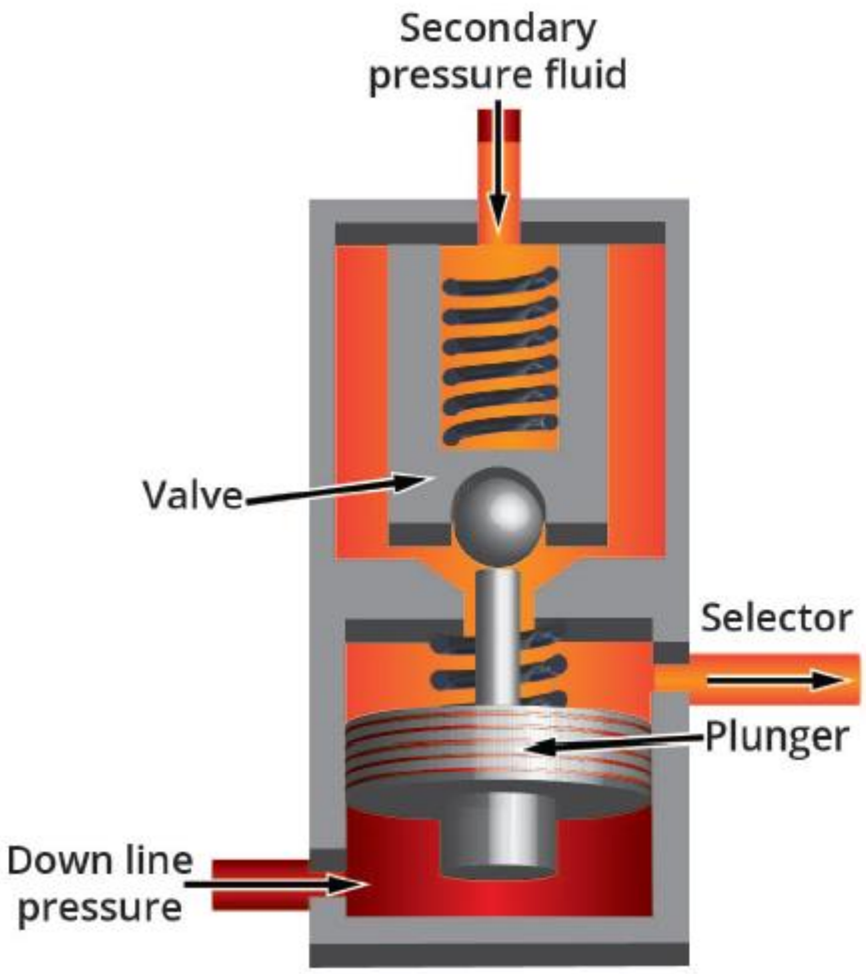
Selector Valves

Selector valves are used to direct fluid to the appropriate side of a jack and connect the other side to return. Some are manually operated, but on large transport aircraft, they are operated remotely either mechanically or electrically. Selectors are of two main types: open centre or closed centre, and they may be rotary or linear in construction.



