

## Chapter 1

# Aircraft Structures

### A Brief History of Aircraft Structures

The history of aircraft structures underlies the history of aviation in general. Advances in materials and processes used to construct aircraft have led to their evolution from simple wood truss structures to the sleek aerodynamic flying machines of today. Combined with continuous powerplant development, the structures of “flying machines” have changed significantly.

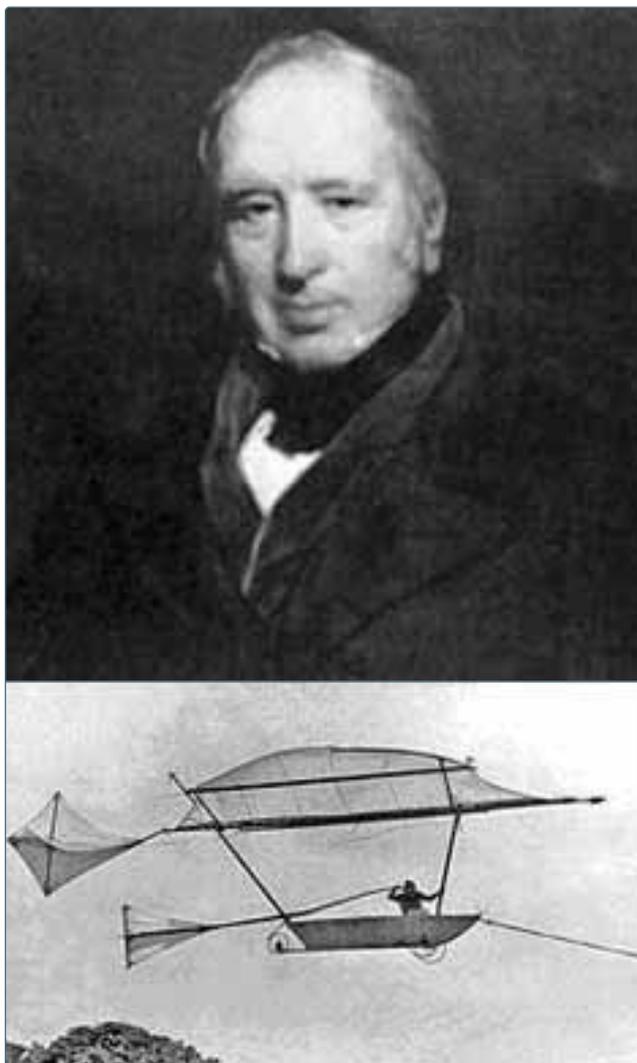
The key discovery that “lift” could be created by passing air over the top of a curved surface set the development of fixed and rotary-wing aircraft in motion. George Cayley developed an efficient cambered airfoil in the early 1800s, as well as successful manned gliders later in that century. He established the principles of flight, including the existence of lift, weight, thrust, and drag. It was Cayley who first stacked wings and created a tri-wing glider that flew a man in 1853.



Earlier, Cayley studied the center of gravity of flying machines, as well as the effects of wing dihedral. Furthermore, he pioneered directional control of aircraft by including the earliest form of a rudder on his gliders. [Figure 1-1]

In the late 1800s, Otto Lilienthal built upon Cayley's discoveries. He manufactured and flew his own gliders on over 2,000 flights. His willow and cloth aircraft had wings designed from extensive study of the wings of birds. Lilienthal also made standard use of vertical and horizontal fins behind the wings and pilot station. Above all, Lilienthal proved that man could fly. [Figure 1-2]

Octave Chanute, a retired railroad and bridge engineer, was active in aviation during the 1890s. [Figure 1-3] His interest was so great that, among other things, he published a definitive work called "Progress in Flying Machines." This was the culmination of his effort to gather and study all the



**Figure 1-1.** George Cayley, the father of aeronautics (top) and a flying replica of his 1853 glider (bottom).



**Figure 1-2.** Master of gliding and wing study, Otto Lilienthal (top) and one of his more than 2,000 glider flights (bottom).

information available on aviation. With the assistance of others, he built gliders similar to Lilienthal's and then his own. In addition to his publication, Chanute advanced aircraft structure development by building a glider with stacked wings incorporating the use of wires as wing supports.

The work of all of these men was known to the Wright Brothers when they built their successful, powered airplane in 1903. The first of its kind to carry a man aloft, the Wright Flyer had thin, cloth-covered wings attached to what was primarily truss structures made of wood. The wings contained forward and rear spars and were supported with both struts and wires. Stacked wings (two sets) were also part of the Wright Flyer. [Figure 1-4]



**Figure 1-3.** *Octave Chanute gathered and published all of the aeronautical knowledge known to date in the late 1890s. Many early aviators benefited from this knowledge.*

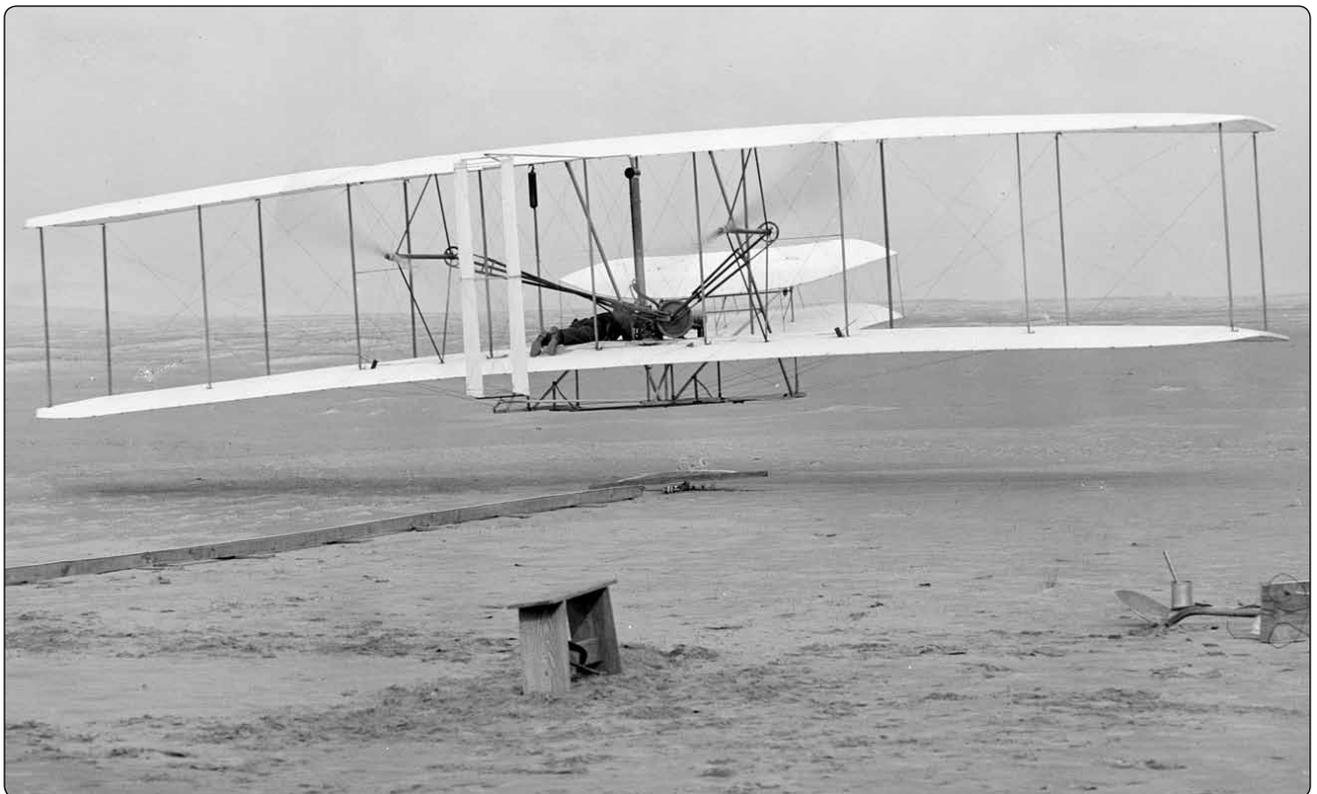
Powered heavier-than-air aviation grew from the Wright design. Inventors and fledgling aviators began building their own aircraft. Early on, many were similar to that constructed by the Wrights using wood and fabric with wires and struts to support the wing structure. In 1909, Frenchman Louis Bleriot produced an aircraft with notable design differences. He built a successful mono-wing aircraft. The wings were

still supported by wires, but a mast extending above the fuselage enabled the wings to be supported from above, as well as underneath. This made possible the extended wing length needed to lift an aircraft with a single set of wings. Bleriot used a Pratt truss-type fuselage frame. [Figure 1-5]



**Figure 1-5.** *The world's first mono-wing by Louis Bleriot.*

More powerful engines were developed and airframe structures changed to take advantage of the benefits. As early as 1910, German Hugo Junkers was able to build an aircraft with metal truss construction and metal skin due to the availability of stronger powerplants to thrust the plane forward and into the sky. The use of metal instead of wood for the primary structure eliminated the need for external wing braces and wires. His J-1 also had a single set of wings (a monoplane) instead of a stacked set. [Figure 1-6]



**Figure 1-4.** *The Wright Flyer was the first successful powered aircraft. It was made primarily of wood and fabric.*



**Figure 1-6.** *The Junker J-1 all metal construction in 1910.*

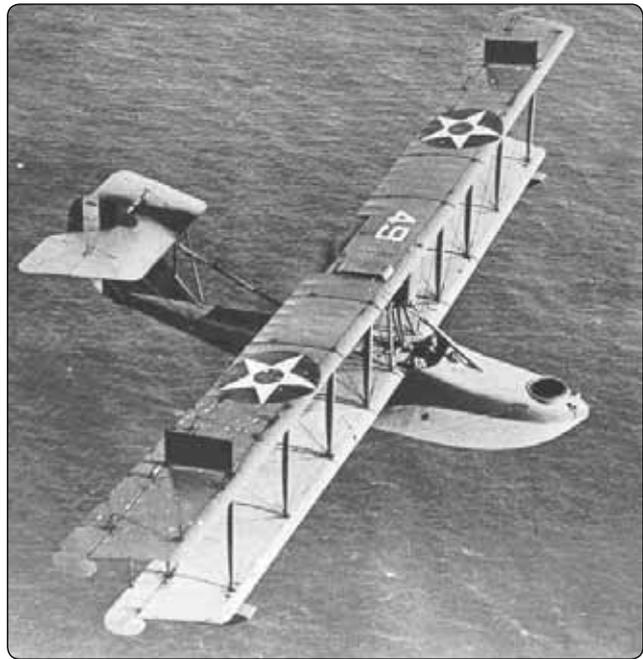
Leading up to World War I (WWI), stronger engines also allowed designers to develop thicker wings with stronger spars. Wire wing bracing was no longer needed. Flatter, lower wing surfaces on high-camber wings created more lift. WWI expanded the need for large quantities of reliable aircraft. Used mostly for reconnaissance, stacked-wing tail draggers with wood and metal truss frames with mostly fabric skin dominated the wartime sky. [Figure 1-7] The Red Baron's Fokker DR-1 was typical.



**Figure 1-7.** *World War I aircraft were typically stacked-wing fabric-covered aircraft like this Breguet 14 (circa 1917).*

In the 1920s, the use of metal in aircraft construction increased. Fuselages able to carry cargo and passengers were developed. The early flying boats with their hull-type construction from the shipbuilding industry provided the blueprints for semimonocoque construction of fuselages. [Figure 1-8] Truss-type designs faded. A tendency toward cleaner monowing designs prevailed.

Into the 1930s, all-metal aircraft accompanied new lighter and more powerful engines. Larger semimonocoque fuselages were complimented with stress-skin wing designs. Fewer truss and fabric aircraft were built. World War II (WWII) brought about a myriad of aircraft designs using all metal technology. Deep fuel-carrying wings were the norm, but the desire for higher flight speeds prompted the development of thin-winged aircraft in which fuel was carried in the fuselage. The first composite structure aircraft, the De Havilland Mosquito, used a balsa wood sandwich material in the



**Figure 1-8.** *The flying boat hull was an early semimonocoque design like this Curtiss HS-2L.*

construction of the fuselage. [Figure 1-9] The fiberglass radome was also developed during this period.

After WWII, the development of turbine engines led to higher altitude flight. The need for pressurized aircraft pervaded aviation. Semimonocoque construction needed to be made even stronger as a result. Refinements to the all-metal semimonocoque fuselage structure were made to increase strength and combat metal fatigue caused by the pressurization-depressurization cycle. Rounded windows and door openings were developed to avoid weak areas where cracks could form. Integrally machined copper alloy aluminum skin resisted cracking and allowed thicker skin and controlled tapering. Chemical milling of wing skin structures provided great strength and smooth high performance surfaces. Variable contour wings became easier



**Figure 1-9.** The DeHavilland Mosquito, the first aircraft with foam core honeycomb in the fuselage.

to construct. Increases in flight speed accompanying jet travel brought about the need for thinner wings. Wing loading also increased greatly. Multispar and box beam wing designs were developed in response.

In the 1960s, ever larger aircraft were developed to carry passengers. As engine technology improved, the jumbo jet was engineered and built. Still primarily aluminum with a semimonocoque fuselage, the sheer size of the airliners of the day initiated a search for lighter and stronger materials from which to build them. The use of honeycomb constructed panels in Boeing's airline series saved weight while not compromising strength. Initially, aluminum core with aluminum or fiberglass skin sandwich panels were used on wing panels, flight control surfaces, cabin floor boards, and other applications.

A steady increase in the use of honeycomb and foam core sandwich components and a wide variety of composite materials characterizes the state of aviation structures from the 1970s to the present. Advanced techniques and material combinations have resulted in a gradual shift from aluminum to carbon fiber and other strong, lightweight materials. These new materials are engineered to meet specific performance requirements for various components on the aircraft. Many airframe structures are made of more than 50 percent advanced composites, with some airframes approaching 100 percent. The term "very light jet" (VLJ) has come to describe a new generation of jet aircraft made almost entirely of advanced composite materials. [Figure 1-10] It is possible that noncomposite aluminum aircraft structures will become obsolete as did the methods and materials of construction used by Cayley, Lilienthal, and the Wright Brothers.



**Figure 1-10.** The nearly all composite Cessna Citation Mustang very light jet (VLJ).

## General

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. [Figure 1-11] 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. [Figure 1-12] 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



**Figure 1-11.** Examples of different categories of aircraft, clockwise from top left: lighter-than-air, glider, rotorcraft, and airplane.



**Figure 1-12.** A monoplane (top), biplane (middle), and tri-wing aircraft (bottom).

coverage of the unique airframe structures and maintenance practices for lighter-than-air flying machines is not included in this handbook.

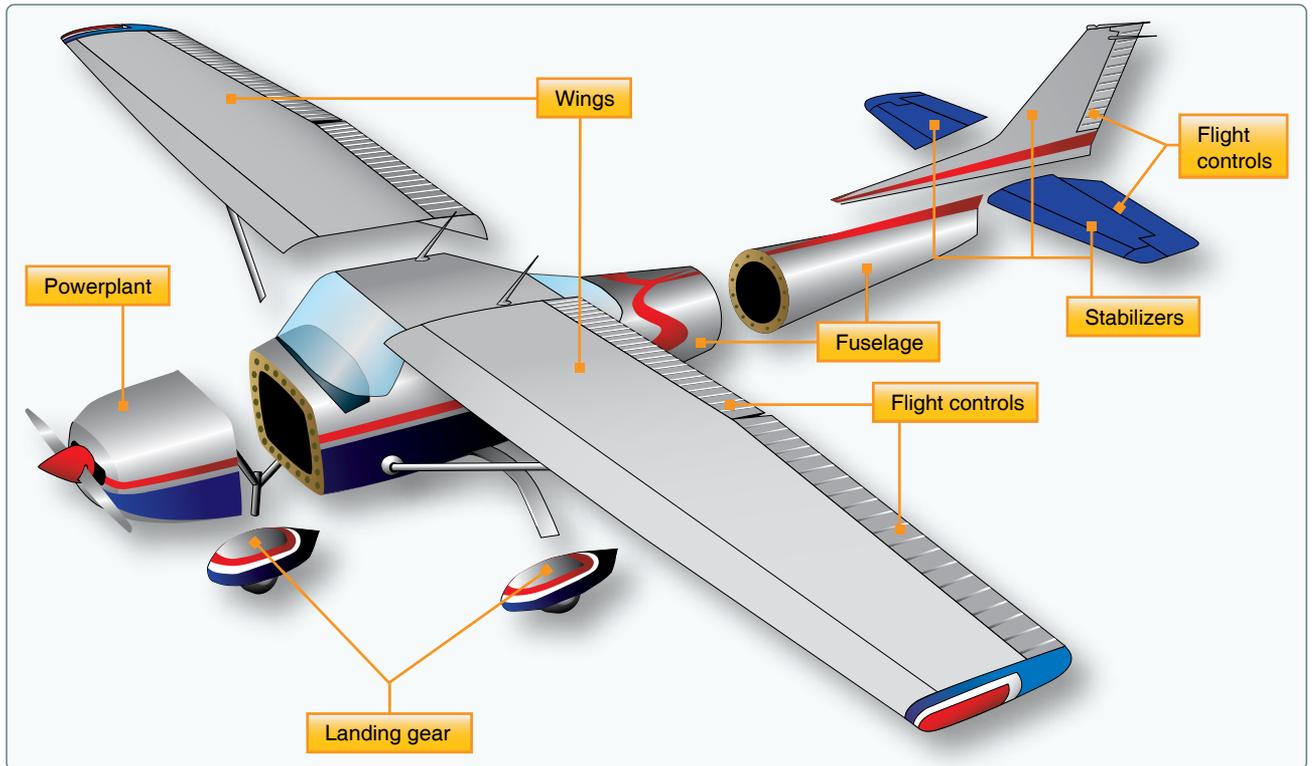
The airframe of a fixed-wing aircraft consists of five principal units: the fuselage, wings, stabilizers, flight control surfaces, and landing gear. [Figure 1-13] Helicopter airframes consist of the fuselage, main rotor and related gearbox, tail rotor (on helicopters with a single main rotor), and the 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.



**Figure 1-13.** *Principal airframe units.*

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 [Figure 1-14] to which all aircraft are subjected:

- Tension
- Compression
- Torsion
- Shear
- Bending

Tension is the stress that resists a force that tends to pull something apart. [Figure 1-14A] The engine pulls the aircraft forward, but air resistance tries to hold it back. The result is

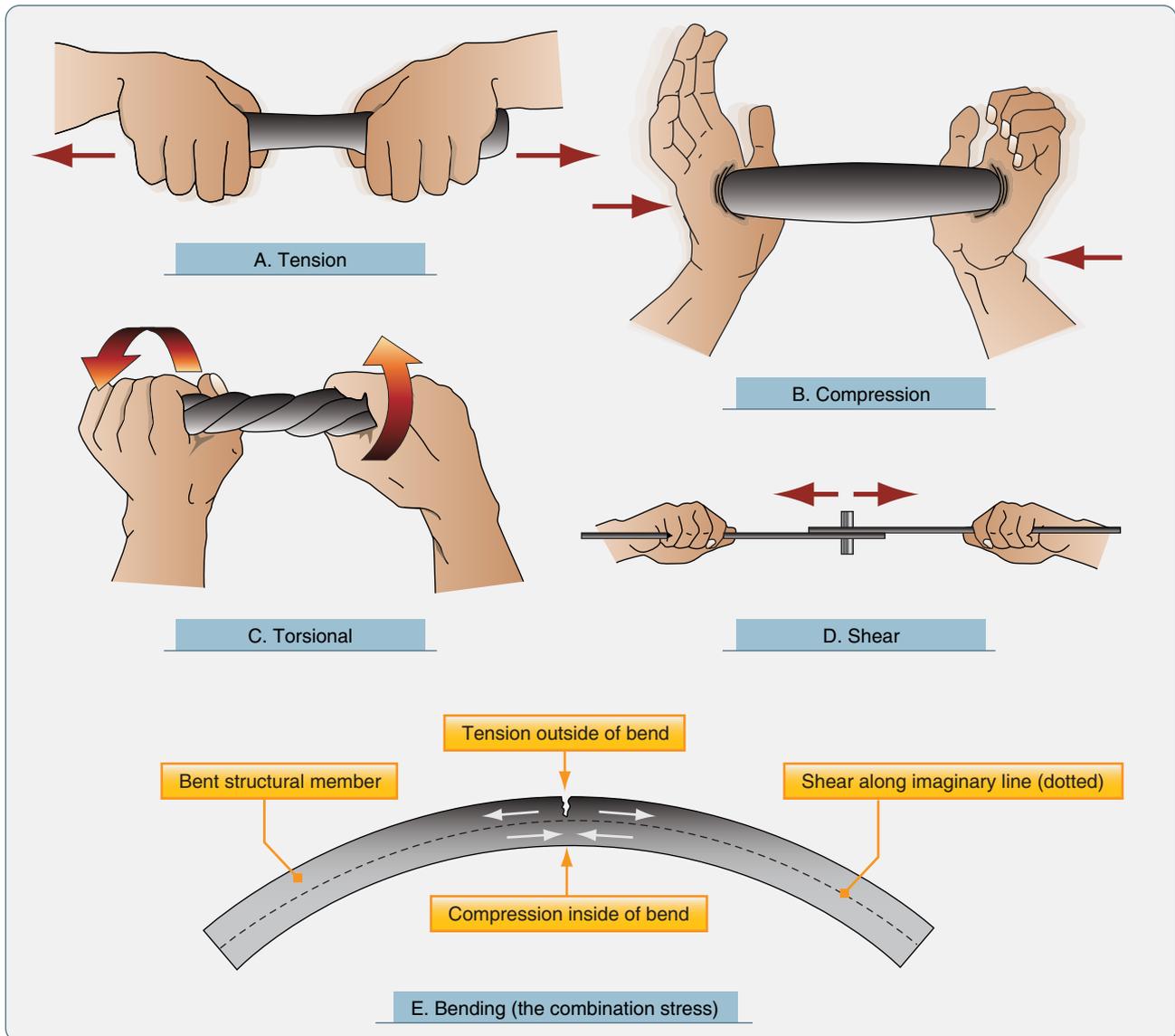
tension, which stretches the aircraft. The tensile strength of a material is measured in pounds per square inch (psi) and is calculated by dividing the load (in pounds) required to pull the material apart by its cross-sectional area (in square inches).

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

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

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

Bending stress is a combination of compression and tension. The rod in Figure 1-14E has been shortened (compressed) on the inside of the bend and stretched on the outside of the bend.



