SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-1 NOTES

FACULTY NAME: D.SUKUMAR **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 7AN6.3 **SEMESTER: VII**

SUBJECT NAME: MAINTENANCE OF AIRFRAME AND SYSTEMS DESIGN

AIRFRAME CONSTRUCTION:

Various types of structures in airframe construction, tubular, braced monocoque, semimoncoque, etc.

longerons, stringers, formers, bulkhead, spars and ribs, honeycomb construction.

Introduction:

An aircraft is a device that is used for, or is intended to be used for, flight in the air. Major categories of aircraft are airplane, rotorcraft, glider, and lighter-than-air vehicles. Each of these may be divided further by major distinguishing features of the aircraft, such as airships and balloons. Both are lighter-than-air aircraft but have differentiating features and are operated differently. The concentration of this handbook is on the airframe of aircraft; specifically, the fuselage, booms, nacelles, cowlings, fairings, airfoil surfaces, and landing gear. Also included are the various accessories and controls that accompany these structures. Note that the rotors of a helicopter are considered part of the airframe since they are actually rotating wings. By contrast, propellers and rotating airfoils of an engine on an airplane are not considered part of the airframe. The most common aircraft is the fixed-wing aircraft. As the name implies, the wings on this type of flying machine are attached to the fuselage and are not intended to move independently in a fashion that results in the creation of lift. One, two, or three sets of wings have all been successfully utilized. Rotary-wing aircraft such as helicopters are also widespread. This handbook discusses features and maintenance aspects common to both fixed wing and rotary-wing categories of aircraft. Also, in certain cases, explanations focus on information specific to only one or the other. Glider airframes are very similar to fixed wing aircraft. Unless otherwise noted, maintenance practices described for fixed-wing aircraft also apply to gliders. The same is true for lighter-than-air aircraft, although thorough coverage of the unique airframe structures and maintenance practices for lighter-than-air flying machines is not included in this handbook. The airframe of a fixed-wing aircraft consists of five principal units: the fuselage, wings, stabilizers, flight control surfaces, and landing gear. Helicopter airframes consist of the fuselage, main rotor and related gearbox, tail rotor (on helicopters with a single main rotor), and the landing gear. Airframe structural components are constructed from a wide variety of materials. The earliest aircraft were constructed primarily of wood. Steel tubing and the most common material, aluminum, followed. Many newly certified aircraft are built from molded composite materials, such as carbon fiber. Structural members of an aircraft′s fuselage include stringers, longerons, ribs, bulkheads, and more. The main structural member in a wing is called the wing spar.

The skin of aircraft can also be made from a variety of materials, ranging from impregnated fabric to plywood, aluminum, or composites. Under the skin and attached to the structural fuselage are the many components that support airframe function. The entire airframe and its components are joined by rivets, bolts, screws, and other fasteners. Welding, adhesives, and special bonding techniques are also used.

Major Structural Stresses

Aircraft structural members are designed to carry a load or to resist stress. In designing an aircraft, every square inch of wing and fuselage, every rib, spar, and even each metal fitting must be considered in relation to the physical characteristics of the material of which it is made. Every part of the aircraft must be planned to carry the load to be imposed upon it.

The determination of such loads is called stress analysis. Although planning the design is not the function of the aircraft technician, it is, nevertheless, important that the technician understand and appreciate the stresses involved in order to avoid changes in the original design through improper repairs.

The term ″stress″ is often used interchangeably with the word ″strain.″ While related, they are not the same thing. External loads or forces cause stress. Stress is a material’s internal resistance, or counterforce, that opposes deformation. The degree of deformation of a material is strain. When a material is subjected to a load or force, that material is deformed, regardless of how strong the material is or how light the load is.

There are five major stresses to which all aircraft are subjected:

• Tension

• Compression

• Torsion

• Shear

• Bending

Tension is the stress that resists a force that tends to pull something apart. *[Figure 1-14A]* The engine pulls the aircraft forward, but air resistance tries to hold it back. The result is tension, which stretches the aircraft. The tensile strength of a material is measured in pounds per square inch (psi) and is calculated by dividing the load (in pounds) required to pull the material apart by its cross-sectional area (in square inches).

Compression is the stress that resists a crushing force. *[Figure 1-14B]* The compressive strength of a material is also measured in psi. Compression is the stress that tends to shorten or squeeze aircraft parts.

Torsion is the stress that produces twisting. *[Figure 1-14C]* While moving the aircraft forward, the engine also tends to twist it to one side, but other aircraft components hold it on course. Thus, torsion is created. The torsion strength of a material is its resistance to twisting or torque.

Shear is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer. *[Figure 1-14D]* Two riveted plates in tension subject the rivets to a shearing force. Usually, the shearing strength of a material is either equal to or less than its tensile or compressive strength. Aircraft parts, especially screws, bolts, and rivets, are often subject to a shearing force.

Bending stress is a combination of compression and tension. The rod in has been shortened (compressed) on the inside of the bend and stretched on the outside of the bend.

A single member of the structure may be subjected to a combination of stresses. In most cases, the structural members are designed to carry end loads rather than side loads. They are designed to be subjected to tension or compression rather than bending. Strength or resistance to the external loads imposed during operation may be the principal requirement in certain structures. However, there are numerous other characteristics in addition to designing to control the five major stresses that engineers must consider. For example, cowling, fairings, and similar parts may not be subject to significant loads requiring a high degree of strength. However, these parts must have streamlined shapes to meet aerodynamic requirements, such as reducing drag or directing airflow.

Fixed-Wing Aircraft

Fuselage

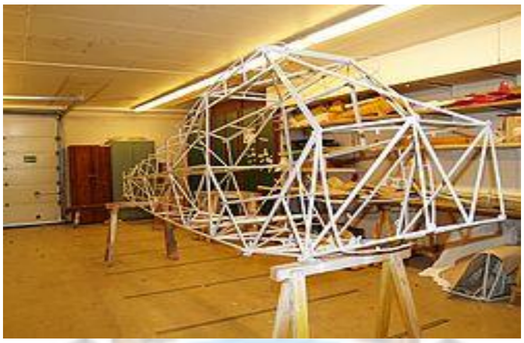
The fuselage is the main structure or body of the fixed-wing aircraft. It provides space for cargo, controls, accessories, passengers, and other equipment. In single-engine aircraft, the fuselage houses the power plant. In multiengine aircraft, the engines may be either in the fuselage, attached to the fuselage, or suspended from the wing structure. There are two general types of fuselage construction: truss and monocoque.

Truss Type

A truss is a rigid framework made up of members, such as beams, struts, and bars to resist deformation by applied loads.

The truss-framed fuselage is generally covered with fabric. The truss-type fuselage frame is usually constructed of steel tubing welded together in such a manner that all members of the truss can carry both tension and compression loads. In some aircraft, principally the light, single engine models, truss fuselage frames may be constructed of aluminum alloy and may be riveted or bolted into one piece, with cross-bracing achieved by using solid rods or tubes.

Most early aircraft used this technique with wood and wire trusses and this type of structure is still in use in many lightweight aircraft using welded steel tube trusses. The truss type fuselage frame is assembled with members forming a rigid frame e.g. beams, bar, tube etc… Primary members of the truss are 4 longerons.



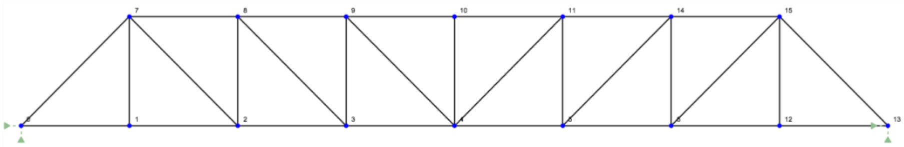
There are two types of truss structure.

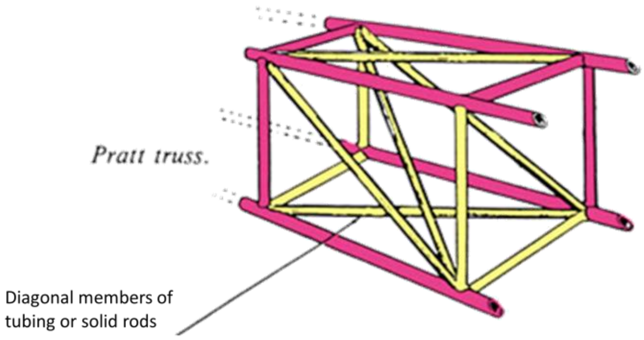
- PRATT TRUSS
- WARREN TRUSS

PRATT TRUSS

A Pratt Truss has been used over the past two centuries as an effective truss method. The vertical members are in compression, whilst the diagonal members are in tension. This simplifies and produces a more efficient design since the steel in the diagonal members (in tension) can be reduced. This has a few effects - it reduces the cost of the structure due to more efficient members, reduces the self weight and eases the constructability of the structure. This type of truss is most appropriate for horizontal spans, where the force is predominantly in the vertical direction.

Below is an example of a Pratt Truss,





A truss-type fuselage with partt truss.

Advantages

- Aware of member's behaviour - diagonal members are in tension, vertical members in compression
- The above can be used to design a cost effective structure
- Simple design
- Well accepted and used design

Disadvantages

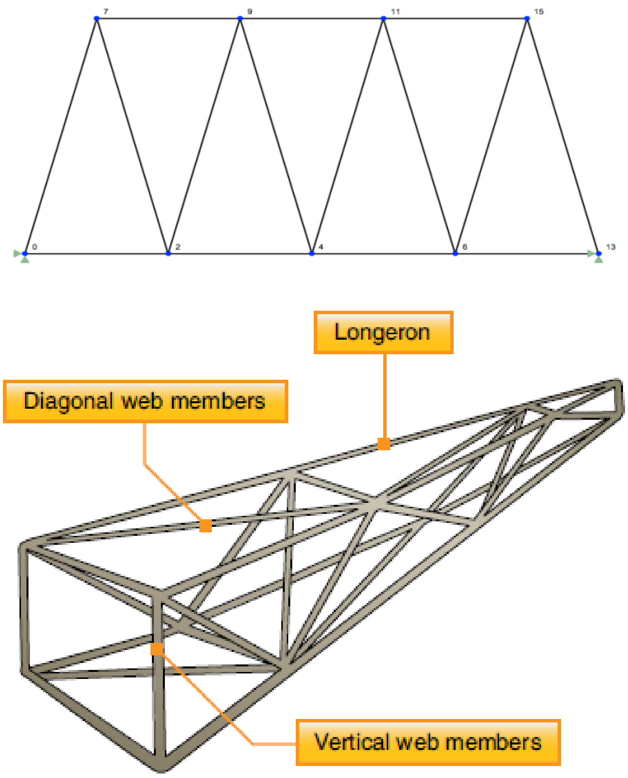
- Not as advantageous if the load is not vertical

Best Used For:

- Where a cost effective design is required
- Where a mix of loads are applied
- Where a simple structure is required

WARREN TRUSS

The Warren Truss is another very popular truss structure system and is easily identified by its construction from equilateral triangles. One of the main advantages of a Warren Truss is its ability to spread the load evenly across a number of different members; this is however generally for cases when the structure is undergoing a spanned load (a distributed load). It's main advantage is also the cause of it's disadvantage - the truss structure will undergo concentrated force under a point load. Under these concentrated load scenarios, the structure is not as good at distributing the load evenly across its members. Therefore the Warren truss type is more advantageous for spanned loads, but not suitable where the load is concentrated at a single point or node. An example of a Warren Truss and its axial forces under a distributed load is shown below.



A truss-type fuselage. A Warren truss uses mostly diagonal bracing.

Advantages

- Spreads load fairly evenly between members
- Fairly simple design

Disadvantages

- Poorer performance under concentrated loads
- Increased constructibility due to additional members

Best Used For:

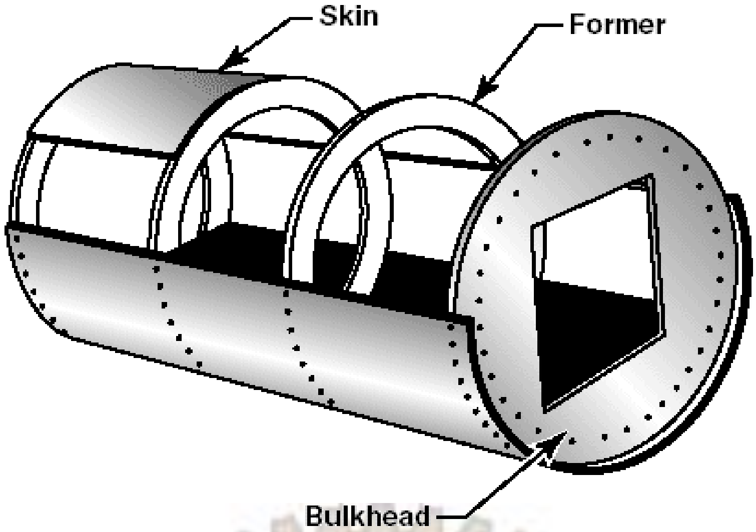
- Long span structures
- Where an evenly distributed load is to be supported
- Where a simple structure is required

Monocoque Type

The monocoque (single shell) fuselage relies largely on the strength of the skin or covering to carry the primary loads.
The design may be divided into two classes:
1. Monocoque
2. Semimonocoque

Different portions of the same fuselage may belong to either of the two classes, but most modern aircraft are considered to be of semi-monocoque type construction.

The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage. The heaviest of these structural members are located at intervals to carry concentrated loads and at points where fittings are used to attach other units such as wings, power plants, and stabilizers. Since no other bracing members are present, the skin must carry the primary stresses and keep the fuselage rigid. Thus, the biggest problem involved in monocoque construction is maintaining enough strength while keeping the weight within allowable limits.



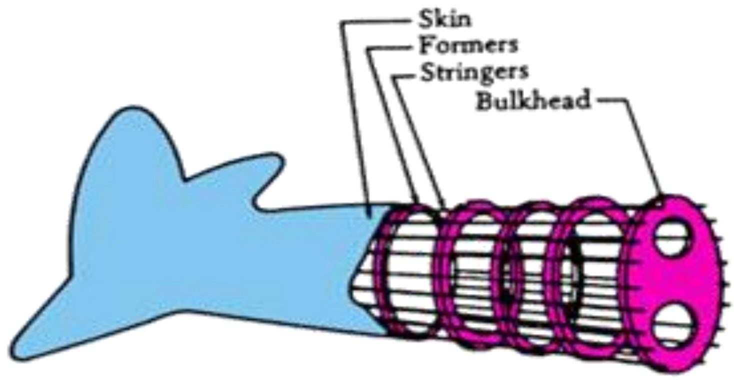
An airframe using monocoque construction.

Semi-monocoque Type

To overcome the strength/weight problem of monocoque construction, a modification called semi-monocoque construction was developed.

It also consists of frame assemblies, bulkheads, and formers as used in the monocoque design but, additionally, the skin is reinforced by longitudinal members called longerons. Longerons usually extend across several frame members and help the skin support primary bending loads. They are typically made of aluminum alloy either of a single piece or a built-up construction.

Stringers are also used in the semimonocoque fuselage. These longitudinal members are typically more numerous and lighter in weight than the longerons. They come in a variety of shapes and are usually made from single piece aluminum alloy extrusions or formed aluminum. Stringers have some rigidity but are chiefly used for giving shape and for attachment of the skin. Stringers and longerons together prevent tension and compression from bending the fuselage.



Semi-monocoque Structure of an airplane

Other bracing between the longerons and stringers can also be used. Often referred to as web members, these additional support pieces may be installed vertically or diagonally. It must be noted that manufacturers use different nomenclature to describe structural members. For example, there is often little difference between some rings, frames, and formers. One manufacturer may call the same type of brace a ring or a frame. Manufacturer instructions and specifications for a specific aircraft are the best guides.

The semi-monocoque fuselage is constructed primarily of alloys of aluminum and magnesium, although steel and titanium are sometimes found in areas of high temperatures. Individually, no one of the aforementioned components is strong enough to carry the loads imposed during flight and landing. But, when combined, those components form a strong, rigid framework. This is accomplished with gussets, rivets, nuts and bolts, screws, and even friction stir welding.

A gusset is a type of connection bracket that adds strength.

Gussets are used to increase strength.

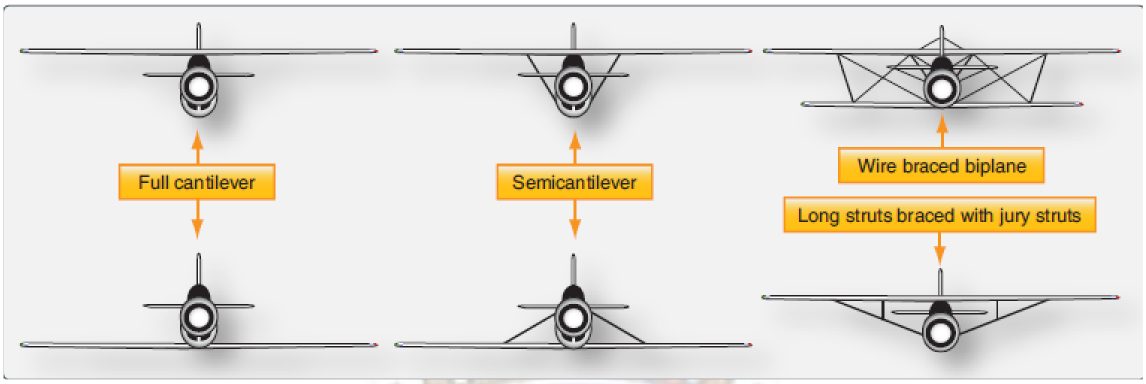
To summarize, in semi-monocoque fuselages, the strong, heavy longerons hold the bulkheads and formers, and these, in turn, hold the stringers, braces, web members, etc. All are designed to be attached together and to the skin to achieve the full strength benefits of semi-monocoque design. It is important to recognize that the metal skin or covering carries part of the load. The fuselage skin thickness can vary with the load carried and the stresses sustained at a particular location.

The advantages of the semi-monocoque fuselage are many. The bulkheads, frames, stringers, and longerons facilitate the design and construction of a streamlined fuselage that is both rigid and strong. Spreading loads among these structures and the skin means no single piece is failure critical. This means that a semi-monocoque fuselage, because of its stressed-skin construction, may withstand considerable damage and still be strong enough to hold together.

Fuselages are generally constructed in two or more sections. On small aircraft, they are generally made in two or three sections, while larger aircraft may be made up of as many as six sections or more before being assembled.

Wing Structure

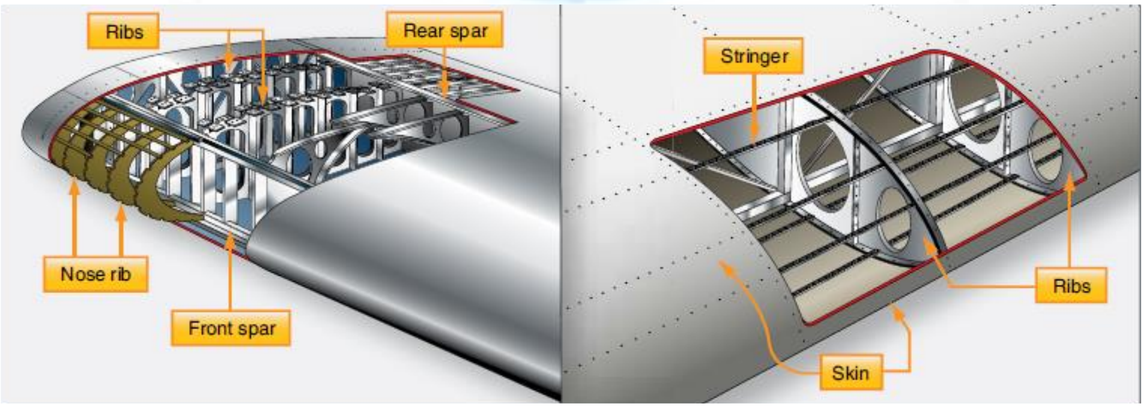
The wings of an aircraft are designed to lift it into the air. Their particular design for any given aircraft depends on a number of factors, such as size, weight, use of the aircraft, desired speed in flight and at landing, and desired rate of climb. The wings of aircraft are designated left and right, corresponding to the left and right sides of the operator when seated in the cockpit. Often wings are of full cantilever design. This means they are built so that no external bracing is needed. They are supported internally by structural members assisted by the skin of the aircraft. Other aircraft wings use external struts or wires to assist in supporting the wing and carrying the aerodynamic and landing loads. Wing support cables and struts are generally made from steel. Many struts and their attach fittings have fairings to reduce drag. Short, nearly vertical supports called jury struts are found on struts that attach to the wings a great distance from the fuselage. This serves to subdue strut movement and oscillation caused by the air flowing around the strut in flight. Figure shows samples of wings using external bracing, also known as semicantilever wings. Cantilever wings built with no external bracing are also shown.



Externally braced wings, also called semicantilever wings, have wires or struts to support the wing. Full cantilever wings have no external bracing and are supported internally.

Aluminum is the most common material from which to construct wings, but they can be wood covered with fabric, and occasionally a magnesium alloy has been used. Moreover, modern aircraft are tending toward lighter and stronger materials throughout the airframe and in wing construction. Wings made entirely of carbon fiber or other composite materials exist, as well as wings made of a combination of materials for maximum strength to weight performance.

The internal structures of most wings are made up of spars and stringers running spanwise and ribs and formers or bulkheads running chordwise (leading edge to trailing edge).
The spars are the principle structural members of a wing. They support all distributed loads, as well as concentrated weights such as the fuselage, landing gear, and engines. The skin, which is attached to the wing structure, carries part of the loads imposed during flight. It also transfers the stresses to the wing ribs. The ribs, in turn, transfer the loads to the wing spars.

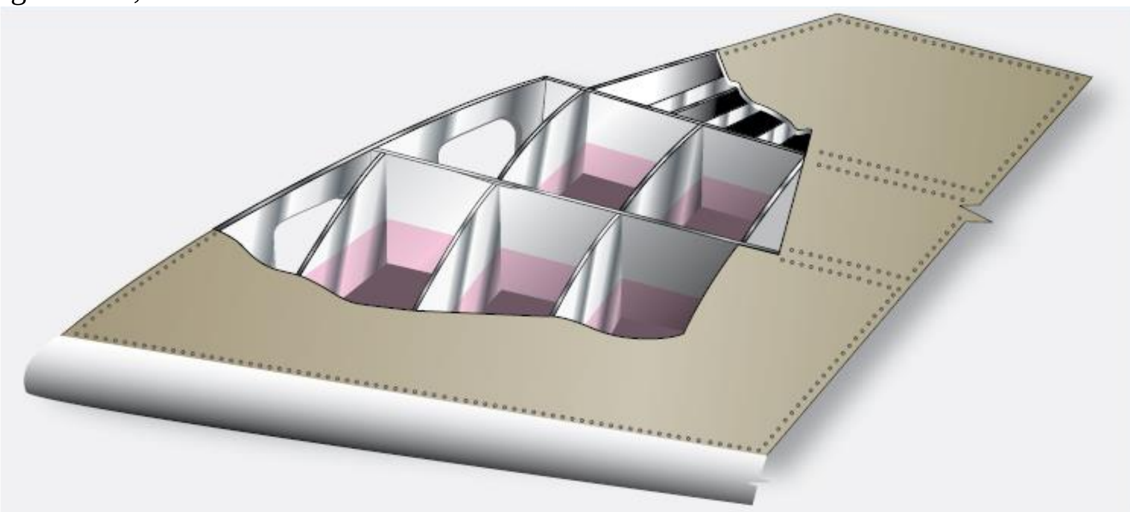


Wing structure nomenclature

In general, wing construction is based on one of three fundamental designs:
1. Monospar
2. Multispar

3. Box beam

Modification of these basic designs may be adopted by various manufacturers. The monospar wing incorporates only one main spanwise or longitudinal member in its construction. Ribs or bulkheads supply the necessary contour or shape to the airfoil. Although the strict monospar wing is not common, this type of design modified by the addition of false spars or light shear webs along the trailing edge for support of control surfaces is sometimes used. The multispar wing incorporates more than one main longitudinal member in its construction. To give the wing contour, ribs or bulkheads are often included.



Box beam construction.

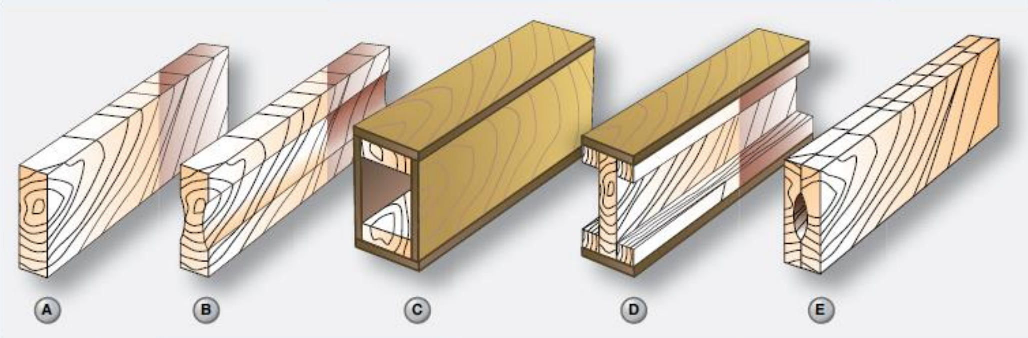
The box beam type of wing construction uses two main longitudinal members with connecting bulkheads to furnish additional strength and to give contour to the wing. A corrugated sheet may be placed between the bulkheads and the smooth outer skin so that the wing can better carry tension and compression loads. In some cases, heavy longitudinal stiffeners are substituted for the corrugated sheets. A combination of corrugated sheets on the upper surface of the wing and stiffeners on the lower surface is sometimes used. Air transport category aircraft often utilize box beam wing construction.

Wing Spars

Spars are the principal structural members of the wing. They correspond to the longerons of the fuselage. They run parallel to the lateral axis of the aircraft, from the fuselage toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or a truss. Spars may be made of metal, wood, or composite materials depending on the design criteria of a specific aircraft.

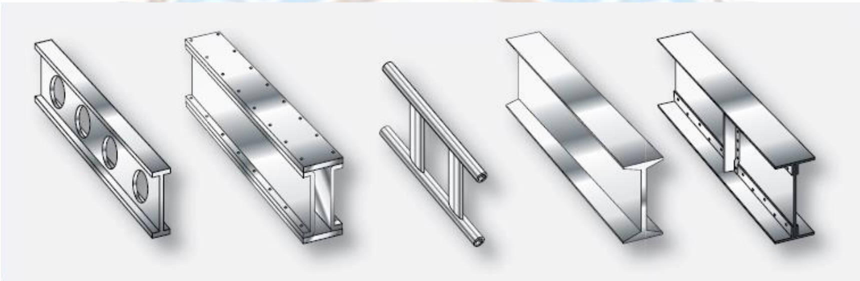
Wooden spars are usually made from spruce. They can be generally classified into four different types by their cross-sectional configuration.

As shown in figure,



They may be (A) solid, (B) box shaped, (C) partly hollow, or (D) in the form of an I-beam. Lamination of solid wood spars is often used to increase strength. Laminated wood can also be found in box shaped spars. The spar in *Figure 1-25E* has had material removed to reduce weight but retains the strength of a rectangular spar. As can be seen, most wing spars are basically rectangular in shape with the long dimension of the cross-section oriented up and down in the wing.

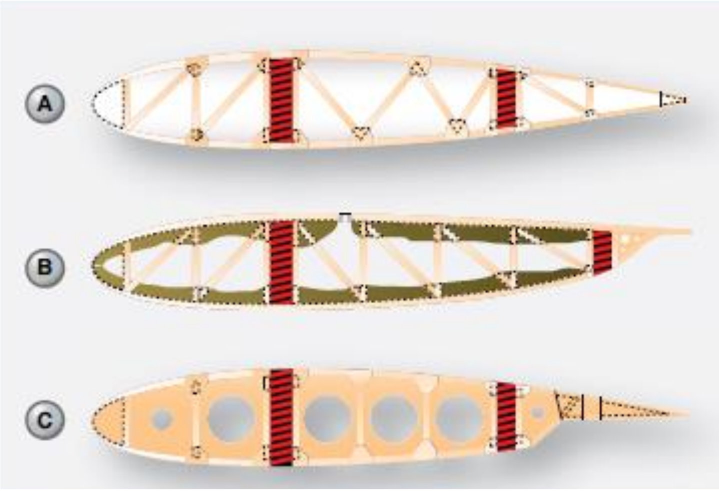
Currently, most manufactured aircraft have wing spars made of solid extruded aluminum or aluminum extrusions riveted together to form the spar. The increased use of composites and the combining of materials should make airmen vigilant for wings spars made from a variety of materials. Figure shows examples of metal wing spar cross-sections.



Wing Ribs

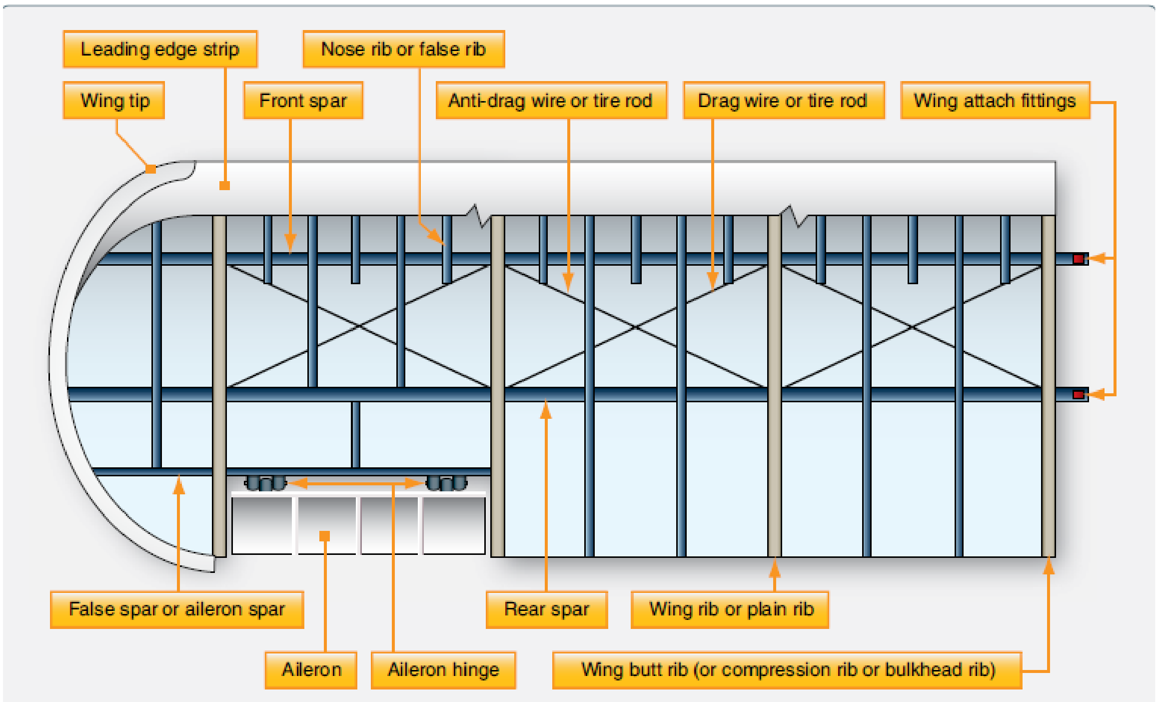
Ribs are the structural crosspieces that combine with spars and stringers to make up the framework of the wing. They usually extend from the wing leading edge to the rear spar or to the trailing edge of the wing. The ribs give the wing its cambered shape and transmit the load from the skin and stringers to the spars. Similar ribs are also used in ailerons, elevators, rudders, and stabilizers. Wing ribs are usually manufactured from either wood or metal. Aircraft with wood wing spars may have wood or metal ribs while most aircraft with metal spars have metal ribs. Wood ribs are usually manufactured from spruce. The three most common types of wooden ribs are the plywood web, the lightened plywood web, and the truss types. Of these three, the truss type is the most efficient because it is strong and lightweight, but it is also the most complex to construct.

Figure shows wood truss web ribs and a lightened plywood web rib. Wood ribs have a rib cap or cap strip fastened around the entire perimeter of the rib. It is usually made of the same material as the rib itself. The rib cap stiffens and strengthens the rib and provides an attaching surface for the wing covering. In *Figure A*, the cross-section of a wing rib with a truss-type web is illustrated. The dark rectangular sections are the front and rear wing spars. Note that to reinforce the truss, gussets are used. In *Figure B,* a truss web rib is shown with a continuous gusset. It provides greater support throughout the entire rib with very little additional weight. A continuous gusset stiffens the cap strip in the plane of the rib. This aid in preventing buckling and helps to obtain better rib/skin joints where nail-gluing is used. Such a rib can resist the driving force of nails better than the other types.



Continuous gussets are also more easily handled than the many small separate gussets otherwise required. *Figure C* shows a rib with a lighten plywood web. It also contains gussets to support the web/cap strip interface. The cap strip is usually laminated to the web, especially at the leading edge.

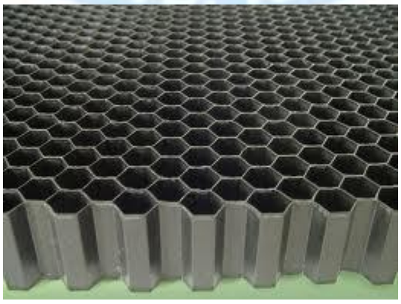
A wing rib may also be referred to as a plain rib or a main rib. Wing ribs with specialized locations or functions are given names that reflect their uniqueness. For example, ribs that are located entirely forward of the front spar that are used to shape and strengthen the wing leading edge are called nose ribs or false ribs. False ribs are ribs that do not span the entire wing chord, which is the distance from the leading edge to the trailing edge of the wing. Wing butt ribs may be found at the inboard edge of the wing where the wing attaches to the fuselage. Depending on its location and method of attachment, a butt rib may also be called a bulkhead rib or a compression rib if it is designed to receive compression loads that tend to force the wing spars together. Since the ribs are laterally weak, they are strengthened in some wings by tapes that are woven above and below rib sections to prevent sidewise bending of the ribs. Drag and anti-drag wires may also be found in a wing. In *Figure*, they are shown crisscrossed between the spars to form a truss to resist forces acting on the wing in the direction of the wing chord. These tension wires are also referred to as tie rods. The wire designed to resist the backward forces is called a drag wire; the anti-drag wire resists the forward forces in the chord direction. *Figure illustrates* the structural components of a basic wood wing.
At the inboard end of the wing spars is some form of wing attach fitting as illustrated in *Figure*. These provide a strong and secure method for attaching the wing to the fuselage.



Basic wood wing structure and components.

Honeycomb construction

Honeycomb structures are natural or man-made structures that have the geometry of a honeycomb to allow the minimization of the amount of used material to reach minimal weight and minimal material cost. The geometry of honeycomb structures can vary widely but the common feature of all such structures is an array of hollow cells formed between thin vertical walls. The cells are often columnar and hexagonal in shape. A honeycomb shaped structure provides a material with minimal density and relative high out-of-plane compression properties and out-of-plane shear properties.



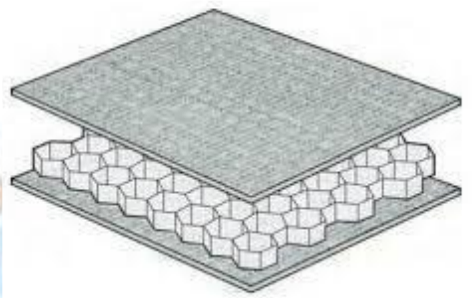
Honeycomb structure

Man-made honeycomb structural materials are commonly made by layering a honeycomb material between two thin layers that provide strength in tension. This forms a plate-like assembly. Honeycomb materials are widely used where flat or slightly curved surfaces are needed and their high strength is valuable. They are widely used in the aerospace industry for this reason, and honeycomb materials in aluminium, fibreglass and advanced composite materials have been featured in aircraft and rockets since the 1950s. They can also be found in many other fields, from packaging materials in the form of paper-based honeycomb cardboard, to sporting goods like skis and snowboards.

The main use of honeycomb is in structural applications. The standard hexagonal honeycomb is the basic and most common cellular honeycomb configuration.

Honeycomb composites

Natural honeycomb structures occur in many different environments, from beehives to honeycomb weathering in rocks. Based on these, man-made honeycomb structures have been built with similar geometry to allow the reduction of the quantity of material used, and thereby realizing minimal weight and material cost.



Honeycomb structure with panels

Man-made honeycomb structures have an array of hollow cells formed between thin vertical walls, so that the material has minimal density, strength in tension and high out-of-plane compression properties.

Geometric types of honeycomb structures

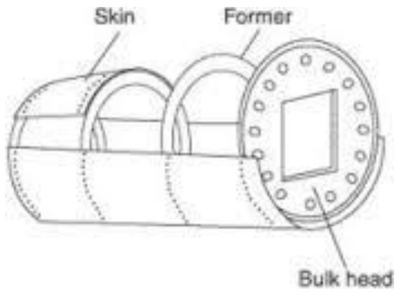
In geometry, a honeycomb is a space filling or close packing of polyhedral or higher-dimensional cells, so that there are no gaps. It is an example of the more general mathematical tiling or tessellation in any number of dimensions.

Honeycombs are usually constructed in ordinary Euclidean ("flat") space. They may also be constructed in non-Euclidean spaces, such as hyperbolic honeycombs. Any finite uniform polytope can be projected to its circumsphere to form a uniform honeycomb in spherical space.

Bulkheads

The bulkheads provide shape for the fuselage. The skin of the fuselage to bear the structural load with bulkheads at each end and forming rings at intervals to maintain the skin shape. A hybrid of truss and monocoque, in semi-monocoque construction panels of aerodynamically-curved skin are riveted on top of an internal structure consisting of bulkheads, stringers and followers to absorb the bending forces. The monocoque design uses stressed skin to support almost all imposed loads. The true monocoque construction mainly consists of the skin, formers, and bulkheads. The formers and bulkheads provide shape for the fuselage.

The semi-monocoque system uses a substructure to which the airplane´s skin is attached. The substructure, which consists of bulkheads and/or formers of various sizes and stringers, reinforces the stressed skin by taking some of the bending stress from the fuselage.



Bulkhead

Stringers

Stringer is a stiffening member which supports a section of the load carrying skin, to prevent buckling under compression or shear loads. Stringers keep the skin from bending. Longitudinal members are sometimes referred to as longitudinal, stringers, or stiffeners.

Role of Stringers in Aircraft Wings

In aircraft construction, a stringer is a thin strip of material to which the skin of the aircraft is fastened. In the fuselage, stringers are attached to formers (also called frames) and run in the longitudinal direction of the aircraft. They are primarily responsible for transferring the aerodynamic loads acting on the skin onto the frames and formers. In the wings or horizontal stabilizer, longerons run span wise and attach between the ribs. The primary function here also is to transfer the bending loads acting on the wings onto the ribs and spar.

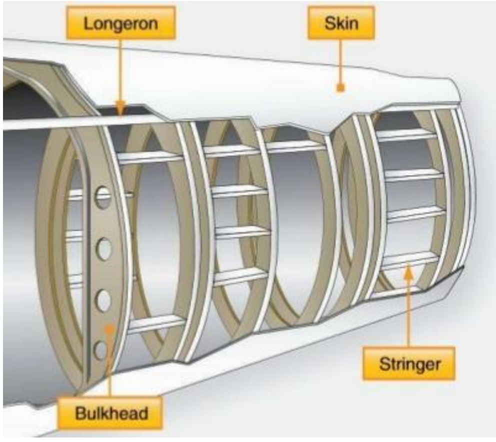
Different Shapes of Stringers

The stringers on an aluminum airplane are normally extruded or bent into shape, and can have a number of different cross sections.

Typically Shapes for stringers are

i. HAT Stringer
ii. I-Stringer
iii. J-Stringer
iv. Y-Stringer
v. Z Stringer.

On wooden airplanes, they are usually spruce square or rectangular cross sections.

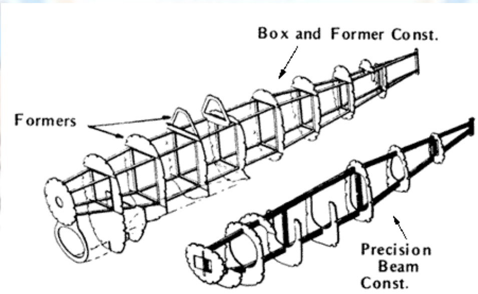


Stringers

Formers

A former is a structural member of an aircraft fuselage, of which a typical fuselage has a series from the nose to the empennage, typically perpendicular to the longitudinal axis of the aircraft. The primary purpose of formers is to establish the shape of the fuselage and reduce the column length of stringers to prevent instability. Formers are typically attached to longerons, which support the skin of the aircraft.

The Former-and-Longeron technique was adopted from boat construction (also called stations and stringers), and was typical of light aircraft built until the advent of structural skins, such as fibreglass and other composite materials.



Longerons

A longeron is part of the structure of an aircraft, designed to add rigidity and strength to the frame. It also creates a point of attachment for other structural supports, as well as the skin of the aircraft. They provide lengthwise support and the number of longerons present in an aircraft varies, depending on the size and how it is designed. Like other structural members, they need to be checked periodically for signs of damage that might compromise their function.

Materials like wood, carbon fiber, and metal can be used in longeron construction. Older aircraft were made almost entirely with wood, while it is a more rare construction material today because it does not provide as much strength and flexibility as other materials. The materials are carefully tested before being installed to make sure there are no cracks or other flaws that might cause them to fail once in place or while the plane is in use.

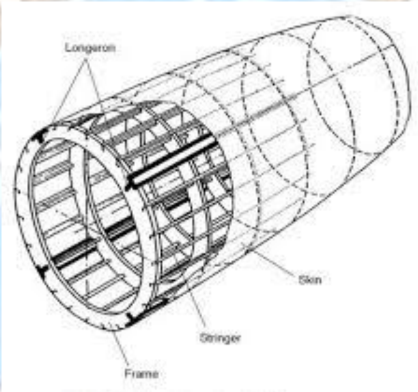
Each longeron attaches directly to the frame of the aircraft using bolts. In some planes, shorter longitudinal supports called stiffeners or stringers are fastened to the longerons. Confusingly, these terms are also sometimes used as alternate names for the longeron. The skin, whether made from metal, leather, canvas, or other materials, can be attached to the aircraft once the longerons are in place. Insulating material and lining may be installed on the other side, depending on how the plane is going to be used.

Longerons functions

They resist bending and axial loads along with the skin.

They divide the skin into small panels and thereby increase its buckling and failure stresses.

They act with the skin in resisting axial loads caused by pressurization.



Longerons

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-II NOTES

FACULTY NAME: D.SUKUMAR **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 7AN6.3 **SEMESTER: VII**

SUBJECT NAME: MAINTENANCE OF AIRFRAME AND SYSTEMS DESIGN

FLIGHT CONTROLS

Airplane controls, ailerons, elevators, rudder, trimming and control tabs, leading and trailing edge flaps, tail plane and fins.

Basics of structure and structural components fabricated from metal, glass fiber, Vinyl, Perspex, composites. Finishing materials, paints, surface finishes and associated materials.

INTRODUCTION

Aircraft flight control systems consist of primary and secondary systems. The ailerons, elevator (or stabiliser), and rudder constitute the primary control system and are required to control an aircraft safely during flight. Wing flaps, leading edge devices, spoilers, and trim systems constitute the secondary control system and improve the performance characteristics of the airplane or relieve the pilot of excessive control forces.

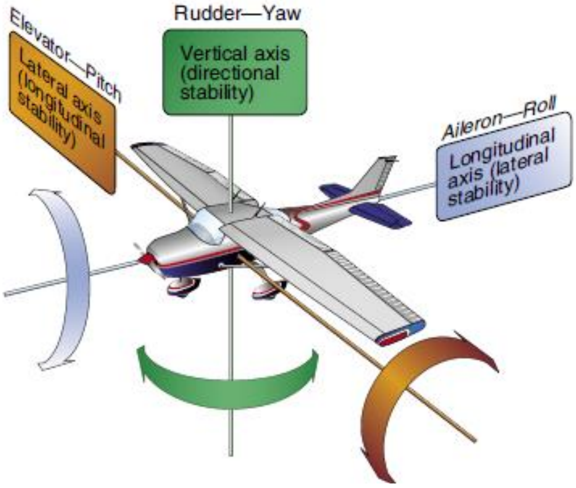
PRIMARY FLIGHT CONTROLS

Aircraft control systems are carefully designed to provide adequate responsiveness to control inputs while allowing a natural feel. At low airspeeds, the controls usually feel soft and sluggish, and the aircraft responds slowly to control applications. At higher airspeeds, the controls become increasingly firm and aircraft response is more rapid.

Movement of any of the three primary flight control surfaces (ailerons, elevator or stabiliser, or rudder), changes the airflow and pressure distribution over and around the airfoil. These changes affect the lift and drag produced by the airfoil/control surface combination, and allows a pilot to control the aircraft about its three axes of rotation.

Design features limit the amount of deflection of flight control surfaces. For example, control-stop mechanisms may be incorporated into the flight control linkages, or movement of the control column and/or rudder pedals may be limited. The purpose of these design limits is to prevent the pilot from inadvertently over controlling and overstressing the aircraft during normal maneuvers.

A properly designed airplane is stable and easily controlled during normal maneuvering. Control surface inputs cause movement about the three axes of rotation. The types of stability an airplane exhibits also relate to the three axes of rotation.

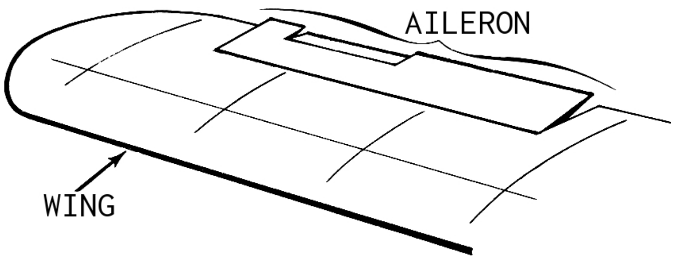


Airplane controls, movement, axes of rotation, and type of stability.

Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Rolling	Longitudinal	Lateral
Elevator	Pitching	Lateral	Longitudinal
Rudder	Yawing	Vertical / Normal	Directional

Ailerons

Ailerons control roll about the longitudinal axis. The ailerons are attached to the outboard trailing edge of each wing and move in the opposite direction from each other. Ailerons are connected by cables, bell cranks, pulleys and/or push-pull tubes to a control wheel or control stick.

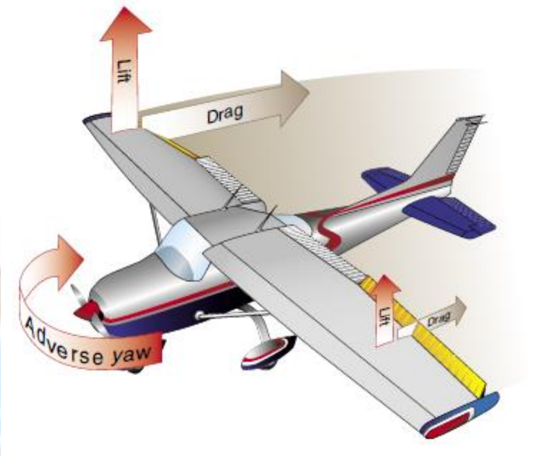


Aileron

Moving the control wheel or control stick to the right causes the right aileron to deflect upward and the left aileron to deflect downward. The upward deflection of the right aileron decreases the camber resulting in decreased lift on the right wing. The corresponding downward deflection of the left aileron increases the camber resulting in increased lift on the left wing. Thus, the increased lift on the left wing and the decreased lift on the right wing cause the airplane to roll to the right.

Adverse Yaw

Since the downward deflected aileron produces more lift as evidenced by the wing raising, it also produces more drag. This added drag causes the wing to slow down slightly. This results in the aircraft yawing toward the wing which had experienced an increase in lift (and drag). From the pilot's perspective, the yaw is opposite the direction of the bank. The adverse yaw is a result of differential drag and the slight difference in the velocity of the left and right wings.



Adverse yaw is caused by higher drag on the outside wing, which is producing more lift

Adverse yaw becomes more pronounced at low airspeeds. At these slower airspeeds aerodynamic pressure on control surfaces are low and larger controls inputs are required to effectively maneuver the airplane. As a result, the increase in aileron deflection causes an increase in adverse yaw. The yaw is especially evident in aircraft with long wing spans.

Application of rudder is used to counteract adverse yaw. The amount of rudder control required is greatest at low airspeeds, high angles of attack, and with large aileron deflections. Like all control surfaces at lower airspeeds, the vertical stabilizer/rudder becomes less effective, and magnifies the control problems associated with adverse yaw.

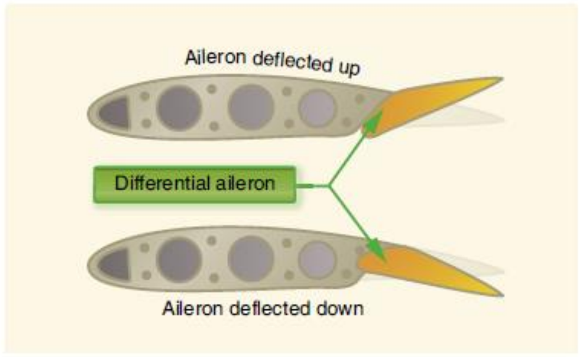
All turns are coordinated by use of ailerons, rudder, and elevator. Applying aileron pressure is necessary to place the aircraft in the desired angle of bank, while simultaneous application of rudder pressure is necessary to counteract the resultant adverse yaw. Additionally, because more lift is required during a turn than when in straight-and-level flight, the angle of attack (AOA) must be increased by applying elevator back pressure. The steeper the turn, the more elevator back pressure is needed.

As the desired angle of bank is established, aileron and rudder pressures should be relaxed. This stops the angle of bank from increasing, because the aileron and rudder control surfaces are in a neutral and streamlined position. Elevator back pressure should be held constant to maintain altitude. The roll-out from a turn is similar to the roll-in, except the flight controls are applied in the opposite direction. Aileron and rudder are applied in the direction of the roll-out or toward the high wing. As the angle of bank decreases, the elevator back pressure should be relaxed as necessary to maintain altitude.

In an attempt to reduce the effects of adverse yaw, manufacturers have engineered four systems: differential ailerons, frise-type ailerons, coupled ailerons and rudder, and flaperons.

Differential Ailerons

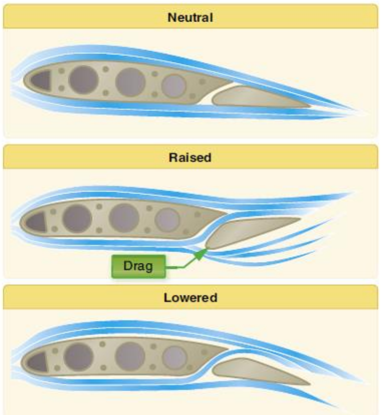
With differential ailerons, one aileron is raised a greater distance than the other aileron is lowered for a given movement of the control wheel or control stick. This produces an increase in drag on the descending wing. The greater drag results from deflecting the up aileron on the descending wing to a greater angle than the down aileron on the rising wing. While adverse yaw is reduced, it is not eliminated completely.



Differential ailerons.

Frise-Type Ailerons

With a frise-type aileron, when pressure is applied to the control wheel or control stick, the aileron that is being raised pivots on an offset hinge. This projects the leading edge of the aileron into the airflow and creates drag. It helps equalize the drag created by the lowered aileron on the opposite wing and reduces adverse yaw.

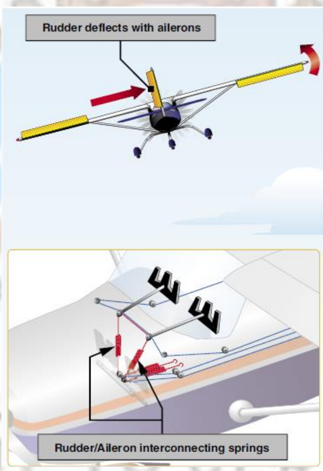


Frise-type ailerons.

The frise-type aileron also forms a slot so air flows smoothly over the lowered aileron, making it more effective at high angles of attack. Frise-type ailerons may also be designed to function differentially. Like the differential aileron, the frise-type aileron does not eliminate adverse yaw entirely. Coordinated rudder application is still needed wherever ailerons are applied.

Coupled Ailerons and Rudder

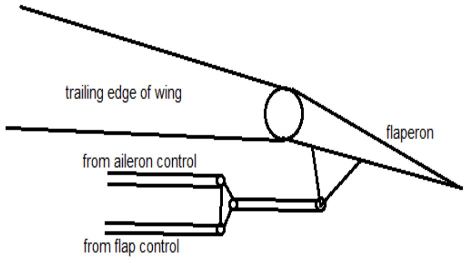
Coupled ailerons and rudder are linked controls. This is accomplished with rudder-aileron interconnect springs, which help correct for aileron drag by automatically deflecting the rudder at the same time the ailerons are deflected. For example, when the control wheel or control stick is moved to produce a left roll, the interconnect cable and spring pulls forward on the left rudder pedal just enough to prevent the nose of the aircraft from yawing to the right. The force applied to the rudder by the springs can be overridden if it becomes necessary to slip the aircraft.



Coupled ailerons and rudder.

Flaperons

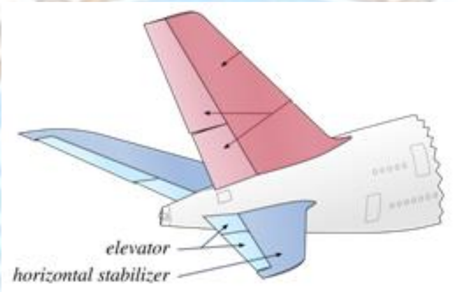
Flaperons combine both aspects of flaps and ailerons. In addition to controlling the bank angle of an aircraft like conventional ailerons, flaperons can be lowered together to function much the same as a dedicated set of flaps. The pilot retains separate controls for ailerons and flaps. A mixer is used to combine the separate pilot inputs into this single set of control surfaces called flaperons. Many designs that incorporate flaperons mount the control surfaces away from the wing to provide undisturbed airflow at high angles of attack and/or low airspeeds.



Flaperons

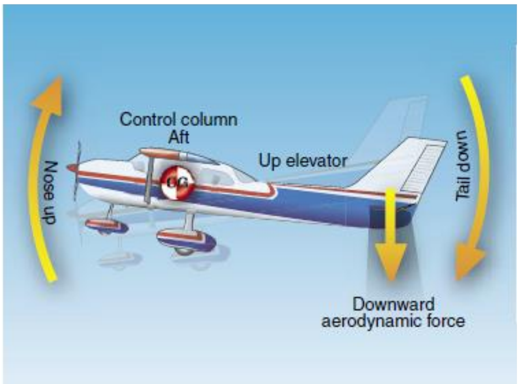
Elevator

The elevator controls pitch about the lateral axis. Like the ailerons on small aircraft, the elevator is connected to the control column in the flight deck by a series of mechanical linkages. Aft movement of the control column deflects the trailing edge of the elevator surface up. This is usually referred to as up "elevator."



Elevator

The up-elevator position decreases the camber of the elevator and creates a downward aerodynamic force, which is greater than the normal tail-down force that exists in straight-and-level flight. The overall effect causes the tail of the aircraft to move down and the nose to pitch up. The pitching moment occurs about the centre of gravity (CG). The strength of the pitching moment is determined by the distance between the CG and the horizontal tail surface, as well as by the aerodynamic effectiveness of the horizontal tail surface. Moving the control column forward has the opposite effect. In this case, elevator camber increases, creating more lift (less tail-down force) on the horizontal stabilizer/elevator. This moves the tail upward and pitches the nose down. Again, the pitching moment occurs about the CG.



As mentioned earlier in the coverage on stability, power, thrust line, and the position of the horizontal tail surfaces on the empennage are factors in elevator effectiveness controlling pitch. For example, the horizontal tail surfaces may be attached near the lower part of the vertical stabilizer, at the midpoint, or at the high point, as in the T-tail design

T-Tail

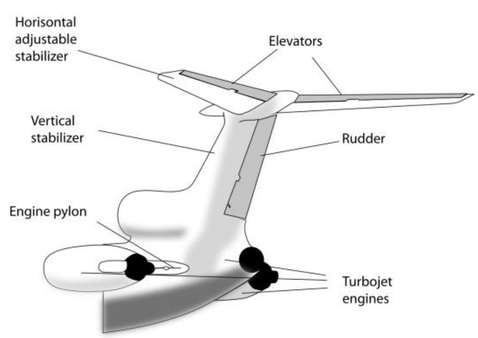
In a T-tail configuration, the elevator is above most of the effects of downwash from the propeller as well as airflow around the fuselage and/or wings during normal flight conditions. Operation of the elevators in this undisturbed air allows control movements that are consistent throughout most flight regimes. T-tail designs have become popular on many light and large aircraft, especially those with aft fuselage-mounted engines because the T-tail configuration removes the tail from the exhaust blast of the engines. Seaplanes and amphibians often have T-tails in order to keep the horizontal surfaces as far from the water as possible. An additional benefit is reduced vibration and noise inside the aircraft.

At slow speeds, the elevator on a T-tail aircraft must be moved through a larger number of degrees of travel to raise the nose a given amount than on a conventional-tail aircraft. This is because the conventional-tail aircraft has the downwash from the propeller pushing down on the tail to assist in raising the nose.

Since controls on aircraft are rigged so that increasing control forces are required for increased control travel, the forces required to raise the nose of a T-tail aircraft are greater than those for a conventional-tail aircraft. Longitudinal stability of a trimmed aircraft is the same for both types of configuration, but the pilot must be aware that the required control forces are greater at slow speeds during takeoffs, landings, or stalls than for similar size aircraft equipped with conventional tails.

T-tail airplanes also require additional design considerations to counter the problem of flutter. Since the weight of the horizontal surfaces is at the top of the vertical stabilizer, the moment arm created causes high loads on the vertical stabilizer which can result in flutter. Engineers must compensate for this by increasing the design stiffness of the vertical stabilizer, usually resulting in a weight penalty over conventional tail designs.

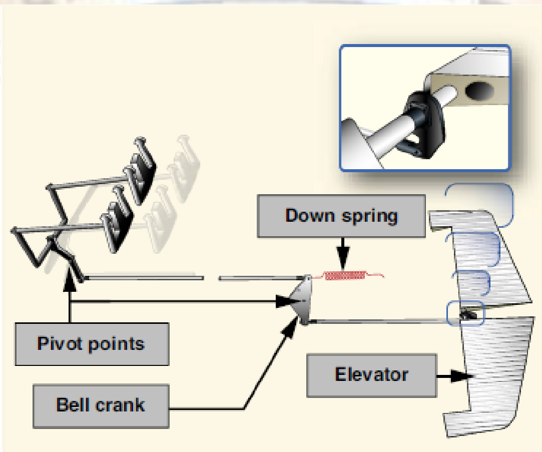
When flying at a very high AOA with a low airspeed and an aft CG, the T-tail aircraft may be susceptible to a deep stall. In a deep stall, the airflow over the horizontal tail is blanketed by the disturbed airflow from the wings and fuselage. In these circumstances, elevator or stabiliser control could be diminished, making it difficult to recover from the stall. It should be noted that an aft CG is often a contributing factor in these incidents, since similar recovery problems are also found with conventional tail aircraft with an aft CG.



Airplane with a T-tail design at a high angle of attack and an aft CG

Since flight at a high AOA with a low airspeed and an aft CG position can be dangerous, many aircraft have systems to compensate for this situation. The systems range from control stops to elevator down springs. An elevator down spring assists in lowering the nose of the aircraft to prevent a stall caused by the aft CG position. The stall occurs because the properly trimmed airplane is flying with the elevator in a trailing edge down position, forcing the tail up and the nose down. In this unstable condition, if the aircraft encounters turbulence and slows down further, the trim tab no longer positions the elevator in the nose-down position. The elevator then streamlines, and the nose of the aircraft pitches upward, possibly resulting in a stall.

The elevator down spring produces a mechanical load on the elevator, causing it to move toward the nose-down position if not otherwise balanced. The elevator trim tab balances the elevator down spring to position the elevator in a trimmed position. When the trim tab becomes ineffective, the down spring drives the elevator to a nose-down position. The nose of the aircraft lowers, speed builds up, and a stall is prevented.



When the aerodynamic efficiency of the horizontal tail surface is inadequate due to an aft CG condition, an elevator down spring may be used to supply a mechanical load to lower the.

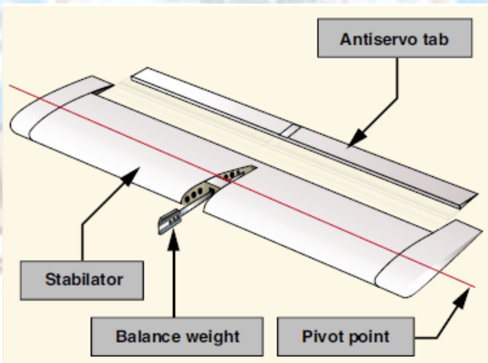
The elevator must also have sufficient authority to hold the nose of the aircraft up during the round out for a landing. In this case, a forward CG may cause a problem. During the landing flare, power is usually reduced, which decreases the airflow over the empennage. This, coupled with the reduced landing speed, makes the elevator less effective.

As this discussion demonstrates, pilots must understand and follow proper loading procedures, particularly with regard to the CG position. More information on aircraft loading, as well as weight and balance, is included in Chapter 9, Weight and Balance.

Stabiliser

A stabiliser is essentially a one-piece horizontal stabilizer that pivots from a central hinge point. When the control column is pulled back, it raises the stabiliser's trailing edge, pulling the airplane's nose up. Pushing the control column forward lowers the trailing edge of the stabiliser and pitches the nose of the airplane down.

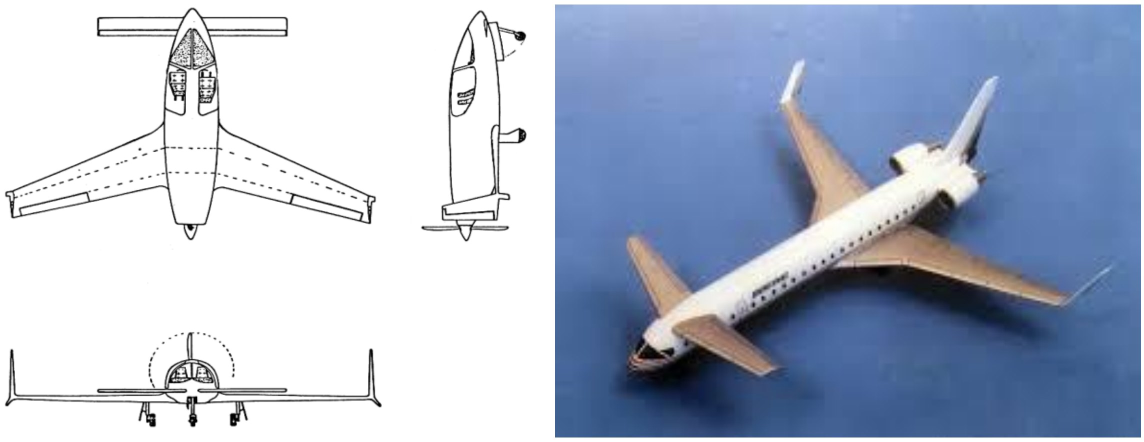
Because stabilisers pivot around a central hinge point, they are extremely sensitive to control inputs and aerodynamic loads. Anti-servo tabs are incorporated on the trailing edge to decrease sensitivity. They deflect in the same direction as the stabiliser. These results in an increase in the force required to move the stabiliser, thus making it less prone to pilot-induced over controlling. In addition, a balance weight is usually incorporated in front of the main spar. The balance weight may project into the empennage or may be incorporated on the forward portion of the stabiliser tips.



The stabiliser is a one-piece horizontal tail surface that pivots up and down about a central hinge point.

Canard

The canard design utilizes the concept of two lifting surfaces, the canard functioning as a horizontal stabilizer located in front of the main wings. In effect, the canard is an airfoil similar to the horizontal surface on a conventional aft-tail design. The difference is that the canard actually creates lift and holds the nose up, as opposed to the aft-tail design which exerts downward force on the tail to prevent the nose from rotating downward.

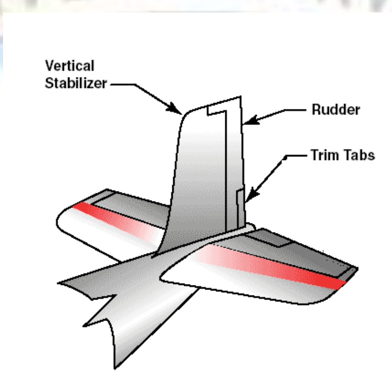


Canard

The canard design dates back to the pioneer days of aviation, most notably used on the Wright Flyer. Recently, the canard configuration has regained popularity and is appearing on newer aircraft. Canard designs include two types–one with a horizontal surface of about the same size as a normal aft-tail design, and the other with a surface of the same approximate size and airfoil of the aft-mounted wing known as a tandem wing configuration. Theoretically, the canard is considered more efficient because using the horizontal surface to help lift the weight of the aircraft should result in less drag for a given amount of lift.

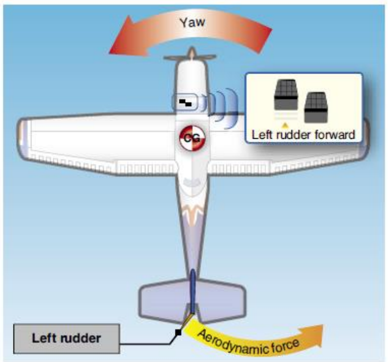
Rudder

The rudder controls movement of the aircraft about its vertical axis. This motion is called yaw. Like the other primary control surfaces, the rudder is a movable surface hinged to a fixed surface, in this case to the vertical stabilizer, or fin. Moving the left or right rudder pedal controls the rudder.



Rudder

When the rudder is deflected into the airflow, a horizontal force is exerted in the opposite direction.

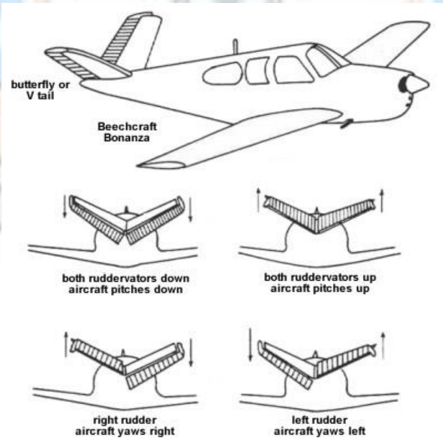


The effect of left rudder pressure.

By pushing the left pedal, the rudder moves left. This alters the airflow around the vertical stabilizer/rudder, and creates a sideward lift that moves the tail to the right and yaws the nose of the airplane to the left. Rudder effectiveness increases with speed; therefore, large deflections at low speeds and small deflections at high speeds may be required to provide the desired reaction. In propeller-driven aircraft, any slipstream flowing over the rudder increases its effectiveness.

V-Tail

The V-tail design utilizes two slanted tail surfaces to perform the same functions as the surfaces of a conventional elevator and rudder configuration. The fixed surfaces act as both horizontal and vertical stabilizers.



V-Tail

The movable surfaces, which are usually called ruddervators, are connected through a special linkage that allows the control wheel to move both surfaces simultaneously. On the other hand, displacement of the rudder pedals moves the surfaces differentially, thereby providing directional control.

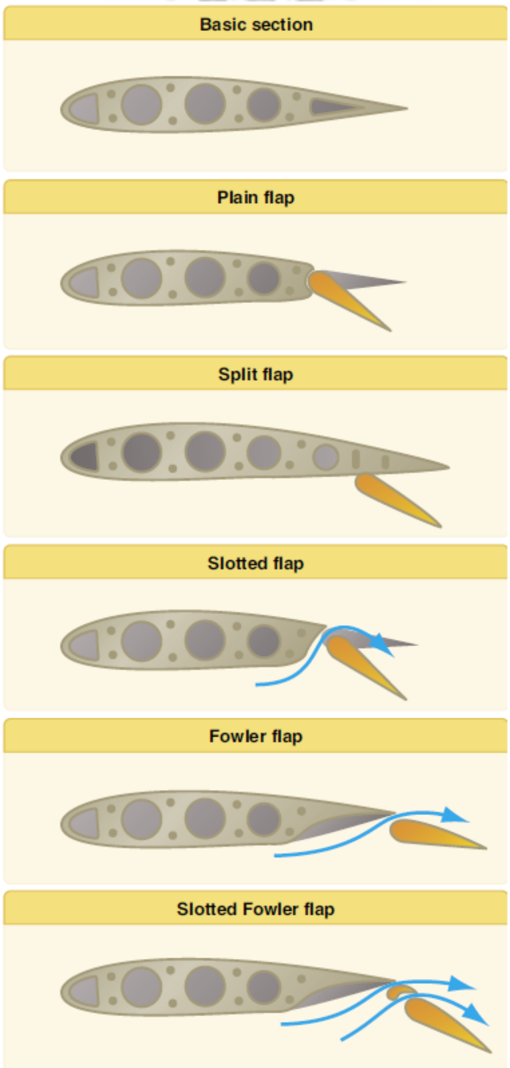
When both rudder and elevator controls are moved by the pilot, a control mixing mechanism moves each surface the appropriate amount. The control system for the V-tail is more complex than that required for a conventional tail. In addition, the V-tail design is more susceptible to Dutch roll tendencies than a conventional tail, and total reduction in drag is minimal.

SECONDARY FLIGHT CONTROLS

Secondary flight control systems may consist of wing flaps, leading edge devices, spoilers, and trim systems.

Flaps

Flaps are the most common high-lift devices used on aircraft. These surfaces, which are attached to the trailing edge of the wing, increase both lift and induced drag for any given AOA. Flaps allow a compromise between high cruising speed and low landing speed, because they may be extended when needed, and retracted into the wing's structure when not needed. There are four common types of flaps: plain, split, slotted, and Fowler flaps.



Five common types of flaps.

The plain flap is the simplest of the four types. It increases the airfoil camber, resulting in a significant increase in the coefficient of lift (CL) at a given AOA. At the same time, it greatly increases drag and moves the centre of pressure (CP) aft on the airfoil, resulting in a nose-down pitching moment.

The split flap is deflected from the lower surface of the airfoil and produces a slightly greater increase in lift than the plain flap. More drag is created because of the turbulent air pattern produced behind the airfoil. When fully extended, both plain and split flaps produce high drag with little additional lift.

The most popular flap on aircraft today is the slotted flap. Variations of this design are used for small aircraft, as well as for large ones. Slotted flaps increase the lift coefficient significantly more than plain or split flaps. On small aircraft, the hinge is located below the lower surface of the flap, and when the flap is lowered, a duct forms between the flap well in the wing and the leading edge of the flap. When the slotted flap is lowered, high energy air from the lower surface is ducted to the flap's upper surface. The high energy air from the slot accelerates the upper surface boundary layer and delays airflow separation, providing a higher CL. Thus, the slotted flap produces much greater increases in maximum coefficient of lift (CL-MAX) than the plain or split flap. While there are many types of slotted flaps, large aircraft often have double- and even triple-slotted flaps. These allow the maximum increase in drag without the airflow over the flaps separating and destroying the lift they produce.

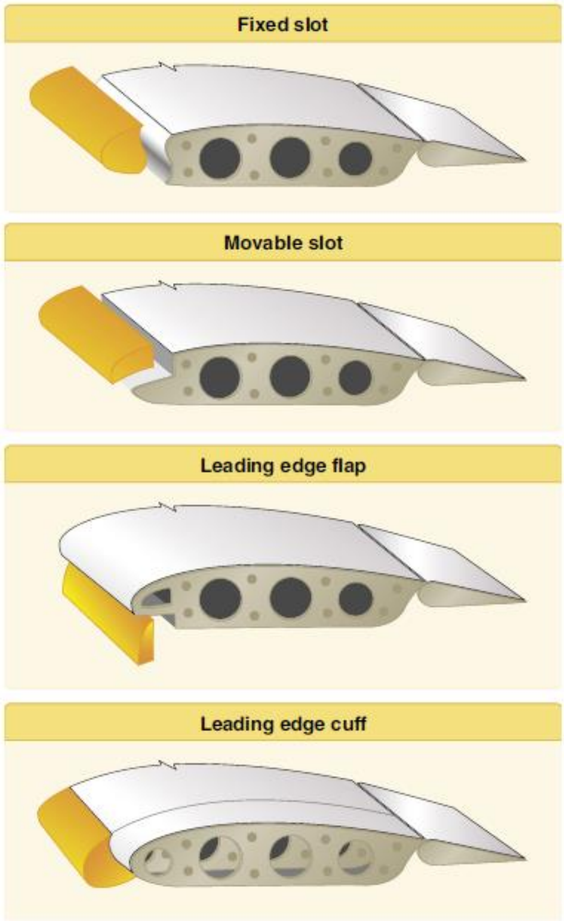
Fowler flaps are a type of slotted flap. This flap design not only changes the camber of the wing, it also increases the wing area. Instead of rotating down on a hinge, it slides backwards on tracks. In the first portion of its extension, it increases the drag very little, but increases the lift a great deal as it increases both the area and camber. As the extension continues, the flap deflects downward. During the last portion of its travel, the flap increases the drag with little additional increase in lift.

Leading Edge Devices

High-lift devices also can be applied to the leading edge of the airfoil. The most common types are fixed slots, movable slats, leading edge flaps, and cuffs. Fixed slots direct airflow to the upper wing surface and delay airflow separation at higher angles of attack. The slot does not increase the wing camber, but allows a higher maximum CL because the stall is delayed until the wing reaches a greater AOA.

Movable slats consist of leading edge segments, which move on tracks. At low angles of attack, each slat is held flush against the wing's leading edge by the high pressure that forms at the wing's leading edge. As the AOA increases, the high-pressure area moves aft below the lower surface of the wing, allowing the slats to move forward. Some slats, however, are pilot operated and can be deployed at any AOA. Opening a slat allows the air below the wing to flow over the wing's upper surface, delaying airflow separation.

Leading edge flaps, like trailing edge flaps, are used to increase both CL-MAX and the camber of the wings. This type of leading edge device is frequently used in conjunction with trailing edge flaps and can reduce the nose-down pitching movement produced by the latter. As is true with trailing edge flaps, a small increment of leading edge flaps increases lift to a much greater extent than drag. As greater amounts of flaps are extended, drag increases at a greater rate than lift.

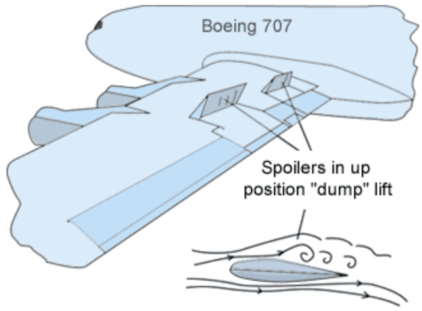


Leading edge high lift devices.

Leading edge cuffs, like leading edge flaps and trailing edge flaps are used to increase both CL-MAX and the camber of the wings. Unlike leading edge flaps and trailing edge flaps, leading edge cuffs are fixed aerodynamic devices. In most cases leading edge cuffs extend the leading edge down and forward. This causes the airflow to attach better to the upper surface of the wing at higher angles of attack, thus lowering an aircraft's stall speed. The fixed nature of leading edge cuffs extracts a penalty in maximum cruise airspeed, but recent advances in design and technology have reduced this penalty.

Spoilers

Found on many gliders and some aircraft, high drag devices called spoilers are deployed from the wings to spoil the smooth airflow, reducing lift and increasing drag. On gliders, spoilers are most often used to control rate of descent for accurate landings. On other aircraft, spoilers are often used for roll control, an advantage of which is the elimination of adverse yaw. To turn right, for example, the spoiler on the right wing is raised, destroying some of the lift and creating more drag on the right. The right wing drops, and the aircraft banks and yaws to the right. Deploying spoilers on both wings at the same time allows the aircraft to descend without gaining speed. Spoilers are also deployed to help reduce ground roll after landing. By destroying lift, they transfer weight to the wheels, improving braking effectiveness.



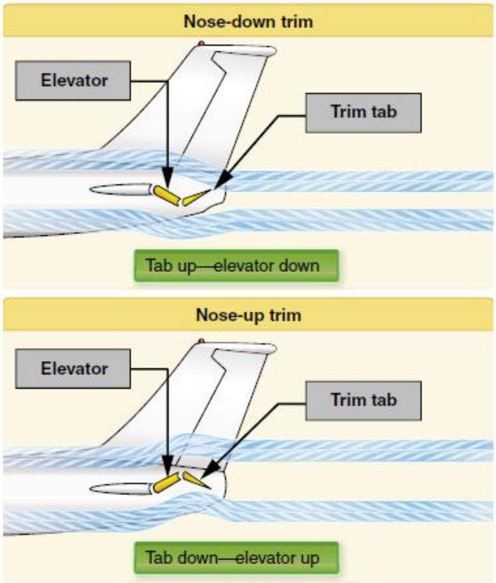
Trim Systems

Although an aircraft can be operated throughout a wide range of attitudes, airspeeds, and power settings, it can be designed to fly hands-off within only a very limited combination of these variables. Trim systems are used to relieve the pilot of the need to maintain constant pressure on the flight controls, and usually consist of flight deck controls and small hinged devices attached to the trailing edge of one or more of the primary flight control surfaces. Designed to help minimize a pilot's workload, trim systems aerodynamically assist movement and position of the flight control surface to which they are attached. Common types of trim systems include trim tabs, balance tabs, anti-servo tabs, ground adjustable tabs, and an adjustable stabilizer.

Trim Tabs

The most common installation on small aircraft is a single trim tab attached to the trailing edge of the elevator. Most trim tabs are manually operated by a small, vertically mounted control wheel. However, a trim crank may be found in some aircraft. The flight deck control includes a trim tab position indicator. Placing the trim control in the full nose-down position moves the trim tab to its full up position. With the trim tab up and into the airstream, the airflow over the horizontal tail surface tends to force the trailing edge of the elevator down. This causes the tail of the airplane to move up, and the nose to move down.

If the trim tab is set to the full nose-up position, the tab moves to its full down position. In this case, the air flowing under the horizontal tail surface hits the tab and forces the trailing edge of the elevator up, reducing the elevator's AOA. This causes the tail of the airplane to move down, and the nose to move up.



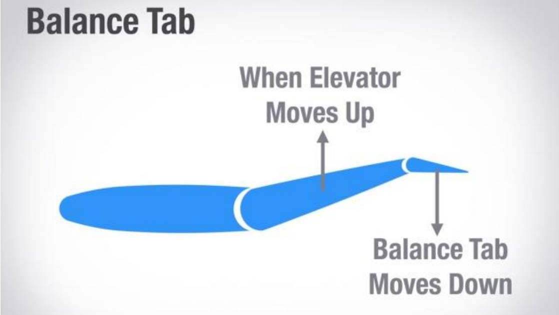
Trim Tabs

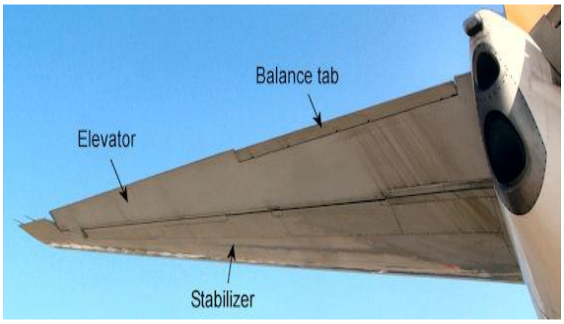
In spite of the opposing directional movement of the trim tab and the elevator, control of trim is natural to a pilot. If the pilot needs to exert constant back pressure on a control column, the need for nose-up trim is indicated. The normal trim procedure is to continue trimming until the aircraft is balanced and the nose-heavy condition is no longer apparent. Pilots normally establish the desired power, pitch attitude and configuration first, and then trim the aircraft to relieve control pressures that may exist for that flight condition. Any time power, pitch attitude, or configuration is changed; expect that retrimming will be necessary to relieve the control pressures for the new flight condition.

Balance Tabs

The control forces may be excessively high in some aircraft, and, in order to decrease them, the manufacturer may use balance tabs. They look like trim tabs and are hinged in approximately the same places as trim tabs. The essential difference between the two is that the balancing tab is coupled to the control surface rod so that when the primary control surface is moved in any direction, the tab automatically moves in the opposite direction. The airflow striking the tab counterbalances some of the air pressure against the primary control surface, and enables the pilot to move more easily and hold the control surface in position.

If the linkage between the balance tab and the fixed surface is adjustable from the flight deck, the tab acts as a combination trim and balance tab that can be adjusted to any desired deflection.

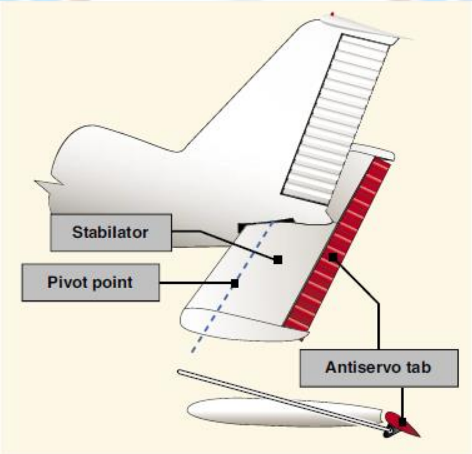




Balance Tabs

Anti-servo Tabs

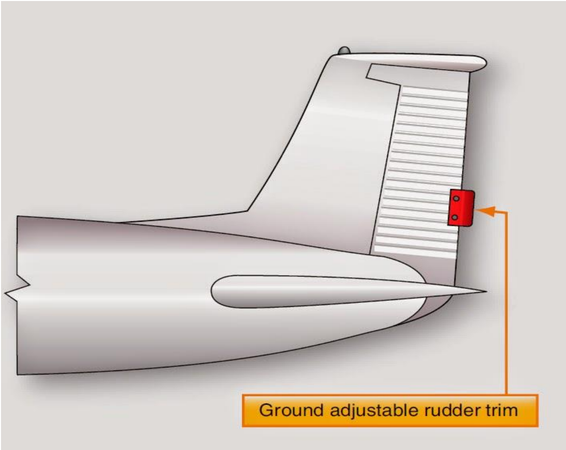
Anti-servo tabs work in the same manner as balance tabs except, instead of moving in the opposite direction, they move in the same direction as the trailing edge of the stabiliser. In addition to decreasing the sensitivity of the stabiliser, an anti-servo tab also functions as a trim device to relieve control pressure and maintain the stabiliser in the desired position. The fixed end of the linkage is on the opposite side of the surface from the horn on the tab; when the trailing edge of the stabiliser moves up, the linkage forces the trailing edge of the tab up. When the stabiliser moves down, the tab also moves down. Conversely, trim tabs on elevators move opposite of the control surface.



An anti-servo tab attempts to streamline the control surface and is used to make the stabiliser less sensitive by opposing

Ground Adjustable Tabs

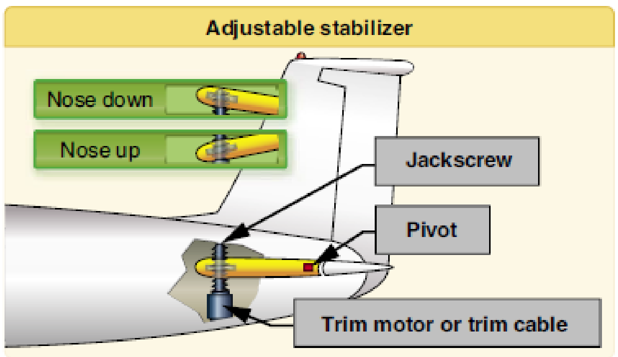
Many small aircraft have a non movable metal trim tab on the rudder. This tab is bent in one direction or the other while on the ground to apply a trim force to the rudder. The correct displacement is determined by trial and error. Usually, small adjustments are necessary until the aircraft no longer skids left or right during normal cruising flight.



Ground Adjustable Tabs

Adjustable Stabilizer

Rather than using a movable tab on the trailing edge of the elevator, some aircraft have an adjustable stabilizer. With this arrangement, linkages pivot the horizontal stabilizer about its rear spar. This is accomplished by use of a jackscrew mounted on the leading edge of the stabiliser.



Some airplanes, including most jet transports, use an adjustable stabilizer to provide the required pitch trim forces.

On small aircraft, the jackscrew is cable operated with a trim wheel or crank. On larger aircraft, it is motor driven. The trimming effect and flight deck indications for an adjustable stabilizer are similar to those of a trim tab.

Secondary/Auxiliary Flight Control Surfaces		
Name	**Location**	**Function**
Flaps	Inboard trailing edge of wings	Extends the camber of the wing for greater lift and slower flight. Allows control at low speeds for short field takeoffs and landings.
Trim tabs	Trailing edge of primary flight control surfaces	Reduces the force needed to move a primary control surface.
Balance tabs	Trailing edge of primary flight control surfaces	Reduces the force needed to move a primary control surface.
Anti-balance tabs	Trailing edge of primary flight control surfaces	Increases feel and effectiveness of primary control surface.
Servo tabs	Trailing edge of primary flight control surfaces	Assists or provides the force for moving a primary flight control.
Spoilers	Upper and/or trailing edge of wing	Decreases (spoils) lift. Can augment aileron function.
Slats	Mid to outboard leading edge of wing	Extends the camber of the wing for greater lift and slower flight. Allows control at low speeds for short field takeoffs and landings.
Slots	Outer leading edge of wing forward of ailerons	Directs air over upper surface of wing during high angle of attack. Lowers stall speed and provides control during slow flight.
Leading edge flap	Inboard leading edge of wing	Extends the camber of the wing for greater lift and slower flight. Allows control at low speeds for short field takeoffs and landings.

Summary of function of control surface

Flight Control Tabs			
Type	**Direction of Motion** (in relation to control surface)	**Activation**	**Effect**
Trim	Opposite	Set by pilot from cockpit. Uses independent linkage.	Statically balances the aircraft in flight. Allows "hands off" maintenance of flight condition.
Balance	Opposite	Moves when pilot moves control surface. Coupled to control surface linkage.	Aids pilot in overcoming the force needed to move the control surface.
Servo	Opposite	Directly linked to flight control input device. Can be primary or back-up means of control.	Aerodynamically positions control surfaces that require too much force to move manually.
Anti-balance or Anti-servo	Same	Directly linked to flight control input device.	Increases force needed by pilot to change flight control position. De-sensitizes flight controls.
Spring	Opposite	Located in line of direct linkage to servo tab. Spring assists when control forces become too high in high-speed flight.	Enables moving control surface when forces are high. Inactive during slow flight.

Various tabs and their uses.

AIRCRAFT MATERIALS

Wood used in the aircraft

Wood was among the first materials used to construct aircraft. Most of the airplanes built during World War I (WWI) were constructed of wood frames with fabric coverings. Wood was the material of choice for aircraft construction into the 1930s. Part of the reason was the slow development of strong, lightweight, metal aircraft structures and the lack of suitable corrosion-resistant materials for all-metal aircraft.

Of all the requirements of wood in aircraft, the procurement of suitable, clear, straight-grained lumber presents the, most important problem, and the suitability of species will be discussed primarily from this standpoint. Further, the question of-suitability can be approached by means of .a comparison of other species, with the woods now employed, which through long use may be considered more or less standard. Following is the list of these woods, together with their principal uses,

White Ash

Longerons, propellers, landing gear Struts, float ribs, reinforcing for structural members, bent work on wings and fuselage's, chines, tail skids, cabane struts, bearing blocks, wing leading edges, float bulkheads, false keels, control handles and fuselage struts .

Balsa wood

Plywood core stock, especially where insulation is desired, as in cabins, filling, streamlining, and fairing strips.

Bass wood

Wing ribs, veneer for plywood, templates and webs.

