

Al-Najaf Technical Institute
Aeronautical Technologies Department
Year One

Subject: - Configuration of Aircrafts
Lecturer Notes by Dr. Essam Al-Zaini

Source 1: - AIRCRAFT DESIGN A Systems Engineering Approach

Source 2: - Aviation Maintenance Technician Handbook—Airframe Volume 1, 2012, U.S.
Department of Transportation FEDERAL AVIATION ADMINISTRATION

Chapter 1 Aircraft Structures

1. Introduction

An aircraft is a device that is used for, or is intended to be used for, flight in the air. Major categories of aircraft are airplane, rotorcraft, glider, and lighter-than-air vehicles. [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.



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

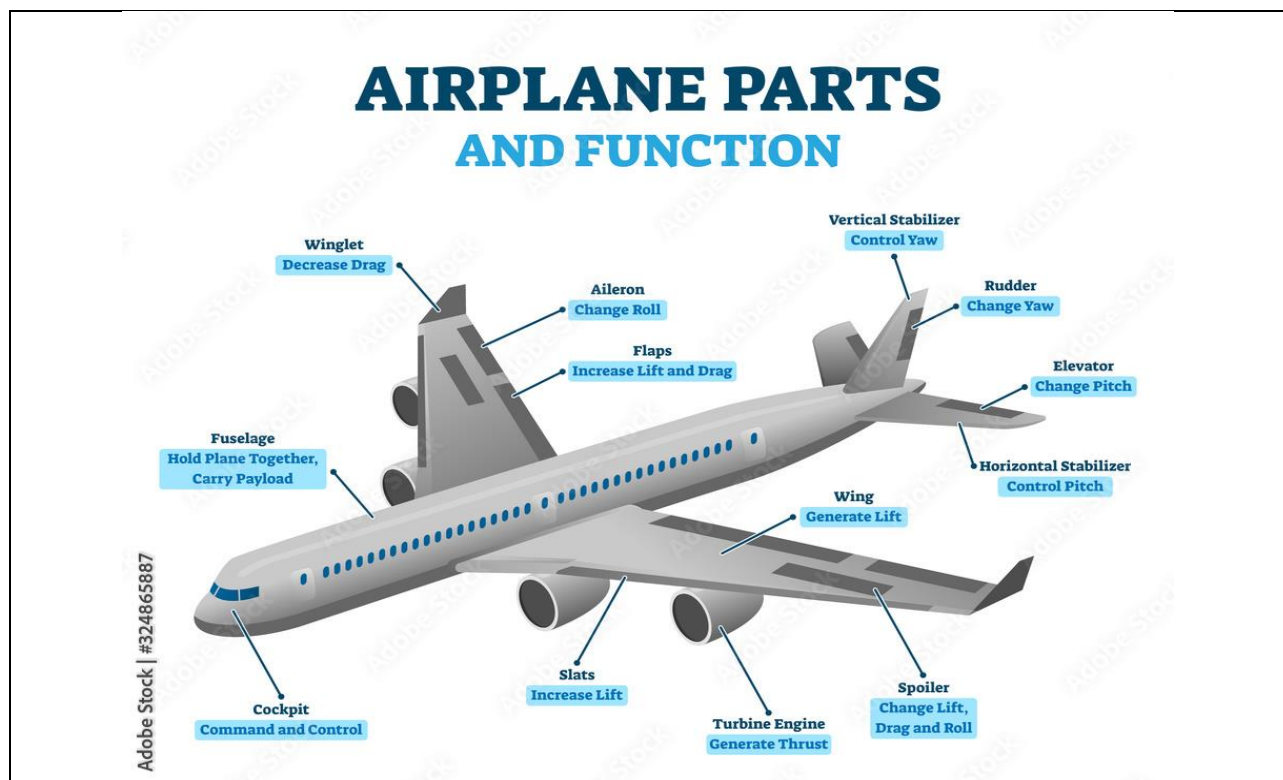
The most common aircraft is the fixed-wing aircraft. As the name implies, the wings on this type of flying machine are attached to the fuselage and are not intended to move independently in a fashion that results in the creation of lift. **In this course we will focus on this type of aircrafts.**



An aircraft comprises several major components. It mainly includes the **wing, horizontal tail, vertical tail (VT), fuselage, propulsion system, landing gear, and control surfaces**. Students must be fully aware of the function of each component. Each aircraft component has inter-relationships with other components.

2. Primary Functions of Aircraft Components

The below six components are assumed to be the fundamental components of an air vehicle. However, there are other components in an aircraft that are not assumed here as major ones.