**Figure 1-14.** *The five stresses that may act on an aircraft and its parts.*

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

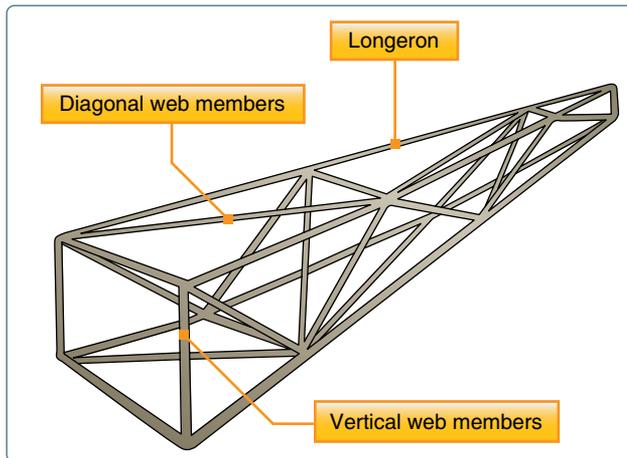
### Fuselage

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 powerplant. 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. [Figure 1-15] 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.



**Figure 1-15.** A truss-type fuselage. A Warren truss uses mostly diagonal bracing.

### 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:

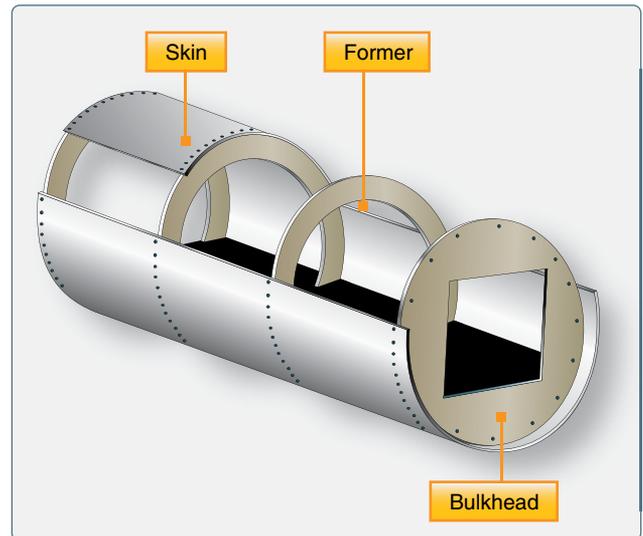
1. Monocoque
2. Semimonocoque

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

The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage. [Figure 1-16] 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, powerplants, 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.

### Semimonocoque Type

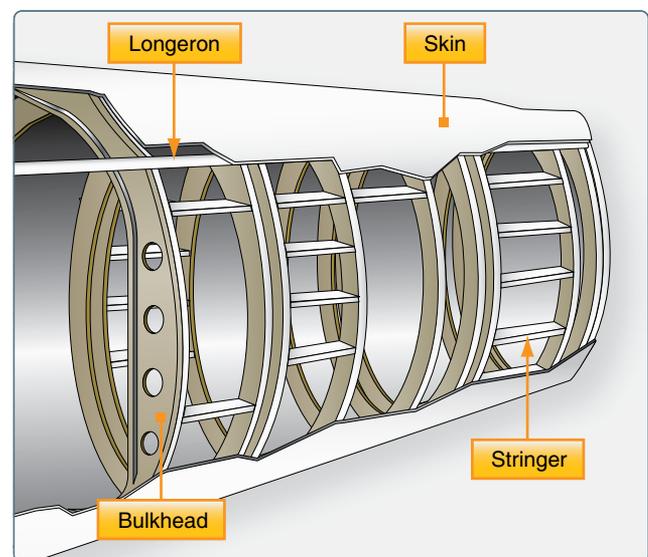
To overcome the strength/weight problem of monocoque construction, a modification called semimonocoque construction was developed. It also consists of frame assemblies, bulkheads, and formers as used in the monocoque



**Figure 1-16.** An airframe using monocoque construction.

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. [Figure 1-17]



**Figure 1-17.** The most common airframe construction is semimonocoque.

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 semimonocoque 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. [Figure 1-18]



**Figure 1-18.** Gussets are used to increase strength.

To summarize, in semimonocoque 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 semimonocoque 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 semimonocoque 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 semimonocoque 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.

### **Pressurization**

Many aircraft are pressurized. This means that air is pumped into the cabin after takeoff and a difference in pressure between the air inside the cabin and the air outside the cabin is established. This differential is regulated and maintained. In this manner, enough oxygen is made available for passengers to breathe normally and move around the cabin without special equipment at high altitudes.

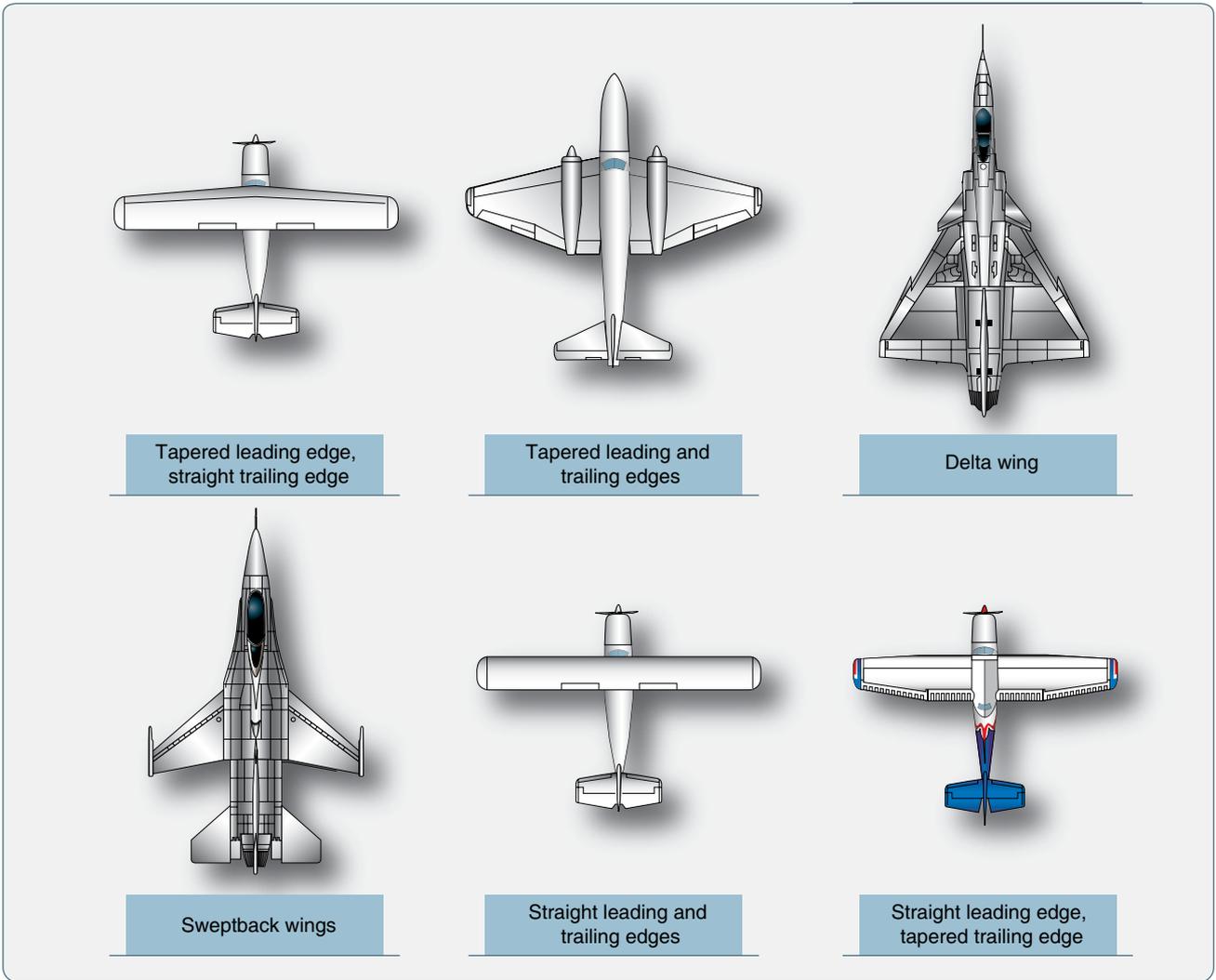
Pressurization causes significant stress on the fuselage structure and adds to the complexity of design. In addition to withstanding the difference in pressure between the air inside and outside the cabin, cycling from unpressurized to pressurized and back again each flight causes metal fatigue. To deal with these impacts and the other stresses of flight, nearly all pressurized aircraft are semimonocoque in design. Pressurized fuselage structures undergo extensive periodic inspections to ensure that any damage is discovered and repaired. Repeated weakness or failure in an area of structure may require that section of the fuselage be modified or redesigned.

## **Wings**

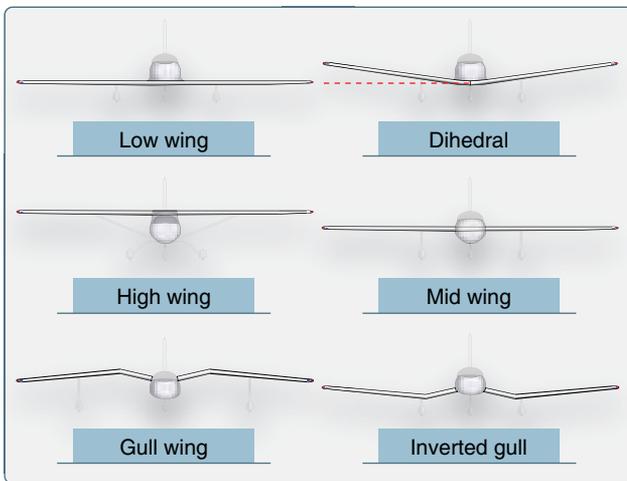
### **Wing Configurations**

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Control at various operating speeds, the amount of lift generated, balance, and stability all change as the shape of the wing is altered. Both the leading edge and the trailing edge of the wing may be straight or curved, or one edge may be straight and the other curved. One or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage. The wing tip may be square, rounded, or even pointed. *Figure 1-19* shows a number of typical wing leading and trailing edge shapes.

The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of the aircraft. *Figure 1-20* shows some common wing attach points and dihedral angle.



**Figure 1-19.** Various wing design shapes yield different performance.

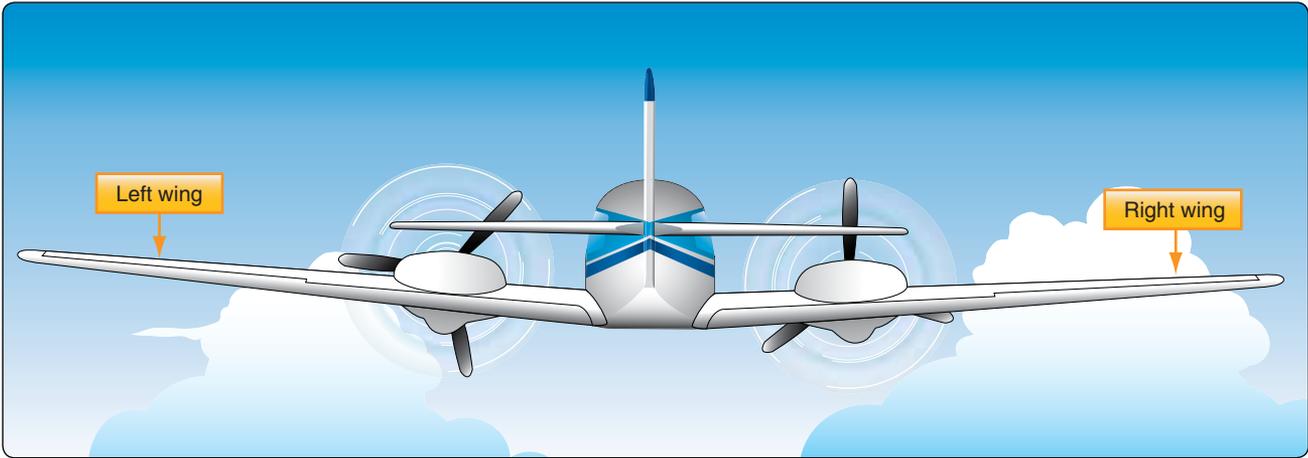


**Figure 1-20.** Wing attach points and wing dihedrals.

### 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. [Figure 1-21]

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



**Figure 1-21.** “Left” and “right” on an aircraft are oriented to the perspective of a pilot sitting in the cockpit.

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 1-22* shows samples of wings using external bracing, also known as semicantilever wings. Cantilever wings built with no external bracing are also shown.

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

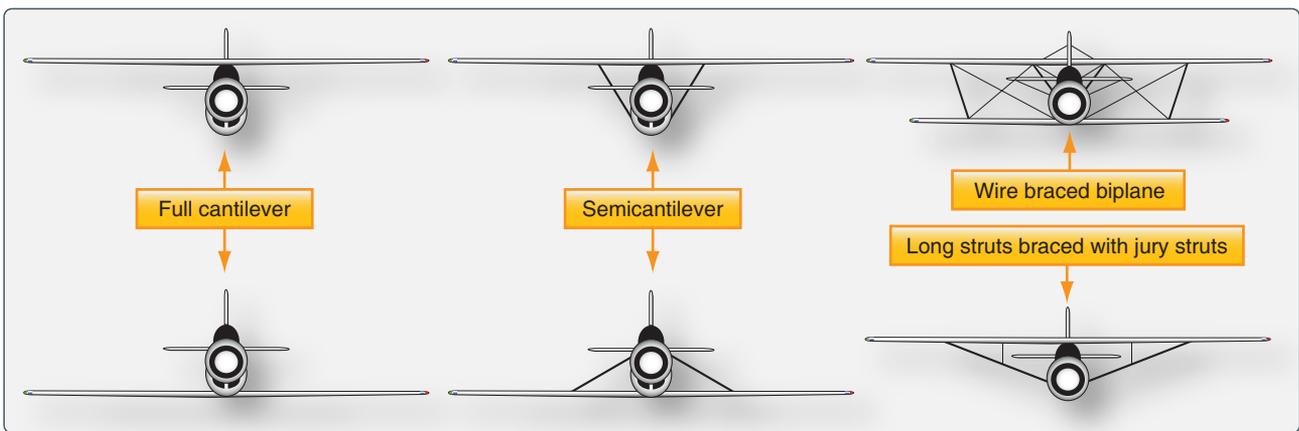
bulkheads running chordwise (leading edge to trailing edge). The spars are the principle structural members of a wing. They support all distributed loads, as well as concentrated weights such as the fuselage, landing gear, and engines. The skin, which is attached to the wing structure, carries part of 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. [*Figure 1-23*]

In general, wing construction is based on one of three fundamental designs:

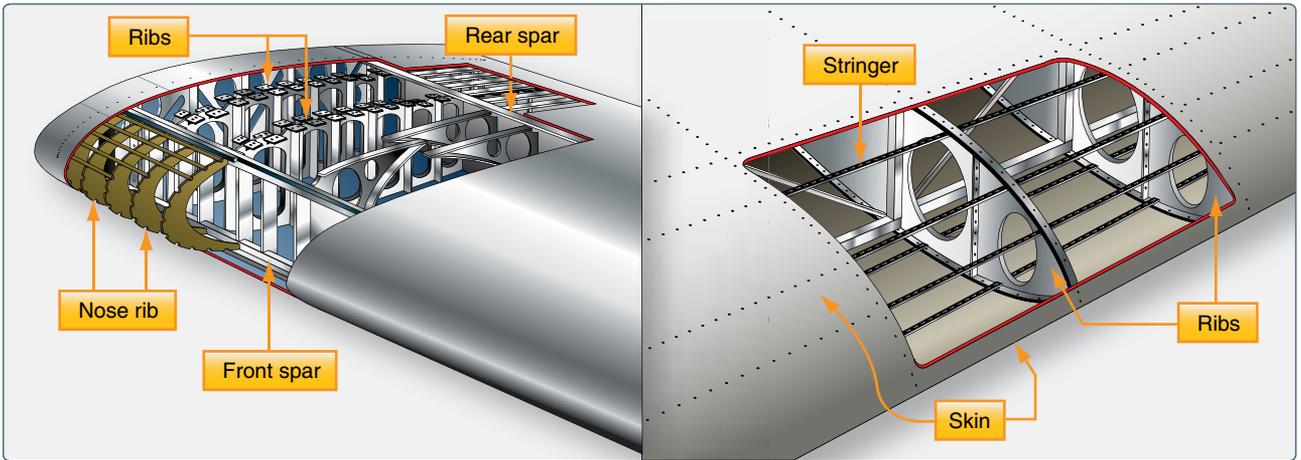
1. Monospar
2. Multispar
3. Box beam

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



**Figure 1-22.** Externally braced wings, also called semicantilever wings, have wires or struts to support the wing. Full cantilever wings have no external bracing and are supported internally.



**Figure 1-23.** *Wing structure nomenclature.*

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.

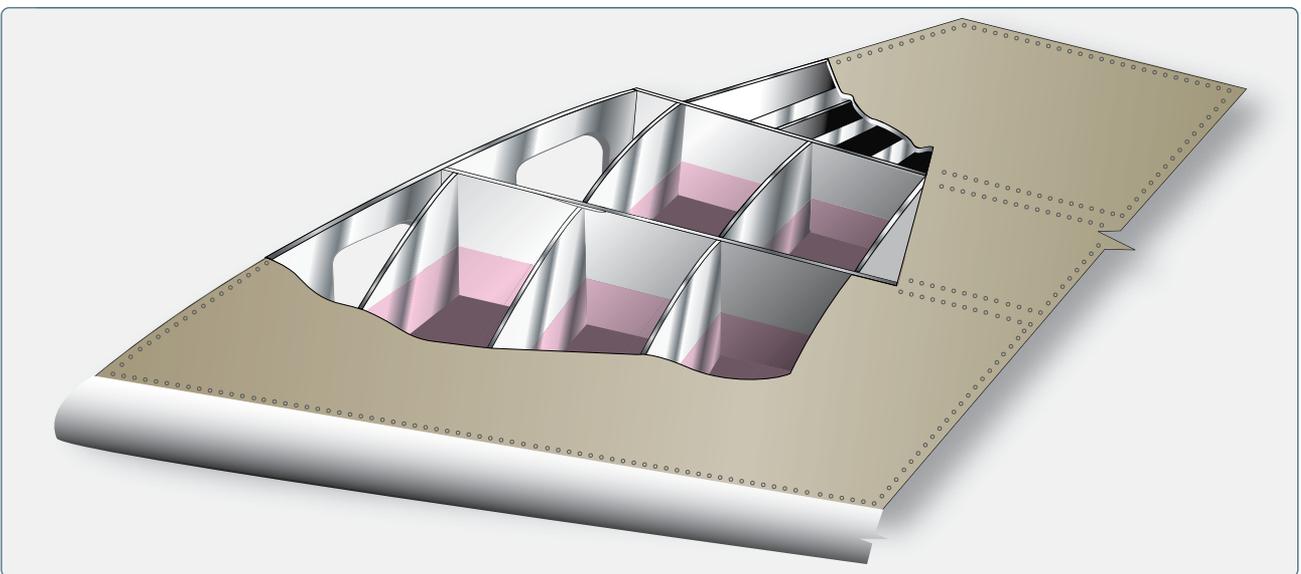
The box beam type of wing construction uses two main longitudinal members with connecting bulkheads to furnish additional strength and to give contour to the wing. [Figure 1-24] A corrugated sheet may be placed between the bulkheads and the smooth outer skin so that the wing can better carry tension 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.

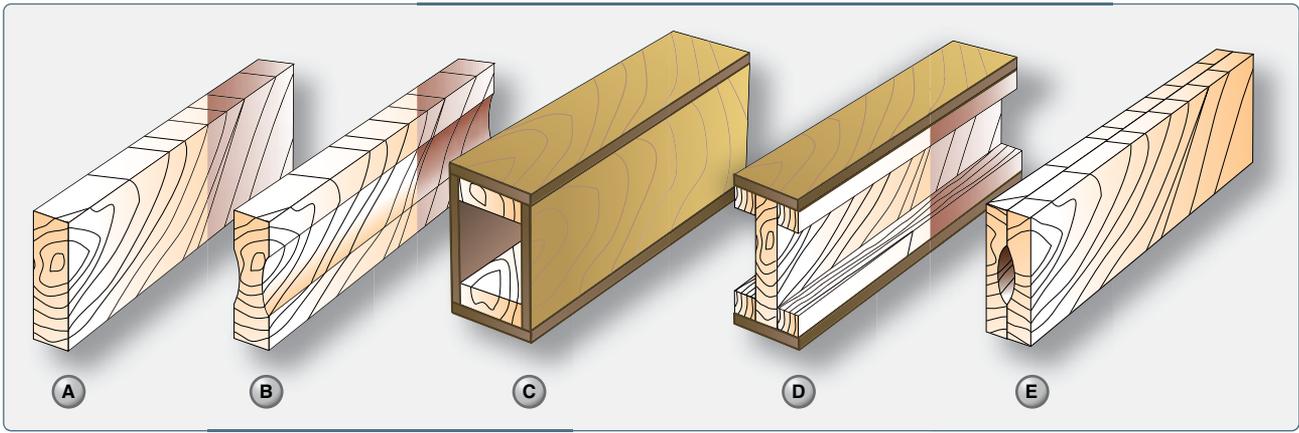
### Wing Spars

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 1-25, 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



**Figure 1-24.** *Box beam construction.*



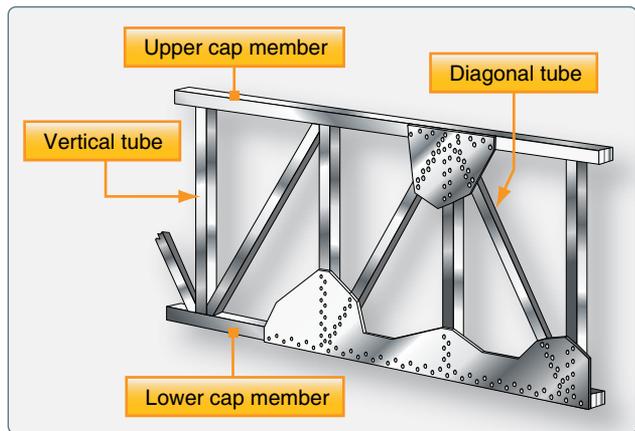
**Figure 1-25.** Typical wooden wing spar cross-sections.

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.

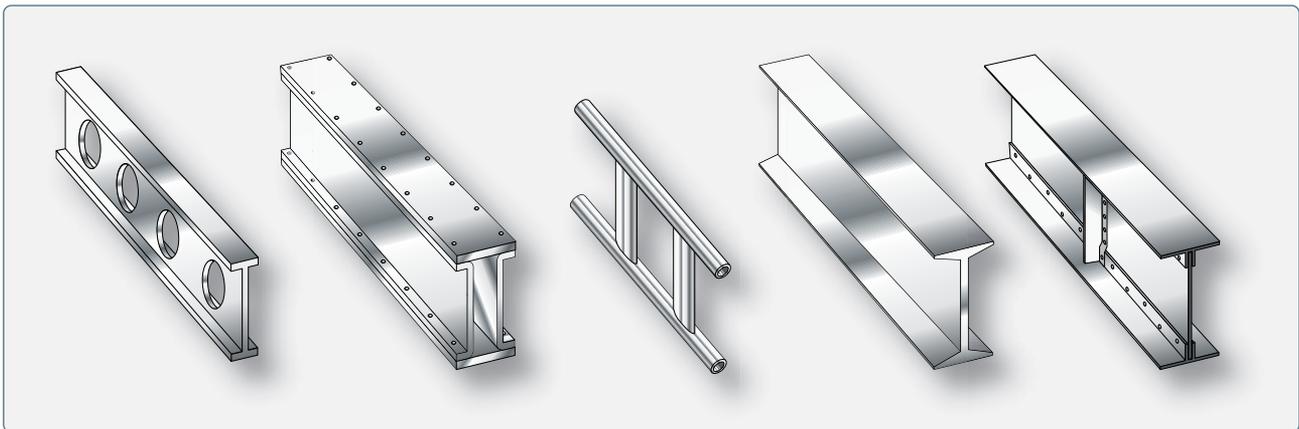
Currently, most manufactured aircraft have wing spars made of solid extruded aluminum or aluminum extrusions riveted together to form the spar. The increased use of composites and the combining of materials should make airmen vigilant for wings spars made from a variety of materials. *Figure 1-26* shows examples of metal wing spar cross-sections.