Yellow Birch

Propellers and veneer for plywood

Mahogany

Deck, bottom and bulkhead planking of hulls and floats, veneer for plywood, such as that used for wing covering, wing tips and wing ribs, propellers control wheels and handles, pattern work interior finish and instrument boards

Sugar maple

Propeller, veneer for plywood, jigs and models, assembly forms, shearing blocks and bearing blocks

Oak

Propellers

White pine

Webs, cap strips, corner blocks, fairing strips, patterns and forms

Yellow poplar

Veneer for ply wood

Red sitka and white spruce

Main structural parts such as wing beams, struts and longerons, float and hull construction, ribs, webs, landing gears, cap strips, stiffeners, flooring, planking and veneer for plywood.

Black walnut

Propellers, cabin furnishing, and instrument panels

PLASTICS

Plastics are used in many applications throughout modern aircraft. These applications range from structural components of thermosetting plastics reinforced with fibreglass to decorative trim of thermoplastic materials to windows.

Transparent Plastics

Transparent plastic materials used in aircraft canopies; windshields, windows and other similar transparent enclosures may be divided into two major classes or groups. These plastics are classified according to their reaction to heat. The two classes are: thermoplastic and thermosetting.

Thermoplastic materials will soften when heated and harden when cooled. These materials can be heated until soft, and then formed into the desired shape. When cooled, they will retain this shape. The same piece of plastic can be reheated and reshaped any number of times without changing the chemical composition of the materials.

Thermosetting plastics harden upon heating, and reheating has no softening effect. These plastics cannot be reshaped once being fully cured by the application of heat.

In addition to the above classes, transparent plastics are manufactured in two forms: monolithic (solid) and laminated. Laminated transparent plastics are made from transparent plastic face sheets bonded by an inner layer material, usually polyvinyl butyryl.
Because of its shatter resistant qualities, laminated plastic is superior to solid plastics and is used in many pressurized aircraft.
Most of the transparent sheet used in aviation is manufactured in accordance with various military specifications. A new development in transparent plastics is stretched acrylic. Stretched acrylic is a type of plastic which, before being shaped, is pulled in both directions to rearrange its molecular structure. Stretched acrylic panels have a greater resistance to impact and are less subject to shatter; its chemical resistance is greater, edging is simpler and crazing and scratches are less detrimental.
Individual sheets of plastic are covered with a heavy masking paper to which a pressure sensitive adhesive has been added. This paper helps to prevent accidental scratching during storage and handling. Be careful to avoid scratches and gouges which may be caused by sliding sheets against one another or across rough or dirty tables. If possible, store sheets in bins which are tilted at approximately 10° from vertical. If they must be stored horizontally, piles should not be over 18 inches high, and small sheets should be stacked on the larger ones to avoid unsupported overhang. Store in a cool, dry place away from solvent fumes, heating coils, radiators, and steam pipes. The temperature in the storage room should not exceed 120 °F. While direct sunlight does not harm acrylic plastic, it will cause drying and hardening of the masking adhesive, making removal of the paper difficult. If the paper will not roll off easily, place the sheet in an oven at 250 °F for 1 minute, maximum. The heat will soften the masking adhesive for easy removal of the paper.
If an oven is not available, remove hardened masking paper by softening the adhesive with aliphatic naphtha. Rub the masking paper with a cloth saturated with naphtha. This will soften the adhesive and free the paper from the plastic. Sheets so treated must be washed immediately with clean water, taking care not to scratch the surfaces.

COMPOSITE MATERIALS

In the 1940s, the aircraft industry began to develop synthetic fibers to enhance aircraft design. Since that time, composite materials have been used more and more. When composites are mentioned, most people think of only fiberglass, or maybe graphite or aramids (Kevlar). Composites began in aviation, but now are being embraced by many other industries, including auto racing, sporting goods, and boating, as well as defence industry uses.

A "composite" material is defined as a mixture of different materials or things. This definition is so general that it could refer to metal alloys made from several different metals to enhance the strength, ductility, conductivity or whatever characteristics are desired. Likewise, the composition of composite materials is a combination of reinforcement, such as a fiber, whisker, or particle, surrounded and held in place by a resin, forming a structure. Separately, the reinforcement and the resin are very different from their combined state.
Even in their combined state, they can still be individually identified and mechanically separated. One composite, concrete, is composed of cement (resin) and gravel or reinforcement rods for the reinforcement to create the concrete.
The list of parts of aircraft made of composite may be summarized as below:

- Gliders
- Helicopter blades
- Transmission shafts
- Ailerons, rudders, elevators, flaps, spoilers etc
- Engine cowlings

- Rocket boosters
- Nozzles
- Antenna cover
- Fin and Fuselage portions
- Nose radome, doors, fairings
- Aircraft wing parts (skin, spars and stiffeners)

Advantages/Disadvantages of Composites

Some of the many advantages for using composite materials are:

- High strength to weight ratio
- Fiber-to-fiber transfer of stress allowed by chemical bonding
- Modulus (stiffness to density ratio) 3.5 to 5 times that of steel or aluminum
- Longer life than metals
- Higher corrosion resistance
- Tensile strength 4 to 6 times that of steel or aluminum
- Greater design flexibility
- Bonded construction eliminates joints and fasteners
- Easily repairable

The disadvantages of composites include:

- Inspection methods difficult to conduct, especially delamination detection (Advancements in technology will eventually correct this problem.)
- Lack of long term design database, relatively new technology methods
- Cost
- Very expensive processing equipment
- Lack of standardized system of methodology
- Great variety of materials, processes, and techniques
- General lack of repair knowledge and expertise
- Products often toxic and hazardous
- Lack of standardized methodology for construction and repairs

The increased strength and the ability to design for the performance needs of the product makes composites much superior to the traditional materials used in Today's aircraft. As more and more composites are used, the costs, design, inspection ease, and information about strength to weight advantages will help composites become the material of choice for aircraft construction.

FIBRE REINFORCED MATERIALS

The purpose of reinforcement in reinforced plastics is to provide most of the strength. The three main forms of fibre reinforcements are particles, whiskers, and fibres.
A particle is a square piece of material. Glass bubbles (Q-cell) are hollow glass spheres, and since their dimensions are equal on all axes, they are called a particle. A whisker is a piece of material that is longer than it is wide. Whiskers are usually single crystals. They are very strong and used to reinforce ceramics and metals.

Fibres are single filaments that are much longer than they are wide. Fibres can be made of almost any material, and are not crystalline like whiskers. Fibres are the base for most composites. Fibers are smaller than the finest human hair and are normally woven into cloth-like materials.

Laminated Structures

Composites can be made with or without an inner core of material. Laminated structure with a core center is called a sandwich structure. Laminate construction is strong and stiff, but heavy. The sandwich laminate is equal in strength, and its weight is much less; less weight is very important to aerospace products.
The core of a laminate can be made from nearly anything. The decision is normally based on use, strength, and fabricating methods to be used. Various types of cores for laminated structures include rigid foam, wood, metal, or the aerospace preference of honeycomb made from paper, Nomex, carbon, fiberglass or metal.
It is very important to follow proper techniques to construct or repair laminated structures to ensure the strength is not compromised. A sandwich assembly is made by taking a high-density laminate or solid face and backplate and sandwiching a core in the middle. The selection of materials for the face and backplate are decided by the design engineer, depending on the intended application of the part. It is important to follow manufacturers′ maintenance manual specific instructions regarding testing and repair procedures as they apply to a particular aircraft.

Reinforced Plastic

Reinforced plastic is a thermosetting material used in the manufacture of radomes, antenna covers, and wingtips, and as insulation for various pieces of electrical equipment and fuel cells. It has excellent dielectric characteristics which make it ideal for radomes; however, its high strength-to-weight ratio, resistance to mildew, rust, and rot, and ease of fabrication make it equally suited for other parts of the aircraft. Reinforced plastic components of aircraft are formed of either solid laminates or sandwich-type laminates.

METALS USED IN AIRCRAFT

Material requirements for aircraft building:
1.small weight
2.high specific strength
3.heat resistance
4.fatigue load resistance
5.crack resistance
6.corrosion resistance

Iron

If carbon is added to iron, in percentages ranging up to approximately 1 percent, the product is vastly superior to iron alone and is classified as carbon steel. Carbon steel forms the base of those alloy steels produced by combining carbon steel with other elements known to improve the properties of steel. A base metal (such as iron) to which small quantities of other metals have been added is called an alloy. The addition of other metals changes or improves the chemical or physical properties of the base metal for a particular use.

Steel and Steel Alloys

To facilitate the discussion of steels, some familiarity with their nomenclature is desirable. A numerical index, sponsored by the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), is used to identify the chemical compositions of the structural steels. In this system, a four-numeral series is used to designate the plain carbon and alloy steels; five numerals are used to designate certain types of alloy steels. The first two digits indicate the type of steel, the second digit also generally (but not always) gives the approximate amount of the major alloying element, and the last two (or three) digits are intended to indicate the approximate middle of the carbon range. However, a deviation from the rule of indicating the carbon range is sometimes necessary. Small quantities of certain elements are present in alloy steels that are not specified as required. These elements are considered as incidental and may be present to the maximum amounts as follows: copper, 0.35 percent; nickel, 0.25 percent; chromium, 0.20 percent; molybdenum, 0.06 percent.

Aluminium & Titanium

Aluminium was widely used in subsonic aircraft. Aerotechnics of supersonic speeds faced with elevated temperatures of the aircraft skin for which aluminium cannot be applied due to low heat resistance. Structural materials reliably operating in complicated combination of force and temperature fields under the influence of corrosive media, radiation and high pressures were required. Titanium and its alloys meet this requirement.

Currently a greater amount of titanium is incorporated in to aircraft. This is connected with the fact that the share of the composite materials with which aluminium intensively interacts and corrodes in the new airplanes is being increased. Titanium is not subjected to these processes and results in increasing the life of components.

Aluminium

Aluminium in Aircraft manufacturing

Wide application of aluminium in industry is mainly explained by its large natural resources as well as a set of chemical, physical and mechanical properties.
Aluminium is one of the most widespread metals, regarding its content in the earth's crust (~8 %).
Among one of aluminium's advantages shall be considered its low density (2.7 g/cm3), relatively high strength properties, good thermal and electric conductivity, technological effectiveness, high corrosion resistance. Due to combination of these properties aluminium is considered to be one of the most important engineering materials.
Aluminium alloys are the main structural material in aircraft industry at the present-day stage of subsonic and supersonic aircraft development.
Alloys of 2xxx, 3xxx, 5xxx, 6xxx and 7xxx series are widely used for aircraft industry in the USA. 2xxx series is recommended for work at high operating temperatures and with increased values of fracture toughness ratio. Alloys of 7xxx series are recommended for operation of significantly loaded parts at lower temperatures and for parts with high corrosion resistance under stress. Alloys of 3xxx, 5xxx and 6xxx series are used for low-loaded assemblies.They are also used in hydraulic, oil and fuel systems.

Al-Zn-Mg-Cu high-strength aluminium alloys hardened by heat treatment and Al-Mg-Cu average- and high-strength aluminium alloys are successfully used for aircraft equipment production in Russia. They are structural material for skin and inner set of airframe components (body, wing, keel, etc.).
1420 alloy pertaining to Al-Zn-Mg system is used for airliner welded body design. Usage of aluminium-magnesium corrosion-resistant welded alloys (AMr5, AMr6) and Al-Zn-Mg alloys (1915, B92, 1420) is provided for hydroplane production.
Aluminium welded alloys have undeniable advantage when designing space technology items. High strength-to-weight ratio, stiffness-to-weight ratio of the material provided for manufacture of missile tanks, inter tank and nose parts with high directional stability. Among the advantages of aluminium alloys (2219 and others) is their operation ability under cryogenic temperatures in contact with liquid oxygen, hydrogen and helium. These alloys are capable of the so-called cryogenic hardening, i.e. strength and ductility increase simultaneously with the decrease of temperature.
1460 alloy pertains to Al-Cu-Li system and is most promising for design and manufacture of tank structures with regard to cryogenic type of fuel - compressed oxygen, hydrogen or natural gas.

Titanium

Titanium was discovered by an English priest named Gregot. A crude separation of titanium ore was accomplished in 1825. In 1906 a sufficient amount of pure titanium was isolated in metallic form to permit a study. Following this study, in 1932, an extraction process was developed which became the first commercial method for producing titanium. The United States Bureau of Mines began making titanium sponge in 1946, and 4 years later the melting process began.

The use of titanium is widespread. It is used in many commercial enterprises and is in constant demand for such items as pumps, screens, and other tools and fixtures where corrosion attack is prevalent. In aircraft construction and repair, titanium is used for fuselage skins, engine shrouds, firewalls, longerons, frames, fittings, air ducts, and fasteners.

Titanium is used for making compressor disks, spacer rings, compressor blades and vanes, through bolts, turbine housings and liners, and miscellaneous hardware for turbine engines.
Titanium, in appearance, is similar to stainless steel. One quick method used to identify titanium is the spark test. Titanium gives off a brilliant white trace ending in a brilliant white burst. Also, identification can be accomplished by moistening the titanium and using it to draw a line on a piece of glass. This will leave a dark line similar in appearance to a pencil mark.
Titanium falls between aluminum and stainless steel interms of elasticity, density, and elevated temperature strength. It has a melting point of from 2,730 °F to 3,155 °F, low thermal conductivity, and a low coefficient of expansion. It is light, strong, and resistant to stress corrosion cracking. Titanium is approximately 60 percent heavier than aluminum and about 50 percent lighter than stainless steel. Because of the high melting point of titanium, high temperature properties are disappointing. The ultimate yield strength of titanium drops rapidly above 800 °F. The absorption of oxygen and nitrogen from the air at temperatures above 1,000 °F makes the metal so brittle on long exposure that it soon becomes worthless.

However, titanium does have some merit for short time exposure up to 3,000 °F where strength is not important. Aircraft firewalls demand this requirement.
Titanium is nonmagnetic and has an electrical resistance comparable to that of stainless steel. Some of the base alloys of titanium are quite hard. Heat treating and alloying do not develop the hardness of titanium to the high levels of some of the heat-treated alloys of steel.
It was only recently that a heat-treatable titanium alloy was developed. Prior to the development of this alloy, heating and rolling was the only method of forming that could be accomplished. However, it is possible to form the new alloy in the soft condition and heats treat it for hardness.
Iron, molybdenum, and chromium are used to stabilize titanium and produce alloys that will quench harden and age harden. The addition of these metals also adds ductility. The fatigue resistance of titanium is greater than that of aluminum or steel.
Titanium becomes softer as the degree of purity is increased. It is not practical to distinguish between the various grades of commercially pure or unalloyed titanium by chemical analysis; therefore, the grades are determined by mechanical properties.

Three major trends of titanium application for aircraft building:

1. fabrication of items of complex space configuration:
   - hatch and door edging where moisture is likely to be accumulated (high corrosion resistance of titanium is used)
   - skins which are affected by engine combustion product flow, flame preventing fire safety-proof membranes (high temperature of melting and chemical inactivity of titanium is used)
   - thin-walled lead pipes of air system (minimum thermal titanium extension ratio compared to all other metals is used)
   - floor decking of the cargo cabin (high strength and hardness is used)

2. Fabrication of designated high-loaded assemblies and units
   - Landing gear
   - Fastening elements (brackets) of the wing
   - hydro cylinders
3. Engine part manufacture.

The following is manufactured from titanium alloys for aircraft applications:
Ailerons, panel and swivel wing assemblies, spar walls, panels, brackets, steering wheels, wedge meshes, air intake ducts, lead pipes, frames, leading edge flaps and flaps, hydraulic systems, fasteners and a number of other parts.

The percentage of titanium contained in the air frame:

Boeing -707 v less than 0,5 %, юN-24 v 0,48 %, pU-154 - 2 %,
Boeing-777 v 8.5 %, pU-334 v 8,7 %, юN-148 v up to 10 %, IL-76 and IL-76p - 12 % of the air frame weight.

Copper and Copper Alloys

Copper is one of the most widely distributed metals. It is the only reddish colored metal and is second only to silver in electrical conductivity. Its use as a structural material is limited because of its great weight. However, some of its outstanding characteristics, such as its high electrical and heat conductivity, in many cases overbalance the weight factor.

Because it is very malleable and ductile, copper is ideal for making wire. It is corroded by salt water but is not affected by fresh water. The ultimate tensile strength of copper varies greatly. For cast copper, the tensile strength is about 25,000 psi, and when cold rolled or cold drawn its tensile strength increases to a range of 40,000 to 67,000 psi.

In aircraft, copper is used primarily in the electrical system for bus bars, bonding, and as lockwire. Beryllium copper is one of the most successful of all the copper base alloys. It is a recently developed alloy containing about 97 percent copper, 2 percent beryllium, and sufficient nickel to increase the percentage of elongation. The most valuable feature of this metal is that the physical properties can be greatly stepped up by heat treatment, the tensile strength rising from 70,000 psi in the annealed state to 200,000 psi in the heat-treated state. The resistance of beryllium copper to fatigue and wear makes it suitable for diaphragms, precision bearings and bushings, ball cages, and spring washers.

Brass is a copper alloy containing zinc and small amounts of aluminum, iron, lead, manganese, magnesium, nickel, phosphorous, and tin. Brass with a zinc content of 30 to 35 percent is very ductile, but that containing 45 percent has relatively high strength.

Muntz metal is a brass composed of 60 percent copper and 40 percent zinc. It has excellent corrosion resistant qualities in salt water. Its strength can be increased by heat treatment. As cast, this metal has an ultimate tensile strength of 50,000 psi, and it can be elongated 18 percent. It is used in making bolts and nuts, as well as parts that come in contact with salt water.

Red brass, sometimes termed "bronze" because of its tin content, is used in fuel and oil line fittings. This metal has good casting and finishing properties and machines freely.

Bronzes are copper alloys containing tin. The true bronzes have up to 25 percent tin, but those with less than 11 percent are most useful, especially for such items as tube fittings in aircraft.

Among the copper alloys are the copper aluminium alloys, of which the aluminum bronzes rank very high in aircraft usage. They would find greater usefulness in structures if it were not for their strength to weight ratio as compared with alloy steels. Wrought aluminium bronzes are almost as strong and ductile as medium carbon steel, and they possess a high degree of resistance to corrosion by air, salt water, and chemicals. They are readily forged, hot or cold rolled, and many react to heat treatment. These copper base alloys contain up to 16 percent of aluminum (usually 5 to 11 percent), to which other metals, such as iron, nickel, or manganese, may be added. Aluminum bronzes have good tearing qualities, great strength, hardness, and resistance to both shock and fatigue. Because of these properties, they are used for diaphragms, gears, and pumps. Aluminum bronzes are available in rods, bars, plates, sheets, strips, and forgings.

Cast aluminum bronzes, using about 89 percent copper, 9 percent aluminum, and 2 percent of other elements, have high strength combined with ductility, and are resistant to corrosion, shock, and fatigue. Because of these properties, cast aluminum bronze is used in bearings and pump parts. These alloys are useful in areas exposed to salt water and corrosive gases.

Manganese bronze is an exceptionally high strength, tough, corrosion resistant copper zinc alloy containing aluminum, manganese, iron and, occasionally, nickel or tin. This metal can be formed, extruded, drawn, or rolled to any desired shape. In rod form, it is generally used for machined parts, for aircraft landing gears and brackets.

Silicon bronze is a more recent development composed of about 95 percent copper, 3 percent silicon, and 2 percent manganese, zinc, iron, tin, and aluminum. Although not a bronze in the true sense because of its small tin content, silicon bronze has high strength and great corrosion resistance.

Monel

Monel, the leading high nickel alloy, combines the properties of high strength and excellent corrosion resistance. This metal consists of 68 percent nickel, 29 percent copper, 0.2 percent iron, 1 percent manganese, and 1.8 percent of other elements. It cannot be hardened by heat treatment.

Monel, adaptable to casting and hot or cold working, can be successfully welded. It has working properties similar to those of steel. When forged and annealed, it has a tensile strength of 80,000 psi. This can be increased by cold working to 125,000 psi, sufficient for classification among the tough alloys.

Monel has been successfully used for gears and chains to operate retractable landing gears, and for structural parts subject to corrosion. In aircraft, Monel is used for parts demanding both strength and high resistance to corrosion, such as exhaust manifolds and carburettor needle valves and sleeves.

K-Monel

K-Monel is a nonferrous alloy containing mainly nickel, copper, and aluminum. It is produced by adding a small amount of aluminum to the Monel formula. It is corrosion resistant and capable of being hardened by heat treatment.

K-Monel has been successfully used for gears, and structural members in aircraft which are subjected to corrosive attacks. This alloy is nonmagnetic at all temperatures. K-Monel sheet has been successfully welded by both oxyacetylene and electric arc welding.

Nickel and Nickel Alloys

There is basically two nickel alloys used in aircraft. They are Monel and Inconel. Monel contains about 68 percent nickel and 29 percent copper, plus small amounts of iron and manganese. Nickel alloys can be welded or easily machined. Some of the nickel Monel, especially the nickel Monels containing small amounts of aluminum, are heat-treatable to similar tensile strengths of steel. Nickel Monel is used in gears and parts that require high strength and toughness, such as exhaust systems that require high strength and corrosion resistance at elevated temperatures.

Inconel alloys of nickel produce a high strength, high temperature alloy containing approximately 80 percent nickel, 14 percent chromium, and small amounts of iron and other elements. The nickel Inconel alloys are frequently used in turbine engines because of their ability to maintain their strength and corrosion resistance under extremely high temperature conditions.

Inconel and stainless steel are similar in appearance and are frequently found in the same areas of the engine. Sometimes it is important to identify the difference between the metal samples. A common test is to apply one drop of cupric chloride and hydrochloric acid solution to the unknown metal and allow it to remain for 2 minutes. At the end of the soak period, a shiny spot indicates the material is nickel Inconel, and a copper colored spot indicates stainless steel.

PAINTING

Paint, or more specifically its overall colour and application, is usually the first impression that is transmitted to someone when they look at an aircraft for the first time. Paint makes a

statement about the aircraft and the person who owns or operates it. The paint scheme may reflect the owner′s ideas and colour preferences for an amateur-built aircraft project, or it may be colours and identification for the recognition of a corporate or air carrier aircraft.
Paint is more than aesthetics; it affects the weight of the aircraft and protects the integrity of the airframe. The topcoat finish is applied to protect the exposed surfaces from corrosion and deterioration. Also, a properly painted aircraft is easier to clean and maintain because the exposed surfaces are more resistant to corrosion and dirt, and oil does not adhere as readily to the surface.
A wide variety of materials and finishes are used to protect and provide the desired appearance of the aircraft. The term ″paint″ is used in a general sense and includes primers, enamels, lacquers, and the various multipart finishing formulas. Paint has three components: resin as coating material, pigment for color, and solvents to reduce the mix to a workable viscosity.
Internal structure and unexposed components are finished to protect them from corrosion and deterioration. All exposed surfaces and components are finished to provide protection and to present a pleasing appearance. Decorative finishing includes trim striping, the addition of company logos and emblems, and the application of decals, identification numbers, and letters.

FINISHING MATERIALS

A wide variety of materials are used in aircraft finishing. Some of the more common materials and their uses are described in the following paragraphs.

Acetone

Acetone is a fast-evaporating colorless solvent. It is used as an ingredient in paint, nail polish, and varnish removers. It is a strong solvent for most plastics and is ideal for thinning fiberglass resin, polyester resins, vinyl, and adhesives. It is also used as a superglue remover. Acetone is a heavy-duty degreaser suitable for metal preparation and removing grease from fabric covering prior to doping. It should not be used as a thinner in dope because of its rapid evaporation, which causes the doped area to cool and collect moisture. This absorbed moisture prevents uniform drying and results in blushing of the dope and a flat no-gloss finish.

Alcohol

Butanol, or butyl alcohol, is a slow-drying solvent that can be mixed with aircraft dope to retard drying of the dope film on humid days, thus preventing blushing. A mixture of dope solvent containing 5 to 10 percent of butyl alcohol is usually sufficient for this purpose. Butanol and ethanol alcohol are mixed together in ratios ranging from 1:1 to 1:3 to use to dilute wash coat primer for spray applications because the butyl alcohol retards the evaporation rate.
Ethanol or denatured alcohol is used to thin shellac for spraying and as a constituent of paint and varnish remover. It can also be used as a cleaner and degreaser prior to painting.
Isopropyl, or rubbing alcohol, can be used as a disinfectant. It is used in the formulation of oxygen system cleaning solutions. It can be used to remove grease pencil and permanent marker from smooth surfaces, or to wipe hand or fingerprint oil from a surface before painting.

Benzene

Benzene is a highly flammable, colorless liquid with a sweet odor. It is a product used in some paint and varnish removers. It is an industrial solvent that is regulated by the Environmental Protection Agency (EPA) because it is an extremely toxic chemical compound when inhaled or absorbed through the skin. It has been identified as a Class A carcinogen known to cause various forms of cancer. It should be avoided for use as a common cleaning solvent for paint equipment and spray guns.

Methyl Ethyl Ketone (MEK)

Methyl ethyl ketone (MEK), also referred to as 2-Butanone, is a highly flammable, liquid solvent used in paint and varnish removers, paint and primer thinners, in surface coatings, adhesives, printing inks, as a catalyst for polyester resin hardening, and as an extraction medium for fats, oils, waxes, and resins. Because of its effectiveness as a quickly evaporating solvent, MEK is used in formulating high solids coatings that help to reduce emissions from coating operations. Persons using MEK should use protective gloves and have adequate ventilation to avoid the possible irritation effects of skin contact and breathing of the vapors.

Methylene Chloride

Methylene Chloride is a colorless, volatile liquid completely miscible with a variety of other solvents. It is widely used in paint strippers and as a cleaning agent/degreaser for metal parts. It has no flash point under normal use conditions and can be used to reduce the flammability of other substances.

Toluene

Referred to as toluol or methylbenzene, toluene is a clear, water-insoluble liquid with a distinct odor similar to that of benzene. It is a common solvent used in paints, paint thinners, lacquers, and adhesives. It has been used as a paint remover in softening fluorescent-finish, clear-topcoat sealing materials. It is also an acceptable thinner for zinc chromate primer. It has been used as an anti-knocking additive in gasoline. Prolonged exposure to toluene vapours should be avoided because it may be linked to brain damage.

Turpentine

Turpentine is obtained by distillation of wood from certain pine trees. It is a flammable, water-insoluble liquid solvent used as a thinner and quick-drier for varnishes, enamels, and other oil-based paints. Turpentine can be used to clean paint equipment and paint brushes used with oil-based paints.

Mineral Spirits

Sometimes referred to as white spirit, Stoddard solvent, or petroleum spirits, mineral spirits is a petroleum distillate used as a paint thinner and mild solvent. The reference to the name Stoddard came from a dry cleaner who helped to develop it in the 1920s as a less volatile dry cleaning solvent and as an alternative to the more volatile petroleum solvents that were being used for cleaning clothes. It is the most widely used solvent in the paint industry, used in aerosols, paints, wood preservatives, lacquers, and varnishes. It is also commonly used to clean paint brushes and paint equipment. Mineral spirits are used in industry for cleaning and degreasing machine tools and parts because it is very effective in removing oils and greases from metal. It has low odor, is less flammable, and less toxic than turpentine.

Naphtha

Naphtha is one of a wide variety of volatile hydrocarbon mixtures that is sometimes processed from coal tar but more often derived from petroleum. Naphtha is used as a solvent for various organic substances, such as fats and rubber, and in the making of varnish. It is used as a cleaning fluid and is incorporated into some laundry soaps. Naphtha has a low flashpoint and is used as a fuel in portable stoves and lanterns. It is sold under different names around the world and is known as white gas, or Coleman fuel, in North America.

Linseed Oil

Linseed oil is the most commonly used carrier in oil paint. It makes the paint more fluid, transparent, and glossy. It is used to reduce semi paste oil colours, such as dull black stencilling paint and insignia colours, to a brushing consistency. Linseed oil is also used as a protective coating on the interior of metal tubing. Linseed oil is derived from pressing the dried ripe flax seeds of the flax plant to obtain the oil and then using a process called solvent extraction. Oil obtained without the solvent extraction process is marketed as flaxseed oil. The term ″boiled linseed oil″ indicates that it was processed with additives to shorten its drying time.

A note of caution is usually added to packaging of linseed oil with the statement, ″Risk of Fire from Spontaneous Combustion Exists with this Product.″ Linseed oil generates heat as it dries. Oily materials and rags must be properly disposed after use to eliminate the possible cause of spontaneous ignition and fire.

Thinners

Thinners include a plethora of solvents used to reduce the viscosity of any one of the numerous types of primers, subcoats, and topcoats. The types of thinner used with the various coatings are addressed in other sections of this chapter.

Varnish

Varnish is a transparent protective finish primarily used for finishing wood. It is available in interior and exterior grades. The exterior grade does not dry as hard as the interior grade, allowing it to expand and contract with the temperature changes of the material being finished. Varnish is traditionally a combination of a drying oil, a resin, and a thinner or solvent. It has little or no color, is transparent, and has no added pigment. Varnish dries slower than most other finishes. Resin varnishes dry and harden when the solvents in them evaporate. Polyurethane and epoxy varnishes remain liquid after the evaporation of the solvent but quickly begin to cure through chemical reactions of the varnish components.

Primers

The importance of primers in finishing and protection is generally misunderstood and underestimated because it is invisible after the topcoat finish is applied. A primer is the foundation of the finish. Its role is to bond to the surface, inhibit corrosion of metal, and provide an anchor point for the finish coats. It is important that the primer pigments be either anodic to the metal surface or passivate the surface should moisture be present. The binder must be compatible with the finish coats. Primers on non-metallic surfaces do not require sacrificial or passivating pigments. Some of the various primer types are discussed below.

Wash Primers

Wash primers are water-thin coatings of phosphoric acid in solutions of vinyl butyral resin, alcohol, and other ingredients. They are very low in solids with almost no filling qualities. Their functions are to passivate the surface, temporarily provide corrosion resistance, and provide an adhesive base for the next coating, such as a urethane or epoxy primer. Wash primers do not require sanding and have high corrosion protection qualities. Some have a very small recoat time frame that must be considered when painting larger aircraft.

The manufacturers′ instructions must be followed for satisfactory results.

Red Iron Oxide

Red oxide primer is an alkyd resin-based coating that was developed for use over iron and steel located in mild environmental conditions. It can be applied over rust that is free of loose particles, oil, and grease. It has limited use in the aviation industry.

Gray Enamel Undercoat

This is a single component, nonsanding primer compatible with a wide variety of topcoats. It fills minor imperfections, dries fast without shrinkage, and has high corrosion resistance. It is a good primer for composite substrates.

Urethane

This is a term that is misused or interchanged by painters and manufacturers alike. It is typically a two-part product that uses a chemical activator to cure by linking molecules together to form a whole new compound. Polyurethane is commonly used when referring to urethane, but not when the product being referred to is acrylic urethane.
Urethane primer, like the urethane paint, is also a two-part product that uses a chemical activator to cure. It is easy to sand and fills well. The proper film thickness must be observed, because it can shrink when applied too heavily. It is typically applied over a wash primer for best results. Special precautions must be taken by persons spraying because the activators contain isocyanates (discussed further in the Protective Equipment section at the end of this chapter).

Epoxy

Epoxy is a synthetic, thermosetting resin that produces tough, hard, chemical-resistant coatings and adhesives. It uses a catalyst to chemically activate the product, but it is not classified as hazardous because it contains no isocyanates.

Epoxy can be used as a nonsanding primer/sealer over bare metal and it is softer than urethane, so it has good chip resistance. It is recommended for use on steel tube frame aircraft prior to installing fabric covering.

Zinc Chromate

Zinc chromate is a corrosion-resistant pigment that can be added to primers made of different resin types, such as epoxy, polyurethane, and alkyd. Older type zinc chromate is distinguishable by its bright yellow color when compared to the light green color of some of the current brand primers.
Moisture in the air causes the zinc chromate to react with the metal surface, and it forms a passive layer that prevents corrosion. Zinc chromate primer was, at one time, the standard primer for aircraft painting. Environmental concerns and new formula primers have all but replaced it.

TYPES OF PAINTS

Dope

When fabric-covered aircraft ruled the sky, dope was the standard finish used to protect and colour the fabric. The dope imparted additional qualities of increased tensile strength, air tightness, weather-proofing, ultraviolet (UV) protection, and tautness to the fabric cover. Aircraft dope is essentially a colloidal solution of cellulose acetate or nitrate combined with plasticizers to produce a smooth, flexible, homogeneous film.
Dope is still used on fabric covered aircraft as part of a covering process. However, the type of fabric being used to cover the aircraft has changed. Grade A cotton or linen was the standard covering used for years, and it still may be used if it meets the requirements of the Federal Aviation Administration (FAA), Technical Standard Order (TSO) C-15d/AMS 3806c.
Polyester fabric coverings now dominate in the aviation industry. These new fabrics have been specifically developed for aircraft and are far superior to cotton and linen. The protective coating and topcoat finishes used with the Ceconite® polyester fabric covering materials are part of a Supplemental Type Certificate (STC) and must be used as specified when covering any aircraft with a Standard Airworthiness Certificate. The Ceconite® covering procedures use specific brand name, nontautening nitrate and butyrate dope as part of the STC.
The Poly-Fiber® system also uses a special polyester fabric covering as part of its STC, but it does not use dope. All the liquid products in the Poly-Fiber® system are made from vinyl, not from cellulose dope. The vinyl coatings have several real advantages over dope: they remain flexible, they do not shrink, they do not support combustion, and they are easily removed from the fabric with MEK, which simplifies most repairs.

Synthetic Enamel

Synthetic enamel is an oil-based single-stage paint (no clear coat) that provides durability and protection. It can be mixed with a hardener to increase the durability and shine while decreasing the drying time. It is one of the more economical types of finish.

Lacquers

The origin of lacquer dates back thousands of years to a resin obtained from trees indigenous to China. In the early 1920s, nitrocellulose lacquer was developed from a process using cotton and wood pulp.

Nitrocellulose lacquers produce a hard, semi flexible finish that can be polished to a high sheen. The clear variety yellows as it ages, and it can shrink over time to a point that the surface crazes. It is easy to spot repair because each new coat of lacquer softens and blends into the previous coat. This was one of the first coatings used by the automotive industry in mass production, because it reduced finishing times from almost two weeks to two days.

Acrylic lacquers were developed to eliminate the yellowing problems and crazing of the nitrocellulose lacquers. General Motors started using acrylic lacquer in the mid-1950s, and they used it into the 1960s on some of their premium model cars. Acrylics have the same working properties but dry to a less brittle and more flexible film than nitrocellulose lacquer.

Lacquer is one of the easiest paints to spray, because it dries quickly and can be applied in thin coats. However, lacquer is not very durable; bird droppings, acid rain, and gasoline spills actually eat down into the paint. It still has limited use on collector and show automobiles because they are usually kept in a garage, protected from the environment.

The current use of lacquer for an exterior coating on an aircraft is almost nonexistent because of durability and environmental concerns. Upwards of 85 percent of the volatile organic compounds (VOCs) in the spray gun ends up in the atmosphere, and some states have banned its use.

There are some newly developed lacquers that use a catalyst, but they are used mostly in the woodworking and furniture industry. They have the ease of application of nitrocellulose lacquer with much better water, chemical, and abrasion resistance. Additionally, catalyzed lacquers cure chemically, not solely through the evaporation of solvents, so there is a reduction of VOCs released into the atmosphere. It is activated when the catalyst is added to the base mixture.

Polyurethane

Polyurethane is at the top of the list when compared to other coatings for abrasion-, stain-, and chemical-resistant properties. Polyurethane was the coating that introduced the wet look. It has a high degree of natural resistance to the damaging effects of UV rays from the sun. Polyurethane is usually the first choice for coating and finishing the corporate and commercial aircraft in today′s aviation environment.

Urethane Coating

The term urethane applies to certain types of binders used for paints and clear coatings. (A binder is the component that holds the pigment together in a tough, continuous film and provides film integrity and adhesion.) Typically, urethane is a two-part coating that consists of a base and catalyst that, when mixed, produces a durable, high-gloss finish that is abrasion and chemical resistant.

Acrylic Urethanes

Acrylic simply means plastic. It dries to a harder surface but is not as resistant to harsh chemicals as polyurethane. Most acrylic urethanes need additional UV inhibitors added when subject to the UV rays of the sun.

Epoxy

Epoxy is a polyurethane paint formed by the reaction of a hardener and a resin. Epoxies are known for good adhesion to surfaces, high heat and chemical resistance and very good electrical insulation, all of which make it better than other paints, such as lacquer, for use with aircraft.

Advantages of Epoxy

Because epoxy holds well to surfaces and doesn't dry as hard as enamel, epoxy doesn't become brittle and crack or chip from the plane. Even when mixed with plasticizers, enamel doesn't have the same flexible properties as epoxy. Similarly, epoxy has a higher resistance to chemicals, meaning it won't break down when exposed, nor does it fade or oxidize as quickly.

Enamel

Industrial enamel is very different from commercial enamel. For aircraft use, enamel is extremely hard and resistant to chemicals and conditions. It also keeps a tremendous shine even after exposure to hard conditions. The toughness of enamel makes it strong enough to handle the conditions to which an aircraft is regularly exposed. However, its hardness also keeps it from bending as the aircraft requires.

Advantages of Enamel

While not as resistant or flexible as epoxy, industrial enamel has two major advantages: cost and health. Polyurethane (epoxy) paints give off cyanide gas when sprayed; thus workers who apply epoxy must be extremely cautions to avoid exposure. As well, enamel paints are considerably cheaper than epoxy. Often the two paints are split by laying a base coat of enamel to provide the color and design for the aircraft and then applying a second coat of clear polyurethane to supply strength and extra shine.

METHODS OF PAINTING

There are several methods of applying aircraft finish. Among the most common are dipping, brushing, and spraying.

Dipping

The application of finishes by dipping is generally confined to factories or large repair stations. The process consists of dipping the part to be finished in a tank filled with the finishing material. Primer coats are frequently applied in this manner.

Brushing

Brushing has long been a satisfactory method of applying finishes to all types of surfaces. Brushing is generally used for small repair work and on surfaces where it is not practicable to spray paint. The material to be applied should be thinned to the proper consistency for brushing. A material that is too thick has a tendency to pull or rope under the brush. If the materials are too thin, they are likely to run or not cover the surface adequately. Proper thinning and substrate temperature allows the finish to flow-out and eliminates the brush marks.

Spraying

Spraying is the preferred method for a quality finish. Spraying is used to cover large surfaces with a uniform layer of material, which results in the most cost effective method of application. All spray systems have several basic similarities. There must be an adequate source of compressed air, a reservoir or feed tank to hold a supply of the finishing material, and a device for controlling the combination of the air and finishing material ejected in an atomized cloud or spray against the surface to be coated.

A self-contained, pressurized spray can of paint meets the above requirements and satisfactory results can be obtained painting components and small areas of touch up.
There are two main types of spray equipment. A spray gun with an integral paint container is adequate for use when painting small areas. When large areas are painted, pressure feed equipment is more desirable since a large supply of finishing material can be applied without the interruption of having to stop and refill a paint container. An added bonus is the lighter overall weight of the spray gun and the flexibility of spraying in any direction with a constant pressure to the gun.

The air supply to the spray gun must be entirely free of water or oil in order to produce the optimum results in the finished product. Water traps, as well as suitable filters to remove any trace of oil, must be incorporated in the air pressure supply line. These filters and traps must be serviced on a regular basis.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-III NOTES

FACULTY NAME: D.SUKUMAR **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 7AN6.3 **SEMESTER: VII**

SUBJECT NAME: MAINTENANCE OF AIRFRAME AND SYSTEMS DESIGN

AIRCRAFT SYSTEMS

Flying controls including power operated controls, hydraulic, pneumatic, landing gear various types, shock struts, nose wheel steering, ice and rain protection, fire detection warning and extinguishing.
Oxygen, air-conditioning and pressurization systems, wheels, tyres brakes, antiskid system. Windows, doors and emergency exists. Reliability and redundancy of systems design.

CONTROL SYSTEMS

Introduction

The architecture of the flight control system, essential for all flight operations, has significantly changed throughout the years. Soon after the first flights, articulated surfaces were introduced for basic control, operated by the pilot through a system of cables and pulleys. This technique survived for decades and is now still used for small airplanes.

The introduction of larger airplanes and the increase of flight envelopes made the muscular effort of the pilot, in many conditions, not sufficient to contrast the aerodynamic hinge moments consequent to the surface deflection; the first solution to this problem was the introduction of aerodynamic balances and tabs, but further grow of the aircraft sizes and flight enveops brought to the need of powered systems to control the articulated aerodynamic surfaces.

Nowadays two great categories of flight control systems can be found: a full mechanical control on gliders and small general aviation, and a powered, or servo-assisted, control on large or combat aircraft.

One of the great additional effects after the introduction of servomechanisms is the possibility of using active control technology, working directly on the flight control actuators, for a series of benefits:

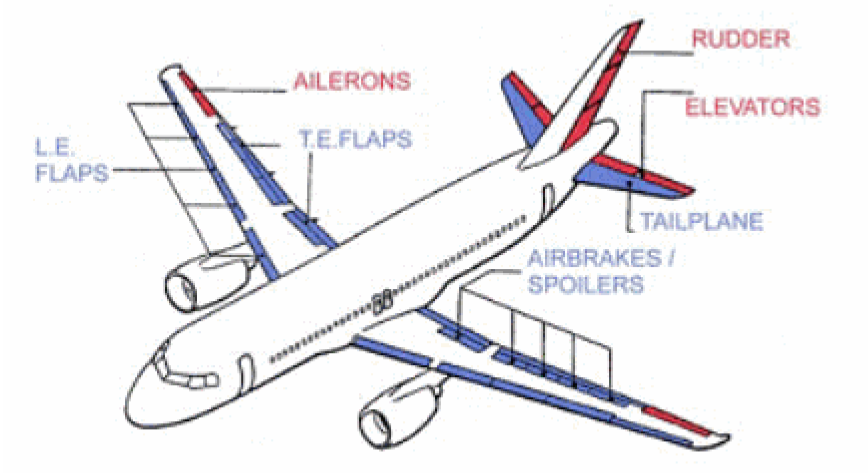
• compensation for deficiencies in the aerodynamics of the basic airframe;

• stabilisation and control of unstable airplanes, that have commonly higher performances;

• flight at high angles of attack;

• automatic stall and spinning protection;

• gust alleviation.



Flight control surfaces on airliner

A further evolution of the servo-assisted control is the fly-by-wire technique, based on signal processing of the pilot's demand before conversion into actuator control.

The number and type of aerodynamic surfaces to be controlled changes with aircraft category. Figure shows the classic layout for a conventional airliner. Aircraft have a number of different control surfaces:

those indicated in red form the primary flight control, i.e. pitch, roll and yaw control, basically obtained by deflection of elevators, ailerons and rudder (and combinations of them); those indicated in blue form the secondary flight control: high-lift and lift-dump devices, airbrakes, tail trimming, etc.

Modern aircraft have often particular configurations, typically as follows:

• elevons on delta wings, for pitch and roll control, if there is no horizontal tail;

• flaperons, or trailing edge flaps-ailerons extended along the entire span:

• tailerons, or stabillisers-ailerons (independently controlled);

• swing wings, with an articulation that allows sweep angle variation;

• Canards, with additional pitch control and stabilization

Primary flight control capability is essential for safety, and this aspect is dramatically emphasized in the modern unstable (military) airplanes, which could be not controlled without the continued operation of the primary flight control surfaces. For this reason the actuation system in charge of primary control has a high redundancy and reliability, and is capable of operating close to full performance after one or more failures.

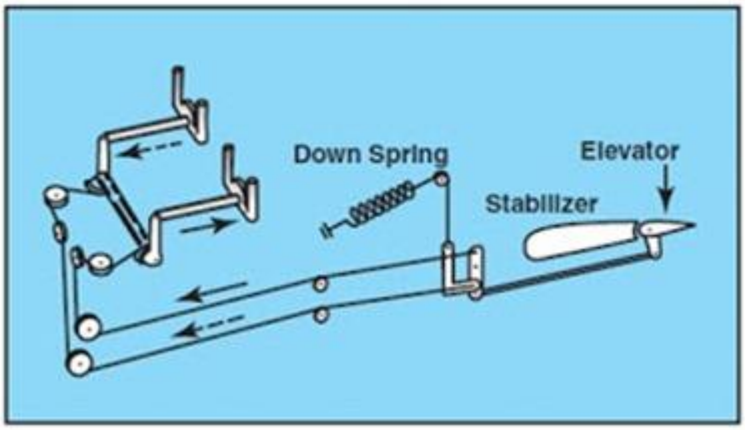
Secondary actuation system failure can only introduce flight restriction, like a flap less landing or reduction in the max angle of attack; therefore it is not necessary to ensure full operation after failures.

FULLY POWERED FLIGHT CONTROLS

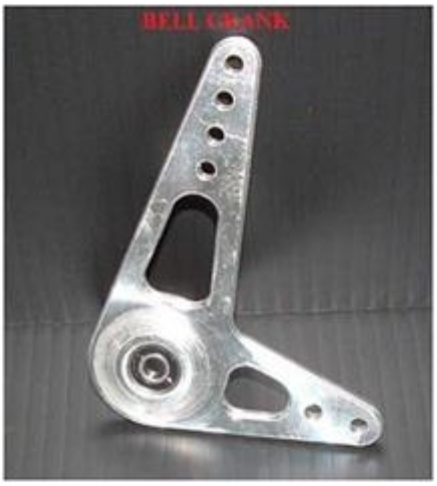
Fully powered Flight Controls

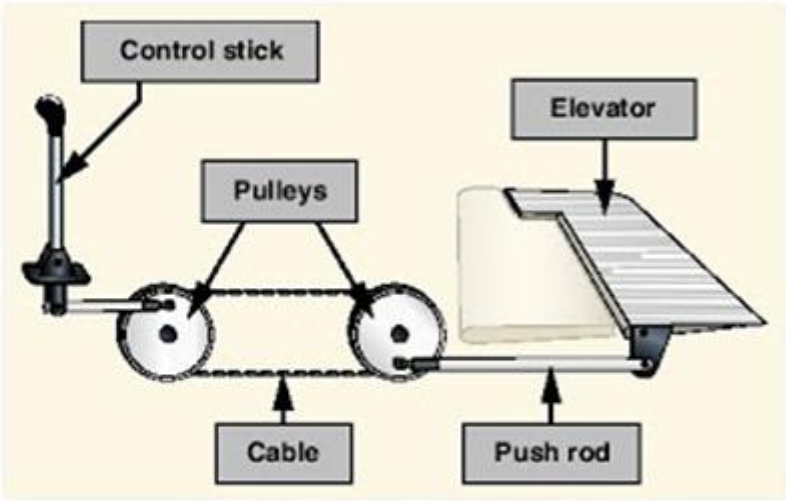
To actuate the control Surface the pilot has to give full effort. This is very tough to actuate the control surfaces through simple mechanical linkages. One can feel the equal toughness when raising the hand perpendicular to the airflow on riding a motorbike.

In this type of flight control system we will have



S.No	Item	Purpose
1	The cable	To transmit the power
2	Cable connector	To connect the cable
3	Turnbuckle	To adjust the Cable length
4	Fairlead	To guide the Cable
5	Pulley	To guide the in radial direction
6	Push pull rod	To go for and aft as per requirement
7	Control stick	To make orders for the remaining circuit





MECHANICAL FLIGHT CONTROL SYSTEM

The most basic flight control system designs are mechanical and date back to early aircraft. They operate with a collection of mechanical parts such as rods, cables, pulleys, and sometimes chains to transmit the forces of the flight deck controls to the control surfaces. Mechanical flight control systems are still used today in small general and sport category aircraft where the aerodynamic forces are not excessive. When the pilot pushes the control stick forward/backward the cable is getting tensed through the linkages and it causes the Control surface to move respectively.

Power actuated systems

Hydraulic control

When the pilot's action is not directly sufficient for a the control, the main option is a powered system that assists the pilot.

A few control surfaces on board are operated by electrical motors: as already discussed in a previous chapter, the hydraulic system has demonstrated to be a more suitable solution for actuation in terms of reliability, safety, weight per unit power and flexibility, with respect to the electrical system, then becoming the common tendency on most modern airplanes: the pilot, via the cabin components, sends a signal, or demand, to a valve that opens ports through which high pressure hydraulic fluid flows and operates one or more actuators.

The valve, that is located near the actuators, can be signalled in two different ways: mechanically or electrically; mechanical signalling is obtained by push-pull rods, or more commonly by cables and pulleys; electrical signalling is a solution of more modern and sophisticated vehicles and will be later on discussed.

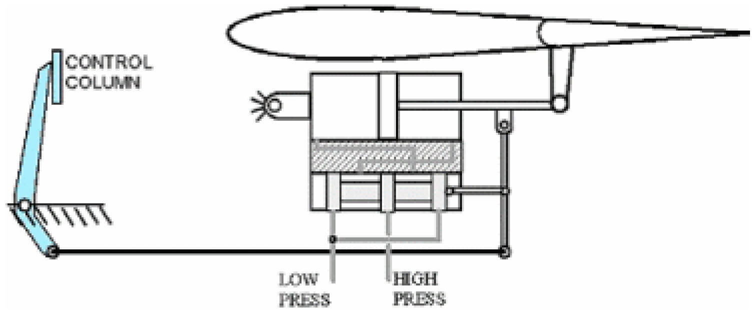
The basic principle of the hydraulic control is simple, but two aspects must be noticed when a powered control is introduced:

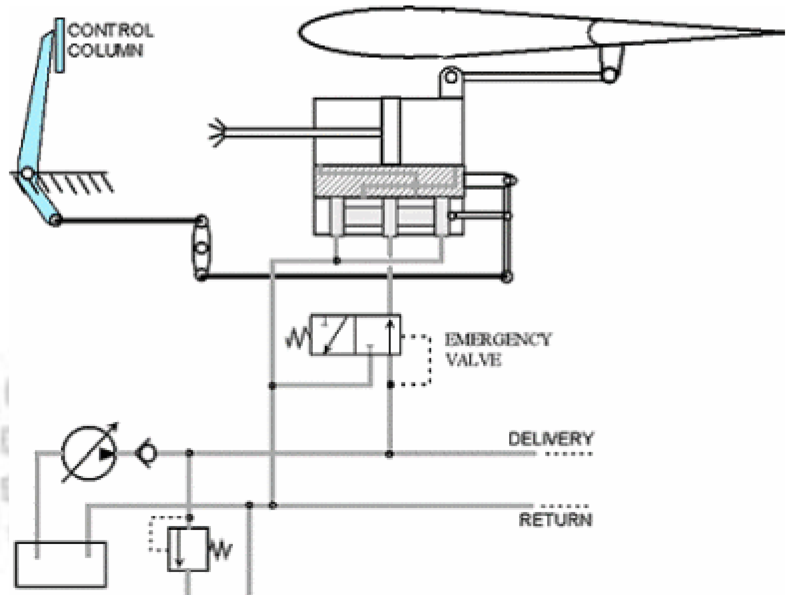
1. the system must control the surface in a proportional way, i.e. the surface response (deflection) must be function to the pilot's demand (stick deflection, for instance);

2. the pilot that with little effort acts on a control valve must have a feedback on the manoeuvre intensity.

The first problem is solved by using (hydraulic) servo-mechanisms, where the components are linked in such a way to introduce an actuator stroke proportional to the pilot's demand; many examples can be made, two of them are sketched, the second one including also the hydraulic circuit necessary for a correct operation.

In both cases the control valve housing is solid with the cylinder and the cabin column





Classic hydraulic servomechanisms

It has a mechanical linkage to drive the valve spool.

In the first case, the cylinder is hinged to the aircraft and, due to valve spool displacement and ports opening, the piston is moved in one direction or the other; the piston rod is also linked to the valve spool stick, in such a way that the piston movement brings the spool back towards its neutral position; when this is reached, the actuator stops, then obtaining a deflection that is proportional to the demand.

In the second case the piston is constrained to the aircraft; the cabin column controls the valve spool stick; this will result in a movement of the cylinder, and this brings the valve housing again towards the valve neutral position, then resulting in a stroke proportional to the pilot’s demand. The hydraulic circuit also includes an emergency valve on the delivery segment to the control valve; if the delivery pressure drops, due for instance to a pump or engine failure, the emergency valve switches to the other position and links all the control valve inlets to the tank; this operation hydraulically unlocks the system, allowing the pilot for manual actuation of the cylinder.

It is clear now that the pilot, in normal hydraulic operating conditions, is requested for a very low effort, necessary to contrast the mechanical frictions of the linkage and the movement of the control valve: the pilot is then no more aware of the load condition being imposed to the aircraft.

For this reason an artificial feel is introduced in powered systems, acting directly on the cabin control stick or pedals. The simplest solution is a spring system, then responding to the pilot's demand with a force proportional to the stick deflection; this solution has of course the limit to be not sensitive to the actual flight conditions. A more sophisticated artificial feel is the so-called Q feel. This system receives data from the pitot-static probes, reading the dynamic pressure, or the difference between total (p_t) and static (p_s) pressure, that is proportional to the aircraft speed v through the air density ρ:

$$p_t - p_s = \frac{1}{2}\rho v^2.$$

This signal is used to modulate a hydraulic cylinder that increases the stiffness in the artificial feel system, in such a way that the pilot is given a contrast force in the pedals or stick that is also proportional to the aircraft speed.

DIGITAL FLY BY WIRE SYSTEMS

Fly-By-Wire

In the 70's the fly-by-wire architecture was developed, starting as an analogue technique and later on, in most cases, transformed into digital. It was first developed for military aviation, where it is now a common solution; the supersonic Concorde can be considered a first and isolated civil aircraft equipped with a (analogue) fly-by-wire system, but in the 80's the digital technique was imported from military into civil aviation by Airbus, first with the A320, then followed by A319, A321, A330, A340, Boeing 777 and A380 (scheduled for 2005).

This architecture is based on computer signal processing and is schematically shown in fig. 6.5: the pilot's demand is first of all transduced into electrical signal in the cabin and sent to a group of independent computers (Airbus architecture substitute the cabin control column with a side stick); the computers sample also data concerning the flight conditions and servo-valves and actuators positions; the pilot's demand is then processed and sent to the actuator, properly tailored to the actual flight status.

The flight data used by the system mainly depend on the aircraft category; in general the following data are sampled and processed:

• pitch, roll, yaw rate and linear accelerations

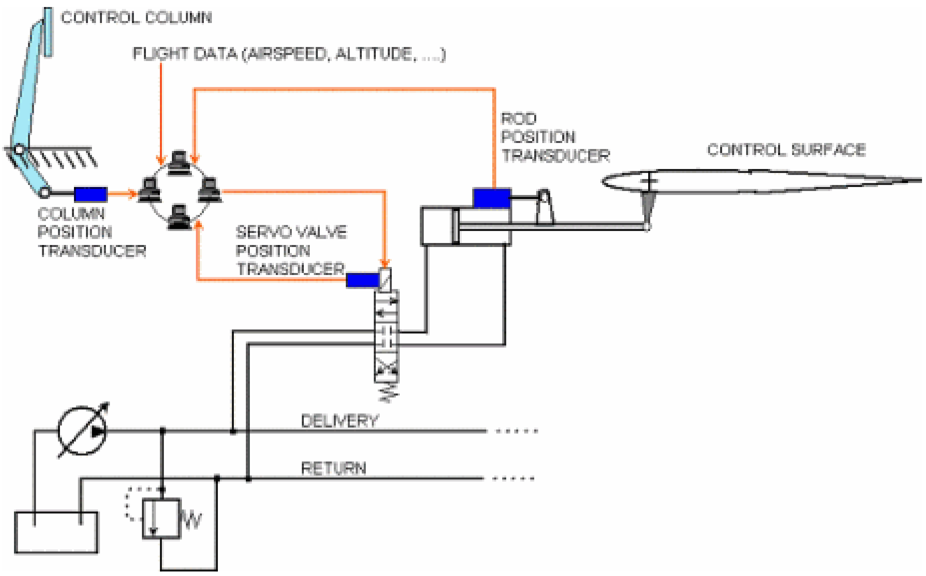
angle of attack and sideslip;

• airspeed/mach number, pressure altitude and radio altimeter indications;

• stick and pedal demands;

• Other cabin commands such as landing gear condition, thrust lever position, etc.

The full system has high redundancy to restore the level of reliability of a mechanical or hydraulic system, in the form of multiple (triplex or quadruplex) parallel and independent lanes to generate and transmit the signals, and independent computers that process them; in many cases both hardware and software are different, to make the generation of a common error extremely remote, increase fault tolerance and isolation; in some cases the multiplexing of the digital computing and signal transmission is supported with an analogue or mechanical back-up system, to achieve adequate system reliability.



Fly-by-wire system

Fly-by-wire system between military and civil aircraft; some of the most important benefits are as follows:

• flight envelope protection (the computers will reject and tune pilot's demands that might exceed the airframe load factors);

• increase of stability and handling qualities across the full flight envelope, including the possibility of flying unstable vehicles;

• turbulence suppression and consequent decrease of fatigue loads and increase of passenger comfort;

• use of thrust vectoring to augment or replace lift aerodynamic control, then extending the aircraft flight envelope;

• drag reduction by an optimised trim setting;

• higher stability during release of tanks and weapons;

• easier interfacing to auto-pilot and other automatic flight control systems;

• weight reduction (mechanical linkages are substituted by wirings);

• maintenance reduction;

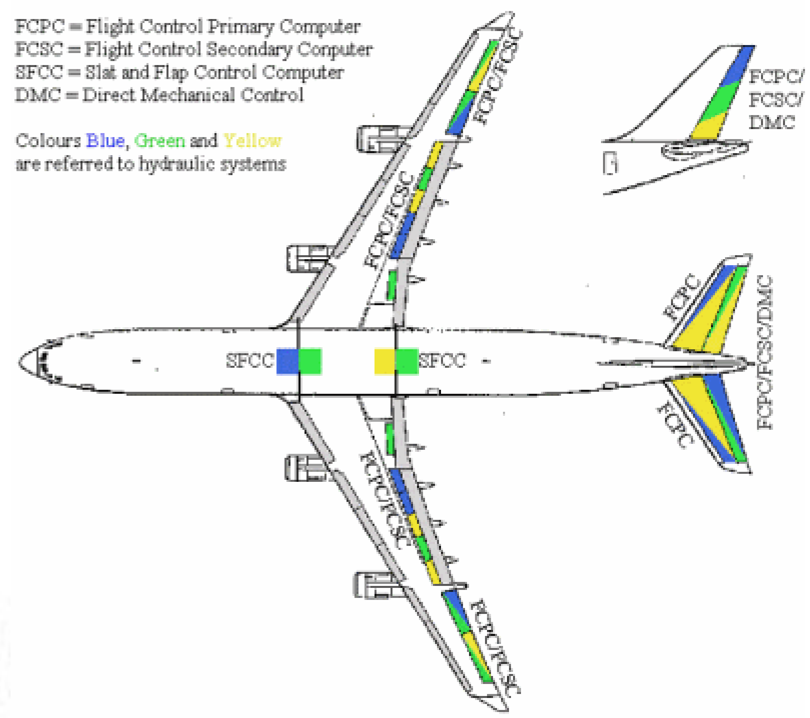
• Reduction of airlines' pilot training costs (flight handling becomes very similar in an whole aircraft family).

the flight mode: ground, take-off, flight and flare. Transition between modes is smooth and the pilot is not affected in its ability to control the aircraft: in ground mode the pilot has control on the nose wheel steering as a function of speed, after lift-off the envelope protection is gradually introduced and in flight mode the aircraft is fully protected by exceeding the maximum negative and positive load factors (with and without high lift devices extracted), angle of attack, stall, airspeed/Mach number, pitch attitude, roll rate, bank angle etc; finally, when the aircraft approaches to ground the control is gradually switched to flare mode, where automatic trim is deactivated and modified flight laws are used for pitch control.

The control software is one of the most critical aspects of fly-by-wire. It is developed in accordance to very strict rules, taking into account the flight control laws, and extensive testing is performed to reduce the probability of error. The risk of aircraft loss due to flight control failure is 2×10^{-6} per flight hour for a sophisticated military airplane that anyway has the ejection seat as ultimate solution; the risk is reduced to 10^{-9} per flight hour for a civil airplane, were occupants cannot evacuate the airplane during flight.

Figure below shows, as example, the fly-by-wire layout for the Airbus 340. Three groups of personal computers are used on board: three for primary control (FCPC), two for secondary control (FCSC) and two for high lift devices control (SFCC). The primary and secondary computers are based on different hardware; computers belonging to the same group have different software.

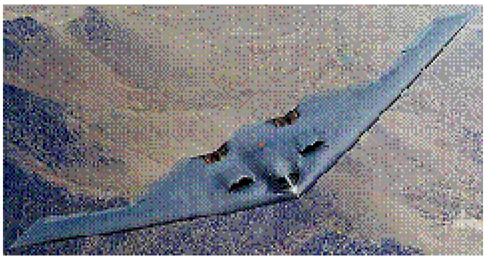
Two additional personal computers are used to store flight data.



A340 fly-by-wire layout, including hydraulic system indications

In the drawing the computer group and hydraulic system that control each surface are indicated (there are three independent hydraulic systems on the A340, commonly indicated as Blue, Yellow and Green). The leading edge flaps are linked together, and so are the trailing edge flaps, and then they are controlled by hydraulic units in the fuselage.

The drawing shows a considerable redundancy of the flight control system: the inboard and outboard ailerons, elevators and rudder are controlled by both the primary and secondary computers and operated by the three hydraulic sub-systems; the high lift devices are controlled by their specific computers and operated by the three hydraulic systems (Blue and Green for the leading edge,Yellow and Green for the trailing edge); the vertical stabiliser, having a secondary role, is controlled only by the secondary computers and operated by two hydraulic sub-systems. Thanks to this layout, first of all, in case of double hydraulic sub-system fault, the aircraft can be basically controlled with one hydraulic sub-system. Moreover, in case of total power black-out, the pilot can control the rudder and elevators by a mechanical back-up system, since the capability of this aircraft to land safely has been demonstrated with only limited pitch and yaw control.

Fly-by-wire architecture is inevitable for some aircraft categories: figure shows a typically unstable aircraft and a tilt rotor aircraft.  **Northrop B-2**	 **Bell-Boeing V-22** Fig – Need of fly-y-wire architecture for unstable (B-2) and thrust vectoring (V-22) airplanes

ENGINE CONTROL SYSTEMS

- It allow the engine to perform at maximum efficiency for a given condition
- Aids the pilot to control and monitor the operation of the aircraft's power plant
- Originally, engine control systems consisted of simple mechanical linkages controlled by the pilot then evolved and became the responsibility of the third pilot-certified crew member, the flight engineer
- By moving throttle levers directly connected to the engine, the pilot or the flight engineer could control fuel flow, power output, and many other engine parameters.
- Following mechanical means of engine control came the introduction of analog electronic engine control.
- Analog electronic control varies an electrical signal to communicate the desired engine settings
- It had its drawbacks including common electronic noise interference and reliability issues
- Full authority analogue control was used in the 1960s.
- It was introduced as a component of the Rolls Royce Olympus 593 engine of the supersonic transport aircraft Concorde. However the more critical inlet control was digital on the production aircraft.
- In the 1970s NASA and Pratt and Whitney experimented with the first experimental FADEC, first flown on an F-111 fitted with a highly modified Pratt & Whitney TF30 left engine.

Rolls Royce Olympus 593 engine

F-111C - Fighter – Bomber

Pratt & Whitney F100 – First Military Engine

Pratt & Whitney PW2000 - First Civil Engine fitted with FADEC

Pratt & Whitney PW4000 - First commercial "dual FADEC" engine.

The Harrier II Pegasus engine by Dowty & Smiths Industries Controls - The first FADEC in service.

Functions

- FADEC works by receiving multiple input variables of the current flight condition including air density, throttle lever position, engine temperatures, engine pressures, and many other parameters
- The inputs are received by the EEC and analyzed up to 70 times per second
- Engine operating parameters such as fuel flow, stator vane position, bleed valve position, and others are computed from this data and applied as appropriate.
- It controls engine starting and restarting.
- Its basic purpose is to provide optimum engine efficiency for a given flight condition.
- It also allows the manufacturer to program engine limitations and receive engine health and maintenance reports. For example, to avoid exceeding a certain engine temperature, the FADEC can be programmed to automatically take the necessary measures without pilot intervention.
- The flight crew first enters flight data such as wind conditions, runway length, or cruise altitude, into the flight management system (FMS). The FMS uses this data to calculate power settings for different phases of the flight.
- At takeoff, the flight crew advances the throttle to a predetermined setting, or opts for an auto-throttle takeoff if available.
- The FADECs now apply the calculated takeoff thrust setting by sending an electronic signal to the engines.
- There is no direct linkage to open fuel flow. This procedure can be repeated for any other phase of flight
- In flight, small changes in operation are constantly made to maintain efficiency.
- Maximum thrust is available for emergency situations if the throttle is advanced to full, but limitations can't be exceeded
- The flight crew has no means of manually overriding the FADEC.
- True full authority digital engine controls have no form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer
- If a total FADEC failure occurs, the engine fails
- If the engine is controlled digitally and electronically but allows for manual override, it is considered solely an EEC or ECU.
- An EEC, though a component of a FADEC, is not by itself FADEC. When standing alone, the EEC makes all of the decisions until the pilot wishes to intervene.

Safety

- With the operation of the engines so heavily relying on automation, safety is a great concern.
- Redundancy is provided in the form of two or more, separate identical digital channels.
- Each channel may provide all engine functions without restriction.
- FADEC also monitors a variety of analog, digital and discrete data coming from the engine subsystems and related aircraft systems, providing for fault tolerant engine control.

Applications

- FADECs are employed by almost all current generation jet engines, and increasingly in piston engines for fixed-wing aircraft and helicopters.
- The system replaces both magnetos in piston-engined aircraft, which makes costly magneto maintenance obsolete and eliminates carburetor heat, mixture controls and engine priming.
- Since, it controls each engine cylinder independently for optimum fuel injection and spark timing, the pilot no longer needs to monitor fuel mixture.
- More precise mixtures create less engine wear, which reduces operating costs and increases engine life for the average aircraft.
- Tests have also shown significant fuel savings

Advantages

- Better fuel efficiency
- Automatic engine protection against out-of-tolerance operations
- Safer as the multiple channel FADEC computer provides redundancy in case of failure
- Care-free engine handling, with guaranteed thrust settings
- Ability to use single engine type for wide thrust requirements by just reprogramming the FADECs.
- Provides semi-automatic engine starting
- Better systems integration with engine and aircraft systems
- Can provide engine long-term health monitoring and diagnostics
- Reduces the number of parameters to be monitored by flight crews
- Due to the high number of parameters monitored, the FADEC makes possible "Fault Tolerant Systems" (where a system can operate within required reliability and safety limitation with certain fault configurations)
- Can support automatic aircraft and engine emergency responses (e.g. in case of aircraft stall, engines increase thrust automatically).

Disadvantages

- No form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer.
- If a total FADEC failure occurs, the engine fails.
- In the event of a total FADEC failure, pilots have no way of manually controlling the engines for a restart, or to otherwise control the engine.
- With any single point of failure, the risk can be mitigated with redundant FADECs
- High system complexity compared to hydro mechanical, analogue or manual control systems
- High system development and validation effort due to the complexity

Auto pilot System

An autopilot is a mechanical, electrical, or hydraulic system used to guide a vehicle without assistance from a human being. An autopilot can refer specifically to aircraft, self-steering gear for boats, or auto guidance of space craft and missiles. The autopilot of an aircraft is sometimes referred to as “George”, after one of the key contributors to its development.

Today, autopilots are sophisticated systems that perform the same duties as a highly trained pilot. In fact, for some in-flight routines and procedures, autopilots are even better than a pair of human hands. They don’t just make flights smoother -they make them safer and more efficient. We'll look at how autopilots work by examining their main components, how they work together — and what happens if they fail.

Autopilots and Avionics

In the world of aircraft, the autopilot is more accurately described as the automatic flight control system (AFCS). An AFCS is part of an aircraft's avionics – the electronic systems, equipment and devices used to control key systems of the plane and its flight. In addition to flight control systems, avionics include electronics for communications, navigation, collision avoidance and weather. The original use of an AFCS was to provide pilot relief during tedious stages of flight, such as high-altitude cruising. Advanced autopilots can do much more, carrying out even highly precise maneuvers, such as landing an aircraft in conditions of zero visibility.

Although there is great diversity in autopilot systems, most can be classified according to the number of parts, or surfaces, they control. To understand this discussion, it helps to be familiar with the three basic control surfaces that affect an airplane's attitude.

Autopilots can control any or all of these surfaces. A single-axis autopilot manages just one set of controls, usually the ailerons. This simple type of autopilot is known as a "wing leveler" because, by controlling roll, it keeps the aircraft wings on an even keel.

A two-axis autopilot manages elevators and ailerons. Finally, a three-axis autopilot manages all three basic control systems: ailerons, elevators and rudder.

The invention of autopilot

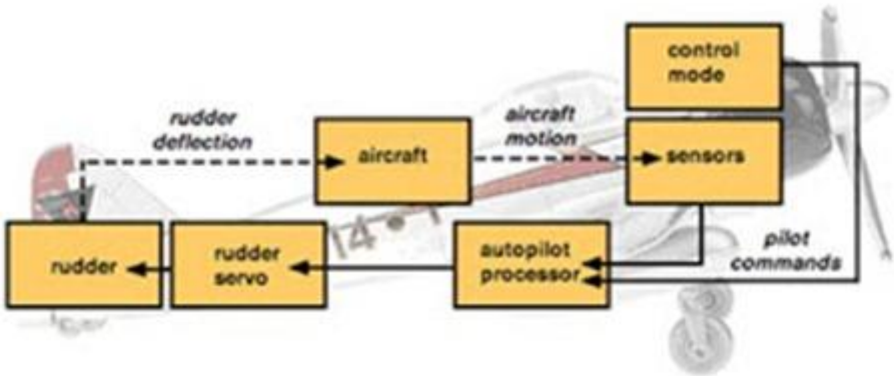
Famous inventor and engineer Elmer Sperry patented the gyrocompass in 1908, but it was his son, Lawrence Burst Sperry, who first flight-tested such a device in an aircraft. The younger Sperry's autopilot used four gyroscopes to stabilize the airplane and led to many flying firsts, including the first night flight in the history of aviation. In 1932, the Sperry Gyroscope Company developed the automatic pilot that Wiley Post would use in his first solo flight around the world.

Autopilot Parts

The heart of a modern automatic flight control system is a computer with several high-speed processors. To gather the intelligence required to control the plane, the processors communicate with sensors located on the major control surfaces. They can also collect data from other airplane systems and equipment, including gyroscopes, accelerometers, altimeters, compasses and airspeed indicators.

The processors in the AFCS then take the input data and, using complex calculations, compare it to a set of control modes. A control mode is a setting entered by the pilot that defines a specific detail of the flight. For example, there is a control mode that defines how an aircraft's altitude will be maintained. There are also control modes that maintain airspeed, heading and flight path.

These calculations determine if the plane is obeying the commands set up in the control modes. The processors then send signals to various servomechanism units. A servomechanism, or servo for short, is a device that provides mechanical control at a distance. One servo exists for each control surface included in the autopilot system. The servos take the computer's instructions and use motors or hydraulics to move the craft's control surfaces, making sure the plane maintains its proper course and attitude.



Block diagram of Autopilot system

The above illustration shows how the basic elements of an autopilot system are related. For simplicity, only one control surface — the rudder — is shown, although each control surface would have a similar arrangement. Notice that the basic schematic of an autopilot looks like a loop, with sensors sending data to the autopilot computer, which processes the information and transmits signals to the servo, which moves the control surface, which changes the attitude of the plane, which creates a new data set in the sensors, which starts the whole process again. This type of feedback loop is central to the operation of autopilot systems.

Autopilot Control Systems

An autopilot is an example of a control system. Control systems apply an action based on a measurement and almost always have an impact on the value they are measuring. A classic example of a control system is the negative feedback loop that controls the thermostat in your home. Such a loop works like this:

1. Its summertime and a homeowner set his thermostat to a desired room temperature say 78°F.

2. The thermostat measures the air temperature and compares it to the preset value.

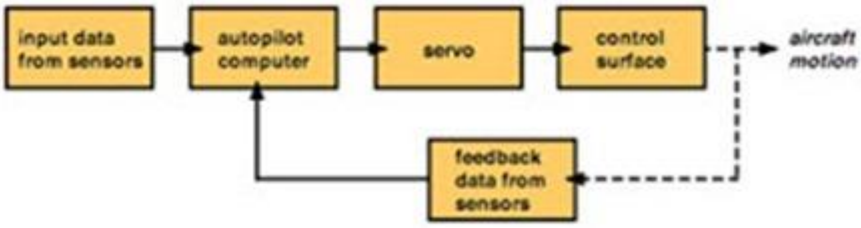
3. Over time, the hot air outside the house will elevate the temperature inside the house. When the temperature inside exceeds 78°F, the thermostat sends a signal to the air conditioning unit.

4. The air conditioning unit clicks on and cools the room.

5. When the temperature in the room returns to 78°F, another signal is sent to the air conditioner, which shuts off.

It’s called a negative feedback loop because the result of a certain action (the air conditioning unit clicking on) inhibits further performance of that action. All negative feedback loops require a receptor, a control center and an effector. In the example above, the receptor is the thermometer that measures air temperature. The control center is the processor inside the thermostat. And the effector is the air conditioning unit.

Automated flight control systems work the same way. Let’s consider the example of a pilot who has activated a single-axis autopilot — the so-called wing leveler we mentioned earlier.



Block diagram of Autopilot system

1. The pilot sets a control mode to maintain the wings in a level position.

2. However, even in the smoothest air, a wing will eventually dip.

3. Position sensors on the wing detect this deflection and send a signal to the autopilot computer.

4. The autopilot computer processes the input data and determines that the wings are no longer level.

5. The autopilot computer sends a signal to the servos that control the aircraft's ailerons. The signal is a very specific command telling the servo to make a precise adjustment.

a) Each servo has a small electric motor fitted with a slip clutch that, through a bridle cable, grips the aileron cable. When the cable moves, the control surfaces move accordingly.

b) As the ailerons are adjusted based on the input data, the wings move back toward level.

c) The autopilot computer removes the command when the position sensor on the wing detects that the wings are once again level.

d) The servos cease to apply pressure on the aileron cables.

This loop, shown above in the block diagram, works continuously, many times a second, much more quickly and smoothly than a human pilot could. Two- and three-axis autopilots obey the same principles, employing multiple processors that control multiple surfaces. Some airplanes even have auto thrust computers to control engine thrust. Autopilot and auto thrust systems can work together to perform very complex maneuvers.

Autopilot Failure

Autopilots can and do fail. A common problem is some kind of servo failure, either because of a bad motor or a bad connection. A position sensor can also fail, resulting in a loss of input data to the autopilot computer. Fortunately, autopilots for manned aircraft are designed as a failsafe — that is, no failure in the automatic pilot can prevent effective employment of manual override. To override the autopilot, a crew member simply has to disengage the system, either by flipping a power switch or, if that doesn't work, by pulling the autopilot circuit breaker.

Some airplane crashes have been blamed on situations where pilots have failed to disengage the automatic flight control system. The pilots end up fighting the settings that the autopilot is administering; unable to figure out why the plane won't do what they're asking it to do. This is why flight instruction programs stress practicing for just such a scenario. Pilots must know how to use every feature of an AFCS, but they must also know how to turn it off and fly without it. They also have to adhere to a rigorous maintenance schedule to make sure all sensors and servos are in good working order. Any adjustments or fixes in key systems may require that the autopilot be tweaked. For example, a change made to gyro instruments will require realignment of the settings in the autopilot's computer.

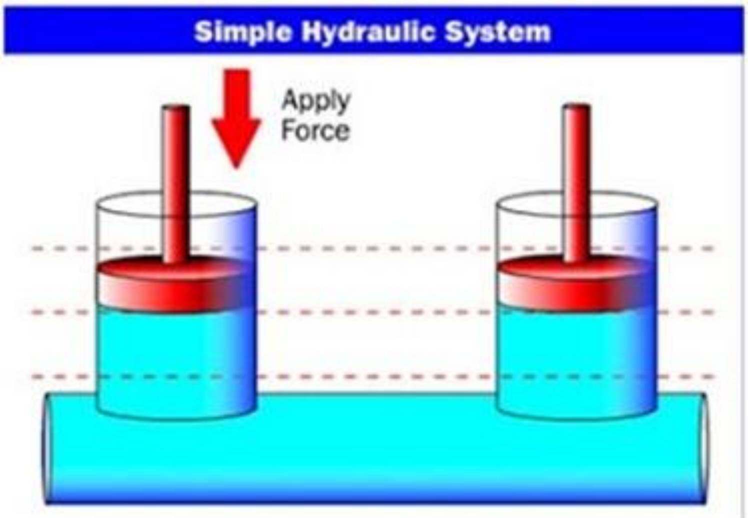
Modern Autopilot Systems

Many modern autopilots can receive data from a Global Positioning System (GPS) receiver installed on the aircraft. A GPS receiver can determine airplane's position in space by calculating its distance from three or more satellites in the GPS network. Armed with such positioning information, an autopilot can do more than keep a plane straight and level — it can execute a flight plan.

Most commercial jets have had such capabilities for a while, but even smaller planes are incorporating sophisticated autopilot systems. New Cessna 182s and 206s are leaving the factory with the Garmin G1000 integrated cockpit, which includes a digital electronic autopilot combined with a flight director. The Garmin G1000 delivers essentially all the capabilities and modes of a jet avionics system, bringing true automatic flight control to a new generation of general aviation planes. Wiley Post could have only dreamed of such technology back in 1933.

Hydraulic system

The word hydraulics is based on the Greek word for water, and originally meant the study of water at rest and in motion. Today the meaning has been expanded to include the physical behavior of all liquids, including hydraulic fluid. With the use of incompressible phenomenon of liquid we can easily make a hydraulic system.



As per Pascal's law "Pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other parts" .The basic idea behind any hydraulic system is very simple: **Force that is applied at one point is transmitted to another point using an incompressible fluid.** The fluid is almost always an oil of some sort. The force is almost always multiplied in the process.

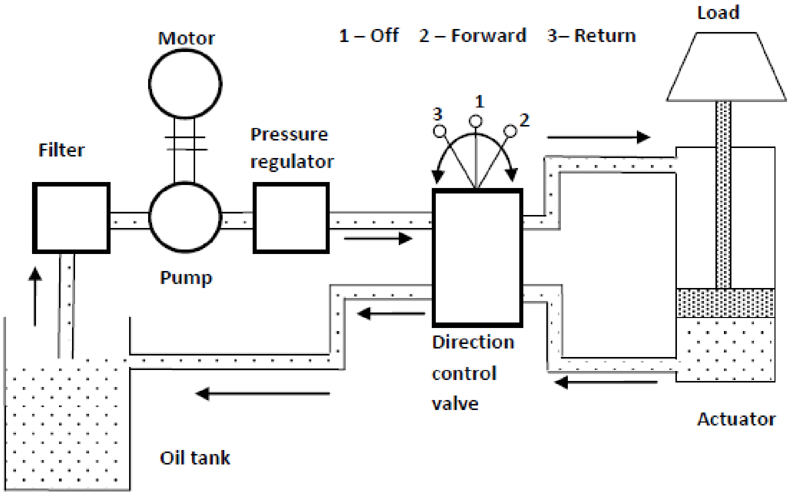
In this drawing, two pistons (red) fit into two glass cylinders filled with oil (light blue) and connected to one another with an oil-filled pipe. If you apply a downward force to one piston (the left one in this drawing), then the force is transmitted to the second piston through the oil in the pipe. Since oil is in-compressible, the efficiency is very good — almost all of the applied force appears at the second piston. The great thing about hydraulic systems is that the pipe connecting the two cylinders can be any length and shape, allowing it to snake through all sorts of things separating the two pistons. The pipe can also fork, so that one **master cylinder** can drive more than one slave cylinder if desired.

Hydraulic system in airplanes

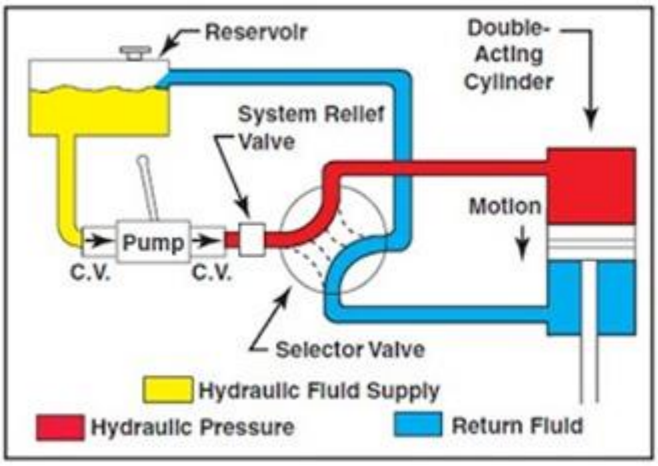
There are multiple applications for hydraulic use in airplanes, depending on the complexity of the airplane. For example, hydraulics is often used on small airplanes to operate wheel brakes, retractable landing gear, and some constant speed propellers. On large airplanes, hydraulics is used for flight control surfaces, wing flaps, spoilers, and other systems.

A basic hydraulic system

Hydraulic systems are power-transmitting assemblies employing pressurized liquid as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work.



A basic hydraulic system schematic diagram



A basic hydraulic system

A basic hydraulic system consists

- Reservoirs
- Pumps
- Selector Valves
- Check Valves
- Hydraulic Fuses
- Accumulators
- Actuators

Functions of the components are as follows:

1. The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear type (e.g., hydraulic cylinder) or rotary type (e.g., hydraulic motor) to provide linear or rotary motion, respectively. Actuators can be either single-acting or double-acting servos based on the needs of the system. This means that the fluid can be applied to one or both sides of the actuators, depending on the actuators type, and therefore provides power in one direction with a single-acting actuator/servo. A servo is a cylinder with a piston inside that turns fluid power into work and creates the power needed to move an aircraft system or flight control. The selector valve allows the fluid direction to be controlled. This is necessary for operations like the extension and retraction of landing gear where the fluid must work in two different directions.

2. The hydraulic pump is used to force the fluid from the reservoir to rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.

3. Valves are used to control the direction, pressure and flow rate of a fluid flowing through the circuit.

4. External power supply (motor) is required to drive the pump.

5. Reservoir is used to hold the hydraulic liquid, usually hydraulic oil.

6. Piping system carries the hydraulic oil from one place to another.

7. Filters are used to remove any foreign particles so as keep the fluid system clean and efficient, as well as avoid damage to the actuator and valves.

8. Pressure regulator regulates (i.e., maintains) the required level of pressure in the hydraulic fluid.

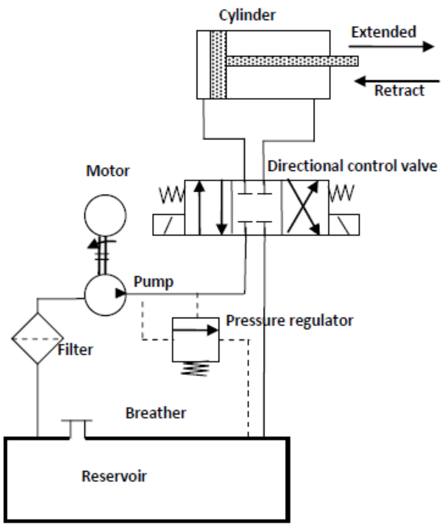
The piping shown in Figure is of closed-loop type with fluid transferred from the storage tank to one side of the piston and returned back from the other side of the piston to the tank. Fluid is drawn from the tank by a pump that produces fluid flow at the required level of pressure. If the fluid pressure exceeds the required level, then the excess fluid returns back to the reservoir and remains there until the pressure acquires the required level.

Cylinder movement is controlled by a three-position change over a control valve.

1. When the piston of the valve is changed to upper position, the pipe pressure line is connected to port A and thus the load is raised.

2. When the position of the valve is changed to lower position, the pipe pressure line is connected to port B and thus the load is lowered.

3. When the valve is at center position, it locks the fluid into the cylinder (thereby holding it in position) and dead-ends the fluid line (causing all the pump output fluid to return to tank via the pressure relief).



A hydraulic systems circuit diagram

In industry, a machine designer conveys the design of hydraulic systems using a circuit diagram. Above Figure shows the components of the hydraulic system using symbols. The working fluid, which is the hydraulic oil, is stored in a reservoir. When the electric motor is switched ON, it runs a positive displacement pump that draws hydraulic oil through a filter and delivers at high pressure. The pressurized oil passes through the regulating valve and does work on actuator. Oil from the other end of the actuator goes back to the tank via return line. To and fro motion of the cylinder is controlled using directional control valve.

HYDRAULIC FLUID

The fluid used in aircraft hydraulic systems is one of the system's most important parts.

- The fluid must flow with a minimum of opposition.
- Must be incompressible
- Good lubricating properties
- Inhibit corrosion and not attack seals
- Must not foam in operation

Some characteristics that must be considered.

- Viscosity
- Chemical Stability
- Flash Point
- Fire Point

Viscosity

Viscosity is the internal resistance to flow.

- Gasoline flows easily (has a low viscosity)
- Tar flows slowly (has a high viscosity)

A satisfactory liquid for a hydraulic system must have enough body t give a good seal at pumps, valves and pistons; but it must not be so thick that it offers excessive resistance to flow.

The average hydraulic liquid has a low viscosity.

Fire Point

Fire Point is the temperature at which a substance gives off vapor in sufficient quantity to ignite and continue to burn when exposed to a spark or flame.

High fire point is required of desirable hydraulic fluids.

Flash Point

Flash Point is the temperature at which a liquid gives off vapor in sufficient quantity to ignite momentarily when a flame is applied.

High flash point is desirable for hydraulic fluids.

Types of Hydraulic Fluid

Vegetable-base

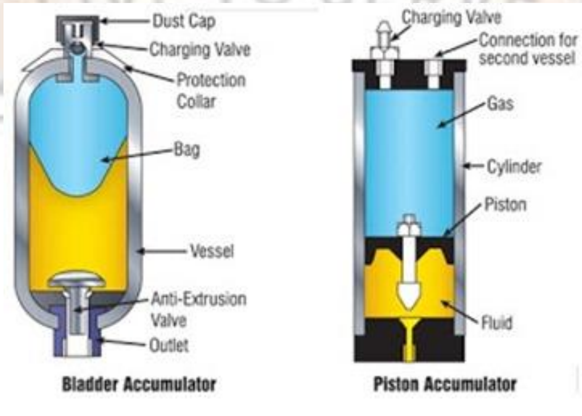
Mineral-base

Synthetic Fluid

A mineral-based fluid is the most widely used type for small airplanes. This type of hydraulic fluid, which is a kerosene-like petroleum product, has good lubricating Properties, as well as additives to inhibit foaming and prevent the formation of corrosion. It is quite stable chemically, has very little viscosity change with temperature, and is dyed for identification. Since several types of hydraulic fluids are commonly used, make sure your airplane is serviced with the type specified by the manufacturer.

The three types of gas-charged accumulators you'll encounter on hydraulic systems are bladder, piston and diaphragm. Accumulators are used to store the fluid under given pressure.

The most popular of these is the bladder type. Bladder accumulators feature fast response (less than 25 milliseconds), a maximum gas compression ratio of around 4:1 and a maximum flow rate of 15 liters (4 gallons) per second, although "high-flow" versions up to 38 liters (10 gallons) per second are available. Bladder accumulators also have good dirt tolerance; they are mostly unaffected by particle contamination in the hydraulic fluid.



Piston accumulators, on the other hand, can handle much higher gas compression ratios (up to 10:1) and flow rates as high as 215 liters (57 gallons) per second. Unlike bladder accumulators, who's preferred mounting position is vertical to prevent the possibility of fluid getting trapped between the bladder and the shell, piston accumulators can be mounted in any position.