Hydraulic Fuses

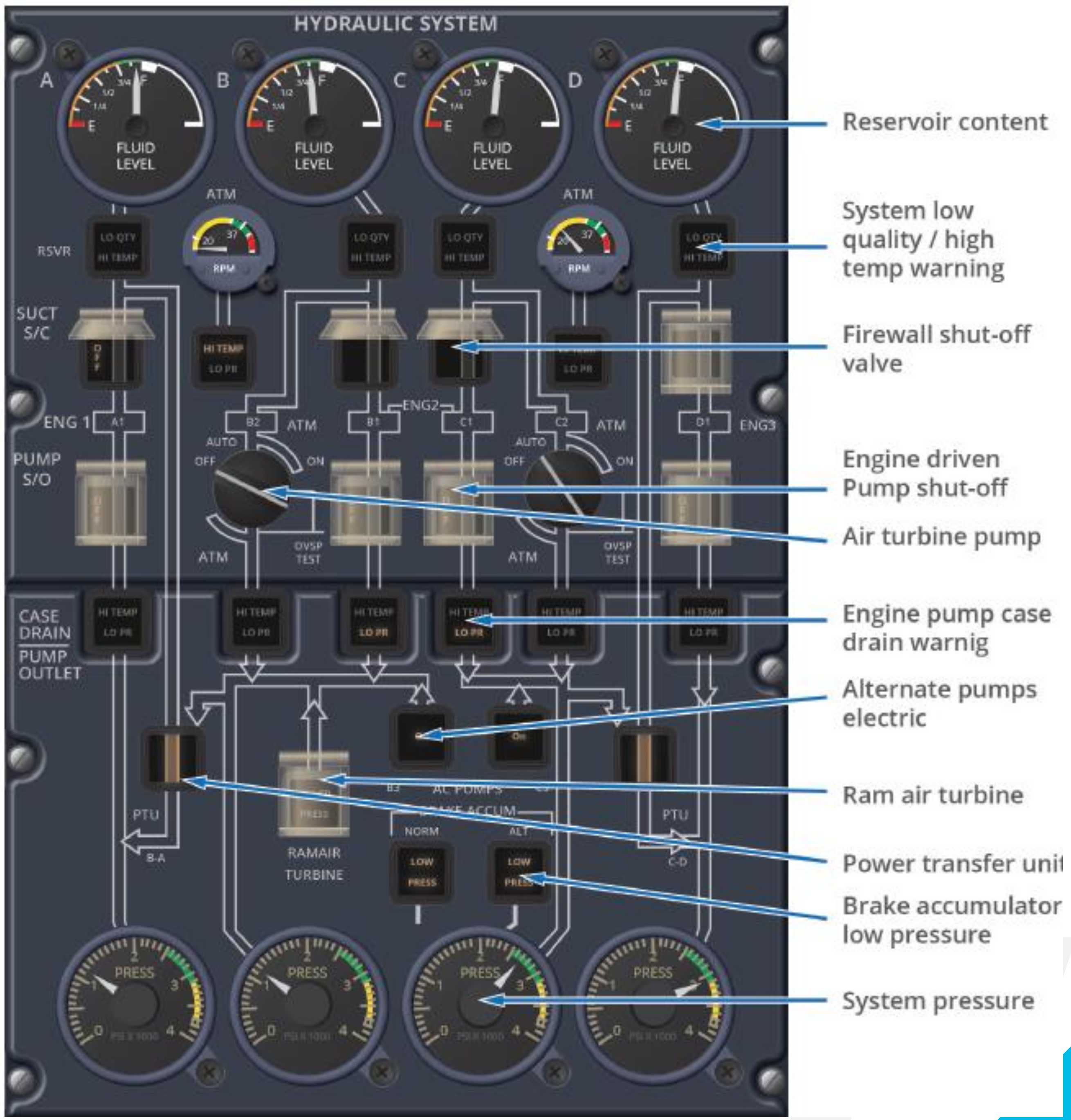
Modern jet aircraft are dependent on their hydraulic systems, not only for raising and lowering the landing gear, but for control system boosts, thrust reversers, flaps, brakes, and many auxiliary systems. Most aircraft use more than one independent system, and in these systems, provisions are made to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



Hydraulic ("DOWN" selected)

System Redundancy

On large modern transport aircraft that use hydraulic power to actuate flying controls and other services, it is vital that the failure of one hydraulic system, due to leakage or pump failure, cause the loss of these services. A modern aircraft will, therefore, have multiple hydraulic systems. Important systems will have actuation from more than one system. To cater for the eventuality of EDP failure causing the system to lose pressure, power transfer units (PTU), air-driven turbine motors (ATM), and ram air turbine can provide pressure to replace the failed EDP.



W W W . W E B S I T E . C O M

W W W . W E B S I T E . C O M

W W W . W E B S I T E . C O M

Justice.

W W W . W E B S I T E . C O M

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