In an I-beam spar, the top and bottom of the I-beam are called the caps and the vertical section is called the web. The entire spar can be extruded from one piece of metal but often it is built up from multiple extrusions or formed angles. The web forms the principal depth portion of the spar and the cap strips (extrusions, formed angles, or milled sections) are attached to it. Together, these members carry the loads caused by wing bending, with the caps providing a

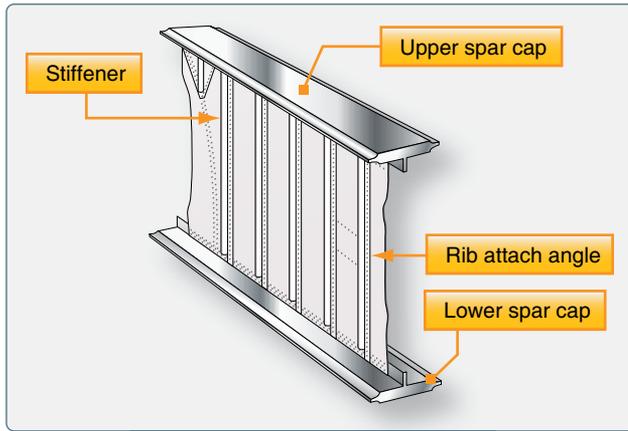
foundation for attaching the skin. Although the spar shapes in *Figure 1-26* are typical, actual wing spar configurations assume many forms. For example, the web of a spar may be a plate or a truss as shown in *Figure 1-27*. It could be built up from light weight materials with vertical stiffeners employed for strength. [*Figure 1-28*]



**Figure 1-27.** A truss wing spar.

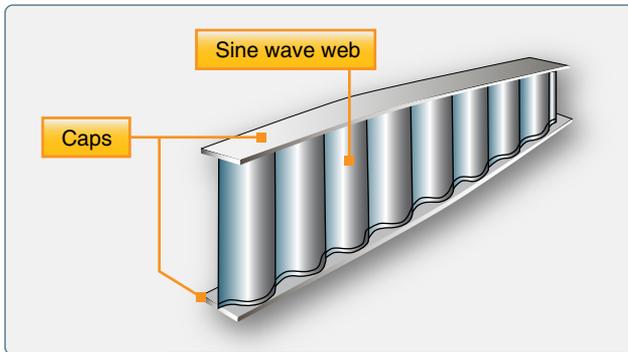


**Figure 1-26.** Examples of metal wing spar shapes.



**Figure 1-28.** A plate web wing spar with vertical stiffeners.

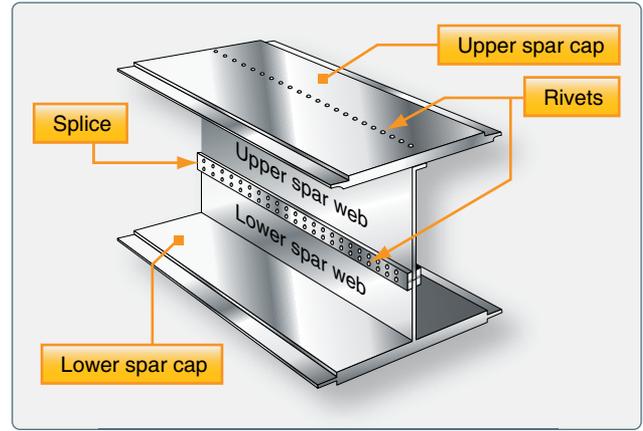
It could also have no stiffeners but might contain flanged holes for reducing weight but maintaining strength. Some metal and composite wing spars retain the I-beam concept but use a sine wave web. [Figure 1-29]



**Figure 1-29.** A sine wave wing spar can be made from aluminum or composite materials.

Additionally, fail-safe spar web design exists. Fail-safe means that should one member of a complex structure fail, some other part of the structure assumes the load of the failed member and permits continued operation. A spar with fail-safe construction is shown in Figure 1-30. This spar is made in two sections. The top section consists of a cap riveted to the upper web plate. The lower section is a single extrusion consisting of the lower cap and web plate. These two sections are spliced together to form the spar. If either section of this type of spar breaks, the other section can still carry the load. This is the fail-safe feature.

As a rule, a wing has two spars. One spar is usually located near the front of the wing, and the other about two-thirds of the distance toward the wing's trailing edge. Regardless of type, the spar is the most important part of the wing. When other structural members of the wing are placed under load, most of the resulting stress is passed on to the wing spar.



**Figure 1-30.** A fail-safe spar with a riveted spar web.

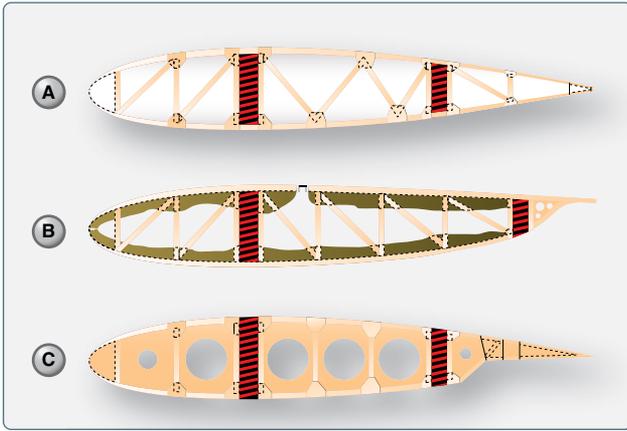
False spars are commonly used in wing design. They are longitudinal members like spars but do not extend the entire spanwise length of the wing. Often, they are used as hinge attach points for control surfaces, such as an aileron spar.

### 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 1-31 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 1-31A, 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 1-31B, 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 aids 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.



**Figure 1-31.** Examples of wing ribs constructed of wood.

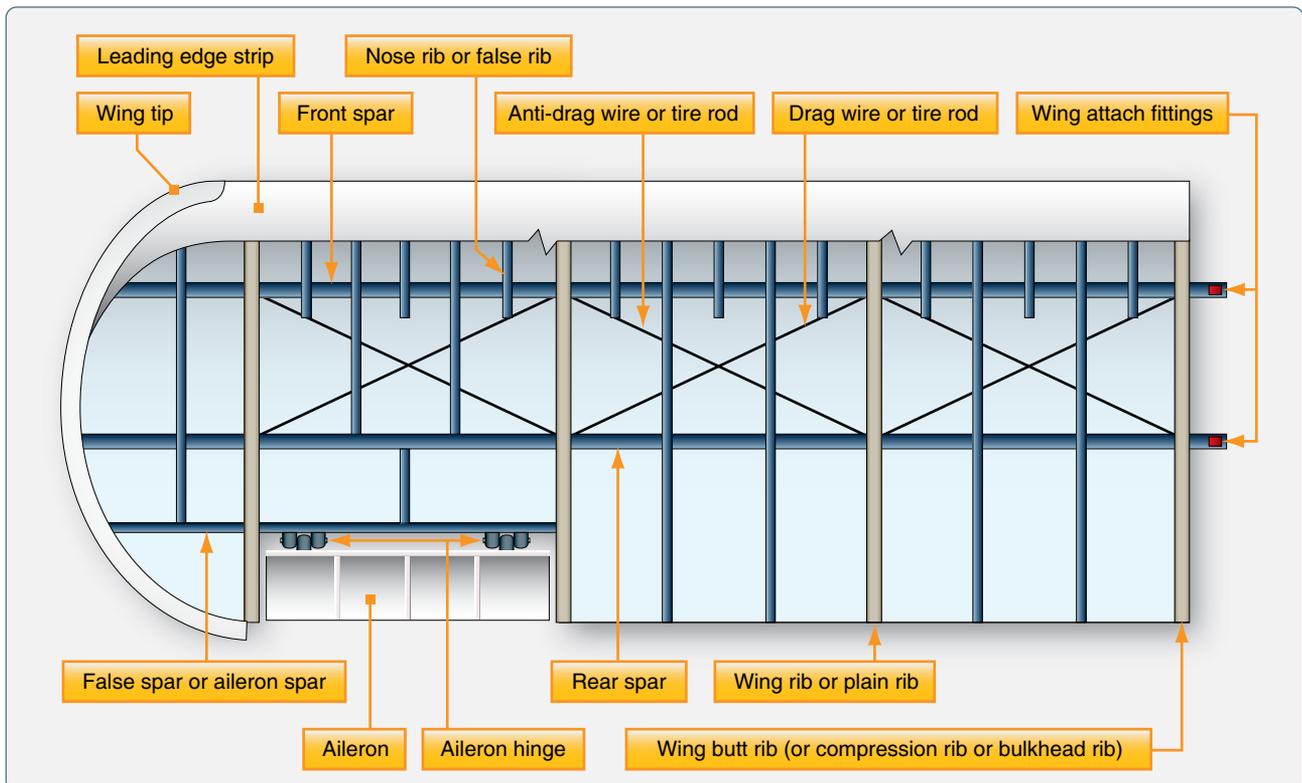
Continuous gussets are also more easily handled than the many small separate gussets otherwise required. *Figure 1-31C* shows a rib with a lightened plywood web. It also contains gussets to support the web/cap strip interface. The cap strip is usually laminated to the web, especially at the leading edge.

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 1-32*, 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 1-32* 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 1-32*. These provide a strong and secure method for attaching the wing to the fuselage. The interface between the wing and fuselage is often covered with a fairing to achieve smooth airflow in this area. The fairing(s) can be removed for access to the wing attach fittings. [*Figure 1-33*]



**Figure 1-32.** Basic wood wing structure and components.



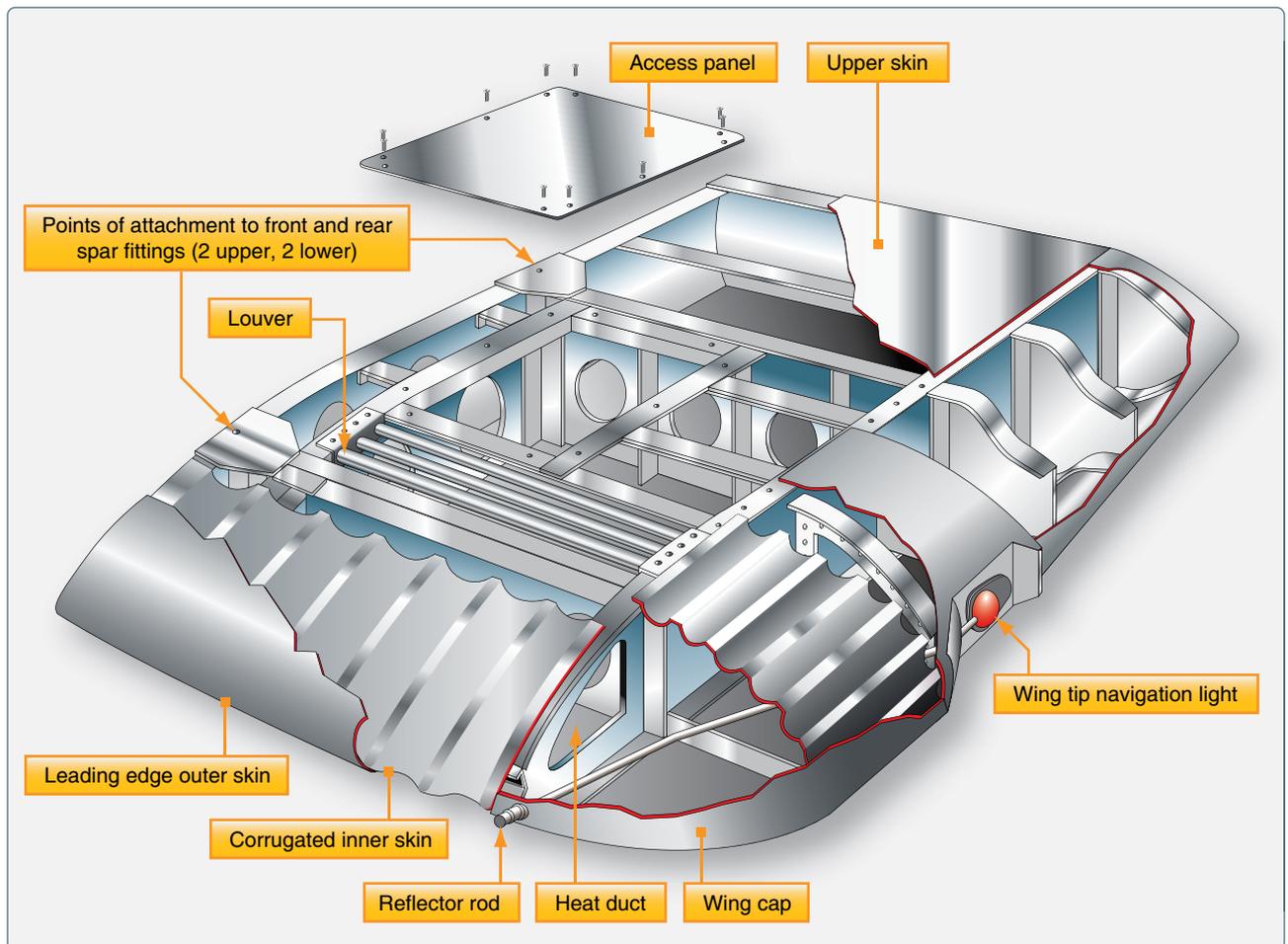
**Figure 1-33.** Wing root fairings smooth airflow and hide wing attach fittings.

The wing tip is often a removable unit, bolted to the outboard end of the wing panel. One reason for this is the vulnerability of the wing tips to damage, especially during ground handling and taxiing. *Figure 1-34* shows a removable wing tip for a large aircraft wing. Others are different. The wing tip assembly is of aluminum alloy construction. The wing tip cap is secured

to the tip with countersunk screws and is secured to the interspar structure at four points with ¼-inch diameter bolts. To prevent ice from forming on the leading edge of the wings of large aircraft, hot air from an engine is often channeled through the leading edge from wing root to wing tip. A louver on the top surface of the wingtip allows this warm air to be exhausted overboard. Wing position lights are located at the center of the tip and are not directly visible from the cockpit. As an indication that the wing tip light is operating, some wing tips are equipped with a Lucite rod to transmit the light to the leading edge.

### Wing Skin

Often, the skin on a wing is designed to carry part of the flight and ground loads in combination with the spars and ribs. This is known as a stressed-skin design. The all-metal, full cantilever wing section illustrated in *Figure 1-35* shows the structure of one such design. The lack of extra internal or external bracing requires that the skin share some of the load. Notice the skin is stiffened to aid with this function.



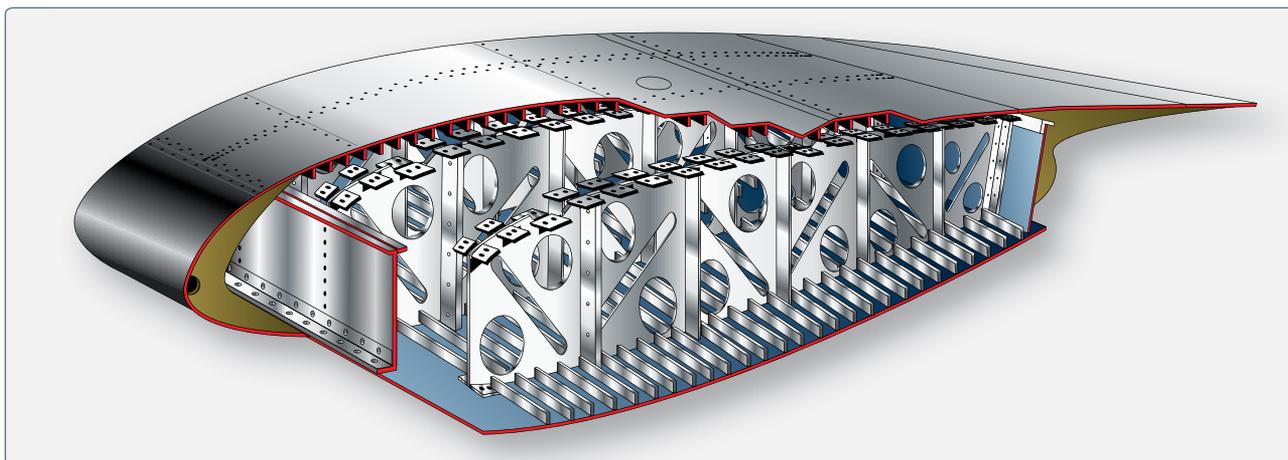
**Figure 1-34.** A removable metal wing tip.

Fuel is often carried inside the wings of a stressed-skin aircraft. The joints in the wing can be sealed with a special fuel resistant sealant enabling fuel to be stored directly inside the structure. This is known as wet wing design. Alternately, a fuel-carrying bladder or tank can be fitted inside a wing. *Figure 1-36* shows a wing section with a box beam structural design such as one that might be found in a transport category aircraft. This structure increases strength while reducing weight. Proper sealing of the structure allows fuel to be stored in the box sections of the wing.

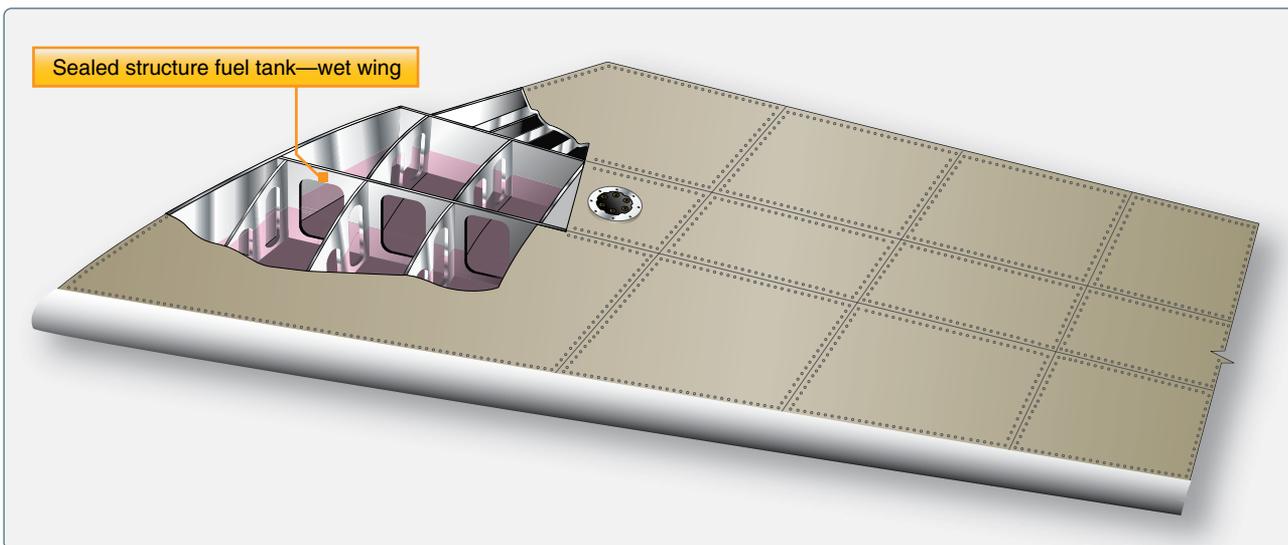
The wing skin on an aircraft may be made from a wide variety of materials such as fabric, wood, or aluminum. But a single thin sheet of material is not always employed. Chemically milled aluminum skin can provide skin of varied thicknesses.

On aircraft with stressed-skin wing design, honeycomb structured wing panels are often used as skin. A honeycomb structure is built up from a core material resembling a bee hive's honeycomb which is laminated or sandwiched between thin outer skin sheets. *Figure 1-37* illustrates honeycomb panels and their components. Panels formed like this are lightweight and very strong. They have a variety of uses on the aircraft, such as floor panels, bulkheads, and control surfaces, as well as wing skin panels. *Figure 1-38* shows the locations of honeycomb construction wing panels on a jet transport aircraft.

A honeycomb panel can be made from a wide variety of materials. Aluminum core honeycomb with an outer skin of aluminum is common. But honeycomb in which the core is



**Figure 1-35.** *The skin is an integral load carrying part of a stressed skin design.*



**Figure 1-36.** *Fuel is often carried in the wings.*

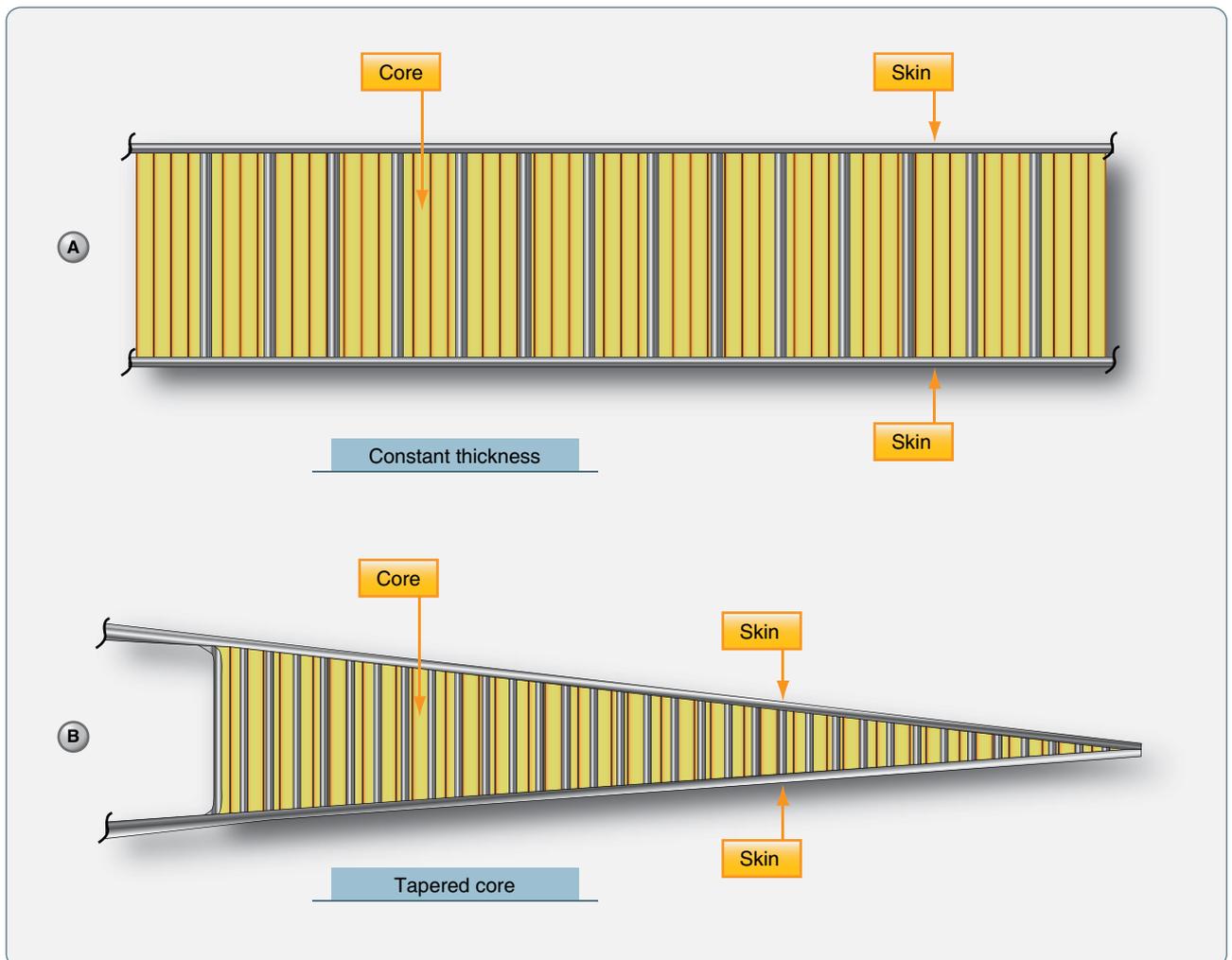
an Arimid® fiber and the outer sheets are coated Phenolic® is common as well. In fact, a myriad of other material combinations such as those using fiberglass, plastic, Nomex®, Kevlar®, and carbon fiber all exist. Each honeycomb structure possesses unique characteristics depending upon the materials, dimensions, and manufacturing techniques employed. *Figure 1-39* shows an entire wing leading edge formed from honeycomb structure.