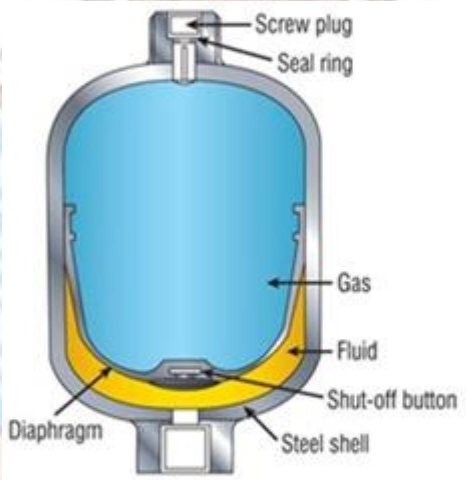
But, piston accumulators also require a higher level of fluid cleanliness than bladder units, have slower response times (greater than 25 milliseconds) – especially at lower pressures –

and exhibit hysteresis. This is explained by the static friction of the piston seal which has to be overcome, and the necessary acceleration and deceleration of the piston mass.

Diaphragm accumulators have most of the advantages of bladder-type units but can handle gas compression ratios up to 8:1. They are limited to smaller volumes, and their performance can sometimes be affected by gas permeation across the diaphragm.

Maintenance Considerations

When charging the gas end of a bladder or diaphragm accumulator, the nitrogen gas should always be admitted very slowly. If the high-pressure nitrogen is allowed to expand rapidly as it enters the bladder, it can chill the bladder's polymeric material to the point where immediate brittle failure occurs. Rapid pre-charging can also force the bladder underneath the poppet at the oil-end, causing it to be cut. If pre-charge pressure is too high or minimum system pressure is reduced without a corresponding reduction in pre-charge pressure, the operation of the accumulator will be affected and damage may also result. Excessive pre-charge of a bladder accumulator can drive the bladder into the poppet assembly during discharge, causing damage to the poppet assembly and/or the bladder. This is a common cause of bladder failure.



Accumulator

Low or no pre-charge also can have drastic consequences for bladder accumulators. It can result in the bladder being crushed into the top of the shell by system pressure. This can cause the bladder to extrude into or be punctured by the gas valve. In this scenario, only one such cycle is required to destroy the bladder.

Similarly, excessively high or low pre-charge of a piston accumulator can cause the piston to bottom out at the end of its stroke, resulting in damage to the piston and its seal. The good news is that, if this happens, an audible warning will result. Even though piston accumulators can be damaged by improper charging, they are much more tolerant of it than bladder accumulators.

Artificial feel devices

With purely mechanical flight control systems, the aerodynamic forces on the control surfaces are transmitted through the mechanisms and are felt directly by the pilot, allowing tactile feedback of airspeed. With hydro mechanical flight control systems, however, the load on the surfaces cannot be felt and there is a risk of overstressing the aircraft through excessive control surface movement. To overcome this problem, artificial feel systems can be used.

For example, for the controls of the RAF's Avro Vulcan jet bomber and the RCAF's Avro Canada CF-105 Arrow supersonic interceptor (both 1950s-era designs), the required force feedback was achieved by a spring device. The fulcrum of this device was moved in proportion to the square of the air speed (for the elevators) to give increased resistance at higher speeds. For the controls of the American Vought F-8 Crusader and the LTV A-7 Corsair II warplanes, a 'bob-weight' was used in the pitch axis of the control stick, giving force feedback that was proportional to the airplane's normal acceleration.

Stick shaker

A stick shaker is a device (available in some hydraulic aircraft) that is fitted into the control column, which shakes the control column when the aircraft is about to stall. Also in some aircraft like the McDonnell Douglas DC-10 there is/was a back-up electrical power supply that the pilot can turn on to re-activates the stick shaker in case the hydraulic connection to the stick shaker is lost.

Boeing 737 Next Generation Hydraulic System

The Boeing 737 Next Generation has three 3,000 psi hydraulic systems: system A, system B, and standby. The standby system is used if system A and/or B pressure is lost.

The hydraulic systems power the following aircraft systems:

• Flight controls

• Leading edge flaps and slats

• Trailing edge flaps

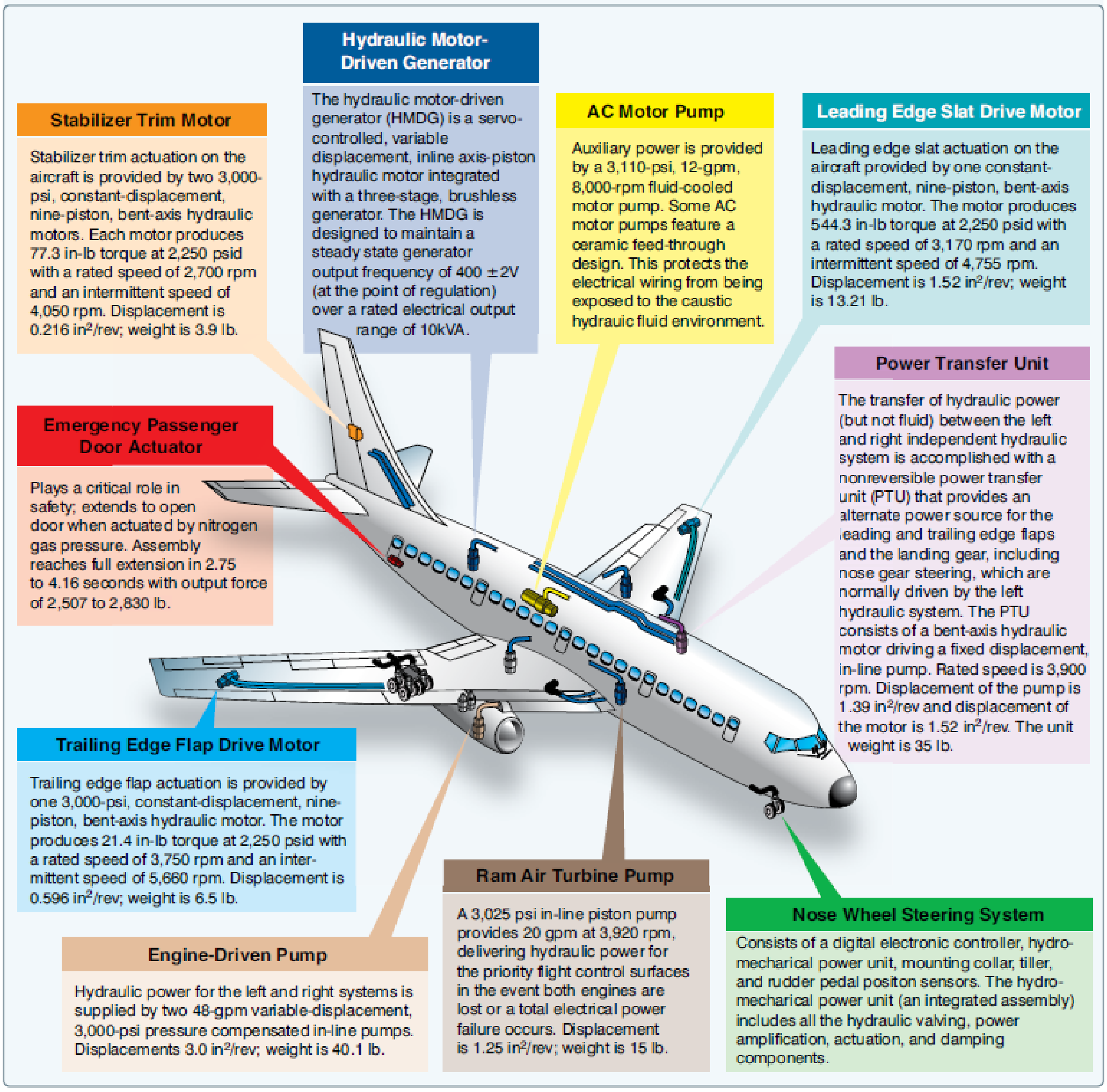
• Landing gear

• Wheel brakes

• Nose wheel steering

• Thrust reversers

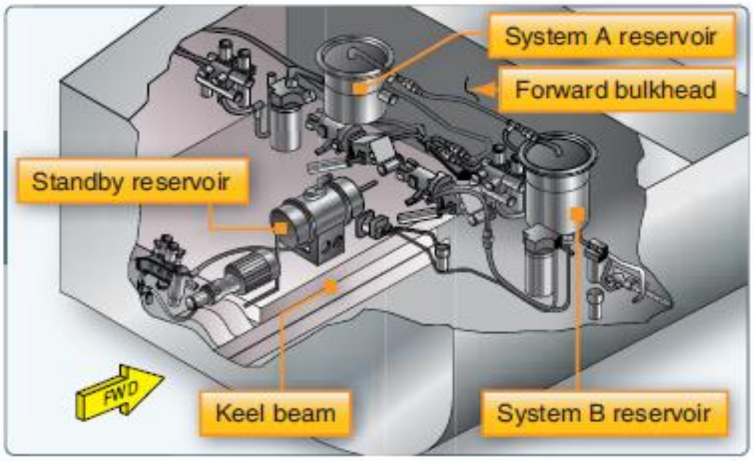
• Autopilots



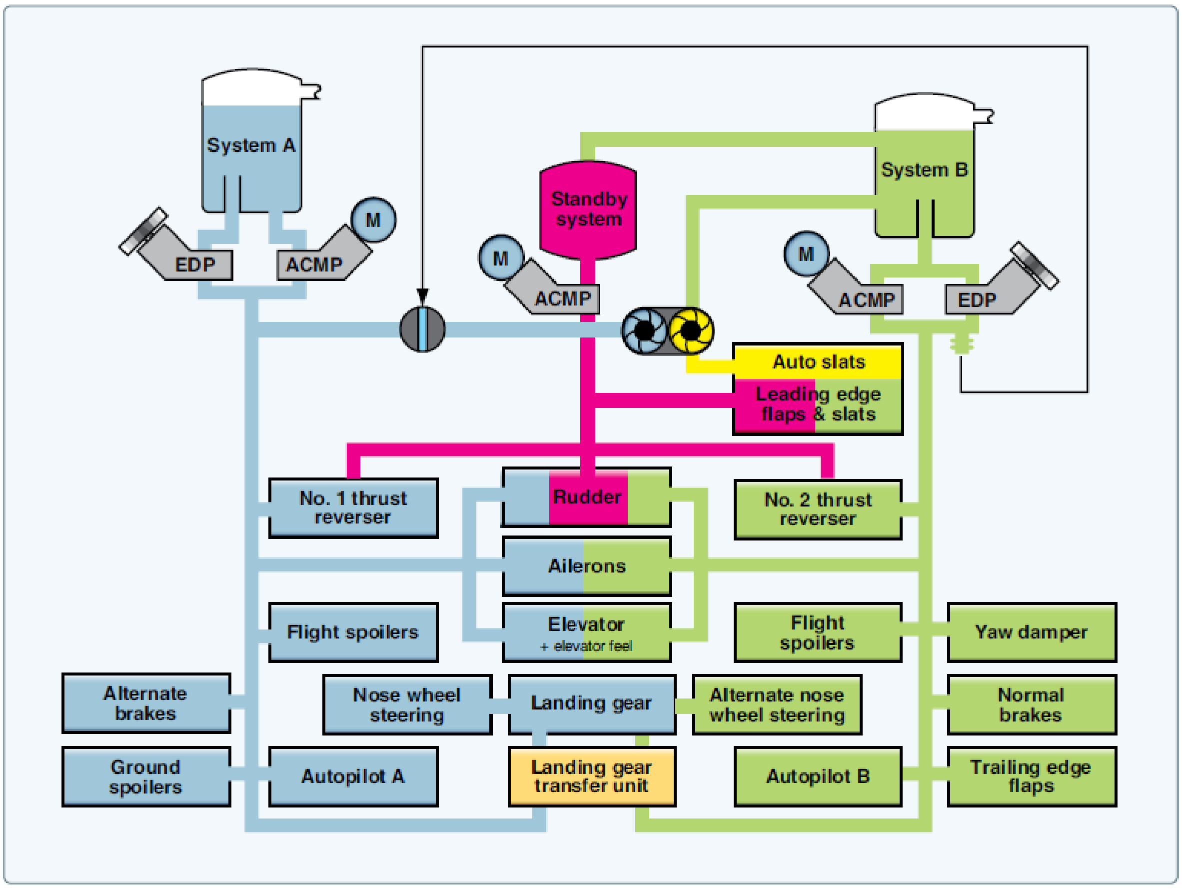
Large aircraft hydraulic systems

Reservoirs

The system A, B, and standby reservoirs are located in the wheel well area. The reservoirs are pressurized by bleed air through a pressurization module. The standby reservoir is connected to the system B reservoir for pressurization and servicing. The positive pressure in the reservoir ensures a positive flow of fluid to the pumps. The reservoirs have a standpipe that prevents the loss of all hydraulic fluid if a leak develops in the engine-driven pump or its related lines. The engine-driven pump draws fluid through a standpipe in the reservoir and the AC motor pump draws fluid from the bottom of the reservoir.



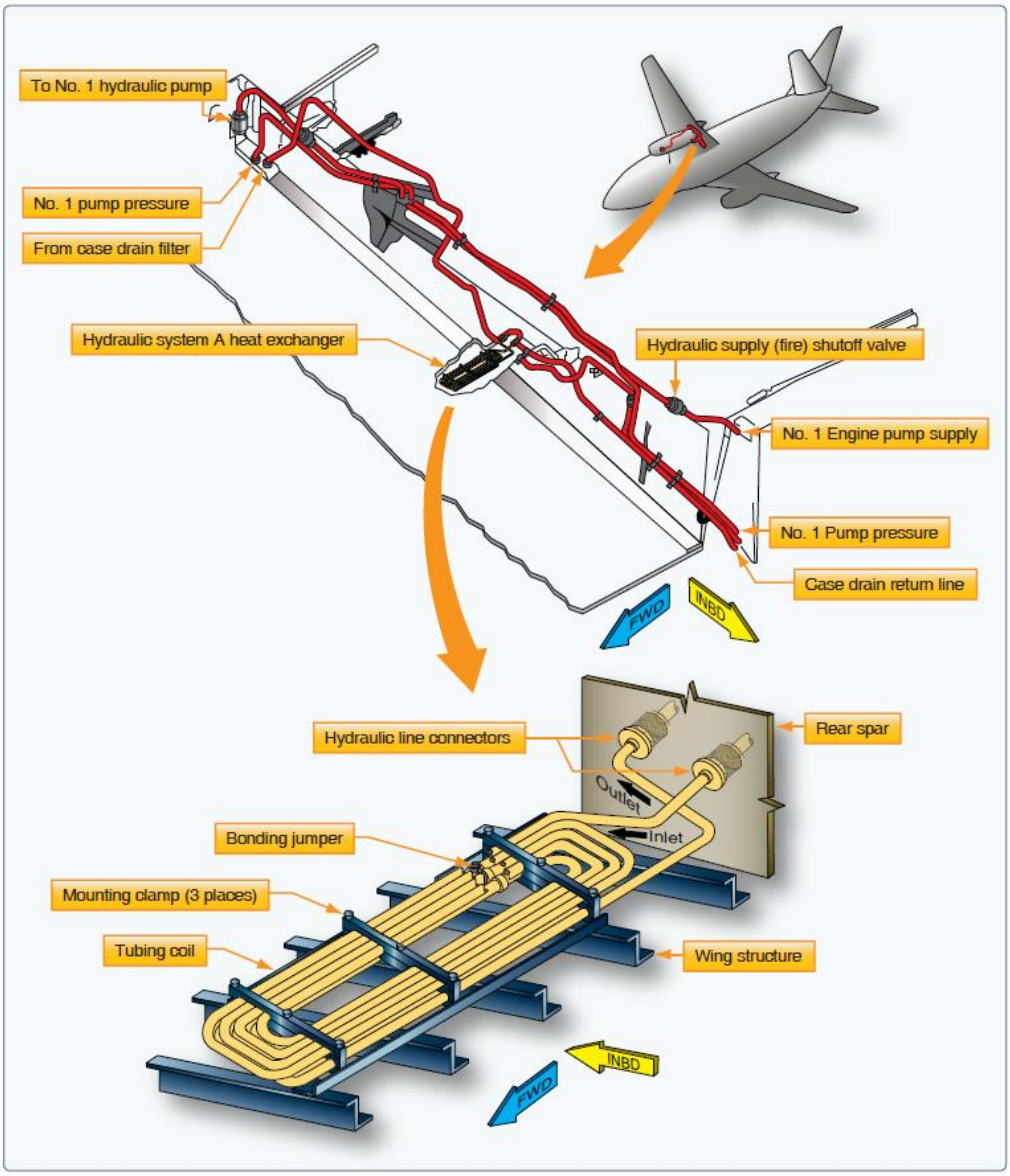
Hydraulic reservoirs on a Boeing 737.



Boeing 737 hydraulic system (simplified).

Pumps

Refer to above *Figure* for the following description. Both A and B hydraulic systems have an engine-driven pump (EDP) and an ACMP. The system A engine-driven pump is installed on the number 1 engine and the system B engine-driven pump is installed on the number 2 engine. The AC pumps are controlled by a switch on the flight deck. The hydraulic case drain fluid that lubricates and cools the pumps return to the reservoir through a heat exchanger.



Boeing 737 hydraulic case drain fluid heat exchanger installed in the fuel tank.

The heat exchanger for the A system is installed in the main fuel tank No. 1, and the heat exchanger for the B system is installed in the main fuel tank No. 2. Minimum fuel for ground operation of electric motor-driven pumps is 1,675 pounds in the related main tank. Pressure switches, located in the EDP and ACMP pump output lines, send signals to illuminate the related LOW PRESSURE light if pump output pressure is low. The related system pressure transmitter sends the combined pressure of the EDP and ACMP to the related hydraulic system pressure indicator.

Filter Units

Filter modules are installed in the pressure, case drain, and return lines to clean the hydraulic fluid. Filters have a differential pressure indicator that pops out when the filter is dirty and needs to be replaced.

Power Transfer Unit (PTU)

The purpose of the PTU is to supply the additional volume of hydraulic fluid needed to operate the auto slats and leading edge flaps and slats at the normal rate when system B EDP malfunctions. The PTU unit consists of a hydraulic motor and hydraulic pump that are connected through a shaft. The PTU uses system A pressure to drive a hydraulic motor. The hydraulic motor of the PTU unit is connected through a shaft with a hydraulic pump that can draw fluid from the system B reservoir. The PTU can only transfer power and cannot transfer fluid. The PTU operates automatically when all of the following conditions are met:

• System B EDP pressure drops below limits.

• Aircraft airborne.

• Flaps are less than 15° but not up.

Landing Gear Transfer Unit

The purpose of the landing gear transfer unit is to supply the volume of hydraulic fluid needed to raise the landing gear at the normal rate when system A EDP is lost. The system B EDP supplies the volume of hydraulic fluid needed to operate the landing gear transfer unit when all of the following conditions are met:

• Aircraft airborne.

• No. 1 engine rpm drops below a limit value.

• Landing gear lever is up.

• Either or both main landing gear not up and locked.

Standby Hydraulic System

The standby hydraulic system is provided as a backup if system A and/or B pressure is lost. The standby system can be activated manually or automatically and uses a single electric ACMP to power:

• Thrust reversers

• Rudder

• Leading edge flaps and slats (extend only)

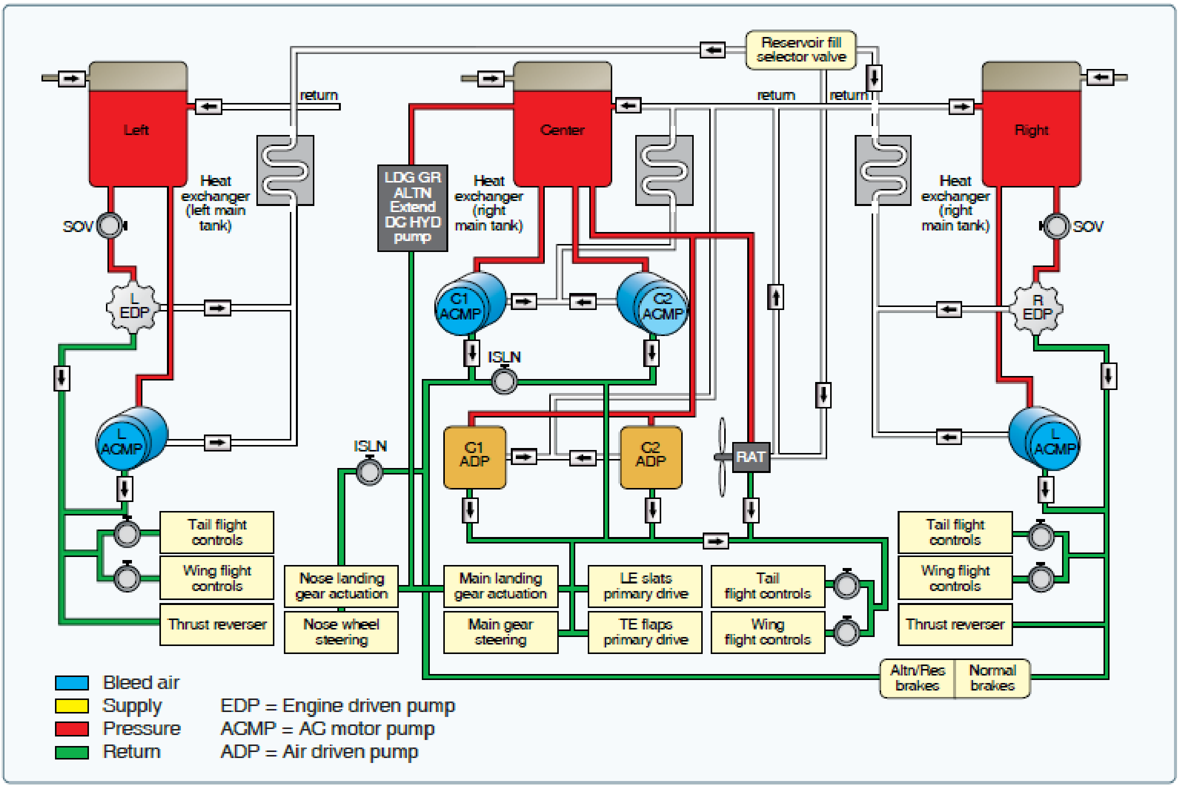
• Standby yaw damper

Indications

A master caution light illuminates if an overheat or low pressure is detected in the hydraulic system. An overheat light on the flight deck illuminates if an overheat is detected in either system A or B and a low-pressure light illuminates if a low pressure is detected in system A and B.

Boeing 777 Hydraulic System

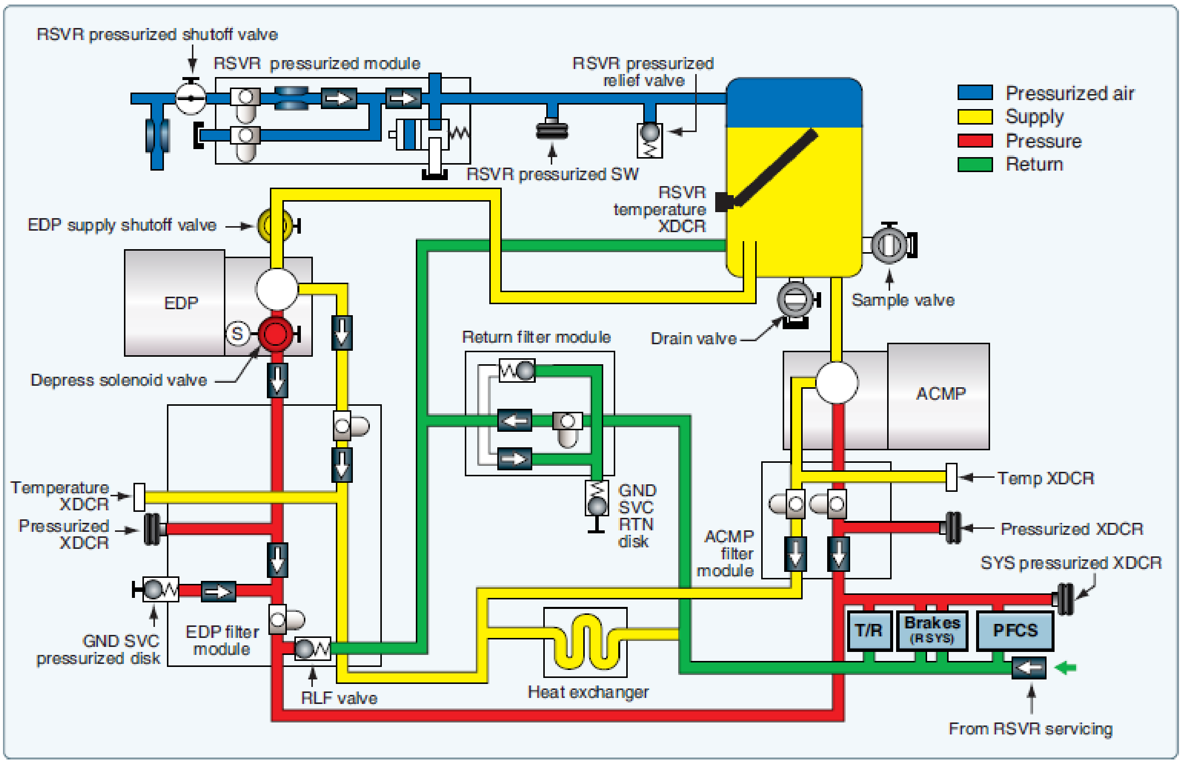
The Boeing 777 is equipped with three hydraulic systems. The left, center, and right systems deliver hydraulic fluid at a rated pressure of 3,000 psi (207 bar) to operate flight controls, flap systems, actuators, landing gear, and brakes. Primary hydraulic power for the left and right systems is provided by two EDPs and supplemented by two on-demand ACMPs. Primary hydraulic power for the center system is provided by two electric motor pumps (ACMP) and supplemented by two on-demand air turbine-driven pumps (ADP). The center system provides hydraulic power for the engine thrust reversers, primary flight controls, landing gear, and flaps/slats. Under emergency conditions, hydraulic power is generated by the ram air turbine (RAT), which is deployed automatically and drives a variable displacement inline pump. The RAT pump provides flow to the center system flight controls.



A Boeing 777 hydraulic system.

Left and Right System Description

The left and right hydraulic systems are functionally the same. The left hydraulic system supplies pressurized hydraulic fluid to operate the left thrust reverser and the flight control systems. The right hydraulic system supplies pressurized hydraulic fluid to operate the right thrust reverser, flight control systems, and the normal brake system.



Right hydraulic system of a Boeing 777. A left system is similar.

Reservoir

The hydraulic system reservoirs of the left and right system contain the hydraulic fluid supply for the hydraulic pumps. The reservoir is pressurized by bleed air through a reservoir pressurization module. The EDP draws fluid through a standpipe. The ACMP draws fluid from the bottom of the reservoir. If the fluid level in the reservoir gets below the standpipe, the EDP cannot draw any fluid any longer, and the ACMP is the only source of hydraulic power. The reservoir can be serviced through a center servicing point in the fuselage of the aircraft. The reservoir has a sample valve for contamination testing purposes, a temperature transmitter for temperature indication on the flight deck, a pressure transducer for reservoir pressure, and a drain valve for reservoir draining.

Pumps

The EDPs are the primary pumps for the left and right hydraulic systems. The EDPs get reservoir fluid through the EDP supply shutoff valves. The EDPs operates whenever the engines operate. A solenoid valve in each EDP controls the pressurization and depressurization of the pump. The pumps are variable displacement inline piston pumps consisting of a first stage impeller pump and a second stage piston pump.

The impeller pump delivers fluid under pressure to the piston pump. The ACMPs are the demand pumps for the left and right hydraulic systems. The ACMPs normally operate only when there is high hydraulic system demand.

Filter Module

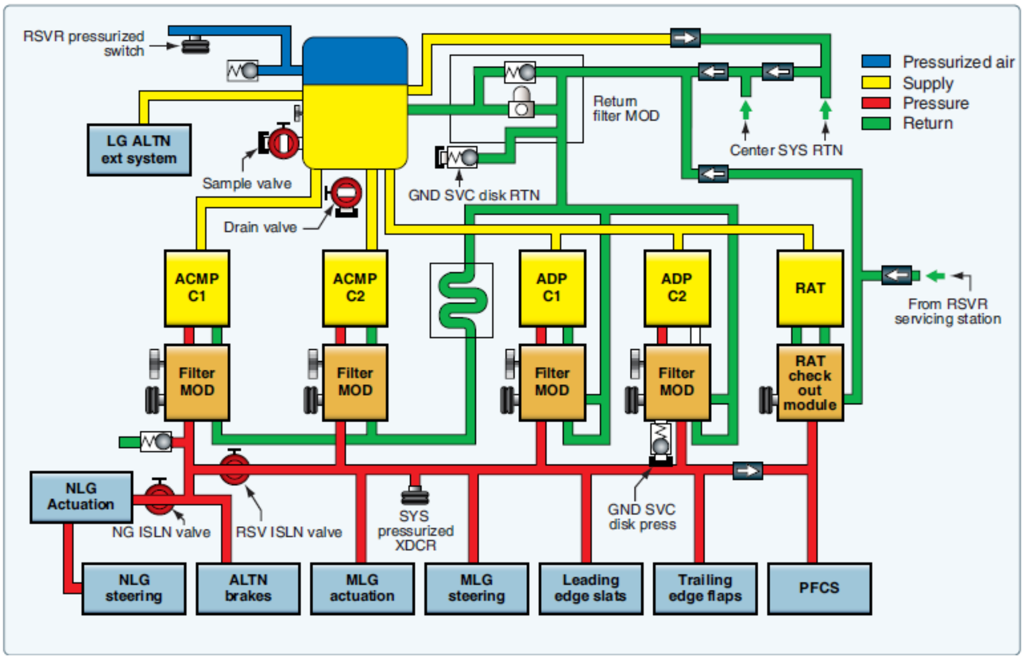
Pressure and case drain filter modules clean the pressure flows and the case drain flows of the hydraulic pumps. A return filter module cleans the return flow of hydraulic fluid from the user systems. The module can be bypassed if the filter clogs, and a visible indicator pops to indicate a clogged filter. The heat exchanger, which is installed in the wing fuel tanks, cools the hydraulic fluid from ACMP and EDP case drain lines before the fluid goes back to the reservoir.

Indication

The hydraulic system sensors send pressure, temperature, and quantity signals to the flight deck. A reservoir quantity transmitter and temperature transducer are installed on each of the reservoirs, and a hydraulic reservoir pressure switch is located on the pneumatic line between the reservoir pressurization module and the reservoir. The ACMP and EDP filter modules each have a pressure transducer to measure pump output pressure. A temperature transducer is installed in the case drain line of each filter module and measures pump case drain fluid temperature. A system pressure transducer measures hydraulic system pressure. A pressure relief valve on the EDP filter module protects the system against over pressurization. (above figure)

Center Hydraulic System

The center hydraulic system supplies pressurized hydraulic fluid to operate these systems:



Center hydraulic system.

• Nose landing gear actuation

• Nose landing gear steering

• Alternate brakes

• Main landing gear actuation

• Main landing gear steering

• Trailing edge flaps

• Leading edge slat

• Flight controls

Reservoir

The hydraulic system reservoir of the center system contains the hydraulic fluid supply for the hydraulic pumps. The reservoir is pressurized by bleed air through a reservoir pressurization module. The reservoir supplies fluid to the ADPs, the RAT, and one of the ACMPs through a standpipe. The other ACMP gets fluid from the bottom of the reservoir. The reservoir also supplies hydraulic fluid to the landing gear alternate extension system.

The ACMPs are the primary pumps in the center hydraulic system and are normally turned on. The ADPs are the demand pumps in the center system. They normally operate only when the center system needs more hydraulic flow capacity. The RAT system supplies an emergency source of hydraulic power to the center hydraulic system flight controls. A reservoir quantity transmitter and temperature transducer are installed on the reservoir. A hydraulic reservoir pressure switch is installed on the pneumatic line between the reservoir and the reservoir pressurization module.

Filter

Filter modules clean the pressure and case drain output of the hydraulic pumps. A return filter module cleans the return flow of hydraulic fluid from the user systems. The module can be bypassed. The heat exchanger cools the hydraulic fluid from the ACMP case drains before the fluid goes back to the reservoir. ADP case drain fluid does not go through the heat exchangers. The ACMP and ADP filter modules each have a pressure transducer to measure pump output pressure. A temperature transducer in each filter module measures the pump case drain temperature. A system pressure transducer measures hydraulic system pressure.

Pressure relief valves in each ADP filter module prevent system overpressurization. A pressure relief valve near ACMP C1 supplies overpressure protection for the center hydraulic isolation system (CHIS).

Center Hydraulic Isolation System (CHIS)

The CHIS supplies engine burst protection and a reserve brakes and steering function. CHIS operation is fully automatic. Relays control the electric motors in the reserve and nose gear isolation valves. When the CHIS system is operational, it prevents hydraulic operation of the leading edge slats.

ACMP C1 gets hydraulic fluid from the bottom of the center system reservoir. All other hydraulic pumps in the center system get fluid through a standpipe in the reservoir. This gives ACMP C1 a 1.2 gallon (4.5 liter) reserve supply of hydraulic fluid. The reserve and nose gear isolation valves are normally open. Both valves close if the quantity in the center system reservoir is low (less than 0.40) and the airspeed is more than 60 knots for more than one second. When CHIS is active, this divides the center hydraulic system into different parts.

The NLG actuation and steering and the leading edge slat hydraulic lines are isolated from center system pressure. The output of ACMP C1 goes only to the alternate brake system. The output of the other center hydraulic system pumps goes to the trailing edge flaps, the MLG actuation and steering, and the flight controls. If there is a leak in the NLG actuation and steering or LE slat lines, there is no further loss of hydraulic fluid. The alternate brakes, the trailing edge flaps, the MLG actuation and steering, and the PFCS continue to operate normally If there is a leak in the trailing edge flaps, the MLG actuation and steering, or the flight control lines, the reservoir loses fluid down to the standpipe level (0.00 indication). This causes a loss of these systems but the alternate brake system continues to get hydraulic power from ACMP C1. If there is a leak in the lines between ACMP C1 and the alternate brake system, all center hydraulic system fluid is lost.

Nose Gear Isolation Valve

The nose gear isolation valve opens for any of these conditions:

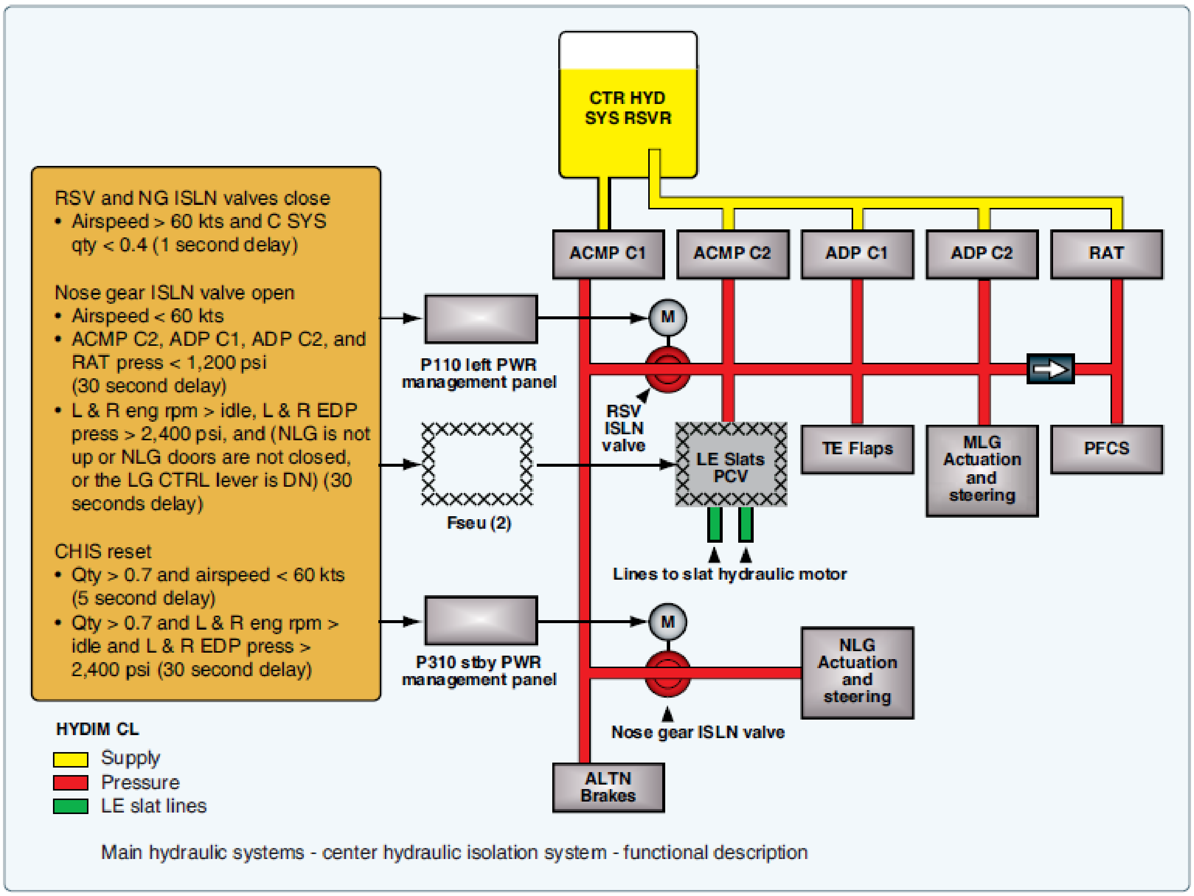
• Airspeed is less than 60 knots.

• Pump pressures for ACMP C2, ADP C1, ADP C2

Left and right engine rpm is above idle, left and right EDP pressure is more than 2,400 psi, and the NLG is not up, the NLG doors are not closed, or the landing gear lever is not up for 30 seconds. The first condition permits the flight crew to operate the LG steering when airspeed is less than 60 knots (decreased rudder control authority during taxi). The second condition permits operation of the NLG actuation and steering if the hydraulic leak is in the part of the center hydraulic system isolated by the reserve isolation valve. The third condition permits operation of the NLG actuation and steering if there has not been an engine burst and the other hydraulic systems are pressurized. The nose gear isolation valve opens when pressure is necessary at the NLG. If the NLG is not fully retracted or the NLG doors are not closed, the nose gear isolation valve opens to let the NLG complete the retraction. When the landing gear lever is moved to the down position, the nose gear isolation valve opens to let the NLG extend with center system pressure.

Central Hydraulic System Reset

Both valves open again automatically when the center system quantity is more than 0.70 and airspeed is less than 60 knots for 5 seconds. Both valves also reset when the center system quantity is more than 0.70 and both engines and both engine-driven pumps operate normally for 30 seconds.



Center hydraulic isolation system.

Advantages of Hydraulic system

1. Large load capacity with almost high accuracy and precision.

2. Smooth movement.

3. Automatic lubricating provision to reduce to wear.

4. Division and distribution of hydraulic force are easily performed.

5. Limiting and balancing of hydraulic forces are easily performed.

Disadvantages of Hydraulic system

1. A hydraulic element needs to be machined to a high degree of precision.

2. Leakage of hydraulic oil poses a problem to hydraulic operators.

3. Special treatment is needed to protect them from rust, corrosion, dirt etc.,

4. Hydraulic oil may pose problems if it disintegrates due to aging and chemical deterioration.

5. Hydraulic oils are messy and almost highly flammable.

Merits and Demerits

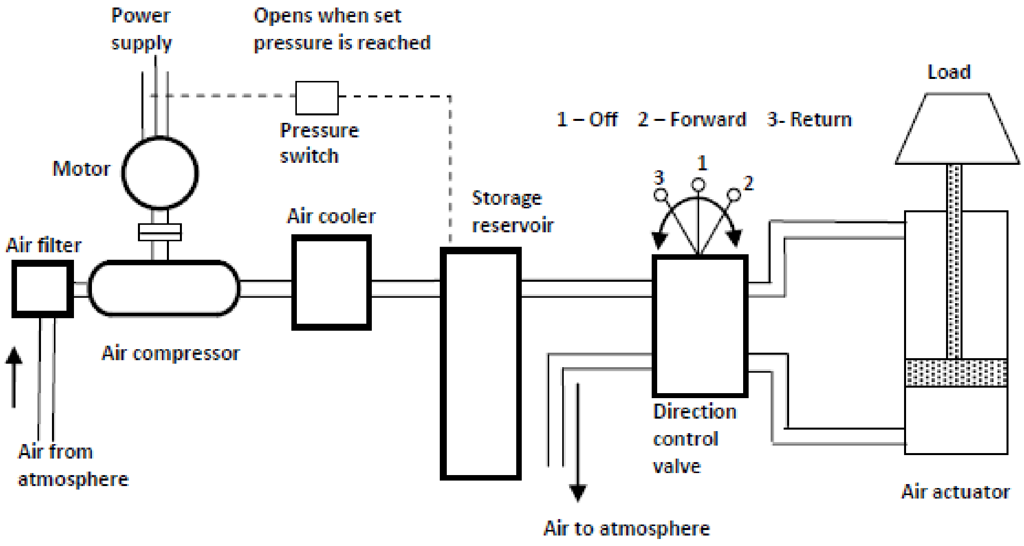
- Ease and accuracy of control: By the use of simple levers and push buttons, the operator of a hydraulic system can easily start, stop, speed up and slow down.
- Multiplication of force: A fluid power system (without using cumbersome gears, pulleys and levers) can multiply forces simply and efficiently from a fraction of a pound, to several hundred tons of output.
- Constant force and torque: Only fluid power systems are capable of providing a constant torque or force regardless of speed changes.
- Simple, safe and economical: In general, hydraulic systems use fewer moving parts in comparison with mechanical and electrical systems. Thus they become simpler and easier to maintain.

In spite of possessing all these highly desirable features, hydraulic systems also have certain drawbacks, some of which are:

  - Handling of hydraulic oils which can be quite messy. It is also very difficult to completely eliminate leakage in a hydraulic system.
  - Hydraulic lines can burst causing serious human injuries.
  - Most hydraulic fluids have a tendency to catch fire in the event of leakage, especially in hot regions.

PNEUMATIC SYSTEM

A pneumatic system carries power by employing compressed gas, generally air, as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work.



Basic Pneumatic System Components

Pneumatic System Components

- Pneumatic actuator
- Compressor
- reservoir
- Valves
- Air filter
- Air cooler
- External power supply (Motor)

The functions of various components shown in Figure are as follows:

1. The pneumatic actuator converts the fluid power into mechanical power to perform useful work.

2. The compressor is used to compress the fresh air drawn from the atmosphere.

3. The storage reservoir is used to store a given volume of compressed air.

4. The valves are used to control the direction, flow rate and pressure of compressed air.

5. External power supply (motor) is used to drive the compressor.

6. The piping system carries the pressurized air from one location to another.

Air is drawn from the atmosphere through air filter and raised to required pressure by an air compressor. As the pressure rises, the temperature also rises and hence air cooler is provided to cool the air with some preliminary treatment to remove the moisture.

Then the treatment pressurized air needs to get stored to maintain the pressure. With the storage reservoir, a pressure switch is fitted to start and stop the electric motor when pressure falls and reached the required level, respectively.

The cylinder movement is controlled by pneumatic valve. One side of the pneumatic valve is connected to the compressed air and silencers for the exhaust air and the other side of the valve is connected to port A and Port B of the cylinder.

Position of the valve is as follows

1. **Raise:** To lift the weight, the compressed air supply is connected to port A and the port B is connected to the exhaust line, by moving the valve position to the “Raise”

2. **Lower:** To bring the weight down, the compressed air line is connected to port B and port A is connected to exhaust air line, by moving the valve position to the “lower”

3**. Off:** The weight can be stopped at a particular position by moving the valve to position to “Off” position. This disconnects the port A and port B from the pressurized line and the retrieval line, which locks the air in the cylinder.

AIRCRAFT PNEUMATIC SYSTEMS

Some aircraft manufacturers have equipped their aircraft with a high pressure pneumatic system (3,000 psi) in the past. The last aircraft to utilize this type of system was the Fokker F27. Such systems operate a great deal like hydraulic systems, except they employ air instead of a liquid for transmitting power. Pneumatic systems are sometimes used for:

• Brakes

• Opening and closing doors

• Driving hydraulic pumps, alternators, starters, water injection pumps, etc.

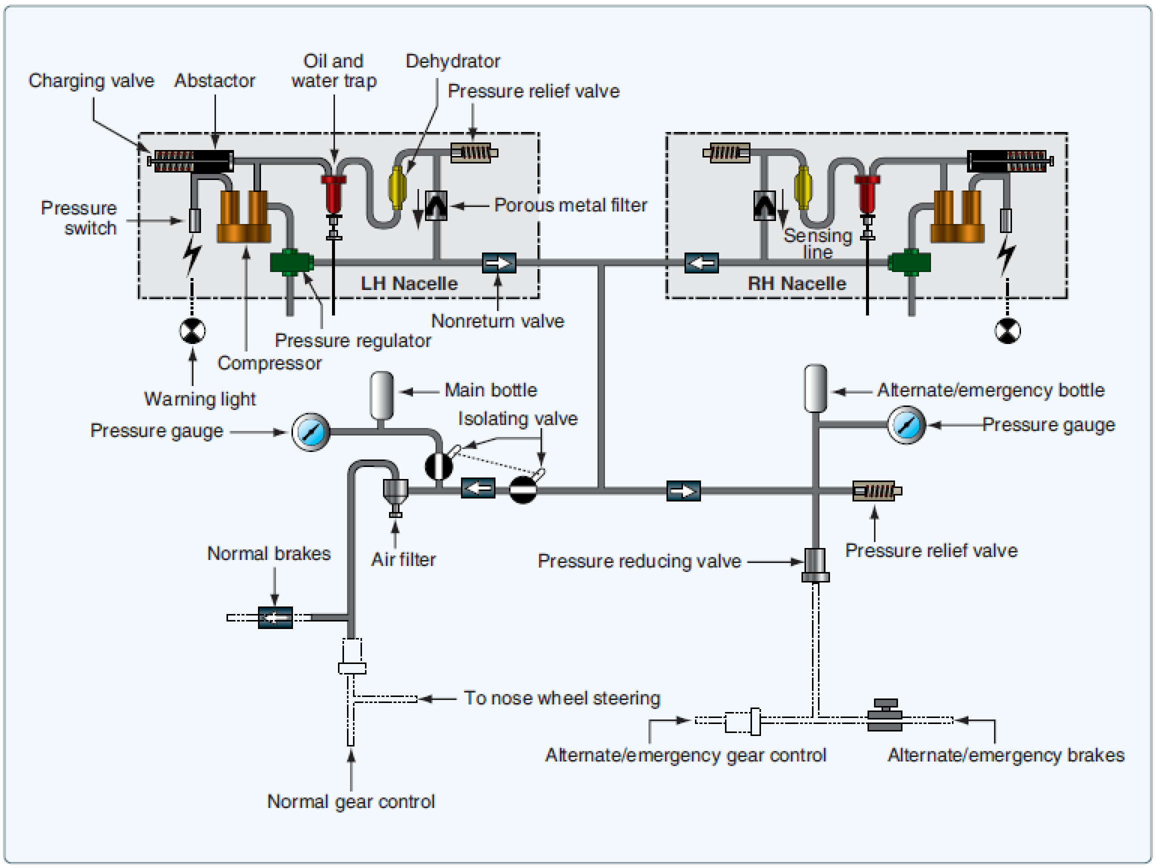
• Operating emergency devices

Both pneumatic and hydraulic systems are similar units and use confined fluids. The word confined means trapped or completely enclosed. The word fluid implies such liquids as water, oil, or anything that flows. Since both liquids and gases flow, they are considered as fluids; however, there is a great deal of difference in the characteristics of the two.

Liquids are practically incompressible; a quart of water still occupies about a quart of space regardless of how hard it is compressed. But gases are highly compressible; a quart of air can be compressed into a thimbleful of space. In spite of this difference, gases and liquids are both fluids and can be confined and made to transmit power. The type of unit used to provide pressurized air for pneumatic systems is determined by the system’s air pressure requirements.

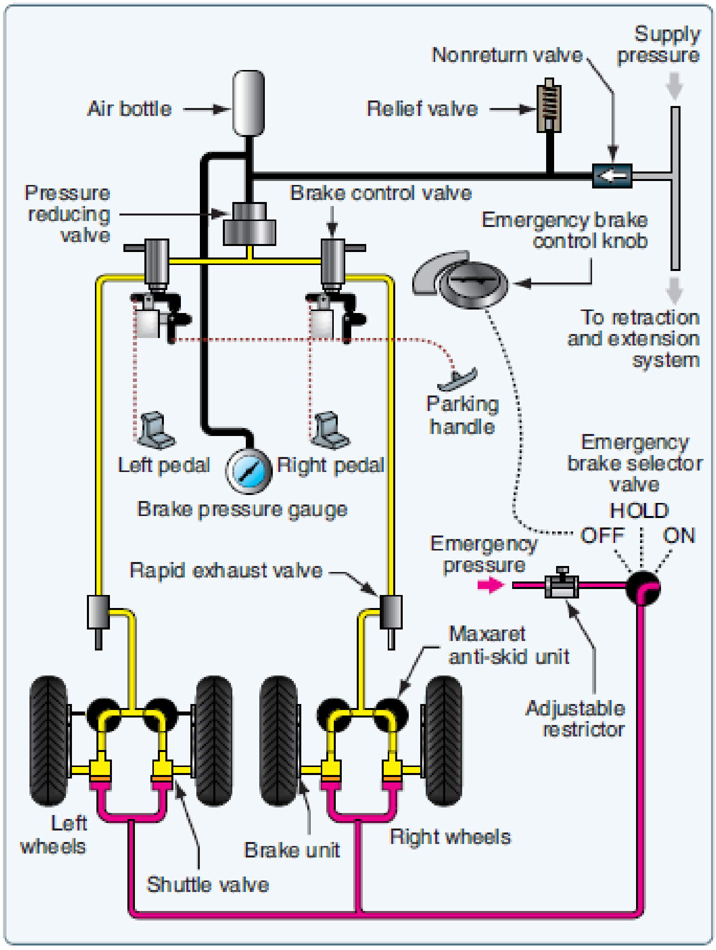
High-Pressure Systems

For high-pressure systems, air is usually stored in metal bottles at pressures ranging from 1,000 to 3,000 psi, depending on the particular system. This type of air bottle has two valves, one of which is a charging valve. A ground-operated compressor can be connected to this valve to add air to the bottle.



High-pressure pneumatic system.

The other valve is a control valve. It acts as a shutoff valve, keeping air trapped inside the bottle until the system is operated. Although the high-pressure storage cylinder is light in weight, it has a definite disadvantage. Since the system cannot be recharged during flight, operation is limited by the small supply of bottled air. Such an arrangement cannot be used for the continuous operation of a system. Instead, the supply of bottled air is reserved for emergency operation of such systems as the landing gear or brakes. The usefulness of this type of system is increased, however, if other air-pressurizing units are added to the aircraft.



Pneumatic brake system.

Pneumatic System Components

Pneumatic systems are often compared to hydraulic systems, but such comparisons can only hold true in general terms. Pneumatic systems do not utilize reservoirs, hand pumps, accumulators, regulators, or engine-driven or electrically driven power pumps for building normal pressure. But similarities do exist in some components.

Air Compressors

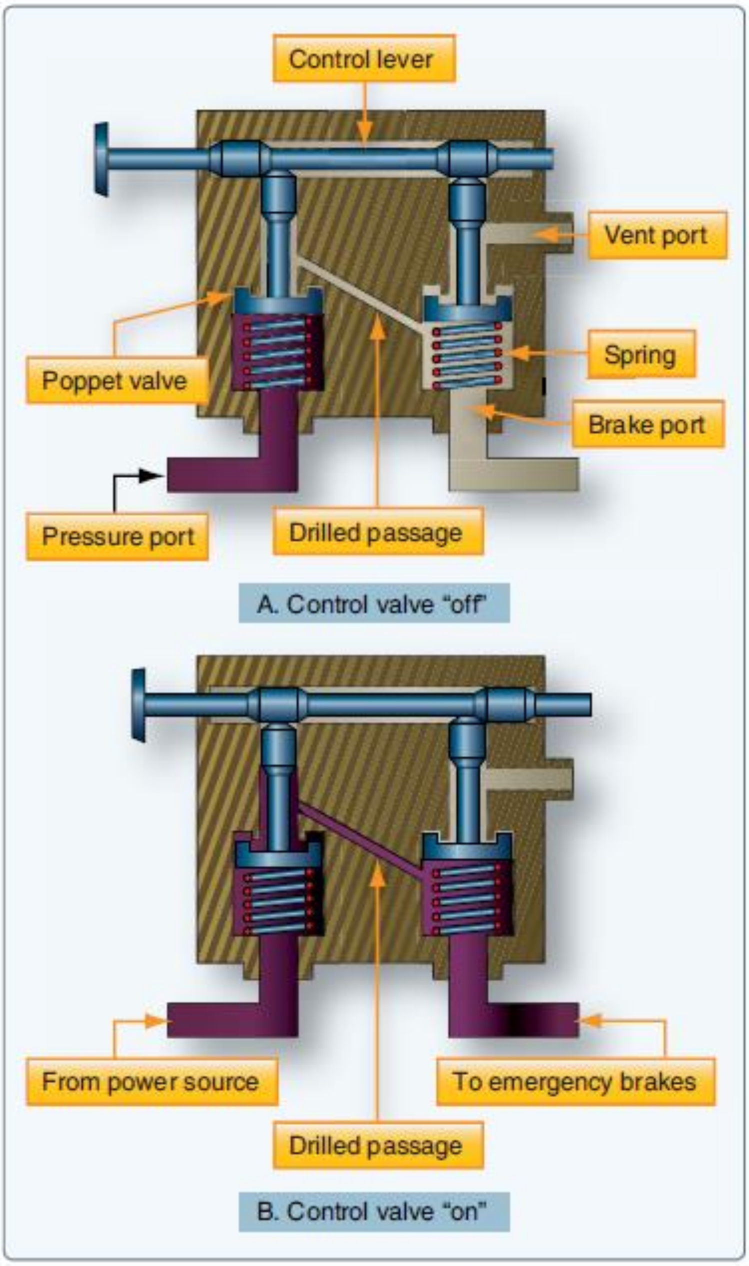
On some aircraft, permanently installed air compressors have been added to recharge air bottles whenever pressure is used for operating a unit. Several types of compressors are used for this purpose. Some have two stages of compression, while others have three, depending on the maximum desired operating pressure.

Relief Valves

Relief valves are used in pneumatic systems to prevent damage. They act as pressure limiting units and prevent excessive pressures from bursting lines and blowing out seals.

Control Valves

Control valves are also a necessary part of a typical pneumatic system.



Pneumatic control valve.

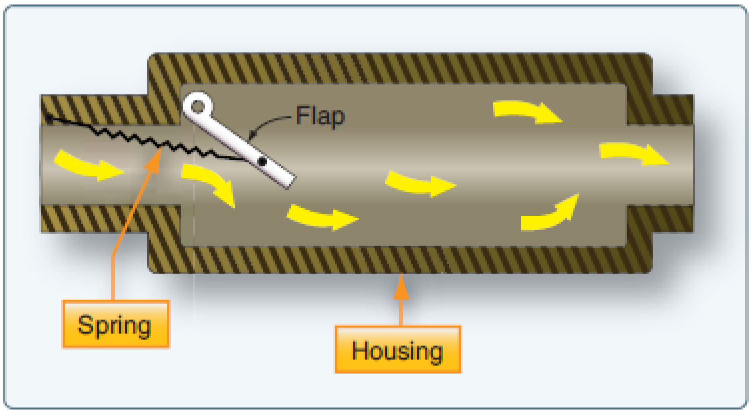
Figure illustrates how a valve is used to control emergency air brakes. The control valve consists of three-port housing, two poppet valves, and a control lever with two lobes.

In *Figure A,* the control valve is shown in the off position. A spring holds the left poppet closed so that compressed air entering the pressure port cannot flow to the brakes. In *Figure-B,* the control valve has been placed in the on position. One lobe of the lever holds the left poppet open, and a spring closes the right poppet. Compressed air now flows around the opened left poppet, through a drilled passage, and into a chamber below the right poppet.

Since the right poppet is closed, the high-pressure air flows out of the brake port and into the brake line to apply the brakes. To release the brakes, the control valve is returned to the off position. *[Figure A]* The left poppet now closes, stopping the flow of high-pressure air to the brakes. At the same time, the right poppet is opened, allowing compressed air in the brake line to exhaust through the vent port and into the atmosphere.

Check Valves

Check valves are used in both hydraulic and pneumatic systems. *Figure* illustrates a flap-type pneumatic check valve.

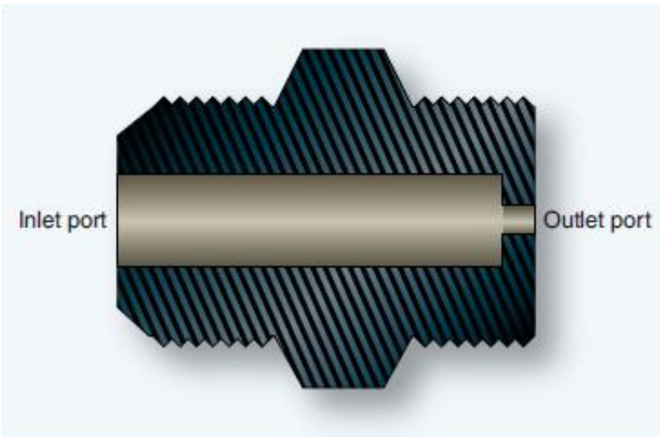


Flap-type pneumatic check valve.

Air enters the left port of the check valve, compresses a light spring, forcing the check valve open and allowing air to flow out the right port. But if air enters from the right, air pressure closes the valve, preventing a flow of air out the left port. Thus, a pneumatic check valve is a one-direction flow control valve.

Restrictors

Restrictors are a type of control valve used in pneumatic systems. *Figure* illustrates an orifice-type restrictor with a large inlet port and a small outlet port.

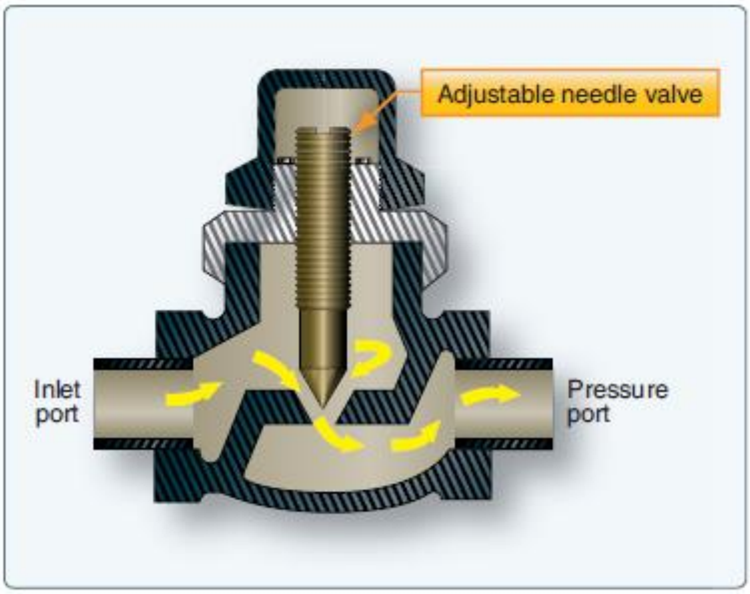


Pneumatic orifice valve.

The small outlet port reduces the rate of airflow and the speed of operation of an actuating unit.

Variable Restrictor

Another type of speed-regulating unit is the variable restrictor.



Variable pneumatic restrictor.

It contains an adjustable needle valve, which has threads around the top and a point on the lower end. Depending on the direction turned, the needle valve moves the sharp point either into or out of a small opening to decrease or increase the size of the opening. Since air entering the inlet port must pass through this opening before reaching the outlet port, this adjustment also determines the rate of airflow through the restrictor.

Filters

Pneumatic systems are protected against dirt by means of various types of filters. A micronic filter consists of housing with two ports, a replaceable cartridge, and a relief valve. Normally, air enters the inlet, circulates around the cellulose cartridge, and flows to the center of the cartridge and out the outlet port. If the cartridge becomes clogged with dirt, pressure forces the relief valve open and allows unfiltered air to flow out the outlet port.

A screen-type filter is similar to the micron filter but contains a permanent wire screen instead of a replaceable cartridge. In the screen filter, a handle extends through the top of the housing and can be used to clean the screen by rotating it against metal scrapers.

Desiccant/Moisture Separator

The moisture separator in a pneumatic system is always located downstream of the compressor. Its purpose is to remove any moisture caused by the compressor. A complete moisture separator consists of a reservoir, a pressure switch, a dump valve, and a check valve.

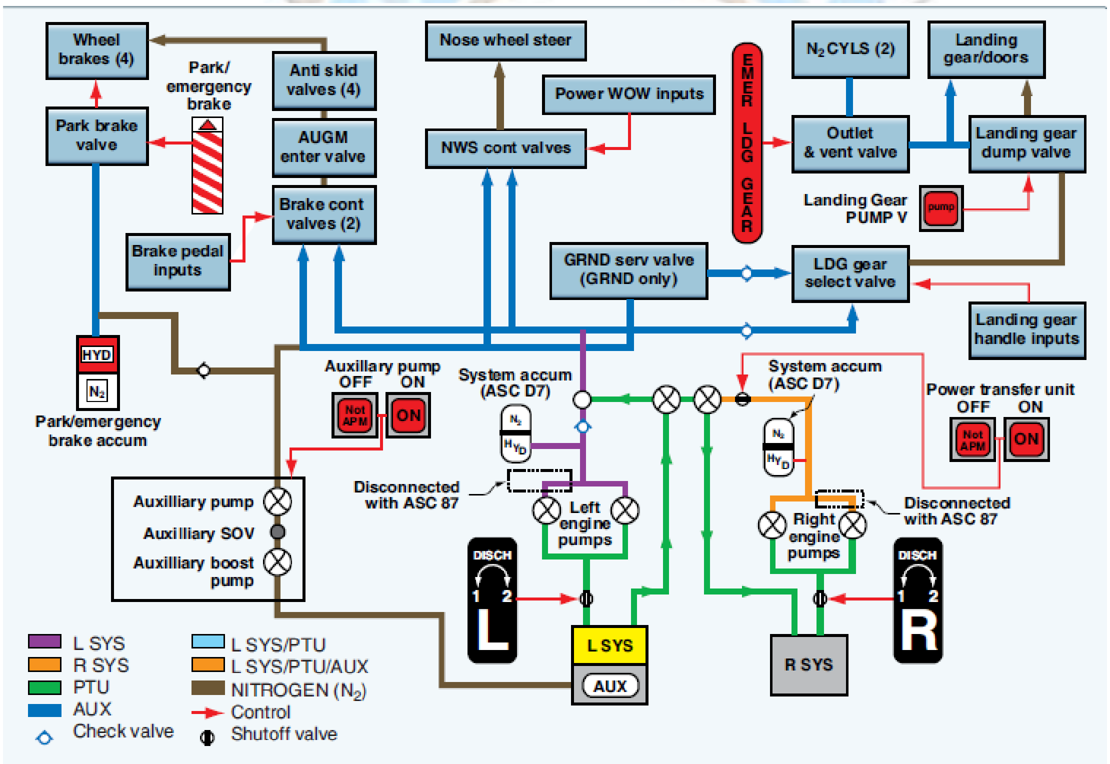
It may also include a regulator and a relief valve. The dump valve is energized and deenergized by the pressure switch. When deenergized, it completely purges the separator reservoir and lines up to the compressor. The check valve protects the system against pressure loss during the dumping cycle and prevents reverse flow through the separator.

Chemical Drier

Chemical driers are incorporated at various locations in a pneumatic system. Their purpose is to absorb any moisture that may collect in the lines and other parts of the system. Each drier contains a cartridge that should be blue in color. If otherwise noted, the cartridge is to be considered contaminated with moisture and should be replaced.

Emergency Backup Systems

Many aircraft use a high-pressure pneumatic back-up source of power to extend the landing gear or actuate the brakes, if the main hydraulic braking system fails. The nitrogen is not directly used to actuate the landing gear actuators or brake units but, instead, it applies the pressurized nitrogen to move hydraulic fluid to the actuator. This process is called pneudraulics. The following paragraph discusses the components and operation of an emergency pneumatic landing gear extension system used on a business jet.



Pneumatic emergency landing gear extension system.

Nitrogen Bottles

Nitrogen used for emergency landing gear extension is stored in two bottles, one bottle located on each side of the nose wheel well. Nitrogen from the bottles is released by actuation of an outlet valve. Once depleted, the bottles must be recharged by maintenance personnel. Fully serviced pressure is approximately 3,100 psi at 70 °F/21 °C, enough for only one extension of the landing gear.

Gear Emergency Extension Cable and Handle

The outlet valve is connected to a cable and handles assembly. The handle is located on the side of the co-pilot's console and is labelled EMER LDG GEAR. Pulling the handle fully upward opens the outlet valve, releasing compressed nitrogen into the landing gear extension system. Pushing the handle fully downward closes the outlet valve and allows any nitrogen present in the emergency landing gear extension system to be vented overboard. The venting process takes approximately 30 seconds.

Dump Valve

As compressed nitrogen is released to the landing gear selector/dump valve during emergency extension, the pneudraulic pressure actuates the dump valve portion of the landing gear selector/dump valve to isolate the landing gear system from the remainder of hydraulic system. When activated, a blue DUMP legend is illuminated on the LDG GR DUMP V switch, located on the cockpit overhead panel. A dump valve reset switch is used to reset the dump valve after the system has been used and serviced.

Emergency Extension Sequence:

1. Landing gear handle is placed in the DOWN position.

2. Red light in the landing gear control handle is illuminated.

3. EMER LDG GEAR handle is pulled fully outward.

4. Compressed nitrogen is released to the landing gear selector/dump valve.

5. Pneudraulic pressure actuates the dump valve portion of the landing gear selector/dump valve.

6. Blue DUMP legend is illuminated on the LDG GR DUMP switch.

7. Landing gear system is isolated from the remainder of hydraulic system.

8. Pneudraulic pressure is routed to the OPEN side of the landing gear door actuators, the UNLOCK side of the landing gear up lock actuators, and the EXTEND side of the main landing gear side brace actuators and nose landing gear extend/retract actuator.

9. Landing gear doors open.

10. Up lock actuators unlock.

11. Landing gear extends down and locks.

12. Three green DOWN AND LOCKED lights on the landing gear control panel are illuminated.

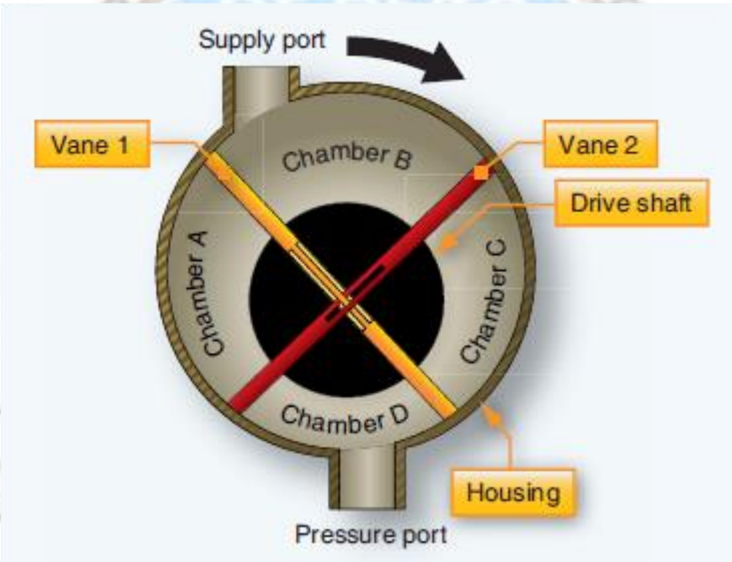
13. Landing gear doors remain open.

Medium-Pressure Systems

A medium-pressure pneumatic system (50–150 psi) usually does not include an air bottle. Instead, it generally draws air from the compressor section of a turbine engine. This process is often called bleed air and is used to provide pneumatic power for engine starts, engine de-icing, wing de-icing, and in some cases, it provides hydraulic power to the aircraft systems (if the hydraulic system is equipped with an air-driven hydraulic pump). Engine bleed air is also used to pressurize the reservoirs of the hydraulic system.

Low-Pressure Systems

Many aircraft equipped with reciprocating engines obtain a supply of low-pressure air from vane-type pumps. These pumps are driven by electric motors or by the aircraft engine.



Schematic of vane-type air pump.

Figure shows a schematic view of one of these pumps, which consists of housing with two ports, a drive shaft, and two vanes. The drive shaft and the vanes contain slots so the vanes can slide back and forth through the drive shaft. The shaft is eccentrically mounted in the housing, causing the vanes to form four different sizes of chambers (A, B, C, and D).

In the position shown, B is the largest chamber and is connected to the supply port. As depicted in *Figure,* outside air can enter chamber B of the pump. When the pump begins to operate, the drive shaft rotates and changes positions of the vanes and sizes of the chambers. Vane No.1 then moves to the right, separating chamber B from the supply port. Chamber B now contains trapped air. As the shaft continues to turn, chamber B moves downward and becomes increasingly smaller, gradually compressing its air. Near the bottom of the pump, chamber B connects to the pressure port and sends compressed air into the pressure line.

Then chamber B moves upward again becoming increasingly larger in area. At the supply port, it receives another supply of air. There are four such chambers in this pump and each goes through this same cycle of operation. Thus, the pump delivers to the pneumatic system a continuous supply of compressed air from 1 to 10 psi. Low-pressure systems are used for wing de-icing boot systems.

Pneumatic Power System Maintenance

Maintenance of the pneumatic power system consists of servicing, troubleshooting, removal, and installation of components, and operational testing. The air compressor's lubricating oil level should be checked daily in accordance with the applicable manufacturer's instructions. The oil level is indicated by means of a sight gauge or dipstick. When refilling the compressor oil tank, the oil (type specified in the applicable instructions manual) is added until the specified level. After the oil is added, ensure that the filler plug is torque and safety wire is properly installed. The pneumatic system should be purged periodically to remove the contamination, moisture, or oil from the components and lines. Purging the system is accomplished by pressurizing it and removing the plumbing from various components throughout the system. Removal of the pressurized lines causes a high rate of airflow through the system, causing foreign matter to be exhausted from the system. If an excessive amount of foreign matter, particularly oil, is exhausted from any one system, the lines and components should be removed and cleaned or replaced. Upon completion of pneumatic system purging and after reconnecting all the system components, the system air bottles should be drained to exhaust any moisture or impurities that may have accumulated there.

After draining the air bottles, service the system with nitrogen or clean, dry compressed air. The system should then be given a thorough operational check and an inspection for leaks and security.

Advantages of Pneumatic system

- Low inertia effect of pneumatic components due to low density of air.
- Pneumatic Systems are light in weight.
- Operating elements are cheaper and easy to operate
- Power losses are less due to low viscosity of air
- High output to weight ratio
- Pneumatic systems offers a safe power source in explosive environment
- Leakage is less and does not influence the systems. Moreover, leakage is not harmful

Disadvantages of Pneumatic systems

- Suitable only for low pressure and hence low force applications
- Compressed air actuators are economical up to 50 kN only.
- Generation of the compressed air is expensive compared to electricity
- Exhaust air noise is unpleasant and silence has to be used.
- Rigidity of the system is poor
- Weight to pressure ratio is large

- Less precise. It is not possible to achieve uniform speed due to compressibility of air
- Pneumatic systems is vulnerable to dirt and contamination

Advantages and Disadvantages of compressed air

Advantages of compressed air	Disadvantages of compressed air
Air is available in unlimited quantities Compressed air is easily conveyed in pipelines even over longer distances	Compressive air is relatively expensive means of conveying energy The higher costs are, however. Largely compensated by the cheaper elements. Simpler and more compact equipment
Compressed air can be stored	Compressed air requires good conditioning. No dirt or moisture residues may be contained in it. Dirt and dust leads to wear on tools and equipment
Compressed air need not be returned. It can be vented to atmosphere after it has performed work	It is not possible to achieve uniform and constant piston speeds(air is compressible)
Compressed air is insensitive to temperature fluctuation. This ensures reliable operation even in extreme temperature conditions	Compressed air is economical only up to certain force expenditure. Owing to the commonly used pressure of 7 bar and limit is about 20 to 50 kN, depending on the travel and the speed. If the force which is required exceeds this level, hydraulics is preferred
Compressed air is clean. This is especially important in food, pharmaceutical, textile, beverage industries	The exhaust is loud. As the result of intensive development work on materials for silencing purposes, this problems has however now largely been solved
Operating elements for compressed air operation are of simple and inexpensive construction.	The oil mist mixed with the air for lubricating the equipment escapes with the exhaust to atmosphere.
Compressed air is fast. Thus, high operational speed can be attained.	Air due to its low conductivity , cannot dissipate heat as much as hydraulic fluid
Speeds and forces of the pneumatics elements can be infinitely adjusted	Air cannot seal the fine gaps between the moving parts unlike hydraulic system
Tools and operating elements are overload proof. Straight line movement can be produced directly	Air is not a good lubricating medium unlike hydraulic fluid.

Comparison between Hydraulic and Pneumatic systems

Sl. No	Hydraulic system	Pneumatic system
1	It employs a pressurized liquid as fluid	it employs a compressed gas usually air as a fluid
2	Oil hydraulics system operates at pressures upto 700 bar.	Pneumatics systems usually operate at 5 to 10 bar.
3	Generally designed for closed systems	Pneumatic systems are usually designed as open system

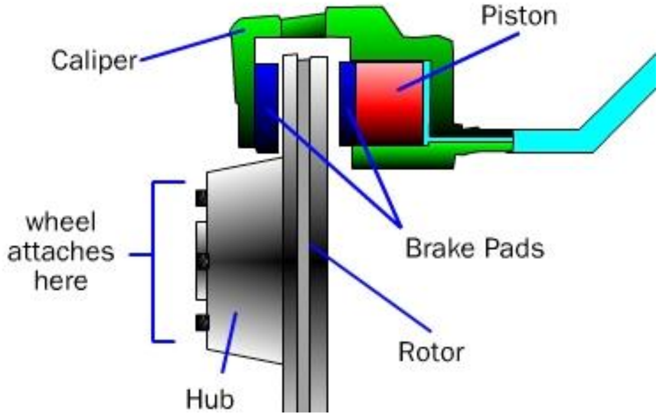
4	System get slow down of leakage occurs	Leakage does not affect the system much more
5	Valve operations are difficult	Easy to operate the valves
6	Heavier in weight	Light in weight
7	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gas
8	System is unsafe to fire hazards	System is free from fire hazards
9	Automatic lubrication is provided	Special arrangements for lubrication needed

AIRCRAFT BRAKING SYSTEM

Brakes are responsible for conversion of excess kinetic energy into thermal energy by increasing the friction. Increasing the amount of friction (i.e. is the resistance offered to motion of a vehicle) reduces the speed of motion of the vehicle. Braking systems employ this principle for slowing down or stopping the vehicles .Braking systems in aircraft are of three basic types: mechanical, hydraulic and pneumatic brakes.

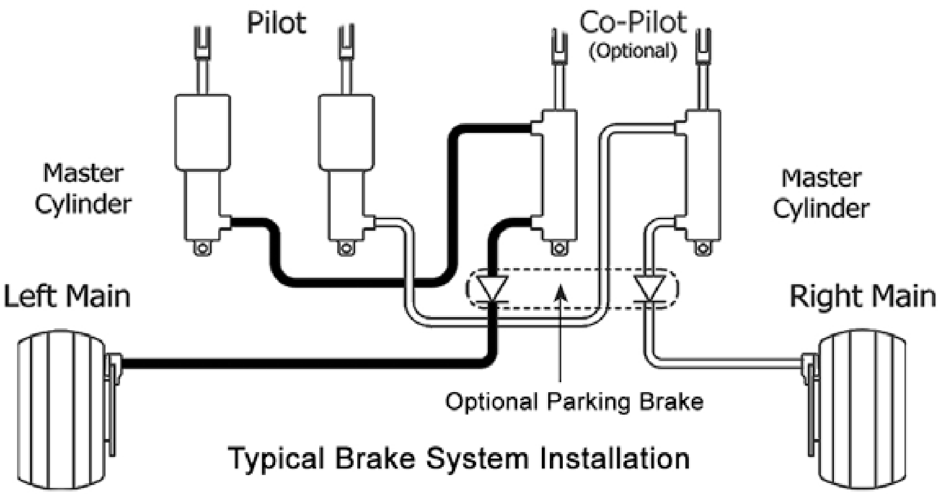
Mechanical brakes are those which are operated by the use of linkages, levers cams etc. Hydraulic brakes make use of fluid pressure for transmission of pressure to the braking components while Pneumatic brakes use air pressure for transmitting brake power. These systems either increase the surrounding air drag with the help of airbrakes, spoilers, flaps, reverse thrusters, drag chutes, etc or increase the ground drag using anchors, skids etc for effective braking.

Aircraft typically use disc and multi-disc brakes .It mainly consists of rotating disc attached to the wheel assembly, brake callipers which are held stationary and contains the brake pads made of material such as asbestos, ceramics, carbon etc. When brake pedal is pressed, brake fluid under pressure flows from master cylinder to the slave cylinder via tubes. The slave cylinder consists of piston which gets actuated by the force of incoming fluid pressure. The piston forces the brake pads against the rotating disc. The friction between the brake pad and disc surface, resist its rotating motion and stops it. Disc brakes used these days are differential type i.e. the left and right unit are independent of one another. This also provides increased manoeuvrability.



Aircraft Disc Brakes

Multiple disc brakes consist of series of discs, the steel stators which is a stationary unit is keyed to the bearing carrier and the rotors form the rotating part and are keyed to the wheel. Automatic adjuster is used for providing clearance between the rotor and stator layers. Under the action of hydraulic pressure, these series of disc get compressed, forcing the wheel to slow down due to friction. These days the discs are provided with slots for better heat dissipation at high temperature. Also, Carbon fibre is being extensively used as rotor material for the brakes because of its low weight and the ability to withstand high heat and temperature. Although it requires lesser maintenance than the conventional brakes but the cost of manufacturing is comparatively high.



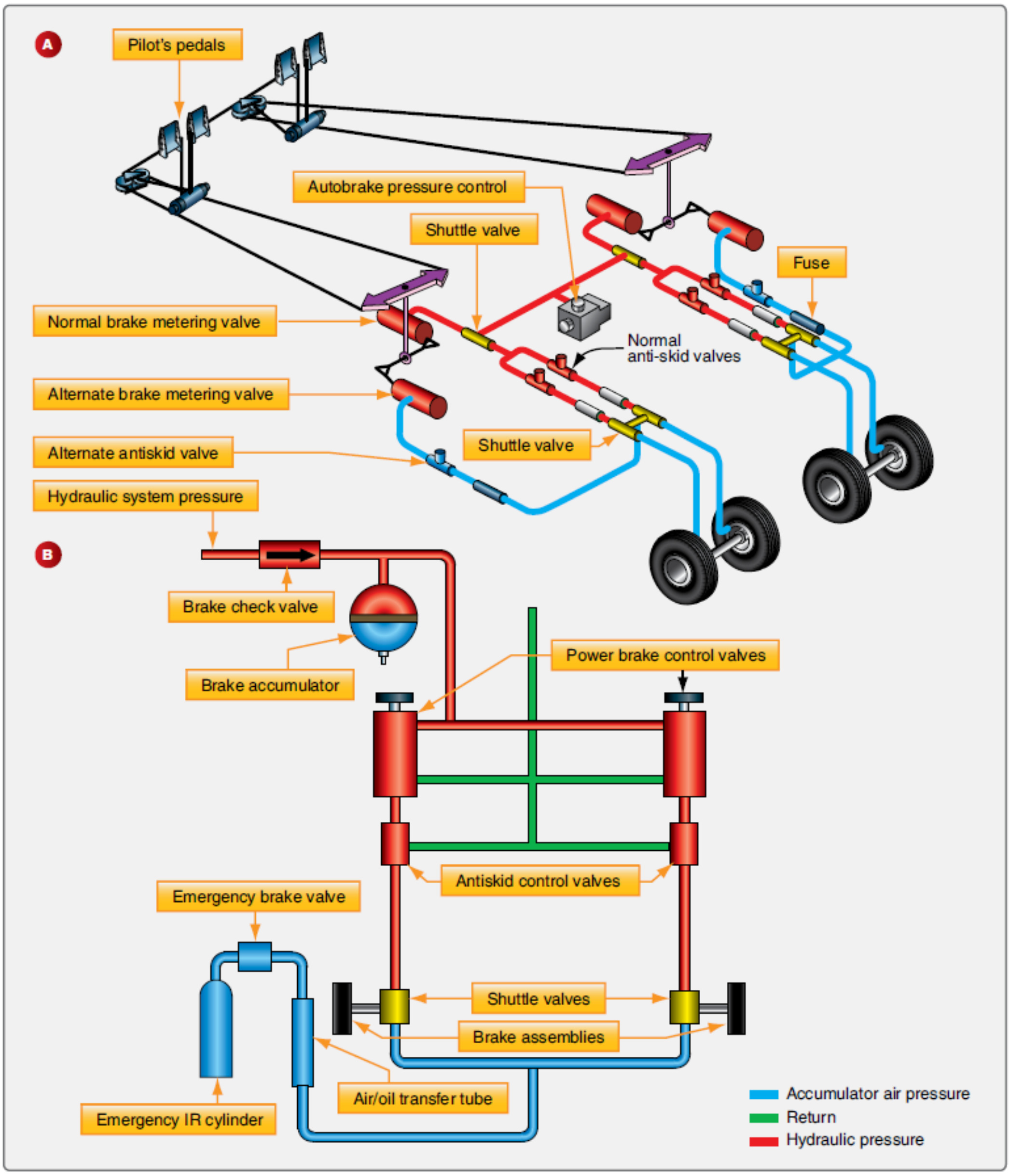
Illustrated to the right is the hydraulic portion of a typical aircraft brake system. In the illustration, the master cylinders on the pilot side incorporate an integral reservoir. Whether you use a master cylinder with integral reservoir, or remote reservoir, the most upstream component must be a reservoir.
It is critically important that the installation allows the brake cylinder piston rod to fully extend when no load is applied.

Types and Construction of Aircraft Brakes

- Single Disc Brakes
- Floating Disc Brakes
- Fixed-Disc Brakes
- Dual-Disc Brakes
- Multiple-Disc Brakes
- Segmented Rotor-Disc Brakes
- Carbon Brakes
- Expander Tube Brakes

Brake Actuating Systems

Different means of delivering the required hydraulic fluid pressure to brake assemblies are discussed in this section. There are three basic actuating systems:
1. An independent system not part of the aircraft main hydraulic system;
2. A booster system that uses the aircraft hydraulic system intermittently when needed; and
3. A power brake system that only uses the aircraft main hydraulic system(s) as a source of pressure.



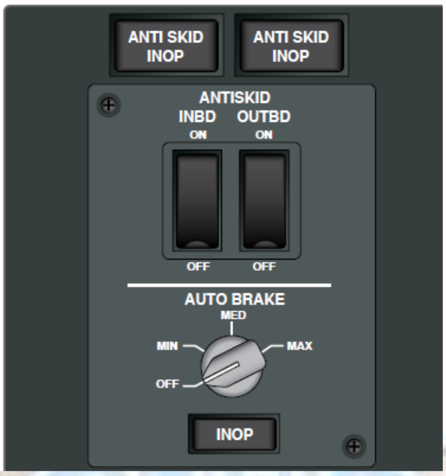
The orientation of components in a basic power brake system is shown in A. The general layout of an airliner power brake system is shown in B.

Anti-Skid

Large aircraft with power brakes require anti-skid systems. It is not possible to immediately ascertain in the flight deck when a wheel stops rotating and begins to skid, especially in aircraft with multiple-wheel main landing gear assemblies. A skid not corrected can quickly lead to a tire blowout, possible damage to the aircraft, and control of the aircraft may be lost.

System Operation

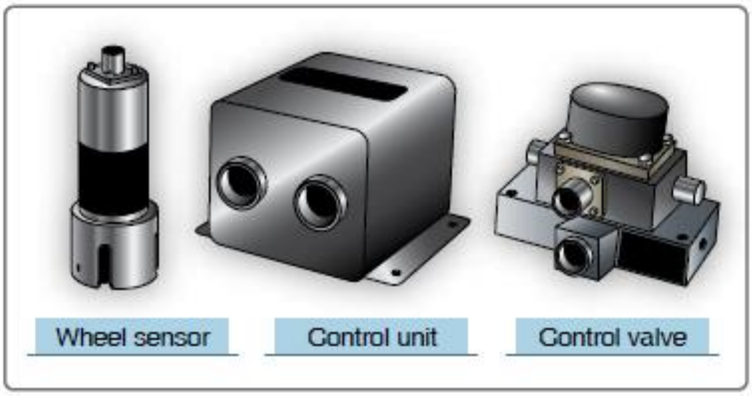
The anti-skid system not only detects wheel skid, it also detects when wheel skid is imminent. It automatically relieves pressure to the brake pistons of the wheel in question by momentarily connecting the pressurized brake fluid area to the hydraulic system return line. This allows the wheel to rotate and avoid a skid. Lower pressure is then maintained to the brake at a level that slows the wheel without causing it to skid. Maximum braking efficiency exists when the wheels are decelerating at a maximum rate but are not skidding. If a wheel decelerates too fast, it is an indication that the brakes are about to lock and cause a skid. To ensure that this does not happen, each wheel is monitored for a deceleration rate faster than a preset rate. When excessive deceleration is detected, hydraulic pressure is reduced to the brake on that wheel. To operate the anti-skid system, flight deck switches must be placed in the ON position.



Antiskid switches in the cockpit.

After the aircraft touches down, the pilot applies and holds full pressure to the rudder brake pedals. The anti-skid system then functions automatically until the speed of the aircraft has dropped to approximately 20 mph. The system returns to manual braking mode for slow taxi and ground maneuvering.

There are various designs of anti-skid systems. Most contain three main types of components: wheel speed sensors, antiskid control valves, and a control unit. These units work together without human interference. Some anti-skid systems provide complete automatic braking. The pilot needs only to turn on the auto brake system, and the anti-skid components slow the aircraft without pedal input. *[Above Figure]* Ground safety switches are wired into the circuitry for anti-skid and auto brake systems. Wheel speed sensors are located on each wheel equipped with a brake assembly. Each brake also has its own anti-skid control valve. Typically, a single control box contains the anti-skid comparative circuitry for all of the brakes on the aircraft.



A wheel sensor (left), a control unit (center), and a control valve (right) are components of an antiskid system. A sensor is located on each wheel equipped with a brake assembly. An antiskid control valve for each brake assembly is controlled from a single central control unit.

