AIRFRAME CONSTRUCTION:

Various types of structures in airframe construction, tubular, braced monocoque, semimonocoque, 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](image)
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.

![Monocoque Construction Diagram](image)

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 Diagram](image)

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.

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.

External 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.

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](image)

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.
**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](image)

**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](image)

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.

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.
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.

<table>
<thead>
<tr>
<th>Primary Control Surface</th>
<th>Airplane Movement</th>
<th>Axes of Rotation</th>
<th>Type of Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aileron</td>
<td>Rolling</td>
<td>Longitudinal</td>
<td>Lateral</td>
</tr>
<tr>
<td>Elevator</td>
<td>Pitching</td>
<td>Lateral</td>
<td>Longitudinal</td>
</tr>
<tr>
<td>Rudder</td>
<td>Yawing</td>
<td>Vertical / Normal</td>
<td>Directional</td>
</tr>
</tbody>
</table>

**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 Diagram](image)

*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.](image1)

**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.](image2)
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](image)

**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.
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.”

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.
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.
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.](image)

**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.

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 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.

![Boeing 707](image)

**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.
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.
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.
Summary of function of control surface

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

Various tabs and their uses.

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


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.

![Bass wood tree](image)

**Yellow Birch**

Propellers and veneer for plywood

![Yellow Birch tree](image)

**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.

![Mahogany tree](image)
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 %, 70N-24 v 0,48 %, pU-154 - 2 %
Boeing-777 v 8,5 %, pU-334 v 8,7 %, 70N-148 v up to 10 %, IL-76 and IL-76р - 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 Monels, 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.