### Nacelles

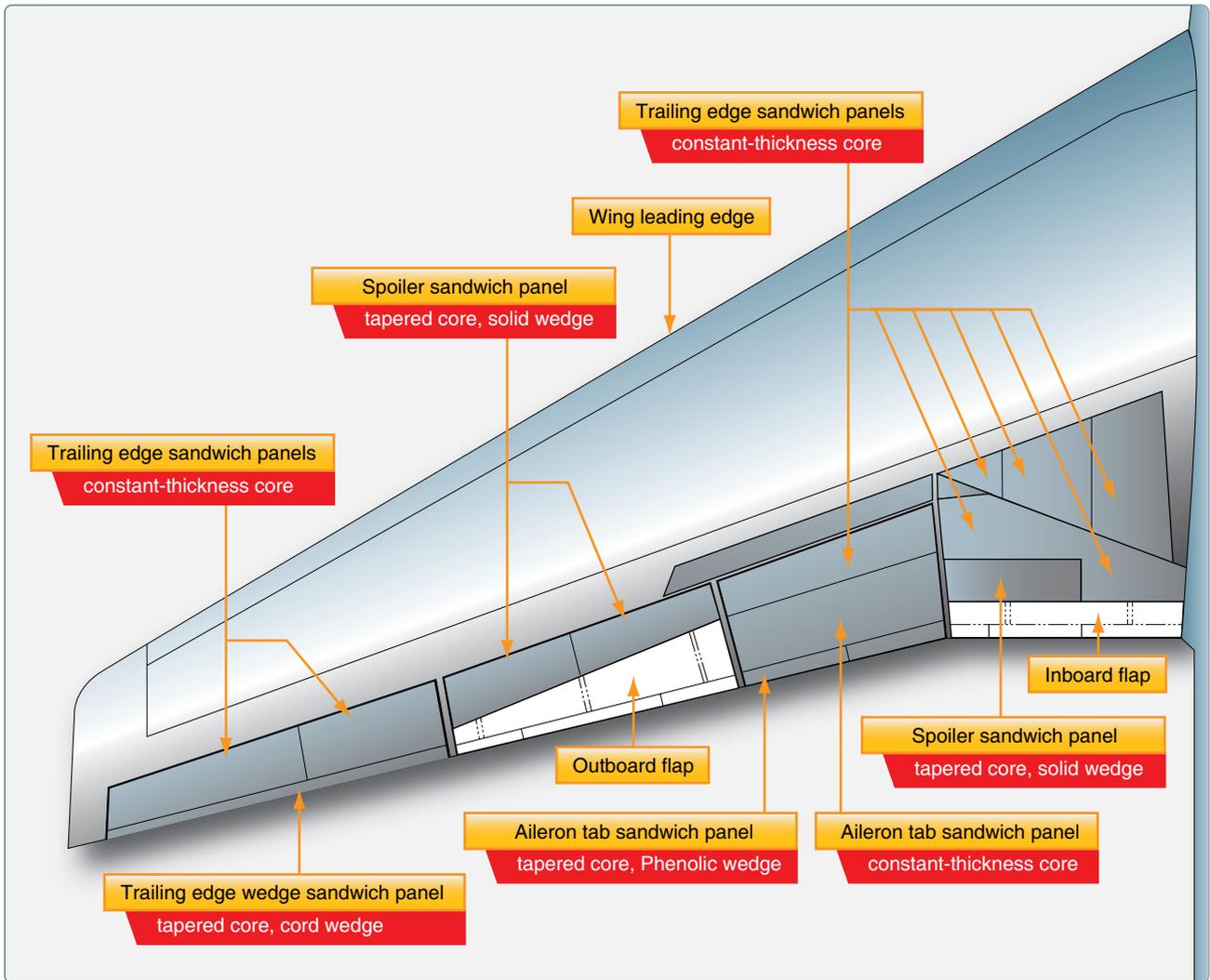
Nacelles (sometimes called “pods”) are streamlined enclosures used primarily to house the engine and its components. They usually present a round or elliptical profile to the wind thus reducing aerodynamic drag. On most single-engine aircraft, the engine and nacelle are at the forward end of the fuselage. On multiengine aircraft, engine

nacelles are built into the wings or attached to the fuselage at the empennage (tail section). Occasionally, a multiengine aircraft is designed with a nacelle in line with the fuselage aft of the passenger compartment. Regardless of its location, a nacelle contains the engine and accessories, engine mounts, structural members, a firewall, and skin and cowling on the exterior to fare the nacelle to the wind.

Some aircraft have nacelles that are designed to house the landing gear when retracted. Retracting the gear to reduce wind resistance is standard procedure on high-performance/high-speed aircraft. The wheel well is the area where the landing gear is attached and stowed when retracted. Wheel wells can be located in the wings and/or fuselage when not part of the nacelle. *Figure 1-40* shows an engine nacelle incorporating the landing gear with the wheel well extending into the wing root.



**Figure 1-37.** The honeycomb panel is a staple in aircraft construction. Cores can be either constant thickness (A) or tapered (B). Tapered core honeycomb panels are frequently used as flight control surfaces and wing trailing edges.



**Figure 1-38.** Honeycomb wing construction on a large jet transport aircraft.

The framework of a nacelle usually consists of structural members similar to those of the fuselage. Lengthwise members, such as longerons and stringers, combine with horizontal/vertical members, such as rings, formers, and bulkheads, to give the nacelle its shape and structural integrity. A firewall is incorporated to isolate the engine compartment from the rest of the aircraft. This is basically a stainless steel or titanium bulkhead that contains a fire in the confines of the nacelle rather than letting it spread throughout the airframe. [Figure 1-41]

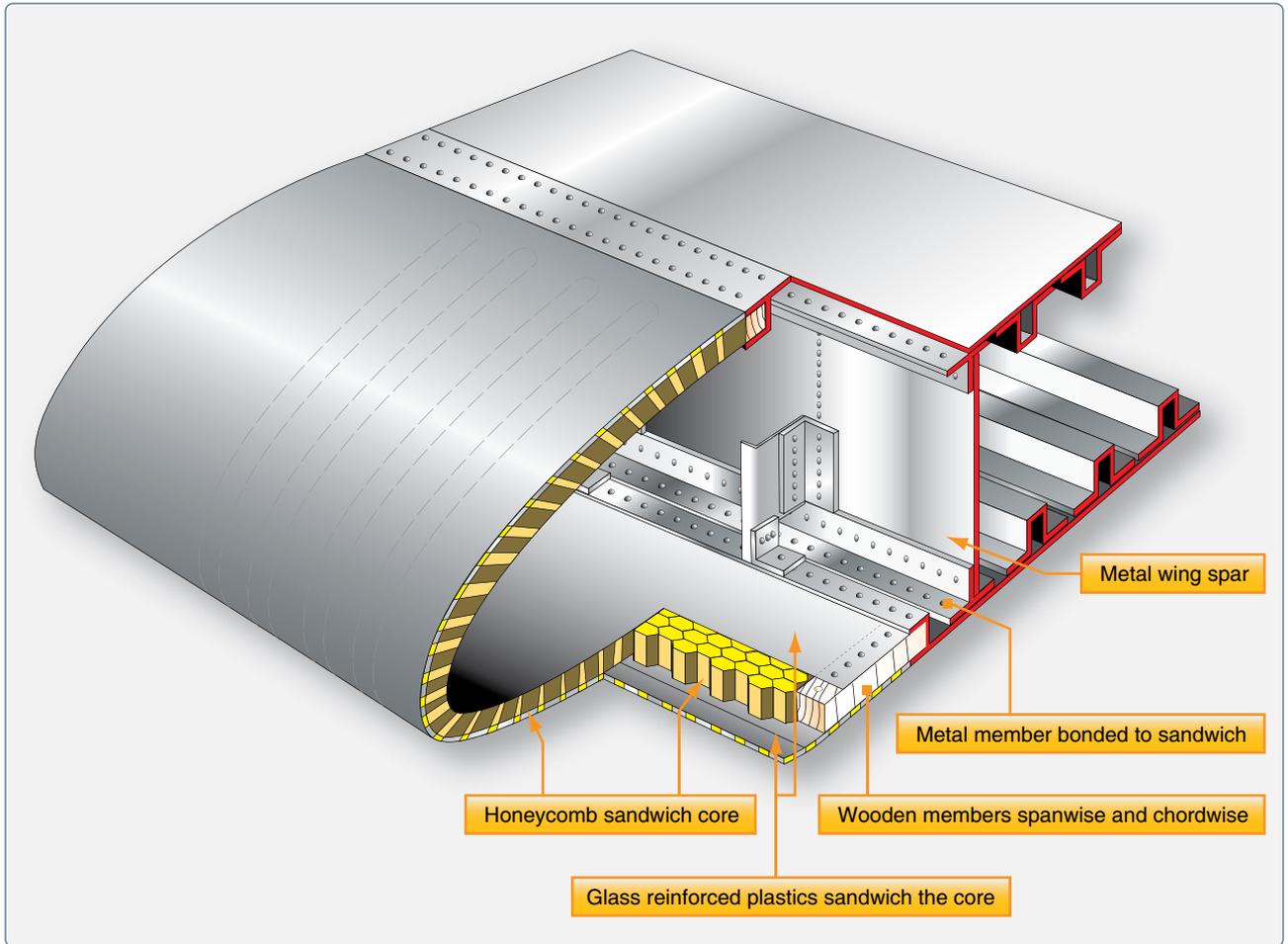
Engine mounts are also found in the nacelle. These are the structural assemblies to which the engine is fastened. They are usually constructed from chrome/molybdenum steel tubing in light aircraft and forged chrome/nickel/molybdenum assemblies in larger aircraft. [Figure 1-42]

The exterior of a nacelle is covered with a skin or fitted with a cowl which can be opened to access the engine and

components inside. Both are usually made of sheet aluminum or magnesium alloy with stainless steel or titanium alloys being used in high-temperature areas, such as around the exhaust exit. Regardless of the material used, the skin is typically attached to the framework with rivets.

Cowling refers to the detachable panels covering those areas into which access must be gained regularly, such as the engine and its accessories. It is designed to provide a smooth airflow over the nacelle and to protect the engine from damage. Cowl panels are generally made of aluminum alloy construction. However, stainless steel is often used as the inner skin aft of the power section and for cowl flaps and near cowl flap openings. It is also used for oil cooler ducts. Cowl flaps are moveable parts of the nacelle cowling that open and close to regulate engine temperature.

There are many engine cowl designs. Figure 1-43 shows an exploded view of the pieces of cowling for a horizontally



**Figure 1-39.** A wing leading edge formed from honeycomb material bonded to the aluminum spar structure.



**Figure 1-40.** Wheel wells in a wing engine nacelle with gear coming down (inset).



**Figure 1-41.** An engine nacelle firewall.

opposed engine on a light aircraft. It is attached to the nacelle by means of screws and/or quick release fasteners. Some large reciprocating engines are enclosed by “orange peel” cowlings which provide excellent access to components inside the nacelle. [Figure 1-44] These cowl panels are attached to the forward firewall by mounts which also serve as hinges for opening the cowl. The lower cowl mounts are secured to the hinge brackets by quick release pins. The side and top panels are held open by rods and the lower panel is retained in the open position by a spring and a cable. All of the cowling panels are locked in the closed position by over-center steel latches which are secured in the closed position by spring-loaded safety catches.

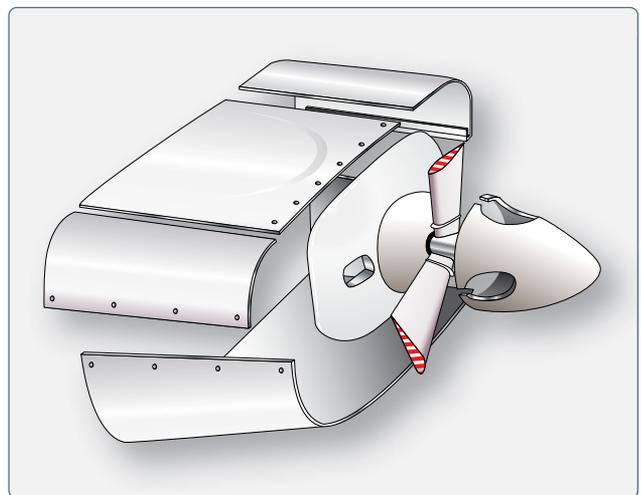
An example of a turbojet engine nacelle can be seen in *Figure 1-45*. The cowl panels are a combination of fixed and easily removable panels which can be opened and closed during maintenance. A nose cowl is also a feature on a jet engine nacelle. It guides air into the engine.

## Empennage

The empennage of an aircraft is also known as the tail section. Most empennage designs consist of a tail cone, fixed aerodynamic surfaces or stabilizers, and movable aerodynamic surfaces.

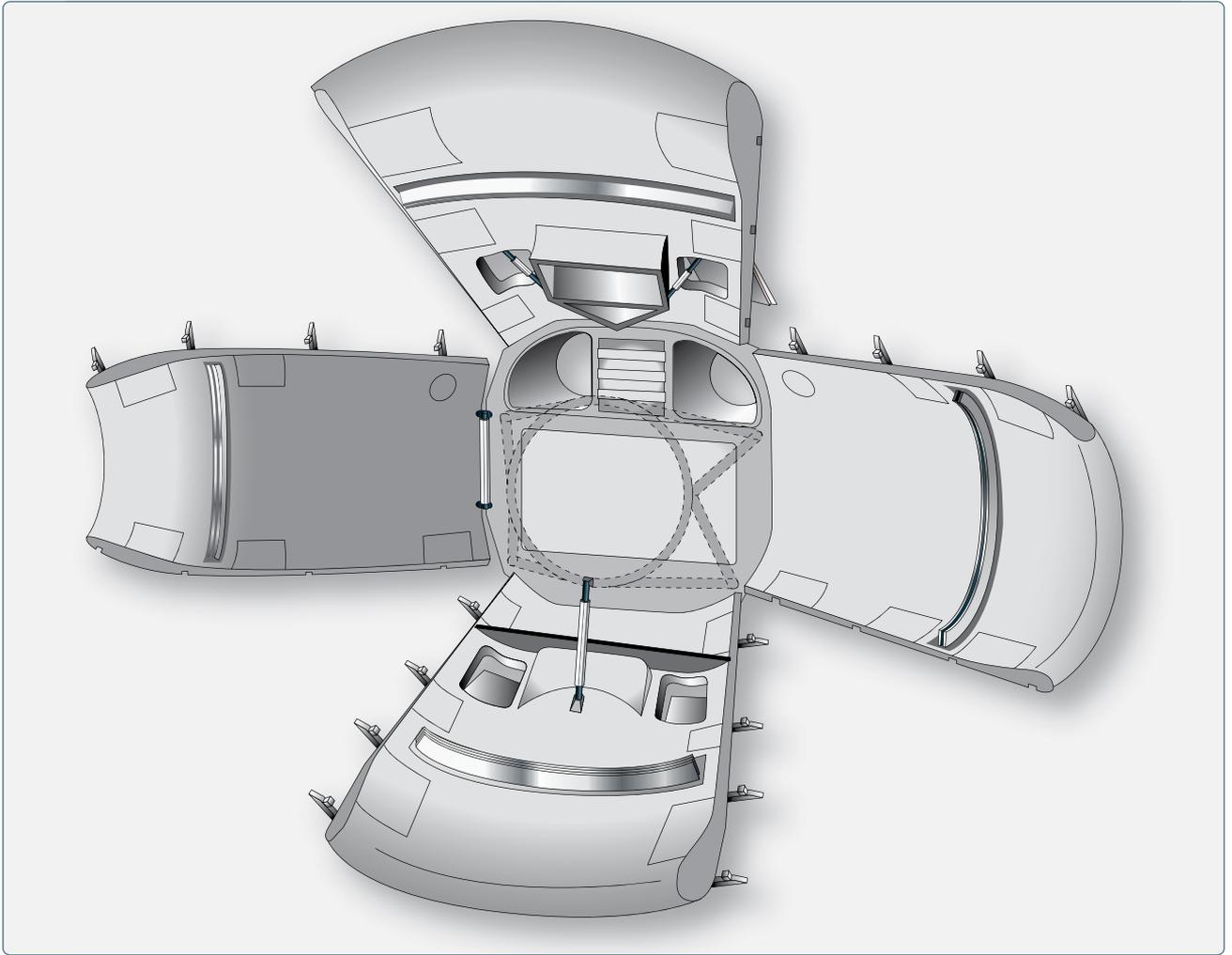


**Figure 1-42.** Various aircraft engine mounts.



**Figure 1-43.** Typical cowling for a horizontally opposed reciprocating engine.

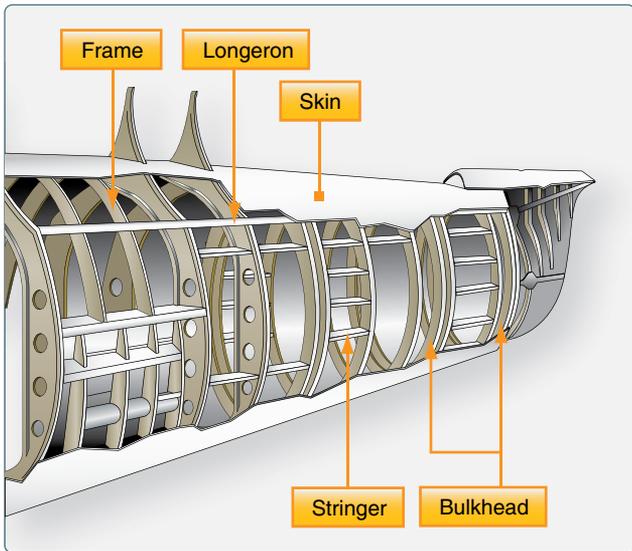
The tail cone serves to close and streamline the aft end of most fuselages. The cone is made up of structural members like those of the fuselage; however, cones are usually of lighter construction since they receive less stress than the fuselage. [Figure 1-46]



**Figure 1-44.** Orange peel cowling for large radial reciprocating engine.

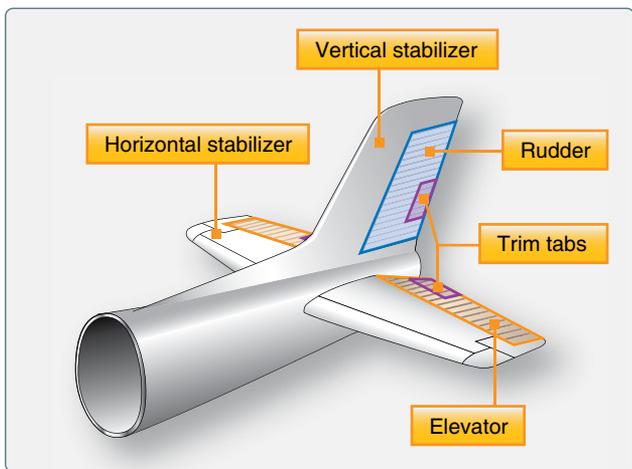


**Figure 1-45.** Cowling on a transport category turbine engine nacelle.



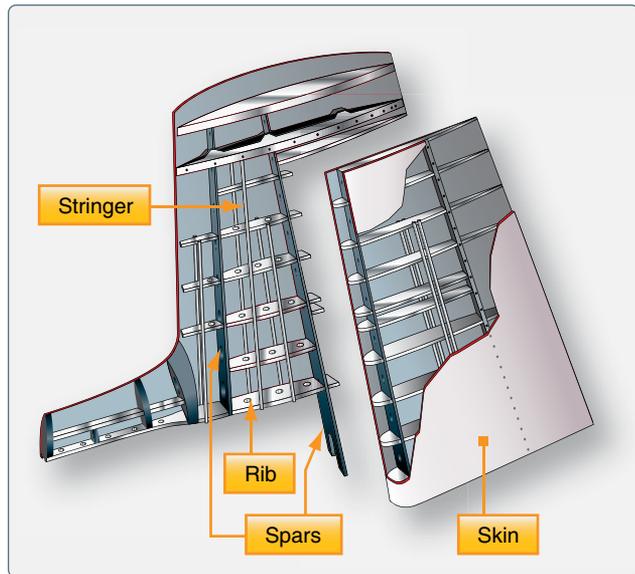
**Figure 1-46.** The fuselage terminates at the tail cone with similar but more lightweight construction.

The other components of the typical empennage are of heavier construction than the tail cone. These members include fixed surfaces that help stabilize the aircraft and movable surfaces that help to direct an aircraft during flight. The fixed surfaces are the horizontal stabilizer and vertical stabilizer. The movable surfaces are usually a rudder located at the aft edge of the vertical stabilizer and an elevator located at the aft edge the horizontal stabilizer. [Figure 1-47]



**Figure 1-47.** Components of a typical empennage.

The structure of the stabilizers is very similar to that which is used in wing construction. Figure 1-48 shows a typical vertical stabilizer. Notice the use of spars, ribs, stringers, and skin like those found in a wing. They perform the same functions shaping and supporting the stabilizer and transferring stresses. Bending, torsion, and shear created by air loads in flight pass from one structural member to another. Each member absorbs some of the stress and passes the remainder on to the others. Ultimately, the spar transmits



**Figure 1-48.** Vertical stabilizer.

any overloads to the fuselage. A horizontal stabilizer is built the same way.