Wheel Speed Sensors

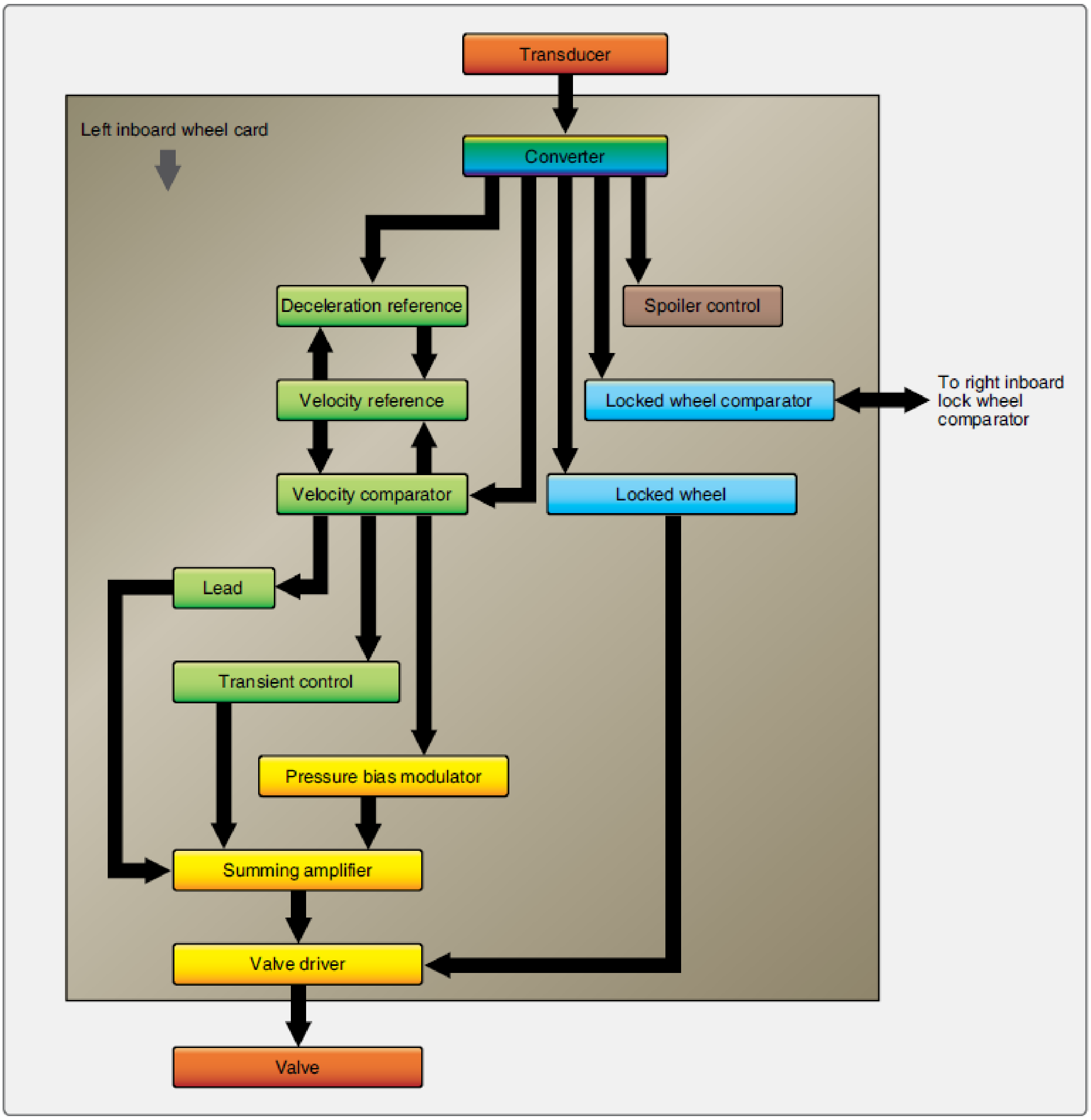
Wheel speed sensors are transducers. They may be alternating current (AC) or direct current (DC). The typical AC wheel speed sensor has a stator mounted in the wheel axle. A coil around it is connected to a controlled DC source so that when energized, the stator becomes an electromagnet. A rotor that turns inside the stator is connected to the rotating wheel hub assembly through a drive coupling so that it rotates at the speed of the wheel. Lobes on the rotor and stator cause the distance between the two components to constantly change during rotation. This alters the magnetic coupling or reluctance between the rotor and stator. As the electromagnetic field changes, a variable frequency AC is induced in the stator coil. The frequency is directly proportional to the speed of rotation of the wheel. The AC signal is fed to the control unit for processing. A DC wheel speed sensor is similar, except that a DC is produced the magnitude of which is directly proportional to wheel speed. *[Above Figure]*

Control Units

The control unit can be regarded as the brain of the antiskid system. It receives signals from each of the wheel sensors. Comparative circuits are used to determine if any of the signals indicate a skid is imminent or occurring on a particular wheel. If so, a signal is sent to the control valve of the wheel to relieve hydraulic pressure to that brake which prevents or relieves the skid. The control unit may or may not have external test switches and status indicating lights. It is common for it to be located in the avionics bay of the aircraft.

A rack mounted antiskid control unit from an airliner.

The Boeing anti-skid control valve block diagram in *Figure* below *gives* further detail on the functions of an antiskid control unit. Other aircraft may have different logic to achieve similar end results. DC systems do not require an input converter since DC is received from the wheel sensors, and the control unit circuitry operates primarily with DC.

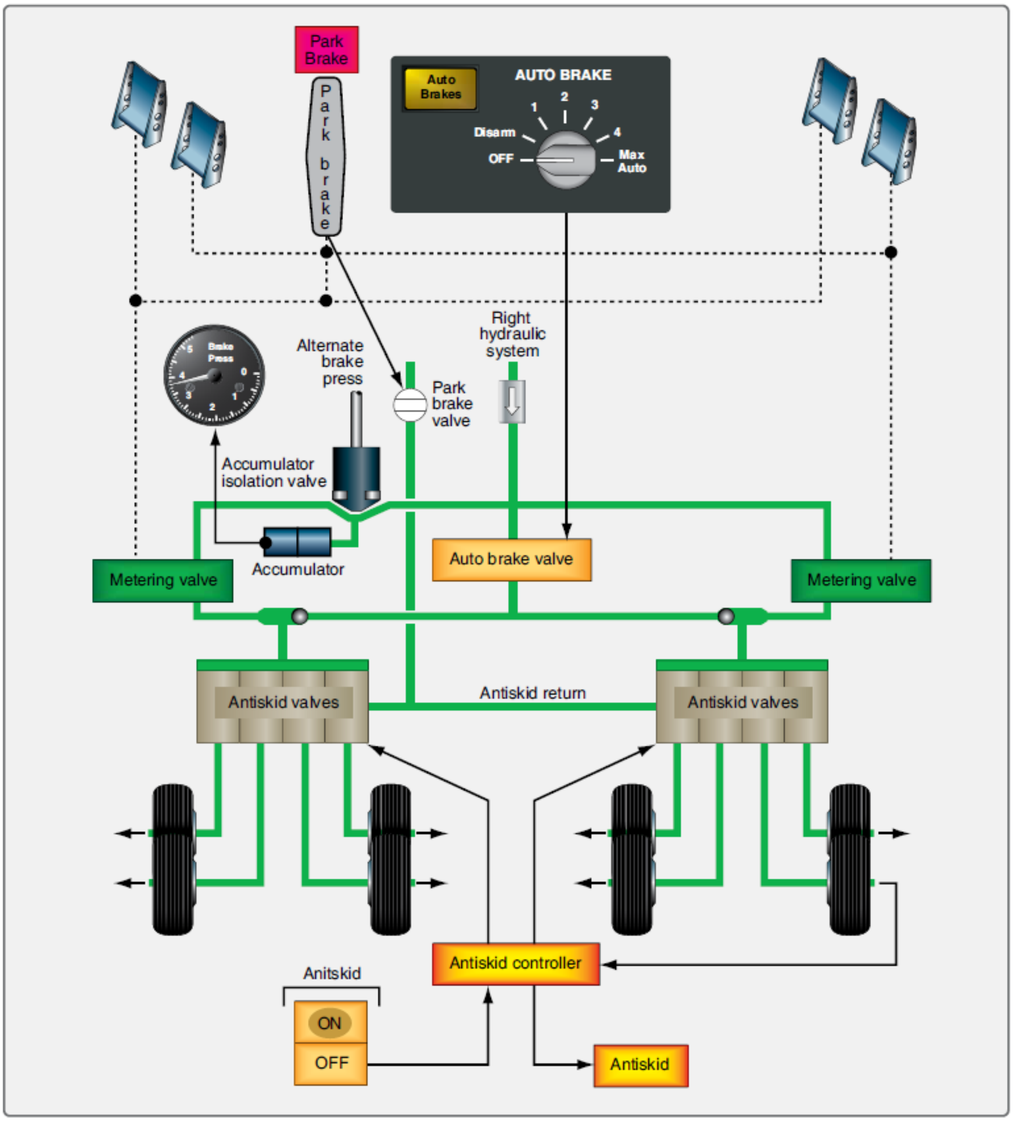


A Boeing 737 antiskid control unit internal block diagram.

Only the functions on one circuit card for one wheel brake assembly are shown in *Figure*. Each wheel has its own identical circuitry card to facilitate simultaneous operation.

All cards are housed in a single control unit that Boeing calls a control shield. The converter shown changes the AC frequency received from the wheel sensor into DC voltage that is proportional to wheel speed. The output is used in a velocity reference loop that contains deceleration and velocity reference circuits. The converter also supplies input for the spoiler system and the locked wheel system, which is discussed at the end of this section. A velocity reference loop output voltage is produced, which represents the instantaneous velocity of the aircraft. This is compared to converter output in the velocity comparator. This comparison of voltages is essentially the comparison of the aircraft speed to wheel speed. The output from the velocity comparator is a positive or negative error voltage corresponding to whether the wheel speed is too fast or too slow for optimum braking efficiency for a given aircraft speed.

The error output voltage from the comparator feeds the pressure bias modulator circuit. This is a memory circuit that establishes a threshold where the pressure to the brakes provides optimum braking. The error voltage causes the modulator to either increase or decrease the pressure to the brakes in attempt to hold the modulator threshold. It produces a voltage output that is sent to the summing amplifier to do this. A lead output from the comparator anticipates when the tire is about to skid with a voltage that decreases the pressure to the brake. It sends this voltage to the summing amplifier as well. A transient control output from the comparator designed for rapid pressure dump when a sudden skid has occurred also sends voltage to the summing amp. As the name suggests, the input voltages to the amplifier are summed, and a composite voltage is sent to the valve driver. The driver prepares the current required to be sent to the control valve to adjust the position of the valve. Brake pressure increases, decreases, or holds steady depending on this value.



The Boeing 757 normal brake system with auto brake and antiskid.

LANDING GEAR SYSTEMS

Aircraft Landing Gear

The landing gear forms the principal support of an aircraft on the surface. The most common type of landing gear consists of wheels, but aircraft can also be equipped with floats for water operations or skis for landing on snow.

The landing gear supports the airplane during the take off, landing, and when parked.

The landing gear on small aircraft consists of three wheels: two main wheels (one located on each side of the fuselage) and a third wheel positioned either at the front or rear of the airplane. Landing gear employing a rear-mounted wheel is called conventional landing gear. Airplanes with conventional landing gear are often referred to as tail wheel airplanes. When the third wheel is located on the nose, it is called a nose wheel, and the design is referred to as a tricycle gear. A steerable nose wheel or tail wheel permits the airplane to be controlled throughout all operations while on the ground.

Tricycle Landing Gear Airplanes

A tricycle gear airplane has three advantages:

1. It allows more forceful application of the brakes during landings at high speeds without causing the aircraft to nose over.
2. It permits better forward visibility for the pilot during takeoff, landing, and taxiing.
3. It tends to prevent ground looping (swerving) by providing more directional stability during ground operation since the aircraft’s center of gravity (CG) is forward of the main wheels. The forward CG keeps the airplane moving forward in a straight line rather than ground looping.

Nose wheels are either steerable or castering. Steerable nose wheels are linked to the rudders by cables or rods, while castering nose wheels are free to swivel. In both cases, the aircraft is steered using the rudder pedals. Aircraft with a castering nose wheel may require the pilot to combine the use of the rudder pedals with independent use of the brakes.

Tail wheel Landing Gear Airplanes

Tail wheel landing gear aircraft have two main wheels attached to the airframe ahead of its CG that support most of the weight of the structure. A tail wheel at the very back of the fuselage provides a third point of support. This arrangement allows adequate ground clearance for a larger propeller and is more desirable for operations on unimproved fields.

With the CG located behind the main gear, directional control of this type aircraft becomes more difficult while on the ground. This is the main disadvantage of the tail wheel landing gear. For example, if the pilot allows the aircraft to swerve while rolling on the ground at a low speed, he or she may not have sufficient rudder control and the CG will attempt to get ahead of the main gear which may cause the airplane to ground loop. Lack of good forward visibility when the tail wheel is on or near the ground is a second disadvantage of tail wheel landing gear aircraft. These inherent problems mean specific training is required in tail wheel aircraft.

Fixed and Retractable Landing Gear

Further classification of aircraft landing gear can be made into two categories: fixed and retractable. Many small, single engine light aircraft have fixed landing gear, as do a few light twins. This means the gear is attached to the airframe and remains exposed to the slipstream as the aircraft is flown. As discussed in Chapter 2 of this handbook, as the speed of an aircraft increases, so does parasite drag. Mechanisms to retract and stow the landing gear to eliminate parasite drag add weight to the aircraft. On slow aircraft, the penalty of this added weight is not overcome by the reduction of drag, so fixed gear is used. As the speed of the aircraft increases, the drag caused by the landing gear becomes greater and a means to retract the gear to eliminate parasite drag is required, despite the weight of the mechanism. A great deal of the parasite drag caused by light aircraft landing gear can be reduced by building gear as aerodynamically as possible and by adding fairings or wheel pants to streamline the airflow past the protruding assemblies. A small, smooth profile to the oncoming wind greatly reduces landing gear parasite drag. Illustrates a Cessna aircraft landing gear used on many of the manufacturer's light planes. The thin cross section of the spring steel struts combine with the fairings over the wheel and brake assemblies to raise performance of the fixed landing gear by keeping parasite drag to a minimum. Retractable landing gear stows in fuselage or wing compartments while in flight. Once in these wheel wells, gears are out of the slipstream and do not because parasites drag. Most retractable gear has a close fitting panel attached to them that fairs with the aircraft skin when the gear is fully retracted. Other aircraft have separate doors that open, allowing the gear to enter or leave, and then close again.

Shock Absorbing and Non-Shock Absorbing

Landing Gear

In addition to supporting the aircraft for taxi, the forces of impact on an aircraft during landing must be controlled by the landing gear.

This is done in two ways:

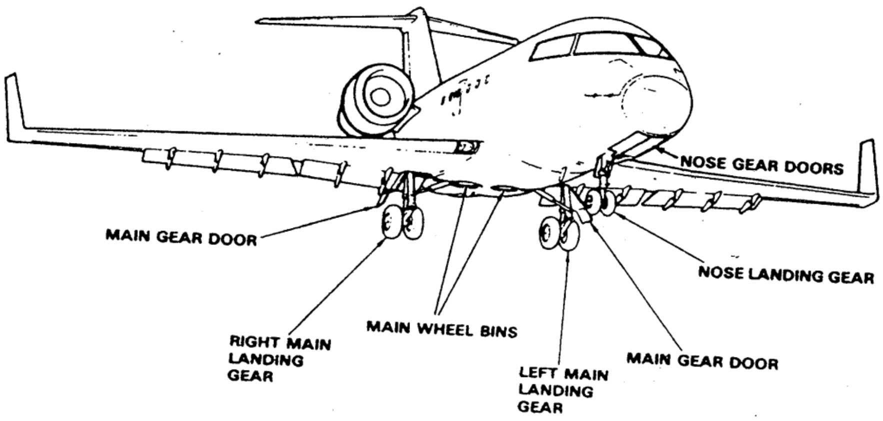
1) The shock energy is altered and transferred throughout the airframe at a different rate and time than the single strong pulse of impact, and

2) The shock is absorbed by converting the energy into heat energy.

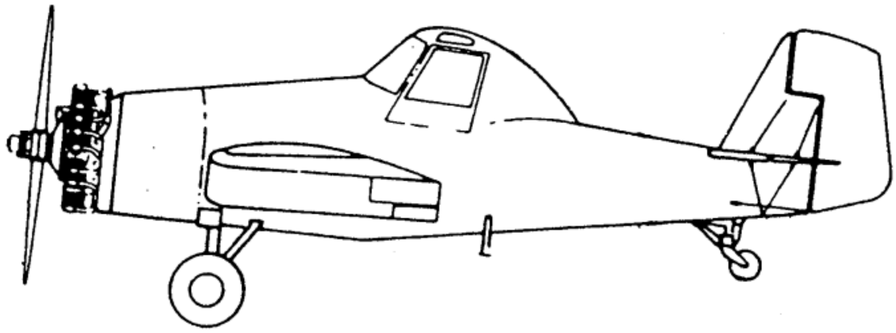
Fixed type of landing gear *Retractable type of landing gear*

Aircraft Landing-Gear System Configuration

i) Conventional Geared Aircraft (Retractable type of landing gear)



ii) Tricycle Landing Gear (Fixed landing gear)

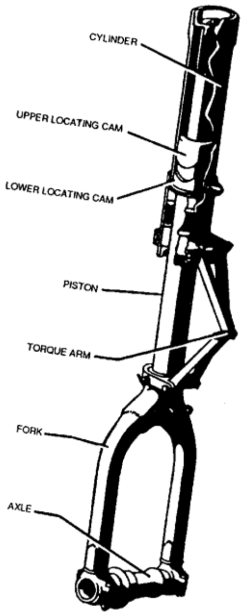


Classification of landing gear

- Non - Absorbing Landing Gear
  - Rigid Landing Gear
  - Shock-Cord Landing Gear
  - Spring-Type Gear
- Shock-Absorbing Landing Gear
  - Spring - Oleo
  - Air- Oleo
- Fixed Gear
- Retractable Gear
- Hulls and Floats

Landing-Gear Components

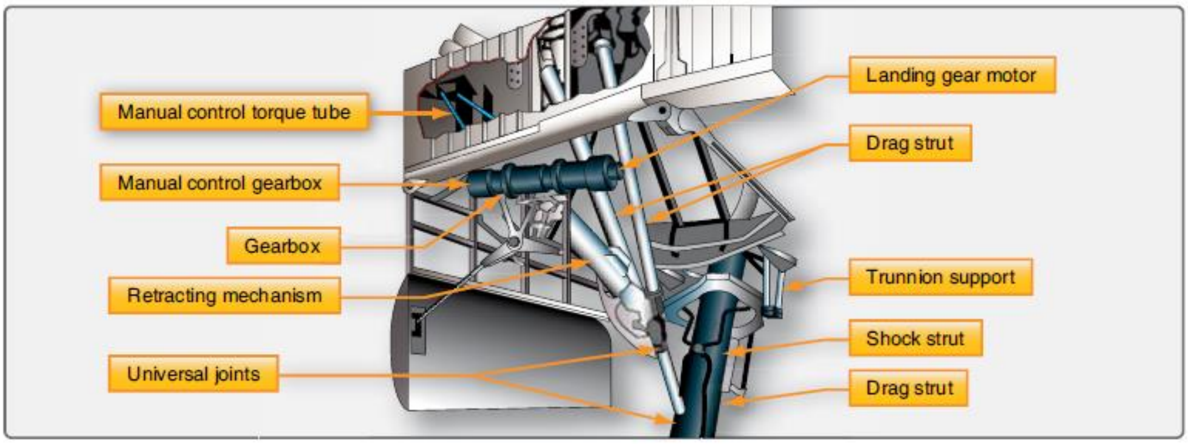
- Trunnion
- Struts
- Torque Links
- Truck or **Bogie**
- Drag Link or **Drag Strut**
- Side Brace Link or **Side Strut**
- Overcenter Link or **Down lock**
- Swivel Gland
- Shimmy Dampers



A typical landing gear strut

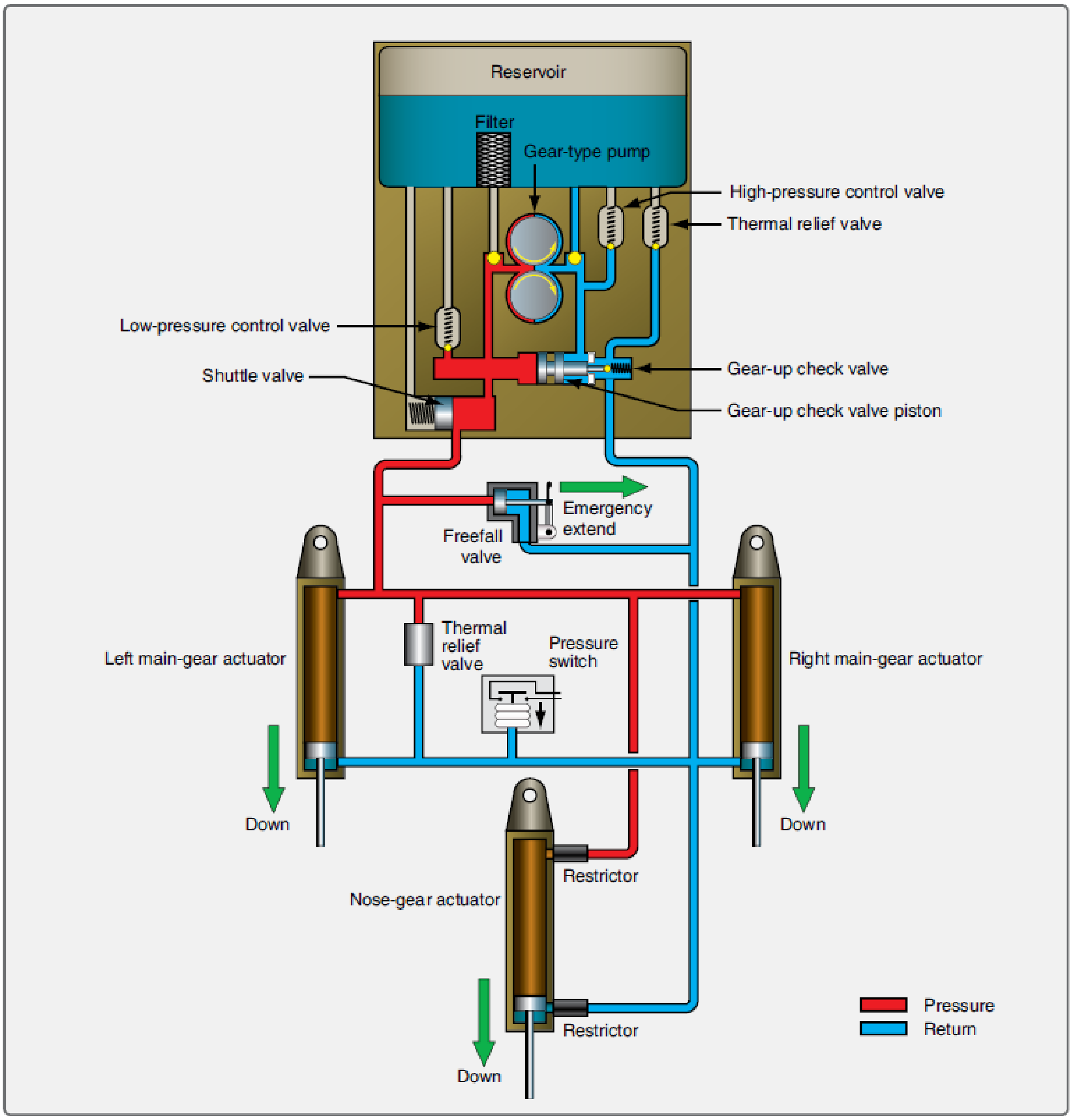
Small Aircraft Retraction Systems

As the speed of a light aircraft increases, there reaches a point where the parasite drag created by the landing gear in the wind is greater than the induced drag caused by the added weight of a retractable landing gear system. Thus, many light aircraft have retractable landing gear. There are many unique designs. The simplest contains a lever in the flight deck mechanically linked to the gear. Through mechanical advantage, the pilot extends and retracts the landing gear by operating the lever. Use of a roller chain, sprockets, and a hand crank to decrease the required force is common. Electrically operated landing gear systems are also found on light aircraft. An all-electric system uses an electric motor and gear reduction to move the gear. The rotary motion of the motor is converted to linear motion to actuate the gear. This is possible only with the relatively lightweight gear found on smaller aircraft. An all-electric gear retraction system is illustrated in *Figure*



A geared electric motor landing gear retraction system.

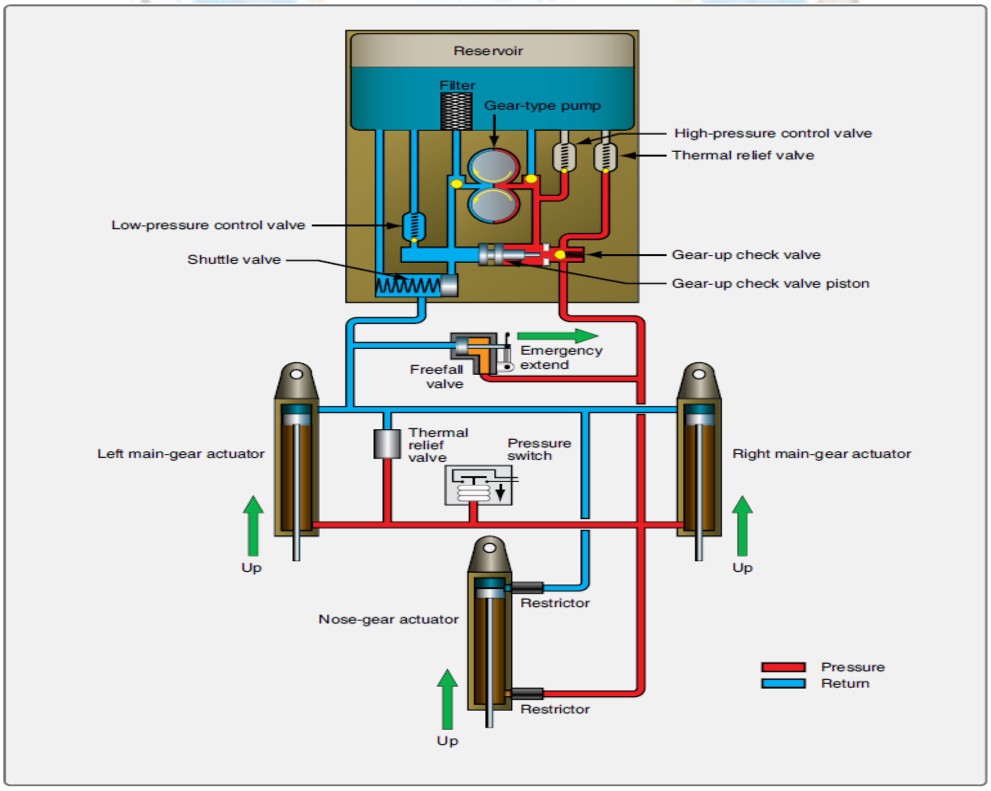
A more common use of electricity in gear retraction systems is that of an electric/hydraulic system found in many Cessna and Piper aircraft. This is also known as a power pack system. A small lightweight hydraulic power pack contains several components required in a hydraulic system. These include the reservoir, a reversible electric motor-driven hydraulic pump, a filter, high-and-low pressure control valves, a thermal relief valve, and a shuttle valve. Some power packs incorporate an emergency hand pump. A hydraulic actuator for each gear is driven to extend or retract the gear by fluid from the power pack. *Figure below* illustrates a power pack system while gear is being lowered.



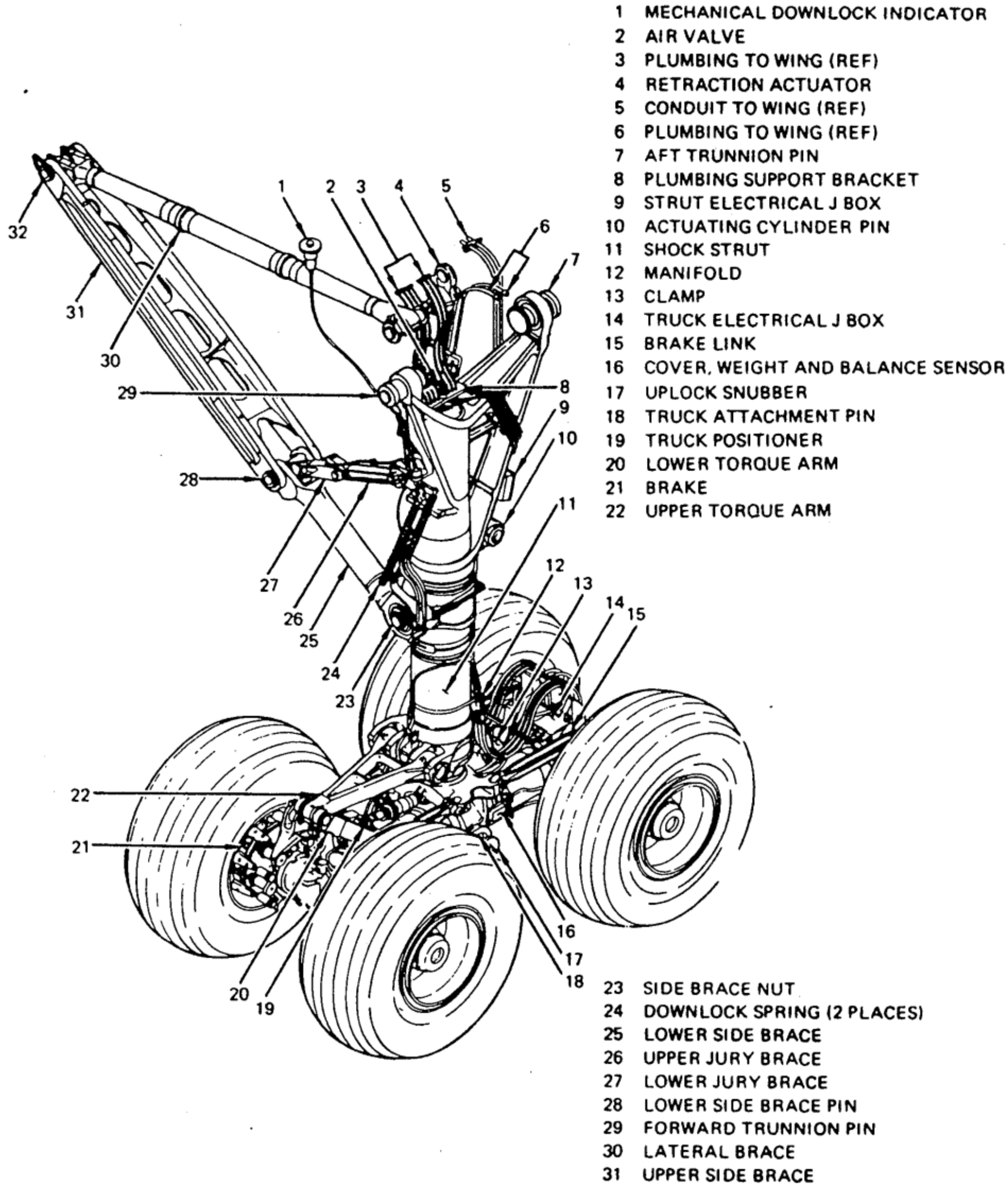
A popular light aircraft gear retraction system that uses a hydraulic power pack in the gear down condition.

Figure below shows the same system while the gear is being raised. When the flight deck gear selection handle is put in the gear down position, a switch is made that turns on the electric motor in the power pack. The motor turns in the direction to rotate the hydraulic gear pump so that it pumps fluid to the gear-down side of the actuating cylinders. Pump pressure moves the spring-loaded shuttle valve to the left to allow fluid to reach all three actuators. Restrictors are used in the nose wheel actuator inlet and outlet ports to slow down the motion of this lighter gear. While hydraulic fluid is pumped to extend the gear, fluid from the upside of the actuators returns to the reservoir through the gear-up check valve. When the gear reach the down and locked position, pressure builds in the gear-down line from the pump and the low-pressure control valve unseats to return the fluid to the reservoir. Electric limit switches turn off the pump when all three gears are down and locked.

To raise the gear, the flight deck gear handle is moved to the gear-up position. This sends current to the electric motor, which drives the hydraulic gear pump in the opposite direction causing fluid to be pumped to the gear-up side of the actuators. In this direction, pump inlet fluid flows through the filter. Fluid from the pump flows thought the gear-up check valve to the gear-up sides of the actuating cylinders. As the cylinders begin to move, the pistons release the mechanical down locks that hold the gear rigid for ground operations. Fluid from the gear-down side of the actuators returns to the reservoir through the shuttle valve. When the three gears are fully retracted, pressure builds in the system, and a pressure switch is opened that cuts power to the electric pump motor. The gears are held in the retracted position with hydraulic pressure. If pressure declines, the pressure switch closes to run the pump and raise the pressure until the pressure switch opens again.



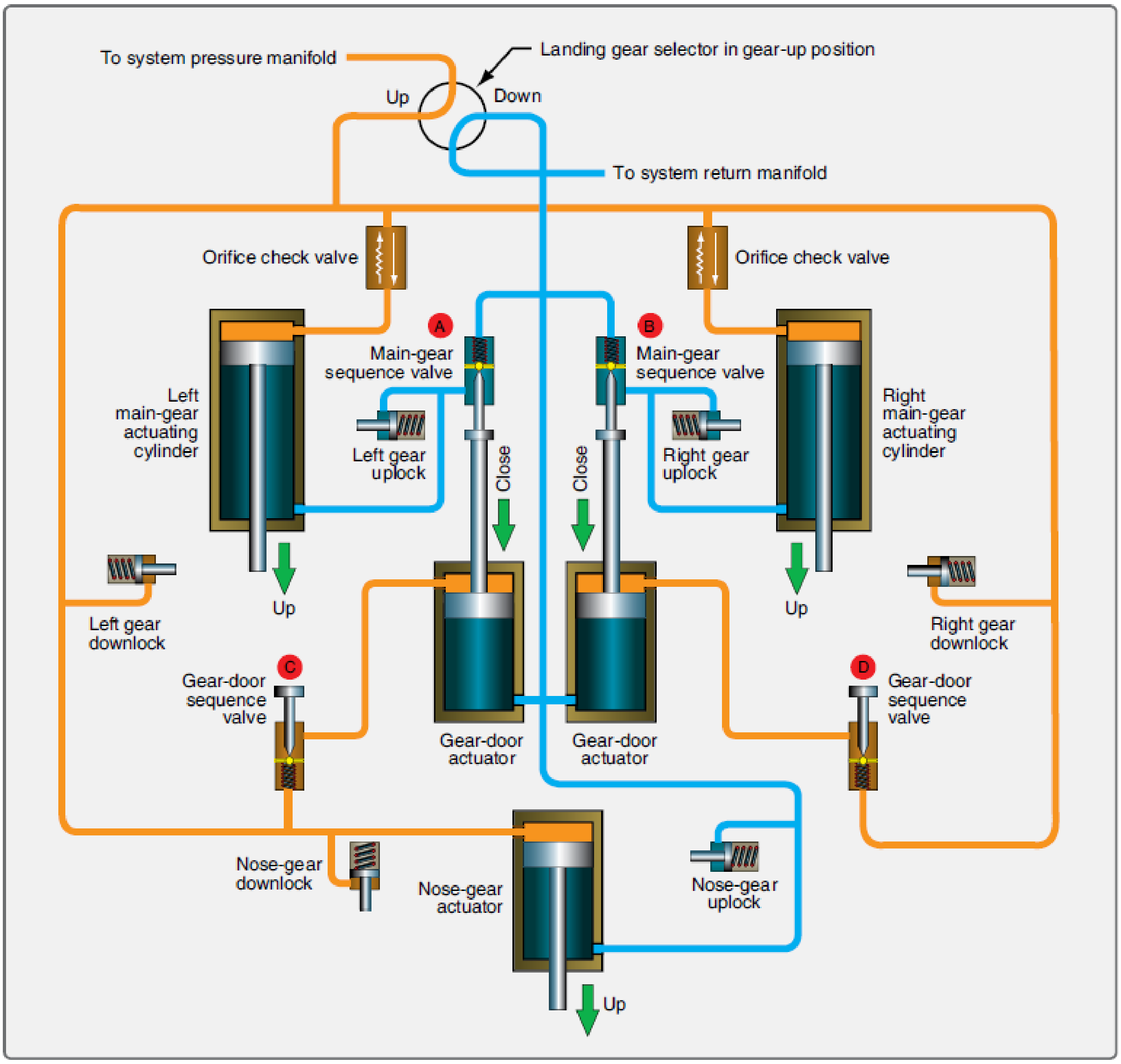
A hydraulic power pack gear retraction system in the gear up condition.



A typical landing gear system

Large Aircraft Retraction Systems

Large aircraft retraction systems are nearly always powered by hydraulics. Typically, the hydraulic pump is driven off of the engine accessory drive. Auxiliary electric hydraulic pumps are also common. Other devices used in a hydraulically-operated retraction system include actuating cylinders, selector valves, up locks, down locks, sequence valves, priority valves, tubing, and other conventional hydraulic system components. These units are interconnected so that they permit properly sequenced retraction and extension of the landing gear and the landing gear doors. The correct operation of any aircraft landing gear retraction system is extremely important.



A simple large aircraft hydraulic gear retraction system.

Figure illustrates an example of a simple large aircraft hydraulic landing gear system. The system is on an aircraft that has doors that open before the gear is extended and close after the gear is retracted. The nose gear doors operate via mechanical linkage and do not require hydraulic power. There are many gear and gear door arrangements on various aircraft. Some aircraft have gear doors that close to fair the wheel well after the gear is extended. Others have doors mechanically attached to the outside of the gear so that when it stows inward, the door stows with the gear and fairs with the fuselage skin.

In the system illustrated in *Figure above*, when the flight deck gear selector is moved to the gear-up position, it positions a selector valve to allow pump pressure from the hydraulic system manifold to access eight different components. The three down locks are pressurized and unlocked so the gear can be retracted. At the same time, the actuator cylinder on each gear also receives pressurized fluid to the gear-up side of the piston through an unrestricted orifice check valve. This drives the gear into the wheel well. Two sequence valves (C and D) also receive fluid pressure. Gear door operation must be controlled so that it occurs after the gear is stowed.

The sequence valves are closed and delay flow to the door actuators. When the gear cylinders are fully retracted, they mechanically contact the sequence valve plungers that openthe valves and allow fluid to flow into the close side of the door actuator cylinders. This closes the doors. Sequence valves A and B act as check valves during retraction. They allow fluid to flow one way from the gear-down side of the main gear cylinders back into the hydraulic system return manifold through the selector valve.

To lower the gear, the selector is put in the gear-down position. Pressurized hydraulic fluid flows from the hydraulic manifold to the nose gear up lock, which unlocks the nose gear. Fluid flows to the gear-down side of the nose gear actuator and extends it. Fluid also flows to the open side of the main gear door actuators. As the doors open, sequence valves A and B block fluid from unlocking the main gear up locks and prevent fluid from reaching the down side of the main gear actuators. When the doors are fully open, the door actuator engages the plungers of both sequence valves to open the valves. The main gear up locks then receives fluid pressure and unlock. The main gear cylinder actuators receive fluid on the down side through the open sequence valves to extend the gear. Fluid from each main gear cylinder up-side flows to the hydraulic system return manifold through restrictors in the orifice check valves. The restrictors slow the extension of the gear to prevent impact damage.

SHOCK ABSORBERS

Landing gear can also be classified as either fixed or retractable. A fixed gear always remains extended and has the advantage of simplicity combined with low maintenance. A retractable gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight.

Leaf-Type Spring Gear

Many aircraft utilize flexible spring steel, aluminum, or composite struts that receive the impact of landing and return it to the airframe to dissipate at a rate that is not harmful. The gear flexes initially and forces are transferred as it returns to its original position. The most common example of this type of non-shock absorbing landing gear are the thousands of single-engine Cessna aircraft that use it. Landing gear struts of this type made from composite materials are lighter in weight with greater flexibility and do not corrode.

Rigid

Before the development of curved spring steel landing struts, many early aircraft were designed with rigid, welded steel landing gear struts. Shock load transfer to the airframe is direct with this design. Use of pneumatic tires aids in softening the impact loads. Modern aircraft that use skid-type landing gear make use of rigid landing gear with no significant ill effects. Rotorcraft, for example, typically experience low impact landings that are able to be directly absorbed by the airframe through the rigid gear (skids).

Bungee Cord

The use of bungee cords on non-shock absorbing landing gear is common. The geometry of the gear allows the strut assembly to flex upon landing impact. Bungee cords are positioned between the rigid airframe structure and the flexing gear assembly to take up the loads and return them to the airframe at a non-damaging rate. The bungees are made of many individual small strands of elastic rubber that must be inspected for condition. Solid, donut-type rubber cushions are also used on some aircraft landing gear.

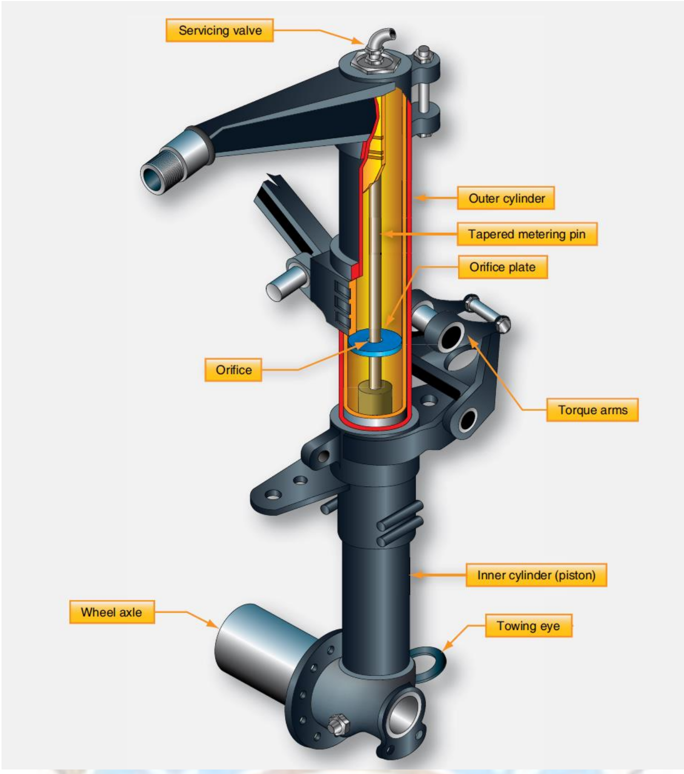
Piper Cub bungee cord landing gear transfer landing loads to the airframe (left and center). Rubber, donut-type shock transfer is used on some Mooney aircraft (right).

Shock Struts

True shock absorption occurs when the shock energy of landing impact is converted into heat energy, as in a shock strut landing gear. This is the most common method of landing shock dissipation in aviation. It is used on aircraft of all sizes. Shock struts are self-contained hydraulic units that support an aircraft while on the ground and protect the structure during landing. They must be inspected and serviced regularly to ensure proper operation there are many different designs of shock struts, but most operate in a similar manner. The following discussion is general in nature.

For information on the construction, operation, and servicing of a specific aircraft shock, consults the manufacturer's maintenance instructions. A typical pneumatic/hydraulic shock strut uses compressed air or nitrogen combined with hydraulic fluid to absorb and dissipate shock loads. It is sometimes referred to as an air/oil or oleo strut.

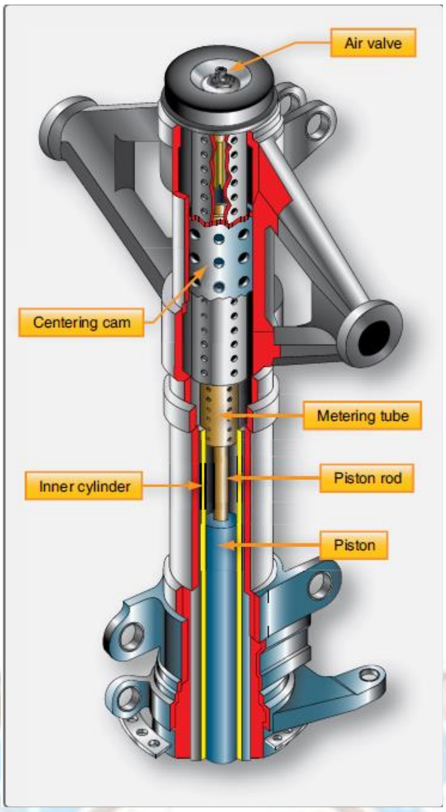
A shock strut is constructed of two telescoping cylinders or tubes that are closed on the external ends. The upper cylinder is fixed to the aircraft and does not move. The lower cylinder is called the piston and is free to slide in and out of the upper cylinder. Two chambers are formed. The lower chamber is always filled with hydraulic fluid and the upper chamber is filled with compressed air or nitrogen. An orifice located between the two cylinders provides a passage for the fluid from the bottom chamber to enter the top cylinder chamber when the strut is compressed.



A landing gear shock strut with a metering pin to control the flow of hydraulic fluid from the lower chamber to the upper chamber during compression.

Most shock struts employ a metering pin for controlling the rate of fluid flow from the lower chamber into the upper chamber. During the compression stroke, the rate of fluid flow is not constant. It is automatically controlled by the taper of the metering pin in the orifice. When a narrow portion of the pin is in the orifice, more fluid can pass to the upper chamber. As the diameter of the portion of the metering pin in the orifice increases, less fluid passes. Pressure build-up caused by strut compression and the hydraulic fluid being forced through the metered orifice causes heat. This heat is converted impact energy. It is dissipated through the structure of the strut

On some types of shock struts, a metering tube is used. The operational concept is the same as that in shock struts with metering pins, except the holes in the metering tube control the flow of fluid from the bottom chamber to the top chamber during compression.



Some landing gear shock struts use an internal metering tube rather than a metering pin to control the flow of fluid from the bottom cylinder to the top cylinder.

Upon lift off or rebound from compression, the shock strut tends to extend rapidly. This could result in a sharp impact at the end of the stroke and damage to the strut. It is typical for shock struts to be equipped with a damping or snubbing device to prevent this. A recoil valve on the piston or a recoil tube restricts the flow of fluid during the extension stroke, which slows the motion and prevents damaging impact forces. Most shock struts are equipped with an axle as part of the lower cylinder to provide installation of the aircraft wheels. Shock struts without an integral axle have provisions on the end of the lower cylinder for installation of the axle assembly. Suitable connections are provided on all shock strut upper cylinders to attach the strut to the airframe.

The upper cylinder of a shock strut typically contains a valve fitting assembly. It is located at or near the top of the cylinder. The valve provides a means of filling the strut with hydraulic fluid and inflating it with air or nitrogen as specified by the manufacturer. A packing gland is employed to seal the sliding joint between the upper and lower telescoping cylinders. It is installed in the open end of the outer cylinder. A packing gland wiper ring is also installed in a groove in the lower bearing or gland nut on most shock struts. It is designed to keep the sliding surface of the piston from carrying dirt, mud, ice, and snow into the packing gland and upper cylinder. Regular cleaning of the exposed portion of the strut piston helps the wiper do its job and decreases the possibility of damage to the packing gland, which could cause the strut to a leak. To keep the piston and wheels aligned, most shock struts are equipped with torque links or torque arms. One end of the links is attached to the fixed upper cylinder. The other end is attached to the lower cylinder (piston) so it cannot rotate. This keeps the wheels aligned. The links also retain the piston in the end of the upper cylinder when the strut is extended, such as after takeoff.

Torque links align the landing gear and retain the piston in the upper cylinder when the strut is extended.

Nose gear shock struts are provided with a locating cam assembly to keep the gear aligned. A cam protrusion is attached to the lower cylinder, and a mating lower cam recess is attached to the upper cylinder. These cams line up the wheel and axle assembly in the straight-ahead position when the shock strut is fully extended. This allows the nose wheel to enter the wheel well when the nose gear is retracted and prevents structural damage to the aircraft. It also aligns the wheels with the longitudinal axis of the aircraft prior to landing when the strut is fully extended. Many nose gear shock struts also have attachments for the installation of an external shimmy damper.

Nose gear struts are often equipped with a locking or disconnect pin to enable quick turning of the aircraft while towing or positioning the aircraft when on the ramp or in a hangar. Disengagement of this pin allows the wheel fork spindle on some aircraft to rotate 360°, thus enabling the aircraft to be turned in a tight radius. At no time should the nose wheel of any aircraft be rotated beyond limit lines marked on the airframe. Nose and main gear shock struts on many aircraft are also equipped with jacking points and towing lugs. Jacks should always be placed under the prescribed points. When towing lugs are provided, the towing bar should be attached only to these lugs.

Shock struts contain an instruction plate that gives directions for filling the strut with fluid and for inflating the strut. The instruction plate is usually attached near filler inlet and air valve assembly. It specifies the correct type of hydraulic fluid to use in the strut and the pressure to which the strut should be inflated. It is of utmost importance to become familiar with these instructions prior to filling a shock strut with hydraulic fluid or inflating it with air or nitrogen.

Shock Strut Operation

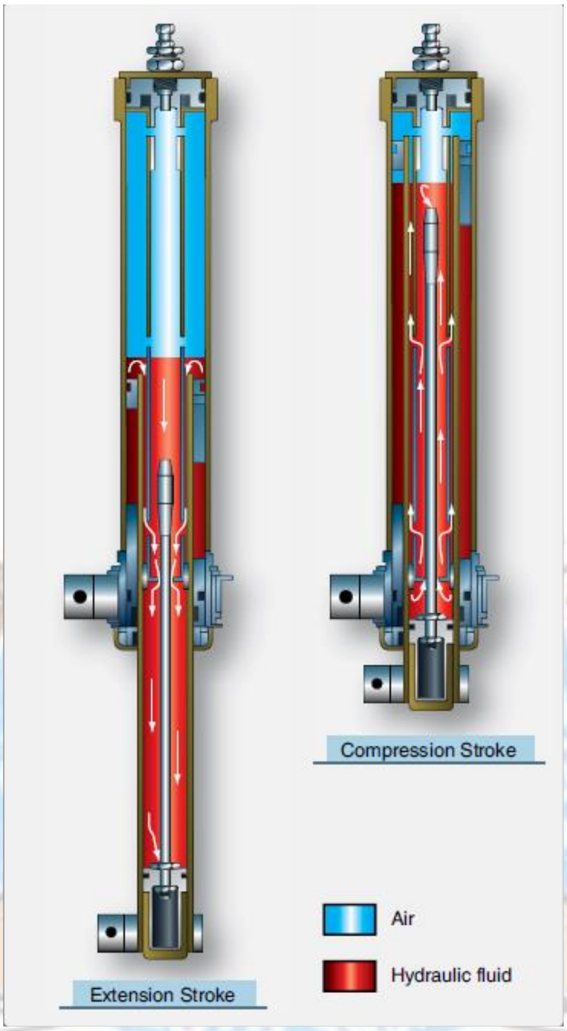


Figure illustrates the inner construction of a shock strut. Arrows show the movement of the fluid during compression and extension of the strut. The compression stroke of the shock strut begins as the aircraft wheels touch the ground. As the center of mass of the aircraft moves downward, the strut

NOSE WHEEL STEERING SYSTEMS

The nose wheel on most aircraft is steerable from the flight deck via a nose wheel steering system. This allows the aircraft to be directed during ground operation. A few simple aircraft have nose wheel assemblies that caster. Such aircraft are steered during taxi by differential braking.

Small Aircraft

Most small aircraft have steering capabilities through the use of a simple system of mechanical linkages connected to the rudder pedals. Push-pull tubes are connected to pedal horns on the lower strut cylinder. As the pedals are depressed, the movement is transferred to the strut piston axle and wheel assembly which rotates to the left or right. *[Figure below]*

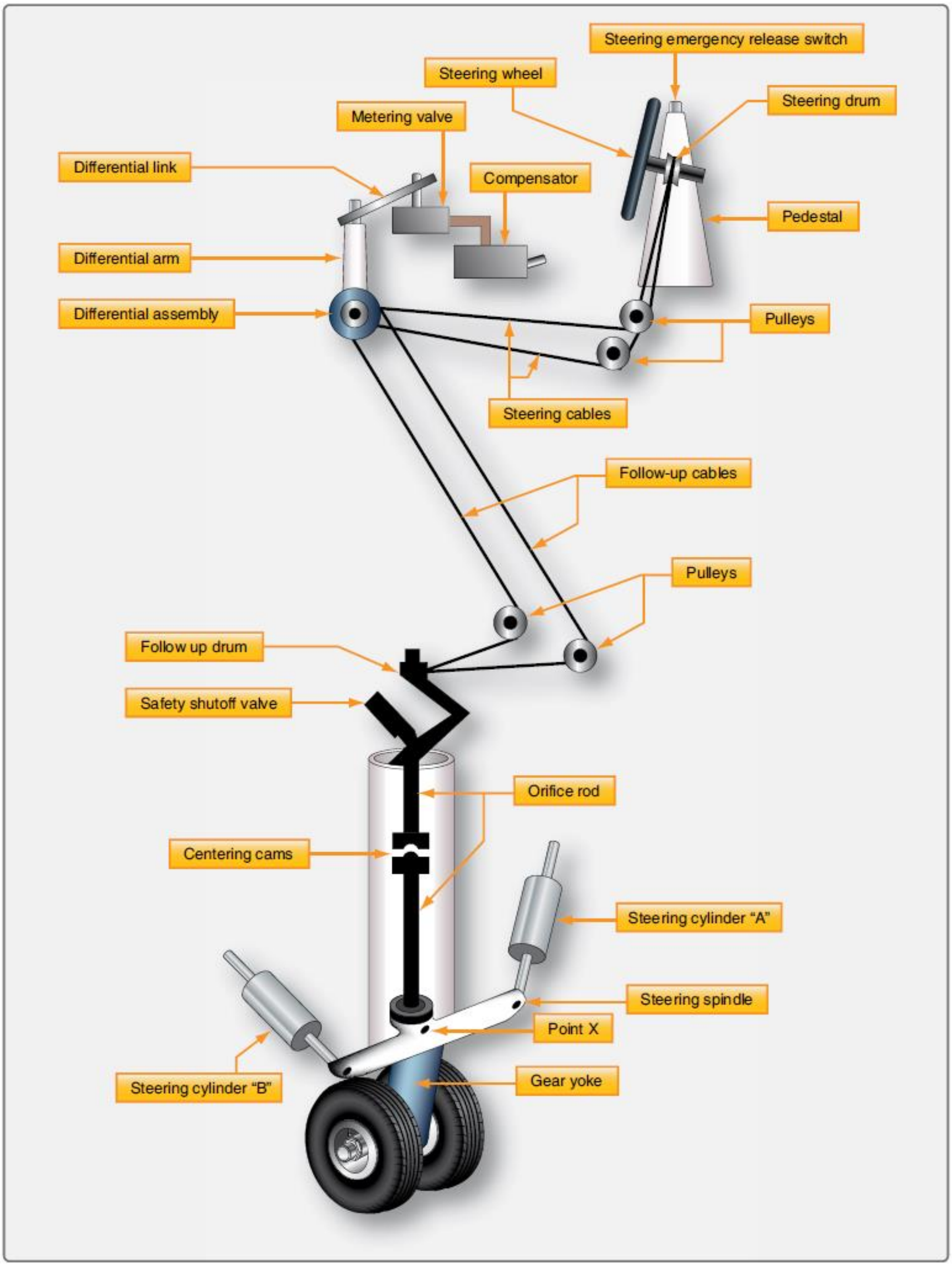
Nose wheel steering on a light aircraft often uses a push-pull rod system connected to the rudder pedals.

Large Aircraft

Due to their mass and the need for positive control, large aircraft utilize a power source for nose wheel steering. Hydraulic power predominates. There are many different designs for large aircraft nose steering systems. Most share similar characteristics and components. Control of the steering is from the flight deck through the use of a small wheel, tiller, or joystick typically mounted on the left side wall. Switching the system on and off is possible on some aircraft.

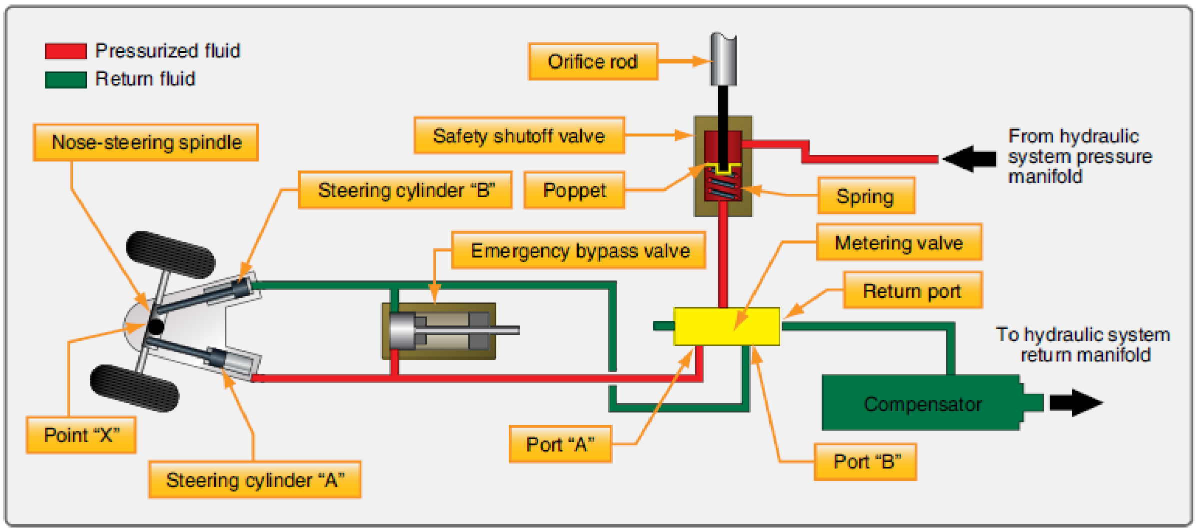
Mechanical, electrical, or hydraulic connections transmit the controller input movement to a steering control unit. The control unit is a hydraulic metering or control valve. It directs hydraulic fluid under pressure to one or two actuators designed with various linkages to rotate the lower strut. An accumulator and relief valve, or similar pressurizing assembly, keeps fluid in the actuators and system under pressure at all times. This permits the steering actuating cylinders to also act as shimmy dampers. A follow-up mechanism consists of various gears, cables, rods, drums, and/or bell-crank, etc. It returns the metering valve to a neutral position once the steering angle has been reached.

Many systems incorporate an input subsystem from the rudder pedals for small degrees of turns made while directing the aircraft at high speed during takeoff and landing. Safety valves are typical in all systems to relieve pressure during hydraulic failure so the nose wheel can swivel.



(A) Example of a large aircraft hydraulic nose wheel steering system with hydraulic and mechanical units.

The nose wheel steering wheel connects through a shaft to a steering drum located inside the flight deck control pedestal. The rotation of this drum transmits the steering signal by means of cables and pulleys to the control drum of the differential assembly. Movement of the differential assembly is transmitted by the differential link to the metering valve assembly where it moves the selector valve to the selected position. This provides the hydraulic power for turning the nose gear.

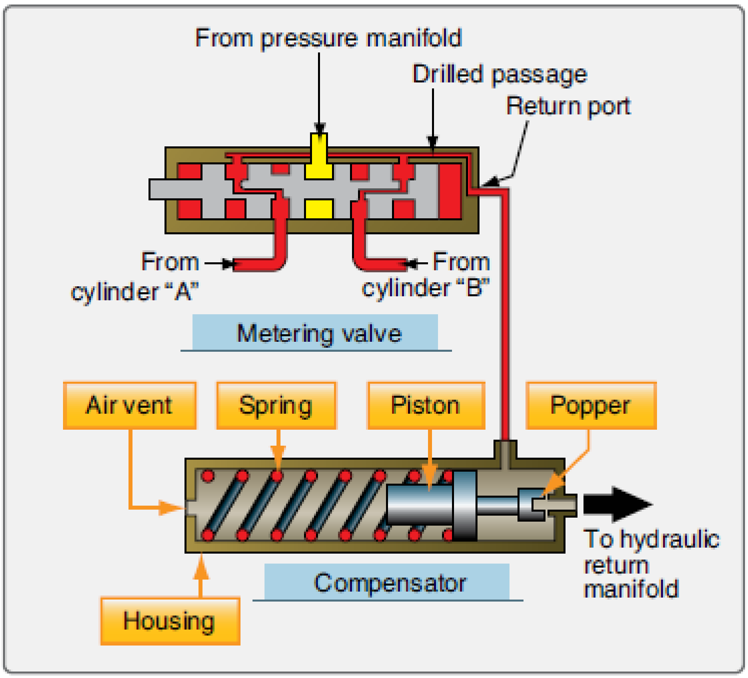


(B) Hydraulic system flow diagram of large aircraft nose wheel steering system.

As shown in above *Figure*, pressure from the aircraft hydraulic system is directed through the open safety shutoff valve into a line leading to the metering valve. The metering valve then routes the pressurized fluid out of port A, through the right turn alternating line, and into steering cylinder A. This is a one-port cylinder and pressure forces the piston to begin extension. Since the rod of this piston connects to the nose steering spindle on the nose gear shock strut which pivots at point X, the extension of the piston turns the steering spindle gradually toward the right. As the nose wheel turns, fluid is forced out of steering cylinder B through the left turn alternating line and into port B of the metering valve. The metering valve directs this return fluid into a compensator that routes the fluid into the aircraft hydraulic system return manifold.

As described, hydraulic pressure starts the nose gear turning. However, the gear should not be turned too far. The nose gear steering system contains devices to stop the gear at the selected angle of turn and hold it there. This is accomplished with follow-up linkage. As stated, the nose gear is turned by the steering spindle as the piston of cylinder A extends.

The rear of the spindle contains gear teeth that mesh with a gear on the bottom of the orifice rod. *[Figure (A)]* As the nose gear and spindle turn, the orifice rod also turns but in the opposite direction. This rotation is transmitted by the two sections of the orifice rod to the scissor follow-up links located at the top of the nose gear strut. As the follow-up links return, they rotate the connected follow-up drum, which transmits the movement by cables and pulleys to the differential assembly. Operation of the differential assembly causes the differential arm and links to move the metering valve back toward the neutral position.



(C) Hydraulic system flow diagram of large aircraft nose wheel steering system.

The metering valve and the compensator unit of the nose wheel steering system are illustrated in *Figure (C)*. The compensator unit system keeps fluid in the steering cylinders pressurized at all times. This hydraulic unit consists of a three-port housing that encloses a spring-loaded piston and poppet. The left port is an air vent that prevents trapped air at the rear of the piston from interfering with the movement of the piston. The second port located at the top of the compensator connects through a line to the metering valve return port. The third port is located at the right side of the compensator. This port connects to the hydraulic system return manifold. It routes the steering system return fluid into the manifold when the poppet valve is open.

The compensator poppet opens when pressure acting on the piston becomes high enough to compress the spring. In this system, 100 psi is required. Therefore, fluid in the metering valve return line is contained under that pressure. The 100 psi pressure also exists throughout the metering valve and back through the cylinder return lines. This pressurizes the steering cylinders at all times and permits them to function as shimmy dampers.

SHIMMY DAMPERS

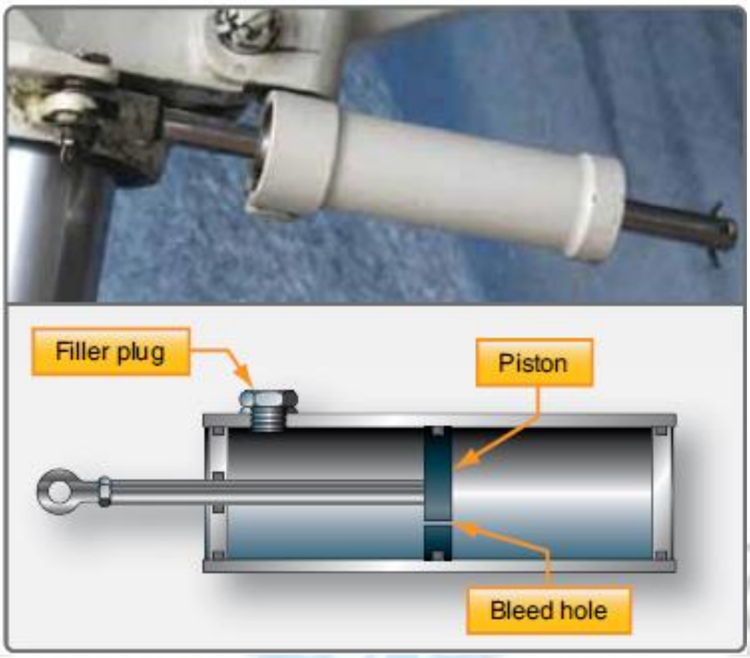
Torque links attached from the stationary upper cylinder of a nose wheel strut to the bottom moveable cylinder or piston of the strut are not sufficient to prevent most nose gear from the tendency to oscillate rapidly, or shimmy, at certain speeds. This vibration must be controlled through the use of a shimmy damper. A shimmy damper controls nose wheel shimmy through hydraulic damping. The damper can be built integrally within the nose gear, but most often it is an external unit attached between the upper and lower shock struts. It is active during all phases of ground operation while permitting the nose gear steering system to function normally.

Steering Damper

As mentioned above, large aircraft with hydraulic steering hold pressure in the steering cylinders to provide the required damping. This is known as steering damping. Some older transport category aircraft have steering dampers that are vane-type. Nevertheless, they function to steer the nose wheel, as well as to dampen vibration.

Piston-Type

Aircraft not equipped with hydraulic nose wheel steering utilize an additional external shimmy damper unit. The case is attached firmly to the upper shock strut cylinder. The shaft is attached to the lower shock strut cylinder and to a piston inside the shimmy damper. As the lower strut cylinder tries to shimmy, hydraulic fluid is forced through a bleed hole in the piston. The restricted flow through the bleed hole dampens the oscillation. *[Figure below]*

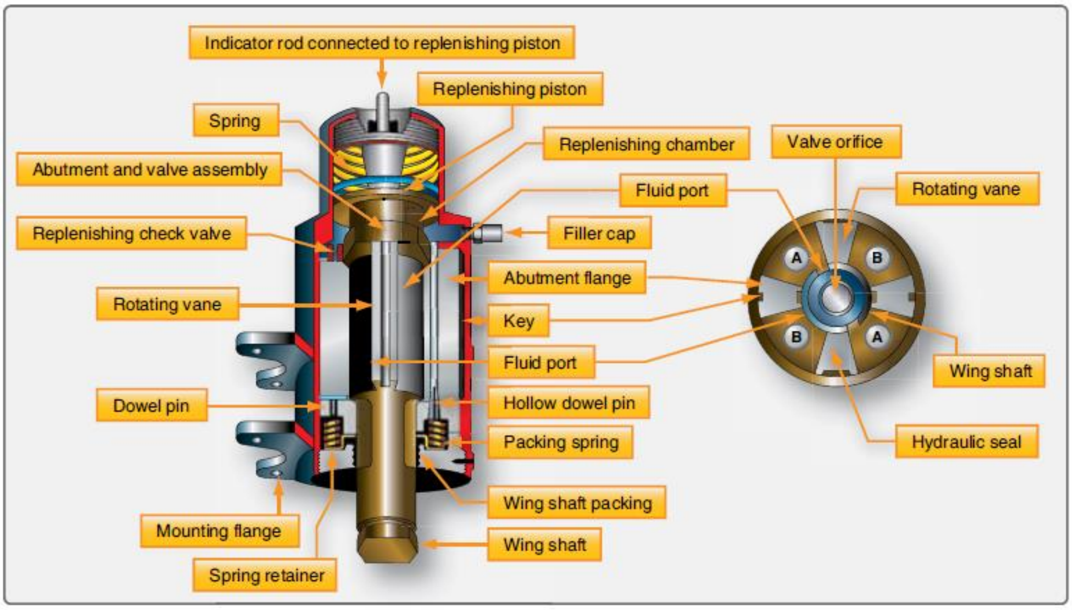


A shimmy damper on the nose struts of a small aircraft. The diagram shows the basic internal arrangement of most shimmy dampers. The damper in the photo is essentially the same except the piston shaft extends through both ends of the damper cylinder body.

A piston-type shimmy damper may contain a fill port to add fluid or it may be a sealed unit. Regardless, the unit should be checked for leaks regularly. To ensure proper operation, a piston-type hydraulic shimmy damper should be filled to capacity.

Vane-Type

A vane-type shimmy damper is sometime used. *[Figure below]* It uses fluid chambers created by the vanes separated by a valve orifice in a center shaft. As the nose gear tries to oscillate, vanes rotate to change the size of internal chambers filled with fluid. The chamber size can only change as fast as the fluid can be forced through the orifice. Thus, the gear oscillation is dissipated by the rate of fluid flow. An internal spring-loaded replenishing reservoir keeps pressurized fluid in the working chambers and thermal compensation of the orifice size is included. As with the piston type shimmy damper, the vane-type damper should be inspected for leaks and kept serviced. A fluid level indicator protrudes from the reservoir end of the unit.



A typical vane-type shimmy damper.

Non-Hydraulic Shimmy Damper

Non-hydraulic shimmy dampers are currently certified for many aircraft. They look and fit similar to piston-type shimmy dampers but contain no fluid inside. In place of the metal piston, a rubber piston presses out against the inner diameter of the damper housing when the shimmy motion is received through the shaft.

The rubber piston rides on a very thin film of grease and the rubbing action between the piston and the housing provides the damping. This is known as surface-effect damping. The materials use to construct this type of shimmy damper provide a long service life without the need to ever add fluid to the unit.*[Figure below]*

A non-hydraulic shimmy damper uses a rubber piston with lubricant that dampens via motion against the inner diameter of the unit housing.

Aircraft Oxygen Systems

The negative effects of reduced atmospheric pressure at flight altitudes, forcing less oxygen into the blood, can be overcome. There are two ways this is commonly done: increase the pressure of the oxygen or increase the quantity of oxygen in the air mixture. Large transport-category and high performance passenger aircraft pressurize the air in the cabin. This serves to push more of the normal 21 percent oxygen found in the air into the blood for saturation. Techniques for pressurization are discussed later in this chapter. When utilized, the percentage of oxygen available for breathing remains the same; only the pressure is increased. By increasing the quantity of oxygen available in the lungs, less pressure is required to saturate the blood. This is the basic function of an aircraft oxygen system. Increasing the level of oxygen above the 21 percent found in the atmosphere can offset the reduced pressure encountered as altitude increases.

Oxygen may be regulated into the air that is breathed so as to maintain a sufficient amount for blood saturation. Normal mental and physical activity can be maintained at indicated altitudes of up to about 40,000 feet with the sole use of supplemental oxygen. Oxygen systems that increase the quantity of oxygen in breathing air are most commonly used as primary systems in small and medium size aircraft designed without cabin pressurization. Pressurized aircraft utilize oxygen systems as a means of redundancy should pressurization fail. Portable oxygen equipment may also be aboard for first aid purposes.

Forms of Oxygen

- Gaseous Oxygen
- Liquid Oxygen
- Chemical or Solid Oxygen

Onboard Oxygen Generating Systems (OBOGS)

The molecular sieve method of separating oxygen from the other gases in air has application in flight, as well as on the ground. The sieves are relatively light in weight and relieve the aviator of a need for ground support for the oxygen supply. Onboard oxygen generating systems on military aircraft pass bleed air from turbine engines through a sieve that separates the oxygen for breathing use. Some of the separated oxygen is also used to purge the sieve of the nitrogen and other gases that keep it fresh for use. Use of this type of oxygen production in civilian aircraft is anticipated. *[Figure 16-8]*

Oxygen Systems and Components

Built-in and portable oxygen systems are used in civilian aviation. They use gaseous or solid oxygen (oxygen generators) as suits the purpose and aircraft. LOX systems and molecular sieve oxygen systems are not discussed, as current applications on civilian aircraft are limited.

Gaseous Oxygen Systems

The use of gaseous oxygen in aviation is common; however, applications vary. On a light aircraft, it may consist of a small carry-on portable cylinder with a single mask attached via a hose to a regulator on the bottle. Larger portable cylinders may be fitted with a regulator that divides the outlet flow for 2–4 people. Built-in oxygen systems on high performance and light twin-engine aircraft typically have a location where oxygen cylinders are installed to feed a distribution system via tubing and a regulator. The passenger compartment may have multiple breathing stations plumbed so that each passenger can individually plug in a hose and mask if oxygen is needed. A central regulator is normally controlled by the flight crew who may have their own separate regulator and oxygen cylinder. Transport category aircraft may use an elaborate built-in gaseous oxygen system as a backup system to cabin pressurization. In all of these cases, oxygen is stored as a gas at atmospheric temperature in high-pressure cylinders. It is distributed through a system with various components that are described in this section.

Oxygen Storage Cylinders

Gaseous oxygen is stored and transported in high-pressure cylinders. Traditionally, these have been heavy steel tanks rated for 1800–1850 psi of pressure and capable of maintaining pressure up to 2,400 psi. While these performed adequately, lighter weight tanks were sought. Some newer cylinders are comprised of a lightweight aluminum shell wrapped by Kevlar®. These cylinders are capable of carrying the same amount of oxygen at the same pressure as steel tanks, but weigh much less. Also available are heavy-walled all-aluminum cylinders. These units are common as carry-on portable oxygen used in light aircraft.

Most oxygen storage cylinders are painted green, but yellow and other colours may be used as well. They are certified to Department of Transportation (DOT) specifications. To ensure serviceability, cylinders must be hydrostatically tested periodically. In general, a hydrostatic test consists of filling the container with water and pressurizing it to 5⁄3 of its certified rating. It should not leak, rupture, or deform beyond an established limit.

Oxygen Systems and Regulators

The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements, and whether the aircraft has a pressurization system. Systems are often characterized by the type of regulator used to dispense the oxygen: continuous-flow and demand flow. In some aircraft, a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the larger transport aircraft. Many aircraft have a combination of both systems that may be augmented by portable equipment.

Continuous-Flow Systems

In its simplest form, a continuous-flow oxygen system allows oxygen to exit the storage tank through a valve and passes it through a regulator/reducer attached to the top of the tank. The flow of high-pressure oxygen passes through a section of the regulator that reduces the pressure of the oxygen, which is then fed into a hose attached to a mask worn by the user. Once the valve is opened, the flow of oxygen is continuous. Even when the user is exhaling, or when the mask is not in use, a preset flow of oxygen continues until the tank valve is closed. On some systems, fine adjustment to the flow can be made with an adjustable flow indicator that is installed in the hose in line to the mask. A portable oxygen setup for a light aircraft exemplifies this type of continuous-flow system.

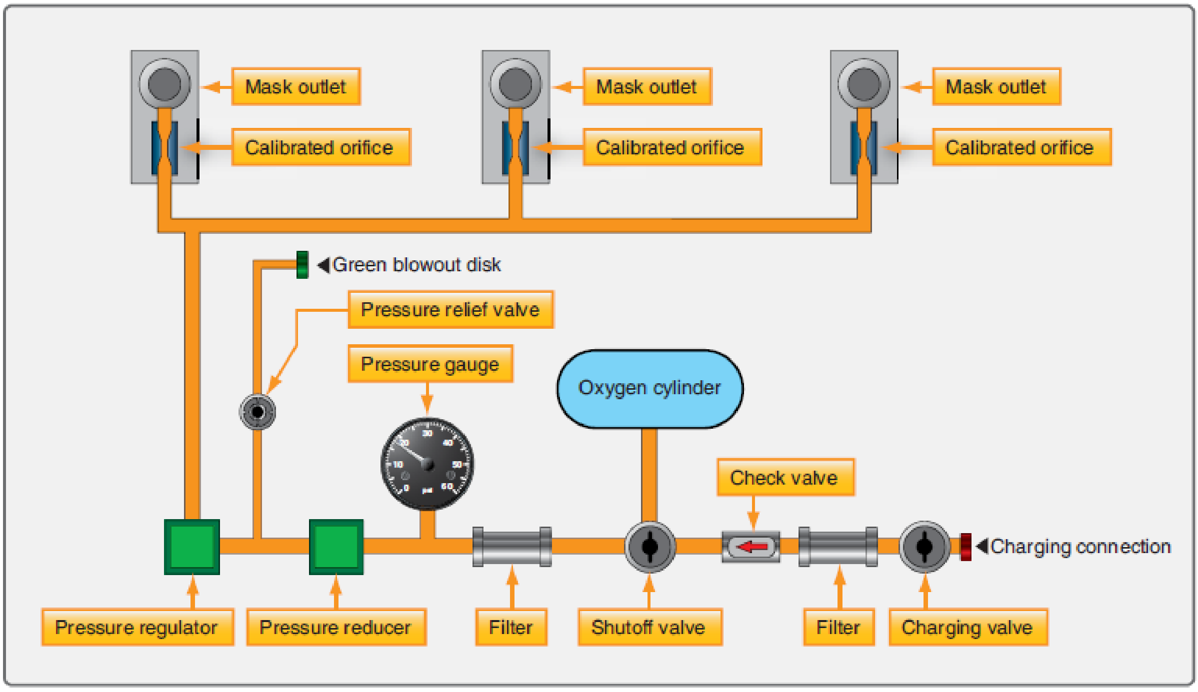
A more sophisticated continuous-flow oxygen system uses a regulator that is adjustable to provide varying amounts of oxygen flow to match increasing need as altitude increases.

These regulators can be manual or automatic in design. Manual continuous-flow regulators are adjusted by the crew as altitude changes. Automatic continuous-flow regulators have a built in aneroid. As the aneroid expands with altitude, a mechanism allows more oxygen to flow though the regulator to the users.

A manual continuous flow oxygen system may have a regulator that is adjusted by the pilot as altitude varies. By turning the knob, the left gauge can be made to match the flight altitude thus increasing and decreasing flow as altitude changes.

Many continuous-flow systems include a fixed location for the oxygen cylinders with permanent delivery plumbing installed to all passenger and crew stations in the cabin.

In large aircraft, separate storage cylinders for crew and passengers are typical. Fully integrated oxygen systems usually have separate, remotely mounted components to reduce pressure and regulate flow. A pressure relief valve is also typically installed in the system, as is some sort of filter and a gauge to indicate the amount of oxygen pressure remaining in the storage cylinder(s). Figure below diagrams the type of continuous-flow system that is found on small to medium sized aircraft.

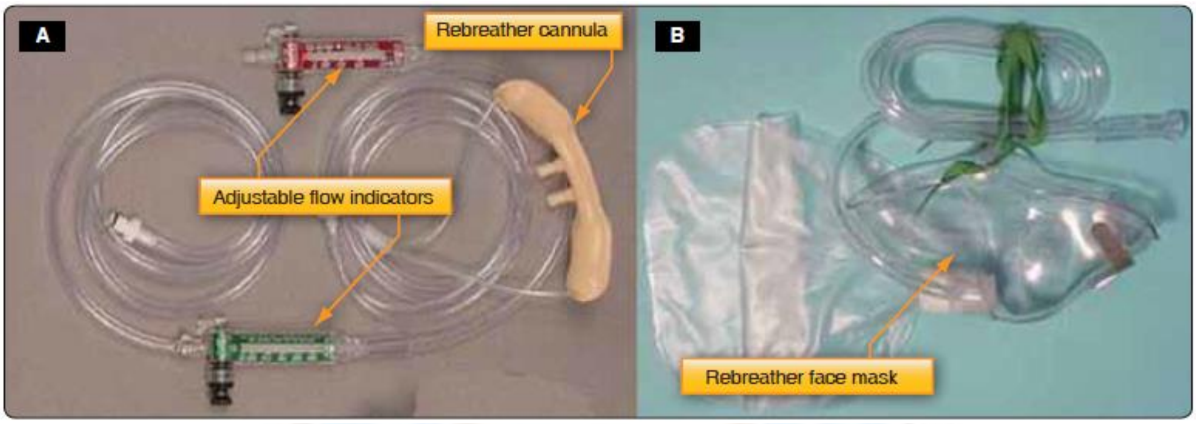


Continuous flow oxygen system found on small to medium size aircraft.

Built-in continuous-flow gaseous oxygen systems accomplish a final flow rate to individual user stations through the use of a calibrated orifice in each mask. Larger diameter orifices are usually used in crew masks to provide greater flow than that for passengers. Special oxygen masks provide even greater flow via larger orifices for passengers travelling with medical conditions requiring full saturation of the blood with oxygen.

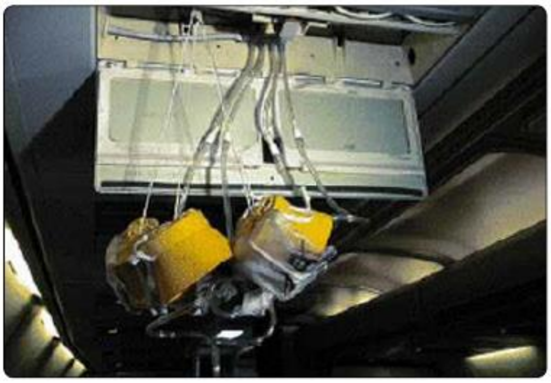
Allowing oxygen to continuously flow from the storage cylinder can be wasteful. Lowest sufficient flow rates can be accomplished through the use of rebreather apparatus.

Oxygen and air that is exhaled still contains usable oxygen. By capturing this oxygen in a bag, or in a cannula with oxygen absorbing reservoirs, it can be inhaled with the next breath, reducing waste.



A rebreather cannula (A) and rebreather bag (B) capture exhaled oxygen to be inhaled on the next breath. This conserves oxygen by permitting lower flow rates in continuous flow systems. The red and green devices are optional flow indicators that allow the user to monitor oxygen flow rate. The type shown also contains needle valves for final regulation of the flow rate to each user.

The passenger section of a continuous-flow oxygen system may consist of a series of plug-in supply sockets fitted to the cabin walls adjacent to the passenger seats to which oxygen masks can be connected. Flow is inhibited until a passenger manually plugs in. When used as an emergency system in pressurized aircraft, depressurization automatically triggers the deployment of oxygen ready continuous-flow masks at each passenger station. A lanyard attached to the mask turns on the flow to each mask when it is pulled toward the passenger for use.



A passenger service unit (psu) is hinged over each row of seats in an airliner. Four yellow continuous flow oxygen masks are shown deployed. They are normally stored behind a separate hinged panel that opens to allow the masks to fall from the PSU for use.

The masks are normally stowed overhead in the passenger service unit (PSU). *[Figure 16-15]* Deployment of the emergency continuous-flow passenger oxygen masks may also be controlled by the crew.

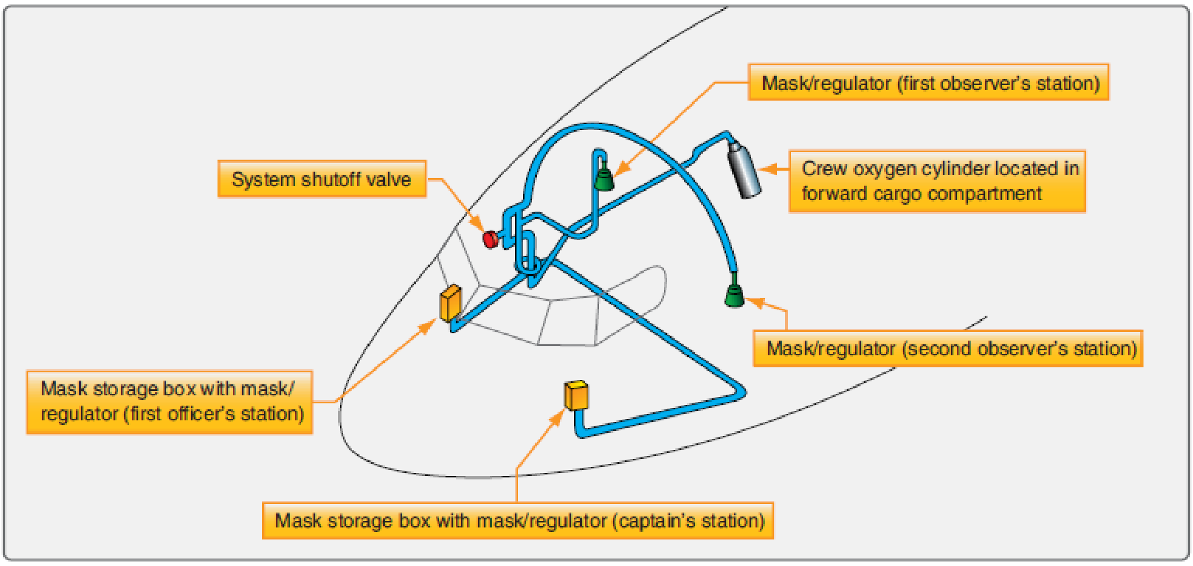
The crew can deploy passenger emergency continuous flow oxygen masks and supply with a switch in the cockpit.

Continuous-flow oxygen masks are simple devices made to direct flow to the nose and mouth of the wearer. They fit snugly but are not air tight. Vent holes allow cabin air to mix with the oxygen and provide escape for exhalation. In a rebreather mask, the vents allow the exhaled mixture that is not trapped in the rebreather bag to escape. This is appropriate, because this is the air-oxygen mixture that has been in the lungs the longest, so it has less recoverable oxygen to be breathed again.

Examples of different continuous-flow oxygen masks.

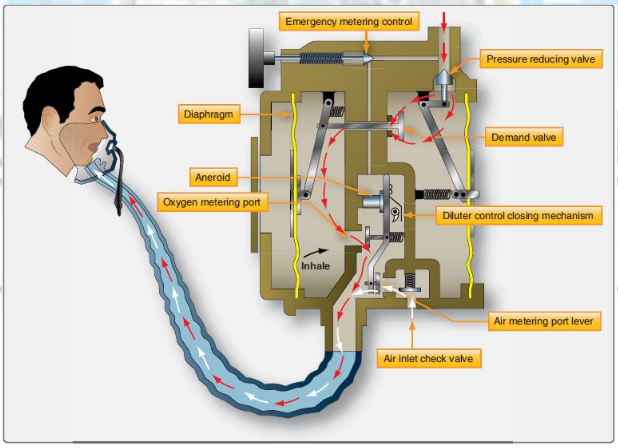
Demand-Flow Systems

When oxygen is delivered only as the user inhales, or on demand, it is known as a demand-flow system. During the hold and exhalation periods of breathing, the oxygen supply is stopped. Thus, the duration of the oxygen supply is prolonged as none is wasted. Demand-flow systems are used most frequently by the crew on high performance and air transport category aircraft.



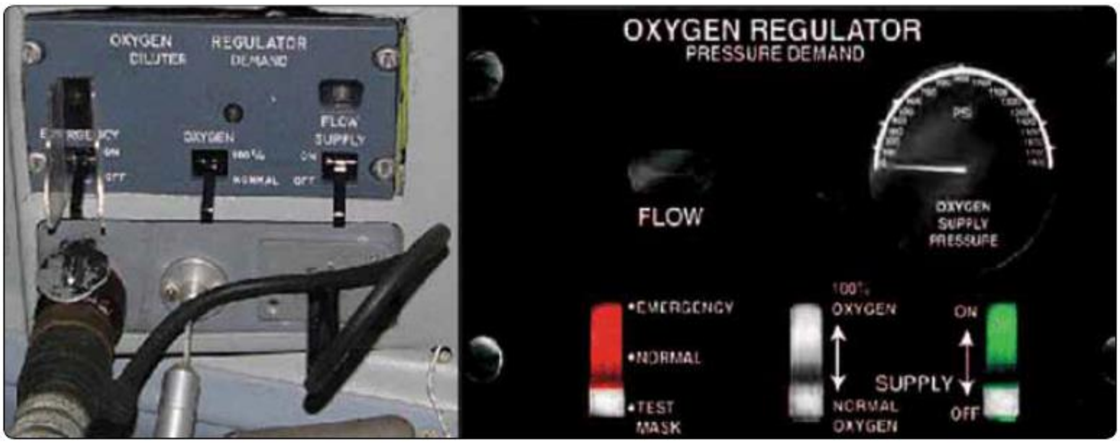
Location of demand-flow oxygen components on a transport category aircraft.

Demand-flow systems are similar to continuous-flow systems in that a cylinder delivers oxygen through a valve when opened. The tank pressure gauge, filter(s), pressure relief valve, and any plumbing installed to refill the cylinder while installed on the aircraft are all similar to those in a continuous flow system. The high-pressure oxygen also passes through a pressure reducer and a regulator to adjust the pressure and flow to the user. But, demand-flow oxygen regulators differ significantly from continuous-flow oxygen regulators. They work in conjunction with close-fitting demand-type masks to control the flow of oxygen. *[Figure 16-19]*



A demand regulator and demand-type mask work together to control flow and conserve oxygen. Demand-flow masks are close fitting so that when the user inhales, low pressure is created in the regulator, which allows oxygen to flow. Exhaled air escapes through ports in the mask, and the regulator ceases the flow of oxygen until the next inhalation.