The rudder and elevator are flight control surfaces that are also part of the empennage discussed in the next section of this chapter.

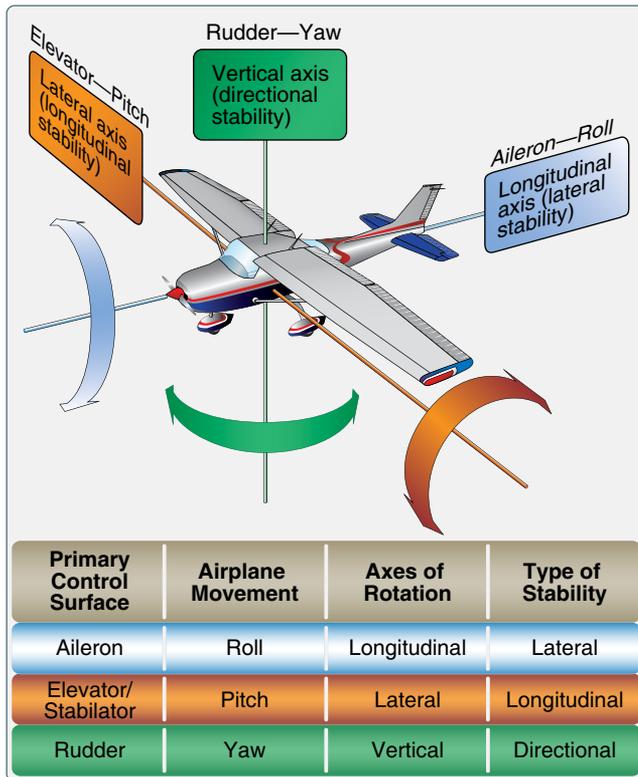
## Flight Control Surfaces

The directional control of a fixed-wing aircraft takes place around the lateral, longitudinal, and vertical axes by means of flight control surfaces designed to create movement about these axes. These control devices are hinged or movable surfaces through which the attitude of an aircraft is controlled during takeoff, flight, and landing. They are usually divided into two major groups: 1) primary or main flight control surfaces and 2) secondary or auxiliary control surfaces.

### Primary Flight Control Surfaces

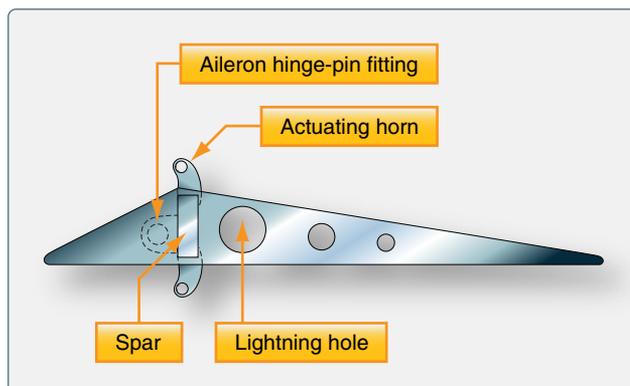
The primary flight control surfaces on a fixed-wing aircraft include: ailerons, elevators, and the rudder. The ailerons are attached to the trailing edge of both wings and when moved, rotate the aircraft around the longitudinal axis. The elevator is attached to the trailing edge of the horizontal stabilizer. When it is moved, it alters aircraft pitch, which is the attitude about the horizontal or lateral axis. The rudder is hinged to the trailing edge of the vertical stabilizer. When the rudder changes position, the aircraft rotates about the vertical axis (yaw). Figure 1-49 shows the primary flight controls of a light aircraft and the movement they create relative to the three axes of flight.

Primary control surfaces are usually similar in construction to one another and vary only in size, shape, and methods of



**Figure 1-49.** Flight control surfaces move the aircraft around the three axes of flight.

attachment. On aluminum light aircraft, their structure is often similar to an all-metal wing. This is appropriate because the primary control surfaces are simply smaller aerodynamic devices. They are typically made from an aluminum alloy structure built around a single spar member or torque tube to which ribs are fitted and a skin is attached. The lightweight ribs are, in many cases, stamped out from flat aluminum sheet stock. Holes in the ribs lighten the assembly. An aluminum skin is attached with rivets. *Figure 1-50* illustrates this type of structure, which can be found on the primary control surfaces of light aircraft as well as on medium and heavy aircraft.



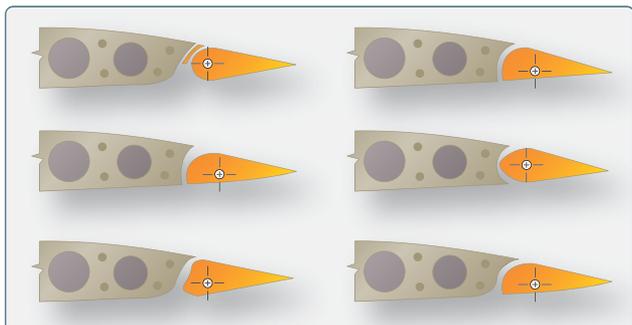
**Figure 1-50.** Typical structure of an aluminum flight control surface.

Primary control surfaces constructed from composite materials are also commonly used. These are found on many heavy and high-performance aircraft, as well as gliders, home-built, and light-sport aircraft. The weight and strength advantages over traditional construction can be significant. A wide variety of materials and construction techniques are employed. *Figure 1-51* shows examples of aircraft that use composite technology on primary flight control surfaces. Note that the control surfaces of fabric-covered aircraft often have fabric-covered surfaces just as aluminum-skinned (light) aircraft typically have all-aluminum control surfaces. There is a critical need for primary control surfaces to be balanced so they do not vibrate or flutter in the wind.



**Figure 1-51.** Composite control surfaces and some of the many aircraft that utilize them.

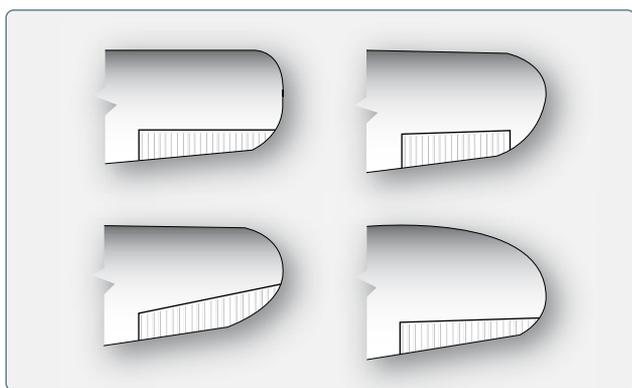
Performed to manufacturer's instructions, balancing usually consists of assuring that the center of gravity of a particular device is at or forward of the hinge point. Failure to properly balance a control surface could lead to catastrophic failure. *Figure 1-52* illustrates several aileron configurations with their hinge points well aft of the leading edge. This is a common design feature used to prevent flutter.



**Figure 1-52.** Aileron hinge locations are very close to but aft of the center of gravity to prevent flutter.

### Ailerons

Ailerons are the primary flight control surfaces that move the aircraft about the longitudinal axis. In other words, movement of the ailerons in flight causes the aircraft to roll. Ailerons are usually located on the outboard trailing edge of each of the wings. They are built into the wing and are calculated as part of the wing's surface area. *Figure 1-53* shows aileron locations on various wing tip designs.



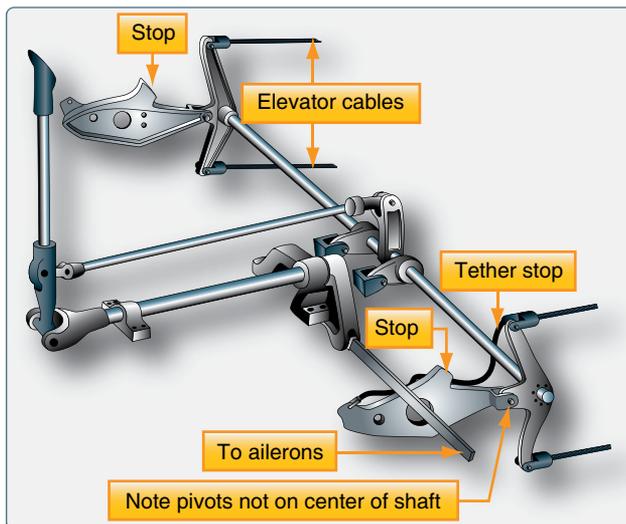
**Figure 1-53.** Aileron location on various wings.

Ailerons are controlled by a side-to-side motion of the control stick in the cockpit or a rotation of the control yoke. When the aileron on one wing deflects down, the aileron on the opposite wing deflects upward. This amplifies the movement of the aircraft around the longitudinal axis. On the wing on which the aileron trailing edge moves downward, camber is increased and lift is increased. Conversely, on the other wing, the raised aileron decreases lift. *[Figure 1-54]* The result is a sensitive response to the control input to roll the aircraft.



**Figure 1-54.** Differential aileron control movement. When one aileron is moved down, the aileron on the opposite wing is deflected upward.

The pilot's request for aileron movement and roll are transmitted from the cockpit to the actual control surface in a variety of ways depending on the aircraft. A system of control cables and pulleys, push-pull tubes, hydraulics, electric, or a combination of these can be employed. *[Figure 1-55]*



**Figure 1-55.** Transferring control surface inputs from the cockpit.

Simple, light aircraft usually do not have hydraulic or electric fly-by-wire aileron control. These are found on heavy and high-performance aircraft. Large aircraft and some high-performance aircraft may also have a second set of ailerons located inboard on the trailing edge of the wings. These are part of a complex system of primary and secondary control surfaces used to provide lateral control and stability in flight. At low speeds, the ailerons may be augmented by the use of flaps and spoilers. At high speeds, only inboard aileron deflection is required to roll the aircraft while the other control surfaces are locked out or remain stationary. *Figure 1-56*

illustrates the location of the typical flight control surfaces found on a transport category aircraft.

### ***Elevator***

The elevator is the primary flight control surface that moves the aircraft around the horizontal or lateral axis. This causes the nose of the aircraft to pitch up or down. The elevator is hinged to the trailing edge of the horizontal stabilizer and typically spans most or all of its width. It is controlled in the cockpit by pushing or pulling the control yoke forward or aft.

Light aircraft use a system of control cables and pulleys or push pull tubes to transfer cockpit inputs to the movement of the elevator. High performance and large aircraft typically employ more complex systems. Hydraulic power is commonly used to move the elevator on these aircraft. On aircraft equipped with fly-by-wire controls, a combination of electrical and hydraulic power is used.

### ***Rudder***

The rudder is the primary control surface that causes an aircraft to yaw or move about the vertical axis. This provides directional control and thus points the nose of the aircraft in the direction desired. Most aircraft have a single rudder hinged to the trailing edge of the vertical stabilizer. It is controlled by a pair of foot-operated rudder pedals in the cockpit. When the right pedal is pushed forward, it deflects the rudder to the right which moves the nose of the aircraft

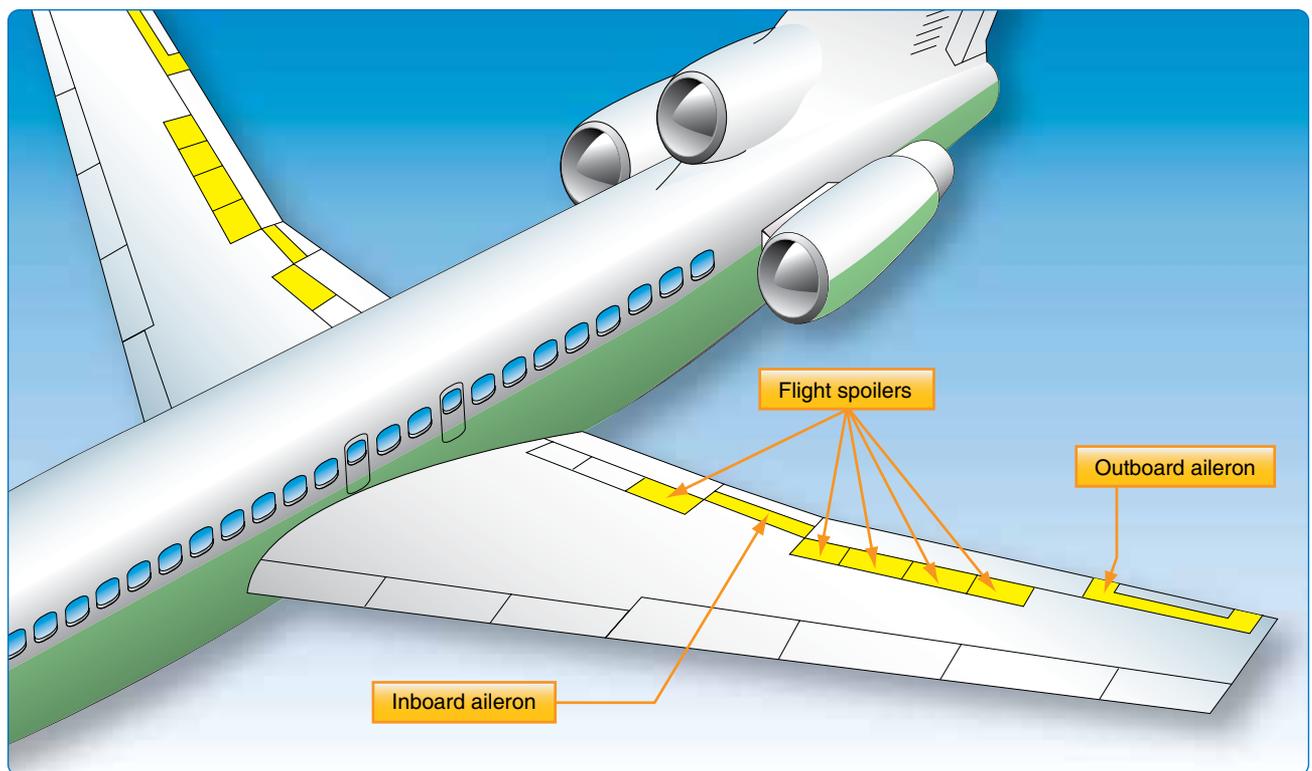
to the right. The left pedal is rigged to simultaneously move aft. When the left pedal is pushed forward, the nose of the aircraft moves to the left.

As with the other primary flight controls, the transfer of the movement of the cockpit controls to the rudder varies with the complexity of the aircraft. Many aircraft incorporate the directional movement of the nose or tail wheel into the rudder control system for ground operation. This allows the operator to steer the aircraft with the rudder pedals during taxi when the airspeed is not high enough for the control surfaces to be effective. Some large aircraft have a split rudder arrangement. This is actually two rudders, one above the other. At low speeds, both rudders deflect in the same direction when the pedals are pushed. At higher speeds, one of the rudders becomes inoperative as the deflection of a single rudder is aerodynamically sufficient to maneuver the aircraft.

### **Dual Purpose Flight Control Surfaces**

The ailerons, elevators, and rudder are considered conventional primary control surfaces. However, some aircraft are designed with a control surface that may serve a dual purpose. For example, elevons perform the combined functions of the ailerons and the elevator. [Figure 1-57]

A movable horizontal tail section, called a stabilator, is a control surface that combines the action of both the horizontal stabilizer and the elevator. [Figure 1-58] Basically, a



**Figure 1-56.** Typical flight control surfaces on a transport category aircraft.



Figure 1-57. Elevons.



Figure 1-58. A stabilizer and index marks on a transport category aircraft.

stabilator is a horizontal stabilizer that can also be rotated about the horizontal axis to affect the pitch of the aircraft. A ruddervator combines the action of the rudder and elevator. [Figure 1-59] This is possible on aircraft with V-tail empennages where the traditional horizontal and vertical stabilizers do not exist. Instead, two stabilizers angle upward and outward from the aft fuselage in a “V” configuration. Each contains a movable ruddervator built into the trailing



Figure 1-59. Ruddervator.

edge. Movement of the ruddervators can alter the movement of the aircraft around the horizontal and/or vertical axis. Additionally, some aircraft are equipped with flaperons. [Figure 1-60] Flaperons are ailerons which can also act as flaps. Flaps are secondary control surfaces on most wings, discussed in the next section of this chapter.



Figure 1-60. Flaperons.

### Secondary or Auxiliary Control Surfaces

There are several secondary or auxiliary flight control surfaces. Their names, locations, and functions of those for most large aircraft are listed in Figure 1-61.

#### Flaps

Flaps are found on most aircraft. They are usually inboard on the wings’ trailing edges adjacent to the fuselage. Leading edge flaps are also common. They extend forward and down from the inboard wing leading edge. The flaps are lowered to increase the camber of the wings and provide greater lift and control at slow speeds. They enable landing at slower speeds and shorten the amount of runway required for takeoff and landing. The amount that the flaps extend and the angle they form with the wing can be selected from the cockpit. Typically, flaps can extend up to 45–50°. Figure 1-62 shows various aircraft with flaps in the extended position.

Flaps are usually constructed of materials and with techniques used on the other airfoils and control surfaces of a particular aircraft. Aluminum skin and structure flaps are the norm on light aircraft. Heavy and high-performance aircraft flaps may also be aluminum, but the use of composite structures is also common.

There are various kinds of flaps. Plain flaps form the trailing edge of the wing when the flap is in the retracted position. [Figure 1-63A] The airflow over the wing continues over the upper and lower surfaces of the flap, making the trailing edge of the flap essentially the trailing edge of the wing. The plain

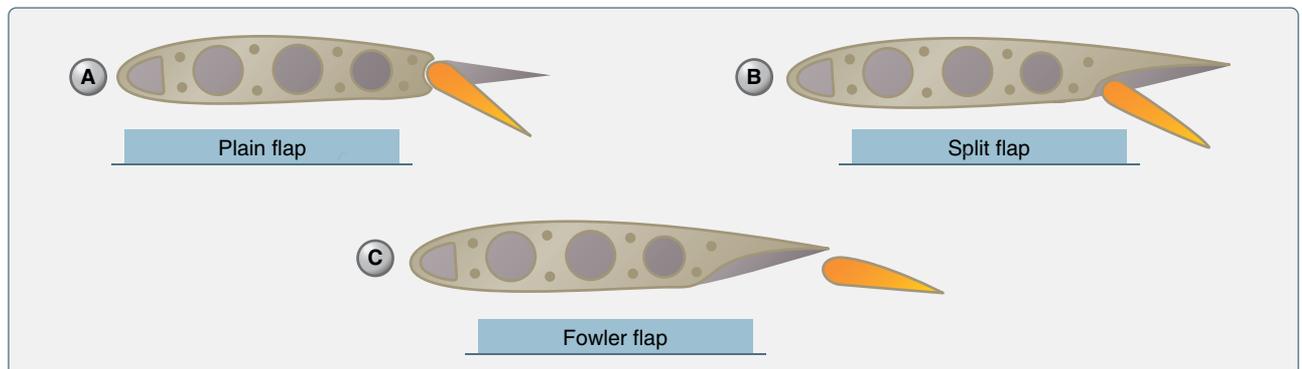
Secondary/Auxiliary Flight Control Surfaces		
Name	Location	Function
Flaps	Inboard trailing edge of wings	Extends the camber of the wing for greater lift and slower flight. Allows control at low speeds for short field takeoffs and landings.
Trim tabs	Trailing edge of primary flight control surfaces	Reduces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

**NOTE: An aircraft may possess none, one, or a combination of the above control surfaces.**

**Figure 1-61.** Secondary or auxiliary control surfaces and respective locations for larger aircraft.



**Figure 1-62.** Various aircraft with flaps in the extended position.



**Figure 1-63.** Various types of flaps.

flap is hinged so that the trailing edge can be lowered. This increases wing camber and provides greater lift.

A split flap is normally housed under the trailing edge of the wing. [Figure 1-63B] It is usually just a braced flat metal plate hinged at several places along its leading edge. The upper surface of the wing extends to the trailing edge of the flap. When deployed, the split flap trailing edge lowers away from the trailing edge of the wing. Airflow over the top of the wing remains the same. Airflow under the wing now follows the camber created by the lowered split flap, increasing lift.

Fowler flaps not only lower the trailing edge of the wing when deployed but also slide aft, effectively increasing the area of the wing. [Figure 1-63C] This creates more lift via the increased surface area, as well as the wing camber. When stowed, the fowler flap typically retracts up under the wing trailing edge similar to a split flap. The sliding motion of a fowler flap can be accomplished with a worm drive and flap tracks.

An enhanced version of the fowler flap is a set of flaps that actually contains more than one aerodynamic surface. Figure 1-64 shows a triple-slotted flap. In this configuration, the flap consists of a fore flap, a mid flap, and an aft flap. When deployed, each flap section slides aft on tracks as it lowers. The flap sections also separate leaving an open slot between the wing and the fore flap, as well as between each of the flap sections. Air from the underside of the wing flows through these slots. The result is that the laminar flow on the upper surfaces is enhanced. The greater camber and effective wing area increase overall lift.

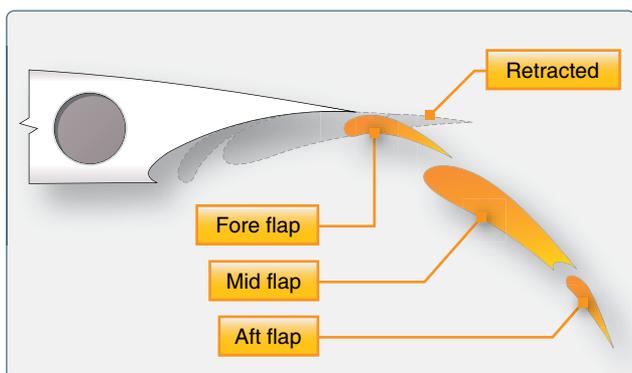


Figure 1-64. Triple slotted flap.

Heavy aircraft often have leading edge flaps that are used in conjunction with the trailing edge flaps. [Figure 1-65] They can be made of machined magnesium or can have an aluminum or composite structure. While they are not installed or operate independently, their use with trailing edge flaps can greatly increase wing camber and lift. When stowed, leading edge flaps retract into the leading edge of the wing.

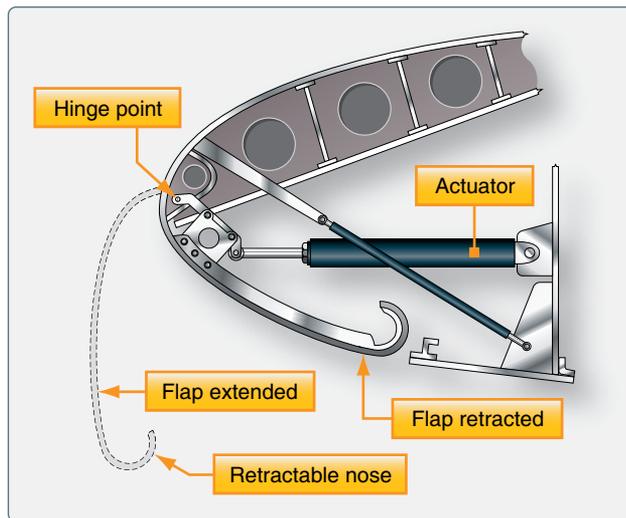


Figure 1-65. Leading edge flaps.