In a demand-flow oxygen system, the system pressure reducing valve is sometimes called a pressure regulator. This device lowers the oxygen pressure from the storage cylinder(s) to roughly 60–85 psi and delivers it to individual regulators dedicated for each user. A pressure reduction also occurs at the inlet of the individual regulator by limiting the size of the inlet orifice. There are two types of individual regulators: the diluter-demand type and the pressure-demand type. *[Figure below]*



The two basic types of regulators used in demand flow oxygen systems. The panel below the diluter demand regulator on the left is available for mask hose plug in (left), lanyard mask hanger (center), and microphone plug in (right). Most high performance demand type masks have a microphone built-in.

The diluter-demand type regulator holds back the flow of oxygen until the user inhales with a demand-type oxygen mask. The regulator dilutes the pure oxygen supply with cabin air each time a breath is drawn. With its control toggle switch set to normal, the amount of dilution depends on the cabin altitude. As altitude increases, an aneroid allows more oxygen and less cabin air to be delivered to the user by adjusting flows through a metering valve. At approximately 34,000 feet, the diluter-demand regulator meters 100 percent oxygen.

This should not be needed unless cabin pressurization fails. Additionally, the user may select 100 percent oxygen delivery at any time by positioning the oxygen selection lever on the regulator. A built-in emergency switch also delivers 100 percent oxygen, but in a continuous flow as the demand function is bypassed. *[Figure below]*

Pressure-demand oxygen systems operate similarly to diluter demand systems, except that oxygen is delivered through the individual pressure regulator(s) under higher pressure. When the demand valve is unseated, oxygen under pressure forces its way into the lungs of the user. The demand function still operates, extending the overall supply of oxygen beyond that of a continuous-flow system. Dilution with cabin air also occurs if cabin altitude is less than 34,000 feet.

Pressure-demand regulators are used on aircraft that regularly fly at 40,000 feet and above. They are also found on many airliners and high-performance aircraft that may not typically fly that high. Forcing oxygen into the lungs under pressure ensures saturation of the blood, regardless of altitude or cabin altitude. Both diluter-demand and pressure-demand regulators also come in mask-mounted versions. The operation is essentially the same as that of panel-mounted regulators. *[Figure below]*

A mask-mounted version of a miniature diluter-demand regulator designed for use in general aviation (left), a mechanical quick-donning diluter-demand mask with the regulator on the mask (center), and an inflatable quick-donning mask (right). Squeezing the red grips directs oxygen into the hollow straps.

Flow Indicators

Flow indicators, or flow meters, are common in all oxygen systems. They usually consist of a lightweight object, or apparatus, that is moved by the oxygen stream. When flow exists, this movement signals the user in some way. Many flow meters in continuous-flow oxygen systems also double as flow rate adjusters. Needle valves fitted into the flow indicator housing can fine-adjust the oxygen delivery rate. Demand-flow oxygen systems usually have flow indicators built into the individual regulators at each user station. Some contain a blinking device that activates when the user inhales and oxygen is delivered. Others move a colored pith object into a window. Regardless, flow indicators provide a quick verification that an oxygen system is functioning.

Different flow indicators are used to provide verification that the oxygen system is functioning. Other demand-flow indicators are built into the oxygen regulators. *[Figure below]*

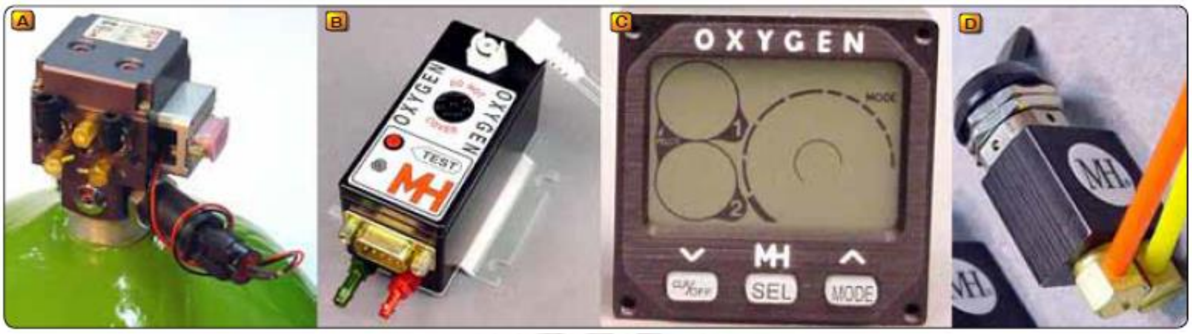
Different flow indicators are used to provide verification that the oxygen system is functioning: continuous-flow, in-line (left); continuous-flow, in-line with valve adjuster (center); and old style demand flow (right).

A recent development in general aviation oxygen systems is the electronic pulse demand oxygen delivery system (EDS). A small, portable EDS unit is made to connect between the oxygen source and the mask in a continuous-flow oxygen system. It delivers timed pulses of oxygen to the wearer on demand, saving oxygen normally lost during the hold and exhale segments of the breathing cycle. Advanced pressure sensing and processing allows the unit to deliver oxygen only when an inhalation starts. It can also sense differences in users' breathing cycles and physiologies and adjust the flow of oxygen accordingly. A built-in pressure-sensing device adjusts the amount of oxygen released as altitude changes.

[Figure below]

A portable two-person electronic pulse-demand (EPD) oxygen regulating unit.

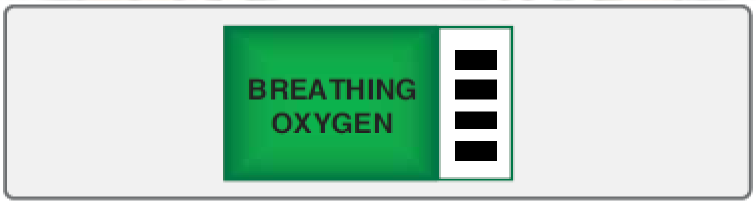
Permanently mounted EPD systems are also available. They typically integrate with an electronic valve/regulator on the oxygen cylinder and come with an emergency bypass switch to provide continuous-flow oxygen should the system malfunction. A liquid crystal display (LCD) monitor/control panel displays numerous system operating parameters and allows adjustments to the automatic settings. This type of electronic metering of oxygen has also been developed for passenger emergency oxygen use in airliners.



The key components of a built-in electronic pulse demand oxygen metering system: (A) electronic regulator, (B) oxygen station distributer unit, (C) command/display unit, (D) emergency bypass switch.

Oxygen Plumbing and Valves

Tubing and fittings make up most of the oxygen system plumbing and connect the various components. Most lines are metal in permanent installations. High-pressure lines are usually stainless steel. Tubing in the low-pressure parts of the oxygen system is typically aluminum. Flexible plastic hosing is used deliver oxygen to the masks; its use is increasing in permanent installations to save weight. Installed oxygen tubing is usually identified with colour coded tape applied to each end of the tubing, and at specified intervals along its length. The tape coding consists of a green band overprinted with the words “BREATHING OXYGEN” and a black rectangular symbol overprinted on a white background border strip.



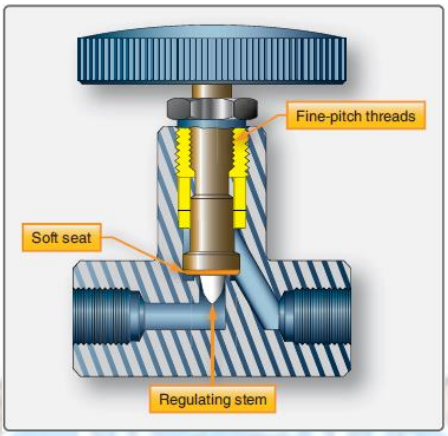
Colour-coded tape used to identify oxygen tubing.

Tubing-to-tubing fittings in oxygen systems are often designed with straight threads to receive flared tube connections. Tubing-to-component fittings usually have straight threads on the tubing end and external pipe threads (tapered) on the other end for attachment to the component.

The fittings are typically made of the same material as the tubing (i.e., aluminum or steel). Flared and flareless fittings are both used, depending on the system. Five types of valves are commonly found in high-pressure gaseous oxygen systems: filler, check, shutoff, pressure reducer, and pressure relief. They function as they would in any other system with one exception: oxygen system shutoff valves are specifically designed to open slowly.

The ignition point for any substances is lower in pure oxygen than it is in air. When high-pressure oxygen is allowed to rush into a low-pressure area, its velocity could reach the speed of sound. If it encounters an obstruction (a valve seat, an elbow, a piece of contaminant, etc.),

the oxygen compresses. With this compression, known as adiabatic compression (since it builds so quickly no heat is lost to its surroundings), comes high temperature. Under pressure, this high temperature exceeds the ignition point of the material the oxygen encounters and a fire or explosion results. A stainless steel line, for example, would not normally burn and is used for carrying numerous fluids under high pressure. But under high pressure and temperature in the presence of 100 percent oxygen, even stainless steel can ignite.
To combat this issue, all oxygen shutoff valves are slow, opening valves designed to decrease velocity.



This high-pressure oxygen system shutoff valve has fine-pitch threads and a regulating stem to slow the flow of oxygen through the valve. A soft valve seat is also included to assure the valve closes completely.

Additionally, technicians should always open all oxygen valves slowly. Keeping oxygen from rushing into a low pressure area should be a major concern when working with high-pressure gaseous oxygen systems.
Oxygen cylinder valves and high-pressure systems are often provided with a relief valve should the desired pressure be exceeded. Often, the valve is ported to an indicating or blowout disk. This is located in a conspicuous place, such as the fuselage skin, where it can be seen during walk-around inspection. Most blowout disks are green. The absence of the green disk indicates the relief valve has opened, and the cause should be investigated before flight.

An oxygen blowout plug on the side of the fuselage indicates when pressure relief has occurred and should be investigated.

Chemical Oxygen Systems

The two primary types of chemical oxygen systems are the portable type, much like a portable carry-on gaseous oxygen cylinder, and the fully integrated supplementary oxygen system used as backup on pressurized aircraft in case of pressurization failure. This latter use of solid chemical oxygen generators is most common on airliners. The generators are stored in the overhead PSU attached to hoses and masks for every passenger on board the aircraft. When a depressurization occurs, or the flight crew activates a switch, a compartment door opens and the masks and hoses fall out in front of the passengers. The action of pulling the mask down to a usable position actuates an electric current, or ignition hammer, that ignites the oxygen candle and initiates the flow of oxygen. Typically, 10 to 20 minutes of oxygen is available for each user. This is calculated to be enough time for the aircraft to descend to a safe altitude for unassisted breathing.

An oxygen generator mounted in place in an overhead passenger service unit of an air transport category aircraft.

Chemical oxygen systems are unique in that they do not produce the oxygen until it is time to be used. This allows safer transportation of the oxygen supply with less maintenance. Chemical oxygen-generating systems also require less space and weigh less than gaseous oxygen systems supplying the same number of people. Long runs of tubing, fittings, regulators, and other components are avoided, as are heavy gaseous oxygen storage cylinders. Each passenger row grouping has its own fully independent chemical oxygen generator. The generators, which often weigh less than a pound, are insulated and can burn completely without getting hot. The size of the orifice opening in the hose-attach nipples regulates the continuous flow of oxygen to the users.

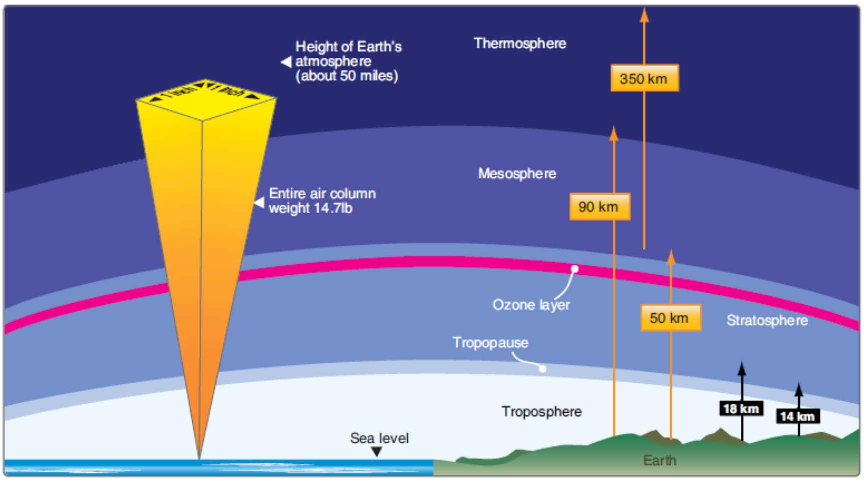
LOX Systems

LOX systems are rarely used in civilian aviation. They may be encountered on former military aircraft now in the civilian fleet. As mentioned, the storage of LOX requires a special container system. The plumbing arrangement to convert the liquid to a usable gas is also unique. It basically consists of a controlled heat exchange assembly of tubing and valves. Overboard pressure relief is provided for excessive temperature situations. Once gaseous, the LOX system is the same as it is in any comparable gaseous oxygen delivery system. Use of pressure-demand regulators and masks is common. Consult the manufacturer's maintenance manual for further information if a LOX system is encountered.

Aircraft Pressurization Systems

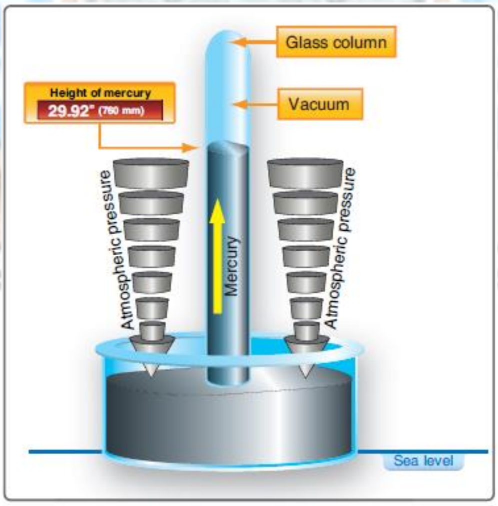
Pressure of the Atmosphere

The gases of the atmosphere (air), although invisible, have weight. A one square inch column of air stretching from sea level into space weighs 14.7 pounds. Therefore, it can be stated that the pressure of the atmosphere, or atmospheric pressure, at sea level is 14.7 psi.



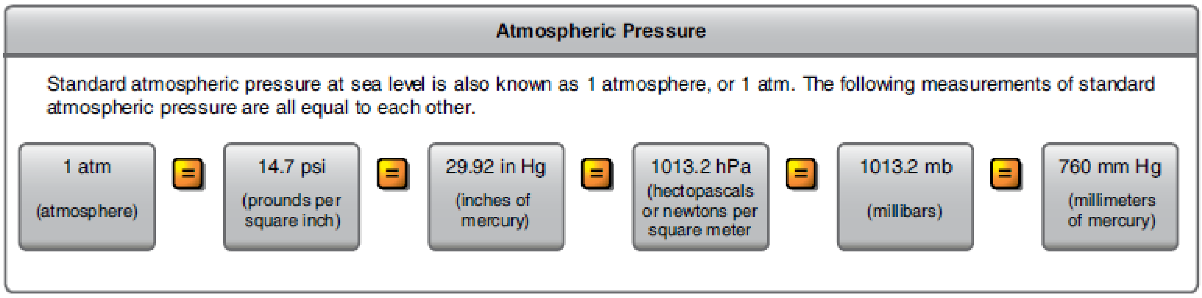
The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.

Atmospheric pressure is also known as barometric pressure and is measured with a barometer. *[Figure below]* Expressed in various ways, such as in inches of mercury or millimetres of mercury, these measurements come from observing the height of mercury in a column when air pressure is exerted on a reservoir of mercury into which the column is set. The column must be evacuated so air inside does not act against the mercury rising. A column of mercury 29.92 inches high weighs the same as a column of air that extends from sea level to the top of the atmosphere and has the same cross-section as the column of mercury.



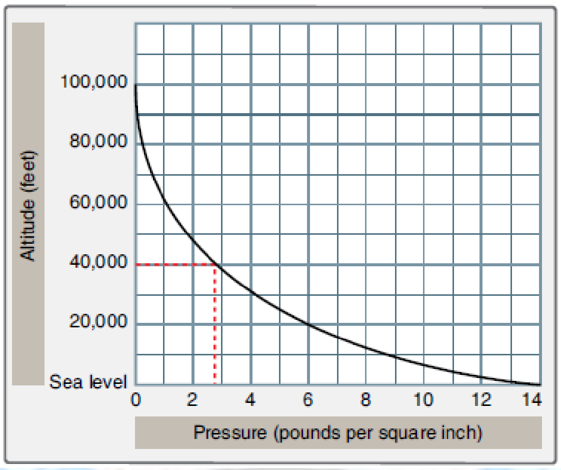
The weight of the atmosphere pushes down on the mercury in the reservoir of a barometer, which causes mercury to rise in the column. At sea level, mercury is forced up into the column approximately 29.92 inches. Therefore, it is said that barometric pressure is 29.92 inches of mercury at sea level.

Aviators often interchange references to atmospheric pressure between linear displacement (e.g., inches of mercury) and units of force (e.g., psi). Over the years, meteorology has shifted its use of linear displacement representation of atmospheric pressure to units of force. However, the unit of force nearly universally used today to represent atmospheric pressure in meteorology is the hectopascal (hPa). A hectopascal is a metric (SI) unit that expresses force in newtons per square meter. 1,013.2 hPa is equal to 14.7 psi.



Various equivalent representations of atmospheric pressure at sea level.

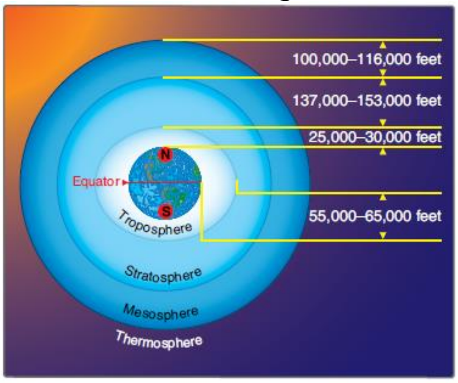
Atmospheric pressure decreases with increasing altitude. The simplest explanation for this is that the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in *Figure below*. The decrease in pressure is a rapid one and, at 50,000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value.



Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40,000 feet, as the dotted lines show, the pressure is only 2.72 psi.

Temperature and Altitude

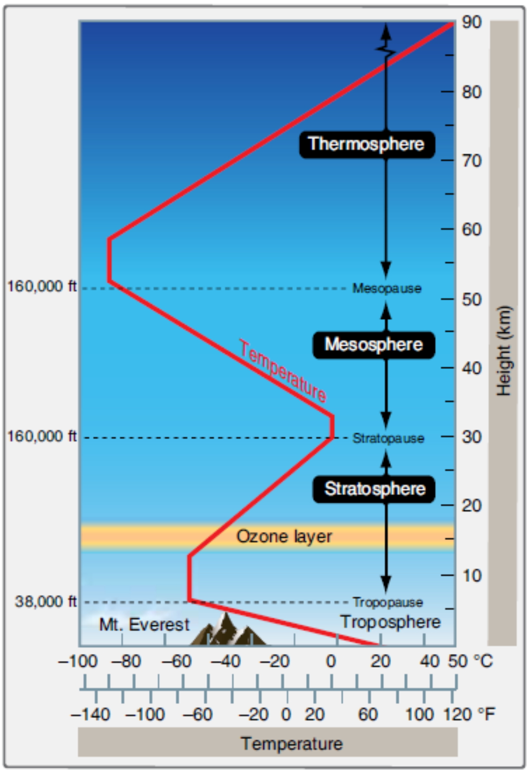
Temperature variations in the atmosphere are of concern to aviators. Weather systems produce changes in temperature near the earth's surface. Temperature also changes as altitude is increased. The troposphere is the lowest layer of the atmosphere. On average, it ranges from the earth's surface to about 38,000 feet above it. Over the poles, the troposphere extends to only 25,000–30,000 feet and, at the equator; it may extend to around 60,000 feet. This oblong nature of the troposphere is illustrated in *Figure below*.



The troposphere extends higher above the earth's surface at the equator than it does at the poles.

Most civilian aviation takes place in the troposphere in which temperature decreases as altitude increases. The rate of change is somewhat constant at about –2 °C or –3.5 °F for every 1,000 feet of increase in altitude. The upper boundary of the troposphere is the tropopause. It is characterized as a zone of relatively constant temperature of –57 °C or –69 °F.

Above the tropopause lies the stratosphere. Temperature increases with altitude in the stratosphere to near 0 °C before decreasing again in the mesosphere, which lies above it. The stratosphere contains the ozone layer that protects the earth's inhabitants from harmful UV rays. Some civilian flights and numerous military flights occur in the stratosphere.



The atmospheric layers with temperature changes depicted by the red line.

When an aircraft is flown at high altitude, it burns less fuel for a given airspeed than it does for the same speed at a lower altitude. This is due to decreased drag that results from the reduction in air density. Bad weather and turbulence can also be avoided by flying in the relatively smooth air above storms and convective activity that occur in the lower troposphere.

To take advantage of these efficiencies, aircraft are equipped with environmental systems to overcome extreme temperature and pressure levels. While supplemental oxygen and a means of staying warm suffice, aircraft pressurization and air conditioning systems have been developed to make high altitude flight more comfortable. *Figure 16-40* illustrates the temperatures and pressures at various altitudes in the atmosphere.

Altitude	Pressure			Temperature	
feet	psi	hPa	in Hg	°F	°C
0	14.69	1013.2	29.92	59.0	15
1,000	14.18	977.2	28.86	55.4	13
2,000	13.66	942.1	27.82	51.9	11
3,000	13.17	908.1	26.82	48.3	9.1
4,000	12.69	875.1	25.84	44.7	7.1
5,000	12.23	843.1	24.90	41.2	5.1
6,000	11.77	812.0	23.98	37.6	3.1
7,000	11.34	781.8	23.09	34.0	1.1
8,000	10.92	752.6	22.23	30.5	–0.8
9,000	10.51	724.3	21.39	26.9	–2.8
10,000	10.10	696.8	20.58	23.3	–4.8
12,000	9.34	644.4	19.03	16.2	–8.8
14,000	8.63	595.2	17.58	9.1	–12.7
16,000	7.96	549.2	16.22	1.9	–16.7
18,000	7.34	506.0	14.94	–5.2	–29.7
20,000	6.76	465.6	13.75	–12.3	–24.6
22,000	6.21	427.9	12.64	–19.5	–28.6
24,000	5.70	392.7	11.60	–26.6	–32.5
26,000	5.22	359.9	10.63	–33.7	–36.5
28,000	4.78	329.3	9.72	–40.9	–40.5
30,000	4.37	300.9	8.89	–48.0	–44.4
32,000	3.99	274.5	8.11	–55.1	–48.4
34,000	3.63	250.0	7.38	–62.2	–52.4
36,000	3.30	227.3	6.71	–69.4	–56.3
38,000	3.00	206.5	6.10	–69.4	–56.5
40,000	2.73	187.5	5.54	–69.4	–56.5
45,000	2.14	147.5	4.35	–69.4	–56.5
50,000	1.70	116.0	3.42	–69.4	–56.5

Cabin environmental systems establish conditions quite different from these found outside the aircraft.

Pressurization Terms

The following terms should be understood for the discussion of pressurization and cabin environmental systems that follows:

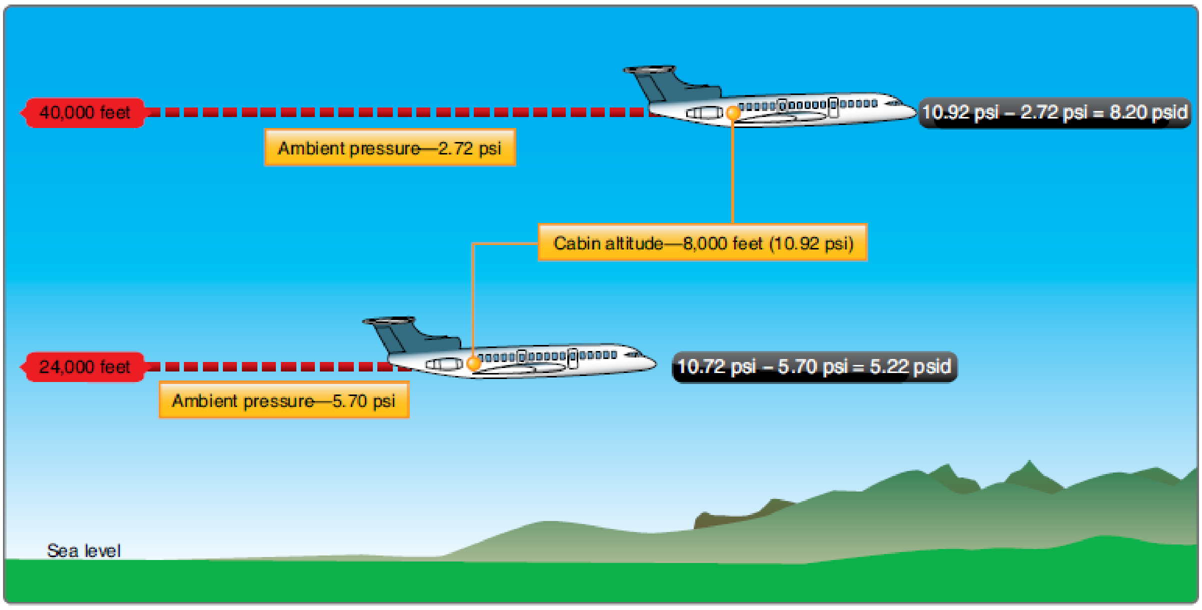
1. Cabin altitude—given the air pressure inside the cabin, the altitude on a standard day that has the same pressure as that in the cabin. Rather than saying the pressure inside the cabin is 10.92 psi, it can be said that the cabin altitude is 8,000 feet (MSL).
2. Cabin differential pressure—the difference between the air pressure inside the cabin and the air pressure outside the cabin. Cabin pressure (psi) – ambient pressure (psi) = cabin differential pressure (psid or Δ psi).
3. Cabin rate of climb—the rate of change of air pressure inside the cabin, expressed in feet per minute (fpm) of cabin altitude change.

Pressurization Issues

Pressurizing an aircraft cabin assists in making flight possible in the hostile environment of the upper atmosphere. The degree of pressurization and the operating altitude of any aircraft are limited by critical design factors. A cabin pressurization system must accomplish several functions if it is to ensure adequate passenger comfort and safety. It must be capable of maintaining a cabin pressure altitude of approximately 8,000 feet or lower regardless of the cruising altitude of the aircraft. This is to ensure that passengers and crew have enough oxygen present at sufficient pressure to facilitate full blood saturation. A pressurization system must also be designed to prevent rapid changes of cabin pressure, which can be uncomfortable or injurious to passengers and crew. Additionally, a pressurization system should circulate air from inside the cabin to the outside at a rate that quickly eliminates odors and to remove stale air. Cabin air must also be heated or cooled on pressurized aircraft. Typically, these functions are incorporated into the pressurization source.

To pressurize, a portion of the aircraft designed to contain air at a pressure higher than outside atmospheric pressure must be sealed. A wide variety of materials facilitate this.

Compressible seals around doors combine with various other seals, grommets, and sealants to essentially establish an air tight pressure vessel. This usually includes the cabin, flight compartment, and the baggage compartments. Air is then pumped into this area at a constant rate sufficient to raise the pressure slightly above that which is needed. Control is maintained by adjusting the rate at which the air is allowed to flow out of the aircraft. A key factor in pressurization is the ability of the fuselage to withstand the forces associated with the increase in pressure inside the structure versus the ambient pressure outside. This differential pressure can range from 3.5 psi for a single engine reciprocating aircraft, to approximately 9 psi on high performance jet aircraft. *[Figure below]* If the weight of the aircraft structure were of no concern, this would not be a problem. Making an aircraft strong for pressurization, yet also light, has been an engineering challenge met over numerous years beginning in the 1930s. The development of jet aircraft and their ability to exploit low drag flight at higher altitude made the problem even more pronounced. Today, the proliferation of composite materials in aircraft structure continues this engineering challenge.



Differential pressure (psid) is calculated by subtracting the ambient air pressure from the cabin air pressure.

In addition to being strong enough to withstand the pressure differential between the air inside and the air outside the cabin, metal fatigue from repeated pressurization and depressurization weakens the airframe. Some early pressurized aircraft structures failed due to this and resulted in fatal accidents. The FAA's aging aircraft program was instituted to increase inspection scrutiny of older airframes that may show signs of fatigue due to the pressurization cycle.

Aircraft of any size may be pressurized. Weight considerations when making the fuselage strong enough to endure pressurization usually limit pressurization to high performance light aircraft and larger aircraft. A few pressurized single-engine reciprocating aircraft exist, as well as many pressurized single-engine turboprop aircraft.

Sources of Pressurized Air

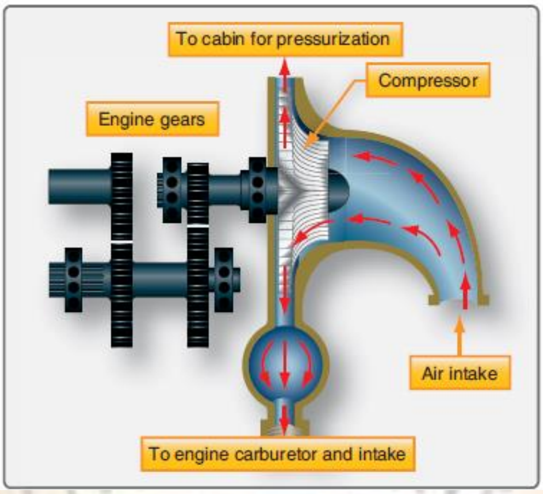
The source of air to pressurize an aircraft varies mainly with engine type. Reciprocating aircraft have pressurization sources different from those of turbine-powered aircraft. Note that the compression of air raises its temperature. A means for keeping pressurization air cool enough is built into most pressurization systems. It may be in the form of a heat exchanger, using cold ambient air to modify the temperature of the air from the pressurization source. A full air cycle air conditioning system with expansion turbine may also be used. The latter provides the advantage of temperature control on the ground and at low altitudes where ambient air temperature may be higher than comfortable for the passengers and crew.

Reciprocating Engine Aircraft

There are three typical sources of air used to pressurize reciprocating aircraft: supercharger, turbocharger, and engine-driven compressor. Superchargers and turbochargers are installed on reciprocating engines to permit better performance at high altitude by increasing the quantity and pressure of the air in the induction system. Some of the air produced by each of these can be routed into the cabin to pressurize it.

A supercharger is mechanically driven by the engine. Despite engine performance increases due to higher induction system pressure, some of the engine output is utilized by the supercharger. Furthermore, superchargers have limited capability to increase engine performance. If supplying both the intake and the cabin with air, the engine performance ceiling is lower than if the aircraft were not pressurized.

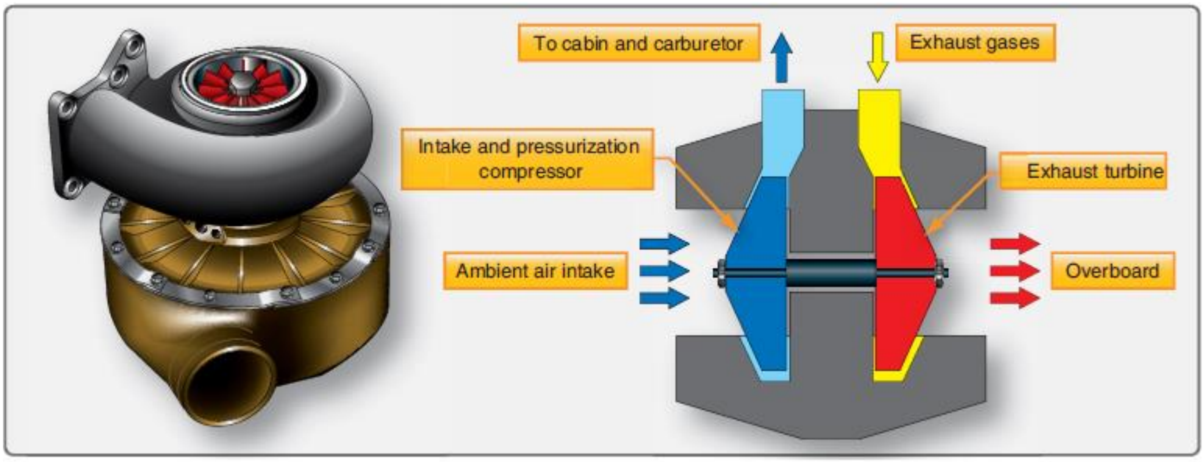
Superchargers must be located upstream of the fuel delivery to be used for pressurization. They are found on older reciprocating engine aircraft, including those with radial engines.



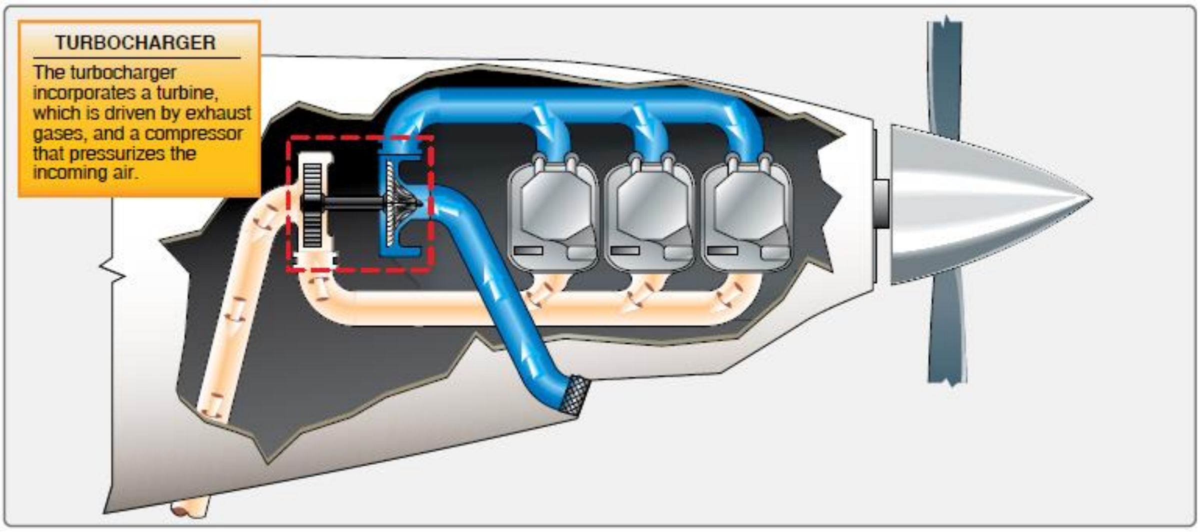
A reciprocating engine supercharger can be used as a source of pressurization if it is upstream of carburetion.

The radial engine supercharger cannot be used since fuel is introduced before the supercharger impeller compresses the air.

Turbochargers, sometimes known as turbo superchargers, are driven by engine exhaust gases. They are the most common source of pressurization on modern reciprocating engine aircraft. The turbocharger impeller shaft extends through the bearing housing to support a compression impeller in a separate housing. By using some of the turbocharger compressed air for cabin pressurization, less is available for the intake charge, resulting in lower overall engine performance. Nonetheless, the otherwise wasted exhaust gases are put to work in the turbocharger compressor, enabling high altitude flight with the benefits of low drag and weather avoidance in relative comfort and without the use of supplemental oxygen. *[Figures below]*



A turbocharger used for pressurizing cabin air and engine intake air on a reciprocating engine aircraft.

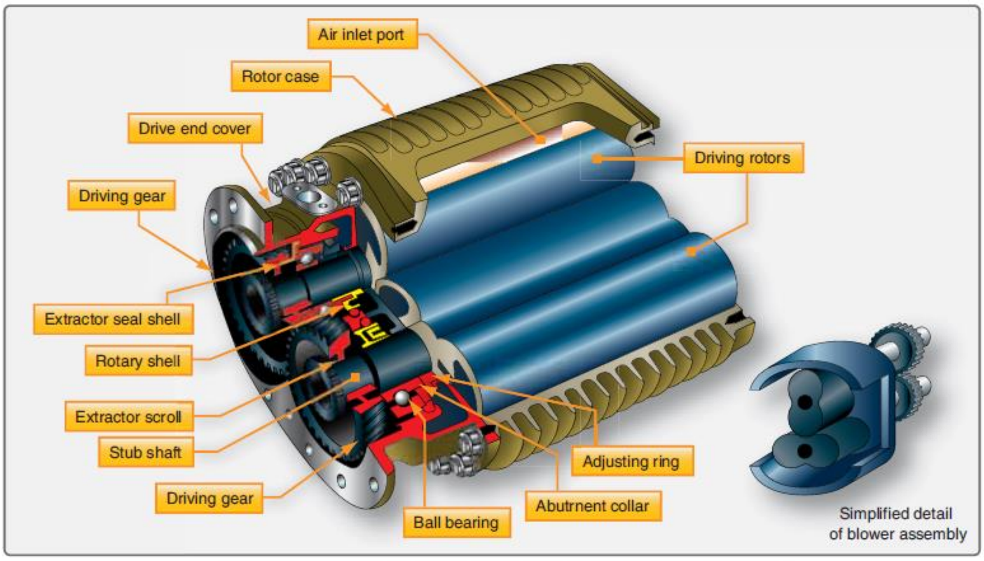


A turbocharger installation on a reciprocating aircraft engine (top left side).

Both superchargers and turbochargers are oil lubricated. The supercharger is part of the fuel intake system and the turbocharger is part of the exhaust system. As such, there is a risk of contamination of cabin air from oil, fuel, or exhaust fumes should a malfunction occur, a shortcoming of these pressurization sources.

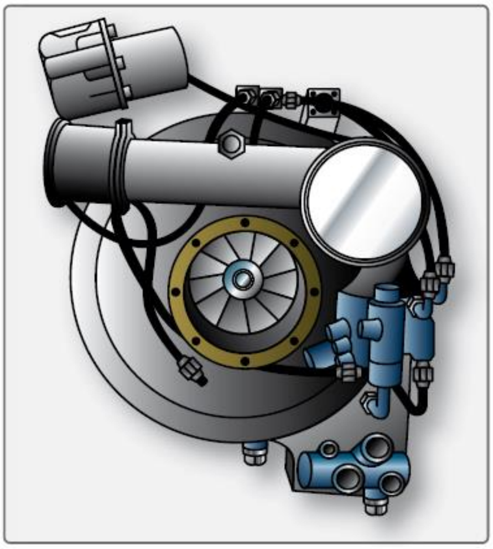
A third source of air for pressurizing the cabin in reciprocating aircraft is an engine driven compressor. Either belt driven or gear driven by the accessory drive, an independent, dedicated compressor for pressurization avoids some of the potential contamination issues of superchargers and turbochargers. The compressor device does, however, add significant weight. It also consumes engine output since it is engine driven.

The roots blower is used on older, large reciprocating engine aircraft. *[Figure below]* The two lobes in this compressor do not touch each other or the compressor housing. As they rotate, air enters the space between the lobes and is compressed and delivered to the cabin for pressurization.



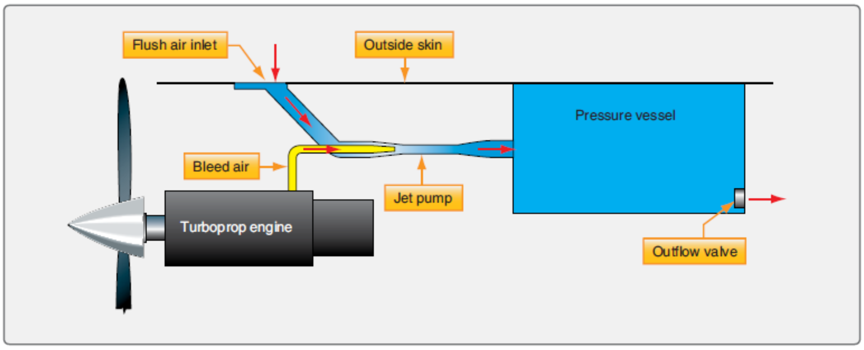
A roots blower found on older pressurized aircraft is gear driven by the engine. It pressurizes air as the rotors rotate very close to each other without touching.

Independent engine-driven centrifugal compressors can also be found on reciprocating engine aircraft. *[Figure below]* A variable ratio gear drive system is used to maintain a constant rate of airflow during changes of engine rpm.



A centrifugal cabin supercharger.

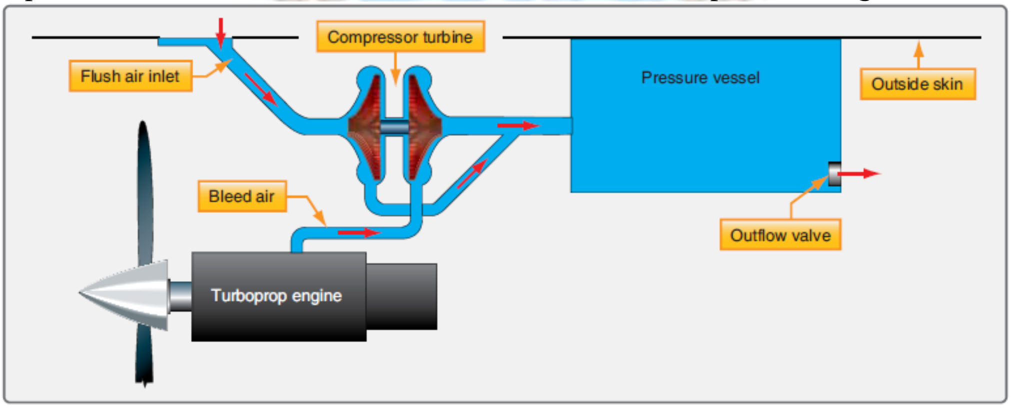
venturi by the bleed air flow, air is drawn in from outside the aircraft. It mixes with the bleed air and is delivered to the pressure vessel to pressurize it. An advantage of this type of pressurization is the lack of moving parts. *[Figure below]* A disadvantage is only a relatively small volume of space can be pressurized in this manner.



A jet pump flow multiplier ejects bleed air into a venturi which draws air for pressurization from outside the aircraft.

Another method of pressurizing an aircraft using turbine engine compressor bleed air is to have the bleed air drive a separate compressor that has an ambient air intake. A turbine turned by bleed air rotates a compressor impellor mounted on the same shaft. Outside air is drawn in and compressed.

It is mixed with the bleed air outflow from the turbine and is sent to the pressure vessel. Turboprop aircraft often use this device, known as a turbo compressor. *[Figure below]*



A turbo compressor used to pressurize cabins mostly in turboprop aircraft.

The most common method of pressurizing turbine-powered aircraft is with an air cycle air conditioning and pressurization system. Bleed air is used, and through an elaborate system including heat exchangers, a compressor, and an expansion turbine, cabin pressurization and the temperature of the pressurizing air are precisely controlled. This air cycle system is discussed in greater detail in the air conditioning section of this chapter. *[Figure below]*

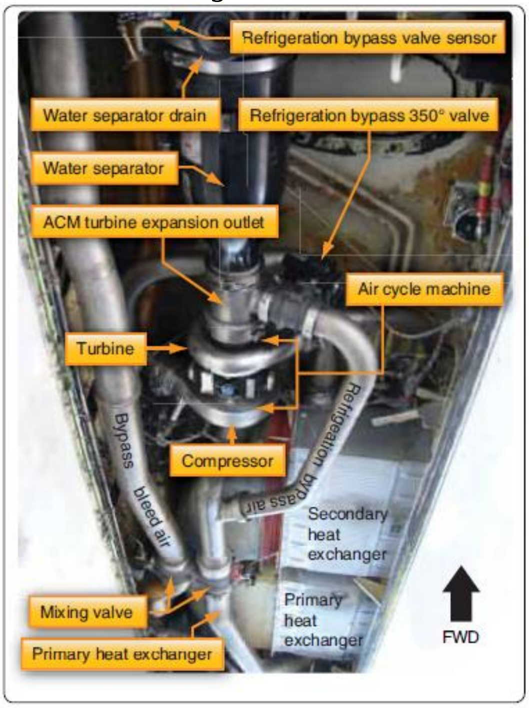
An air cycle air conditioning system used to pressurize the cabin of a business jet

Air Conditioning Systems

There are two types of air conditioning systems commonly used on aircraft. Air cycle air conditioning is used on most turbine-powered aircraft. It makes use of engine bleed air or APU pneumatic air during the conditioning process. Vapour-cycle air conditioning systems are often used on reciprocating aircraft. This type system is similar to that found in homes and automobiles. Note that some turbine-powered aircraft also use vapour cycle air conditioning.

Air Cycle Air Conditioning

Air cycle air conditioning prepares engine bleed air to pressurize the aircraft cabin. The temperature and quantity of the air must be controlled to maintain a comfortable cabin environment at all altitudes and on the ground. The air cycle system is often called the air conditioning package or pack. It is usually located in the lower half of the fuselage or in the tail section of turbine-powered aircraft. *[Figure below]*

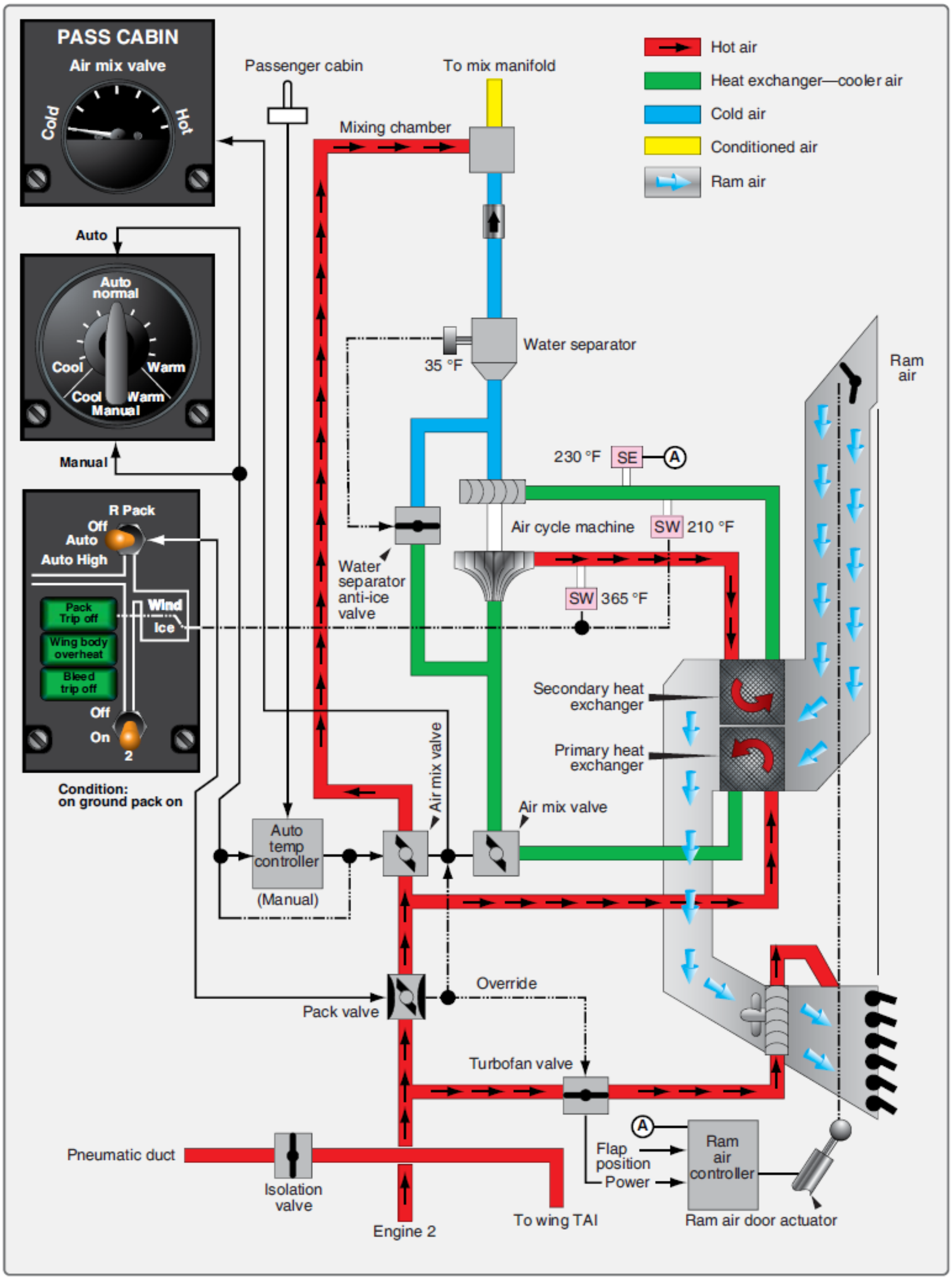


Boeing 737 air cycle system. The photo is taken looking up into the air conditioning bay located in the lower fuselage on each side of the aircraft.

System Operation

Even with the frigid temperatures experienced at high altitudes, bleed air is too hot to be used in the cabin without being cooled. It is let into the air cycle system and routed through a heat exchanger where ram air cools the bleed air.

This cooled bleed air is directed into an air cycle machine. There, it is compressed before flowing through a secondary heat exchange that cools the air again with ram air. The bleed air then flows back into the air cycle machine where it drives an expansion turbine and cools even further. Water is then removed and the air is mixed with bypassed bleed air for final temperature adjustment. It is sent to the cabin through the air distribution system. By examining the operation of each component in the air cycle process, a better understanding can be developed of how bleed air is conditioned for cabin use. Refer to *Figure below*, which diagrams the air cycle air conditioning system of the Boeing 737.



The air cycle air conditioning system on a Boeing 737.

Pneumatic System Supply

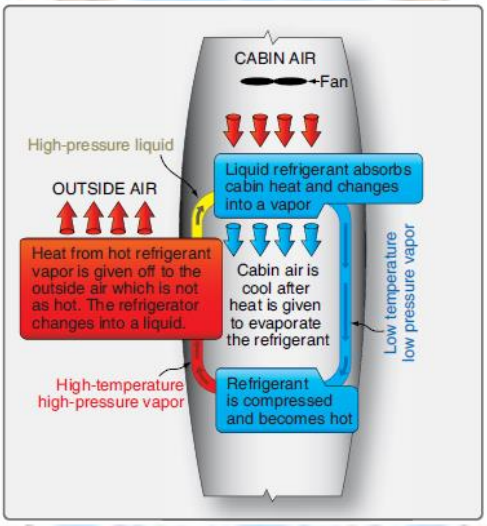
The air cycle air conditioning system is supplied with air by the aircraft pneumatic system. In turn, the pneumatic system is supplied by bleed air tap-offs on each engine compressor section or from the APU pneumatic supply. An external pneumatic air supply source may also be connected while the aircraft is stationary on the ground. In normal flight operations, a pneumatic manifold is supplied by the engine bleed air through the use of valves, regulators, and ducting. The air conditioning packs are supplied by this manifold as are other critical airframe systems, such as the anti-ice and hydraulic pressurization system.

Vapour Cycle Air Conditioning

The absence of a bleed air source on reciprocating engine aircraft makes the use of an air cycle system impractical for conditioning cabin air. Vapour cycle air conditioning is used on most non turbine aircraft that are equipped with air conditioning. However, it is not a source of pressurizing air as the air cycle system conditioned air is on turbine powered aircraft. The vapour cycle system only cools the cabin. If an aircraft equipped with a vapour cycle air conditioning system is pressurized, it uses one of the sources discussed in the pressurization section above. Vapour cycle air conditioning is a closed system used solely for the transfer of heat from inside the cabin to outside of the cabin. It can operate on the ground and in flight.

Theory of Refrigeration

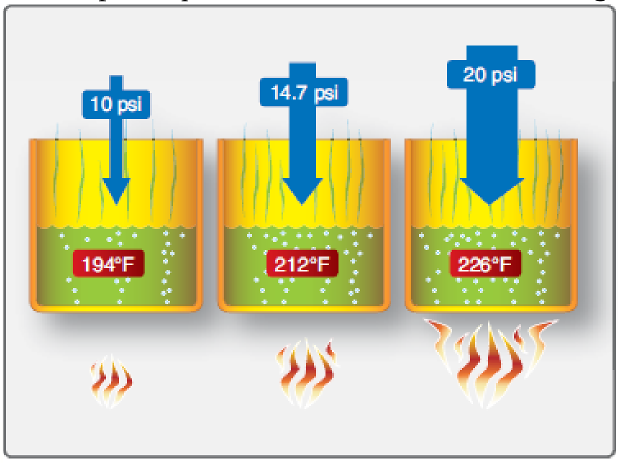
Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapour cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapour. The vapour is compressed and becomes very hot. It is removed from the cabin where the very hot vapour refrigerant transfers its heat energy to the outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer. *[Figure below]*



In vapour cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapour and back again.

Heat is an expression of energy, typically measured by temperature. The higher the temperature of a substance, the more energy it contains. Heat always flows from hot to cold.
These terms express the relative amount of energy present in two substances. They do not measure the absolute amount of heat present. Without a difference in energy levels, there is no transfer of energy (heat).
Adding heat to a substance does not always raise its temperature. When a substance changes state, such as when a liquid changes into a vapour, heat energy is absorbed. This is called latent heat. When a vapour condenses into a liquid, this heat energy is given off. The temperature of a substance remains constant during its change of state. All energy absorbed or given off, the latent heat is used for the change process. Once the change of state is complete, heat added to a substance raises the temperature of the substance. After a substance changes state into a vapour, the rise in temperature of the vapour caused by the addition of still more heat is called superheat.
The temperature at which a substance changes from a liquid into a vapour when heat is added is known as its boiling point. This is the same temperature at which a vapour condenses into a

liquid when heat is removed. The boiling point of any substance varies directly with pressure. When pressure on a liquid is increased, its boiling point increases, and when pressure on a liquid is decreased, its boiling point also decreases. For example, water boils at 212 °F at normal atmospheric temperature (14.7 psi). When pressure on liquid water is increased to 20 psi, it does not boil at 212 °F. More energy is required to overcome the increase in pressure. It boils at approximately 226.4 °F. The converse is also true.
Water can also boil at a much lower temperature simply by reducing the pressure upon it. With only 10 psi of pressure upon liquid water, it boils at 194 °F. *[Figure below]*



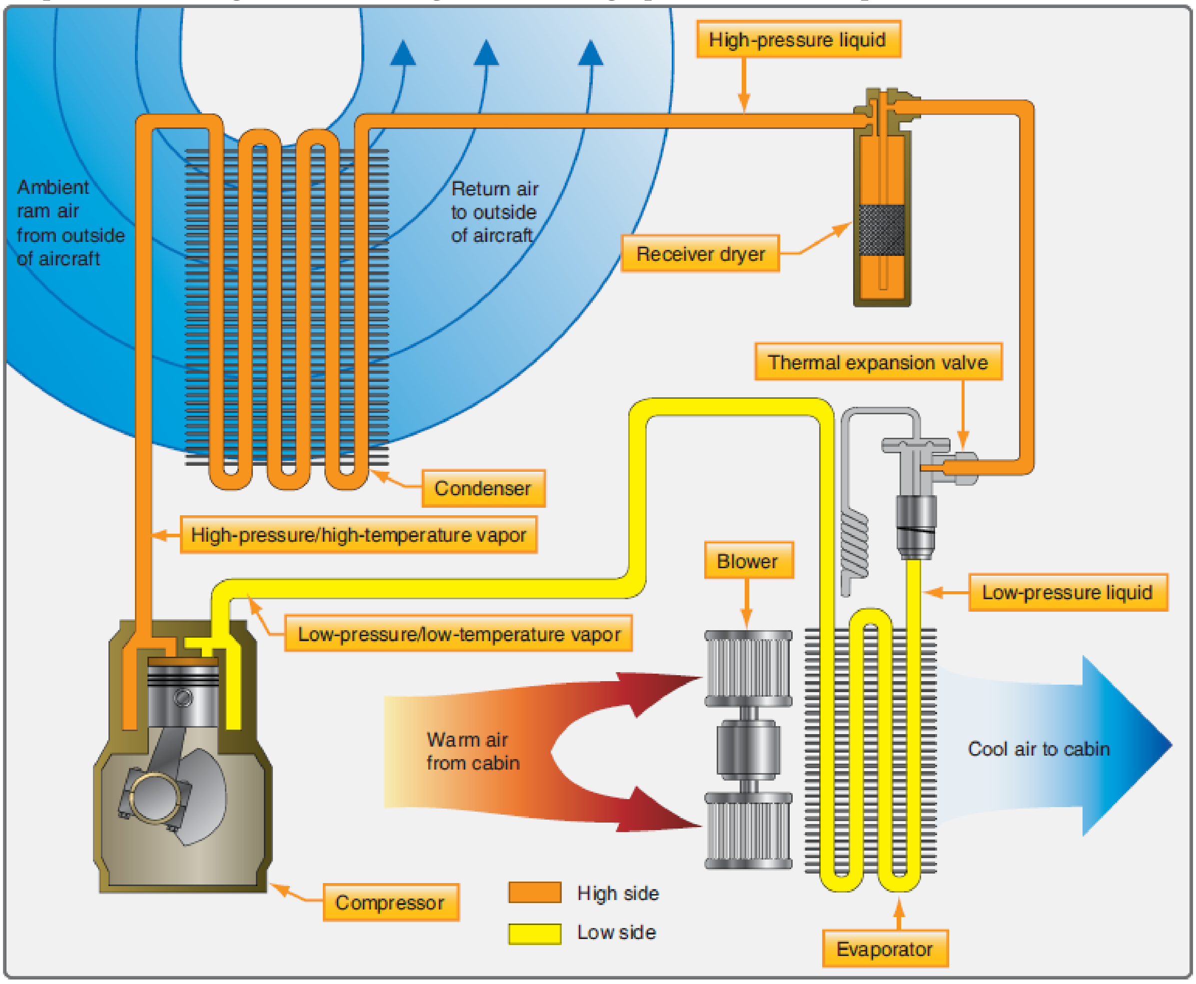
Boiling point of water changes as pressure changes.

Vapour pressure is the pressure of the vapour that exists above a liquid that is in an enclosed container at any given temperature. The vapour pressure developed by various substances is unique to each substance. A substance that is said to be volatile develops high vapour pressure at standard day temperature (59 °F). This is because the boiling point of the substance is much lower. The boiling point of tetrafluoroethane (R134a), the refrigerant used in most aircraft vapour cycle air conditioning systems, is approximately –15 °F. Its vapour pressure at 59 °F is about 71 psi. The vapour pressure of any substance varies directly with temperature.

Basic Vapour Cycle
Vapour cycle air conditioning is a closed system in which a refrigerant is circulated through tubing and a variety of components. The purpose is to remove heat from the aircraft cabin. While circulating, the refrigerant changes state. By manipulating the latent heat required to do so, hot air is replaced with cool air in the aircraft cabin.
To begin, R134a is filtered and stored under pressure in a reservoir known as a receiver dryer. The refrigerant is in liquid form. It flows from the receiver dryer through tubing to an expansion valve. Inside the valve, a restriction in the form of a small orifice blocks most of the refrigerant. Since it is under pressure, some of the refrigerant is forced through the orifice. It emerges as a spray of tiny droplets in the tubing downstream of the valve. The tubing is coiled into a radiator type assembly known as an evaporator. A fan is positioned to blow cabin air over the surface of the evaporator. As it does, the heat in the cabin air is absorbed by the refrigerant, which uses it to change state from a liquid to a vapour. So much heat is absorbed that the cabin air blown by the fan across the evaporator cools significantly. This is the vapour cycle conditioned air that lowers the temperature in the cabin.
The gaseous refrigerant exiting the evaporator is drawn into a compressor. There, the pressure and the temperature of the refrigerant are increased. The high-pressure high-temperature gaseous refrigerant flows through tubing to a condenser. The condenser is like a

radiator comprised of a great length of tubing with fins attached to promote heat transfer. Outside air is directed over the condenser. The temperature of the refrigerant inside is higher than the ambient air temperature, so heat is transferred from the refrigerant to the outside air.

The amount of heat given off is enough to cool the refrigerant and to condense it back to a high-pressure liquid. It flows through tubing and back into the receiver dryer, completing the vapour cycle.
There are two sides to the vapour cycle air conditioning system. One accepts heat and is known as the low side. The other gives up heat and is known as the high side. The low and high refer to the temperature and pressure of the refrigerant. As such, the compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. *[Figure below]* Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.



A basic vapour cycle air conditioning system. The compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. This figure illustrates this division. Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.

ICE CONTROL SYSTEMS

Rain, snow, and ice are transportation's long-time enemies. Flying has added a new dimension, particularly with respect to ice. Under certain atmospheric conditions, ice can build rapidly on airfoils and air inlets. On days when there is visible moisture in the air, ice can form on aircraft leading edge surfaces at altitudes where freezing temperatures start. Water droplets in the air can be super cooled to below freezing without actually turning into ice unless they are disturbed in some manner. This unusual occurrence is partly due to the surface tension of the water droplet not allowing the droplet to expand and freeze. However, when aircraft surfaces disturb these droplets, they immediately turn to ice on the aircraft surfaces.

The two types of ice encountered during flight are clear and rime. Clear ice forms when the remaining liquid portion of the water drop flows out over the aircraft surface, gradually freezing as a smooth sheet of solid ice. Formation occurs when droplets are large, such as in rain or in cumuliform clouds. Clear ice is hard, heavy, and tenacious. Its removal by deicing equipment is especially difficult. Rime ice forms when water drops are small, such as those in stratified clouds or light drizzle. The liquid portion remaining after initial impact freezes rapidly before the drop has time to spread over the aircraft surface. The small frozen droplets trap air giving the ice a white appearance. Rime ice is lighter in weight than clear ice and its weight is of little significance.

However, its irregular shape and rough surface decrease the effectiveness of the aerodynamic efficiency of airfoils, reducing lift and increasing drag. Rime ice is brittle and more easily removed than clear ice.

Mixed clear and rime icing can form rapidly when water drops vary in size or when liquid drops intermingle with snow or ice particles. Ice particles become imbedded in clear ice, building a very rough accumulation sometimes in a mushroom shape on leading edges. Ice may be expected to form whenever there is visible moisture in the air and temperature is near or below freezing. An exception is carburetor icing, which can occur during warm weather with no visible moisture present.

Ice or frost forming on aircraft creates two basic hazards:

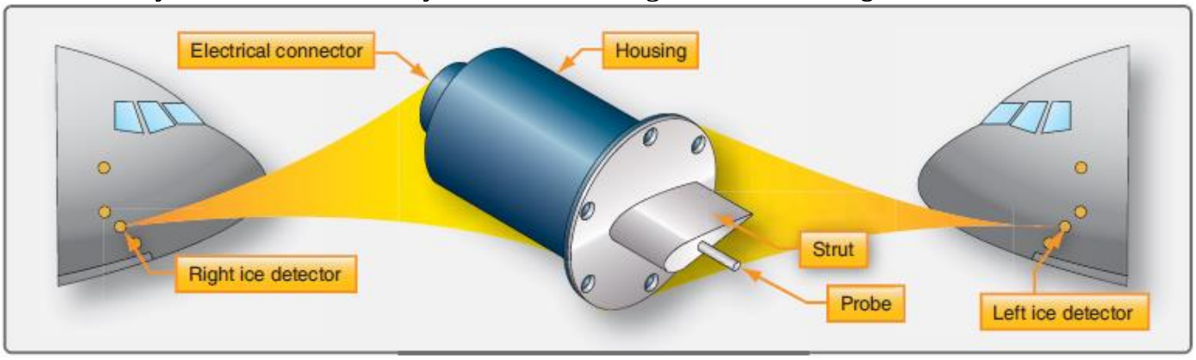
1. The resulting malformation of the airfoil that could decrease the amount of lift.
2. The additional weight and unequal formation of the ice that could cause unbalancing of the aircraft, making it hard to control.

Enough ice to cause an unsafe flight condition can form in a very short period of time, thus some method of ice prevention or removal is necessary. *Figure below* shows the effects of ice on a leading edge.

Formation of ice on aircraft leading edge.

ICE DETECTOR SYSTEM:

Ice can be detected visually, but most modern aircraft have one or more ice detector sensors that warn the flight crew of icing conditions. An annuciator light comes on to alert the flight crew. In some aircraft models, multiple ice detectors are used, and the ice detection system automatically turns on the WAI systems when icing is detected. *[Figure below]*



An ice detector alerts the flight crew of icing conditions and, on some aircraft, automatically activates ice protection systems. One or more detectors are located on the forward fuselage.

Ice Prevention

Several means to prevent or control ice formation are used in aircraft today:

1. Heating surfaces with hot air
2. Heating by electrical elements
3. Breaking up ice formations, usually by inflatable boots
4. Chemical application

Equipment is designed for anti-icing or for de-icing. Anti-icing equipment is turned on before entering icing conditions and is designed to prevent ice from forming. A surface may be anti-iced by keeping it dry, by heating to a temperature that evaporates water upon impingement, or by heating the surface just enough to prevent freezing, maintaining it running wet.

De-icing equipment is designed to remove ice after it begins to accumulate typically on the wings and stabilizer leading edges. Ice may be controlled on aircraft structure by the methods described in *Figure below*.

Location of ice	Method of control
Leading edge of the wing	Thermal pneumatic, thermal electric, chemical, and pneumatic (deice)
Leading edges of vertical and horizontal stabilizers	Thermal pneumatic, thermal electric, and pneumatic (deice)
Windshield, windows	Thermal pneumatic, thermal electric, and chemical
Heater and engine air inlets	Thermal pneumatic and thermal electric
Pitot and static air data sensors	Thermal electric
Propeller blade leading edge and spinner	Thermal electric and chemical
Carburetor(s)	Thermal pneumatic and chemical
Lavatory drains and portable water lines	Thermal electric

Typical ice control methods.

Stabilizer Anti-Icing Systems

The wing leading edges, or leading edge slats, and horizontal and vertical stabilizer leading edges of many aircraft make and models have anti-icing systems installed to prevent the formation of ice on these components. The most common anti-icing systems used are thermal pneumatic, thermal electric, and chemical. Most general aviation (GA) aircraft equipped to fly in icing conditions use pneumatic deicing boots, a chemical anti-ice system. High-performance aircraft may have “weeping wings.” Large transport-category aircraft are equipped with advanced thermal pneumatic or thermal electric anti-icing systems that are controlled automatically to prevent the formation of ice.

Thermal Pneumatic Anti-icing

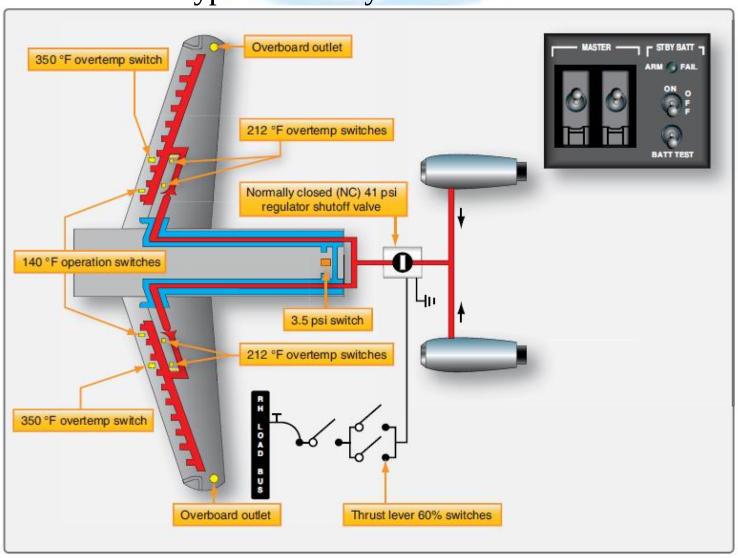
Thermal systems used for the purpose of preventing the formation of ice or for de-icing airfoil leading edges usually use heated air ducted span wise along the inside of the leading edge of the airfoil and distributed around its inner surface. These thermal pneumatic anti-icing systems are used for wings, leading edge slats, horizontal and vertical stabilizers, engine inlets, and more. There are several sources of heated air, including hot air bled from the turbine compressor, engine exhaust heat exchangers, and ram air heated by a combustion heater.

Wing Anti-Ice (WAI) System

Thermal wing anti-ice (WAI or TAI) systems for business jet and large-transport category aircraft typically use hot air bled from the engine compressor. *[Figure below]* Relatively large amounts of very hot air can be bled off the compressor, providing a satisfactory source of anti-icing heat.

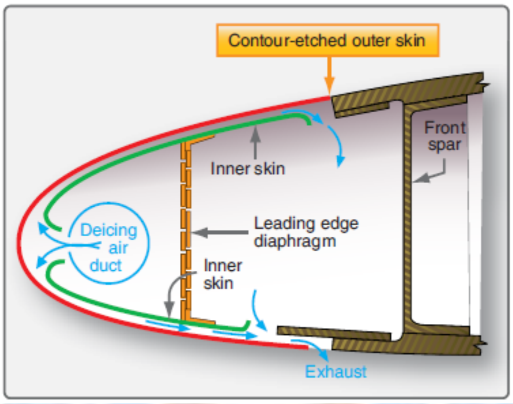
Aircraft with thermal WAI system.

The hot air is routed through ducting, manifolds, and valves to components that need to be anti-iced. *Figure below* shows a typical WAI system schematic for a business jet.



Thermal WAI system.

The bleed air is routed to each wing leading edge by an ejector in each wing inboard area. The ejector discharges the bleed air into piccolo tubes for distribution along the leading edge. Fresh ambient air is introduced into the wing leading edge by two flush-mounted ram air scoops in each wing leading edge, one at the wing root and one near the wingtip. The ejectors entrain ambient air, reduce the temperature of the bleed air, and increase the mass airflow in the piccolo tubes. The wing leading edge is constructed of two skin layers separated by a narrow passageway. *[Figure below]* The air directed against the leading edge can only escape through the passageway, after which it is vented overboard through a vent in the bottom of the wingtip.



Heated wing leading edge.

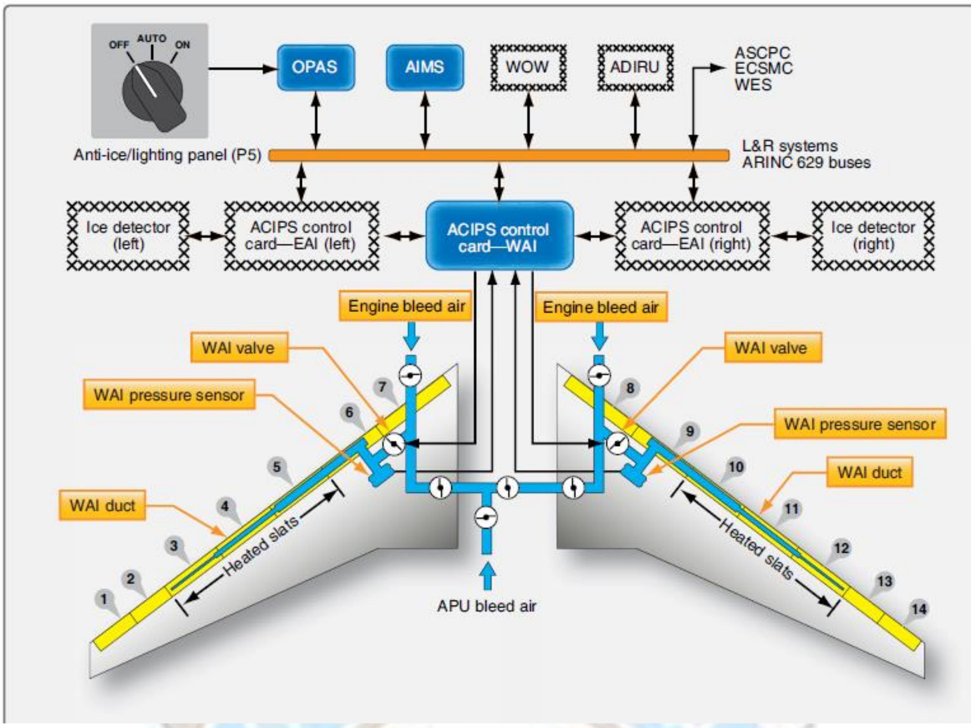
When the WAI switch is turned on, the pressure regulator is energized and the shutoff valve opens. When the wing leading edge temperature reaches approximately +140 °F, temperature switches turn on the operation light above the switch. If the temperature in the wing leading edge exceeds approximately +212 °F (outboard) or +350 °F (inboard), the red WING OV HT warning light on the annunciator panel illuminates. When installing a section of duct, make certain that the seal bears evenly against and is compressed by the adjacent joint’s flange. When specified, the ducts should be pressure tested at the pressure recommended by the manufacturer of the aircraft concerned. Leak checks are made to detect defects in the duct that would permit the escape of heated air. The rate of leakage at a given pressure should not exceed that recommended in the aircraft maintenance manual.

Air leaks can often be detected audibly and are sometimes revealed by holes in the lagging or thermal insulation material. However, if difficulty arises in locating leaks, a soap-and water solution may be used. All ducting should be inspected for security, general condition, or distortion. Lagging or insulating blankets must be checked for security and must be free of flammable fluids, such as oil or hydraulic fluid.

Leading Edge Slat Anti-Ice System

Aircraft that utilize leading edge slats often use bleed air from the engine compressor to prevent the formation of frost on these surfaces. On a modern transport category aircraft, the pneumatic system supplies bleed air for this purpose. WAI valves control the air flow from the pneumatic system to WAI ducts. The WAI ducts carry the air to the slats. Holes in the bottom of each slat let the air out.

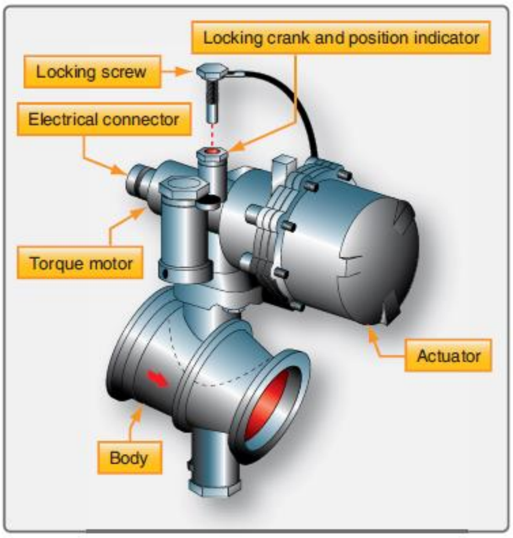
The airfoil and cowl ice protection system (ACIPS) computer card controls the WAI valves, and pressure sensors send duct air pressure data to the computer. The aircrew can select an auto or manual mode with the WAI selector. In the auto mode, the system turns on when the ice detection system detects ice. The off and on positions are used for manual control of the WAI system. The WAI system is only used in the air, except for ground tests. The weight on wheels system and/ or airspeed data disarms the system when the aircraft is on the ground. *[Figure below]*



Wing leading edge slat anti-ice system

WAI Valve

The WAI valve controls the flow of bleed air from the pneumatic system to the WAI ducts. The valve is electrically controlled and pneumatically actuated. The torque motor controls operation of the valve. With no electrical power to the torque motor, air pressure on one side of the actuator holds the valve closed. Electrical current through the torque motor allows air pressure to open the valve. As the torque motor current increases, the valve opening increases. *[Figure below]*



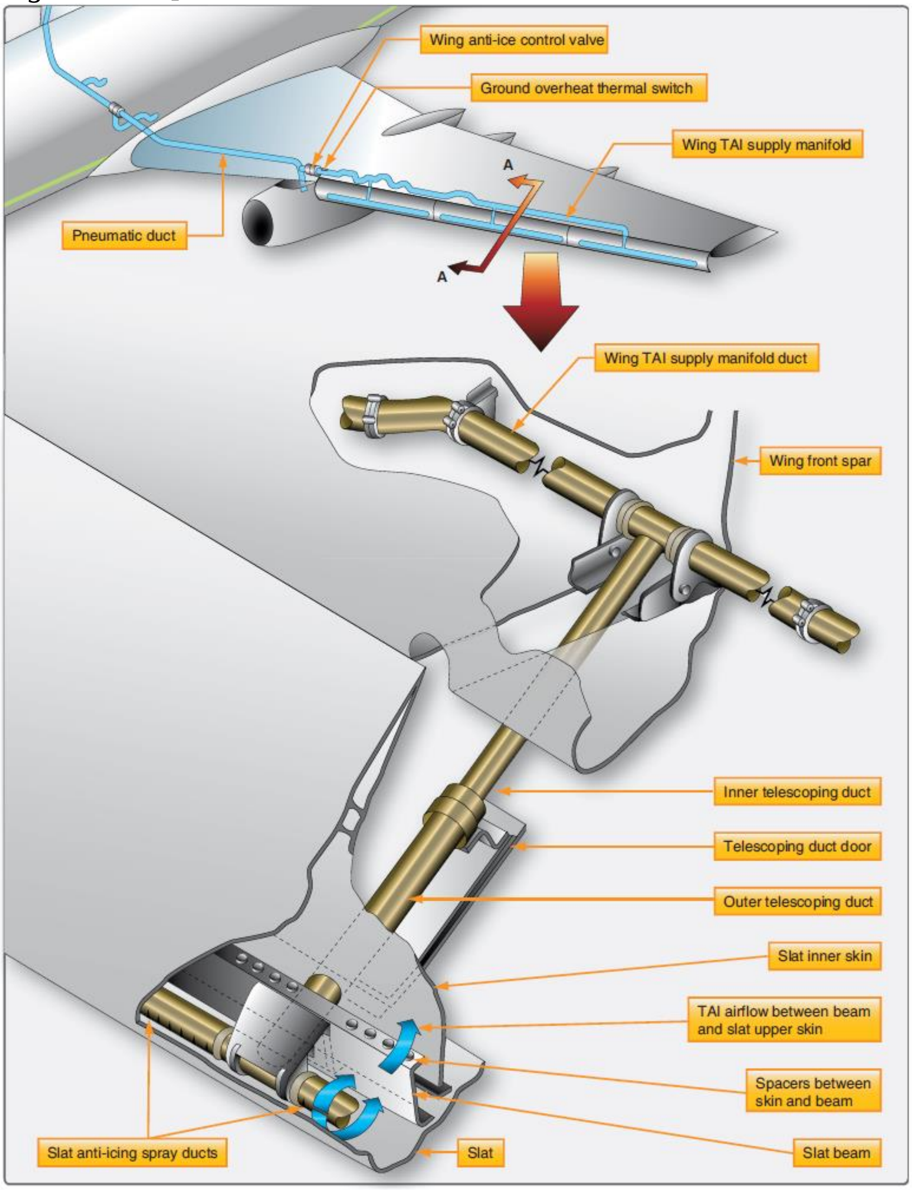
A wing anti-ice valve.

WAI Pressure Sensor

The WAI pressure sensor senses the air pressure in the WAI duct after the WAI valve. The ACIPS system card uses the pressure information to control the WAI system.

WAI Ducts
The WAI ducts move air from the pneumatic system through the wing leading edge to the leading edge slats.

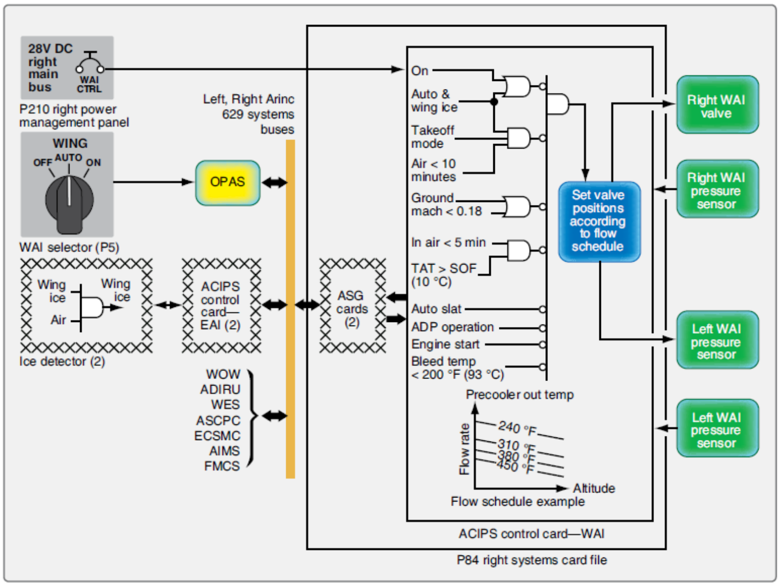
Figure Wing leading edge slat anti-ice system shows that only leading edge slat sections 3, 4, and 5 on the left wing and 10, 11, and 12 on the right wing receive bleed air for WAI. Sections of the WAI ducting are perforated. The holes allow air to flow into the space inside the leading edge slats. The air leaves the slats through holes in the bottom of each slat. Some WAI ducts have connecting "T" ducts that telescope to direct air into the slats while extended. The telescoping section attached to the slat on one end, slides over the narrow diameter "T" section that is connected into the WAI duct. A seal prevents any loss of air. This arrangement allows warm air delivery to the slats while retracted, in transit, and fully deployed. *[Figure below]*



WAI ducting.

WAI Control System
Modern aircraft use several onboard computers to control aircraft systems. The WAI system is controlled by the ACIPS computer card. The ACIPS computer card controls both WAI

valves. The required positions of the WAI valves change as bleed air temperature and altitude change. The left and right valves operate at the same time to heat both wings equally. This keeps the airplane aerodynamically stable in icing conditions. The WAI pressure sensors supply feedback information to the WAI ACIPS computer card for WAI valve control and position indication. If either pressure sensor fails, the WAI ACIPS computer card sets the related WAI valve to either fully open or fully closed. If either valve fails closed, the WAI computer card keeps the other valve closed.
There is one selector for the WAI system. The selector has three positions: auto, on, and off. With the selector in auto and no operational mode inhibits, the WAI ACIPS computer card sends a signal to open the WAI valves when either ice detector detects ice. The valves close after a 3-minute delay when the ice detector no longer detects ice. The time delay prevents frequent on/off cycles during intermittent icing conditions. With the selector on and no operational mode inhibits, the WAI valves open. With the selector off, the WAI valves close. The operational mode for the WAI valves can be inhibited by many different sets of conditions. *[Figure below]*



WAI inhibit logic schematic.

The operational mode is inhibited if all of these conditions occur:

- ➢ Auto mode is selected
- ➢ Takeoff mode is selected
- ➢ Airplane has been in the air less than 10 minutes

With auto or on selected, the operational mode is inhibited if any of these conditions occur:

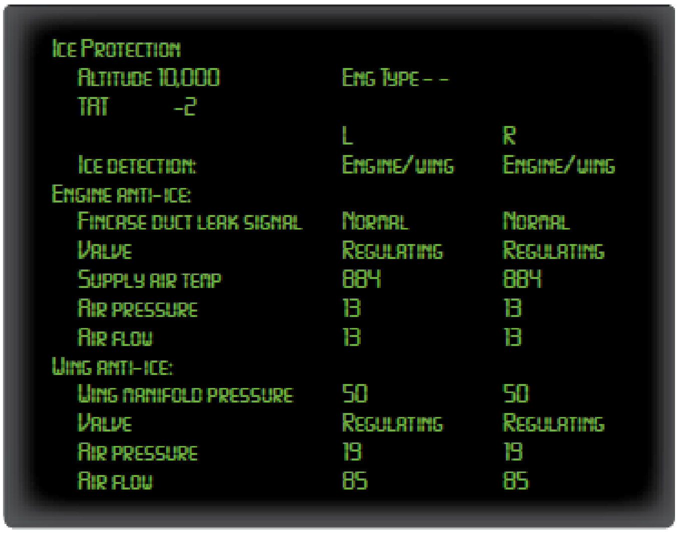
- ❖ Airplane on the ground (except during an initiated or periodic built-in test equipment (BITE) test)
- ❖ Total Air Temperature (TAT) is more than 50 °F (10 °C) and the time since takeoff is less than 5 minutes
- ❖ Auto slat operation
- ❖ Air-driven hydraulic pump operation
- ❖ Engine start
- ❖ Bleed air temperature less than 200 °F (93 °C).

The WAI valves stay closed as long as the operational mode inhibit is active. If the valves are already open, the operational mode inhibit causes the valves to close.

WAI Indication System

The aircrew can monitor the WAI system on the onboard computer maintenance page. *[Figure below]* The following information is shown:

- WING MANIFOLD PRESS—pneumatic duct pressure in PSIG
- VALVE—WAI valve open, closed, or regulating
- AIR PRESS—pressure downstream of the WAI valves in PSIG
- AIR FLOW—air flow through the WAI valves in pounds per minute.

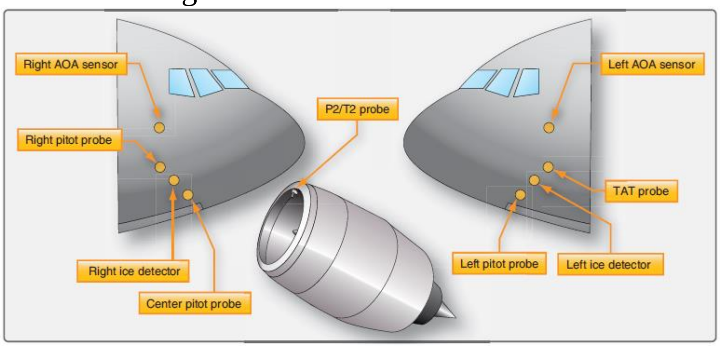


Ice protection onboard computer maintenance page.

Thermal Electric Anti-Icing

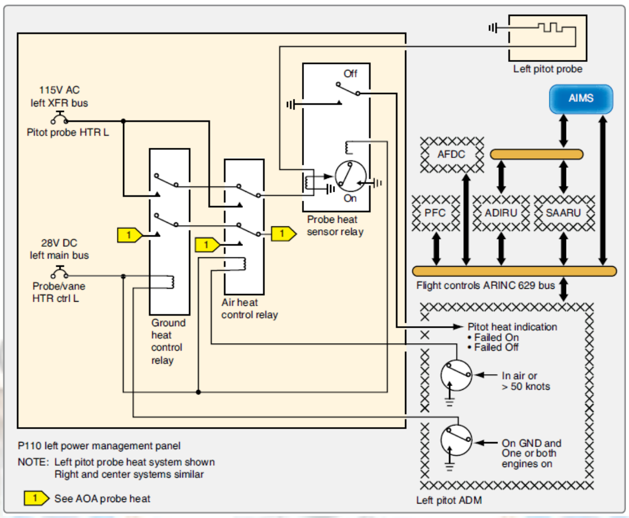
Electricity is used to heat various components on an aircraft so that ice does not form. This type of anti-ice is typically limited to small components due to high amperage draw. Effective thermal electric anti-ice is used on most air data probes, such as pitot tubes, static air ports, TAT and AOA probes, ice detectors, and engine P2/T2 sensors. Water lines, waste water drains, and some turboprop inlet cowls are also heated with electricity to prevent ice from forming. Transport category and high performance aircraft use thermal electric anti-icing in windshields. In devices that use thermal electric anti-ice, current flows through an integral conductive element that produces heat.

The temperature of the component is elevated above the freezing point of water so ice cannot form. Various schemes are used, such as an internal coil wire, externally wrapped blankets or tapes, as well as conductive films and heated gaskets. A basic discussion of probe heat follows. Windshield heat and portable water heat anti-ice are discussed later in this chapter. Propeller deices boots, which also are used for anti-ice, are also thermal electric and discussed in this chapter. Data probes that protrude into the ambient airstream are particularly susceptible to ice formation in flight.



Probes with thermal electric anti-icing on one commercial airliner.