The differing designs of leading edge flaps essentially provide the same effect. Activation of the trailing edge flaps automatically deploys the leading edge flaps, which are driven out of the leading edge and downward, extending the camber of the wing. Figure 1-66 shows a Krueger flap, recognizable by its flat mid-section.

### Slats

Another leading-edge device which extends wing camber is a slat. Slats can be operated independently of the flaps with their own switch in the cockpit. Slats not only extend out of the leading edge of the wing increasing camber and lift, but most often, when fully deployed leave a slot between their trailing edges and the leading edge of the wing. [Figure 1-67] This increases the angle of attack at which the wing will maintain its laminar airflow, resulting in the ability to fly the aircraft slower and still maintain control.

### Spoilers and Speed Brakes

A spoiler is a device found on the upper surface of many heavy and high-performance aircraft. It is stowed flush to the wing's upper surface. When deployed, it raises up into the airstream and disrupts the laminar airflow of the wing, thus reducing lift.

Spoilers are made with similar construction materials and techniques as the other flight control surfaces on the aircraft. Often, they are honeycomb-core flat panels. At low speeds, spoilers are rigged to operate when the ailerons operate to assist with the lateral movement and stability of the aircraft. On the wing where the aileron is moved up, the spoilers also raise thus amplifying the reduction of lift on that wing. [Figure 1-68] On the wing with downward aileron deflection, the spoilers remain stowed. As the speed of the aircraft



**Figure 1-66.** Side view (left) and front view (right) of a Krueger flap on a Boeing 737.



**Figure 1-67.** Air passing through the slot aft of the slat promotes boundary layer airflow on the upper surface at high angles of attack.

increases, the ailerons become more effective and the spoiler interconnect disengages.

Spoilers are unique in that they may also be fully deployed on both wings to act as speed brakes. The reduced lift and increased drag can quickly reduce the speed of the aircraft in flight. Dedicated speed brake panels similar to flight spoilers in construction can also be found on the upper surface of the wings of heavy and high-performance aircraft. They are designed specifically to increase drag and reduce the speed of the aircraft when deployed. These speed brake panels do not operate differentially with the ailerons at low speed.



**Figure 1-68.** Spoilers deployed upon landing on a transport category aircraft.

The speed brake control in the cockpit can deploy all spoiler and speed brake surfaces fully when operated. Often, these surfaces are also rigged to deploy on the ground automatically when engine thrust reversers are activated.

### ***Tabs***

The force of the air against a control surface during the high speed of flight can make it difficult to move and hold that control surface in the deflected position. A control surface might also be too sensitive for similar reasons. Several different tabs are used to aid with these types of problems. The table in *Figure 1-69* summarizes the various tabs and their uses.

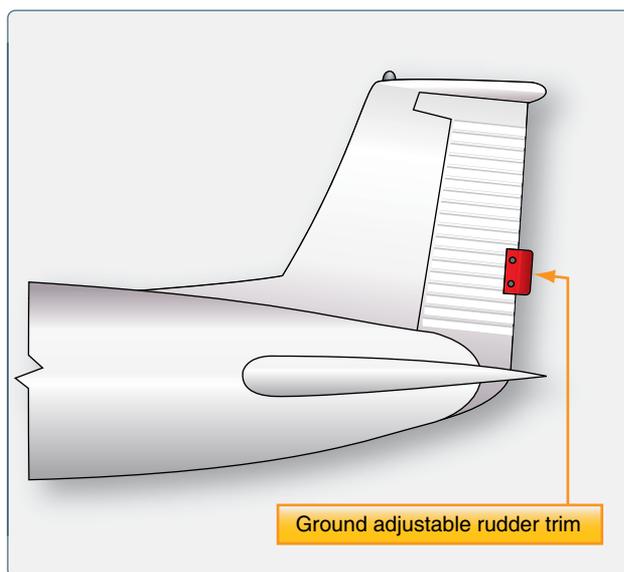
Flight Control Tabs			
Type	Direction of Motion (in relation to control surface)	Activation	Effect
Trim	Opposite	Set by pilot from cockpit. Uses independent linkage.	Statically balances the aircraft in flight. Allows “hands off” maintenance of flight condition.
Balance	Opposite	Moves when pilot moves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

**Figure 1-69.** Various tabs and their uses.

While in flight, it is desirable for the pilot to be able to take his or her hands and feet off of the controls and have the aircraft maintain its flight condition. Trims tabs are designed to allow this. Most trim tabs are small movable surfaces located on the trailing edge of a primary flight control surface. A small movement of the tab in the direction opposite of the direction the flight control surface is deflected, causing air to strike the tab, in turn producing a force that aids in maintaining the flight control surface in the desired position. Through linkage set from the cockpit, the tab can be positioned so that it is actually holding the control surface in position rather than the pilot. Therefore, elevator tabs are used to maintain the speed of the aircraft since they assist in maintaining the selected pitch. Rudder tabs can be set to hold yaw in check and maintain heading. Aileron tabs can help keep the wings level.

Occasionally, a simple light aircraft may have a stationary metal plate attached to the trailing edge of a primary flight control, usually the rudder. This is also a trim tab as shown in *Figure 1-70*. It can be bent slightly on the ground to trim the aircraft in flight to a hands-off condition when flying straight and level. The correct amount of bend can be determined only by flying the aircraft after an adjustment. Note that a small amount of bending is usually sufficient.

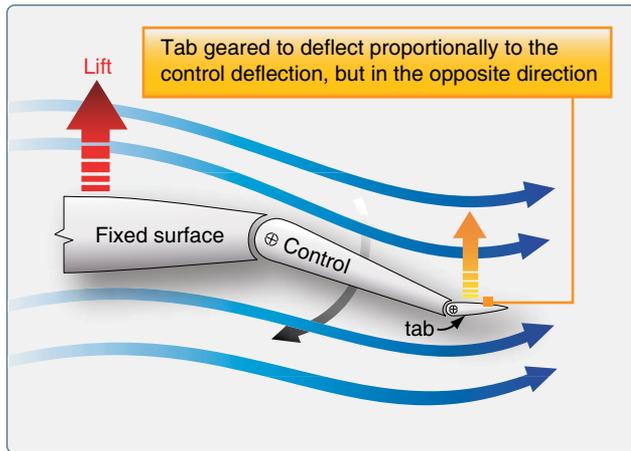
The aerodynamic phenomenon of moving a trim tab in one direction to cause the control surface to experience a force moving in the opposite direction is exactly what occurs with the use of balance tabs. [Figure 1-71] Often, it is difficult to move a primary control surface due to its surface area and the speed of the air rushing over it. Deflecting a balance tab hinged at the trailing edge of the control surface in the opposite



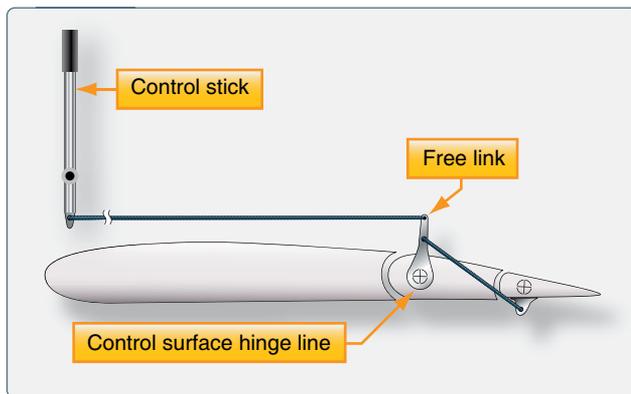
**Figure 1-70.** Example of a trim tab.

direction of the desired control surface movement causes a force to position the surface in the proper direction with reduced force to do so. Balance tabs are usually linked directly to the control surface linkage so that they move automatically when there is an input for control surface movement. They also can double as trim tabs, if adjustable in the flight deck.

A servo tab is similar to a balance tab in location and effect, but it is designed to operate the primary flight control surface, not just reduce the force needed to do so. It is usually used as a means to back up the primary control of the flight control surfaces. [Figure 1-72]



**Figure 1-71.** Balance tabs assist with forces needed to position control surfaces.

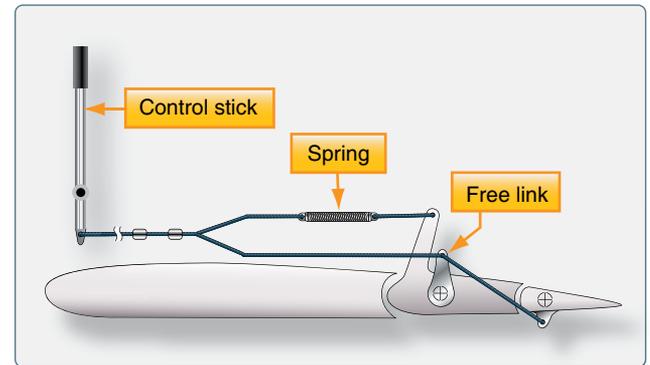


**Figure 1-72.** Servo tabs can be used to position flight control surfaces in case of hydraulic failure.

On heavy aircraft, large control surfaces require too much force to be moved manually and are usually deflected out of the neutral position by hydraulic actuators. These power control units are signaled via a system of hydraulic valves connected to the yoke and rudder pedals. On fly-by-wire aircraft, the hydraulic actuators that move the flight control

surfaces are signaled by electric input. In the case of hydraulic system failure(s), manual linkage to a servo tab can be used to deflect it. This, in turn, provides an aerodynamic force that moves the primary control surface.

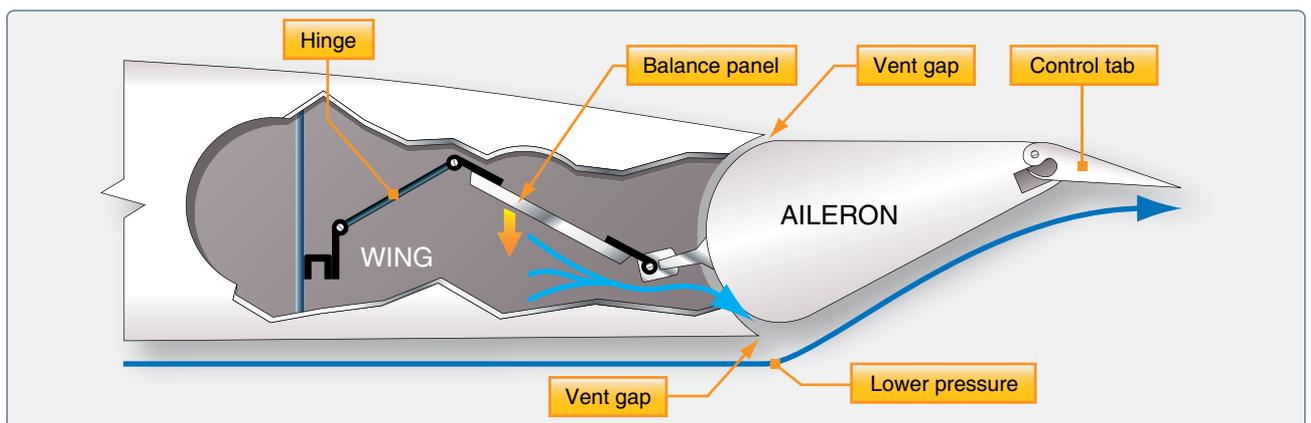
A control surface may require excessive force to move only in the final stages of travel. When this is the case, a spring tab can be used. This is essentially a servo tab that does not activate until an effort is made to move the control surface beyond a certain point. When reached, a spring in line of the control linkage aids in moving the control surface through the remainder of its travel. [Figure 1-73]



**Figure 1-73.** Many tab linkages have a spring tab that kicks in as the forces needed to deflect a control increase with speed and the angle of desired deflection.

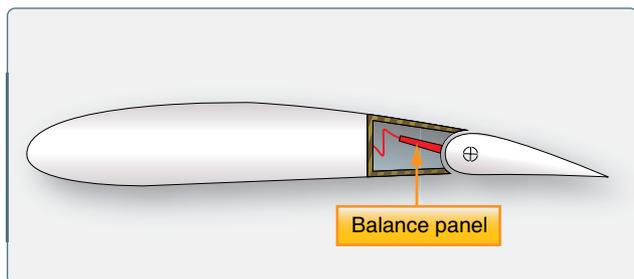
Figure 1-74 shows another way of assisting the movement of an aileron on a large aircraft. It is called an aileron balance panel. Not visible when approaching the aircraft, it is positioned in the linkage that hinges the aileron to the wing.

Balance panels have been constructed typically of aluminum skin-covered frame assemblies or aluminum honeycomb structures. The trailing edge of the wing just forward of the leading edge of the aileron is sealed to allow controlled airflow in and out of the hinge area where the balance panel is located.



**Figure 1-74.** An aileron balance panel and linkage uses varying air pressure to assist in control surface positioning.

[Figure 1-75] When the aileron is moved from the neutral position, differential pressure builds up on one side of the balance panel. This differential pressure acts on the balance panel in a direction that assists the aileron movement. For slight movements, deflecting the control tab at the trailing edge of the aileron is easy enough to not require significant assistance from the balance tab. (Moving the control tab moves the ailerons as desired.) But, as greater deflection is requested, the force resisting control tab and aileron movement becomes greater and augmentation from the balance tab is needed. The seals and mounting geometry allow the differential pressure of airflow on the balance panel to increase as deflection of the ailerons is increased. This makes the resistance felt when moving the aileron controls relatively constant.



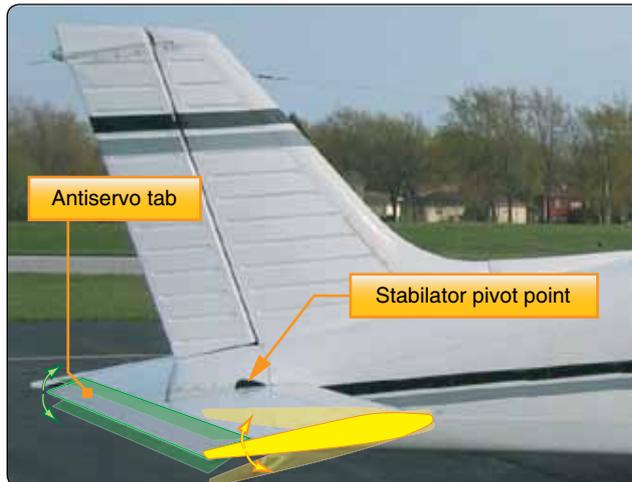
**Figure 1-75.** The trailing edge of the wing just forward of the leading edge of the aileron is sealed to allow controlled airflow in and out of the hinge area where the balance panel is located.

Antiservo tabs, as the name suggests, are like servo tabs but move in the same direction as the primary control surface. On some aircraft, especially those with a movable horizontal stabilizer, the input to the control surface can be too sensitive. An antiservo tab tied through the control linkage creates an aerodynamic force that increases the effort needed to move the control surface. This makes flying the aircraft more stable for the pilot. *Figure 1-76* shows an antiservo tab in the near neutral position. Deflected in the same direction as the desired stabilator movement, it increases the required control surface input.

### Other Wing Features

There may be other structures visible on the wings of an aircraft that contribute to performance. Winglets, vortex generators, stall fences, and gap seals are all common wing features. Introductory descriptions of each are given in the following paragraphs.

A winglet is an obvious vertical upturn of the wing's tip resembling a vertical stabilizer. It is an aerodynamic device designed to reduce the drag created by wing tip vortices in flight. Usually made from aluminum or composite materials, winglets can be designed to optimize performance at a desired speed. [Figure 1-77]



**Figure 1-76.** An antiservo tab moves in the same direction as the control tab. Shown here on a stabilator, it desensitizes the pitch control.



**Figure 1-77.** A winglet reduces aerodynamic drag caused by air spilling off of the wing tip.

Vortex generators are small airfoil sections usually attached to the upper surface of a wing. [Figure 1-78] They are designed to promote positive laminar airflow over the wing and control surfaces. Usually made of aluminum and installed in a spanwise line or lines, the vortices created by these devices swirl downward assisting maintenance of the boundary layer of air flowing over the wing. They can also be found on the fuselage and empennage. *Figure 1-79* shows the unique vortex generators on a Symphony SA-160 wing.

A chordwise barrier on the upper surface of the wing, called a stall fence, is used to halt the spanwise flow of air. During low speed flight, this can maintain proper chordwise airflow reducing the tendency for the wing to stall. Usually made of aluminum, the fence is a fixed structure most common on swept wings, which have a natural spanwise tending boundary air flow. [Figure 1-80]

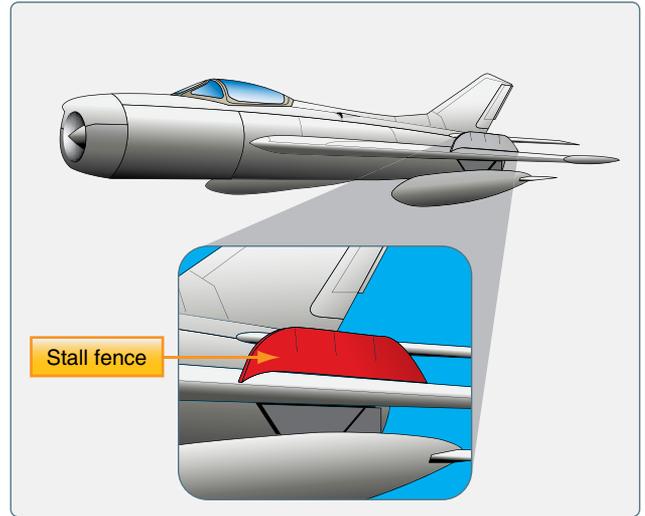


**Figure 1-78.** Vortex generators.



**Figure 1-79.** The Symphony SA-160 has two unique vortex generators on its wing to ensure aileron effectiveness through the stall.

Often, a gap can exist between the stationary trailing edge of a wing or stabilizer and the movable control surface(s). At high angles of attack, high pressure air from the lower wing surface can be disrupted at this gap. The result can be turbulent airflow, which increases drag. There is also a tendency for some lower wing boundary air to enter the gap



**Figure 1-80.** A stall fence aids in maintaining chordwise airflow over the wing.

and disrupt the upper wing surface airflow, which in turn reduces lift and control surface responsiveness. The use of gap seals is common to promote smooth airflow in these gap areas. Gap seals can be made of a wide variety of materials ranging from aluminum and impregnated fabric to foam and plastic. *Figure 1-81* shows some gap seals installed on various aircraft.

## Landing Gear

The landing gear supports the aircraft during landing and while it is on the ground. Simple aircraft that fly at low speeds generally have fixed gear. This means the gear is stationary and does not retract for flight. Faster, more complex aircraft have retractable landing gear. After takeoff, the landing gear is retracted into the fuselage or wings and out of the airstream. This is important because extended gear create significant parasite drag which reduces performance. Parasite drag is caused by the friction of the air flowing over the gear. It increases with speed. On very light, slow aircraft, the



**Figure 1-81.** Gap seals promote the smooth flow of air over gaps between fixed and movable surfaces.

extra weight that accompanies a retractable landing gear is more of a detriment than the drag caused by the fixed gear. Lightweight fairings and wheel pants can be used to keep drag to a minimum. *Figure 1-82* shows examples of fixed and retractable gear.

Landing gear must be strong enough to withstand the forces of landing when the aircraft is fully loaded. In addition to strength, a major design goal is to have the gear assembly be as light as possible. To accomplish this, landing gear are made from a wide range of materials including steel, aluminum, and magnesium. Wheels and tires are designed specifically for aviation use and have unique operating characteristics. Main wheel assemblies usually have a braking system. To aid with the potentially high impact of landing, most landing gear have a means of either absorbing shock or accepting shock and distributing it so that the structure is not damaged.

Not all aircraft landing gear are configured with wheels. Helicopters, for example, have such high maneuverability and low landing speeds that a set of fixed skids is common and quite functional with lower maintenance. The same is true for free balloons which fly slowly and land on wood skids affixed to the floor of the gondola. Other aircraft landing gear are equipped with pontoons or floats for operation on water. A large amount of drag accompanies this type of gear, but an aircraft that can land and take off on water can be very useful in certain environments. Even skis can be found under some aircraft for operation on snow and ice. *Figure 1-83* shows some of these alternative landing gear, the majority of which are the fixed gear type.



**Figure 1-82.** Landing gear can be fixed (top) or retractable (bottom).

Amphibious aircraft are aircraft that can land either on land or on water. On some aircraft designed for such dual usage, the bottom half of the fuselage acts as a hull. Usually, it is accompanied by outriggers on the underside of the wings near the tips to aid in water landing and taxi. Main gear that retract into the fuselage are only extended when landing on



**Figure 1-83.** Aircraft landing gear without wheels.

the ground or a runway. This type of amphibious aircraft is sometimes called a flying boat. [Figure 1-84]



**Figure 1-84.** An amphibious aircraft is sometimes called a flying boat because the fuselage doubles as a hull.

Many aircraft originally designed for land use can be fitted with floats with retractable wheels for amphibious use. [Figure 1-85] Typically, the gear retracts into the float when not needed. Sometimes a dorsal fin is added to the aft underside of the fuselage for longitudinal stability during water operations. It is even possible on some aircraft to direct this type of fin by tying its control into the aircraft's rudder pedals. Skis can also be fitted with wheels that retract to allow landing on solid ground or on snow and ice.



**Figure 1-85.** Retractable wheels make this aircraft amphibious.

### Tail Wheel Gear Configuration

There are two basic configurations of airplane landing gear: conventional gear or tail wheel gear and the tricycle gear. Tail wheel gear dominated early aviation and therefore has become known as conventional gear. In addition to its two main wheels which are positioned under most of the weight of the aircraft, the conventional gear aircraft also has a smaller wheel located at the aft end of the fuselage. [Figure 1-86] Often this tail wheel is able to be steered

by rigging cables attached to the rudder pedals. Other conventional gear have no tail wheel at all using just a steel skid plate under the aft fuselage instead. The small tail wheel or skid plate allows the fuselage to incline, thus giving clearance for the long propellers that prevailed in aviation through WWII. It also gives greater clearance between the propeller and loose debris when operating on an unpaved runway. But the inclined fuselage blocks the straight ahead vision of the pilot during ground operations. Until up to speed where the elevator becomes effective to lift the tail wheel off the ground, the pilot must lean his head out the side of the cockpit to see directly ahead of the aircraft.



**Figure 1-86.** An aircraft with tail wheel gear.

The use of tail wheel gear can pose another difficulty. When landing, tail wheel aircraft can easily ground loop. A ground loop is when the tail of the aircraft swings around and comes forward of the nose of the aircraft. The reason this happens is due to the two main wheels being forward of the aircraft's center of gravity. The tail wheel is aft of the center of gravity. If the aircraft swerves upon landing, the tail wheel can swing out to the side of the intended path of travel. If far enough to the side, the tail can pull the center of gravity out from its desired location slightly aft of but between the main gear. Once the center of gravity is no longer trailing the mains, the tail of the aircraft freely pivots around the main wheels causing the ground loop.