Figure above illustrates the types and location probes that use thermal electric heat on one airliner. A pitot tube, for example, contains an internal electric element that is controlled by a switch in the cockpit. Use caution checking the function of the pitot heat when the aircraft is on the ground. The tube gets extremely hot since it must keep ice from forming at altitude in temperatures near -50 °F at speeds possibly over 500 miles per hour. An ammeter or load meter in the circuit can be used as a substitute to touching the probe, if so equipped.
Simple probe heat circuits exist on GA aircraft with a switch and a circuit breaker to activate and protect the device.
Advanced aircraft may have more complex circuitry in which control is by computer and flight condition of the aircraft is considered before thermal electric heaters are activated automatically.

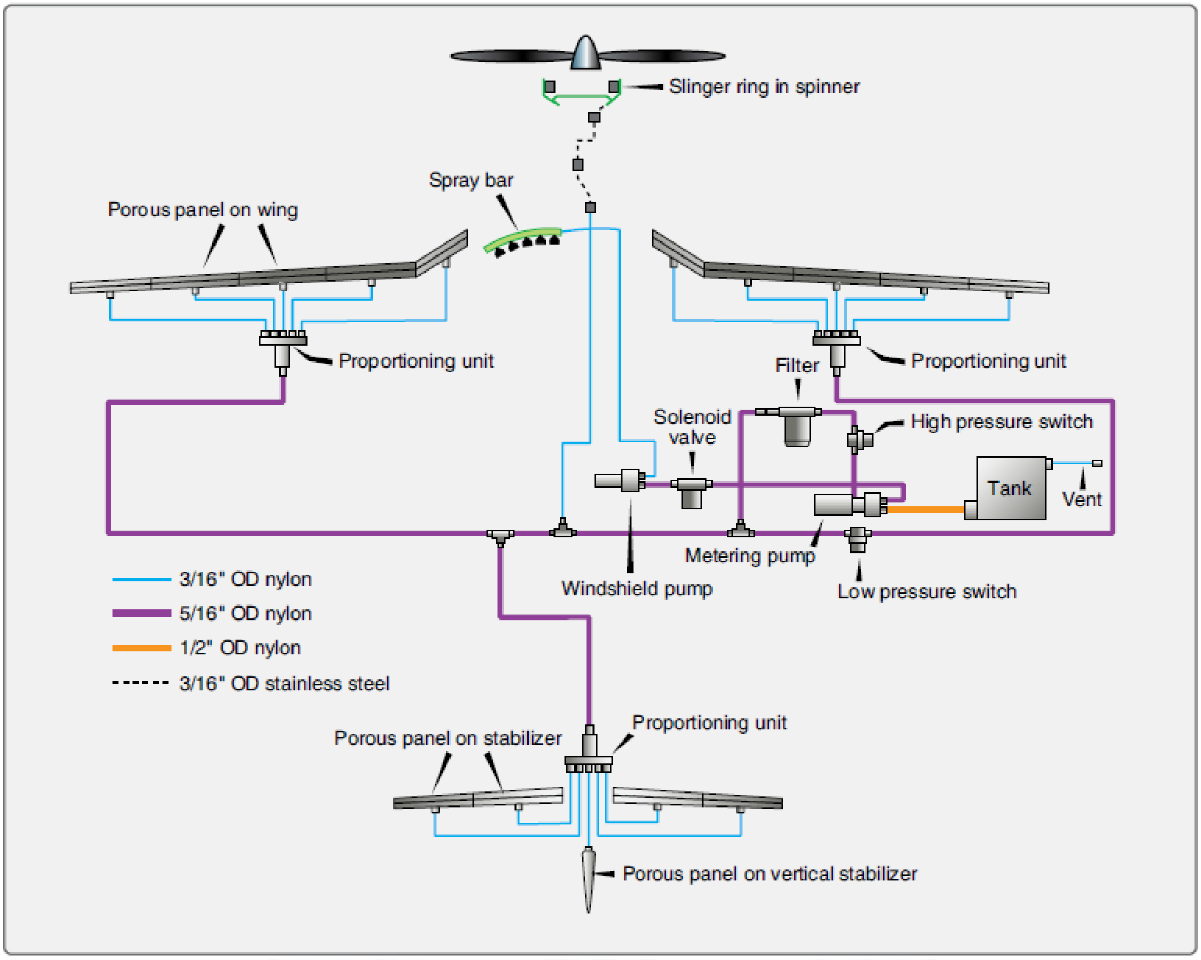


Pitot probe heat system.

Figure above shows such a circuit for a pitot tube. The primary flight computer (PFC) supplies signals for the air data card (ADC) to energize ground and air heat control relays to activate probe heat. Information concerning speed of the aircraft, whether it is in the air or on the ground, and if the engines are running are factors considered by the ADC logic. Similar control is use for other probe heaters.

Chemical Anti-Icing

Chemical anti-icing is used in some aircraft to anti-ice the leading edges of the wing, stabilizers, windshields, and propellers. The wing and stabilizer systems are often called weeping wing systems or are known by their trade name of TKS™ systems. Ice protection is based upon the freezing point depressant concept. An antifreeze solution is pumped from a reservoir through a mesh screen embedded in the leading edges of the wings and stabilizers. Activated by a switch in the cockpit, the liquid flows over the wing and tail surfaces, preventing the formation of ice as it flows.
The solution mixes with the super cooled water in the cloud, depresses its freezing point, and allows the mixture to flow off of the aircraft without freezing. The system is designed to anti-ice, but it is also capable of de-icing an aircraft as well. When ice has accumulated on the leading edges, the antifreeze solution chemically breaks down the bond between the ice and airframe. This allows aerodynamic forces to carry the ice away. Thus, the system clears the airframe of accumulated ice before transitioning to anti-ice protection. *Figure below* shows a chemical anti-ice system.



Chemical de-icing system.

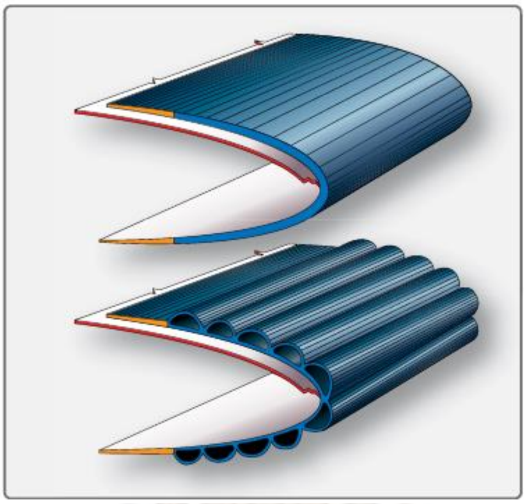
The TKS™ weeping wing system contains formed titanium panels that are laser drilled with over 800 tiny holes (.0025 inch diameter) per square inch. These are mated with non perforated stainless steel rear panels and bonded to wing and stabilizer leading edges. As fluid is delivered from a central reservoir and pump, it seeps through the holes. Aerodynamic forces cause the fluid to coat the upper and lower surfaces of the airfoil. The glycol based fluid prevents ice from adhering to the aircraft structure. Some aircraft with weeping wing systems are certified to fly into known icing conditions. Others use it as a hedge against unexpected ice encountered in flight. The systems are basically the same. Reservoir capacity permits 1- 2 hours of operation. TKSTM weeping wings are used primarily on reciprocating aircraft that lack a supply of warm bleed air for the installation of a thermal anti-ice system. However, the system is simple and effective leading to its use on some turbine powered corporate aircraft as well.

Pneumatic Deice Boot System for GA Aircraft

GA aircraft, especially twin-engine models, are commonly equipped with pneumatic deicer systems. Rubber boots are attached with glue to the leading edges of the wings and stabilizers. These boots have a series of inflatable tubes. During operation, the tubes are inflated and deflated in an alternating cycle.

[Figure below] This inflation and deflation causes the ice to crack and break off. The ice is then carried away by the airstream. Boots used in GA aircraft typically inflate and deflate along the length of the wing. In larger turbo prop aircraft, the boots are installed in sections along the wing with the different sections operating alternately and symmetrically about the

fuselage. This is done so that any disturbance to airflow caused by an inflated tube is kept to a minimum by inflating only short sections on each wing at a time.



Cross-section of a pneumatic de-icing boot uninflected (top) and inflated (bottom).

Ice and Snow Removal

Probably the most difficult deposit to deal with is deep, wet snow when ambient temperatures are slightly above the freezing point. This type of deposit should be removed with a soft brush or squeegee. Use care to avoid damage to antennas, vents, stall warning devices, vortex generators, etc., that may be concealed by the snow. Light, dry snow in subzero 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. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of de-icing operations, inspect the aircraft to ensure that its condition is satisfactory for flight. All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control gaps and hinges.

Check the drain and pressure sensing ports for obstructions. When it becomes necessary to physically remove a layer of snow, all protrusions and vents should be examined for signs of damage. Control surfaces should be moved to ascertain that they have full and free movement. The landing gear mechanism, doors and bay, and wheel brakes should be inspected for snow or ice deposits and the operation of up locks and micro switches checked.

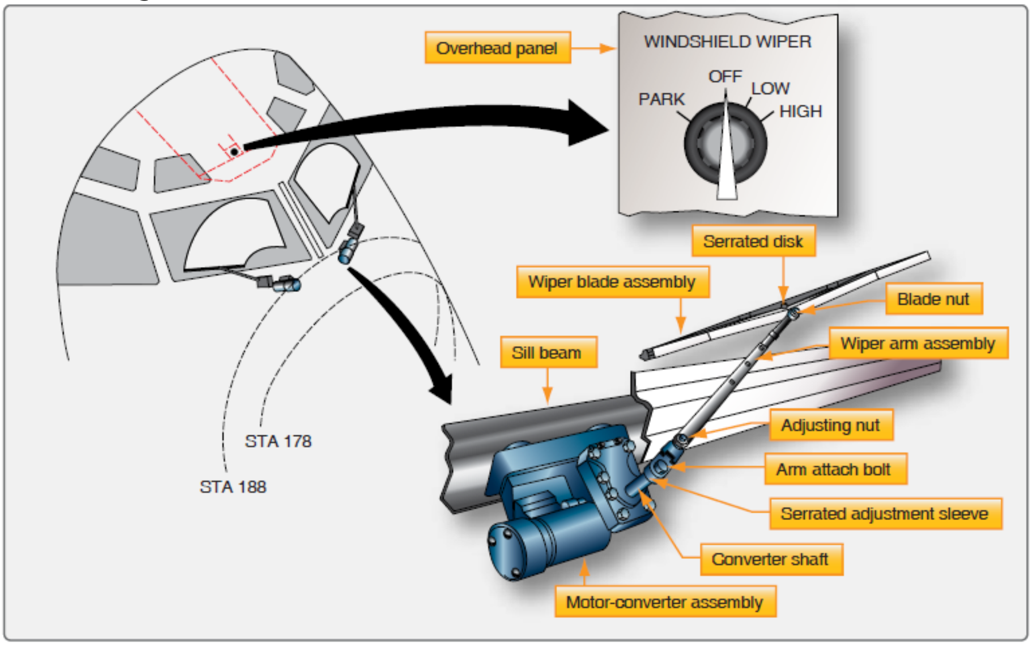
Snow or ice can enter turbine engine intakes and freeze in the compressor. If the compressor cannot be turned by hand for this reason, hot air should be blown through the engine until the rotating parts are free.

Rain Control Systems

There are several different ways to remove the rain from the windshields. Most aircraft use one or a combination of the following systems: windshield wipers, chemical rain repellent, pneumatic rain removal (jet blast), or windshields treated with a hydrophobic surface seal coating.

Windshield Wiper Systems

In an electrical windshield wiper system, the wiper blades are driven by an electric motor(s) that receive (s) power from the aircraft's electrical system. On some aircraft, the pilot's and co-pilot's windshield wipers are operated by separate systems to ensure that clear vision is maintained through one of the windows should one system fail. Each windshield wiper assembly consists of a wiper, wiper arm, and a wiper motor/converter. Almost all windshield wiper systems use electrical motors. Some older aircraft might be equipped with hydraulic wiper motors. *[Figure below]*



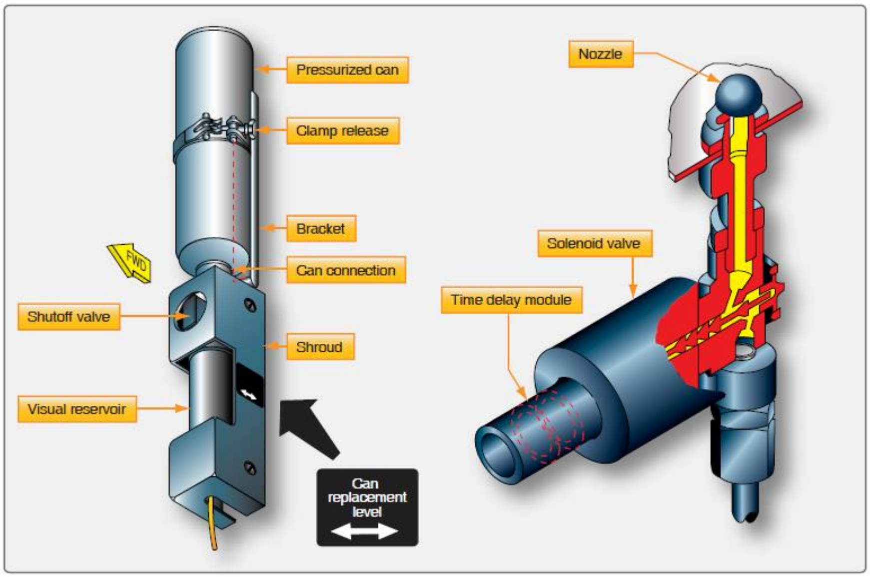
Windshield wiper assembly/installation on a transport category aircraft. The motor-converter is mounted under the aircraft skin.

Maintenance performed on windshield wiper systems consists of operational checks, adjustments and troubleshooting. An operational check should be performed whenever a system component is replaced or whenever the system is suspected of not working properly. During the check, make sure that the windshield area covered by the wipers is free of foreign matter and is kept wet with water. Adjustment of a windshield wiper system consists of adjusting the wiper blade tension, the angle at which the blade sweeps across the windshield, and proper parking of the wiper blades.

Chemical Rain Repellent

Water poured onto clean glass spreads out evenly. Even when the glass is held at a steep angle or subjected to air velocity, the glass remains wetted by a thin film of water. However, when glass is treated with certain chemicals, a transparent film is formed that causes the water to behave very much like mercury on glass. The water draws up into beads that cover only a portion of the glass and the area between beads is dry. The water is readily removed from the glass. This principle lends itself quite naturally to removing rain from aircraft windshields. The high-velocity slipstream continually removes the water beads, leaving a large part of the window dry.

A rain repellent system permits application of the chemical repellent by a switch or push button in the cockpit. The proper amount of repellent is applied regardless of how long the switch is held. On some systems, a solenoid valve controlled by a time delay module meters the repellent to a nozzle which sprays it on the outside of the windshield. Two such units exist — one each for the forward glass of the pilot and co-pilot. *[Figure below]*

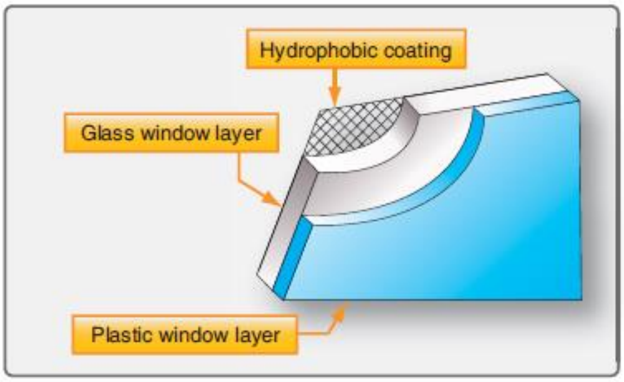


Cockpit rain repellant canister and reservoir.

This system should only be used in very wet conditions. The rain repellent system should not be operated on dry windows because heavy undiluted repellent restricts window visibility. Should the system be operated inadvertently, do not operate the windshield wipers or rain clearing system as this tends to increase smearing. Also, the rain repellent residues caused by application in dry weather or very light rain can cause staining or minor corrosion of the aircraft skin. To prevent this, any concentrated repellent or residue should be removed by a thorough fresh water rinse at the earliest opportunity. After application, the repellent film slowly deteriorates with continuing rain impingement. This makes periodic reapplication necessary. The length of time between applications depends upon rain intensity, the type of repellent used, and whether windshield wipers are used.

Windshield Surface Seal Coating

Some aircraft models use a surface seal coating, also called hydrophobic coating that is on the outside of the pilot's/ co-pilot's windshield. *[Figure below]* The word hydrophobic means to repel or not absorb water. The windshield hydrophobic coating is on the external surface of the windows (windshields). The coatings cause raindrops to bead up and roll off, allowing the flight crew to see through the windshield with very little distortion. The hydrophobic windshield coating reduces the need for wipers and gives the flight crew better visibility during heavy rain.

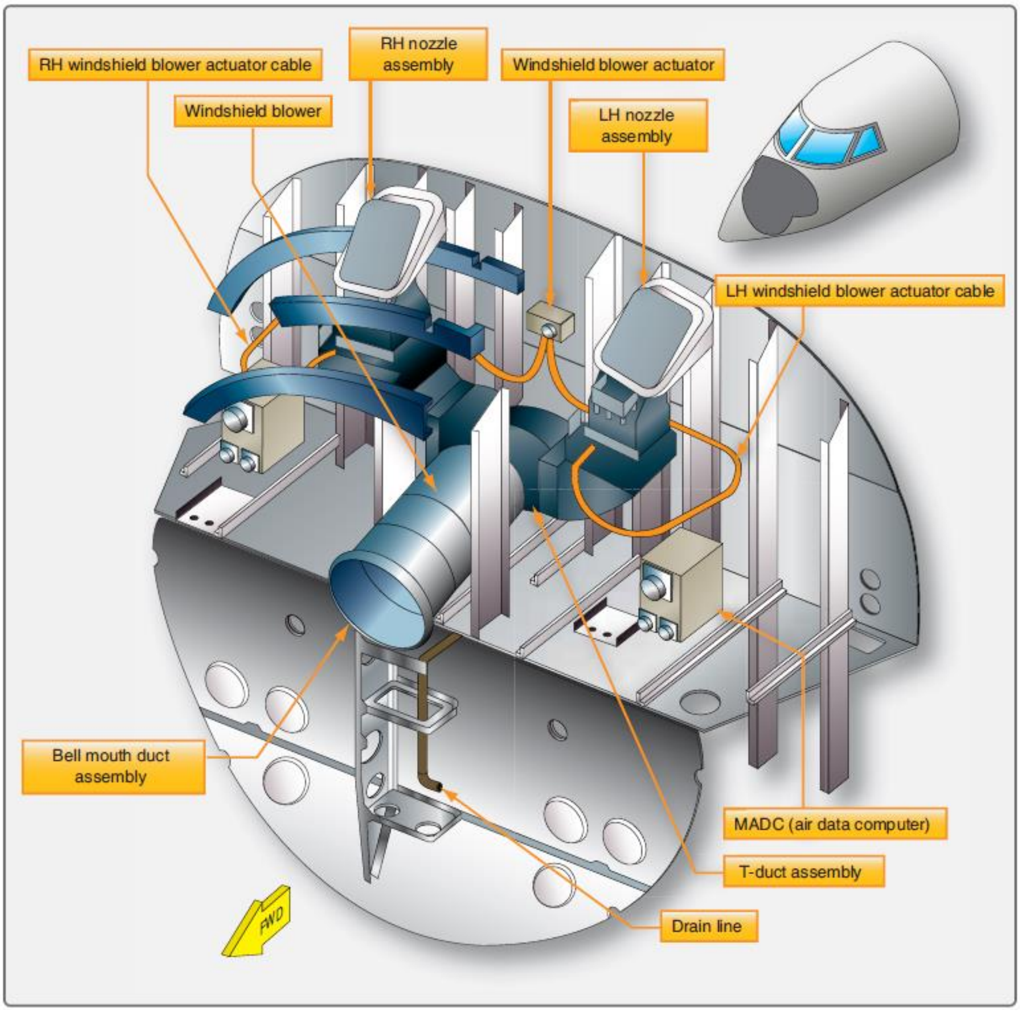


Hydrophobic coating on windshield.

Most new aircraft windshields are treated with surface seal coating. The manufacturer's coating process deeply penetrates the windshield surface providing hydrophobic action for quite some time. When effectiveness declines, products made to be applied in the field are used. These liquid treatments rubbed onto the surface of the windshield maintain the beading action of rain water. They must be applied periodically or as needed.

Pneumatic Rain Removal Systems

Windshield wipers characteristically have two basic problem areas. One is the tendency of the slipstream aerodynamic forces to reduce the wiper blade loading pressure on the window, causing ineffective wiping or streaking. The other is in achieving fast enough wiper oscillation to keep up with high rain impingement rates during heavy rain falls. As a result, most aircraft wiper systems fail to provide satisfactory vision in heavy rain.



Windshield rain and frost removal system.

The rain removal system shown in *Figure above* controls windshield icing and removes rain by directing a flow of heated air over the windshield. This heated air serves two purposes. First, the air breaks the rain drops into small particles that are then blown away. Secondly, the air heats the windshield to prevent the moisture from freezing. The air can be supplied by an electric blower or by bleed air.

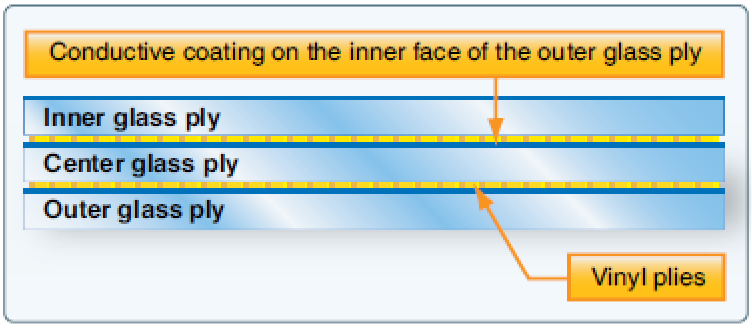
Windshield Frost, Fog, and Ice Control Systems

In order to keep windshield areas free of ice, frost, and fog, window anti-icing, de-icing, and defogging systems are used. These can be electric, pneumatic, or chemical depending on the type and complexity of the aircraft. A few of these systems are discussed in this section.

Electric

High performance and transport category aircraft windshields are typically made of laminated glass, polycarbonate, or similar ply material. Typically clear vinyl plies are also included to improve performance characteristics. The laminations create the strength and impact resistance of the windshield assembly. These are critical feature for windshields as they are subject to a wide range of temperatures and pressures. They must also withstand the force of a 4 pound bird strike at cruising speed to be certified.

The laminated construction facilitates the inclusion of electric heating elements into the glass layers, which are used to keep the windshield clear of ice, frost, and fog. The elements can be in the form of resistance wires or a transparent conductive material may be used as one of the window plies. To ensure enough heating is applied to the outside of the windshield, heating elements are placed on the inside of the outer glass ply. Windshields are typically bonded together by the application of pressure and heat without the use of cement.

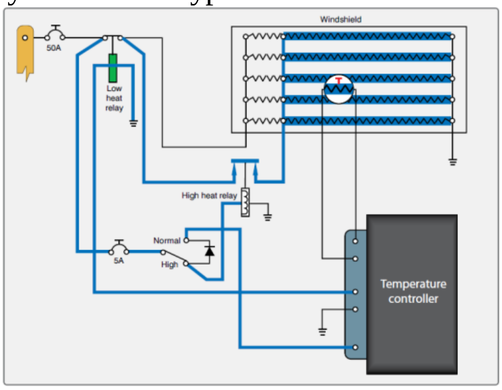


Cross-section of a transport category windshield.

Figure above illustrates the plies in one transport category aircraft windshield.

Whether resistance wires or a laminated conductive film is used, aircraft window heat systems have transformers to supply power and feedback mechanisms, such as thermistors, to provide a window heat control unit with information used to keep operating temperature within acceptable limits. Some systems are automatic while others are controlled by cockpit switches. Separate circuits for pilot and co-pilot are common to ensure visibility in case of a malfunction. Consult the manufacturer's maintenance information for details on the particular window heat system in question.

Some windshield heating systems can be operated at two heat levels. On these aircraft, NORMAL heating supplied heat to the broadest area of windshield. HIGH heating supplies a higher intensity of heat to a smaller but more essential viewing area. Typically, this window heating system is always on and set in the NORMAL position. *Figure below* illustrates a simplified windshield heat system of this type.



Electric windshield heat schematic.

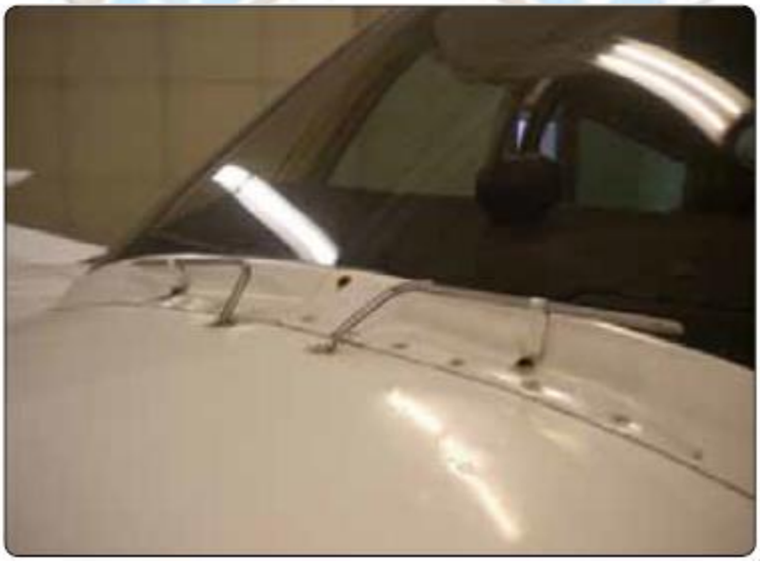
Pneumatic

Some laminated windshields on older aircraft have a space between the plies that allows the flow of hot air to be directed between the glass to keep it warm and fog free. The source of air is bleed air or conditioned air from the environmental control system. Small aircraft may utilize ducted warm air, which is release to flow over the windshield inner surface to defrost and defog. These systems are similar to those used in automobiles. The source of air could be ambient (defog only), the aircraft's heating system, or a combustion heater. While these pneumatic windshield heat systems are effective for the aircraft on which they are installed, they are not approved for flying into known icing conditions and, as such, are not effective for anti-ice.

Large aircraft equipped with pneumatic jet blast rain repellent systems achieve some anti-icing effects from operating this system although electric windshield heat is usually used.

Chemical

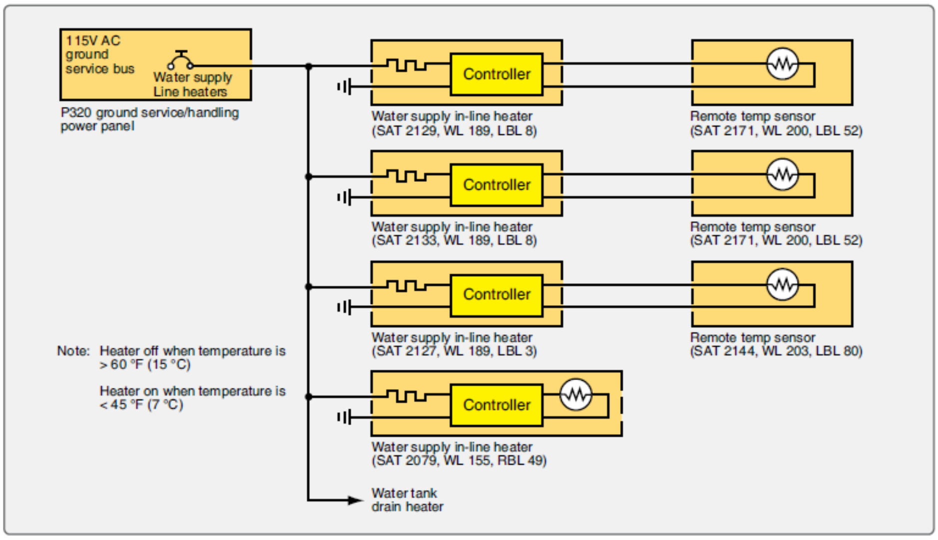
As previously mentioned in this chapter, chemical anti-ice systems exist generally for small aircraft. This type of anti-ice is also used on windshields. Whether alone or part of a TKSTM system or similar, the liquid chemical is sprayed through a nozzle onto the outside of the windshield which prevents ice from forming. The chemical can also deice the windshield of ice that may have already formed. Systems such as these have a fluid reservoir, pump, control valve, filter, and relief valve. Other components may exist. *Figure below* shows a set of spray tubes for application of chemical anti-ice on an aircraft windshield.



Chemical deicing spray tubes.

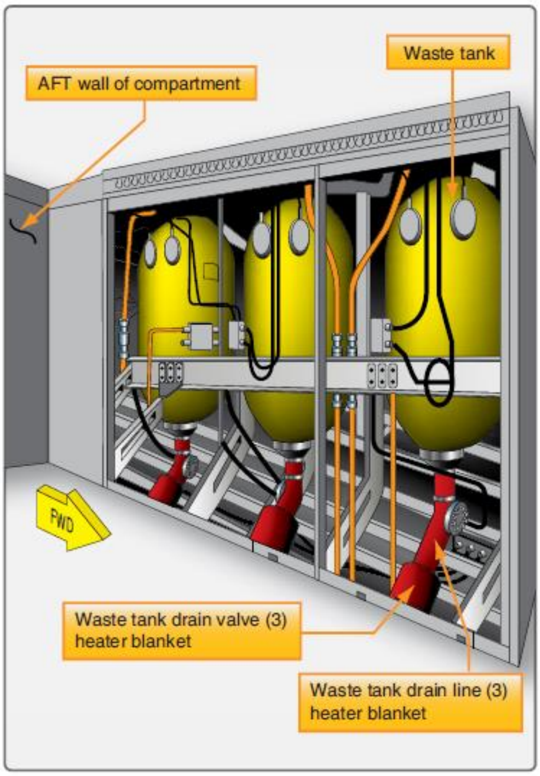
Portable Water Tank Ice Prevention

Transport type aircraft have water and waste systems on board, and electrical heaters are often used to prevent the formation of ice in the water lines of these systems. Water lines carry water from the portable tanks to the lavatories and galleys. The waste water tanks collect the gray water from the galleys and lavatories. Heater blankets, in-line heaters, or heater boots are often used to heat the water supply lines, water tank drain hoses, waste drain lines, waste tank rinse fittings, and drain masts. Thermostats in the water lines supply temperature data to the control unit that turns the electrical heaters on and off. When the temperature falls below freezing, the electrical heaters turn on and stay on until the temperature reaches a safe temperature.



Water supply line heater system.

Figure above is a schematic of a water supply line heater system, and *Figure below* shows the location of the waste water tanks and heater blanket.



Waste water tanks and heater blankets.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-IV NOTES

FACULTY NAME: D.SUKUMAR **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 7AN6.3 **SEMESTER: VII**

SUBJECT NAME: MAINTENANCE OF AIRFRAME AND SYSTEMS DESIGN

Basic Inspection

Basic principles of inspection, gauges, and tools. Standard inspection techniques and procedures.
Go/No go gauges, gauge calibration and maintenance, limits and tolerance. NDT techniques.

Basic Inspection

Techniques/Practices

Before starting an inspection, be certain all plates, access doors, fairings, and cowling have been opened or removed and the structure cleaned. When opening inspection plates and cowling and before cleaning the area, take note of any oil or other evidence of fluid leakage.

Preparation

In order to conduct a thorough inspection, a great deal of paperwork and/or reference information must be accessed and studied before actually proceeding to the aircraft to conduct the inspection. The aircraft logbooks must be reviewed to provide background information and a maintenance history of the particular aircraft. The appropriate checklist or checklists must be utilized to ensure that no items will be forgotten or overlooked during the inspection. Also, many additional publications must be available, either in hard copy or in electronic format to assist in the inspections. These additional publications may include information provided by the aircraft and engine manufacturers, appliance manufacturers, parts venders, and the Federal Aviation Administration (FAA).

Aircraft Logs

"Aircraft logs," as used in this handbook, is an inclusive term which applies to the aircraft logbook and all supplemental records concerned with the aircraft. They may come in a variety of formats. For a small aircraft, the log may indeed be a small 5″ × 8″ logbook. For larger aircraft, the logbooks are often larger, in the form of a three-ring binder. Aircraft that have been in service for a long time are likely to have several logbooks.
The aircraft logbook is the record in which all data concerning the aircraft is recorded. Information gathered in this log is used to determine the aircraft condition, date of inspections, time on airframe, engines and propellers. It reflects a history of all significant events occurring to the aircraft, its components, and accessories, and provides a place for indicating compliance with FAA airworthiness directives or manufacturers' service bulletins. The more comprehensive the logbook, the easier it is to understand the aircraft's maintenance history. When the inspections are completed, appropriate entries must be made in the aircraft logbook certifying that the aircraft is in an airworthy condition and may be

returned to service. When making logbook entries, exercise special care to ensure that the entry can be clearly understood by anyone having a need to read it in the future. Also, if making a hand-written entry, use good penmanship and write legibly. To some degree, the organization, comprehensiveness, and appearance of the aircraft logbooks have an impact on the value of the aircraft. High quality logbooks can mean a higher value for the aircraft.

Checklists

Always use a checklist when performing an inspection. The checklist may be of your own design, one provided by the manufacturer of the equipment being inspected, or one obtained from some other source. The checklist should include the following:

1. Fuselage and hull group.
   a. Fabric and skin—for deterioration, distortion, other evidence of failure, and defective or insecure attachment of fittings.
   b. Systems and components—for proper installation, apparent defects, and satisfactory
   operation.
   c. Envelope gas bags, ballast tanks, and related parts—for condition.

2. Cabin and cockpit group.
   a. Generally—for cleanliness and loose equipment that should be secured.
   b. Seats and safety belts—for condition and security.
   c. Windows and windshields—for deterioration and breakage.
   d. Instruments—for condition, mounting, marking, and (where practicable) for proper operation.
   e. Flight and engine controls—for proper installation and operation.
   f. Batteries—for proper installation and charge.
   g. All systems—for proper installation, general condition, apparent defects, and security of attachment.

3. Engine and nacelle group.
   a. Engine section—for visual evidence of excessive oil, fuel, or hydraulic leaks, and sources of such leaks.
   b. Studs and nuts—for proper torquing and obvious defects.
   c. Internal engine—for cylinder compression and for metal particles or foreign matter on screens and sump drain plugs. If cylinder compression is weak, check for improper internal condition and improper internal tolerances.
   d. Engine mounts-for cracks, looseness of mounting, and looseness of engine to mount.
   e. Flexible vibration dampeners-for condition and deterioration.
   f. Engine controls-for defects, proper travel, and proper safety.
   g. Lines, hoses, and clamps-for leaks, condition, and looseness.
   h. Exhaust stacks-for cracks, defects, and proper attachment.
   i. Accessories-for apparent defects in security of mounting.
   j. All systems-for proper installation, general condition defects, and secure attachment.
   k. Cowling-for cracks and defects.
   l. Ground run-up and functional check-check all power-plant controls and systems for correct response, all instruments for proper operation and indication.

4. Landing gear group.
   a. All units-for condition and security of attachment.
   b. Shock absorbing devices-for proper oleo fluid level.
   c. Linkage, trusses, and members-for undue or excessive wear, fatigue, and distortion.
   d. Retracting and locking mechanism-for proper operation.
   e. Hydraulic lines-for leakage.
   f. Electrical system-for chafing and proper operation of switches.
   g. Wheels-for cracks, defects, and condition of bearings.
   h. Tires-for wear and cuts.
   i. Brakes-for proper adjustment.
   j. Floats and skis-for security of attachment and obvious defects.

5. Wing and center section.
   a. All components-for condition and security.
   b. Fabric and skin-for deterioration, distortion, other evidence of failure, and security of attachment.
   c. Internal structure (spars, ribs compression members)-for cracks, bends, and security.
   d. Movable surfaces-for damage or obvious defects, unsatisfactory fabric or skin attachment and proper travel.
   e. Control mechanism-for freedom of movement, alignment, and security.
   f. Control cables-for proper tension, fraying, wear and proper routing through fairleads and pulleys.

6. Empennage group.
   a. Fixed surfaces-for damage or obvious defects, loose fasteners, and security of attachment.
   b. Movable control surfaces-for damage or obvious defects, loose fasteners, loose fabric,
   or skin distortion.
   c. Fabric or skin-for abrasion, tears, cuts or defects, distortion, and deterioration.

7. Propeller group.
   a. Propeller assembly-for cracks, nicks, bends,and oil leakage.
   b. Bolts-for proper torquing and safetying.
   c. Anti-icing devices-for proper operation and obvious defects.
   d. Control mechanisms-for proper operation, secure mounting, and travel.

8. Communication and navigation group.
   a. Radio and electronic equipment-for proper installation and secure mounting.
   b. Wiring and conduits-for proper routing, secure mounting, and obvious defects.
   c. Bonding and shielding-for proper installation and condition.
   d. Antennas-for condition, secure mounting, and proper operation.

9. Miscellaneous.
   a. Emergency and first aid equipment-for general condition and proper stowage.
   b. Parachutes, life rafts, flares, and so forth- inspect in accordance with the manufacturer’s recommendations.

c. Autopilot system-for general condition, security of attachment, and proper operation.

Name	Description
Bore Gauge	A Device Used For Measuring Holes.
Calliper	A Device Used To Measure The Distance Between Two Opposing Sides Of An Object.
Centre Gauges And Fishtail Gauges	Are Engineering Gauges Used In Lathe Work For Checking The Angles When Grinding The Profiles Of Single-Point Screw-Cutting Tool Bits And Centers.
Comb Type Gage	A Ruler-Shaped Gage With Two Supports At Each Of Its Six Sides, Having Tabs Of Varying Lengths. For Measuring The Comb Gage Is Pushed Perpendicular Into The Film Using The Measuring Range That Corresponds To The Expected Film Thickness. The Wet Film Thickness Will Fall Between The Clearance Of The Shortest Tab That Is Wet And The Clearance Of The Next Shortest Dry Tab.
Dial Indicator, Also Known As A Dial Test Indicator, Dial Gauge, Or Probe Indicator	An Instrument Used To Accurately Measure Small Linear Distances.
Feeler Gauge	A Simple Tool Used To Measure Gap Widths.
Gauge Block, (Also Known As A Gage Block, Johansson Gauge, Slip Gauge, Or Jo Block)	A Precision Ground And Lapped Length Measuring Standard. It Is Used As A Reference For The Setting Of Measuring Equipment Used In Machine Shops, Such As Micrometers, Sine Bars, Calipers, And Dial Indicators (When Used In An Inspection Role).
Gauge Pin Is Similar To A Gauge Block. It Is A Precision Ground Cylindrical Bar For Use Ingo/No Go Gauges Or Similar	

Applications.	
Go/No Go Gauge	An Inspection Tool Used To Check A Workpiece Against Its Allowed Tolerances. Its Name Derives From Its Use: The Gauge Has Two Tests; The Check Involves The Workpiece Having To Pass One Test (*Go*) And Fail The Other (*No Go*).
Grind Gage	A Flat Steel Block In The Surface Of Which Are Two Flat-Bottomed Grooves Varying Uniformly In Depth From A Maximum At One End Of The Block To Zero Near The Other End. Groove Depth Is Graduated On The Block According To One Or More Scales Used For Measuring Particle Size. Most Gages Will Have One Scale Marked In Either Mils Or Micrometers.
Load Cell	A Transducer That Is Used To Convert A Force Into Electrical Signal. This Conversion Is Indirect And Happens In Two Stages. Through A Mechanical Arrangement, The Force Being Sensed Deforms A Strain Gauge. The Strain Gauge Converts The Deformation (Strain) To Electrical Signals. A Load Cell Usually Consists Of Four Strain Gauges In A Wheatstone Bridge Configuration. Load Cells Of One Strain Gauge (Quarter Bridge) Or Two Strain Gauges (Half Bridge) Are Also Available. The Electrical Signal Output Is Typically In The Order Of A Few Millivolts And Requires Amplification By An Instrumentation Amplifier Before It Can Be Used. The Output Of The Transducer Is Plugged Into An Algorithm To Calculate The Force Applied To The Transducer.
The Linear Variable Differential Transformer(LVDT)	A Type Of Electrical Transformer Used For Measuring Linear Displacement. The Transformer Has Three Solenoidal Coils Placed End-To-End Around A Tube. The Center Coil Is The Primary, And The Two Outer Coils Are The Secondaries. A Cylindrical Ferromagnetic Core, Attached To The Object Whose Position Is To Be Measured, Slides Along The Axis Of The Tube.
Micrometer, Sometimes Known	A Device Incorporating A Calibrated Screw Used

As A "Micrometer Screw Gauge"	Widely For Precise Measurement Of Small Distances In Mechanical Engineering And Machining As Well As Most Mechanical Trades, Along With Other Metrological Instruments Such As Dial, Vernier, And Digital Calipers. Micrometers Are Often, But Not Always, In The Form Of Calipers.
Pressure Gauge Or Vacuum Gauge	A Device Used For Pressure Measurement.
Profile Gauge Or Contour Gauge	A Tool For Recording The Cross-Sectional Shape Of A Surface.
Radius Gauge, Also Known As A Fillet Gauge	A Tool Used To Measure The Radius Of An Object. Radius Gauges Require A Bright Light Behind The Object To Be Measured. The Gauge Is Placed Against The Edge To Be Checked And Any Light Leakage Between The Blade And Edge Indicates A Mismatch That Requires Correction.
Ring Gauge	A Cylindrical Ring Of Steel Whose Inside Diameter Is Finished To Gauge Tolerance And Is Used For Checking The External Diameter Of A Cylindrical Object.
Strain Gauge	A Device Used To Measure The Strain Of An Object.
Stream Gauge	A Site Along A Stream Where Measurements Of Water Surface Elevation ("Stage") And/Or Volumetric Discharge (Flow) Are Made.
Thermometer Ortemperature Gauge	A Device That Measures Temperature Or Temperature Gradient Using A Variety Of Different Principles.
Thread Pitch Gauge, Also Called A Threading Gauge, Pitch Gauge, Or Screw Gauge	A Device Used To Measure The Pitch Or Lead Of Screw Threads.
Tide Gauge	A Device For Measuring Sea Level And Detecting Tsunamis.

Vernier Height Gauge	A Measuring Device Used Either For Determining The Height Of Something, Or For Repetitious Marking Of Items To Be Worked On. The Former Type Of Height Gauge Is Often Used In Doctor's Surgeries To Find The Height Of People.
Wire Gauge	Measuring Tool Determines The Thickness Of A Wire.

Publications

Aeronautical publications are the sources of information for guiding aviation mechanics in the operation and maintenance of aircraft and related equipment. The proper use of these publications will greatly aid in the efficient operation and maintenance of all aircraft.

These include manufacturers' service bulletins, manuals, and catalogs; FAA regulations; airworthiness directives; advisory circulars; and aircraft, engine and propeller specifications. Manufacturers' Service Bulletins/Instructions Service bulletins or service instructions are two of several types of publications issued by airframe, engine, and component manufacturers. The bulletins may include:

(1) Purpose for issuing the publication

(2) Name of the applicable airframe, engine, or component

(3)Detailed instructions for service, adjustment, modification or inspection, and source of parts, if required

(4) Estimated number of man hours required to accomplish the job.

Maintenance Manual

The manufacturer's aircraft maintenance manual contains complete instructions for maintenance of all systems and components installed in the aircraft. It contains information for the mechanic who normally works on components, assemblies, and systems while they are installed in the aircraft, but not for the overhaul mechanic.

- A typical aircraft maintenance manual contains:
- A description of the systems (i.e., electrical, hydraulic, fuel, control)
- Lubrication instructions setting forth the frequency and the lubricants and fluids which are to be used in the various systems,
- Pressures and electrical loads applicable to the various systems,
- Tolerances and adjustments necessary to proper functioning of the airplane,
- Methods of levelling, rising, and towing,
- Methods of balancing control surfaces,
- Identification of primary and secondary structures,
- Frequency and extent of inspections necessary to the proper operation of the airplane,
- Special repair methods applicable to the airplane,
- Special inspection techniques requiring x-ray, ultrasonic or magnetic particle inspection

- A list of special tools.

Overhaul Manual

The manufacturer's overhaul manual contains brief descriptive information and detailed step by step instructions covering work normally performed on a unit that has been removed from the aircraft. Simple, inexpensive items, such as switches and relays on which overhaul is uneconomical, are not covered in the overhaul manual.

Structural Repair Manual

This manual contains the manufacturer's information and specific instructions for repairing primary and secondary structures. Typical skin, frame, rib, and stringer repairs are covered in this manual. Also included are material and fastener substitutions and special repair techniques.

Illustrated Parts Catalog

This catalog presents component breakdowns of structure and equipment in disassembly sequence. Also included are exploded views or cutaway illustrations for all parts and equipment manufactured by the aircraft manufacturer.

Code of Federal Regulations (CFRs)

The CFRs were established by law to provide for the safe and orderly conduct of flight operations and to prescribe airmen privileges and limitations. A knowledge of the CFRs is necessary during the performance of maintenance, since all work done on aircraft must comply with CFR provisions.

Airworthiness Directives

A primary safety function of the FAA is to require correction of unsafe conditions found in an aircraft, aircraft engine, propeller, or appliance when such conditions exist and are likely to exist or develop in other products of the same design. The unsafe condition may exist because of a design defect, maintenance, or other causes. Title 14 of the Code of Federal Regulations (14 CFR) part 39, Airworthiness Directives, defines the authority and responsibility of the Administrator for requiring the necessary corrective action.

The Airworthiness Directives (ADs) are published to notify aircraft owners and other interested persons of unsafe conditions and to prescribe the conditions under which the product may continue to be operated.

Airworthiness Directives are Federal Aviation Regulations and must be complied with unless specific exemption is granted.

Airworthiness Directives may be divided into two categories:

(1) Those of an emergency nature requiring immediate compliance upon receipt and

(2) Those of a less urgent nature requiring compliance within a relatively longer period of time. Also, ADs may be a onetime compliance item or a recurring item that requires future inspection on an hourly basis (accrued flight time since last compliance) or a calendar time basis.

The contents of ADs include the aircraft, engine, propeller, or appliance model and serial numbers affected. Also included are the compliance time or period, a description of the difficulty experienced, and the necessary corrective action.

Type Certificate Data Sheets

The type certificate data sheet (TCDS) describes the type design and sets forth the limitations prescribed by the applicable CFR part. It also includes any other limitations and information found necessary for type certification of a particular model aircraft. Type certificate data sheets are numbered in the upper right-hand corner of each page. This number is the same as the type certificate number. The name of the type certificate holder, together with all of the approved models, appears immediately below the type certificate number. The issue date completes this group. This information is contained within a bordered text box to set it off.

The data sheet is separated into one or more sections. Each section is identified by a Roman numeral followed by the model designation of the aircraft to which the section pertains. The category or categories in which the aircraft can be certificated are shown in parentheses following the model number. Also included is the approval date shown on the type certificate.

The data sheet contains information regarding:

1. Model designation of all engines for which the aircraft manufacturer obtained approval for use with this model aircraft.

2. Minimum fuel grade to be used.

3. Maximum continuous and take-off ratings of the approved engines, including manifold pressure (when used), rpm, and horsepower (hp).

4. Name of the manufacturer and model designation for each propeller for which the aircraft manufacturer obtained approval will be shown together with the propeller limits and any operating restrictions peculiar to the propeller or propeller engine combination.

5. Airspeed limits in both mph and knots.

6. Centre of gravity range for the extreme loading conditions of the aircraft is given in inches from the datum. The range may also be stated in percent of MAC (Mean Aerodynamic Chord) for transport category aircraft.

7. Empty weight centre of gravity (CG) range (when established) will be given as fore and aft limits in inches from the datum. If no range exists, the word “none” will be shown following the heading on the data sheet.

8. Location of the datum.

9. Means provided for levelling the aircraft.

10. All pertinent maximum weights.

11. Number of seats and their moment arms.

12. Oil and fuel capacity.

13. Control surface movements.

14. Required equipment.

15. Additional or special equipment found necessary for certification.

16. Information concerning required placards.

It is not within the scope of this handbook to list all the items that can be shown on the type certificate data sheets. Those items listed above serve only to acquaint aviation mechanics with the type of information generally included on the data sheets. Type certificate data sheets may be many pages in length. Figure 8-1 shows a typical TCDS.

When conducting a required or routine inspection, it is necessary to ensure that the aircraft and all the major items on it are as defined in the type certificate data sheets. This is called a conformity check, and verifies that the aircraft conforms to the specifications of the aircraft as it was originally certified. Sometimes alterations are made that are not specified or authorized in the TCDS. When that condition exists, a supplemental type certificate (STC) will be issued. STCs are considered a part of the permanent records of an aircraft, and should be maintained as part of that aircraft's logs.

Routine/Required Inspections

For the purpose of determining their overall condition, 14 CFR provides for the inspection of all civil aircraft at specific intervals, depending generally upon the type of operations in which they are engaged. The pilot in command of a civil aircraft is responsible for determining whether that aircraft is in condition for safe flight.

Therefore, the aircraft must be inspected before each flight. More detailed inspections must be conducted by aviation maintenance technicians at least once each 12 calendar months, while inspection is required for others after each 100 hours of flight. In other instances, an aircraft may be inspected in accordance with a system set up to provide for total inspection of the aircraft over a calendar or flight time period.

To determine the specific inspection requirements and rules for the performance of inspections, refer to the CFR, which prescribes the requirements for the inspection and maintenance of aircraft in various types of operations.

Pre-flight/Post-flight Inspections

Pilots are required to follow a checklist contained within the Pilot's Operating Handbook (POH) when operating aircraft. The first section of a checklist includes a section entitled Pre-flight Inspection. The pre-flight inspection checklist includes a "walk-around" section listing items that the pilot is to visually check for general condition as he or she walks around the airplane. Also, the pilot must ensure that fuel, oil and other items required for flight are at the proper levels and not contaminated. Additionally, it is the pilot's responsibility to review the airworthiness certificate, maintenance records, and other required paperwork to verify that the aircraft is indeed airworthy. After each flight, it is recommended that the pilot or mechanic conduct a post-flight inspection to detect any problems that might require repair or servicing before the next flight.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

A25CE
Revision 11
CESSNA
404
406
June 15, 1995

TYPE CERTIFICATE DATA SHEET NO. A25CE

This data sheet which is part of Type Certificate No. A25CE prescribes conditions and limitations under which the product for which the type certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder	Cessna Aircraft Company P. O. Box 7704 Wichita, Kansas 67277

I - Model 404, Titan, (Normal Category), Approved July 21, 1976

Engines	Two Teledyne Continental GTSIO-520-M Reduction gear ratio .667:1
Fuel	100/130 or 100 low-lead minimum grade aviation gasoline See NOTE 3 for optional anti-icing additive
Engine Limits	For all operations, 2235 propeller r.p.m. (375 hp.) 40.0 in. Hg. mp. up to critical altitude of 16,000 feet in standard atmosphere. Above 16,000 feet the following maximum mp. applies for maximum r.p.m.

GROUND SERVICING OF SUB SYSTEMS AND SUPPORT EQUIPMENT:

Air conditioning:

The A/C Pack exhaust air is ducted into the pressurized fuselage, where it is mixed with filtered air from the recirculation fans, and fed into the “mix manifold”. On nearly all modern jetliners, the airflow is approximately 50% “outside air” and 50% “filtered air.”

Modern jetliners use “High Efficiency Particulate Arresting” HEPA filters, which trap >99% of all bacteria and clustered viruses.

Air from the “mix manifold” is directed to overhead distribution nozzles in the various “zones” of the aircraft. Temperature in each zone may be adjusted by adding small amounts of “Trim Air”, which is low-pressure, high temperature air tapped off the A/C Pack upstream of the TCV. Air is also supplied to individual gaspers: small, circular vents above each passenger seat that can be adjusted by passengers for their personal comfort. A revolving control on the vent can be turned to adjust ventilation between no air output at all and a fairly substantial breeze.

Gaspers usually receive their air from the air conditioning packs aboard the aircraft, which in turn receive compressed, clean air from the compressor stages of the aircraft’s jet engines or when on the ground from the APU or a ground source. A master control for gaspers is located in the cockpit, and gaspers may be temporarily turned off during certain phases of flight, when the load on the engines from bleed-air demands must be minimized (e.g. take-off and climb).

Pressurization:

Airflow into the fuselage is approximately constant, and pressure is maintained by varying the opening of the “Out Flow Valve” (OFV). Most modern jetliners have a single OFV located near the bottom aft end of the fuselage, although some larger aircraft like the 747 and 777 have two.

In the event the OFV should fail closed, at least two Positive Pressure Relief Valves (PPRV) and at least one Negative Pressure Relief Valve (NPRV) are provided to protect the fuselage from over- and under- pressurization.

Aircraft cabin pressure is commonly pressurized to a “cabin altitude” of 8000 feet or less. That means that the pressure is 10.9 psi (75 kPa), which is the ambient pressure at 8000 feet (2,400 m). Note that a lower cabin altitude is a higher pressure. The cabin pressure is controlled by a “Cabin Pressure Schedule,” which associates each aircraft altitude with a cabin altitude. The new airliners such as the Airbus A380 and Boeing 787 will have lower maximum cabin altitudes which help in passenger fatigue reduction during flights.

The atmosphere at typical jetliner cruising altitudes is generally very dry and cold; the outside air pumped into the cabin on a long flight has the potential to cause condensationwhich might in turn cause corrosion or electrical faults, and is thus is eliminated. Consequently when humid air at lower altitudes is encountered and drawn in, the ECS dries it through the warming and cooling cycle and the water separator mentioned above, so that even with high external relative humidity, inside the cabin it will usually be not much higher than 10% relative humidity.

Although low cabin humidity has health benefits of preventing the growth of fungus andbacteria, the low humidity causes drying of the skin, eyes and mucosal membranes and contributes to dehydration, leading to fatigue, discomfort and health issues. In one study the majority of flight attendants reported discomfort and health issues from low humidity.In a statement to Congress in 2003 a member of the Committee on Air Quality in Passenger Cabins of Commercial Aircraft said “low relative humidity might cause some temporary discomfort (e.g., drying eyes, nasal passages, and skin), but other possible short- or long-term effects have not been established”.

A cabin humidity control system may be added to the ECS of some aircraft to keep relative humidity from extremely low levels, consistent with the need to prevent condensation. Furthermore the Boeing 787 and Airbus 350, by using more corrosion-resistant composites in their construction, can operate with a cabin relative humidity of 16% on long flights.

Description

The oxygen system consists of a Scott Aviation 76.5 cubic foot cylinder mounted to the fuselage exterior right hand side. The cylinder head assembly incorporates a regulator and an on/off mechanical valve. The mechanical valve, however, is not used. An inline electrical shut off valve is installed adjacent to the bottle on the low pressure supply line. The valve is controlled by two switches, one in the cabin and one in the cockpit. The cockpit control has priority. The switch is a push button type that indicates the status of the valve. A cylinder contents gauge is located in the aft cabin area to allow the crew to monitor the amount of oxygen available for use. The oxygen cylinder is serviced through a calibrated fill port located at the bottle to a nominal pressure to 1850 PSI 2 @ 75° F. Low pressure oxygen is supplied on demand at 45 to 65 PSI depending on altitude temperature and remaining contents in the cylinder.

Servicing - Oxygen System

General

1. The oxygen filler valve is located adjacent to the bottle under a service door.

2. The oxygen system gauge should be checked for anticipated requirements before each flight.

3. Whenever pressure drops below necessary levels refill with aviator's breathing oxygen Military Specifications MIL-O-27210 or medical oxygen supplied by a certified vendor.

Charging Oxygen System

1. Remove oxygen filler valve cap and connect charging unit.

2. Charge the oxygen cylinder to proper PSI as indicated on cylinder placard and in accordance with Oxygen Cylinder Filling Pressure Table.

Initial Temp °F	Filling Pressure PSIG	Initial Temp °F	Filling Pressure PSIG	Initial Temp °F	Filling Pressure PSIG
0	1600	40	1775	90	2000
10	1650	50	1825	100	2050
20	1675	60	1875	110	2100
30	1725	70	1925	120	2150
		80	1950	130	2200

3. Shut off oxygen supply, disconnect charging unit, install filler cap.

Discharge Oxygen System:

1. Push oxygen control knob to ON position.

2. Insert fitting and hose in outlet in cabin and route hose outside cabin.

Purge Oxygen System:

1. Charge the oxygen system.

2. Move aircraft outdoors if possible. If unable to move aircraft outdoors, make sure area is roped off, no smoking or open flame permitted in the area, no grease or lubricant near area, cabin door and foul weather windows open.

3. Plug all masks into outlets and purge system by allowing the oxygen to flow for at least 10 minutes. Smell the oxygen flowing from the outlets and continue to purge until the oxygen is odorless. Refill cylinder as required during and after purging.

IV. Maintenance Practices

1. Tools and Equipment

Name	Number	Manufacturer	Use
Anti-seize Compound	MIL-T-5542	Commercially available	To lubricate threads & fittings
Trichloroethylene	MIL-T-7003	Commercially available	To clean oxygen lines
Naphtha	TT-N-95		Flush Oxygen lines
Anti-Icing	MIL-F05566		Flush Oxygen lines

2. General Maintenance Precautions.

A. Before any maintenance is performed on the oxygen system personnel should read and thoroughly understand the following. Careful adherence to these instructions will aid in maintaining a trouble-free system.

B. If maintenance is performed on the aircraft oxygen system or on any other system in the aircraft requiring removal of any oxygen system component, strict adherence to the following procedures and precautions is required.

(1) Use extreme caution to assure every port on the stem is kept thoroughly clean and free of water, oil, grease, and solvent contamination.

(2) Cap all openings immediately upon removal of any component. Do not use tape or caps which will induce moisture.

(1) Use extreme caution to assure every port on the stem is kept thoroughly clean and free of water, oil, grease, and solvent contamination.

(2) Cap all openings immediately upon removal of any component. Do not use tape or caps which will induce moisture.

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(3) Lines & fitting shall be clean and dry. One of the following methods may be used to clean lines.

(a) A vapor degreasing solution of stabilized trichloroethylene conforming to Specifications MIL-T-7003, followed by flowing tubing clean and dry with a jet of nitrogen gas (BB-N411) Type 1, Class 1, Grade A or Technical Agron (MIL-A-18455).

b) Flush with naphtha conforming to Specification TT-N-95, then blow clean and dry with cloth, dry, filtered air. Flush with anti-icing fluid, conforming to MIL-F-5566 or anhydrous ethyl alcohol. Rinse thoroughly with fresh water and dry with a jet of nitrogen gas (BB-N-411) Type 1, Class 1, Grade A or Technical Argon (MIL-A-18455).

c) Flush with hot inhibited alkaline cleaner until free from oil and grease. Rinse with fresh water and dry with a jet of nitrogen gas (BB-N-411) Type 1, Class 1, Grade A or Technical Argon (MIL-A-18455).

e) Maintenance personnel must assure that their hands are free of dirt or grease prior to installation of oxygen tubing or fittings.

f) All tools used for installation of oxygen tubes or fittings must be free of dirt, grease or oils.

WARNING: USE NON-SPARKING TOOLS.

CAUTION: WITH OXYGEN BOTTLE CHARGED, DO NOT MOVE SHUT-OFF VALVE TO THE ON POSITION WITH OUTLET PORTS (LOW PRESSURE) OPEN TO ATMOSPHERE. DAMAGE TO REGULATOR METERING POPPET MAY OCCUR.

CAUTION: WHENEVER A COMPONENT OF THE OXYGEN SYSTEM HAS BEEN REMOVED, RE-INSTALLED, REPLACE OR SYSTEM HAS BEEN OPENED IN ANYWAY, THE OXYGEN SYSTEM MUST BE LEAK CHECKED AND PURGED.

C. Do not attempt to charge the cylinder if any of the following conditions exists:

(1) Contaminated or corroded fitting on servicing cylinder of filler valve.
(2) Cylinder out of hydrostatic test date.
(3) Cylinder bears no D.O.T. designation.
(4) Cylinder completely empty after shut-off valve has been turned off for a length of time. Must be completely disassembled and inspected in an FAA approved facility before charging.

D. To assist in cylinder identification, the following information is reflected on each oxygen cylinder.

(1) Cylinder specification followed by service pressure as "ICC-3HT185" will be stamped on the shoulder or neck of each cylinder.

NOTE: Effective January 1, 1970, all newly manufactured cylinders are stamped "DOT" (Department of Transportation in lieu of "ICC" (Interstate Commerce Commission).

(2) Cylinder serial number will be stamped below or directly following the cylinder specification.

(3) Hydrostatic test date will be stamped directly below the original manufacture date and shall include the month of year of the hydrostatic test date.

Adjustment/Test

1. Tool and Equipment

Name	Number	Manufacturer	Use
Sherlock Leak Detector	Type CG (MIL-L-25567A)	Puritan-Zep El Segundo, CA	For leak test fluid
Pressure Gauge (0-100-PSIG)		Commercially available	To check oxygen flow pressure

2. Leak Test Oxygen System

(1) Charge the oxygen system.
(2) Allow thirty minutes for cylinder pressure to stabilize between 1750 and 1800 PSIG, indicated on pressure gauge.
(3) Record the cylinder pressure and ambient temperature.
(4) After 24 hours, record cylinder pressure and ambient temperature. Maximum allowable pressure drop is 50 PSIG (correcting from temperature change, using formula of $\pm 1° = 3.4$ PSIG).
(5) If the pressure drop derived from the formula in the proceeding step exceeds 50 PSIG, test the oxygen system for leakage by applying detector fluid type CG-1 to all fittings and connections and observe for formation of bubbles.
(6) Remove all traces of solution and repair or replaces leaky fitting and repeat the proceeding procedures.

NOTES:

1. Isolated pits of small cross section involving loss of wall thickness by corrosive media. Small isolated pits with a main depth as shown are acceptable.

2. If depth exceed figure shown, cylinder must be returned to the manufacturer for disposition.

3. Local pitting or corrosion or line corrosion involving lose of wall thickness by corrosive media with a pattern of pits which are connected to others in a band or line. A small area with a minimum depth as shown is acceptable. Areas extending beyond 3 inches in diameter or 4 inches long shall be considered general corrosion.

4. General corrosion (sometime accompanied by pitting involving loss of wall thickness by corrosive media covering a considerable area. Cylinder must be returned to the manufacturer for hydrostatic testing.

5. Deformation caused by contact with a sharp object cutting or upsetting the material of the cylinder, decreasing the wall thickness. Maximum defects permissible without corrective action. If this depth is exceeded, the cylinder must be returned to the manufacturer for removal of defects and verification of cylinder strength by hydrostatic testing.

6. Deformations caused by contact with blunt objects in such manner that the thickness of the metal is not impaired. The major diameter of the dent must be equal to or greater than 32 times the depth of the dent. Sharper dents (or deeper dents that this are considered too abrupt and must be returned to the cylinder manufacturer for disposition.

7. Fire damage is indicated by charring or burning or sintering of the metal, charring or burning of the paint, distortion of the cylinder, functioned safety relief devices, melting of valve parts, etc. Cylinders must be returned to the cylinder manufacturer for disposition.

8. Bulged cylinders are not acceptable. Cylinders must be returned to the cylinder manufacturer for disposition.

NOTE: The above data may be used to determine that oxygen cylinders are acceptable for service. This criteria should be used prior to charging cylinders.

E. Hydrostatic Test Oxygen System Cylinder

1. Light weight (ICC or DOT-3HT 1850) cylinders must be hydrostatically tested to 5/3 their working pressure every three years starting with the date of the last hydrostatic test.

2. Light weight (ICC or DOT-3HT 1850) cylinders must be retired from service after twenty four years to 4380 filling cycles after date of manufacture, whichever' occurs first.

NOTE: These test requirements are established by the Interstate Commerce Code of Federal Regulations, Title 49, Chapter I, Paragraph 173.34.

NOTE: As defined by D.O.T. order 8000.40 dated 2 June 1977, cylinders which remain charged or partially charged on the due date of it's hydrostatic test may remain in service beyond the test date providing the cylinder is re-tested prior to its' next full or partial filling.

V. Inspection

Inspect Oxygen System Components

(1) A careful visual inspection of the oxygen cylinder should be performed during routine maintenance and periodic inspections. If any bad dents, scratches or areas of corrosion are found, the cylinders must be checked per the Inspection Criteria for Acceptance of Oxygen Cylinder, Table 1.

NOTE: If the acceptability of the cylinder is questionable after using inspection criteria, return the cylinder to an FAA approved facility with appropriate ratings to per

Cleaning and Painting

Cleaning Oxygen System Components

A. Cleaning Filler Valve
   (1) The filler valve should be cleaned with trichloroethylene MIL-T-7003.
   (2) Clean Freon MIL-C_8638 or alcohol may be used as an alternate.

B. Cleaning Regulator and Cylinder.
   (1) Clean regulator and cylinder with a clean cloth.

C. Cleaning Oxygen Masks and Hoses.
   (1) Clean the mask and hoses with a mild solution of soap and water. Rinse thoroughly with clean water and allow to dry.

NOTE: Ensure all soap is removed by rinsing. Masks may be disinfected with a hospital type antiseptic spray or Zep Aero SBTO-12.

Annual/100-Hour Inspections

Title 14 of the Code of Federal Regulations (14 CFR) part 91 discusses the basic requirements for annual and 100-hour inspections. With some exceptions, all aircraft must have a complete inspection annually.

Aircraft that are used for commercial purposes and are likely to be used more frequently than non-commercial aircraft must have this complete inspection every 100 hours. The scope and detail of items to be included in annual and 100-hour inspections is included as appendix D of 14 CFR part 43.

A properly written checklist, such as the one shown earlier in this chapter, will include all the items of appendix D. Although the scope and detail of annual and 100-hour inspections is identical, there are two significant differences. One difference involves persons authorized to conduct them. A certified airframe and power-plant maintenance technician can conduct a

100-hour inspection, whereas an annual inspection must be conducted by a certified airframe and power-plant maintenance technician with inspection authorization (IA). The other difference involves authorized over-flight of the maximum 100 hours before inspection. An aircraft may be flown up to 10 hours beyond the 100-hour limit if necessary to fly to a destination where the inspection is to be conducted.

Progressive Inspections

Because the scope and detail of an annual inspection is very extensive and could keep an aircraft out of service for a considerable length of time, alternative inspection programs designed to minimize down time may be utilized. A progressive inspection program allows an aircraft to be inspected progressively.

Appendix D to Part 43—Scope and Detail of Items (as Applicable to the Particular Aircraft) To Be Included in Annual and 100-Hour Inspections (continued)

weak cylinder compression, for improper internal condition and improper internal tolerances.

(4) Engine mount—for cracks, looseness of mounting, and looseness of engine to mount.

(5) Flexible vibration dampeners—for poor condition and deterioration.

(6) Engine controls—for defects, improper travel, and improper safetying.

(7) Lines, hoses, and clamps—for leaks, improper condition, and looseness.

(8) Exhaust stacks—for cracks, defects, and improper attachment.

(9) Accessories—for apparent defects in security of mounting.

(10) All systems—for improper installation, poor general condition, defects, and insecure attachment.

(11) Cowling—for cracks and defects.

(f) Each person performing an annual or 100-hour inspection shall inspect (where applicable) all components of the wing and center section assembly for poor general condition, fabric or skin deterioration, distortion, evidence of failure, and insecurity of attachment.

(g) Each person performing an annual or 100-hour inspection shall inspect (where applicable) all components and systems that make up the complete empennage assembly for poor general condition, fabric or skin deterioration, distortion, evidence of failure, insecure attachment, improper component installation, and improper component operation.

(h) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the propeller group:

(1) Propeller assembly—for cracks, nicks, binds, and oil leakage.

(2) Bolts—for improper torquing and lack of safetying.

(e) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the landing gear group:

(1) All units—for poor condition and insecurity of attachment.

(2) Shock absorbing devices—for improper oleo fluid level.

(3) Linkages, trusses, and members—for undue or excessive wear fatigue, and distortion.

(4) Retracting and locking mechanism—for improper operation.

(5) Hydraulic lines—for leakage.

(6) Electrical system—for chafing and improper operation of switches.

(7) Wheels—for cracks, defects, and condition of bearings.

(8) Tires—for wear and cuts.

(9) Brakes—for improper adjustment.

(10) Floats and skis—for insecure attachment and obvious or apparent defects.

(3) Anti-icing devices—for improper operations and obvious defects.

(4) Control mechanisms—for improper operation, insecure mounting, and restricted travel.

(i) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the radio group:

(1) Radio and electronic equipment—for improper installation and insecure mounting.

(2) Wiring and conduits—for improper routing, insecure mounting, and obvious defects.

(3) Bonding and shielding—for improper installation and poor condition.

(4) Antenna including trailing antenna—for poor condition, insecure mounting, and improper operation.

(j) Each person performing an annual or 100-hour inspection shall inspect (where applicable) each installed miscellaneous item that is not otherwise covered by this listing for improper installation and improper operation.

The scope and detail of an annual inspection is essentially divided into segments or phases (typically four to six). Completion of all the phases completes a cycle that satisfies the requirements of an annual inspection.

The advantage of such a program is that any required segment may be completed overnight and thus enable the aircraft to fly daily without missing any revenue earning potential. Progressive inspection programs include routine items such as engine oil changes and detailed items such as flight control cable inspection.

Routine items are accomplished each time the aircraft comes in for a phase inspection and detailed items focus on detailed inspection of specific areas. Detailed inspections are typically done once each cycle. A cycle must be completed within 12 months. If all required phases are not completed within 12 months, the remaining phase inspections must be conducted before the end of the 12th month from when the first phase was completed.

Each registered owner or operator of an aircraft desiring to use a progressive inspection program must submit a written request to the FAA Flight Standards District Office (FSDO) having jurisdiction over the area in which the applicant is located. Title 14 of the Code of Federal Regulations (14 CFR) part 91, §91.409(d) establishes procedures to be followed for progressive inspections and is shown in Figure

§91.409 Inspections.

(d) **Progressive inspection.** Each registered owner or operator of an aircraft desiring to use a progressive inspection program must submit a written request to the FAA Flight Standards district office having jurisdiction over the area in which the applicant is located, and shall provide—

(3) Enough housing and equipment for necessary disassembly and proper inspection of the aircraft; and

(4) Appropriate current technical information for the aircraft.

(1) A certificated mechanic holding an inspection authorization, a certificated airframe repair station, or the manufacturer of the aircraft to supervise or conduct the progressive inspection;

(2) A current inspection procedures manual available and readily understandable to pilot and maintenance personnel containing, in detail—

(i) An explanation of the progressive inspection, including the continuity of inspection responsibility, the making of reports, and the keeping of records and technical reference material;

(ii) An inspection schedule, specifying the intervals in hours or days when routine and detailed inspections will be performed and including instructions for exceeding an inspection interval by not more than 10 hours while en route and for changing an inspection interval because of service experience;

(iii) Sample routine and detailed inspection forms and instructions for their use; and

(iv) Sample reports and records and instructions for their use;

The frequency and detail of the progressive inspection shall provide for the complete inspection of the aircraft within each 12 calendar months and be consistent with the manufacturer's recommendations, field service experience, and the kind of operation in which the aircraft is engaged. The progressive inspection schedule must ensure that the aircraft, at all times, will be airworthy and will conform to all applicable FAA aircraft specifications, type certificate data sheets, airworthiness directives, and other approved data. If the progressive inspection is discontinued, the owner or operator shall immediately notify the local FAA Flight Standards district office, in writing, of the discontinuance. After the discontinuance, the first annual inspection under §91.409(a)(1) is due within 12 calendar months after the last complete inspection of the aircraft under the progressive inspection. The 100-hour inspection under §91.409(b) is due within 100 hours after that complete inspection. A complete inspection of the aircraft, for the purpose of determining when the annual and 100-hour inspections are due, requires a detailed inspection of the aircraft and all its components in accordance with the progressive inspection. A routine inspection of the aircraft and a detailed inspection of several components is not considered to be a complete inspection.

Figure - 14 CFR §91.409(d) Progressive inspection.

Continuous Inspections

Continuous inspection programs are similar to progressive inspection programs, except that they apply to large or turbine-powered aircraft and are therefore more complicated. Like progressive inspection programs, they require approval by the FAA Administrator. The approval may be sought based upon the type of operation and the CFR parts under which the aircraft will be operated.

The maintenance program for commercially operated aircraft must be detailed in the approved operations specifications (OpSpecs) of the commercial certificate holder. Airlines utilize a continuous maintenance program that includes both routine and detailed inspections. However, the detailed inspections may include different levels of detail. Often referred to as "checks," the A-check, B-check, C-check, and D-checks involve increasing levels of detail. A-checks are the least comprehensive and occur frequently. D-checks, on the other hand, are extremely comprehensive, involving major disassembly, removal, overhaul, and inspection of systems and components. They might occur only three to six times during the service life of an aircraft.

Altimeter and Transponder Inspections

Aircraft that are operated in controlled airspace under instrument flight rules (IFR) must have each altimeter and static system tested in accordance with procedures described in 14 CFR part 43, appendix E, within the preceding 24 calendar months. Aircraft having an air traffic control (ATC) transponder must also have each transponder checked within the preceding 24 months.
All these checks must be conducted by appropriately certified individuals.

ATA iSpec 2200

In an effort to standardize the format for the way in which maintenance information is presented in aircraft maintenance manuals, the Air Transport Association of America (ATA) issued specifications for Manufacturers Technical Data. The original specification was called ATA Spec 100. Over the years, Spec 100 has been continuously revised and updated. Eventually, ATA Spec 2100 was developed for electronic documentation. These two specifications evolved into one document called ATA iSpec 2200. As a result of this standardization, maintenance technicians can always find information regarding a particular system in the same section of an aircraft maintenance manual, regardless of manufacturer. For example, if you are seeking information about the electrical system on any aircraft, you will always find that information in section (chapter) 24. The ATA Specification 100 has the aircraft divided into systems, such as air conditioning, which covers the basic air conditioning system (ATA 21). Numbering in each major system provides an arrangement for breaking the system down into several subsystems. Late model aircraft, both over and under the 12,500 pound designation, have their parts manuals and maintenance manuals arranged according to the ATA coded system. The following abbreviated table of ATA System, Subsystem, and Titles is included for familiarization purposes.

ATA Specification 100Systems

Sys. Sub. Title

21 AIR CONDITIONING

21 00 General

21 10 Compression

21 20 Distribution

21 30 Pressurization Control

21 40 Heating

21 50 Cooling

21 60 Temperature Control

21 70 Moisture/Air Contaminate Control

The remainder of this list shows the systems and title with subsystems deleted in the interest of brevity. Consult specific aircraft maintenance manuals for a complete description of the subsystems used in them.

22 AUTO FLIGHT

23 COMMUNICATIONS

24 ELECTRICAL POWER

25 EQUIPMENT/FURNISHINGS

26 FIRE PROTECTION

27 FLIGHT CONTROLS

28 FUEL

29 HYDRAULIC POWER

30 ICE AND RAIN PROTECTION

31 INDICATING/RECORDING SYSTEMS
32 LANDING GEAR
33 LIGHTS
34 NAVIGATION
35 OXYGEN
36 PNEUMATIC
37 VACUUM/PRESSURE
38 WATER/WASTE
39 ELECTRICAL/ELECTRONIC PANELS AND
MULTIPURPOSE COMPONENTS
49 AIRBORNE AUXILIARY POWER
51 STRUCTURES
52 DOORS
53 FUSELAGE
54 NACELLES/PYLONS
55 STABILIZERS
56 WINDOWS
57 WINGS
61 PROPELLERS
65 ROTORS
71 POWERPLANT
72 (T) TURBINE/TURBOPROP
72 (R) ENGINE RECIPROCATING
73 ENGINE FUEL AND CONTROL
74 IGNITION
75 BLEED AIR
76 ENGINE CONTROLS
77 ENGINE INDICATING
78 ENGINE EXHAUST
79 ENGINE OIL
80 STARTING
81 TURBINES (RECIPROCATING ENG)
82 WATER INJECTION
83 REMOTE GEAR BOXES (ENG DR)

Keep in mind that not all aircraft will have all these systems installed. Small and simple aircraft have far fewer systems than larger more complex aircraft.

Go/No go gauges

A go-no gauge (or go/no-go) refers to an inspection tool used to check a work piece against its allowed tolerances. Its name is derived from two tests: the check involves the work piece having to pass one test (*go*) and fail the other (*no-go*).

ISO 1502 sets a standard for threads and gauging to test them. It establishes the attribute T as *go* for the major diameter and the attribute Z as *no-go* for the pitch diameter. The inspection tool has two threaded components. For example, there would be two female sections on a gauge to test a threaded male work piece such as a screw. If the major diameter of a screw is too large, it will not fit in the T test thread at all (fail). If the major diameter is too small, the fit is sloppy (fail). If the thread has been cut too deep, it screws into the Z test thread (fail). If the fit is right and only does about three turns, the fit is right (pass).

A go/no-go gauge is an integral part of the quality process that is used in the manufacturing industry to ensure interchange ability of parts between processes or even between different manufacturers. It does not return a *size* or actual measurement in the conventional sense, but instead returns a *state*, which is either acceptable (the part is within tolerance and may be used) or unacceptable (the part must be rejected).

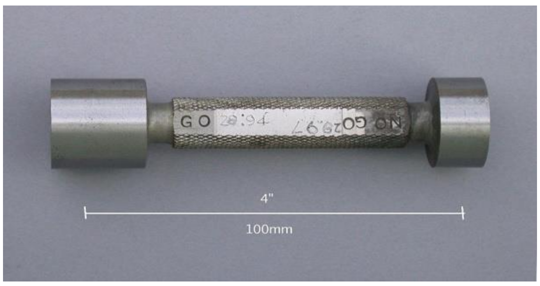
They are well suited for use in the production area of the factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

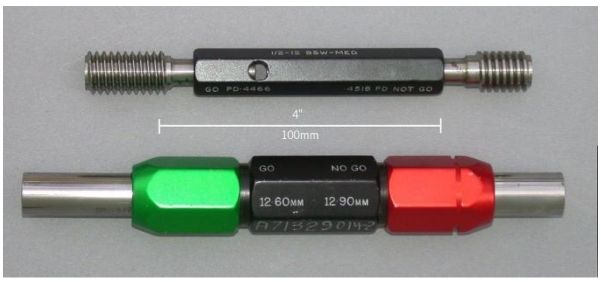
Plug Gauges

These gauges are referred to as plug gauges; they are used in the manner of a plug. They are generally assembled from standard parts, where the gauge portion is interchangeable with other gauge pieces (obtained from a set of pin type and a body that uses the collect principle to hold the gauges firmly. To use this style of gauge, one end is inserted into the part first, and depending on the result of that test, the other end is tried.

In the right image, the top gauge is a thread gauge that is screwed into the part to be tested, the "GO" end should fully enter the part; the "NOT GO" end should not. The lower image is a plain plug gauge used to check the size of a hole; the green end is the *go*, and the red end is the *no-go*. The tolerance of the part that this gauge checks is 0.30 mm, where the lower size of the hole is 12.60 mm and the upper size is 12.90 mm, every size outside this range is *out of tolerance*. This may be initially expressed on the parts drawing in a number of styles; three possibilities may be

- 12.75±0.15 mm
- 12.60+0.30−0.00 mm
- 12.90+0.00−0.30 mm





Hardened and ground plug gauge & Replaceable thread and plug gauges

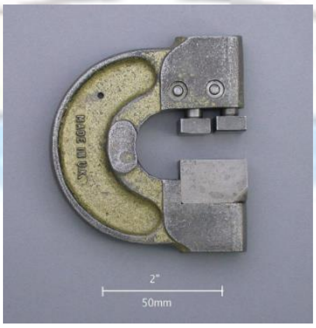
Pin Gauges

The image on the right is a set of pin gauges used to measure holes only a few millimeters in diameter.

A set of pins from 1.550–6.725 mm

Snap gauges

Snap gauges are often used when a large quantity of work pieces must be inspected. The snap gauge has four *anvils* or *jaws*, the first one or pair (outermost) are set using the upper limit (tolerance) of the part and the inner set adjusted to the lower limit of the part. A correctly machined part will pass the first set of jaws and stop at the second — end of test. In this manner, a part may be checked in one action, unlike the plug gauge that needs to be used twice and flipped to access the second gauge. The first go/no-go snap gage for checking thread rolls was invented in 1943 to speed production of parts during WWII.



Snap go/no-go gauge for the OD of a cylindrical work piece

Nondestructive testing or **non-destructive testing** (**NDT**)

Nondestructive testing or **non-destructive testing** (**NDT**) is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage. The terms **nondestructive examination** (**NDE**), **nondestructive inspection** (**NDI**), and **non-destructive evaluation** (**NDE**) are also commonly used to describe this technology. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research. The six most frequently used NDT methods are eddy-current, magnetic-particle, liquid penetrant, radiographic, ultrasonic, and visual testing. NDT is commonly used in forensic engineering, mechanical engineering, petroleum engineering, electrical engineering,civil engineering, systems engineering, aeronautical engineering, medicine, and art. Innovations in the field of nondestructive testing have had a profound impact on medical imaging, including on echocardiography, medical ultrasonography, and digital radiography.

Visual Inspection:

The most obvious form of NDI is the visual check. This check may be performed with the naked eye or assisted by magnification. Magnification is specified to terms of power. The most frequently used magnification level employed in aviation is 10 power, designated as "10X." Many inspection documents begin with the instruction to clean the aircraft or the area of the aircraft to be inspected. It is, however, advisable that technicians involved in general visual-type inspections observe the aircraft before the cleaning process is begun. Clues to discrepancies may often be removed during the cleaning process, making discrepancy identification more difficult. For example, loose or improperly installed countersunk rivets disrupt the airflow around the rivet. As the air flows around these rivets, dirt in the air accumulates, leaving what appears to be a dirt trail around the rivet. It is much easier to identify these dirt trails prior to cleaning the aircraft than after the cleaning process is completed. It should be noted that a pre-cleaning inspection, although often beneficial, does not satisfy the requirements of a traditional complete inspection. The technician can also use the sense of touch to help identify discrepant items. Running the hand or fingernails over a surface can assist the technician in finding cracks. More detailed inspections of an area may be performed by *dye-penetrant inspection, magnetic-particle inspection, X-ray inspection, fluorescent-penetrant inspection, ultrasonic inspection, and eddy-current inspection.* These inspection processes are used to detect discrepancies that are not detectable using only the human senses.

Dye-Penetrant Inspection:

Inspection of a metal structure is easily accomplished by means of dye-penetrant inspection. In this process, the dye penetrates any small cracks or fissures and then seeps out when a developer is applied to the joint. Thus the crack is revealed as a bright red line.

Fluorescent-Penetrant Inspection:

It can be used for detecting cracks or other flaws in a welded structure. A liquid containing a fluorescent material is applied to the part to be inspected and is allowed to penetrate cracks, laps, and other discontinuities. The part is then washed with a suitable solvent and dried, after which a developing powder is applied to draw the penetrant to the surface. Excess powder is brushed off, and the part is examined under ultraviolet light (black light). Cracks and other flaws are revealed as fluorescent markings.

Magnetic-Particle Inspection: (magnaflux)

By means of magnetic powder applied to a magnetized part is an efficient, practical, and nondestructive method that will reveal the presence of tiny cracks and other flaws in a part. The surface to be examined should be reasonably smooth and free from scale, because it is difficult to find cracks in the irregular surface of the weld metal. Sandblasting is a suitable method for cleaning the surface of metal parts in preparation for the magnetic particle inspection. Magnetization of tubular clusters and other welded joints in tubular structures is usually accomplished by means of cables wrapped in coils around the area to be inspected. The technician must follow the appropriate instructions to ensure that the magnetization is produced in the correct direction. After the inspection the magnetization must be neutralized with an alternating-current field coil.

Radiological Inspection:

It was limited in value in the past because of the inaccessibility of many joints and the necessity of taking exposures from several angles to make certain that all defects were found. However, the results are very satisfactory and the recent developments in this field have reduced the cost and time. The use of radioactive cobalt "bombs" has made it possible to X-ray joints at almost any location.

Ultrasonic Inspection:

This technique apply high-frequency sound waves to the part being inspected. These sound waves are reflected from the opposite side of the material or from any flaw that they encounter. Wav signals from the flaw are compared with the normal wave to determine the location and size of the flaw.

Eddy-Current Inspection:

In an eddy-current inspection, electrical currents are generated in the part by means of electromagnetic waves. The electrical current flows in the part in a circular fashion, similar to the eddies observed when draining a bath tub. If a flaw exists, the indicator will show a value different from the normal response. A well-qualified operator can diagnose the response to determine the nature of the flaw. These descriptions are condensed but provide an overview of the inspection techniques used or observed by the technician. For a more complete description of these techniques, the reader is referred to the companion text Aircraft Power plants.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-V NOTES

FACULTY NAME: D.SUKUMAR **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 7AN6.3 **SEMESTER: VII**

SUBJECT NAME: MAINTENANCE OF AIRFRAME AND SYSTEMS DESIGN

MAJOR INSPECTIONS

Major and minor damage, damage tolerance. Corrosion and corrosion prevention. Major and minor defects. Defect reporting rectification and investigation. Rigging of aircraft, symmetry checks. Balancing of control surfaces, Periodical inspections, heavy landing, overweight landing checks, abnormal flight loads. Aircraft weighing, weight schedule, calculation of centre of gravity. Electrostatic Sensitive Devices, Electromagnetic Environment

Aircraft component:

It means any part, the soundness and correct functioning of which, when fitted on an aircraft, is essential to the continued airworthiness or safety of the aircraft, or its occupants.

Classification of Damage

After the extent of damage has been determined, it should be classified in one of the following categories: negligible damage, damage repairable by patching, damage repairable by insertion, or damage requiring replacement of parts. See figure 13-56. Before proceeding with the repair of the airframe, it is necessary that the applicable structural repair manual be consulted for the procedures and materials to be used. If the applicable manual is not available, the *General Manual for Structural Repair*, NA 01-1A-1, may be used. If any conflict should exist between the two manuals, the specific manual takes precedence.

NEGLIGIBLE DAMAGE.— Negligible damage is that damage or distortion that may be allowed to exist as is or corrected by some simple procedure, such as removing dents, stop-drilling cracks, burnishing scratches or abrasions, without placing a restriction on the flight status of the aircraft. Before classifying damage as negligible, make sure the damage complies with the manufacturer’s specified limits of negligible damage.

DAMAGE REPAIRABLE BY PATCHING— Damage that can be repaired by installing a reinforcement or patch to bridge the damaged portion of a part may be classified as damage repairable by patching. Reinforcement members are attached to the undamaged portions of the part to restore full load-carrying characteristics and airworthiness of the aircraft. Damage repairable by patching is specified for each member of the airframe.

DAMAGE REPAIRABLE BY INSERTION.— Damage that is extensive enough to involve a major portion of a member, but which is not so extensive as to require replacement, is classified as damage repairable by insertion. The repair is made by inserting a new section and splicing it to the affected member.

DAMAGE REQUIRING REPLACEMENT.— Damage that cannot be repaired by any practical means is classified as damage requiring replacement. Short structural members usually must be replaced because repair of such members is generally impractical.