Conventional gear is useful and is still found on certain models of aircraft manufactured today, particularly aerobatic aircraft, crop dusters, and aircraft designed for unpaved runway use. It is typically lighter than tricycle gear which requires a stout, fully shock absorbing nose wheel assembly. The tail wheel configuration excels when operating out of unpaved runways. With the two strong main gear forward providing stability and directional control during takeoff roll, the lightweight tail wheel does little more than keep the aft end of the fuselage from striking the ground. As mentioned, at a certain speed, the air flowing over the elevator is sufficient for it to raise the

tail off the ground. As speed increases further, the two main wheels under the center of gravity are very stable.

### Tricycle Gear

Tricycle gear is the most prevalent landing gear configuration in aviation. In addition to the main wheels, a shock absorbing nose wheel is at the forward end of the fuselage. Thus, the center of gravity is then forward of the main wheels. The tail of the aircraft is suspended off the ground and clear view straight ahead from the cockpit is given. Ground looping is nearly eliminated since the center of gravity follows the directional nose wheel and remains between the mains.

Light aircraft use tricycle gear, as well as heavy aircraft. Twin nose wheels on the single forward strut and massive multistrut/multiwheel main gear may be found supporting the world's largest aircraft, but the basic configuration is still tricycle. The nose wheel may be steered with the rudder pedals on small aircraft. Larger aircraft often have a nose wheel steering wheel located off to the side of the cockpit. *Figure 1-87* shows aircraft with tricycle gear. Chapter 13, Aircraft Landing Gear Systems, discusses landing gear in detail.

### Maintaining the Aircraft

Maintenance of an aircraft is of the utmost importance for safe flight. Licensed technicians are committed to perform timely maintenance functions in accordance with the manufacturer's instructions and under the 14 CFR. At no time is an act of aircraft maintenance taken lightly or improvised. The consequences of such action could be fatal and the technician could lose his or her license and face criminal charges.

Airframe, engine, and aircraft component manufacturers are responsible for documenting the maintenance procedures that guide managers and technicians on when and how to perform maintenance on their products. A small aircraft may only require a few manuals, including the aircraft maintenance manual. This volume usually contains the most frequently

used information required to maintain the aircraft properly. The Type Certificate Data Sheet (TCDS) for an aircraft also contains critical information. Complex and large aircraft require several manuals to convey correct maintenance procedures adequately. In addition to the maintenance manual, manufacturers may produce such volumes as structural repair manuals, overhaul manuals, wiring diagram manuals, component manuals, and more.

Note that the use of the word "manual" is meant to include electronic as well as printed information. Also, proper maintenance extends to the use of designated tools and fixtures called out in the manufacturer's maintenance documents. In the past, not using the proper tooling has caused damage to critical components, which subsequently failed and led to aircraft crashes and the loss of human life. The technician is responsible for sourcing the correct information, procedures, and tools needed to perform airworthy maintenance or repairs.

Standard aircraft maintenance procedures do exist and can be used by the technician when performing maintenance or a repair. These are found in the Federal Aviation Administration (FAA) approved advisory circulars (AC) 43.13-2 and AC 43.13-1. If not addressed by the manufacturer's literature, the technician may use the procedures outlined in these manuals to complete the work in an acceptable manner. These procedures are not specific to any aircraft or component and typically cover methods used during maintenance of all aircraft. Note that the manufacturer's instructions supersede the general procedures found in AC 43.13-2 and AC 43.13-1.

All maintenance related actions on an aircraft or component are required to be documented by the performing technician in the aircraft or component logbook. Light aircraft may have only one logbook for all work performed. Some aircraft may have a separate engine logbook for any work performed on the engine(s). Other aircraft have separate propeller logbooks.



**Figure 1-87.** Tricycle landing gear is the most predominant landing gear configuration in aviation.

Large aircraft require volumes of maintenance documentation comprised of thousands of procedures performed by hundreds of technicians. Electronic dispatch and recordkeeping of maintenance performed on large aircraft such as airliners is common. The importance of correct maintenance recordkeeping should not be overlooked.

### Location Numbering Systems

Even on small, light aircraft, a method of precisely locating each structural component is required. Various numbering systems are used to facilitate the location of specific wing frames, fuselage bulkheads, or any other structural members on an aircraft. Most manufacturers use some system of station marking. For example, the nose of the aircraft may be designated “zero station,” and all other stations are located at measured distances in inches behind the zero station. Thus, when a blueprint reads “fuselage frame station 137,” that particular frame station can be located 137 inches behind the nose of the aircraft.

To locate structures to the right or left of the center line of an aircraft, a similar method is employed. Many manufacturers consider the center line of the aircraft to be a zero station from which measurements can be taken to the right or left to locate an airframe member. This is often used on the horizontal stabilizer and wings.

The applicable manufacturer’s numbering system and abbreviated designations or symbols should always be reviewed before attempting to locate a structural member. They are not always the same. The following list includes location designations typical of those used by many manufacturers.

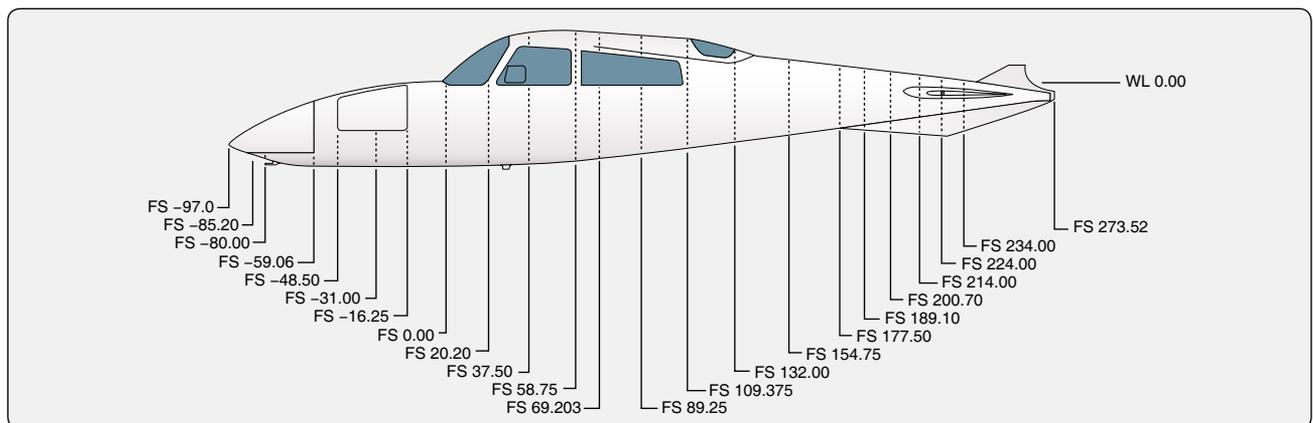
- Fuselage stations (Fus. Sta. or FS) are numbered in inches from a reference or zero point known as the reference datum. [Figure 1-88] The reference datum is an imaginary vertical plane at or near the nose of

the aircraft from which all fore and aft distances are measured. The distance to a given point is measured in inches parallel to a center line extending through the aircraft from the nose through the center of the tail cone. Some manufacturers may call the fuselage station a body station, abbreviated BS.

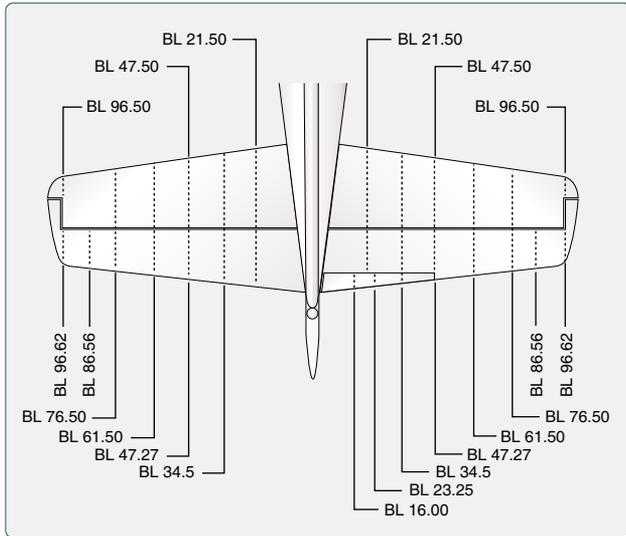
- Buttock line or butt line (BL) is a vertical reference plane down the center of the aircraft from which measurements left or right can be made. [Figure 1-89]
- Water line (WL) is the measurement of height in inches perpendicular from a horizontal plane usually located at the ground, cabin floor, or some other easily referenced location. [Figure 1-90]
- Aileron station (AS) is measured outboard from, and parallel to, the inboard edge of the aileron, perpendicular to the rear beam of the wing.
- Flap station (KS) is measured perpendicular to the rear beam of the wing and parallel to, and outboard from, the inboard edge of the flap.
- Nacelle station (NC or Nac. Sta.) is measured either forward of or behind the front spar of the wing and perpendicular to a designated water line.

In addition to the location stations listed above, other measurements are used, especially on large aircraft. Thus, there may be horizontal stabilizer stations (HSS), vertical stabilizer stations (VSS) or powerplant stations (PPS). [Figure 1-91] In every case, the manufacturer’s terminology and station location system should be consulted before locating a point on a particular aircraft.

Another method is used to facilitate the location of aircraft components on air transport aircraft. This involves dividing the aircraft into zones. These large areas or major zones are further divided into sequentially numbered zones and subzones. The digits of the zone number are reserved and



**Figure 1-88.** The various body stations relative to a single point of origin illustrated in inches or some other measurement (if of foreign development).



**Figure 1-89.** Butt line diagram of a horizontal stabilizer.

indexed to indicate the location and type of system of which the component is a part. *Figure 1-92* illustrates these zones and subzones on a transport category aircraft.

### Access and Inspection Panels

Knowing where a particular structure or component is located on an aircraft needs to be combined with gaining access to that area to perform the required inspections or maintenance. To facilitate this, access and inspection panels are located on most surfaces of the aircraft. Small panels that are hinged or removable allow inspection and servicing. Large panels and doors allow components to be removed and installed, as well as human entry for maintenance purposes.

The underside of a wing, for example, sometimes contains dozens of small panels through which control cable components can be monitored and fittings greased. Various drains and jack points may also be on the underside of the wing. The upper surface of the wings typically have fewer access panels because a smooth surface promotes

better laminar airflow, which causes lift. On large aircraft, walkways are sometimes designated on the wing upper surface to permit safe navigation by mechanics and inspectors to critical structures and components located along the wing's leading and trailing edges. Wheel wells and special component bays are places where numerous components and accessories are grouped together for easy maintenance access.

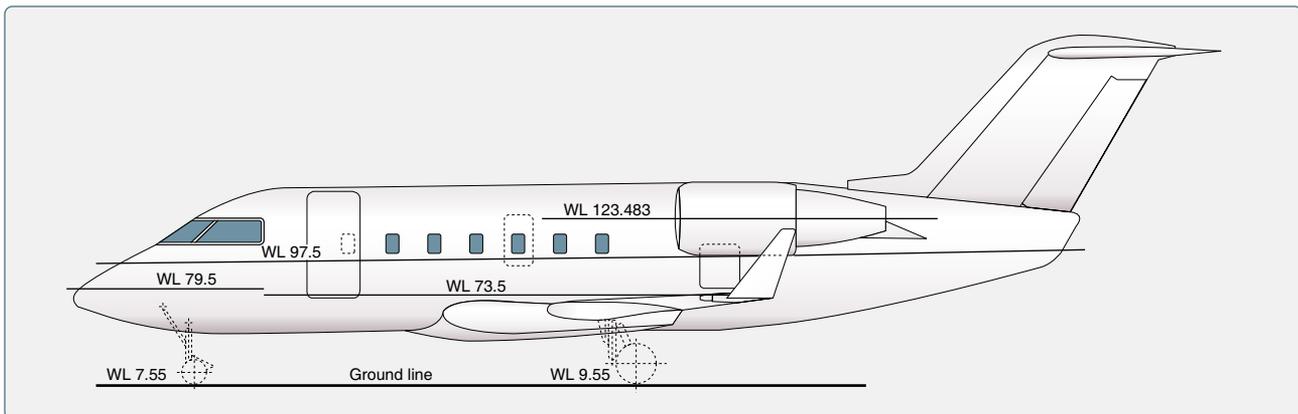
Panels and doors on aircraft are numbered for positive identification. On large aircraft, panels are usually numbered sequentially containing zone and subzone information in the panel number. Designation for a left or right side location on the aircraft is often indicated in the panel number. This could be with an "L" or "R," or panels on one side of the aircraft could be odd numbered and the other side even numbered. The manufacturer's maintenance manual explains the panel numbering system and often has numerous diagrams and tables showing the location of various components and under which panel they may be found. Each manufacturer is entitled to develop its own panel numbering system.

### Helicopter Structures

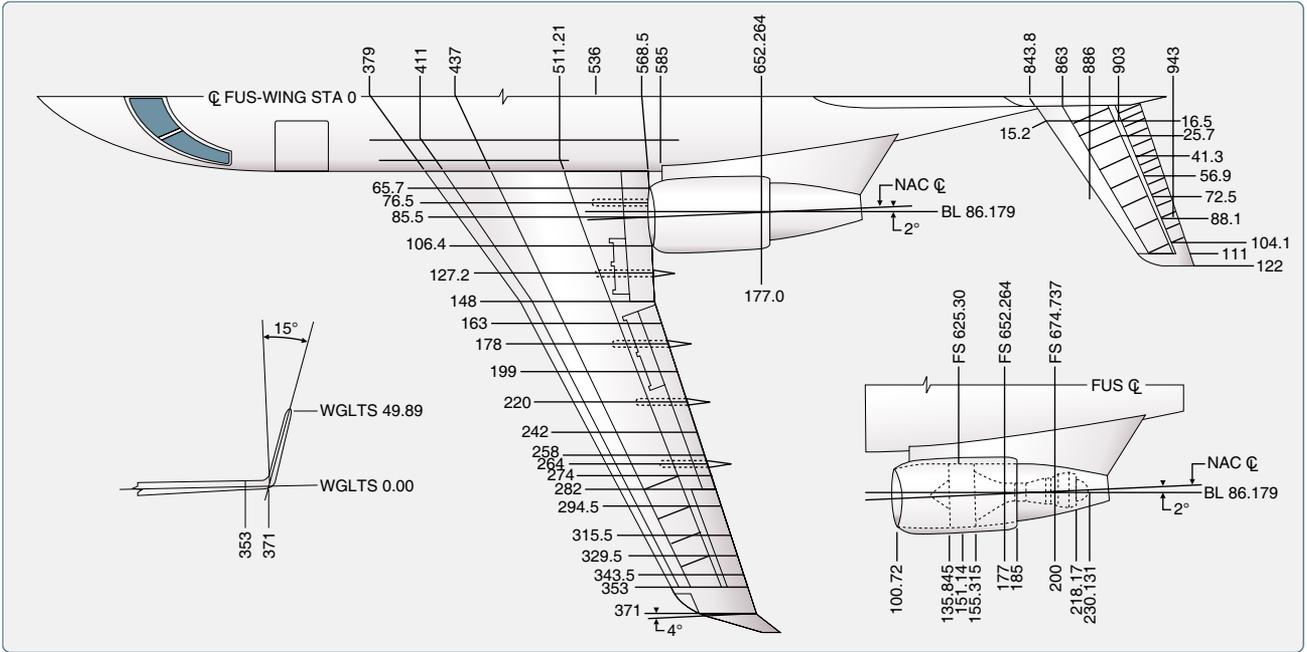
The structures of the helicopter are designed to give the helicopter its unique flight characteristics. A simplified explanation of how a helicopter flies is that the rotors are rotating airfoils that provide lift similar to the way wings provide lift on a fixed-wing aircraft. Air flows faster over the curved upper surface of the rotors, causing a negative pressure and thus, lifting the aircraft. Changing the angle of attack of the rotating blades increases or decreases lift, respectively raising or lowering the helicopter. Tilting the rotor plane of rotation causes the aircraft to move horizontally. *Figure 1-93* shows the major components of a typical helicopter.

### Airframe

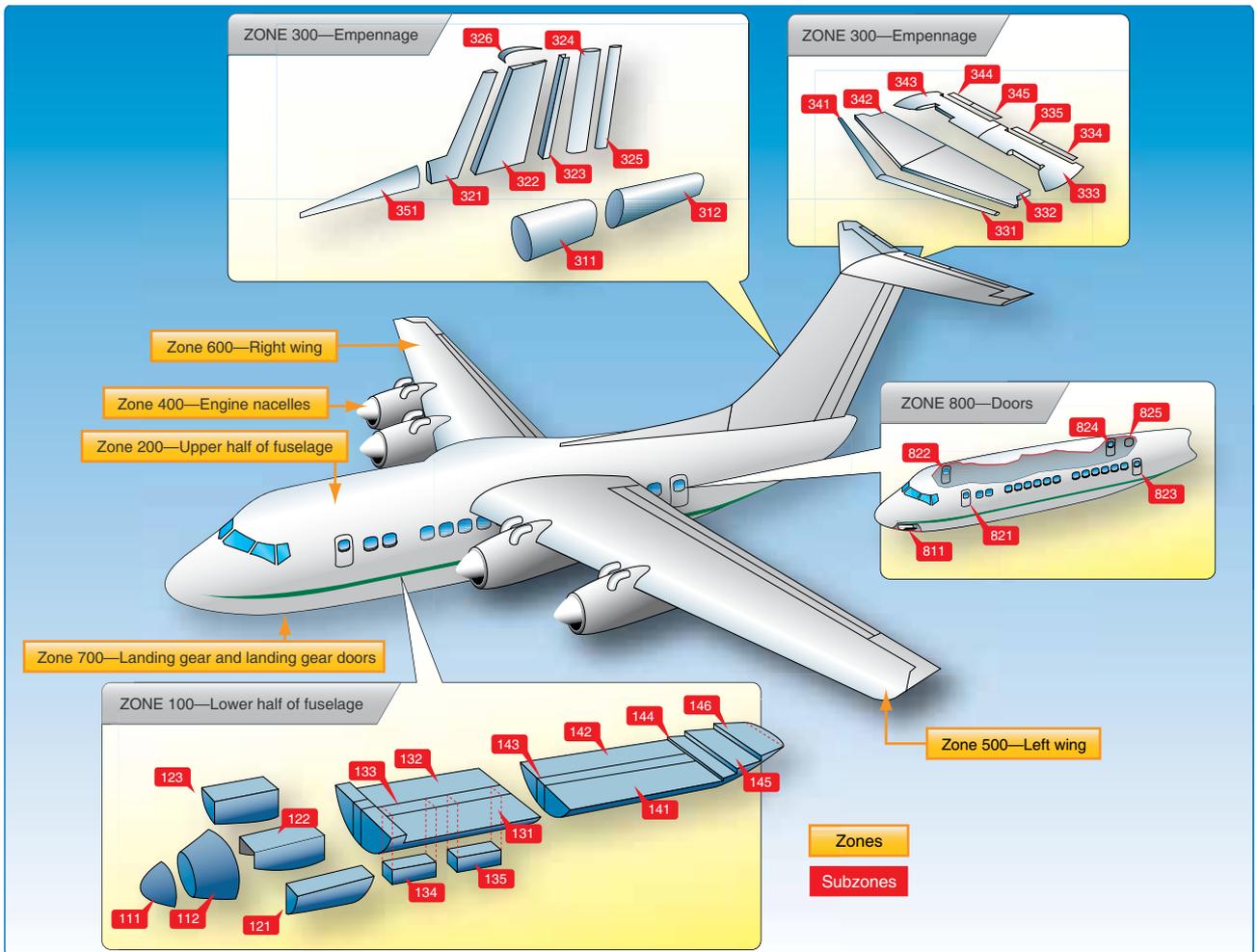
The airframe, or fundamental structure, of a helicopter can be made of either metal or wood composite materials, or some combination of the two. Typically, a composite component



**Figure 1-90.** Water line diagram.



**Figure 1-91.** Wing stations are often referenced off the butt line, which bisects the center of the fuselage longitudinally. Horizontal stabilizer stations referenced to the butt line and engine nacelle stations are also shown.



**Figure 1-92.** Large aircraft are divided into zones and subzones for identifying the location of various components.

consists of many layers of fiber-impregnated resins, bonded to form a smooth panel. Tubular and sheet metal substructures are usually made of aluminum, though stainless steel or titanium are sometimes used in areas subject to higher stress or heat. Airframe design encompasses engineering, aerodynamics, materials technology, and manufacturing methods to achieve favorable balances of performance, reliability, and cost.

### Fuselage

As with fixed-wing aircraft, helicopter fuselages and tail booms are often truss-type or semimonocoque structures of stress-skin design. Steel and aluminum tubing, formed aluminum, and aluminum skin are commonly used. Modern helicopter fuselage design includes an increasing utilization of advanced composites as well. Firewalls and engine decks are usually stainless steel. Helicopter fuselages vary widely from those with a truss frame, two seats, no doors, and a monocoque shell flight compartment to those with fully enclosed airplane-style cabins as found on larger twin-engine helicopters. The multidirectional nature of helicopter flight makes wide-range visibility from the cockpit essential. Large, formed polycarbonate, glass, or plexiglass windscreens are common.

### Landing Gear or Skids

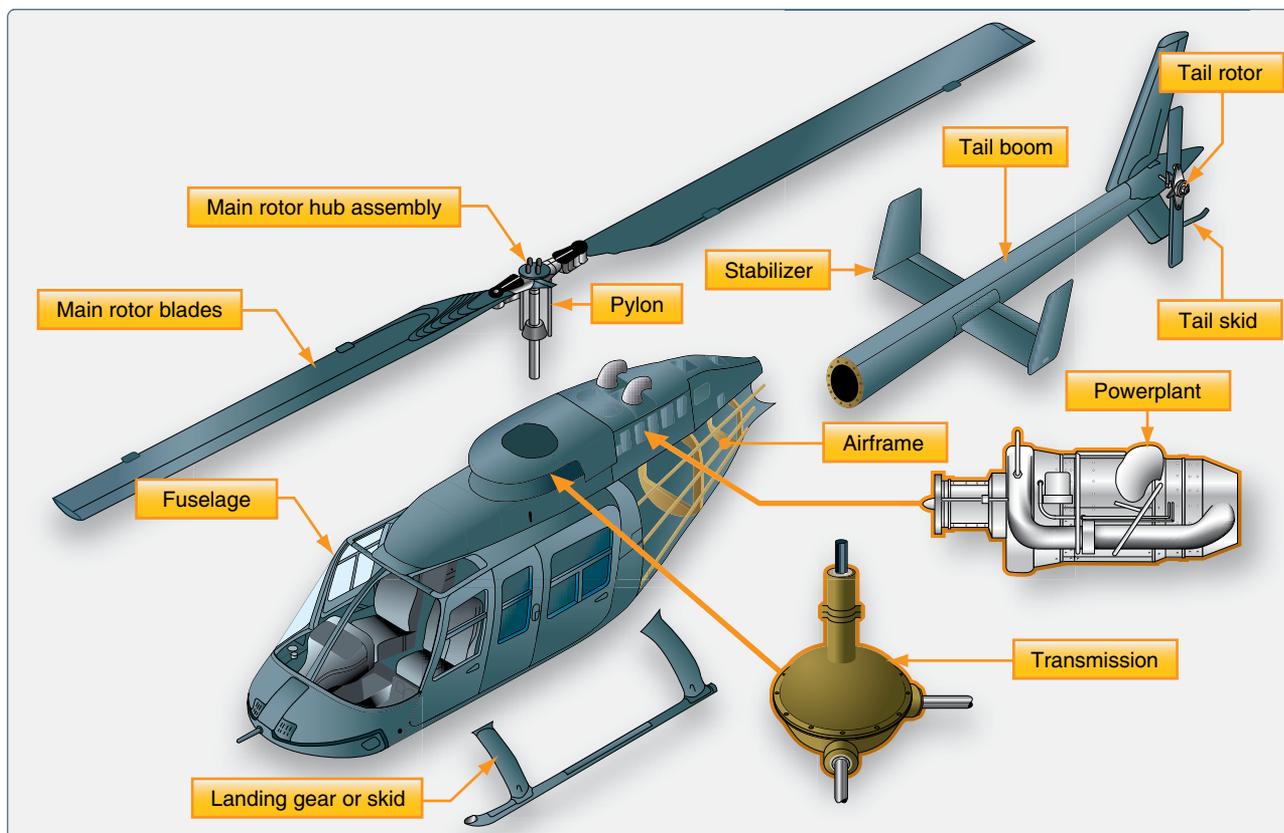
As mentioned, a helicopter's landing gear can be simply a set of tubular metal skids. Many helicopters do have landing gear with wheels, some retractable.

### Powerplant and Transmission

The two most common types of engine used in helicopters are the reciprocating engine and the turbine engine. Reciprocating engines, also called piston engines, are generally used in smaller helicopters. Most training helicopters use reciprocating engines because they are relatively simple and inexpensive to operate. Refer to the Pilot's Handbook of Aeronautical Knowledge for a detailed explanation and illustrations of the piston engine.

### Turbine Engines

Turbine engines are more powerful and are used in a wide variety of helicopters. They produce a tremendous amount of power for their size but are generally more expensive to operate. The turbine engine used in helicopters operates differently than those used in airplane applications. In most applications, the exhaust outlets simply release expended gases and do not contribute to the forward motion of the helicopter. Because the airflow is not a straight line pass through as in jet engines and is not used for propulsion, the



**Figure 1-93.** The major components of a helicopter are the airframe, fuselage, landing gear, powerplant/transmission, main rotor system, and antitorque system.

cooling effect of the air is limited. Approximately 75 percent of the incoming airflow is used to cool the engine.

The gas turbine engine mounted on most helicopters is made up of a compressor, combustion chamber, turbine, and accessory gearbox assembly. The compressor draws filtered air into the plenum chamber and compresses it. Common type filters are centrifugal swirl tubes where debris is ejected outward and blown overboard prior to entering the compressor, or engine barrier filters (EBF), similar to the K&N filter element used in automotive applications. This design significantly reduces the ingestion of foreign object debris (FOD). The compressed air is directed to the combustion section through discharge tubes where atomized fuel is injected into it. The fuel/air mixture is ignited and allowed to expand. This combustion gas is then forced through a series of turbine wheels causing them to turn. These turbine wheels provide power to both the engine compressor and the accessory gearbox. Depending on model and manufacturer, the rpm range can vary from a range low of 20,000 to a range high of 51,600.

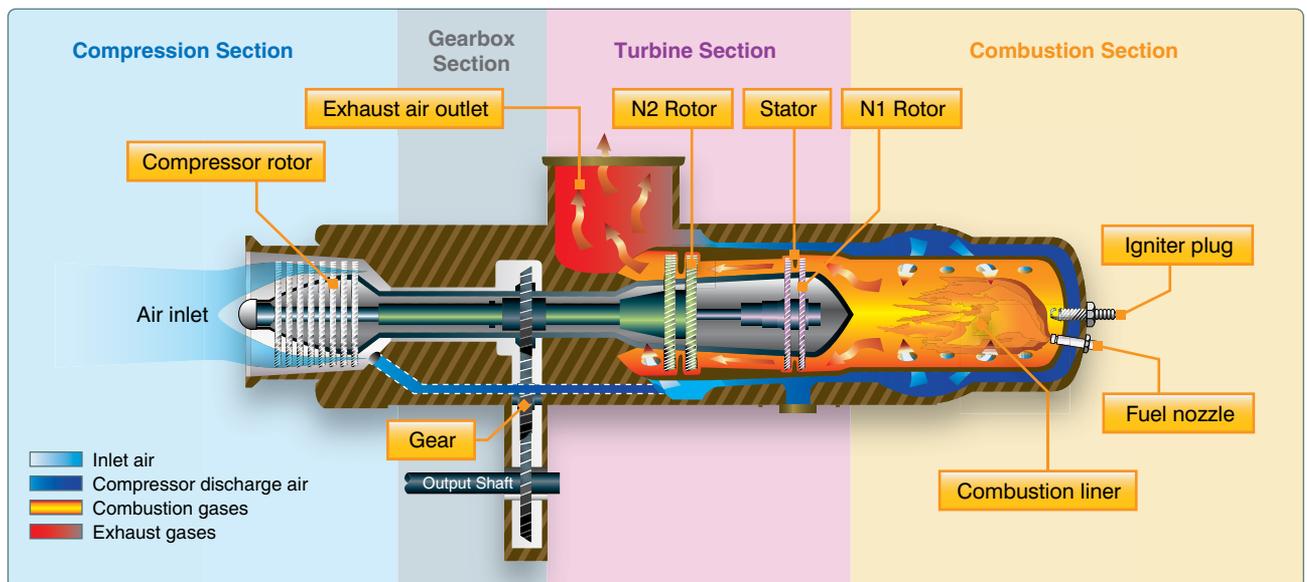
Power is provided to the main rotor and tail rotor systems through the freewheeling unit which is attached to the accessory gearbox power output gear shaft. The combustion gas is finally expelled through an exhaust outlet. The temperature of gas is measured at different locations and is referenced differently by each manufacturer. Some common terms are: inter-turbine temperature (ITT), exhaust gas temperature (EGT), or turbine outlet temperature (TOT). TOT is used throughout this discussion for simplicity purposes. [Figure 1-94]

## Transmission

The transmission system transfers power from the engine to the main rotor, tail rotor, and other accessories during normal flight conditions. The main components of the transmission system are the main rotor transmission, tail rotor drive system, clutch, and freewheeling unit. The freewheeling unit, or autorotative clutch, allows the main rotor transmission to drive the tail rotor drive shaft during autorotation. Helicopter transmissions are normally lubricated and cooled with their own oil supply. A sight gauge is provided to check the oil level. Some transmissions have chip detectors located in the sump. These detectors are wired to warning lights located on the pilot's instrument panel that illuminate in the event of an internal problem. Some chip detectors on modern helicopters have a "burn off" capability and attempt to correct the situation without pilot action. If the problem cannot be corrected on its own, the pilot must refer to the emergency procedures for that particular helicopter.

## Main Rotor System

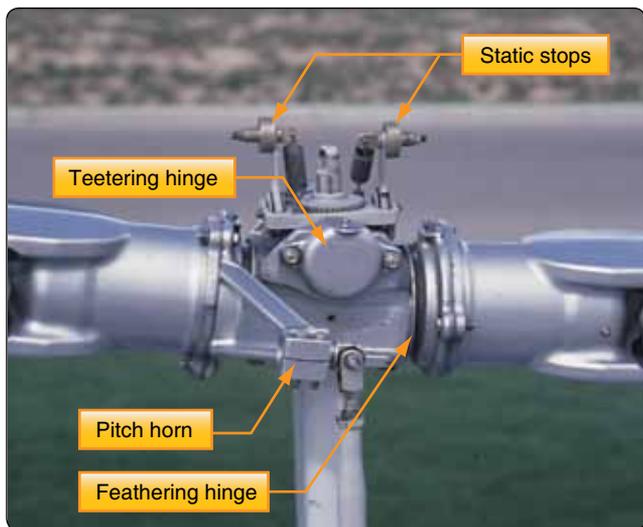
The rotor system is the rotating part of a helicopter which generates lift. The rotor consists of a mast, hub, and rotor blades. The mast is a cylindrical metal shaft that extends upwards from and is driven, and sometimes supported, by the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub by any number of different methods. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: rigid, semirigid, or fully articulated.



**Figure 1-94.** Many helicopters use a turboshaft engine to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through the expulsion of exhaust gases.

## Rigid Rotor System

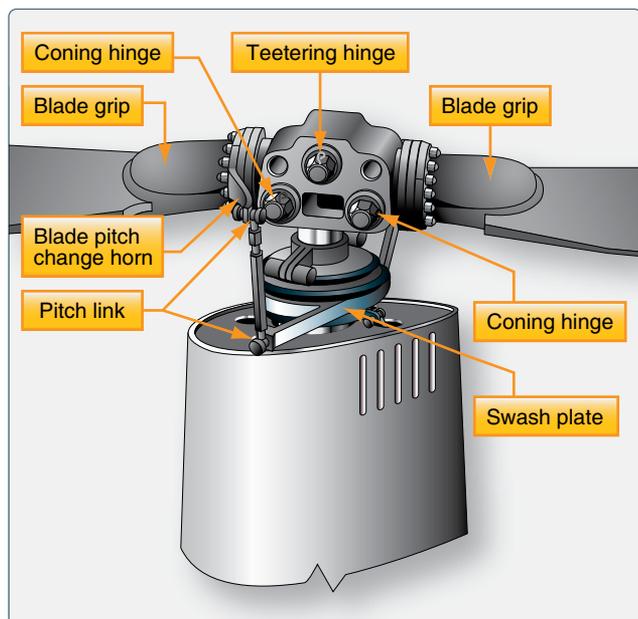
The simplest is the rigid rotor system. In this system, the rotor blades are rigidly attached to the main rotor hub and are not free to slide back and forth (drag) or move up and down (flap). The forces tending to make the rotor blades do so are absorbed by the flexible properties of the blade. The pitch of the blades, however, can be adjusted by rotation about the spanwise axis via the feathering hinges. [Figure 1-95]



**Figure 1-95.** The teetering hinge allows the main rotor hub to tilt, and the feathering hinge enables the pitch angle of the blades to change.

## Semirigid Rotor System

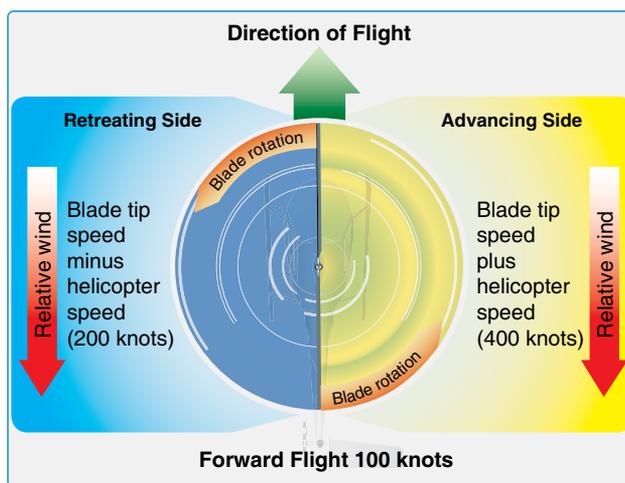
The semirigid rotor system in Figure 1-96 makes use of a teetering hinge at the blade attach point. While held in check from sliding back and forth, the teetering hinge does allow



**Figure 1-96.** The semirigid rotor system of the Robinson R22.

the blades to flap up and down. With this hinge, when one blade flaps up, the other flaps down.

Flapping is caused by a phenomenon known as dissymmetry of lift. As the plane of rotation of the rotor blades is tilted and the helicopter begins to move forward, an advancing blade and a retreating blade become established (on two-bladed systems). The relative windspeed is greater on an advancing blade than it is on a retreating blade. This causes greater lift to be developed on the advancing blade, causing it to rise up or flap. When blade rotation reaches the point where the blade becomes the retreating blade, the extra lift is lost and the blade flaps downward. [Figure 1-97]



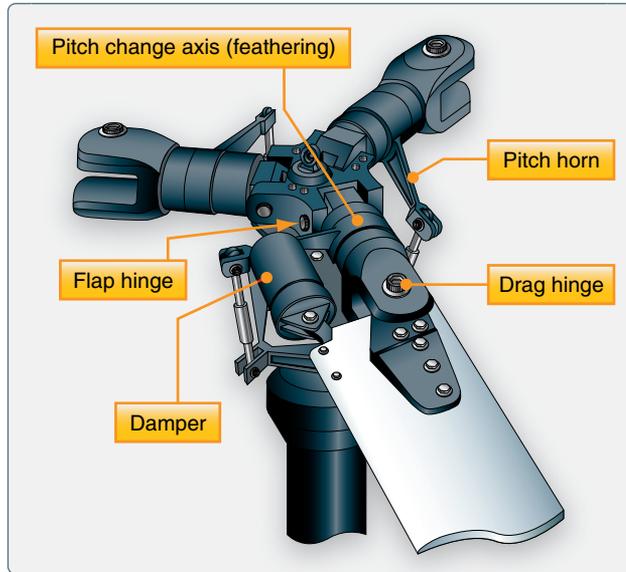
**Figure 1-97.** The blade tip speed of this helicopter is approximately 300 knots. If the helicopter is moving forward at 100 knots, the relative windspeed on the advancing side is 400 knots. On the retreating side, it is only 200 knots. This difference in speed causes a dissymmetry of lift.

## Fully Articulated Rotor System

Fully articulated rotor blade systems provide hinges that allow the rotors to move fore and aft, as well as up and down. This lead-lag, drag, or hunting movement as it is called is in response to the Coriolis effect during rotational speed changes. When first starting to spin, the blades lag until centrifugal force is fully developed. Once rotating, a reduction in speed causes the blades to lead the main rotor hub until forces come into balance. Constant fluctuations in rotor blade speeds cause the blades to “hunt.” They are free to do so in a fully articulating system due to being mounted on the vertical drag hinge.

One or more horizontal hinges provide for flapping on a fully articulated rotor system. Also, the feathering hinge allows blade pitch changes by permitting rotation about the spanwise axis. Various dampers and stops can be found on different designs to reduce shock and limit travel in certain

directions. *Figure 1-98* shows a fully articulated main rotor system with the features discussed.



**Figure 1-98.** Fully articulated rotor system.

Numerous designs and variations on the three types of main rotor systems exist. Engineers continually search for ways to reduce vibration and noise caused by the rotating parts of the helicopter. Toward that end, the use of elastomeric bearings in main rotor systems is increasing. These polymer bearings have the ability to deform and return to their original shape. As such, they can absorb vibration that would normally be transferred by steel bearings. They also do not require regular lubrication, which reduces maintenance.

Some modern helicopter main rotors have been designed with flexures. These are hubs and hub components that are made out of advanced composite materials. They are designed to take up the forces of blade hunting and dissymmetry of lift by flexing. As such, many hinges and bearings can be eliminated from the tradition main rotor system. The result is a simpler rotor mast with lower maintenance due to fewer moving parts. Often designs using flextures incorporate elastomeric bearings. [*Figure 1-99*]

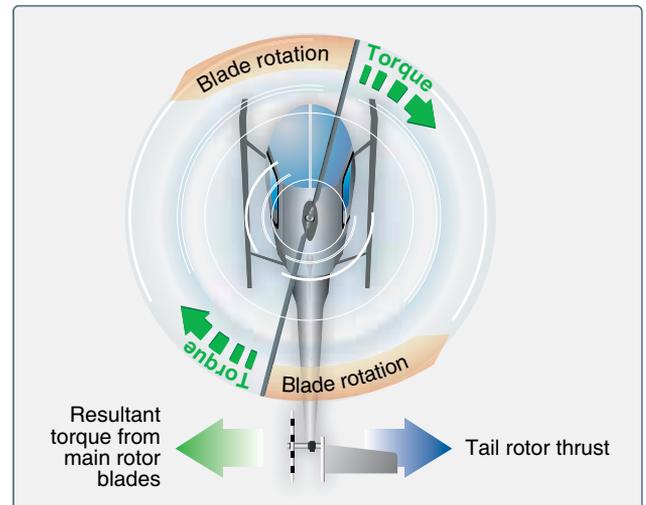
### Antitorque System

Ordinarily, helicopters have between two and seven main rotor blades. These rotors are usually made of a composite structure. The large rotating mass of the main rotor blades of a helicopter produce torque. This torque increases with engine power and tries to spin the fuselage in the opposite direction. The tail boom and tail rotor, or antitorque rotor, counteract this torque effect. [*Figure 1-100*] Controlled with foot pedals, the countertorque of the tail rotor must be modulated as engine power levels are changed. This is done



**Figure 1-99.** Five-blade articulated main rotor with elastomeric bearings.

by changing the pitch of the tail rotor blades. This, in turn, changes the amount of countertorque, and the aircraft can be rotated about its vertical axis, allowing the pilot to control the direction the helicopter is facing.



**Figure 1-100.** A tail rotor is designed to produce thrust in a direction opposite to that of the torque produced by the rotation of the main rotor blades. It is sometimes called an antitorque rotor.

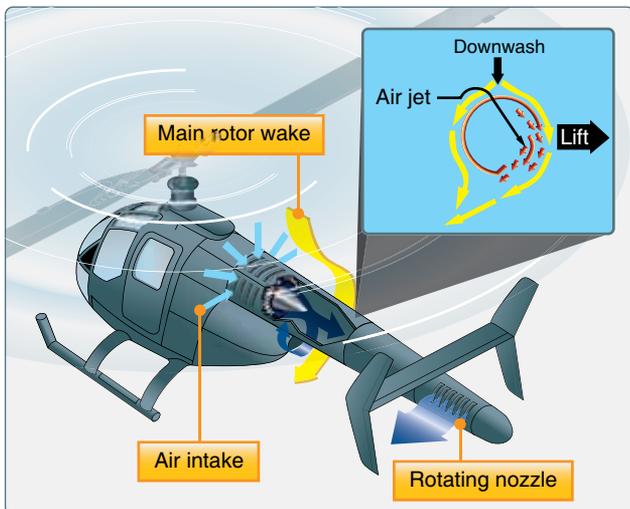
Similar to a vertical stabilizer on the empennage of an airplane, a fin or pylon is also a common feature on rotorcraft. Normally, it supports the tail rotor assembly, although some tail rotors are mounted on the tail cone of the boom. Additionally, a horizontal member called a stabilizer is often constructed at the tail cone or on the pylon.

A Fenestron® is a unique tail rotor design which is actually a multiblade ducted fan mounted in the vertical pylon. It works the same way as an ordinary tail rotor, providing sideways thrust to counter the torque produced by the main rotors. [*Figure 1-101*]



**Figure 1-101.** A Fenestron or “fan-in-tail” antitorque system. This design provides an improved margin of safety during ground operations.

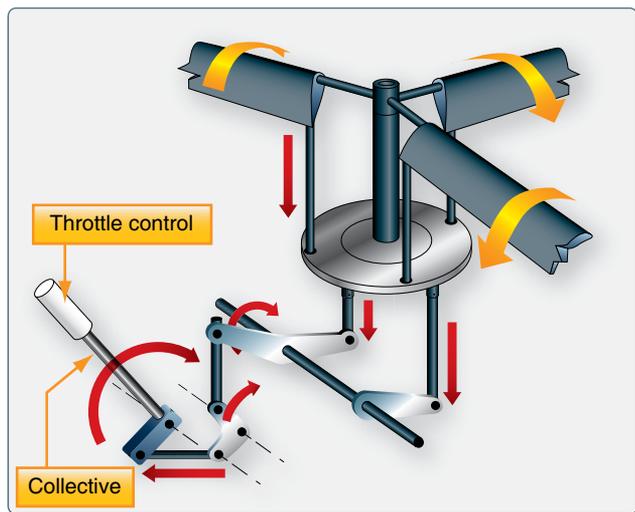
A NOTAR<sup>®</sup> antitorque system has no visible rotor mounted on the tail boom. Instead, an engine-driven adjustable fan is located inside the tail boom. NOTAR<sup>®</sup> is an acronym that stands for “no tail rotor.” As the speed of the main rotor changes, the speed of the NOTAR<sup>®</sup> fan changes. Air is vented out of two long slots on the right side of the tail boom, entraining main rotor wash to hug the right side of the tail boom, in turn causing laminar flow and a low pressure (Coanda Effect). This low pressure causes a force counter to the torque produced by the main rotor. Additionally, the remainder of the air from the fan is sent through the tail boom to a vent on the aft left side of the boom where it is expelled. This action to the left causes an opposite reaction to the right, which is the direction needed to counter the main rotor torque. [Figures 1-102]



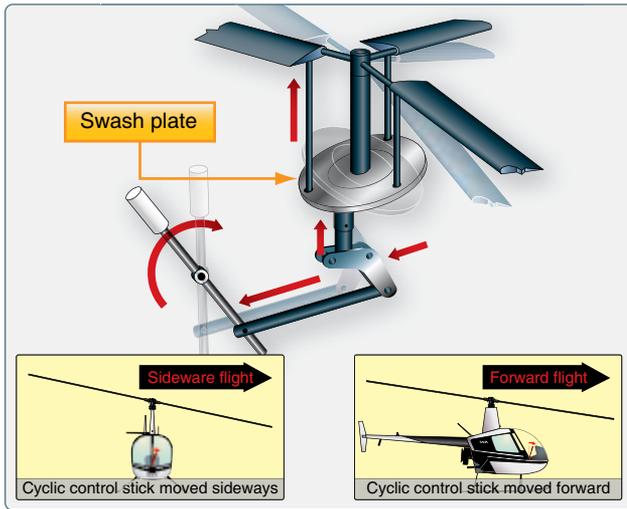
**Figure 1-102.** While in a hover, Coanda Effect supplies approximately two-thirds of the lift necessary to maintain directional control. The rest is created by directing the thrust from the controllable rotating nozzle.

## Controls

The controls of a helicopter differ slightly from those found in an aircraft. The collective, operated by the pilot with the left hand, is pulled up or pushed down to increase or decrease the angle of attack on all of the rotor blades simultaneously. This increases or decreases lift and moves the aircraft up or down. The engine throttle control is located on the hand grip at the end of the collective. The cyclic is the control “stick” located between the pilot’s legs. It can be moved in any direction to tilt the plane of rotation of the rotor blades. This causes the helicopter to move in the direction that the cyclic is moved. As stated, the foot pedals control the pitch of the tail rotor blades thereby balancing main rotor torque. Figures 1-103 and 1-104 illustrate the controls found in a typical helicopter.



**Figure 1-103.** The collective changes the pitch of all of the rotor blades simultaneously and by the same amount, thereby increasing or decreasing lift.



**Figure 1-104.** *The cyclic changes the angle of the swash plate which changes the plane of rotation of the rotor blades. This moves the aircraft horizontally in any direction depending on the positioning of the cyclic.*