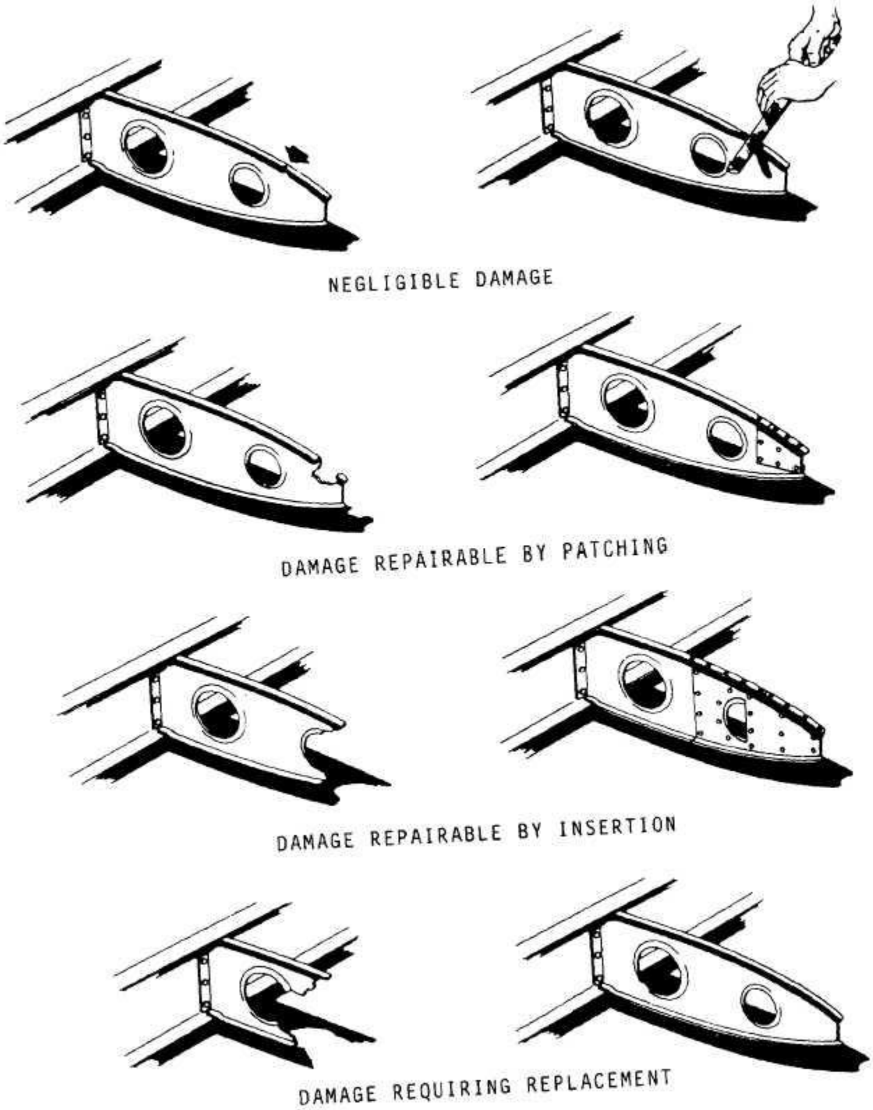
DAMAGE REPAIR PROCEDURES

Damage repair procedures vary greatly from aircraft to aircraft and the type of repair that is going to be performed. Also consult the applicable aircraft MIMs and the applicable aircraft structural repair manual before performing any structural repairs.

Selection of Repair Material

The major requirement in making a repair is the duplication of strength of the original structure. You should consult the structural repair manual for the aircraft concerned for the alloy thickness and temper designation of the repair material to be used. This manual will also designate the type and spacing of rivets or fasteners to be used in the repair.

In some instances, substitutions of materials are allowed. When you are making a substitution of materials and conflicting information between manuals exists, the structural repair manual for the aircraft being repaired should be used.



You have several steps to take to find the correct repair materials and procedures in a structural repair manual. Figure above shows each of the steps.

NOTE: The aircraft structural repair manual, shown in figure 13-57, was selected as a typical manual. The procedures that follow are typical but are not standard. Various manufacturers use different methods to indicate the types of materials used and special instructions for using their particular manual.

1. The extent of the damage to the aircraft is determined by the inspection of the damaged area, as previously explained.

2. Using a master index diagram, identify the damaged group of the aircraft. From the table shown on the diagram, determine the section of the manual where the component is found.

3. After locating the correct group master index diagram, obtain the correct item number for the damaged component from the illustration.

4. Find the index number for the damaged unit from the component diagram.

5. The index number is (hen matched with the item number on the repair material chart. This chart will normally give the part's description, drawing number, gauge, type of material, and location of repair diagram.

6. You can find the repair diagram by locating the required section of the manual and turning to the correct figure in that section. Access provisions and negligible damage information are given on the repair diagrams. After the damage has been cleaned, determine whether or not the damage is negligible according to the repair diagram. If the damage is within the limits of negligible damage, it may be disregarded unless it is necessary to close the hole for aerodynamic smoothness. If the damage exceeds the limits of negligible damage, it must be repaired according to the repair diagram or replaced.

Damage Tolerance

Damage tolerance, or safety by inspection, was developed as a design philosophy in the 1970s as an improvement on the fail-safe principle for structural deterioration.

The damage tolerance approach is based on the principle that while cracks due to fatigue and corrosion will develop in the aircraft structure, the process can be understood and controlled. A key element is the development of a comprehensive programme of inspections to detect cracks before they can affect flight safety. That is, damage tolerant structures are designed to sustain cracks without catastrophic failure until the damage is detected in scheduled inspections and the damaged part is repaired or replaced.

Damage Tolerance Analysis

In ensuring the continued safe operation of the damage tolerant structure, inspection schedules are devised. This schedule is based on many criteria, including:

- assumed initial damaged condition of the structure
- stresses in the structure (both fatigue and operational maximum stresses) that cause crack growth from the damaged condition
- geometry of the material which intensifies or reduces the stresses on the crack tip
- ability of the material to withstand cracking due to stresses in the expected environment
- largest crack size that the structure can endure before catastrophic failure
- likelihood that a particular inspection method will reveal a crack
- acceptable level of risk that a certain structure will be completely failed
- expected duration after manufacture until a detectable crack will form

- assumption of failure in adjacent components which may have the effect of changing stresses in the structure of interest

These factors affect how long the structure may operate normally in the damaged condition before one or more inspection intervals have the opportunity to discover the damaged state and effect a repair. The interval between inspections must be selected with a certain minimum safety, and also must balance the expense of the inspections, the weight penalty of lowering fatigue stresses, and the opportunity costs associated with a structure being out of service for maintenance.

Corrosion

Corrosion on aircraft is nothing more than rust of the metal parts, although aluminum corrosion doesn’t produce the reddish color most people think of as rust. Rather, it usually first shows as a whitish or gray “dulling” of the aluminum surface, then progresses to more and more severe pitting and eventual destruction of the metal. Left untreated, corrosion can make an aircraft unairworthy in just a few years.

Types of corrosion normally found on aircraft include:

- **Uniform surface attack.** This is the most common type and is caused simply by exposing the metal to oxygen in the air, such as when paint is worn off wing skin or the fuselage. Poor pre-paint preparation at the factory, fumes, acid, pollutants, or high humidity accelerate the decay.
- **Intergranular corrosion.** Normally worst on 7000-series alloys (those with an appreciable amount of zinc, like wing spars, stringers and other high-strength aircraft parts), this is not frequently found but is a particularly nasty type of corrosion. It can be difficult to detect, and once you see it, it’s too late: that piece of metal is toast.
- **Stress corrosion.** In highly stressed parts like landing gear or engine crankshafts, this type may develop from a scratch or surface corrosion. Crankshaft failures are often due to undetected corrosion of this type.
- **Crevice or deposit corrosion.** This can occur anywhere there is an area where moisture or other pollutants are trapped. Lapped skin joints or rivets on an oil-stained belly are examples of prime corrosion spots.
- **Filiform corrosion.** Particularly on aluminum surfaces poorly prepared for polyurethane paints, this type of corrosion will show up as fine, worm-like lines of corrosion under the paint that will eventually lead to bubbling and flaking.

Particular Aircraft Affected

Any metal aircraft is a candidate for corrosion, but thousands of single-engine Cessna’s built from 1977 through 1982 seem to be particularly susceptible to the worm-like filiform corrosion that starts under the paint. According to Aviation Consumer magazine, Cessna’s problems started when the company switched to the then-new polyurethane paints for aircraft built in its Pawnee, Kansas, assembly plant. Although the paint was considered superior to old-fashioned enamels and lacquers, Cessna apparently did not follow the paint manufacturer’s recommendations for more extensive preparation of the aluminum surface. A special program to help owners with repainting (called SP79-3S) was set up by Cessna but not widely publicized.

Hazardous Locales

As the general aviation fleet ages, corrosion is becoming an increasingly common problem. Since moisture is a culprit for most common types of corrosion, aircraft based in coastal areas are often in particular danger. Many potential aircraft buyers will shy away from a bird that has spent much time in Florida, along the Gulf Coast or in Pacific Coast areas of the west. Said one aircraft appraiser, "there's just too much chance that such airplanes are rust buckets."

Recently repainted aircraft offered for sale from such areas are regarded with particular suspicion by knowledgeable buyers because the paint could be covering up serious corrosion.

Hangaring, frequent washing, and regular treatment with rust inhibitors, such as ACF-50 (Aircraft Corrosion Formula 50), can help dramatically in slowing the deterioration of aircraft from corrosion.

Recognizing Corrosion

A very thorough visual inspection will reveal most corrosion, and Advisory Circular 43-4A describes corrosion inspections and control for aircraft in great detail. Look for grayish-white powder on aluminum and reddish deposits on ferrous metals. Bumps or blisters in paint signify corrosion occurring under the surface, especially the filiform type common on aluminum that has been poorly prepared for painting. Filiform corrosion looks a little like cottage cheese under the paint.

Pay close attention to the trailing edges of control surfaces where the skins come together. Also, the inside of wheel wells on retractable models is a prime location for corrosion, not surprising considering its exposure to acids, salts, gravel, and other corrosion-producing substances. Use of a magnifying glass may reveal beginnings of corrosion not visible to the naked eye.

Checking for damage inside the aircraft is more difficult but necessary. Remove all inspection plates, and spend some time with a mechanic's mirror (a mirror mounted on a stick) and a good strong flashlight. You're looking for gray or whitish deposits on aluminum and the trademark rust on steel.

Areas of airplanes often damaged by corrosion include the propeller, cylinder fins, areas around fuel tanks or bladders, piano-type control hinges, and the battery box. Propeller corrosion occurs in two basic areas: on the surface of the blade, which is constantly abraded and exposed to the elements, and the hub of constant-speed propellers.

Corrosion Treatment

Corrosion is Mother Nature's way to bringing your airplane back to its natural state, and there's no reversing Mother Nature. Preventing corrosion is much easier than treating it, and one of the best ways is to base the airplane in a dry part of the country, as the Air Force does when it mothballs aircraft in the Arizona desert near Tucson. Other steps include protecting the aircraft in a hangar, washing it often to remove pollutants and dirt, and treating it with ACF-50 or other corrosion inhibitors. If you don't have a hangar, make use of cabin covers, and ensure that all windows seal tightly to prevent moisture from attacking the fuselage from the inside out.

Removing corrosion is the only sure fix once it's found. Light surface corrosion can be removed with abrasion (the specifics of which depend on the metallurgy of the corroded part), then application of a corrosion inhibitor, such as zinc-chromate primer, another primer, and then paint. Be careful when removing the corrosion with common steel brushes or stainless brushes that have been used on steel or rust; they will work steel into the aluminum, where it will ruin the paint job. If corrosion is severe enough to have removed a significant amount of metal, replacement of the part is usually the only solution. One corrosion inhibitor commonly used is ACF-50, manufactured by Lear Chemical Research Corporation in Mississauga, Ontario, Canada. It is a thin film compound formulated to penetrate corrosion deposits to the base of the corrosion cell, where it emulsifies and encapsulates the electrolyte, lifting it away from the metal surface. It penetrates seams, lap joints, cracks, and rivet heads and is normally applied at annual inspection time. Another product, called Boeshield T-9, is made of 13 solvents and oils, along with a wax that remains as a barrier film after the other components have evaporated. It is manufactured by PMS Products, Inc., in Holland, Michigan, and has an initially thin viscosity that is intended to allow it reach into assembled components, dissolve minor corrosion, displace moisture, and leave a coating. Both products come in cans and are sprayed under pressure.

Defect:

It means a condition existing in an aircraft (including its systems) or aircraft component arising from any cause other than damage, which would preclude it or another aircraft component from performing their intended functions or would reduce the expected service life of the aircraft or aircraft component.

Major Defect:

It means a defect of such nature that reduces the safety of the aircraft or its occupants and includes defects discovered as a result of the occurrence of any emergency or in the course of normal operation of maintenance.

Repetitive Defect:

It means a defect in an aircraft (including its components and systems) which recurs, inspite of rectification attempt, on the same aircraft.

CLASSIFICATION OF MAJOR DEFECTS

Given below is a list of Major defects, classified into two Groups i.e. Group-I and Group-II. The list is only a guideline and is not exhaustive. Each operator shall report the occurrence or detection of any one or more major defect so classified either in Group-I or Group-II.

Group-I

a. Fires during flight;
b. Fires during flight not protected by a related fire warning system;
c. An engine exhausts system that causes damage during flight to the engine, adjacent structure, equipment or components;
d. Engine shutdown during flight with external damage to the engine or aircraft structure occurs;
e. Defect to an aircraft component that causes accumulation or circulation of smoke, vapour, or toxic or noxious fumes in the crew compartment or passenger cabin during flight;
f. Any other major damage/ defect requiring extensive repair/ inspection/ modification to the aircraft (or/and in cases as desired by local DAW office).

Group-II

a. False fire warnings during flight;
b. Engine shutdown during flight because of flame-out;
c. Engine shutdown during flight due to foreign object ingestion or icing;
d. Shutdown during flight of more than one engine;
e. Defect of a propeller feathering system or ability of the system to control over -speed during flight;
f. Defect of a fuel or fuel-dumping system that affects fuel flow or causes hazardous leakage during flight;

g. Defect related to landing gear extension or retraction, or opening or closing of landing gear doors , during flight;
h. Brake system components that result in loss of brake actuating force when the aircraft is in motion on the ground;
i. Damage to aircraft structure that requires major repair;
j. Cracks, permanent deformation, or corrosion of aircraft structure, if more than the maximum acceptable to the manufacturer or the DGCA;
k. Damage of aircraft components or systems that result in taking emergency actions during flight (except action to shut down an engine);
l. Each interruption to a flight , unscheduled change of aircraft en route, or unscheduled stop or diversion from a route, caused by known or suspected mechanical difficulties or malfunctions;

Maintenance:

The performance of tasks required to ensure the continuing airworthiness of an aircraft including any one or combination of overhaul, inspection, replacement, defect rectification, and the embodiment of a modification or repair.

Repair:

The restoration of an Aeronautical product to an airworthy condition to ensure that the aircraft continues to comply with the design aspects of the appropriate airworthiness requirements used for the issuance of the Type Certificate for the respective aircraft type, after it has been damaged or subjected to wear.

Major Repair

It means a design change that is intended to restore an aeronautical product to an airworthy condition.

(i) When the damage or wear being repaired or restored to airworthiness condition might appreciably affect the weight, balance, structural strength, performance, power plant operation, flight characteristics, or other qualities affecting airworthiness or environmental characteristics or

(ii) That will be embodied in the product using nonstandard practices.

Minor Repair

It means a repair other than a major repair.

Operator

It means a person, organisation or enterprise engaged in or offering to engage in aircraft operation;

Scheduled Operator:

It means an aircraft operator which operates its fleet, whole or part of it, as per a published schedule.

Approved Organization (AO)

It means an organization approved by DGCA engaged in manufacture, maintenance, processing, testing, storage and distribution of civil aircraft, aircraft components, items of equipment, aircraft goods and Training School.

Approved Maintenance Organization (AMO)

It means an organization approved by DGCA in Category “C” in accordance with CAR Section 2 Series E part I.

Procedures for defect recording, reporting, investigation, rectification and analysis:

I. All organizations as stated in Para 3 above shall have a system in their organization to ensure that all defects, minor or others, whether reported by Flight Crew or observed by Maintenance Crew (including those occurred due to improper maintenance practices) are recorded and investigated for taking appropriate rectification action.

II. The rectification action taken in respect of each defect shall be recorded alongside of the snag reported.

III. "Classification of Defects": All recorded defects shall be examined by experienced and qualified personnel of the operator for the purpose of classification. A list 0f defects classified as major defects in Group I & Group II is indicated as a guideline at Appendix I.

IV. Where an Operator / Organisation has contracted the maintenance of its aircraft to an Approved Maintenance Organisation (AMO) , it shall be the responsibility of the operator to comply with this CAR and report such defects observed on its (Operator‘s) aircraft during maintenance at the AMO facilities. Further both Operators / Organisation and the AMO shall evolve a system between themselves in such a manner so as to comply with all the requirements of this CAR. The system so established shall be included in the Quality Control Manual and / or Operations Manual (as the case may be) of both the Organisations. The AMO shall however maintain record of all the defects observed on the aircraft, of an operator, in respect of which the maintenance has been contracted to it (AMO). The AMO will produce such records for scrutiny by DGCA officers when required.

V. **"Initial Information”: -** All defects classified as "major" or those requiring "major repair" or which are serious in nature and attracting public attention shall be intimated immediately on telephone by all Operators / Organisations to RAWO followed by written information . The written information containing complete details shall be forwarded , in Case of ;

Scheduled Operators:

Within 24 hours of the occurrence.

Operators Other Than Scheduled Operators

Within three days of the occurrence of the defect. At least the following information will be indicated

a. Name of the Organization / Operator

b. Aircraft type and registration No.

c. Date and place of occurrence of the defect

d. Details of the defect(s) and the rectification action taken

VI. All defects, whether major or not and including repetitive ones, shall be taken into account for computing statistics for determining components/systems reliability indices in case of scheduled operators, as called for in the CAR Series 'C' Part V, and each repetition of the defect shall be considered as "a defect" for the purpose of computation of reliability index provided rectification was attempted.

VII. **Review of Defects Reported on aircraft :**

All operators shall evolve a system for undertaking a prompt review, by experienced and qualified technical personnel, of the nature of defects (whether major or other) and the adequacy of rectification action taken in respect of each defect (including that of repetitive defects) reported/observed on each aircraft of its fleet, no sooner the aircraft returns to its "main base (including temporary base)", from where it had departed last.

Scheduled Operators: Scheduled Operators shall carry out "Daily Review "of the defects reported on the aircraft of the fleet.

Operators Other Than Scheduled Operators: The periodicity of review of the defects reported on the aircraft of the fleet of operators other than scheduled operators may be fixed by the operator in consultation with the RAWO. Depending upon the type / quantum of operation and size of the fleet of aircraft.

The **Regional Airworthiness Officers** may associate themselves with this review and ask for any additional information, or performance of such additional work considered necessary to rectify the defect and to render the aircraft serviceable.

VIII. **Investigation of Delays & Defects ;**

Scheduled Operators "Defects causing Mechanical delays on aircraft operated by Scheduled operators" : Delay to a scheduled service of 15 minutes' duration or more, on account of aircraft defect (whether major or not), shall be reported to Regional Airworthiness Office within 24 hours (working hours of Airworthiness Office) of receipt of information about the delay by the "main maintenance base" (for the type of aircraft involved) of an operator as per the format given in ' Appendix III ' or giving at least the following information:-

(a) Service Number, date and place of delay

(b) Type and Registration No. of the aircraft

(c) Duration of Delay

(d) Brief reason for the delay and the rectification action taken.

For investigation of defects as per para 4.1, including defects causing delay a senior Technical Person of the operator, acceptable to DGCA, shall be approved by DGCA for supervising the compliance of the system and shall form a part of the Quality Control Organization of the operator. The system shall also be included in the operator's approved Quality Control Manual. The senior technical person shall have adequate number of technical persons, approved by the Quality Control Manager of the operator in accordance with the qualifications and experience norms as stipulated by DGCA, to assist him in different aspects of various investigations.

Operators Other Than Scheduled Operators,

Quality Control Manager or his representative shall supervise the compliance of the system for investigation of defects detailed in preceding paragraphs.

The investigation of all defects and particularly of Major Defects and Mechanical Delays (referred in para 4.8 above), shall be completed expeditiously, so as to take preventive/corrective action at the earliest possible. In case the completion of investigation of a major defect is likely to take longer than one month, then investigation progress reports must be rendered to concerned Regional Airworthiness Office every month till the finalization of the report. All efforts must be made by an operator to complete the investigation of every major defect within 3 months of its occurrence.

The major defect, (including those requiring "major repair") will be investigated by the operator in association with the concerned Regional or Sub-Regional Airworthiness Offices. Airworthiness Officer(s) may require the operator or the owner of the organization, to submit components, work sheets, documents and information connected with the defect, for such investigation.

The investigation reports on major defects / mechanical delays shall be sent by the operator / organisation, in duplicate, to concerned Regional Airworthiness Office soon after finalisation. The final report shall contain at least the following information, in addition to these forwarded vide para 4.5 (above):-

(a) Identification of parts/systems involved.

(b) Apparent or actual cause of the defect.

(c) Life of affected component since new and since last inspection, in terms of flight hours/landings/cycles.

(d) Action taken by the operator to prevent recurrence.

(e) Any disciplinary action, taken by the operator, against any of its employees, and

(f) Whether the operator considers the investigation "closed" or "open" and if "open "the time it would take to complete the investigation.

Defect monitoring:

- The Regional Airworthiness Officers may require operators/maintenance organisations to furnish such additional information about the investigation of the defect as considered necessary by them, either for "closing” the case or for conducting further investigation on their own. The operator shall furnish such additional information.
- The Regional Airworthiness Offices shall ensure that Quality Control Department of all operators/Aircraft maintenance Organisations (AMOs) are adequately staffed to discharge the duties and responsibilities prescribed in paras 4.1 to 4.8 The Regional Airworthiness offices may also carry out spot checks on the records of operators to ascertain if the system spelt out in preceding paragraphs, and particularly the classification of defects, as called for in para 4.3 above, is being followed.
- The major defect, (including those requiring "major repair") will be investigated by the operator in association with the concerned Regional or Sub-Regional Airworthiness Offices. Airworthiness Officer(s) may require the operator or the owner of the organization, to submit components, work sheets, documents and information connected with the defect, for such investigation.

- The operator shall intimate the corrective action(s) taken on the recommendation(s) made in the investigation report (finalised in accordance with para 5.3 above) along with a copy of the investigation report to the Regional Airworthiness Office. A copy of the report shall also be forwarded to DGCA (Headquarters - Attention DAW).
- An operator/ AMO shall periodically, at least once in three months , analyse the investigation results of all the defects, whether major or not, collectively to determine, weakness, if any , in the basic design of a component or in the layout of a system or in the maintenance technique adopted to perform the work involved , exists. If weaknesses are detected, then necessary corrective action shall be taken by the operator / AMO under intimation to Regional Airworthiness Office. All faults, malfunctions, defects and other occurrences which cause or may cause service difficulties or any adverse effects on the continuing airworthiness of the aircraft shall be reported by all operators / approved maintenance organizations, to the manufacturers/designer of the aircraft/engine/propeller/system/ components at the earliest but not later than seven days of the occurrence , for a continuous assessment of the design features of the aircraft. The type of information which the operator should provide to the manufacturer assessing the reported service difficulties and rendering advice is given at 'Appendix IV ' to this CAR.
- Operators / Organisation shall ensure;

  a) Continued Airworthiness of the aircraft during its service life.

  b) Compliance with the appropriate airworthiness requirements after a modification, repair or installation of replacement part; and

  c) That the aircraft is maintained in an airworthy condition as per the maintenance programme and is in compliance with the maintenance requirements specified in Aircraft Rules , CAR and by the manufacturer of the aircraft .

- The Regional or Sub-Regional Airworthiness Office, may require any operator, notwithstanding the requirements stipulated in this part of the CAR, in the interest of safety of aircraft, to submit:-

(a) Full details of any defect(s), or

(b) Any component associated with the defect or delay investigation.

The said components shall not be disposed off in any manner without the prior approval of the concerned Regional / Sub-Regional Airworthiness Office.

PRESERVATION OF RECORDS AND COMPONENTS:

- The records, associated with the defects and their rectification actions, shall be preserved for a period of one year and may be required for consultation at the time of renewal of C of A of an aircraft.
- The components, associated with the major defects shall be preserved for a period of two weeks from the date of intimation of the defect, unless required (in writing), by the concerned Regional and Sub-Regional Airworthiness Office, to be preserved longer.

JACK IDENTIFICATION

All aircraft hydraulic jacks are either axle or airframe (tripod) jacks. These jacks use standard, authorized aircraft hydraulic fluid. They have a safety bypass valve that prevents damage when a load in excess of 10 percent over the rated capacity is applied. For example, the safety valve on a 10-ton jack will bypass fluid at 11 tons of pressure.

Axle Jacks

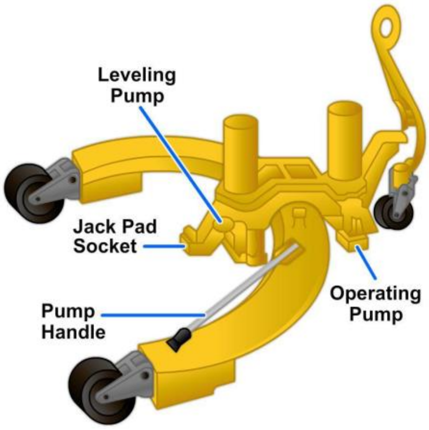
Axle jacks are used for raising one main landing gear or the nose gear of an aircraft for maintenance of tires, wheels, and struts. There are four different types of axle jacks and many different sizes (lifting capacity in tons). The smaller hydraulic axle jacks are normally squadron or unit permanent custody equipment. That means your outfit is responsible for making sure the jacks are load tested at the support equipment (SE) division of the FRC before being put into service, and annually thereafter. Special inspections include 13-week inspections at FRC SE, but a load test is not required every 13 weeks. A record of maintenance, inspections, technical directives, and load testing is kept on OPNAV Form 4790/51.

All model designations for axle jacks begin with the letter *A*, for axle, such as A10-1HC. The number following the *A* shows the jack capacity in tons, such as 10 for a 10-ton jack. This is followed by a dash (-) and the specific jack identification number. Then comes two letters that show the type of jack (HC = hand-carried, HS = horseshoe, and OR = outrigger). The three types of axle jacks are discussed below.

HAND-CARRIED — These axle jacks (*Figure below*) are portable, self-contained units, with single or double manually operated pumps. They have carrying handles, pump handles, reservoir vent valves, release valves, and safety valves. The different model sizes vary from 4 3/4 inches to 9 inches high (closed). Their weights vary from 26 to 120 pounds.

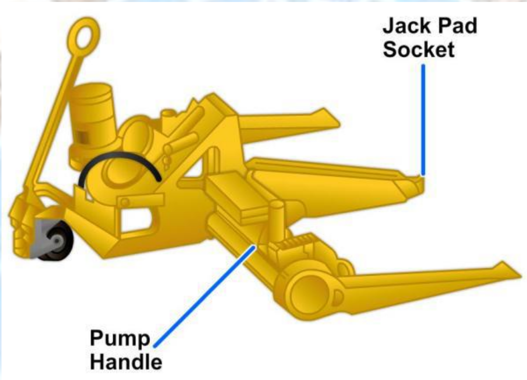
Hand-carried axle jack.

HORSESHOE — Horseshoe axle (*Figure below*), or crocodile jacks, consist of a lifting arm supported by two hydraulic cylinders. The cylinders move up over the stationary pistons when the manual pump operates. The A25-1HS is a large jack—5 feet long, 5 feet 8 inches wide, standing 2 feet 1 3/4 inches high, and weighing 900 pounds.



Horseshoe axle jack.

OUTRIGGER — This cantilever axle jack (*Figure below*) is a very large and heavy jack. It weighs 2,190 pounds and is 7 feet 3 inches long, 6 feet 8 inches wide, and 2 feet 3 inches high. A double (two-speed) pump mounts on the left-hand side of the frame to operate the hydraulic cylinder.



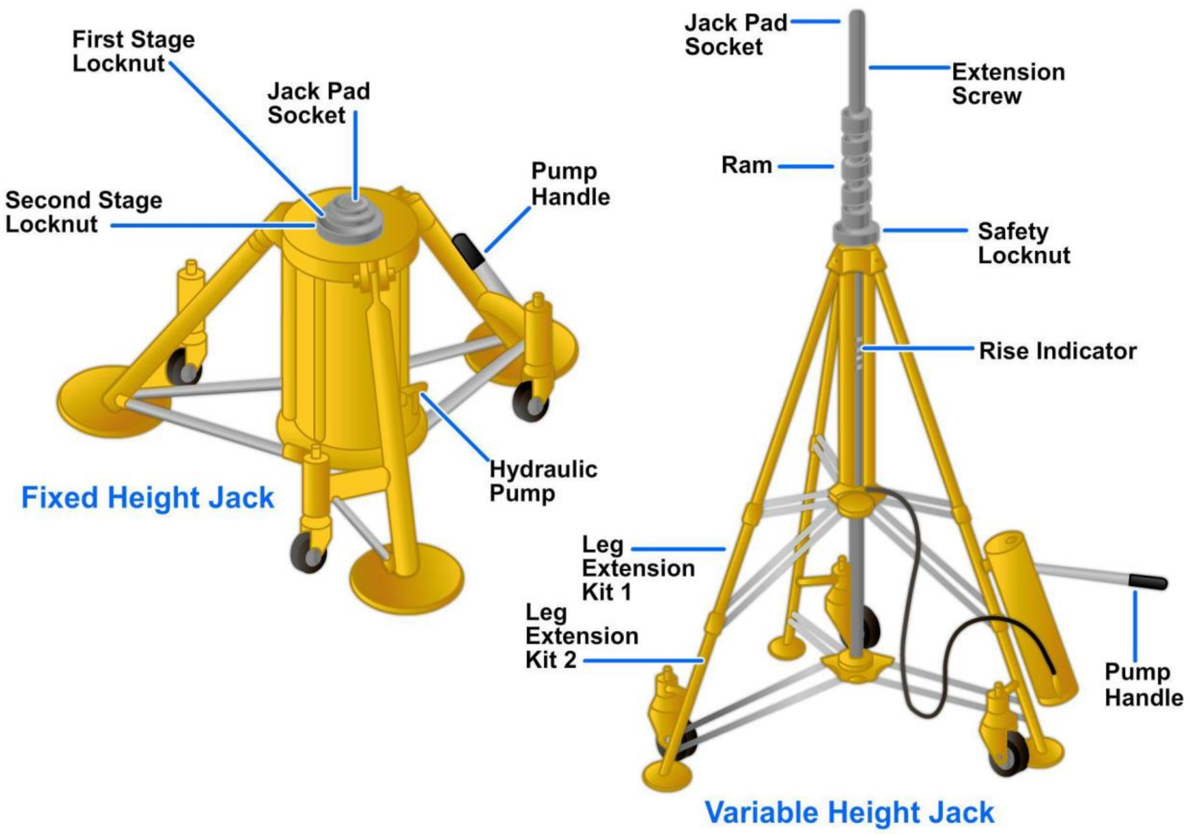
Outrigger axle jack.

Airframe (Tripod) Jacks

Airframe (tripod) jacks are used for lifting the entire aircraft off the ground or deck. Airframe jacks are commonly called tripod jacks. You may hear them called wing, nose, fuselage, or tail jacks. These names come from the jack placement on the aircraft. The points for jacking vary with the type of aircraft, and can be found in the MIM for each type of aircraft.

There are two different types of tripod jacks—fixed height and variable height. Both are mobile, self-contained, hydraulically operated units. They consist of three basic assemblies. These assemblies are the hydraulic cylinder, the tubular steel wheel tripod leg structure, and the hydraulic pump. The main difference between the two types is that the tripod structure on a variable height jack can be adjusted to different heights by adding leg extensions.

All model designations for tripod jacks begin with the letter *T*, for Tripod, such as T10-2FL or T20-1VH5. The number following the *T* indicates the jack capacity in tons, such as 10 for a 10-ton jack. This is followed by a dash (-) and the specific jack identification number. Then comes two letters indicating the type of tripod jack (*FH* = fixed height, or *VH* = variable height). The number that follows the *VH* in variable height jacks indicates the number of leg extension kits available for that jack. *Figure below* shows a T20-1VH5 jack with only two of five extension leg kits installed. Each leg extension kit increases the effective height of the basic jack by 18 inches. The airframe tripod jacks weight varies from 275 pounds to 837 pounds.



Airframe (tripod) jacks.

Several safety features are built into the tripod jacks. A locknut—also called a ring or collar—on the ram mechanically locks the ram in position. The locknut prevents the ram from settling in the event of hydraulic failure or inadvertent lowering. A safety bypass valve in the system bypasses fluid from the pump or ram when excessive pressure is built up.

Airframe (tripod) jacks are normally checked out from the SE division (FRC) when needed. Since transporting these heavy and cumbersome jacks is a problem, they often remain in custody of an organization for a prolonged period of time. The organization must be responsible for their care and cleanliness during periods when not in use. As with axle jacks, these jacks need to be load tested prior to being placed in service—and annually thereafter. Special inspections are performed every 13 weeks at FRC SE and recorded on the OPNAV Form 4790/51.

The MIM will show what type of aircraft jack to use at each position. During deployment, the jacks that are called for in the MIM may not be available. The *Index and Application Tables for Aircraft Jacks*, NAVAIR 19-70-46, contain a list of approved prime and alternate jacks for all Navy and Marine aircraft. It was prepared under the direction of the Commander, Naval Air System Command, by the Naval Air Engineering Center.

PREOPERATIONAL INSPECTION

The same basic safety precautions apply to all jacks. A good preoperational inspection should be conducted before use. NAVAIR 19-600-135-6-1 is the general pre-op MRC for all jacks. The jack must have been tested within the last 13 weeks and if the jack is dirty, it should be wiped down. Cracks or broken welds can't be seen under dirt. If the jack is covered with hydraulic fluid, it may be leaking and should be inspected more closely.

The reservoir should be checked and it should be full with the jack ram fully collapsed. If the reservoir is low, it should be checked for leaks somewhere. The reservoir should be filled with clean, fresh, hydraulic fluid and the filler plug vent valve checked to make sure it is not clogged. If the plug is blocked, it may get an air lock, and the jack may not operate correctly. Pressure could also build up in the reservoir and cause a rupture. The pump handle needs to be checked for bends and the pump rocker arm and link for elongated or out-of-round holes. These are signs that the jack may have been overloaded, and that the safety bypass valve is malfunctioning.

With the filler plug air vent valve open and the release valve closed, the ram should be pumped up and checked for leaks and full extension. When the ram reaches full extension, the pumping pressure will increase. It is important not to continue to pump or it may cause damage to the internal ram stops because there is no load on the jack.

The ram and screw should be lowered out the extension screw, but not forcibly overextended past the internal stops. It should be checked that it is clean and oiled. If it is dirty, it should be wiped clean and coated with a light film of MIL-PRF-7870 oil.

On jacks equipped with wheels, the wheels and springs suspension assemblies must be checked to make sure they are in good condition. Towing or dragging these jacks around with broken wheels will damage the frame or reservoir.

Since many leaks in jacks will only appear when the jack is under a load, possible leaks can be found when jacking the aircraft. If a leak or other defect is found during the preoperational inspection, use of the jack should be discontinued. The jack should be downed, red-lined, tagged as bad, reported, and turned into the SE division (FRC) for repairs. A defective jack should never be left where someone else may use it.

HANDLING AND MOVEMENT

Handling airframe jacks can be hazardous. The jacks are heavy—anywhere from 110 to 900 pounds—and the wheels are free-swiveling and small. Directional stability is poor, and pushing one into position around an aircraft is no simple chore. A jack moved or positioned by one person is hazardous. If the jack is dirty and covered with grease or fluid, it's even more hazardous. The jack footplates and wheels at the base of the tripod stick out, and are notorious "foot-crunchers" and "shin-knockers." It's not hard to damage an aircraft tire, wheel brake assembly, hydraulic lines, landing gear door, or any other part of an aircraft if someone is careless and rams it with a jack.

Movement of jacks aboard ship during any pitch or roll of the deck is extremely hazardous. Even with a calm sea, a smart turn into the wind by the ship while you're moving an airframe jack can be disastrous. Movement of jacks from hangar to hangar, through hangar bays, and across hangar tracks and ramp seams can easily damage a jack and put it out of commission—just when someone needs it!

Transportation of jacks over longer distances ashore, such as from the SE pool to a hangar on the other side of the field, can be a real problem. If the SE division (FRC) has locally fabricated a special "jack transporter" trailer, you're in luck. If any other type of trailer, truck, or flatbed is used, sufficient manpower must be available to get the jacks on and off the vehicle safely. Jacks are heavy and cumbersome to handle. Loading and unloading is hazardous even when there are enough people.

Usually, a locally fabricated sling and some sort of hoist are necessary. Forklifts should never be used to handle or lift jacks. The tripod cross braces are not strong enough, and this will damage the jack. The chances of dropping it are also high. Forklifts must NOT be used to handle jacks.

The wheels on a tripod jack are not made for towing the jack. They are small, allow only a couple of inches of clearance, and are spring loaded. Bouncing over uneven surfaces will usually cause the jack footplates to hit the ground, and that can spin the jack around, tip it over, or damage the tripod structure. Airframe jacks don't have tow bars, the wheels can't be locked in position so they track, and there are no brakes. NEVER try to tow airframe jacks.

Free-swiveling casters and no brakes also mean that jacks can move by themselves if not properly secured. A loose, 900-pound tripod jack on a pitching hangar deck could be disastrous. Jacks can also be moved by jet or prop blast. Therefore, any jack that isn't tied down can be a hazard. Since there are no tie-down rings on the jacks, care must be taken in attaching the tie-down chains or ropes to prevent damage to the jack. This is particularly true aboard ship where the jacks are likely to be "working" against the tie-downs in rough seas.

General Hazards

The extension screws on jacks have a maximum extension range. This range is stenciled on the jack. An internal stop prevents overextending the screw. If the screw is forcibly overextended—which isn't hard to do—not only could damage be done to the internal stop mechanism, but the jack may be rendered unsafe and hazardous to use. An overextended screw is very likely to bend or break off from any side motion.

Each extension screw on a jack is equipped with a jack pad socket. The aircraft jack pad fits into this socket and into a fitting or socket in the aircraft. The sockets and pads are designed to take vertical loads but not much horizontal pressure. The pads can shear or slip from either the jack or aircraft socket if enough side load is applied.

Side loads normally result when the jacks are not raised at the same rate. This causes the aircraft to tilt or pitch. When that happens, the distance between the jacking points becomes closer in the ground plane—like the ends of a ruler will cover less distance across a desk top as you raise one end. With the weight of the aircraft holding the jacks in one place that "shrink" in distance between the jack points creates a tremendous side load on the jacks, and eventually they will break or slip. The same thing happens if all the jacks aren't lowered at the same rate to keep the aircraft level or at the same attitude it was in when jacking started.

Lowering the jack can be very hazardous. The rate of descent of a jack depends on how far the release valve is opened. Control can be very tricky when trying to coordinate three jacks at once. Usually, it takes only a small amount of rotation on the valve to get a fast rate of descent. If the valve was tightened hard before jacking, it will take force to open it. Care must be taken so extra force doesn’t cause the valve to open more than expected. The valves may vary in different jacks, so it is best to get an idea of how an individual release valve reacts during the preop check. But remember it comes down a lot quicker with a 30-ton load than with a 5-ton load.

There is a safeguard to prevent the jack from lowering too fast—the safety locknut. The safety locknuts on jacks are a very important safeguard in preventing the aircraft from falling off the jacks in the event of jack failure. However, using them during raising, and particularly during lowering operations, is hazardous to hands and fingers. To be effective, the locknut must be kept about one-half thread above the top surface of the jack (the top of the ram cylinder or second ram, depending upon the model of jack). It is important to carefully keep fingers and hands clear of the area between the locknut and cylinder head so they won't be pinched or crushed. This will be easier while the jack is being raised and the locknut rotated down. Variable height jack rams have spiral grooves, which allow the locknut to rotate down the ram by its own weight. However, this means that while lowering the jack, the locknut must be held up as it is rotated up the ram. This makes it more dangerous. Depending upon the height of the jack, it normally takes two people to operate the jack and the safety nut. Do NOT try to do it by yourself.

Jacking Restrictions

There are many restrictions to jacking for each type aircraft. If any of these restrictions are violated, there is a good chance that there will be an accident, damage to the aircraft, or injury. The restrictions generally concern aircraft gross weight and configuration. Some of the considerations are fuel dispersion in fuselage and wing tanks, engines in or out, and tail hook up or down.

Details on restrictions and procedures are in the MIMs. These should be learned and followed exactly. Many squadrons will have their own local standing instructions for jacking aircraft, which contain additional safety precautions and restrictions to be followed.

JACKING PROCEDURES

The jacking procedures vary for each aircraft type and configuration. The procedures that follow are examples of what could be encountered. Fairly exacting steps are given to provide clarity. Remember, these steps are for representative type aircraft, and are not necessarily accurate for all. When actually jacking aircraft, the exact procedures described in the MIMs must be followed.

The location of the aircraft will determine what is needed for equipment. Jacking procedures on a ship require tie-down procedures to prevent aircraft from shifting on jacks. When tie-down chains are to be used, they should be positioned in accordance with the MIM, so as not to interfere with the landing gear during the drop check of the gear. Jacking procedures on land do not require tie-downs, except in high-wind conditions.

Aboard ship, squadron maintenance controls will request, through the carrier air group (CAG), permission to place an aircraft on jacks. The MIM should be checked for jacking restrictions, warnings, and cautions. The support equipment required by the MIM should be obtained, ensuring all preoperational inspections have been completed. All protective covers and ground safety devices should be installed, as required by the MIM. The surrounding area around the aircraft must be roped off during the entire aircraft jacking operation, and signs posted stating **"DANGER: AIRCRAFT ON JACKS."** The area below and around the aircraft must be cleared of all equipment not required for the jacking operation. Jack adapters must be installed, as well as aircraft mooring adapters and tie-down chains as required by the MIM. *Figure 5-27* shows an example of carrier tie-down for aircraft jacking. Wing and nose jacks must be positioned and extended until seated on wing jack and tie-down adapters.

Raising Aircraft

Jack pressure should be applied on each jack without lifting the aircraft, and checked to see that the base of each jack is evenly seated. The base position of the jack should be corrected, as required, for firm base seating. For shipboard operations, all jacks must be tie-down before jacking aircraft with a minimum of three tie-down chains per jack. The jack must be tied down at the spring-loaded wheel caster mounts, allowing the jacks to make small movements with the aircraft jack points. The aircraft parking brake must be released and main landing gear chocks removed. The aircraft should be jacked evenly and tie-down chains extended while jacking. Extension of tie-down chains must be coordinated in a way that preload on each tie-down chain is partially removed before jacking. Partial preload is maintained with jacking of aircraft by rotation of the chain tensioning grip.

NOTE

Some aircraft require the extension of the center screw to provide for clearance of the gear doors.

⚠ CAUTION ⚠

Use extreme care to raise wing jacks in coordinated, small, equal amounts. Preload on the tie-down chain is too high when tensioning grip cannot be rotated manually.

As each jack is being extended, the lock collar must be screwed down. The aircraft should be jacked until its wheels clear the deck, and the lock collar set hand tight. Each tie-down chain must be set to preload by manually rotating and tightening tensioning grip.

JACKING UP OF AN AIRCRAFT

To jack (LIFT UP) the aircraft from its steady position

OCCASION

When aircraft is need to be inspected for damage to change type and during rigging check from OGCA jacking of an aircraft has to be carried out

REQUIREMENTS

- Man power=3+1
- Man hours=3 hrs
- Documents of aircraft maintenance manual

TOOLS,EQUIPMENT REQUIRED

- Jacking pad
- Necessary jacks, bottle jack1, wheel chocks

PRECAUTIONS

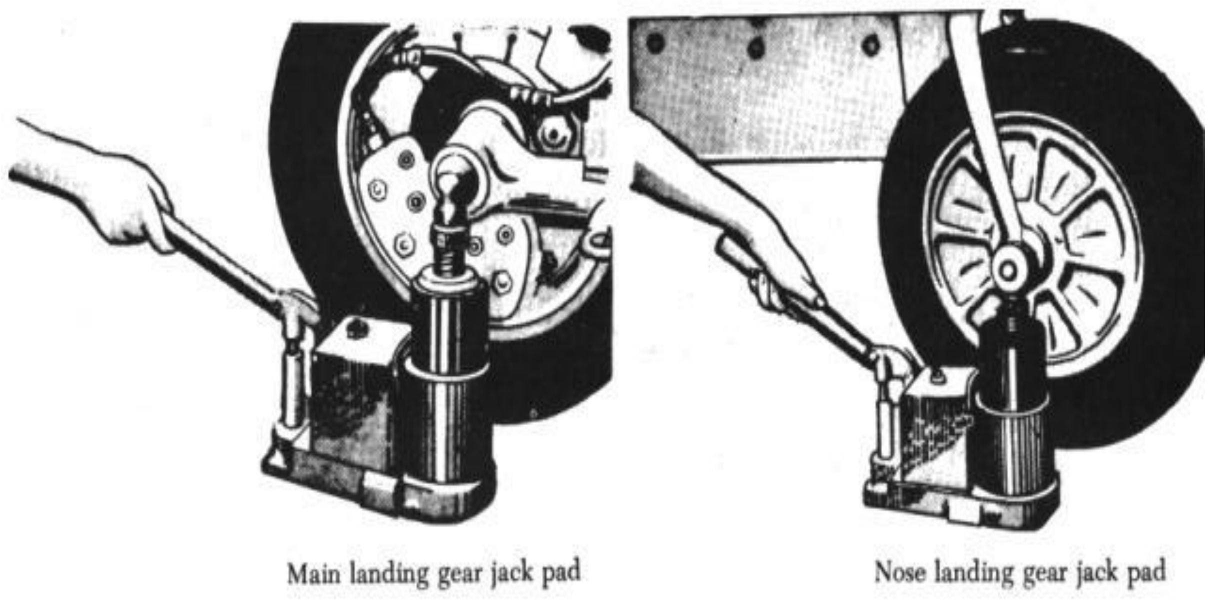
- Refer aircraft maintenance manual , ensure the capacity and semi circularity of jack
- The jacking area should be oil free
- The jacking point should of which 2 at wings and one at maximum c.g location
- There should be no person inside the aircraft while jacking
- Central surfaces should be locked
- The ballasted weight should be removed before jacking
- Jack handle should not damage structure of weight
- Clearance of propeller should be ensured before jacking

PROCEDURE

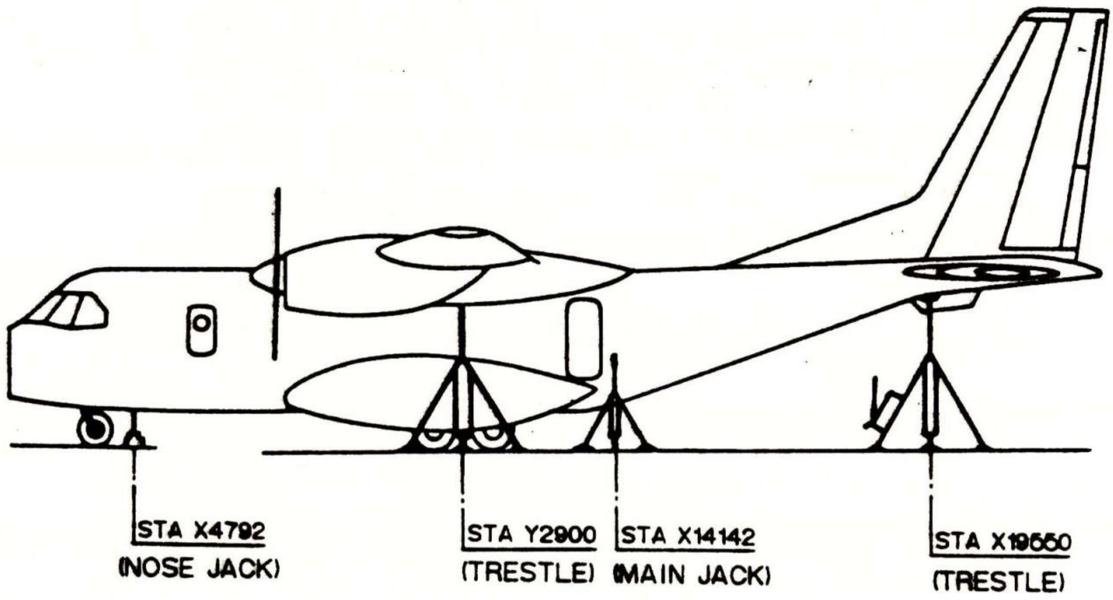
- It differs from various aircraft and refer respective aircraft maintenance manual
- Remove the mooring
- Identify the jacking points of the aircraft by placing it in level

- After finding the jacking points place the jacks at the points.
- Place a person at the jacking point to look after the raised jacks
- All the jacks should be simultaneously raised.
- After jacking, jack locks should be checked for stability and tightened.
- The necessary inspection has to be carried out.
- If the aircraft is likely to be checked for more than 24 hrs, place the adjustable truss at specified station
- Place the displace board aircraft jacks near the aircraft.

Jacking of a Complete Aircraft



Jacking One Wheel



Jacking of a Complete Aircraft

LEVELLING OF PUSHPAK AIRCRAFT

To level the aircraft for inspection purpose

LEVELING

- Leveling is the process of placing an aircraft in its rigging position by means of hydraulic or screw jacks
- The rigging position is the position of the aircraft at which longitudinal and lateral axis are parallel to ground.
- Leveling means leveling the aircraft in the horizontal position for rigging. There are three types of leveling. They are as follows
  - Straight edge method
  - Grid plate method
  - Engineers transmit method

OCCASION

During replacement or renewal of major components, rigging checks, symmetry checks and as when DGCA require leveling process is carried out.

REQUIREMENTS

- Man hours = 3 hrs
- Man power= 3+1
- Documents= Aircraft maintenance manual

TOOLS REQUIREMENT

- Tripod screw/hydraulic jack
- Spirit level [adjustable/fixed]
- Leveling boards
- Tail trestles[fixed/adjustable]

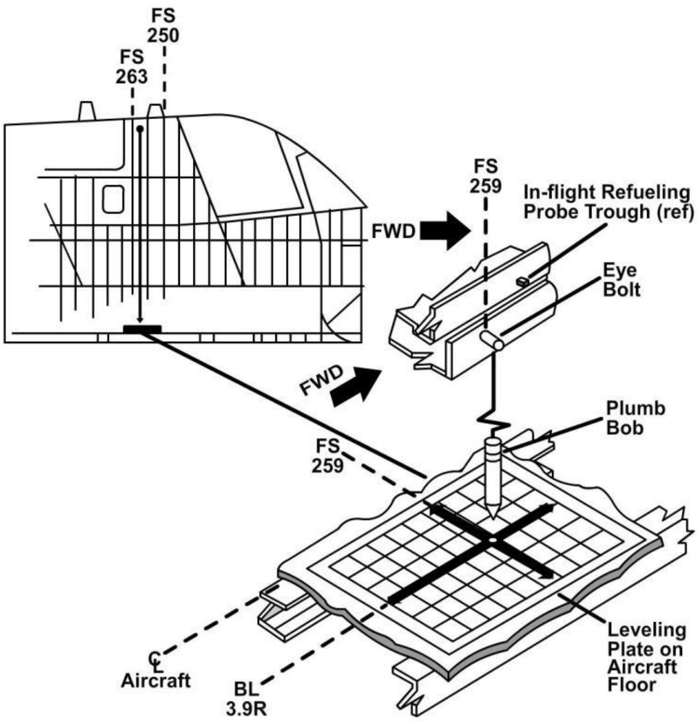
PRECAUTION

- Observe on safety precautions for jack up
- Check the accuracy of spirit level
- Always finish leveling procedure once by checking the [longitudinal level without any adjustment]

PROCEDURE

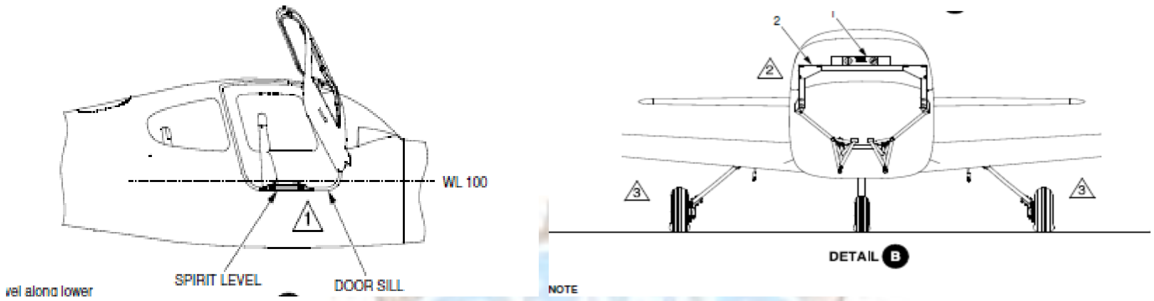
- Place the main jack below the undercarriage near the fuselage
- Place the trestle of the specified station by lifting the tail unit
- Place the longitudinal leveling board at both side of cockpit
- Place the lateral leveling board at rear of the slats
- Place the spirit level over it and adjust main jack till the bubble of spirit level is brought in centre
- Recheck the longitudinal level
- If the bubble is in the centre in both the spirit level, the aircraft is considered to be brought into level condition
- If not, then repeat the operation from step 3 to 7

An aircraft levelling technique is shown in *Figure*.

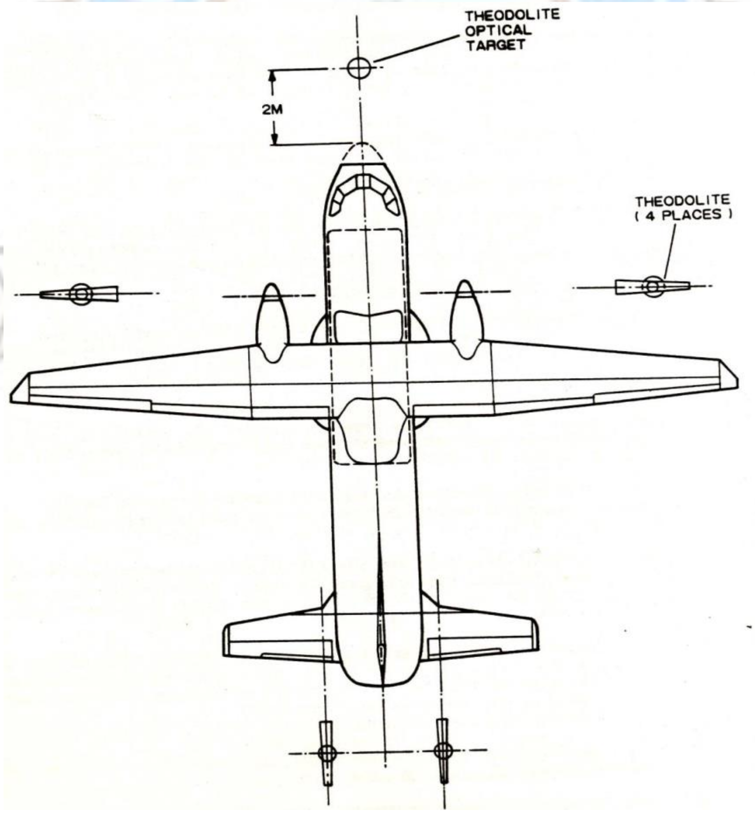


Aircraft levelling

Aircraft should be jacked at wing and nose jack point as described earlier. The plumb bob and string should be attached to the eye bolt at FS 259 (fuselage station) and positioned directly over the levelling plate on floor of aircraft. The aircraft should be levelled laterally (left to right) by adjusting wing jacks until the plumb bob tip is directly above the centre line in the levelling plate. The aircraft should be levelled longitudinally (forward and aft) by adjusting the nose jack until the plumb bob tip is directly above FS 259 line on the levelling plate. This procedure varies greatly with different types of aircraft. The applicable MIM must be used to perform a levelling procedure.



Aircraft levelling



Jacking of a Complete Aircraft

Thus the aircraft is leveled and is made ready for further checks.

Mooring:

The following is a list of equipment need to park and/or moor (tie down) the airplane.
• 4 wheel chocks
• 3 screw-in mooring rings (left and right wing, and tail)
• 3 ropes (nylon or other non-shrinking/non-stretching synthetic material)

If wheel brakes are hot from prolonged taxi, allow brakes to cool before setting parking brake.

Controls may be secured with ailerons neutral and horizontal stabilizers leading edge down by pulling the control stick aft as far as possible and fastening seat belt snugly around it.

SHORT-TERM PARKING

Perform this procedure for short-term parking of the airplane.
1. Taxi or tow airplane to desired parking position.
2. Align nose of airplane into the wind.
3. Ensure nose wheel is centered.
4. In windy or gusty weather, moor (tie down) the airplane, see Section 10-20 Mooring (Tying Down) on page 11 of this chapter.
5. Set the parking brake. If wheel brakes are hot from prolonged taxi, allow brakes to cool before setting parking brake.
6. Place chocks in front of and behind main wheels.
7. Release the parking brake.
8. Secure flight controls in neutral position; retract flaps.
Controls may be secured with ailerons neutral and horizontal stabilizers leading edge down by pulling the control stick aft as far as possible and fastening seat belt snugly around it.
9. Close and lock the doors.

LONG-TERM PARKING
Perform this procedure for long-term parking of the airplane.
1. Perform the steps for short-term: parking.
2. Moor (tie down) the airplane, is shown below
3. Install external rudder lock if available.

ALL GUST LOCKS MUST BE REMOVED FROM THE AIRCRAFT PRIOR TO TAXI AND FLIGHT. CARE SHOULD BE TAKEN NOT TO DEFORM OR DAMAGE THE STRUCTURE DURING INSTALLATION AND REMOVAL OF THESE LOCKS. ALL DEFOMRATION, DAMAGE AND INTERFERENCE MUST BE REVIEWED BY A QUALIFIED MECHANIC OR TECHNICIAN PRIOR TO FLIGHT.
4. Install pitot/static, canopy, and propeller covers as applicable.
5. Refer to engine, electrical, and fuel system chapters of this manual for information on required servicing for long-term storage.

The airplane has three mooring points: one under each wing, and one under the tail. Mooring rings are provided to secure tie down ropes into the mooring points. Park the airplane; see the procedures for short and long term parking of the airplane.

Attach tie-down ropes to ground tie-downs and aircraft mooring rings. Leave sufficient play or looseness in the ropes to prevent inadvertent loading of the structure. Also, if using a rope, tie a bowline knot to allow tension freedom.

Figure 10-1 Mooring Points on the Wings

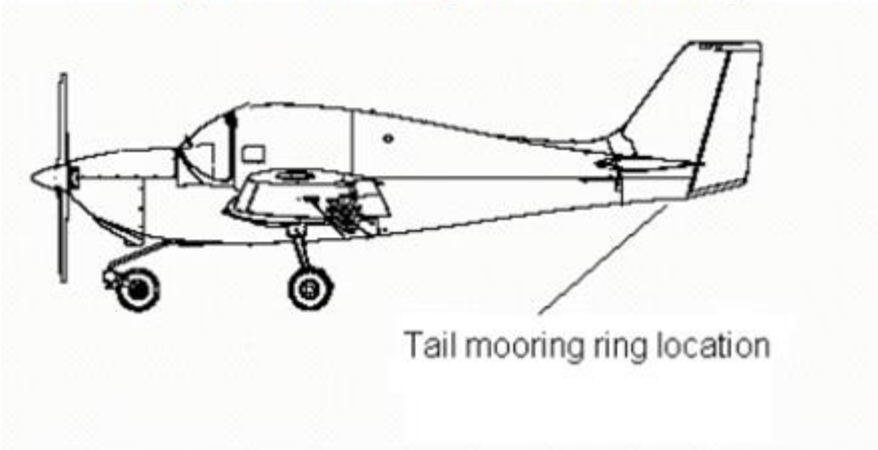


Figure 10-2 Mooring Point on the Tail

Proper tie-down procedure is the best precaution against damage to the aircraft by gusty or strong winds. To tie-down the aircraft securely, proceed as follows:

1. Head the aircraft into the wind

2. Place chocks fore and aft of each main wheel.

When chocking the wheels, ensure that the chocks used are not too large to come in contact with the wheel fairings. The use of chocks that are too large may damage the fairings.

3. Drive stakes into the ground approximately three feet outboard of each wing tip and to either side of tail wheel.
4. Install one tie-down ring in each wing tip rib.
5. Tie a sufficiently strong rope to each wing tie-down ring and anchor to the ground stakes. Allow a little slack in each tiedown rope.
6. Tie the center of the rope to the tail wheel fork and anchor the rope ends to the ground stakes at either side of the tail wheel.
7. Ensure that the canopy is closed waterproof and locked.

AIRCRAFT RIGGING

The term "rigging" has been around a lot longer than airplanes have. It's one of the many carry-over terms from the sailing world that aided aviation during its infancy, and still holds them close together. After all, we use "nautical miles" for distance, "knots" for speed, and both pursuits have an uncanny way of emptying one's wallet.
Just as in sailing, trimming and tuning the way that we harness the wind is the key to performance and efficiency. Chances are that your aircraft's performance is somewhat less than the numbers in your operations manual. While it's questionable whether any of our planes actually ever flew quite as fast as the original advertisements boasted, there is a lot that you can do to get close.

Airframe Alignment

Due to the handmade nature of general aviation aircraft, a certain degree of variation in the manufacturing process is inevitable. Manufacturers employ jigs and fixtures to get each part as close as possible to the ideal blueprint design.
However, most designs also employ methods of fine-tuning the airframe such as spacers and shims to ensure that the proper dihedral is in the wings, angle of incidence is correct on all flying surfaces, and the airframe is as straight as possible.

General aviation aircraft tend to lead long lives, and those lives can include all sorts of accidents, incidents, hangar rash, and other activities that can change the alignment of the airframe. In some cases, checking the alignment of the airframe is fairly straightforward; in others it can require specialized tools. However, there are a few simple checks that you can do to verify the basics.

Begin the process by levelling the aircraft. Every aircraft has a level point at which the aircraft must first be levelled laterally. In many aircraft, the levelling point is between the two control yokes. This makes it easy to balance a bubble level across the yokes or the control shafts. Ideally, this process is conducted on a level surface, but as long as the parking spot isn't too bad, you should be able to get the aircraft level by simply adjusting the air pressure in the tires. (Don't forget to re-inflate the tires before flying.). While you're in the cockpit, the first thing to do is to ensure that the aircraft instruments are reading what the aircraft is actually doing.

The turn and bank indicator and the attitude indicator should be showing the aircraft to be perfectly level. If they're not, each instrument can be adjusted by loosening the front mounting screws and gently rotating the instrument to the correct position. I've heard of more than a few cases where pilots thought the aircraft was flying with a wing down, only to discover that the instruments were in need of adjustment.

The next step is to ensure that the fixed surfaces of the aircraft are in alignment. Using a tape or string that does not stretch measure the distance from each wingtip to a point on the centerline of the tail cone. The same technique can be used to check the horizontal stabilizer by measuring to a central point at the front of the aircraft. Do not use the front of the vertical stabilizer or the spinner as a measuring point because many aircraft are designed with asymmetric mountings to help reduce P-factor. The left and right measurements should be equal. If they're not, the aircraft may have been improperly repaired following an accident.

If your shop floor is perfectly flat, you may be able to measure the wing dihedral, but you'll need to have access to the proper rigging tools to check the wing and tail angle of incidence. In most cases, you'll find everything in order, but it always pays to check the fixed surfaces first, before spending time and money on the control surfaces.

Engine Alignment

As we stated earlier, many aircraft designs set the engine thrust line at an angle to help reduce P-factor. In most aircraft, this alignment is built into the engine mount design. However, if corrections are required, washer spacers are inserted, as necessary, between the rubber dampers (LORD mounts) and the engine case.

Most mounts consist of two solid rubber "biscuits" that encase a gelfilled core. When they are in good condition, they do an excellent job of isolating the engine from the steel engine mount. However, as they age, they begin to harden and sag under the weight of the engine. In addition, it's quite possible that the engine alignment may not have been properly done at the last engine change. The bottom line is that if your prop isn't pulling the plane in the direction you want to go, chances are that you're not getting to your destination as efficiently as possible.

Adjusting your engine's alignment is not a difficult task. The first step is to determine whether you have an alignment problem. On most aircraft, this can be easily accomplished by examining the alignment of the spinner to the nose bowl. Even small variations left, right, up, or down can cause problems.

Adjusting the alignment is fairly straight forward. The mounts are loosened and spacers are inserted, as needed, between the rubber dampers and the engine case until the alignment is correct.

Control Surface Rigging

Control surface rigging checks are probably the most neglected maintenance procedure on general aviation aircraft.

If you don't believe me, pick up your maintenance logbooks and look for an entry that says something like this:
Control surface rigging checked and adjusted per manufacturer's instructions.
It's a well-known fact that drag reduction is the best way to increase aircraft performance. When we think traditionally about drag reduction, things like fairings and removing steps and antennas come to mind. However, improperly rigged control surfaces top the list for reasons two aircraft of the same model can have very different performance numbers.
A properly rigged aircraft should be able to fly level and hands-off so long as the loading is balanced. If yours doesn't, that's a sure sign to check the rigging of the control surfaces. Other signs of rigging problems can include fixed trim tabs that are significantly bent to allow the aircraft to fly level, or the need to use regular aileron and rudder trim in straight and level flight.
However, even if these symptoms are not present, it doesn't hurt to go through a complete rigging check. It's extremely unlikely that your aircraft is already properly rigged, and I have yet to hear of an aircraft that didn't require adjustments following a rigging check.
The rigging process for every aircraft varies by manufacturer. A good starting point is to check and set the cable tensions.
A calibrated cable tensiometer is a must for this task, and the adjustment process can be quite complex on some aircraft. Every action has some reaction. For example, adjusting the cable tension at one point may cause the control surfaces to become misaligned with respect to each other. This is why it is extremely important to follow the manufacturer's rigging instructions carefully.
Flaps and ailerons are probably the most common source of misalignment.
Not only does each surface need to be set for the proper travel and alignment with the yoke, but each side must be aligned with its counterpart on the opposite side. Surprisingly, flaps are a very common cause of banking problems, and they can also have a significant effect on climb and cruise performance.
Drooping flaps can induce a lot of drag. Depending on the aircraft, the flap-adjustment procedure may require applying upward pressure on the flaps to take out any play and properly check the alignment.
Aircraft designs, such as the Maule, reflex the flaps upward to reduce wing drag during cruise flight. This is also a technique used by some air racers. Reflexing the flaps effectively reduces the chord of the wing and, therefore, reduces drag in cruise. However, be warned that setting the flaps outside of the manufacturer's specifications is illegal on certificated aircraft and makes you an unwitting test pilot regardless of the aircraft category.
Once all of the control surfaces are properly rigged, you should straighten any fixed trim tabs so that you will have a clean starting point from which to work.
Then you can proceed to the flight-testing and trim-tab adjustment phase.

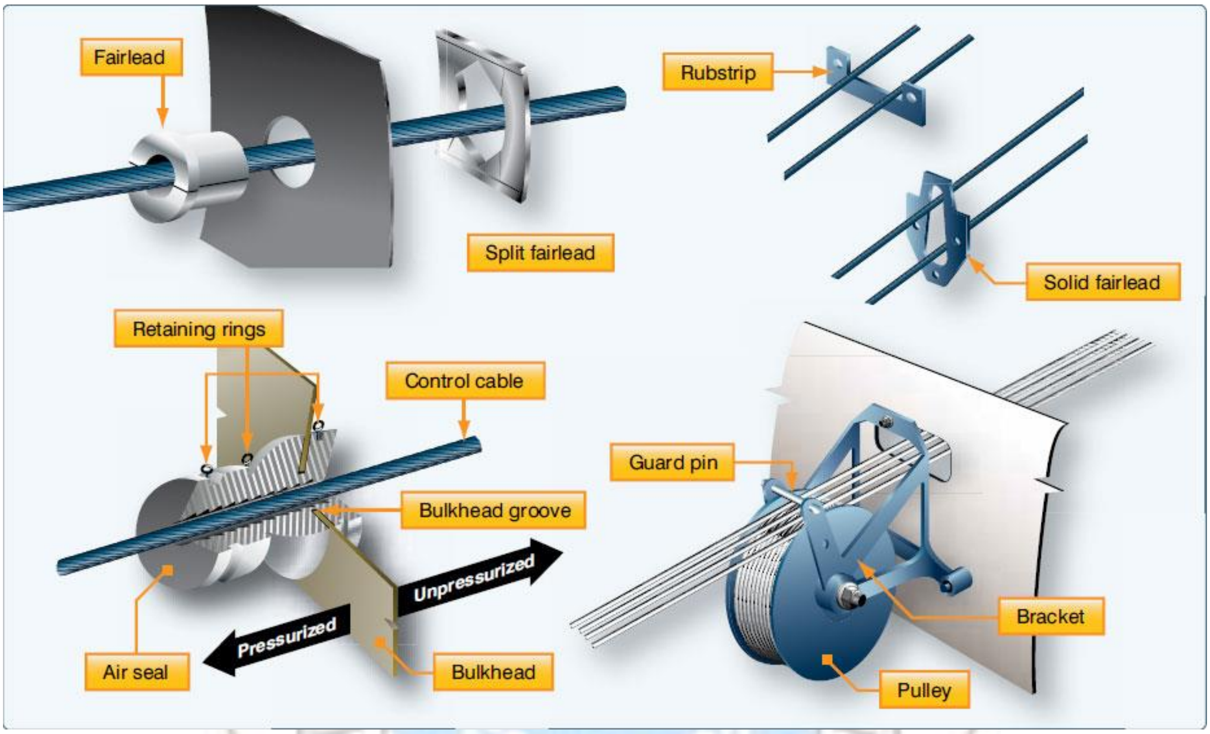
Flight Test

When flight testing, be sure to pick a calm day and begin by setting up a stable cruise speed. The aircraft should be loaded as it would be on your typical flights. Trim the elevator first so that the aircraft does not tend to pitch up or down when flying hands-off. Next, take your feet off the rudder pedals and check the ball to see if the aircraft is yawing left or right. If the aircraft has adjustable rudder trim, trim out any undesired yaw. If not, you will need to land to adjust the fixed-rudder trim tab and repeat the process.
With the rudder trim properly set, you can proceed to the aileron trim. Again, set the aircraft for stable, level flight with a centered ball in the turn and bank. If the aircraft has adjustable

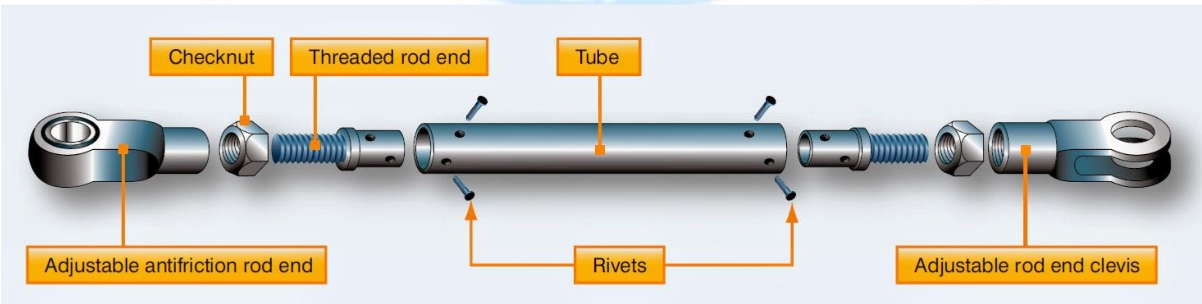
aileron trim, you can complete the process in the air. But, for most aircraft, you'll need to land and adjust the aileron trim tabs.

Once the aircraft is perfectly trimmed, make a note of the position of the trim tabs. Only minor inputs should have been necessary to achieve coordinated flight. If the tabs need to be excessively bent to achieve level flight, it's quite possible that something else is going on with the aircraft and further investigation is warranted.

A well-rigged aircraft is a pleasure to fly. With a little effort and the right set of tools, you can eliminate the constant crosswind you've been fighting, gain a knot or two, and renew your love affair with your favourite bird!



AIRCRAFT RIGGING



Special Inspections

During the service life of an aircraft, occasions may arise when something out of the ordinary care and use of an aircraft might happen that could possibly affect its airworthiness. When these situations are encountered, special inspection procedures should be followed to determine if damage to the aircraft structure has occurred. The procedures outlined on the following pages are general in nature and are intended to acquaint the aviation mechanic with the areas which should be inspected. As such, they are not all inclusive. When performing any of these special inspections, always follow the detailed procedures in the aircraft maintenance manual. In situations where the manual does not adequately address the situation, seek advice from other maintenance technicians who are highly experienced with them.

Hard or Overweight Landing Inspection

The structural stress induced by a landing depends not only upon the gross weight at the time but also upon the severity of impact. However, because of the difficulty in estimating vertical velocity at the time of contact, it is hard to judge whether or not a landing has been sufficiently severe to cause structural damage. For this reason, a special inspection should be performed after a landing is made at a weight known to exceed the design landing weight or after a rough landing, even though the latter may have occurred when the aircraft did not exceed the design landing weight. Wrinkled wing skin is the most easily detected sign of an excessive load having been imposed during a landing.

Another indication which can be detected easily is fuel leakage along riveted seams. Other possible locations of damage are spar webs, bulkheads, nacelle skin and attachments, firewall skin, and wing and fuselage stringers. If none of these areas show adverse effects, it is reasonable to assume that no serious damage has occurred. If damage is detected, a more extensive inspection and alignment check may be necessary.

Severe Turbulence Inspection/Over "G"

When an aircraft encounters a gust condition, the airload on the wings exceeds the normal wingload supporting the aircraft weight. The gust tends to accelerate the aircraft while its inertia acts to resist this change. If the combination of gust velocity and airspeed is too severe, the induced stress can cause structural damage.

A special inspection should be performed after a flight through severe turbulence. Emphasis should be placed upon inspecting the upper and lower wing surfaces for excessive buckles or wrinkles with permanent set.

Where wrinkles have occurred, remove a few rivets and examine the rivet shanks to determine if the rivets have sheared or were highly loaded in shear. Through the inspection doors and other accessible openings, inspect all spar webs from the fuselage to the tip. Check for buckling, wrinkles, and sheared attachments. Inspect for buckling in the area around the nacelles and in the nacelle skin, particularly at the wing leading edge. Check for fuel leaks. Any sizeable fuel leak is an indication that an area may have received overloads which have broken the sealant and opened the seams. If the landing gear was lowered during a period of severe turbulence, inspect the surrounding surfaces carefully for loose rivets, cracks, or buckling. The interior of the wheel well may give further indications of excessive gust conditions. Inspect the top and bottom fuselage skin. An excessive bending moment may have left wrinkles of a diagonal nature in these areas. Inspect the surface of the empennage for wrinkles, buckling, or sheared attachments. Also, inspect the area of attachment of the empennage to the fuselage. The above inspections cover the critical areas. If excessive damage is noted in any of the areas mentioned, the inspection should be continued until all damage is detected.

Lightning Strike

lthough lightning strikes to aircraft are extremely rare, if a strike has occurred, the aircraft must be carefully inspected to determine the extent of any damage that might have occurred. When lightning strikes an aircraft, the electrical current must be conducted through the structure and be allowed to discharge or dissipate at controlled locations. These controlled locations are primarily the aircraft's static discharge wicks, or on more sophisticated aircraft, null field dischargers.

When surges of high voltage electricity pass through good electrical conductors, such as aluminum or steel, damage is likely to be minimal or non-existent. When surges of high voltage electricity pass through non-metallic structures, such as a fiberglass radome, engine cowl or fairing, glass or plastic window, or a composite structure that does not have built-in electrical bonding, burning and more serious damage to the structure could occur. Visual inspection of the structure is required. Look for evidence of degradation, burning or erosion of the composite resin at all affected structures, electrical bonding straps, static discharge wicks and null field dischargers.

Fire Damage

Inspection of aircraft structures that have been subjected to fire or intense heat can be relatively simple if visible damage is present. Visible damage requires repair or replacement. If there is no visible damage, the structural integrity of an aircraft may still have been compromised. Since most structural metallic components of an aircraft have undergone some sort of heat treatment process during manufacture, an exposure to high heat not encountered during normal operations could severely degrade the design strength of the structure. The strength and airworthiness of an aluminum structure that passes a visual inspection but is still suspect can be further determined by use of a conductivity tester. This is a device that uses eddy current and is discussed later in this chapter. Since strength of metals is related to hardness, possible damage to steel structures might be determined by use of a hardness tester such as a Rockwell C hardness tester.

Flood Damage

Like aircraft damaged by fire, aircraft damaged by water can range from minor to severe, depending on the level of the flood water, whether it was fresh or salt water and the elapsed time between the flood occurrence and when repairs were initiated. Any parts that were totally submerged should be completely disassembled, thoroughly cleaned, dried and treated with a corrosion inhibitor. Many parts might have to be replaced, particularly interior carpeting, seats, side panels, and instruments. Since water serves as an electrolyte that promotes corrosion, all traces of water and salt must be removed before the aircraft can again be considered airworthy.

Seaplanes

Because they operate in an environment that accelerates corrosion, seaplanes must be carefully inspected for corrosion and conditions that promote corrosion. Inspect bilge areas for waste hydraulic fluids, water, dirt, drill chips, and other debris. Additionally, since seaplanes often encounter excessive stress from the pounding of rough water at high speeds, inspect for loose rivets and other fasteners; stretched, bent or cracked skins; damage to the float attach fitting; and general wear and tear on the entire structure.

Aerial Application Aircraft

Two primary factors that make inspecting these aircraft different from other aircraft are the corrosive nature of some of the chemicals used and the typical flight profile. Damaging effects of corrosion may be detected in a much shorter period of time than normal use aircraft.

Chemicals may soften the fabric or loosen the fabric tapes of fabric covered aircraft. Metal aircraft may need to have the paint stripped, cleaned, and repainted and corrosion treated annually. Leading edges of wings and other areas may require protective coatings or tapes. Hardware may require more frequent replacement. During peak use, these aircraft may fly up to 50 cycles (take-offs and landings) or more in a day, most likely from an unimproved or grass runway. This can greatly accelerate the failure of normal fatigue items. Landing gear and related items require frequent inspections. Because these aircraft operate almost continuously at very low altitudes, air filters tend to become obstructed more rapidly.

Aerodynamic balancing

The ways and means of reducing the magnitudes of $C_{h\alpha t}$ and $C_{h\delta e}$ are called aerodynamic balancing.

The methods for aerodynamic balancing are:

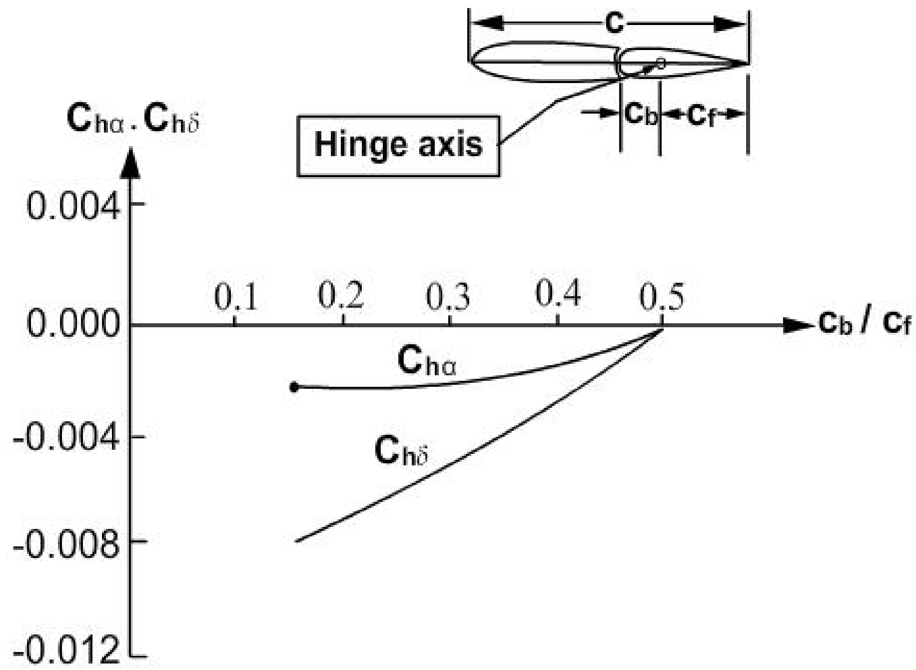
1. Set back hinge,

2. Horn balance and

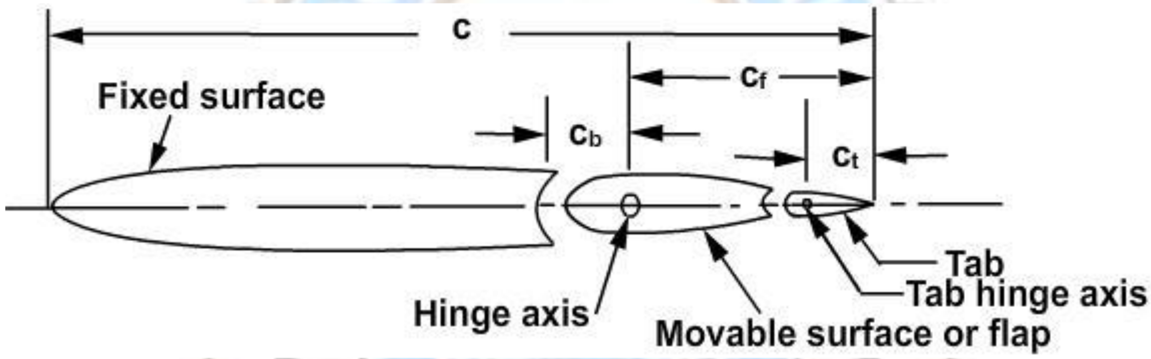
3. Internal balance.

Set back hinge or over hang balance

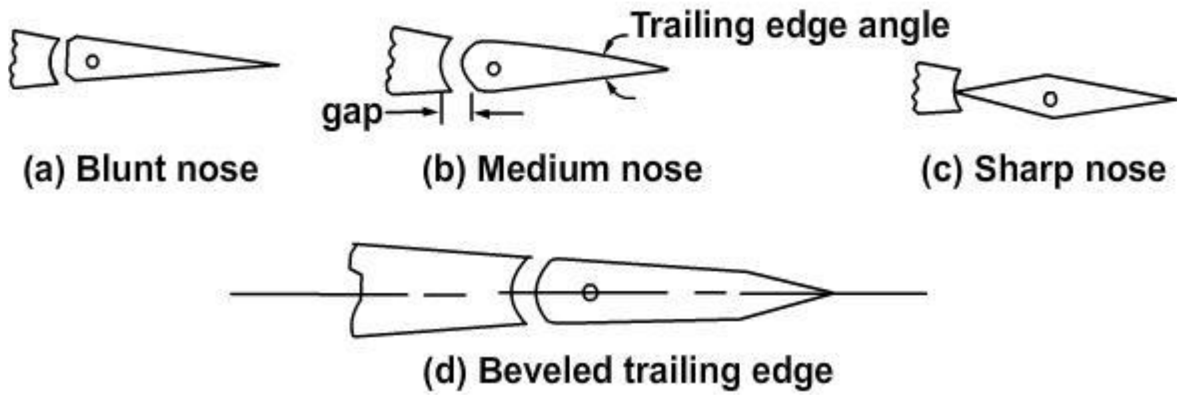
In this case, the hinge line is shifted behind the leading edge of the control (see upper part of Fig.6.6). As the hinge line shifts, the area of the control surface ahead of the hinge line increases and from the pressure distribution in Fig.3.3 it is evident that $|C_{h\alpha t}|$ and $|C_{h\delta e}|$ would decrease. The overhang is characterized by C_b / C_f .Figure 6.6 also shows typical experimental data on variations of $C_{h\alpha}$ and $C_{h\delta}$ with C_b / C_f. It may be added that the changes in $C_{h\alpha}$ and $C_{h\delta}$ also depend on (a) gap between nose of the control surface and the main surface, (b) nose shape and (c) trailing edge angle (Fig. below).



Effect of setback hinge on $C_{h\alpha}$ and $C_{h\delta}$ – NACA 0015 Airfoil with blunt nose and sealed gap



Parameters of control surface - chord lengths



Parameters of control surface- shapes of nose and trailing edge

Horn balance

In this method of aerodynamic balancing, a part of the control surface near the tip is ahead of the hinge line (Fig below). There are two types of horn balances – shielded and unshielded (Fig a). The following parameter is used to describe the effect of horn balance on $C_{h\alpha}$ and $C_{h\delta}$.

$$\text{Parameter} = \frac{(\text{Area of horn}) \times (\text{mean chord of horn})}{(\text{Area of control}) \times (\text{mean chord of control})}$$

Figure b shows the areas of the horn and control surface. Figure b also shows the changes $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ due to horn as compared to a control surface without horn. Horn balance is sometimes used on horizontal and vertical tails of low speed airplanes (see Fig c).

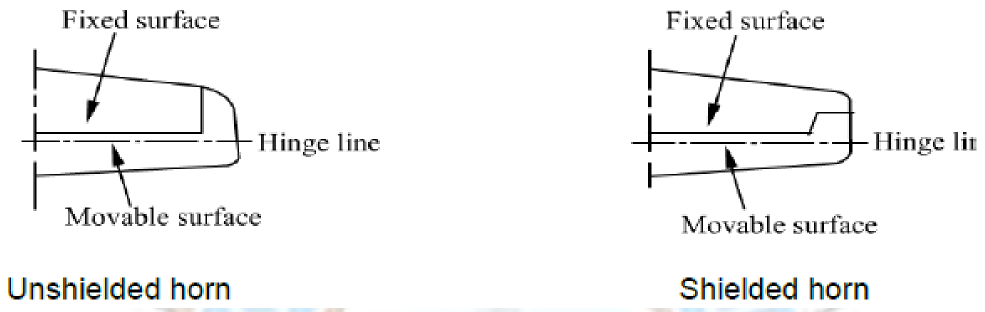


Fig a) Unshielded and shielded horn

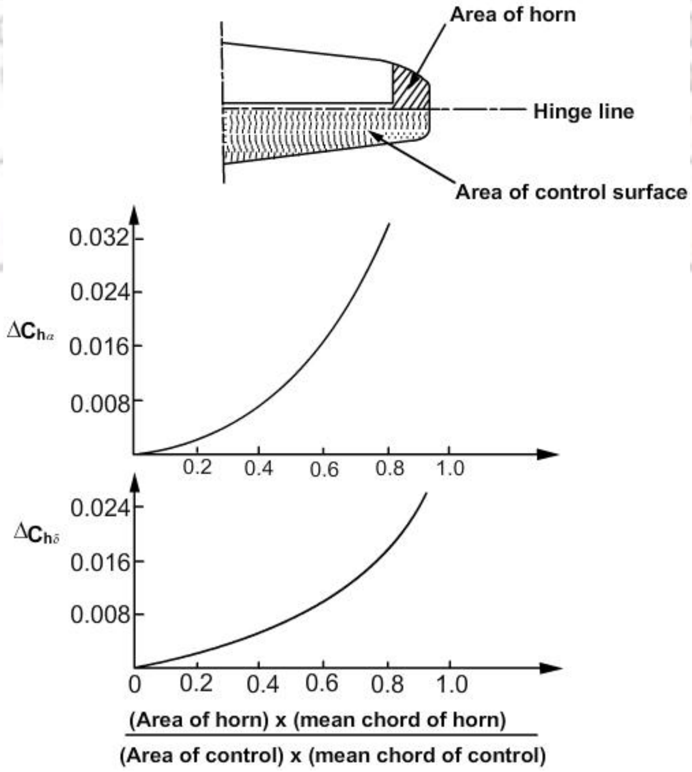


Fig b) Unshielded horn and the changes $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ as compare to control surface without horn

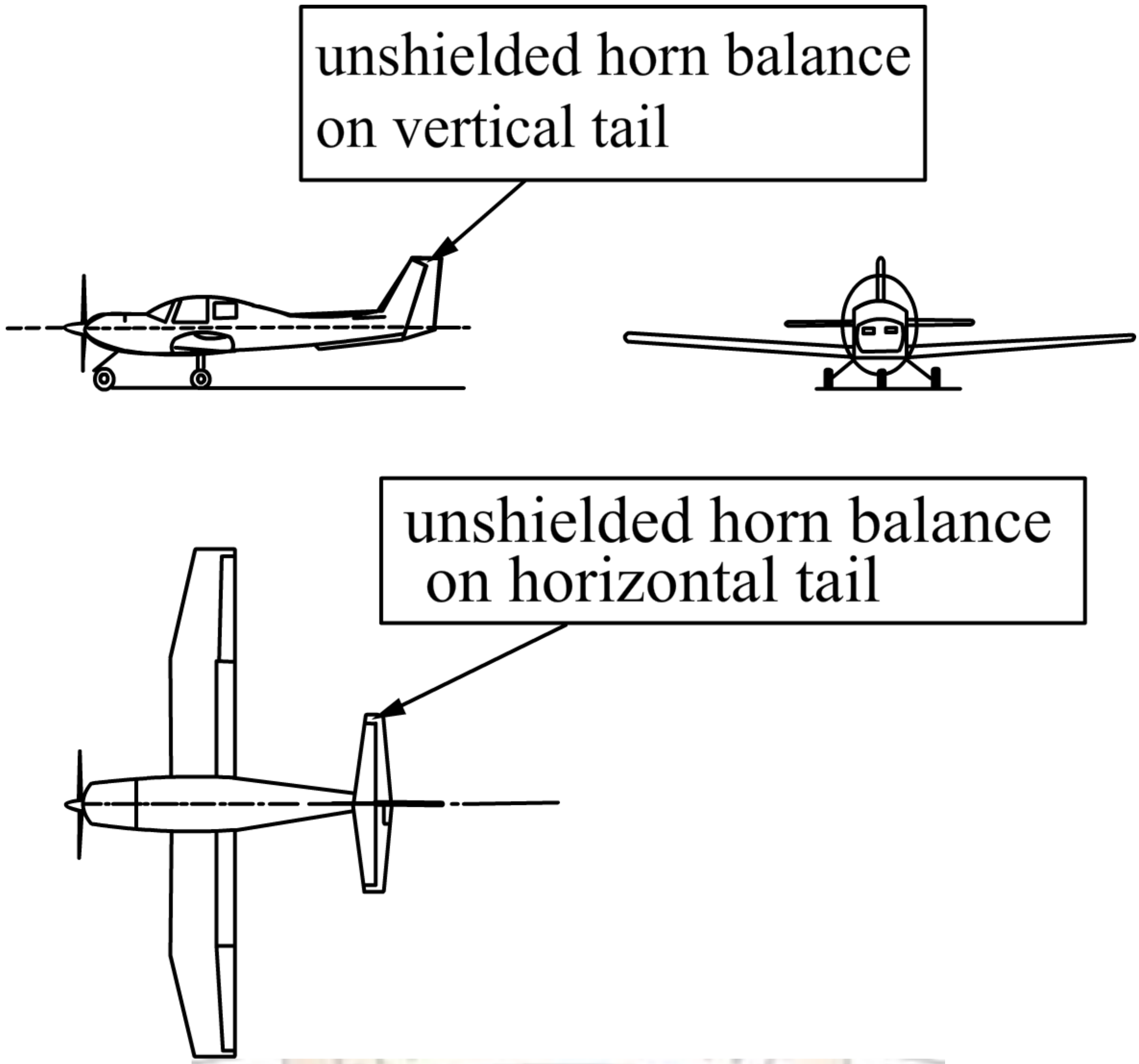


Fig c) Airplane with horn balance on horizontal tail and vertical tail.

Internal balance or internal seal

In this case, the portion of the control surface ahead of the hinge line, projects in the gap between the upper and lower surfaces of the stabilizer. The upper and lower surfaces of the projected portion are vented to the upper and lower surface pressures respectively at a chosen chord wise position (upper part of Fig. below). A seal at the leading edge of the projecting portion ensures that the pressures on the two sides of the projection do not equalize. Figure below also shows the changes $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ due to internal seal balance. This method of aerodynamic balancing is complex but is reliable. It is used on large airplanes to reduce $C_{h\alpha}$ and $C_{h\delta}$.

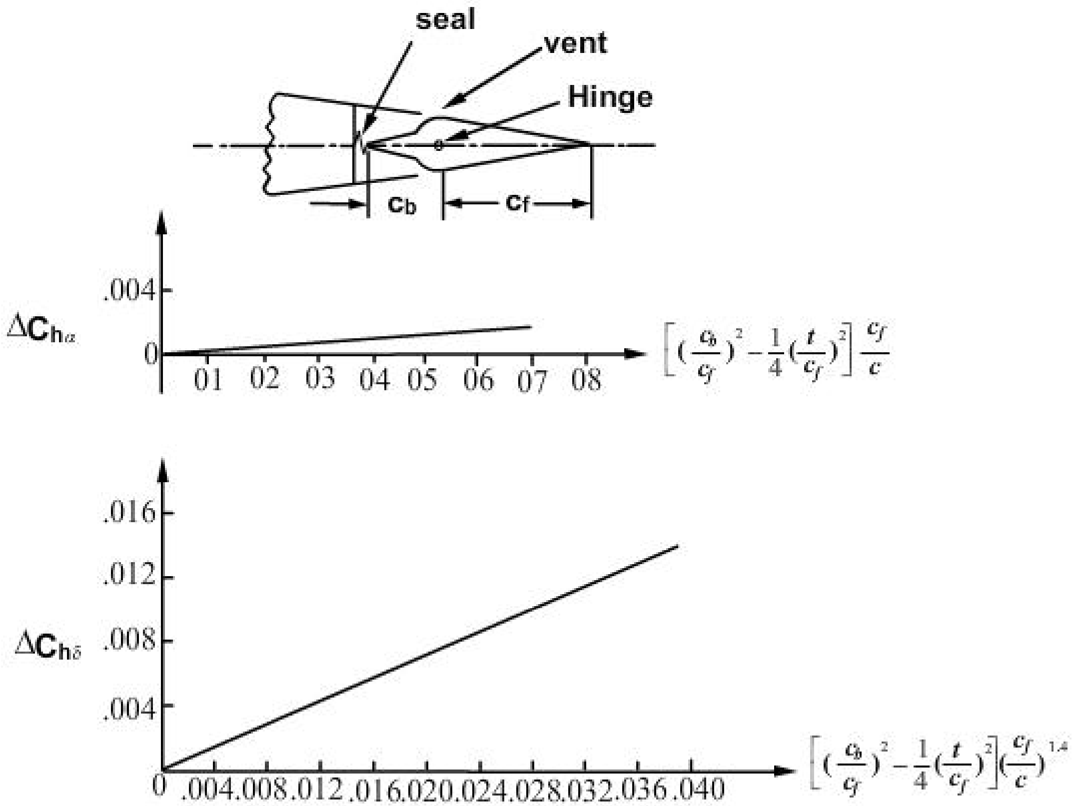
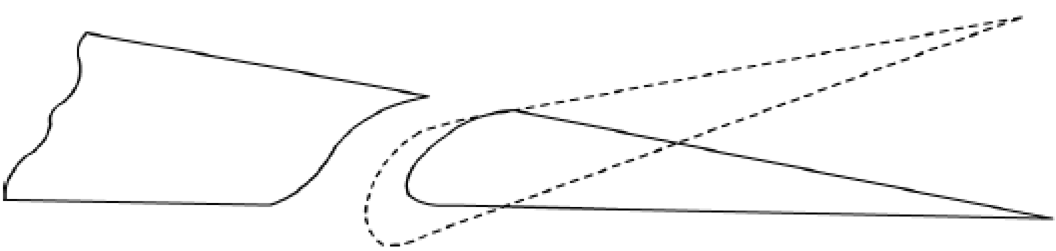


Fig: Internal seal and the changes $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ as compared to control surface with $C_b / C_f = 0$

Frise aileron

The frise aileron is shown in Fig below. The leading edge of the aileron has a specific shape. The downward deflected aileron has negative $C_{h\delta}$ and the upward deflected aileron has positive $C_{h\delta}$. This reduces the net control force. Further, owing to the special shape of the leading edge, the upward deflected aileron projects into the flow field and increases the drag. This reduces adverse yaw.



Frise aileron

Tabs – introductory remark

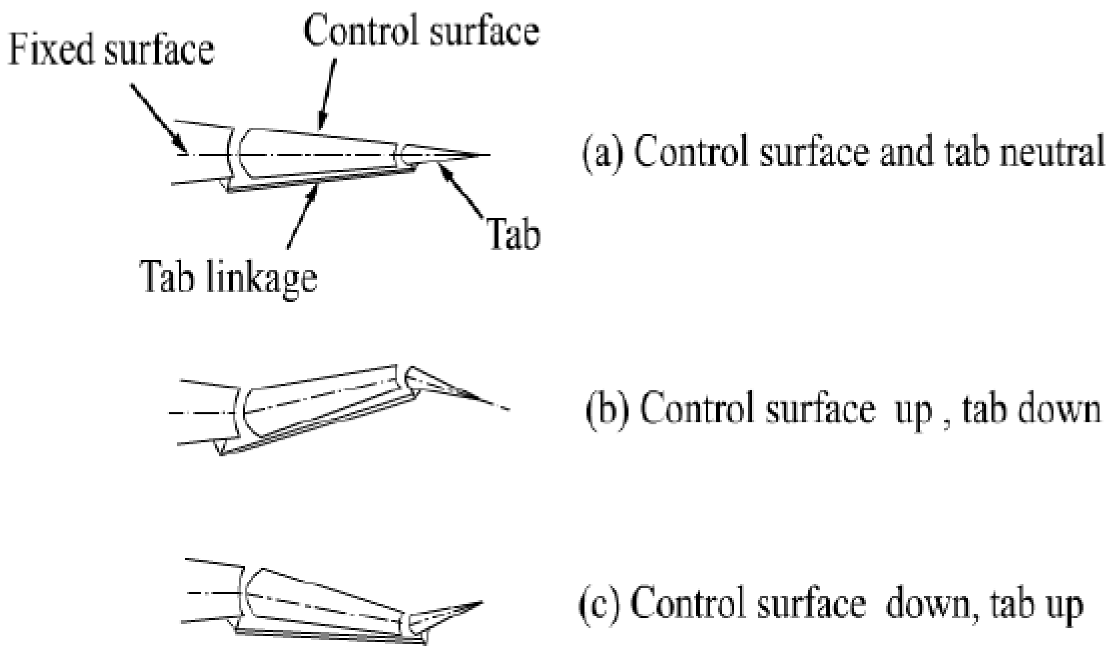
The methods of aerodynamic balancing described earlier are sensitive to fabrication defects and surface curvature. Hence, tabs are used for finer adjustment to make the hinge moment zero. Tabs are also used for other purposes. A brief description of different types of tabs is given in the following subsections.

Trim tab

It is used to trim the stick or bring C_h to zero by tab deflection. After the desired elevator deflection (δe) is achieved, the tab is deflected in a direction opposite to that of the elevator so that the hinge moment becomes zero. Since the tab is located far from the hinge line, a small amount of tab deflection is adequate to bring C_{he} to zero. As the lift due to the tab is in a direction opposite to that of the elevator, a slight adjustment in elevator deflection would be needed after application of tab. Though the pilot subsequently does not have to hold the stick all the time, the initial effort to move the control is not reduced when this tab is used.

Link balance Tab

In this case the tab is linked to the main control surface. As the main surface moves up the tab deflects in the opposite direction in a certain proportion (Fig. below). This way the tab reduces the hinge moment and hence it is called „Balance tab‟.



Link balance tab

Servo tab

In this case the pilot does not move the main surface which is free to rotate about the hinge. Instead the pilot moves only the tab as a result of which the pressure distribution is altered on the main control surface and it attains a floating angle such that Ch is zero .The action of the tab is like a servo action and hence it is called “Servo tab”. This type of tab is used on the control surfaces of large airplanes.

Mass balancing of control

This ensures that the c.g. of the control surface lies ahead or on the hinge line.

All movable tail

In some military and large civil airplanes the entire horizontal tail is hinged and rotated to obtain larger longitudinal control.

Elevons

In a tailless configuration (e.g. Concorde airplane) the functions of the elevator and the aileron are combined in control surfaces called elevons. Like ailerons they are located near the wing tip but the movable surfaces on the two wing halves can move in the same direction or in different directions. When they move in the same direction, they provide pitch control and when they move in different directions they provide control in roll.

V– Tail

In some older airplanes the functions of horizontal and vertical tails were combined in a V-shaped tail. Though the area of the V-tail is less than the sum of the areas of the horizontal and vertical tail, it leads to undesirable coupling of lateral and longitudinal motions and is seldom used.

Configuration with two vertical tails

At supersonic speeds the slope of the lift curve ($dC_L/d\alpha$) is proportional to $1/(M_\infty^2-1)^{1/2}$, where M_∞ is the free stream Mach number. Thus, $C_{L\alpha}$ and in turn the tail effectiveness decreases significantly at high Mach numbers. Hence some military airplanes have two moderate sized vertical tails instead of one large tail. For example see MiG-29M (Fig below).

Airplane with two vertical tails MIG-29M

Empty Weight:

Means the measured or computed weight of an aircraft, excluding the weight of all removable equipment and other items of disposable load, but including the weight of all items of fixed operating equipment or other equipment which are mandatory for all operations like fixed ballast, engine coolant, hydraulic fluid and fuel and oil quantities (both trapped and unusable) in the aircraft and engine system.

Limits of Centre of Gravity:

Means the most forward and most rearward Centre of Gravity position within which an aircraft may be operated safely. These limits are specified in Certificate of Airworthiness/Flight Manual of an aircraft.

Maximum Take-off Weight:

Means the maximum weight, according to its Certificate of Airworthiness or Flight Manual, at which an aircraft is permitted to take-off.

Removable Equipment:

Means items of equipment which are carried on some of or on all flights, but which are not included in Empty weight and which are not mandatory for the type of operation being conducted.

INITIAL WEIGHMENT:

Every aircraft shall be weighed before the issue of Certificate of Airworthiness. In case a new aircraft is imported from outside the country, weight schedules issued by the manufacturer or the previous operator weight schedule based on the manufacturer's certificated weight and balance documents would be acceptable.

Requirements for Reweighing of an Aircraft of Maximum Take-off weight (MTOW) less than 2000 kg.

Aircraft weighing less than 2000 kg need not be reweighed on routine basis, unless it is required to be reweighed in accordance with CAR.

Requirements for Reweighing Aircraft of Maximum Take-off weight (MTOW) more than 2000 kg.

Aircraft weighing more than 2000 kg. shall be re-weighed every five years unless it is required to be re-weighed in accordance with the CAR. However operators may approach Regional Airworthiness Offices (through the Sub-Regional Airworthiness Offices, as applicable) for an adhoc extension of the weighment period of an aircraft by a maximum of 3 months to tide over the operational exigencies. Such requests for extension may be agreed upon by Regional Airworthiness Office, if satisfied with the reasons advanced by the operator for his request. Extension of weighment beyond 3 months may be granted by Director of Airworthiness of the concerned region under intimation to Headquarters promptly.

Requirements for Reweighing after major Repair/ Alterations:

An aircraft shall be required to be reweighed if it has undergone major repair or major alteration or there has been major change in the interior arrangement of pilot/pax/cargo compartments which affect already determined weight and balance data and which cannot be accurately computed without fresh weighment. Decision of the DGCA whether the aircraft requires reweighing after major repair/ alteration, or change in interior arrangement, shall be final.

- The renewal of the Certificate of Airworthiness of an aircraft shall be subjected to following of the requirements of CAR.
- Director General of Civil Aviation may require the reweighment of an aircraft at any time if he considers it necessary.

FORM OF WEIGHT SCHEDULE:

After the aircraft has been weighed as required, the following persons shall prepare the weight Schedule.

(i) A person specifically approved by DGCA for the purpose in any organization.

OR

(ii) A person specifically approved by Quality Manager in an organization approved under CAR 145 provided procedure for grant of such approval is documented in Maintenance Organization Exposition.

OR

(iii) A Category "B" licensed AME as reflected in item no XIV (a) Annexure to the CAR-66 licence (privileges inherited from the AME licence held prior to CAR-66 licence).

The Weight Schedule shall contain at least the following information :-

(i) Type of Aircraft.

(ii) Registration marking and Serial No. of aircraft.

(iii) Empty weight including weight of unusable quantity of fuel and oil (kg.).

(iv) Item wise Weight and details of removable equipment (kg.) (Including wireless equipment).

(v) Maximum fuel capacity (Usable) in liters and kg.

(vi) Maximum oil capacity (Usable) in liters and kg.

(vii) Maximum commercial weight with fuel and oil tanks full.

(viii) MTOW (as per Certificate of Airworthiness/ Flight Manual) (kg.).

(xi) Empty weight Centre of Gravity.

(xii) Centre of Gravity Range and datum.

(xiii) Maximum number of passengers.

(xiv) Signature of appropriately licensed AME/ Approved person.

(xv) Date of weighment.

APPROVAL BY AIRWORTHINESS OFFICE:

The Regional/Sub-regional Airworthiness office shall be intimated in advance about the weighing of the aircraft that may associate with the weighing process. The weighing of the aircraft shall be done in supervision of the Quality Manager or his representative, who shall be responsible for following the documented procedures of weighment. The duly signed weight schedule shall be submitted to Regional /Sub-Regional Airworthiness Office along with the computation details and weighment printout if available. After scrutiny the weight schedule shall be approved by Regional Airworthiness Office.

AIRCRAFT WEIGHING PROCEDURE

Before beginning a study of aircraft weighing procedure or attempting the actual weighing of an aircraft, it is necessary to become familiar with the weight and balance information in the applicable Aircraft Specification or Type Certificate Data Sheet.

The specification for Taylorcraft, model BC and BCS airplanes, illustrated in figure 3-6 has been reproduced in its entirety. A few of the items need explaining; the rest are self-explanatory.

The designation 2 PCLM is read "2 place, closed land monoplane" and indicates that the airplane seats two persons, has an enclosed cockpit, can be operated from the solid part of the earth's surface, and has only one wing. Two PCSM indicates that the airplane is a "2 place, closed sea monoplane." It should be noted that the CG range, EWCG range, and the maximum weight are different for the landplane and the seaplane. The location of the seats indicates a side-byside arrangement. The datum and the leveling means are shown in the portion of the specification that is pertinent to all models. Since the datum and the leveling means are directly connected to weight and balance, they would be among the first items referred to in planning the weighing operation.

A typical aircraft specification.

Although the location or arrangement of the landing gear, this information is given in the Aircraft Specification or Type Certificate Data Sheets and the maintenance manual. The location of the wheels has important significance, since this can be used as a double check against actual measurements taken at the time of weighing.

Weighing an Aircraft

Weighing an aircraft is a very important and exacting phase of aircraft maintenance and must be carried out with accuracy and good workmanship. Thoughtful preparation saves time and prevents mistakes.

To begin, assemble all the necessary equipment, such as:

1. Scales, hoisting equipment, jacks, and leveling equipment

2. Blocks, chocks, or sandbags for holding the airplane on the scales.

3. Straightedge, spirit level, plumb bobs, chalk line, and a measuring tape.

4. Applicable Aircraft Specifications and weight and balance computation forms.

If possible, aircraft should be weighed in a closed building where there are no air currents to cause incorrect scale readings. An outside weighing is permissible if wind and moisture are negligible.

Prepare Aircraft for Weighing

Drain the fuel system until the quantity indication reads zero, or empty, with the aircraft in a level attitude. If any fuel is left in the tanks, the aircraft will weigh more, and all later calculations for useful load and balance will be affected. Only trapped or unusable fuel (residual fuel) is considered part of the aircraft empty weight. Fuel tank caps should be on the tanks or placed as close as possible to their correct locations, so that the weight distribution will be correct.

In special cases, the aircraft may be weighed with the fuel tanks full, provided a means of determining the exact weight of the fuel is available. Consult the aircraft manufacturer's instructions to determine whether a particular model aircraft should be weighed with full fuel or with the fuel drained.

If possible, drain all engine oil from the oil tanks. The system should be drained with all drain valves open. Under these conditions, the amount of oil remaining in the oil tank, lines, and engine is termed residual oil and is included in the empty weight. If impractical to drain, the oil tanks should be completely filled.

The position of such items as spoilers, slats, flaps, and helicopter rotor systems is an important factor when weighing an aircraft. Always refer to the manufacturer's instructions for the proper position of these items.

Unless otherwise noted in the Aircraft Specifications or manufacturer's instructions, hydraulic reservoirs and systems should be filled; drinking and washing water reservoirs and lavatory tanks should be drained; and constant speed drive oil tanks should be filled.

Inspect the aircraft to see that all items included in the certificated empty weight are installed in the proper location. Remove items that are not regularly carried in flight. Also look in the baggage compartments to make sure they are empty. Replace all inspection plates, oil and fuel tank caps, junction box covers, cowling, doors, emergency exits, and other parts that have been removed. All doors, windows, and sliding canopies should be in their normal flight position.

Remove excessive dirt, oil, grease, and moisture from the aircraft.

Properly calibrate, zero, and use the weighing scales in accordance with the manufacturer's instructions.

Some aircraft are not weighed with the wheels on the scales, but are weighed with the scales placed either at the jacking points or at special weighing points. Regardless of what provisions are made for placing the aircraft on the scales or jacks, be careful to prevent it from falling or rolling off, thereby damaging the aircraft and equipment. When weighing an aircraft with the wheels placed on the scales, release the brakes to reduce the possibility of incorrect readings caused by side loads on the scales.

All aircraft have levelling points or lugs, and care must be taken to level the aircraft, especially along the longitudinal axis.

With light, fixed wing airplanes, the lateral level is not as critical as it is with heavier airplanes. However, a reasonable effort should be made to level the light airplanes around the lateral axis. Accuracy in levelling all aircraft longitudinally cannot be overemphasized.

Measurements

The distance from the datum to the main weighing point centreline, and the distance from the main weighing point centerline to the tail (or nose) weighing point centerline must be known to determine the CG relative to the main weighing point and the datum.

These distances may be calculated using information from the Aircraft Specifications or Type Certificate Data Sheets.

However, it will often be necessary to determine them by actual measurement.

After the aircraft has been placed on the scales (figure 3- 9) and leveled, hang plumb bobs from the datum, the main weighing point, and the tail or nose weighing point so that the points of the plumb bobs touch the floor.

Make a chalk mark on the floor at the points of contact. If desired, a chalk line may be drawn connecting the chalk marks. This will make a clear pattern of the weighing point distances and their relation to the datum. Record the weights indicated on each of the scales and make the necessary measurements while the aircraft is still level.

After all weights and measurements are obtained and recorded, the aircraft may be removed from the scales. Weigh the tare and deduct its weight from the scale reading at each respective weighing point where tare is involved.

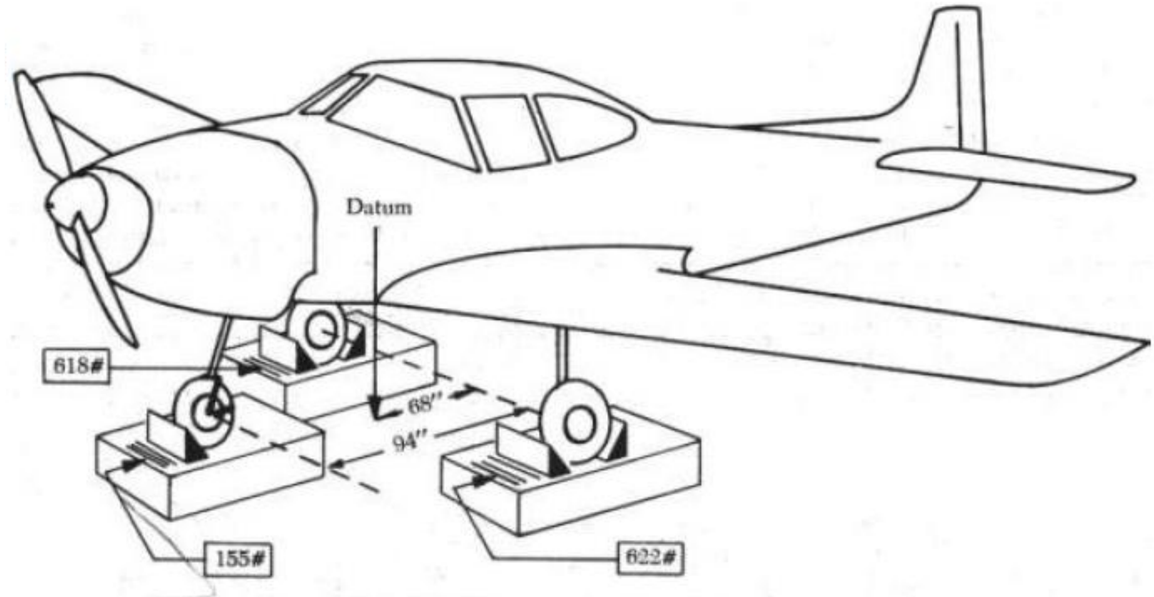


FIGURE 3-9. Weighing an aircraft using platform scales.

Balance Computation

To obtain gross weight and the CG location of the loaded airplane, first determine the empty weight and the EWCG location. When these are known, it is easy to compute the effect of fuel, crew, passengers, cargo, and expendable weight as they are added. This is done by adding all the weights and moments of these additional items and recalculating the CG for the loaded airplane.

Empty Weight

The empty weight of the aircraft is determined by adding the net weight on each weighing point. The net weight is the actual scale reading, less the tare weight.

Weighing scale point	Scale reading (lbs)	Tare (lbs)	Net weight (lbs)
Left main wheel	622.00	-5.00	617.00
Right main wheel	618.00	-4.00	614.00
Nosewheel	155.00	-3.00	152.00
Total			1,383.00

This gives the aircraft weight as weighed.

Empty Weight CG

The CG location is found through the progressive use of two formulas. First calculate the total moments using the following formulas:

Moment = Arm x Weight

Weight point	Net weight (lbs)		Arm (in)		Moment (lb-in)
Left main wheel	617.0	x	68"	=	41,956.0
Right main wheel	614.0	x	68"	=	41,752.0
Nosewheel	152.0	x	-26"	=	-3,952.0
	1,383.0				79,756.0

Then divide the sum of the moments by the total weights involved:

$$CG = \frac{\text{Total moment}}{\text{Total weight}} = \frac{79{,}756.0}{1{,}383} = 57.67 \text{ in}$$

Consequently, the CG, as weighed, is 57.67 in from the datum.
Since the aircraft was weighed with the oil tank full, it is necessary to remove the oil to obtain the empty weight and empty weight CG.
Again using the formula:

$$CG = \frac{\text{Total moment}}{\text{Total weight}} = \frac{81{,}556.0}{1{,}323} = 61.64 \text{ in}$$

The EWCG is located 61.64 in aft of the datum.
The maximum allowable gross weight as shown in the Aircraft Specifications is 1,733 pounds. By subtracting the aircraft empty weight from this figure, the useful load is determined to be 450 pounds.

COMPUTATION OF CENTRE OF GRAVITY:

- For all flights, it shall be the responsibility of the Pilot-in-Command to ensure that the aircraft is satisfactorily loaded with respect to the total load, the distribution of the load and proper securing of the load in aircraft (lashing of the load). The distribution of the load shall be such that the C.G. position will remain within the specified limits at the time of take off, during the progress of the flight and at the time of landing.

- In the case of scheduled operator, the responsibility for loading, lashing and computing C.G. position, for take-off and landing phases of flight as stated in the previous paragraph may be delegated to a person nominated by the operator, who is specifically trained and authorised (by the operator) for the purpose. However, Centre of Gravity position computed by the nominated person shall be signed and dated by him and the same shall be submitted to the Pilot-in-Command of the aircraft for his scrutiny and acceptance; the acceptance would be denoted by the pilot by affixing the dated signature.
- In case a method other than the "direct calculating method" for the purpose of computing C.G. is employed, the same shall be submitted to the Regional Airworthiness Office for approval before adoption.
- Every operator including scheduled, non-scheduled, State Government and private aircraft operator shall prepare load and trim sheet for aircraft where the manufacturer has provided necessary documentation for the purpose. The load and trim sheet shall indicate the composition and the distribution of the total load carried on board the aircraft as well as the calculated C.G. position for "take-off and landing" configurations before the commencement of the flight. Such load sheets shall be prepared and signed by the Pilot-in-Command or persons duly trained in accordance with CAR Section 8 Series 'D' Part I and responsible for supervising the loading of aircraft. In case the load and trim sheet is prepared by a person other than the Pilot-in-Command, the same shall be submitted to the Pilot for his scrutiny and signatures before the commencement of the flight. One copy of the load sheet shall be carried on board the aircraft and one copy shall be retained by the operator for record purposes for a period of altleast four months from the date of issue.

STANDARD WEIGHT OF FLIGHT CREW/ PASSENGERS:
For preparation of load sheet and calculation of Centre of Gravity as mentioned in para above, the minimum standard weight (including handbag) as given below, shall be applied in all civil registered aircraft:

1.	Crew	85 (75+10) kg.
2.	Adult passenger (both Male & Female)	75 kg.
3.	Child (Between 2 years and 12 years age)	35 kg.
4.	Infant (Less than two years)	10 kg.

Notwithstanding para 10.1, the actual weight of the passenger could be considered for aircraft MTOW upto 2000 kg provided the arrangement for passenger weighment with sufficient accuracy is ensured.

CALIBRATION OF WEIGHING SCALES:
The weighing scales used for the purpose of weighment of passenger baggage, goods etc. shall be calibrated at specified intervals to the satisfaction of the Quality Manager/ DGCA. The Quality Manager is required to bring this requirement to the notice of the concerned persons for compliance.

The weighing scales used for the purpose of weighment of aircraft shall be calibrated at specified intervals. This requirement may be reflected in the Maintenance Organisation Exposition.

INSTRUCTIONS FOR SAFE LOADING:

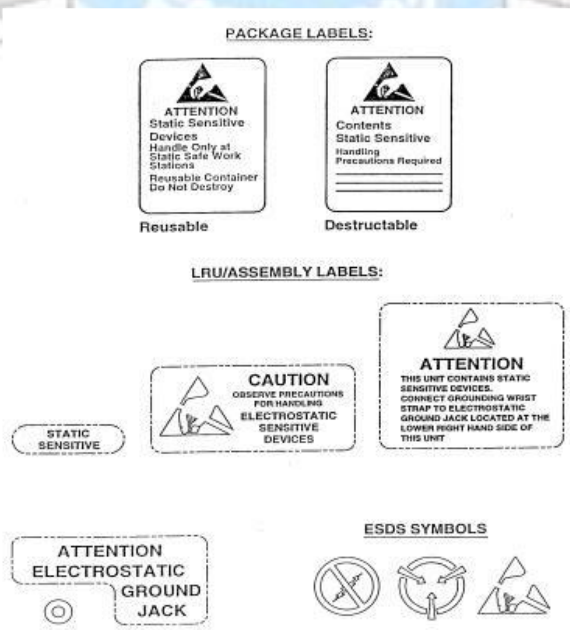
1 Specific seat shall be allotted to all passengers boarding at originating stations of flights so that centre of gravity of the aircraft can be calculated accurately and the C.G. is kept within the permissible limits.
2 During loading, it must be ensured that aircraft cabin floor loading limitations are not exceeded.
3 The load must be securely tied so that there is no possibility of the load shifting in flight and disturbing the calculated C.G. position.
4 The load must be tied at the specified places provided in the aircraft and the tying ropes must be of sufficient strength to withstand the loads imposed on it in flight.
5 While placing cargo in the passenger cabin during mixed version (passenger cum freight) operation, the load must be placed ahead of the passengers in the cabin, the load must not block "emergency exit" meant to be used by the passengers during “emergencies ".

Observance of Safety Instructions:

The safety instructions required to be observed, as detailed in para above, shall be observed by Pilot-in-Command of non-scheduled operators, aerial work aircraft operators including flying clubs and private aircraft operators.
In the case of scheduled operators, a comprehensive manual (Weight and Balance Manual) shall be prepared describing the safety requirements of para above for compliance by the concerned staff.

ELECTROSTATIC SENSITIVE DEVICES:

Some of the electronic components/semiconductor devices installed on modern aircraft are highly sensitive and prone to damages due to discharge of static electricity. These extremely sensitive components/devices are called as ELECTROSTATIC DISCHARGE SENSITIVE (ESDS) DEVICES. Affixing special label on them identifies such devices.
Different types of labels used for this purpose are shown below



The human body, all work surfaces, floors, personnel clothing, packaging materials are prime generators of electrostatic voltages.
A person walking on aircraft carpet, removing his shirt, rubbing his hair accumulates electrostatic charge of over 1000 volts. If such a person touches an ESDS, the device gets damaged due to static discharge. Most people cannot feel an electrostatic discharge below 3000 volts. A visible spark occurs normally above 12000 volts.
Therefore, the person may become charged during normal work and damage an ESDS even without realizing it
A list of sources of electrostatic charge and the charge developed thereof is tabulated below.

TYPICAL ELECTROSTATIC VOLTAGES

MEANS OF STATIC GENERATION	RELATIVE HUMIDITY LOW 10-20%	RELATIVE HUMIDITY HIGH -65-90%
Walking across carpet	35,000V	1,500V
Walking over vinyl floor	12,000V	2,500V
Worker at bench	6,000v	100V
Vinyl envelopes for work instructions	7,000v	600V
Poly bag picked up from bench	20,000V	1,200V
Work chair padded with urethane foam	18,000V	1,500V
16-lead"Dips'in plastic box	12,000V	3,500V

The primary objective of all electrostatic prevention method is to prevent static charge accumulation.
This Advisory Circular aims in dealing with the general precautions to be taken by personnel while handling ESDS equipment and procedure to be adopted for repair, storage of such devices. In addition, it is essential that precautions issued by the individual vendors for each component should be meticulously followed.

Precautions to be taken while installing/removing ESDS devices:

(i) Electrical power sources must be removed.
(ii) Wear a wrist strap around the bare wrist that in turn is connected to ground by means of a wire and plug.
(iii) If an ESDS sub-assembly is removed from the aircraft, its connecting pins/leads must be shorted together by means of wires, shorting clips, metal foil or conductive foam. Printed circuit board connections must also be shorted as above to keep all components at the same voltage potential.
(iv) Top level assemblies or equipment that is fully assembled with all covers are not normally considered electrostatic sensitive. However, connectors of such ESDS units should be properly blanked with antistatic blanks, packed in protective antistatic packing material (pink poly) and transported as per para 3.

The blanking, packing and containers of serviceable ESDS equipment/Line replaceable units (LRUs) should be used for unserviceable components removed from aircraft.

Precautions to be taken while transporting ESDS:

The unit should be placed in a special container to protect from static electricity, after taking precautions as given in para 2(iii) and (iv). A semi-conductive bag is often used for this purpose.

Precautions to be taken in the shop:

(i) The working environment in the shop should be conducive to prevent discharge of static electricity. The air in the shop should be dry and have a relative humidity of 40% to 60%. (Dry air will not discharge the static electricity as quickly as moist air). In special circumstances an air-ioniser blower which continuously blows air containing positive and negative ions onto the work surface and onto the hands of the person working may be used.
(ii) The work surface of the bench should be covered with a conductive mats/dissipative surface, which should be secured to the bench so as to prevent it from moving.
(iii) The floor area in front of the working bench should also have conductive mat similar to the working bench. This mat should be electrically bonded to the work surface by means of a bonding strap. The bonding strap should have a resistance of 2000-4000 ohms per linear foot and should be as short as possible.
(iv) The working personnel must wear bonding strap on the wrist as given in para 2(ii). The strap should be connected to the workbench. The strap should have a resistance of 200k ohms to 1 M ohms.
(v) The work surface should be connected to a suitable ground
Note: Under no circumstances the work surface of a static free workstation be connected to the electrical power supply ground circuit of the building.
(vi) When air ioniser blower is used, allow the blower to blow air for about 2-3 minutes before starting the work. The person should also move his hand into the ionised air stream for a few seconds, to allow for charge dissipation, before handling ESDS devices.
(vii) Electric soldering iron in use should be grounded at the tip.
(viii) The connector leads or edge of PCB's containing ESDS devices should not be touched.
(ix) Ensure that the body is grounded.
(x) All testing of equipment with ESDS devices should strictly be in accordance with manufacturer's instructions.
(xi) Hand tools with painted wooden or plastic handles should not be used in a static controlled work area in case the operator does not use ground wrist strap.
(xii) Tools with highly static generative handle should be avoided and should be checked for static generation with an Electro-static detecting meter before use.
(xiii) Manuals and Technical documents should not be carried into a static control workstation in plain plastic envelope. This can be carried in cardboard binder or stiff paper.

Precautions to be taken during storage:

(i) Electro static devices must never be stored alongside non-electrostatic devices.
(ii) ESDS components must be packed in conductive material, which will ensure that the entire package is maintained at the same potential.
(iii) A conductive mat should be provided on the metal racks for storing ESDS devices.
(iv) The metal racks/cupboards should be grounded.

(v) All packages containing components coming into the bonded stores should be checked for the presence of ESDS by reference to external markings and reference numbers. Any package containing ESDS but not properly marked should be labelled accordingly and should be handled and stored as mentioned above.

General:

(i) Personnel working on ESDS should avoid wearing dress made of nylon or synthetic fabric.
(ii) Ensure that the body is grounded before commencing any work on the ESDS.
(iii) Proper safety techniques as recommended by the vendors should be strictly followed while testing the units with ESDS devices under power.
(iv) The effectiveness of an electrostatic free workstation should be periodically checked using electrostatic detecting meter. This meter can detect the polarity and level of static electricity ranging from 30 to 50,000 volts at distances of 6.5 to 30 cm.
(v) Periodic checking of work bench the ground connection, cords, limiting resistors, work mats to be carried out preferably once in six months.
(vi) Wrist strap integrity may be measured with wrist strap tester or standard ohmmeter, which should be between 2,50,000 ohms to 1.5 meg. Ohms.
(vii) For conductive work surface the measured value should be less than 1000 meg. Ohms.
(viii) For conductive floor and anti static work surface, the measured value should be less than one teraohms.
(ix) Operator using ESDS equipment should intimate officials of customs department for proper handling.
(x) Following word should be displayed in the workstation in capital letters:

The advent of digital electronic technology in electrical/electronic systems has enabled unprecedented expansion of aircraft system functionality and evolution of aircraft function automation. As a result, systems incorporating such technology are used more and more to implement aircraft functions, including Level A systems that affect the safe operation of the aircraft; however, such capability does not come free. The EME (electromagnetic environment) is a form of energy, which is the same type of energy (electrical) that is used by electrical/electronic equipment to process and transfer information. As such, this environment represents a fundamental threat to the proper operation of systems that depend on such equipment. It is a common mode threat that can defeat fault-tolerant strategies reliant upon redundant electrical/electronic systems.
Electrical/electronic systems, characterized as Level A, provide functions that can affect the safe operation of an aircraft and depend upon information (i.e., guidance, control, etc.) processed by electronic equipment. Thus, the EME threat to such systems may translate to a threat to the airplane itself. The computers associated with modern aircraft guidance and control systems are susceptible to upset from lightning and sources that radiate RF at frequencies predominantly between 1 and 500 MHz and produce aircraft internal field strengths of 5 to 200 V/m or greater. Internal field strengths greater than 200 V/m are usually periodic pulses with pulse widths less than 10μs. Internal lightning-induced voltages and currents can range from approximately 50 V and 20 A to over 3000 V and 5000 A.
Electrical/electronic system susceptibility to such an environment has been suspect as the cause of “nuisance disconnects,” “hardovers,” and “upsets.” Generally, this form of system upset occurs at significantly lower levels of EM field strength than that which could cause component failure, leaves no trace, and is usually no repeatable.

EME Energy Susceptibility

It is clear that the sources of electromagnetic (EM) threats to the electrical/electronic system, either digital or analog, are numerous. Although both respond to the same threats, there are factors that can make the threat response to a momentary transient (especially intense transients like those that can be produced by lightning) far more serious in digital processing systems than in analog systems. For example, the information bandwidth and, therefore, the upper noise response cut-off frequency in analog devices is limited to, at most, a few megahertz. In digital systems it is often in excess of 100 MHz and continues to increase.

This bandwidth difference, which is at least 10 times more severe in digital systems, allows substantially more energy and types of energy to be coupled into the digital system. Moreover, the bandwidths of analog circuits associated with autopilot and flight management systems are on the order of 50 Hz for servo loops and much less for other control loops (less than 1 Hz for outer loops). Thus, if the disturbance is short relative to significant system time constants, even though an analog circuit device possessing a large gain and a broad bandwidth may be momentarily upset by an electromagnetic transient, the circuit will recover to the proper state. It should be recognized that, to operate at high speeds, proper circuit card layout control and application of high-density devices is a must. When appropriate design tools (signal integrity, etc.) are applied, effective antenna loop areas of circuit card tracks become extremely small, and the interfaces to a circuit card track (transmission line) are matched. Older (1970s–1980s) technology with wirewrap backplanes and processors built with discrete logic devices spread over several circuit cards were orders of magnitude more susceptible. Unlike analog circuits, digital circuits and corresponding computational units, once upset, may not recover to the proper state and may require external intervention to resume normal operation. It should be recognized that (for a variety of reasons) large-gain bandwidth devices are and have been used in the digital computing platforms of aircraft systems. A typical discrete transistor can be upset with 10^{-5}J, 2000 V at 0.1 mA for 50µs. A typical integrated circuit can be upset with only 10^{-9}J, 20 V at 1µA for 50µs. As time goes on and processor semiconductor junction feature sizes get smaller and smaller, this problem becomes worse.

It should be noted that in addition to upset, lightning-induced transients appearing at equipment interfaces can, because of the energy they possess, produce hard faults (i.e., damage circuit components) in interface circuits of either analog or digital equipment. Mechanical, electromechanical, electro hydraulic, etc. elements associated with conventional (not electronic primary flight controls with associate “smart” actuators) servo loops and control surface movement are either inherently immune or vastly more robust to EME energy effects than the electronic components in an electrical/electronic system.

Immunity of electronic components to damage is a consideration that occurs as part of the circuit design process. The circuit characteristic (immunity to damage) is influenced by a variety of factors:

1. Circuit impedances (resistance, inductance, capacitance), which may be distributed as well as lumped;
2. The impedances around system component interconnecting loops along with the characteristic (surge) impedance of wiring interfacing with circuit components;
3. Properties of the materials used in the construction of a component (e.g., thick-film/thin-film resistors);
4. Threat level (open circuit voltage/short circuit current), resulting in a corresponding stress on insulation, integrated circuit leads, PC board trace spacing, etc.; and
5. Semiconductor device nonlinearities (e.g., forward biased junctions, channel impedance, junction/ gate breakdown).

Immunity to upset for analog processors is achieved through circuit design measures, and for digital processors it is achieved through architectural as well as circuit design measures.

Civil Airworthiness Authority Concerns

The Federal Aviation Administration (FAA) and European Joint Aviation Authorities (more commonly known as JAA) have identified the lightning and High Intensity Radiated Field (HIRF) elements of the EME as a safety issue for aircraft functions provided by electrical/electronic systems.

The following factors, identified by the FAA and JAA, have led to this concern about lightning and

HIRF effects:

• Increased reliance on electrical and electronic systems to perform functions that may be necessary for the continued safe flight and landing of the aircraft.

• Reduction of the operating power level of electronic devices that may be used in electrical and electronic systems, which may cause circuits to be more reactive to induced lightning and RF voltages and currents leading to malfunction or failure.

• Increased percentage of composite materials in aircraft construction. Because of their decreased conductivity, composite materials may result in less inherent shielding by the aircraft structure.

• Since current flowing in the lightning channel will be forced (during lightning attachment) into and through the aircraft structure without attenuation, decreased conductivity for aircraft structure materials can be particularly troubling for lightning.

The direct effects of lightning (dielectric puncture, blasting, melting, fuel ignition, etc.) have been recognized as flight hazards for decades, and in 1972 the SAE formed the AE4 Special Task F (which later became AE4L) to address this issue. In the early 1980s, the FAA began developing policy relative to the effects of lightning on electrical/electronic systems (indirect effects) and AE4L supported the FAA and JAA by providing the technical basis for international standards (rules/regulations) and guidance material that, for aircraft type certification, would provide acceptable means for demonstrating compliance to those rules/regulations. AE4L also supported RTCA Special Committee 135 (SC-135) to integrate lightning environment conditions and test procedures into airborne equipment standards (DO-160) and the EUROCAE standards counterpart (ED-14). In 1987, EUROCAE formed Working Group 31 to be the European counterpart of AE4L.

In 1986, the FAA and JAA identified High Energy Radio Frequency (HERF) electromagnetic fields as an issue for aircraft electrical/electronic systems. Sometime later the term HERF was changed to its present designation, which is High Intensity Radiated Field (HIRF). Subsequent to the FAA identifying HIRF as a safety issue, SAE and EUROCAE formed Committee AE4R and Working Group 33, respectively, to support the FAA and JAA in much the same way as was the case with AE4L and lightning. In addition, unlike the case for lightning, RTCA SC-135 formed a HIRF working group (the corresponding European group was already part of EUROCAE/WG33) to integrate HIRF requirements into DO-160/ED-14.

In the interim between the absence and existence of a rule for lightning and HIRF, special conditions have been or are issued to applicants for aircraft type certification (TC, STC, ATC). The rationale for the special condition is given in words to the effect:

These series of aircraft will have novel or unusual design features associated with the installation of new technology electrical and electronic systems, which perform critical or essential functions. The applicable airworthiness regulation does not contain adequate or appropriate safety standards for the protection of these systems from the effects of lightning and radio frequency (RF) energy. This notice contains the additional safety standards that the

Administrator considers necessary to ensure that critical and essential functions the new technology electrical and electronic systems perform are maintained when the airplane is exposed to lightning and RF energy.
Presently, the FAA's Federal Aviation Regulations (FARs) have been updated to include the "indirect effects" of lightning, but not HIRF. In the time period between the absence and existence of a rule for HIRF, special conditions for HIRF are being issued to applicants for aircraft certification. However, the FAA has established the Aviation Rule-Making Advisory Committee, which in turn established the Electromagnetic Effects Harmonization Working Group (EEHWG) to develop the rule-making package for HIRF and for amendments to the lightning rules.
Portable electronic devices (PEDs) have not been identified for regulatory action, but in 1992 the FAA requested the RTCA to study the EME produced by PEDs. In response to an FAA request relative to PEDs, RTCA formed Special Committee 177 (SC-177) in 1992. In 1996, SC-177 issued a report titled "Portable Electronic Devices Carried Onboard Aircraft" (DO-233). Currently, control of PEDs and their associated electromagnetic (EM) emissions are handled by integrating some of the RTCA recommendations into airline policy regarding instructions (prohibition of personal cellular phone use, turn-off of PEDs during taxi, take-off, and landing, etc.) given to passengers.

FAA/JAA FAR(s)/JAR(s) require compliance demonstration either explicitly or implicitly for the following
EME elements:
• Lightning
• HIRF (FAA)
• HIRF (JAA)
• EMC
At the aircraft level, the emphasis should be on lightning and HIRF because most of the energy and system hazards arise from these threats. Their interaction with aircraft systems is global and also the most complex, requiring more effort to understand. Intrasystem electromagnetic emissions fall under the broad discipline of EMC. PEDs are a source of EM emissions that fall outside of the categories of equipment normally included in the EMC discipline. Like lightning and HIRF, the interaction of PED emissions with aircraft electrical/electronic systems is complex and could be global.
The electrical and/or electronic systems that perform functions "critical" to flight must be identified by the applicant with the concurrence of the cognizant FAA ACO. This may be accomplished by conducting a functional hazard assessment and, if necessary, preliminary system safety assessments (see SAE ARP 4761). The term "critical" means those functions whose failure would contribute to, or cause, a catastrophic failure condition (loss of aircraft). Table below provides the relationship between function failure effects and development assurance levels associated with those systems that implement functions that can affect safe aircraft operation.

TABLE 25.1 Nomenclature Cross Reference Between AC25.1309 and SAE-ARP 4754

Failure Condition Classification	Development Assurance Level
Catastrophic	Level A
Severe Major/Hazardous	Level B
Major	Level C
Minor	Level D
No Effect	Level E

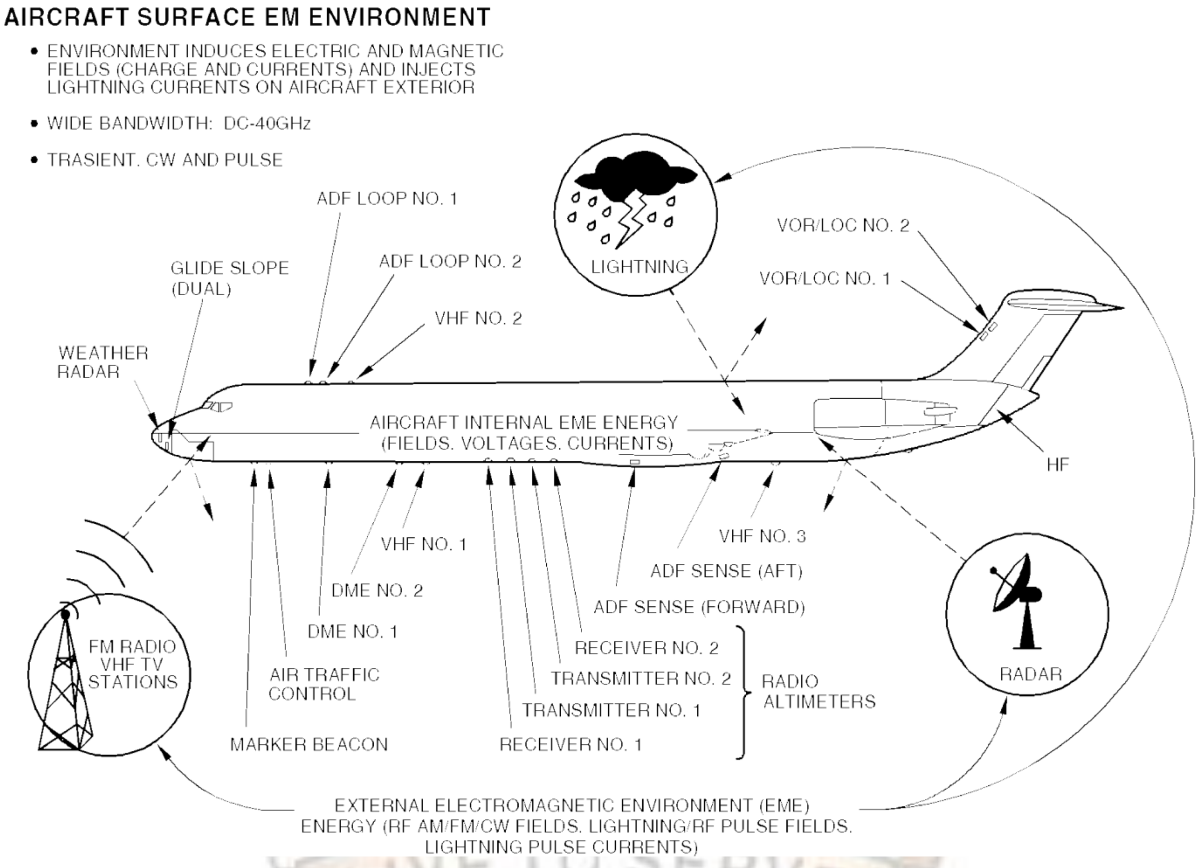
The terms “Level A,” etc. designates particular system development assurance levels. System development assurance levels refer to the rigor and discipline of processes used during system development (design, implementation, verification/certification, production, etc.). It was deemed necessary to focus on the development processes for systems based upon “highly integrated” or “complex” (whose safety cannot be shown solely by test and whose logic is difficult to comprehend without the aid of analytical tools) elements, i.e., primarily digital electronic elements.
Development assurance activities are ingredients of the system development processes. As has been noted, systems and appropriate associated components are assigned “development assurance levels” based on failure condition classifications associated with aircraft-level functions implemented by systems and components.

The rigor and discipline needed in performing the supporting processes will vary, depending on the assigned development assurance level.
There is no development process for aircraft functions. Basically, they should be regarded as intrinsic to the aircraft and are categorized by the role they play for the aircraft (control, navigation, communication, etc.). Relative to safety, they are also categorized (from FAA advisory material) by the effect of their failures, i.e., catastrophic, severe major/hazardous, major, etc.
EMC has been included in FAA regulations since the introduction of radio and electrical/electronic systems into aircraft. Electrical equipment, controls, and wiring must be installed so that operation of any one unit, or system of units, will not adversely affect the simultaneous operation of any other electrical unit or system essential to aircraft safe operation. Cables must be grouped, routed, and spaced so that damage to essential circuits will be minimized if there are faults in heavy current-carrying cables. In showing compliance with aircraft electrical/electronic system safety requirements with respect to radio and electronic equipment and their installations, critical environmental conditions must be considered.
Radio and electronic equipment, controls, and wiring must be installed so that operation of any one component or system of components will not adversely affect the simultaneous operation of any other radio or electronic unit, or system of units, required by aircraft functions.
Relative to safety and electrical/electronic systems, the systems, installations, and equipment whose functioning is required for safe aircraft operation must be designed to ensure that they perform their intended functions under all foreseeable operating conditions. Aircraft systems and associated components considered separately and in relation to other systems, must be designed so that:
• The occurrence of any failure condition that would prevent the continued safe flight and landing of the airplane is extremely improbable.
• The occurrence of any other failure condition that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.

EME Energy Propagation

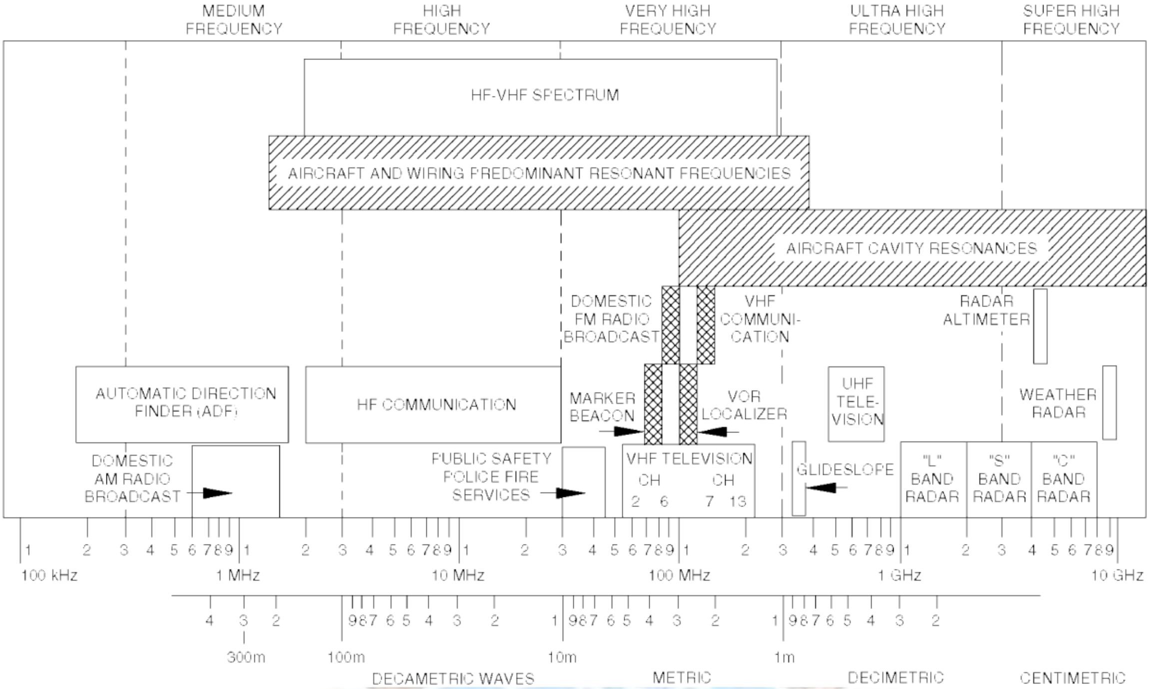
As has been noted in the introductory paragraph and illustrated in Figure below, lightning and HIRF are threats to the overall aircraft. Since they are external EME elements, of the two, lightning produces the most intense environment, particularly by direct attachment.
Both lightning and HIRF interactions produce internal fields. Lightning can also produce substantial voltage drops across the aircraft structure. Such structural voltages provide another mechanism (in addition to internal fields) for energy to propagate into

electrical/electronic systems. Also, the poorer the conductivity of structural materials, the greater the possibility that there are
• Voltage differences across the structure
• Significant lightning diffusion magnetic fields
• Propagation of external environment energy



External EME (HIRF, lightning) interaction.

Figure below gives the HIRF spectrum and associated aircraft/installations features of interest.
In general, the propagation of external EME energy into the aircraft interior and electrical/electronic systems is a result of complex interactions of the EME with the aircraft exterior structures, interior structures, and system installations (see Figures 25.3 through 25.7).

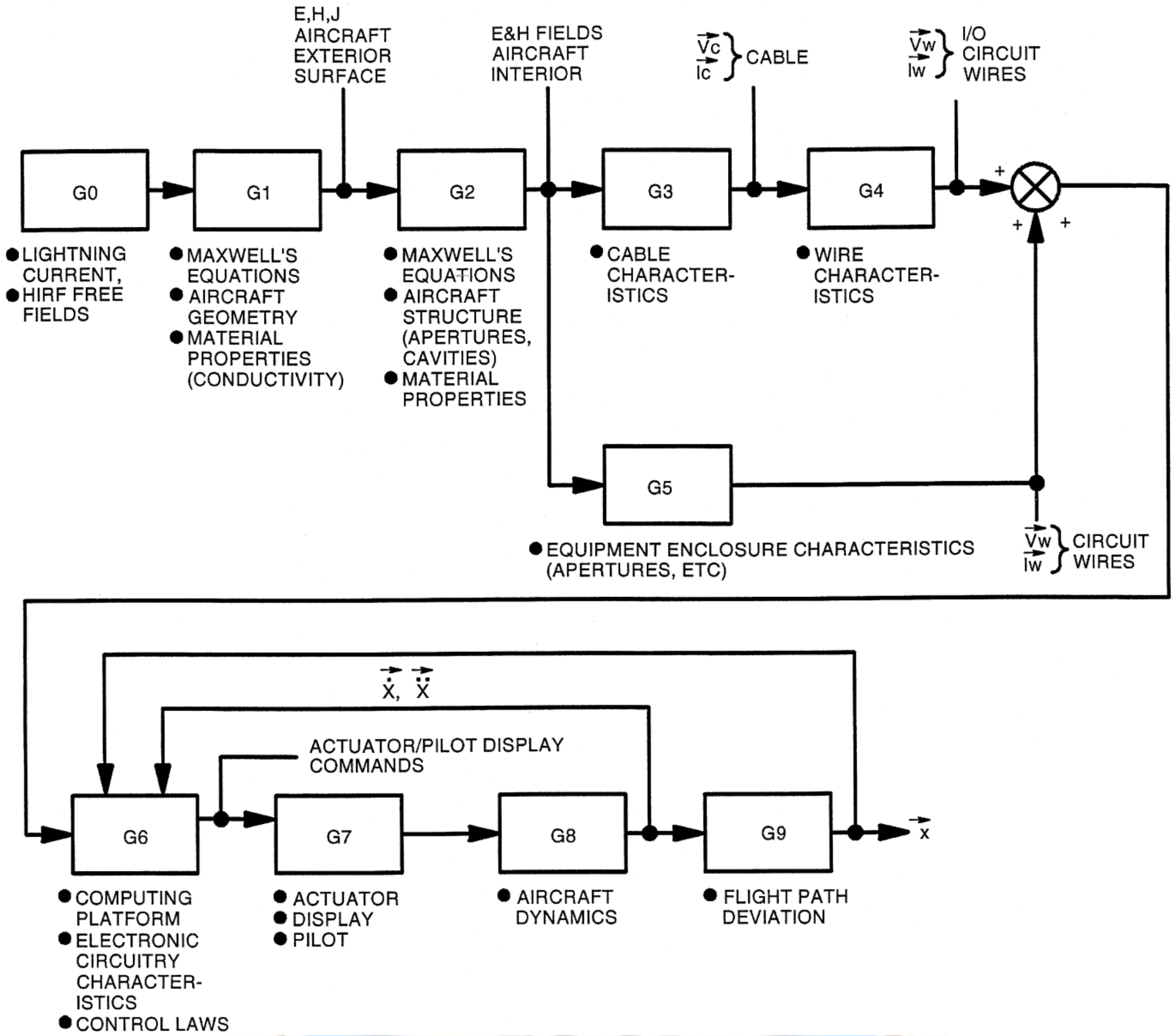


RF spectrum and associated installation dimensions of interest

Figure 25.8 gives representative transfer functions, in the frequency domain, of energy propagation into electrical/electronic systems, and Figure 25.9 provides time domain responses to a lightning pulse resulting from transfer functions having the low-frequency characteristic $V_o(f) = kf[Hi(f)]$ and a high frequency “moding” (resonant) characteristic (e.g., open loop voltage of cabling excited by a magnetic field; see Figure 25.8).

Paths of electromagnetic wave entry from the exterior to the interior equipment regions are sometimes referred to as points of entry. Examples of points of entry may be seams, cable entries, windows, etc.

As noted, points of entry are driven by the local environment, not the incident environment. The internal field levels are dependent on both the details of the point of entry and the internal cavity.



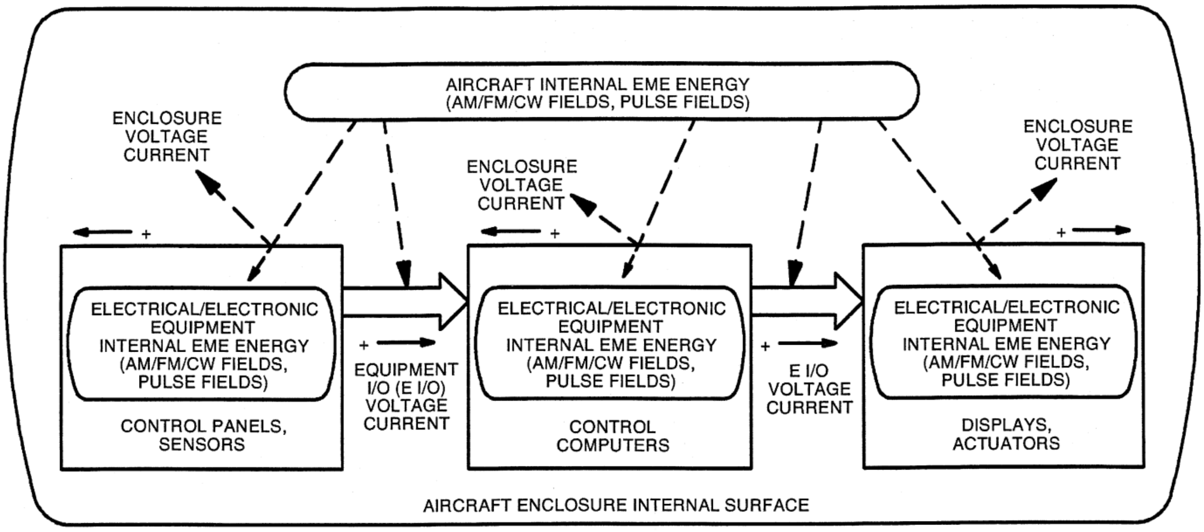
EME propagation process transfer function perspective.

Resulting internal fields can vary over a wide range of intensity, wave shape, and wave impedance. (Below 10 MHz within a metal aircraft, the magnetic fields due to lightning predominate because of the electric field shielding properties of metal skins. For HIRF "high-frequency" bands in some internal regions, internal field levels may exceed the incident field levels.)

The EME local to the equipment or system within the installation (the EME energy coupled to installation wiring which appears at equipment interface circuits) and the degree of attenuation or enhancement achieved for any region are the product of many factors such as external EME characteristics, materials, bonding of structure, dimensions and geometric form of the region, and the location and size of any apertures allowing penetration into the aircraft (G0 through G5 of Figure 25.4 which could have any of the characteristics of Figure 25.8.)

In HIRF high-frequency bands (frequencies on the order of 100 MHz and higher) the internal field resulting from such influences, as noted above, will in most cases produce a nonuniform field within the region or location of the system or equipment. The field cannot be considered as uniform and homogeneous. The field will not necessarily allow the adoption of single-point measurement techniques for the accurate determination of the equivalent internal field for to be used as the test level for systems.

Several hot spots typically exist within any subsection of the aircraft. This is particularly true at cavity resonant conditions. Intense local effects are experienced at all frequencies in the immediate vicinity of any apertures for a few wavelengths away from the aperture itself. For apertures small with respect to wavelength, measurements of the fields within the aperture would yield fields much larger than those



- External energy penetrates to interior via apertures, composites, seams, joints, and antennas
- Voltages and currents induced on flight control system components and cables
  - RF energy below 1 megahertz - induced coupling at these frequencies is inefficient and thus will probably be of lesser concern
  - RF energy between 1 and 300 megahertz is of major concern as aircraft wiring, when their lengths are on the order of a wavelength divided by two ($\lambda/2$) or longer at these frequencies, acts as a highly efficient antenna
  - RF energy coupling to aircraft wiring drops off at frequencies above 300 megahertz (at these higher frequencies, the EM energy tends to couple through box apertures rather than through aircraft wiring)

Aircraft internal EME energy electrical/electronic system.

further inside the aircraft because the fields fall off inversely proportional to radius cubed. For apertures on the order of a wavelength in size or larger, the fields may penetrate unattenuated.

The HIRF spectrum of RF energy that couples into aircraft wiring and electrical/electronic systems can be summarized into three basic ranges:

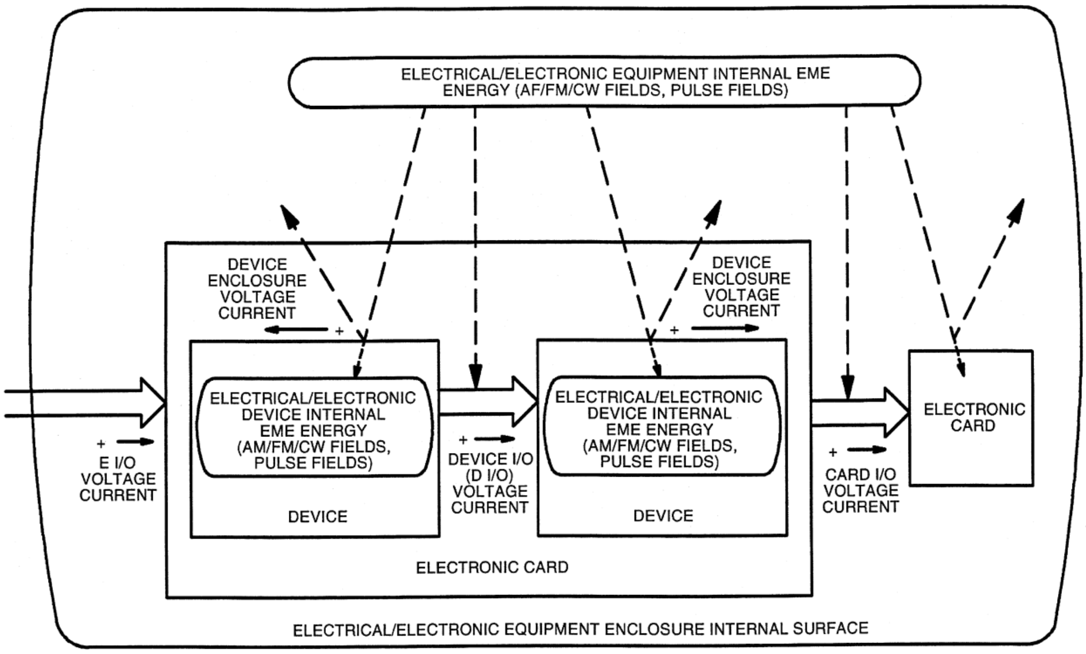
• HIRF energy below 1 MHz — induced coupling at these frequencies is inefficient and thus will be of lesser concern.

• HIRF energy between 1 and 400 MHz — induced coupling is of major concern since aircraft wiring acts as a highly efficient antenna at these frequencies.

• HIRF energy above 400 MHz — coupling to aircraft wiring drops off at frequencies above 400 MHz. At these higher frequencies the EM energy tends to couple through equipment apertures and seams and to the quarter wavelength of wire attached to the line replaceable unit (LRU). In this frequency range, aspects of equipment enclosure construction become important.

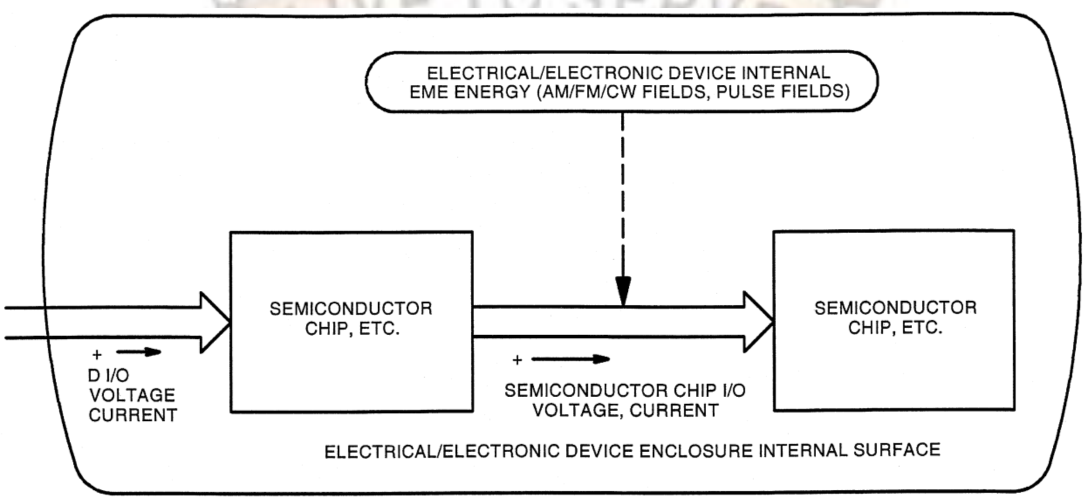
The extension of electrical/electronic systems throughout the aircraft ranges from highly distributed (e.g., flight controls) to relatively compact. Wiring associated with distributed systems penetrates several aircraft regions. Some of these regions may be more open to the electromagnetic environment than others, and wiring passing through the more open regions is exposed to a higher environment. Thus, at frequencies below 400 MHz, the wiring of a highly distributed system could have a relatively wide range of induced voltages and currents that would appear at equipment interface circuits.

The flight deck of the aircraft is an example of an open region. The windscreen "glass" presents approximately zero attenuation to an incoming field at and above the frequency for which its perimeter is one wavelength. Some enhancement above the incident field level generally exists in and around the aperture at this resonance condition.



- Voltage, fields, currents and charge on system components penetrate into equipment enclosure interiors via holes, seams, and airplane wiring (cables)
- Energy (voltage and current) picked up by wires and printed conductors on cards and carried to electronic devices

FIGURE 25.6 Electrical/electronic equipment internal EME interaction electrical/electronic circuitry.



- Card and device conductors carry energy to the semiconductor chips, etc.
- Possible effects
  - Damage
  - Upset

FIGURE 25.7 Electrical/electronic device internal EME interaction electrical/electronic circuitry.

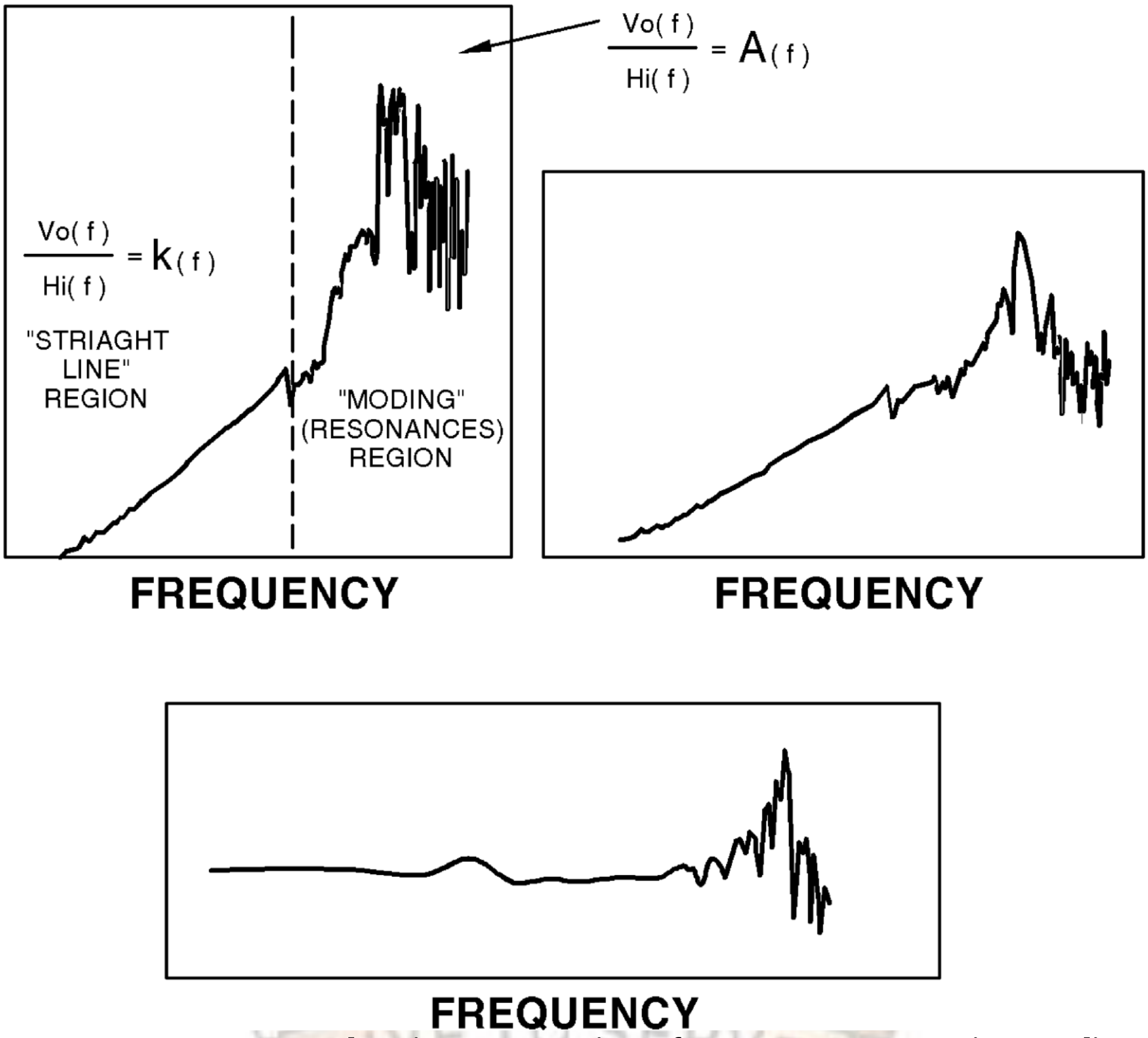


FIGURE 25.8 Frequency domain representations of EME energy attenuation/coupling transfer functions.

Lightning is a transient electromagnetic event, as is the resulting internal environment. Relative to a spectral representation, lightning energy would be concentrated in the zero to 50 MHz range (most energy is below 3 MHz). However, since lightning is such an intense transient, significant energy can be present up to and sometimes above 10 MHz.

Relative to the higher frequency range (above 100 MHz) strong resonances of aircraft interior volumes (cavities) such as the flight deck, equipment bay, etc, could occur. At the very high frequencies the EME can be in the form of both very intense and very short duration. From a cavity resonance issue, since the time constant of a relatively good cavity resonator is on the order of 1µs, the pulse can be gone before significant field energy is developed within the cavity.

Architecture Options for Fault Mitigation

New system architecture measures have been evolving which could complement/augment traditional schemes to provide protection against EME energy effects. Architecture options can be applied at the overall system level or within the digital computing platform for the system. These options include the following:

• Distributed bus architecture
• Error Detection and Corrective (EDC) schemes
• Fiber optic data transfer
• Computation recovery

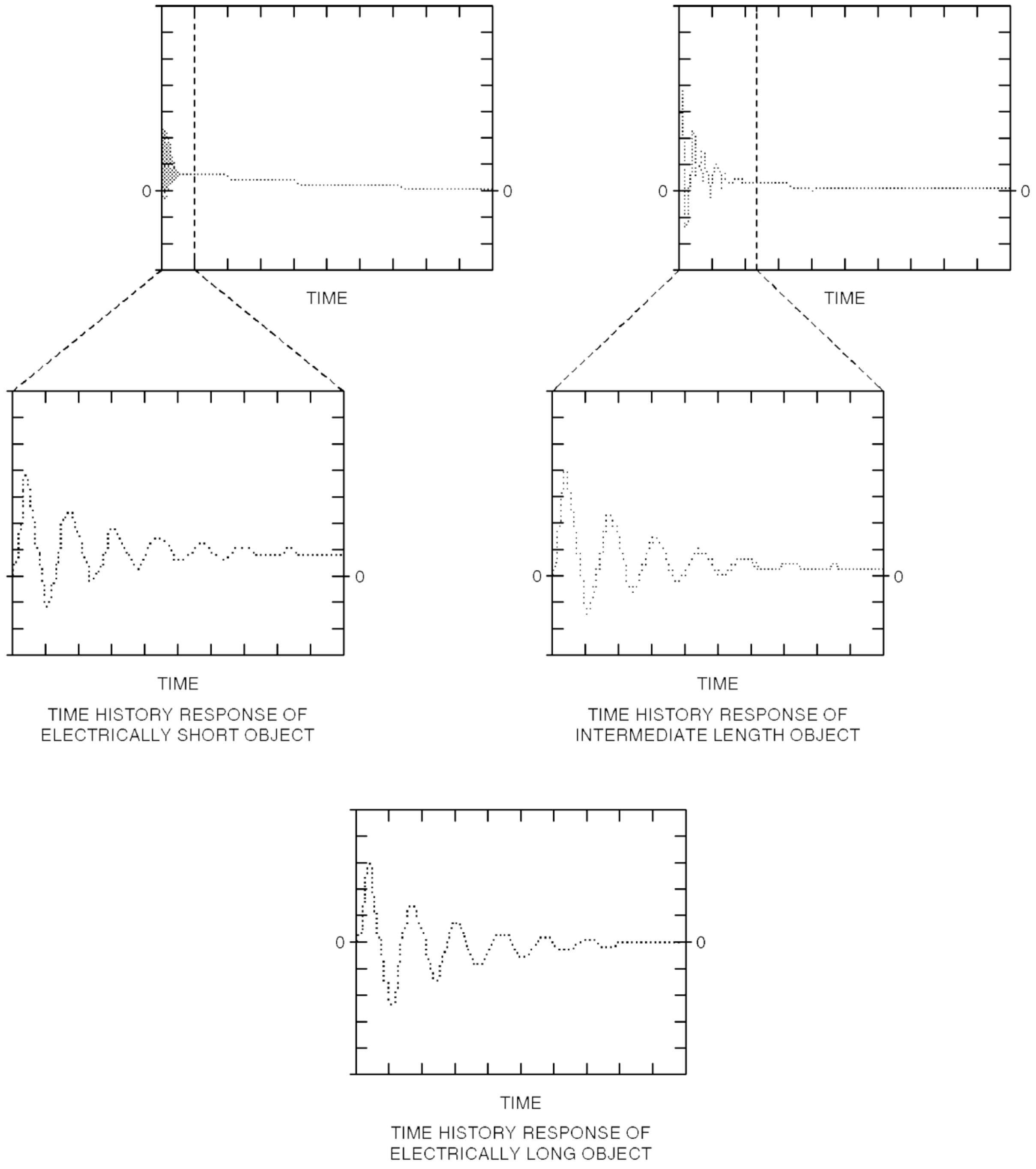


FIGURE 25.9 Responses for lightning EM pulse field interaction with objects of different "electrical lengths."

Electrical/Electronic System

In the past, soft faults in digital avionics were physically corrected by manual intervention, recycle power, etc. More recently, system-level measures for the automatic correction of soft faults have begun to be developed. It is perceived that significant benefits can be gained through soft fault protection measures designed into the basic system mechanization. System-level soft fault protection methodologies provide the ability to tolerate disruption of either input/output data or internal computation. Accordingly, there are two distinct classes of disruption:

• Disruption at the system equipment interface boundary causing corruption of data flowing to or from the affected subsystem.

Disruption that reaches within system equipment to corrupt internal data and computation. As a worst case scenario, it must be presumed that any memory elements within the computational machine (registers, memory, etc.) may be affected at the time of disruption.

The short-term disruption of input/output data at an equipment boundary can be managed via a variety of existing methodologies. Data errors must be detected and the associated data suppressed until the error status is cleared. The data processing algorithm should tolerate data loss without signaling a hard fault. The length of time that can be tolerated between valid refreshes depends on the data item and the associated time constants (response) of the system and corresponding function being implemented.

The ability to tolerate disruption that reaches computation and memory elements internal to system equipment without propagation of the associated fault effect is a more difficult problem. For systems with redundant channels, this means tolerance of the disruption without loss of any of the redundant channels. Fault clearing and computation recovery must be rapid enough to be "transparent" relative to functional operation and flight deck effects.

Such computational recovery requires that the disruption be detected and then the state of the affected system be restored. Safety-critical systems are almost always mechanized with redundant channels.

Outputs of channels are compared in real time, and an errant channel is blocked from propagating a fault effect. One means available for safety-critical systems to detect disruption is the same cross-channel monitor. If miscompare between channels occurs, a recovery is attempted. For a hard fault, the miscompare condition will not have been remedied by the recovery attempt.

A basic approach to "rapid" computational recovery would be to transmit function state variable data from valid channels to the channel that has been determined faulted and for which a recovery is to be attempted (Figure 25.10). However, the cross-channel mechanization is ineffective against a disruption that has the potential to affect all channels.

Digital Computing Platform

The platform for the Airplane Information Management System (AIMS) used on Boeing 777 aircraft and Versatile Integrated Avionics (VIA) technology is an example of an architectural philosophy in the design of computing platforms. Essentially, VIA is a repackaged version of the AIMS technology. As mentioned, first-generation digital avionics have been plagued with high MTBUR (no-fault-found) rates.

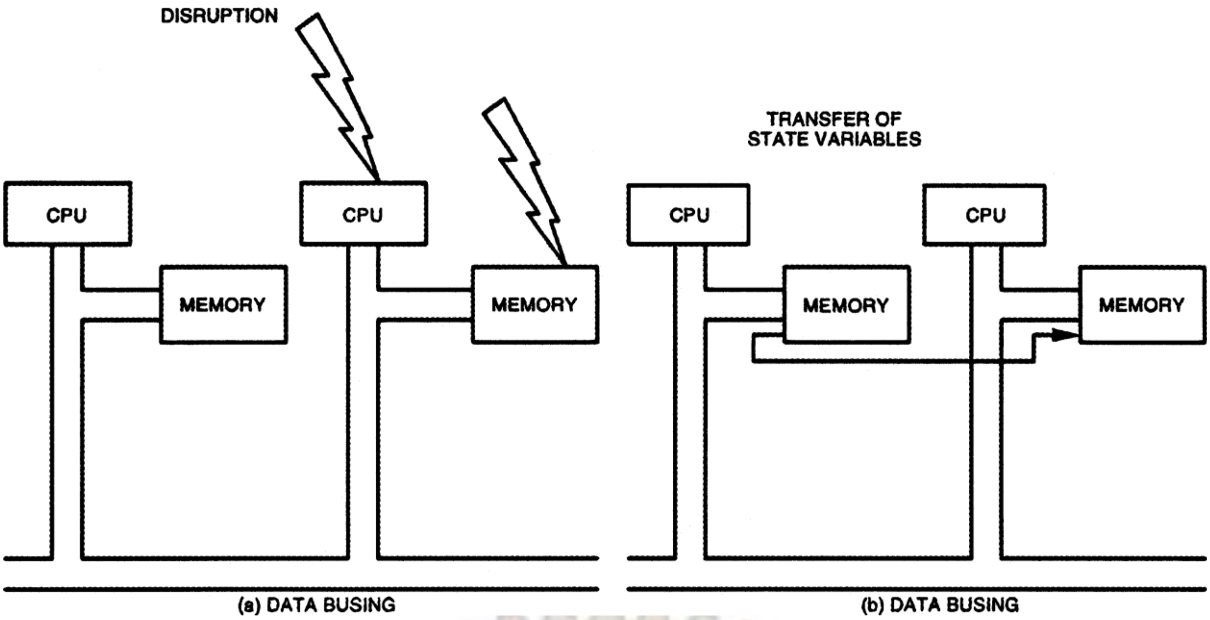


FIGURE 25.10 Redundant CPUs cross-lane recovery (can accomplish some degree of "rapid" recovery).

One primary goal of the Boeing 777 program was to greatly improve operational readiness and associated life-cycle cost performance for the airlines. The AIMS functionally redundant, self-checking pairs architecture was specifically selected to attack these problems. The high integration supported by AIMS required a very comprehensive monitoring environment that is ideal for in-channel "graceful" recovery.

In AIMS, the more dramatic step of making hardware monitoring active on every CPU clock cycle was taken. All computing and I/O management resources are lockstep compared on a processor cycleby- cycle basis. All feasible hardware soft or hard faults are detected. In this approach, if a soft or hard fault event occurs, the processor module is immediately trapped to service handlers and no data can be exported. In past systems, the latency between such an event and eventual detection (or washout) was the real culprit. The corrupted data would propagate through computations and eventually affect some output. To recover, drastic actions (reboots or rearms) were often necessary. In AIMS, critical functions such as displays (because the flight crew could "see" hiccups) have a "shadowing" standby computational resource. The shadow sees the same input set at the same time as the master self-checking pair. If the master detects an event, within nanoseconds the faulty unit is blocked from generating outputs. The Honeywell SAFE bus® system detects the loss of output by the master and immediately passes the shadow's correct data for display.

In the faulted processor module, the core system has two copies of processor "state data" fundamental in the self-checking pair. Unlike past systems where the single thread processor may be so defective it cannot record any data, at least one half of the AIMS self-checking pair should be successful. Thus, the process of diagnosing hardware errors involves comparing what each half of the pair thought was going on. Errors, down to processor address, control, or data bits can be easily isolated. If the event was a soft fault, the core system allows a graceful recovery before the processor module is again allowed to export data. On the surface it appears to be a more sensitive system. However, even with the comprehensive monitoring (potentially a brittle operation), from the standpoint of a self-checking (dual-lockstep) pairs processor data comparison, in these platforms the automatic recovery capabilities should provide a compensating, more robust operation. In other words, from a macro time perspective, system functions will continue to be performed even though, on a micro time basis, a soft fault occurred.

In addition to the isolation of hardware faults (hard or soft), effective temporal and physical partitioning for execution of application software programs involving a variety of software levels has been achieved by the monitoring associated with the self-checking pairs processor and a SAFEbus® communication technology approach.

Defining Terms

DO-160: RTCA Document 160, Environmental Conditions and Test Procedures for Airborne Equipment, produced by RTCA Special Committee 135. Harmonized with ED-14.

ED-14: EUROCAE Document 14, Counterpart to DO-160, produced by EUROCAE Working Groups 14, 31, and 33. Harmonized with DO-160.

EMC: Electromagnetic Compatibility is a broad discipline dealing with EM emissions from and susceptibility to electrical/electronic systems and equipment.

EME: Electromagnetic Environment, which for commercial aircraft, consists of lightning, HIRF, and the electrical/electronic system and equipment emissions (intra and inter) portion (susceptibility not included) of EMC.

MTBF: Mean Time Between Failures (World Airlines Technical Operations Glossary).

MTBUR: Mean Time Between Unscheduled Removals (World Airlines Technical Operations Glossary).

EUROCAE: European Organization for Civil Aviation Equipment; for the European aerospace community, serving a role comparable to that of the RTCA and SAE.

PED: Portable Electronic Device, an emerging source of EM emissions not included in the EMC discipline.