- 1. Wing.** The main function of the wing is to generate the aerodynamic force of lift to keep the aircraft airborne. The wing tends to generate two other unwanted aerodynamic productions: an **aerodynamic drag force plus an aerodynamic pitching moment**. Furthermore, the wing is an essential component in providing the aircraft lateral stability, which is fundamentally significant for flight safety.
- 2. Fuselage.** The primary function of the fuselage is to accommodate the payload which includes **passengers, cargo, luggage, and other useful loads**. The fuselage is often a home for the pilot and crew members, and most of the time fuel tanks and engine (s). Since the fuselage provides a moment arm to the horizontal and VT, it plays an influential role in

longitudinal and directional stability and control. If the fuselage is decided to be short, a boom must be provided to allow for the tails to have sufficient arm.

- 3. Horizontal tail.** The horizontal tail's primary function is to generate an aerodynamic force to longitudinally trim the aircraft. Furthermore, the VT is an essential component in providing the aircraft longitudinal stability, which is a fundamental requirement for flight safety. In the majority of aircraft, the elevator is a movable part of the horizontal tail, so longitudinal control and maneuverability are applied through the horizontal tail.
- 4. Vertical tail.** The VT's primary function is to generate an aerodynamic force to directionally trim the aircraft. Furthermore, the VT is an essential component in providing the aircraft directional stability, which is a fundamental requirement for flight safety. In the majority of aircraft, the rudder is a movable part of the VT, so directional control and maneuverability are applied through the VT.
- 5. Engine.** The engine is the main component in the aircraft propulsion system to generate power and/or thrust. The aircraft requires a thrust force to move forward (as in any other vehicle), so the engine's primary function is to generate the thrust. The fuel is considered to be a necessary item of the propulsion system and it sometimes constitutes a large part of the aircraft weight. An aircraft without an engine is not able to take off independently, but is capable of gliding and landing, as performed by sailplanes and gliders. Sailplanes and gliders take off with the help of other aircraft or outside devices (such as a winch), and climb with the help of wind and thermal currents.
- 6. Landing gear.** The primary function of the landing gear is to facilitate take-off and landing operations. During take-off and landing operations, the fuselage, wing, tail, and aircraft components are kept away from the ground through the landing gear. The wheels of the landing gear in land-based and ship-based aircraft also play a crucial role in safe acceleration and deceleration of the aircraft. Rolling wheels as part of the landing gear allow the aircraft to accelerate without spending a considerable amount of thrust to overcome friction.

Wing Configuration

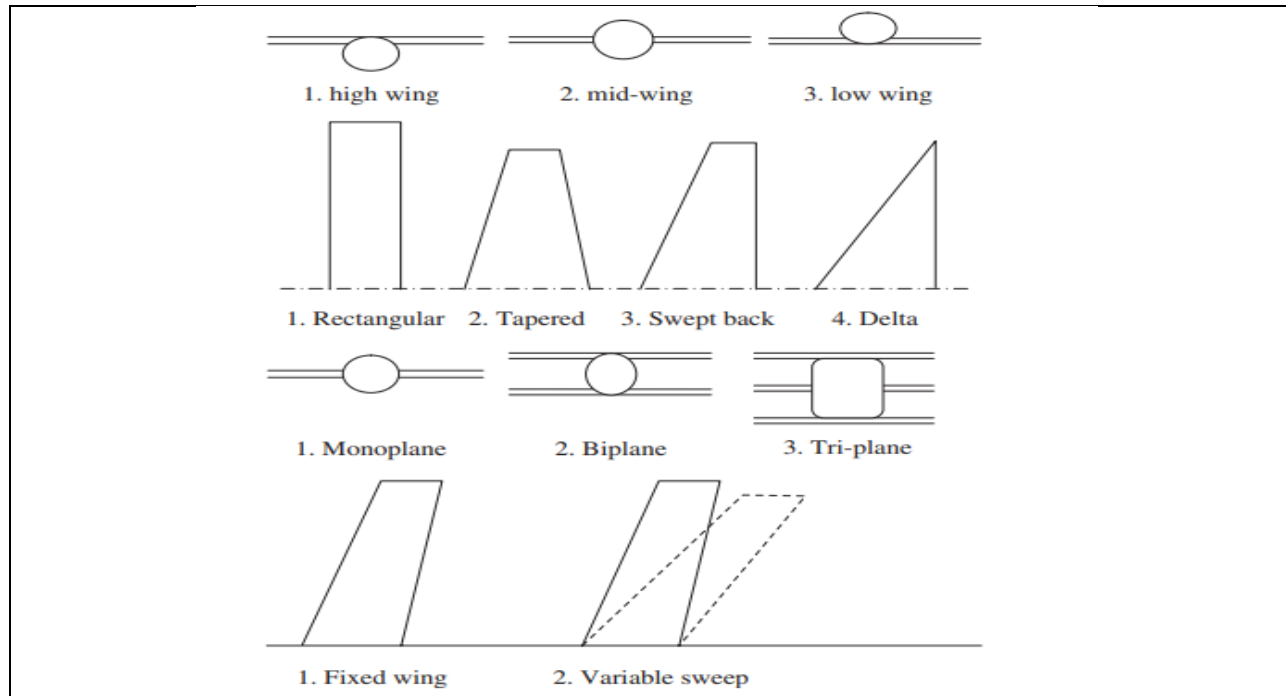
In general, the wing configuration alternatives from seven different aspects are as follows:

1. Number of wings

- a. Monoplane
- b. Biplane
- c. Triplane

2. Wing location

- a. High wing
- b. Mid-wing
- c. Low wing
- d. Parasol wing



3. Wing type

- a. Rectangular
- b. Tapered
- c. Delta
- d. Swept back
- e. Swept forward
- f. Elliptical

4. High-lift device

- a. Plain flap
- b. Split flap
- c. Slotted flap
- d. Kruger flap
- e. Double-slotted flap
- f. Triple-slotted flap
- g. Leading edge flap
- h. Leading edge slot

5. Sweep configuration

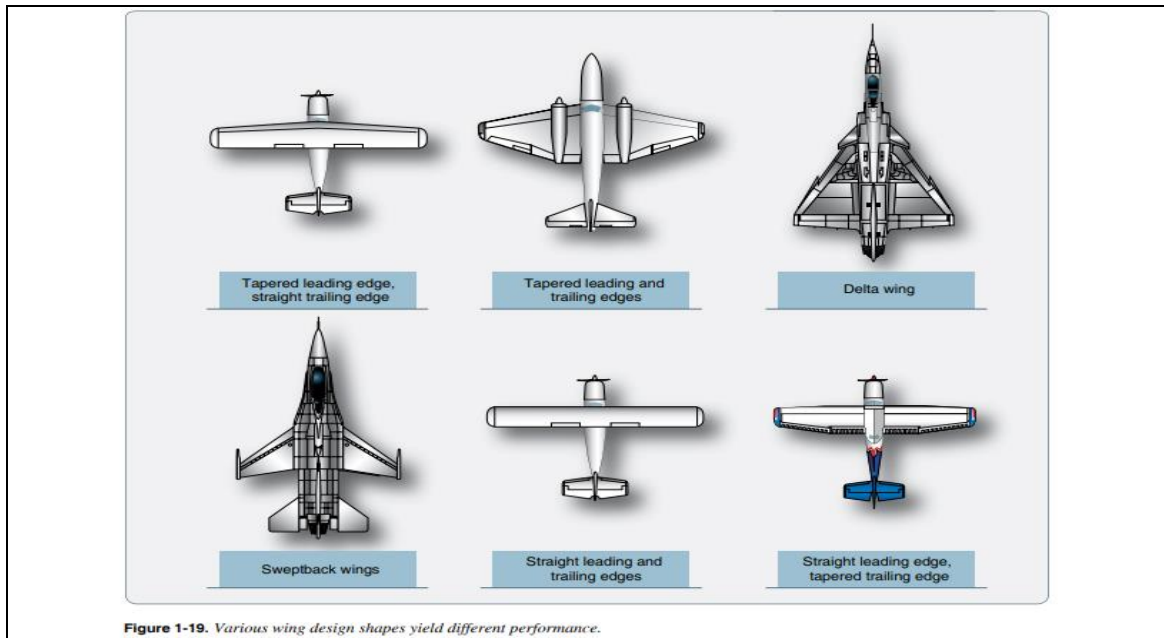
- a. Fixed wing
- b. Variable sweep

6. Shape

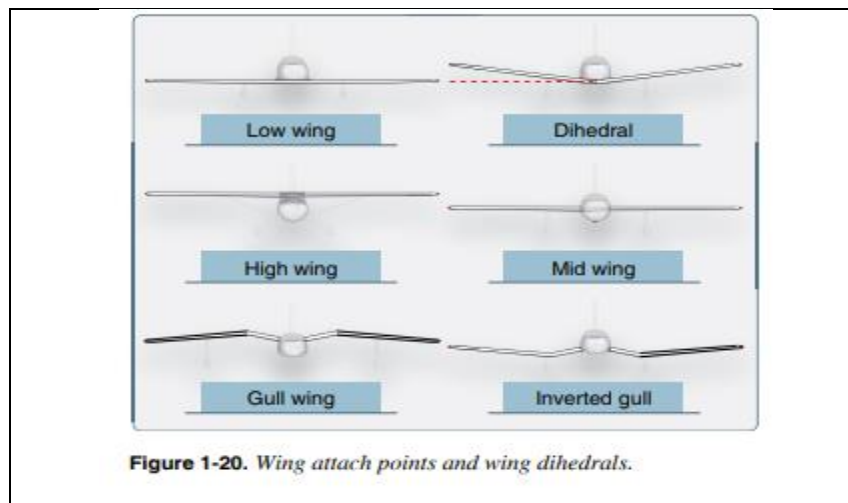
- a. Fixed shape
- b. Morphing wing

7. Structural configuration

- a. Cantilever
- b. Strut-braced
 - i. faired
 - ii. Un-faired

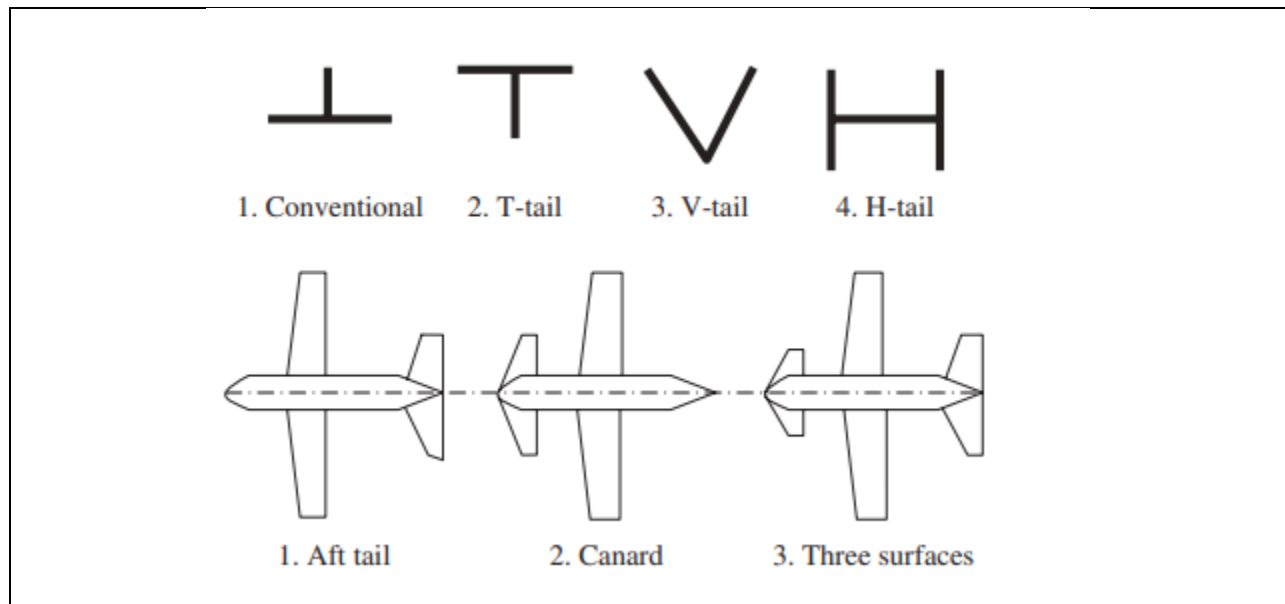


The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. **This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of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



Tail Configuration

In general, the tail configuration alternatives from three different aspects are as follows:



1. Aft or forward

- a. Aft conventional tail
- b. Canard (foreplane)
- c. Three surfaces

2. Horizontal and vertical tail

- a. Conventional
- b. V-tail
- c. T-tail
- d. H-tail
- e. Inverted U

3. Attachment

- a. Fixed tail
- b. Moving tail
- c. Adjustable tail

Propulsion System Configuration

In general, the propulsion system configuration alternatives from four different aspects are as follows:

1. Engine type

- a. Human-powered
- b. Solar-powered
- c. Piston prop

- d. Turboprop
- e. Turbofan
- f. Turbojet
- g. Rocket

2. Engine and the aircraft center of gravity

- a. Pusher
- b. Tractor

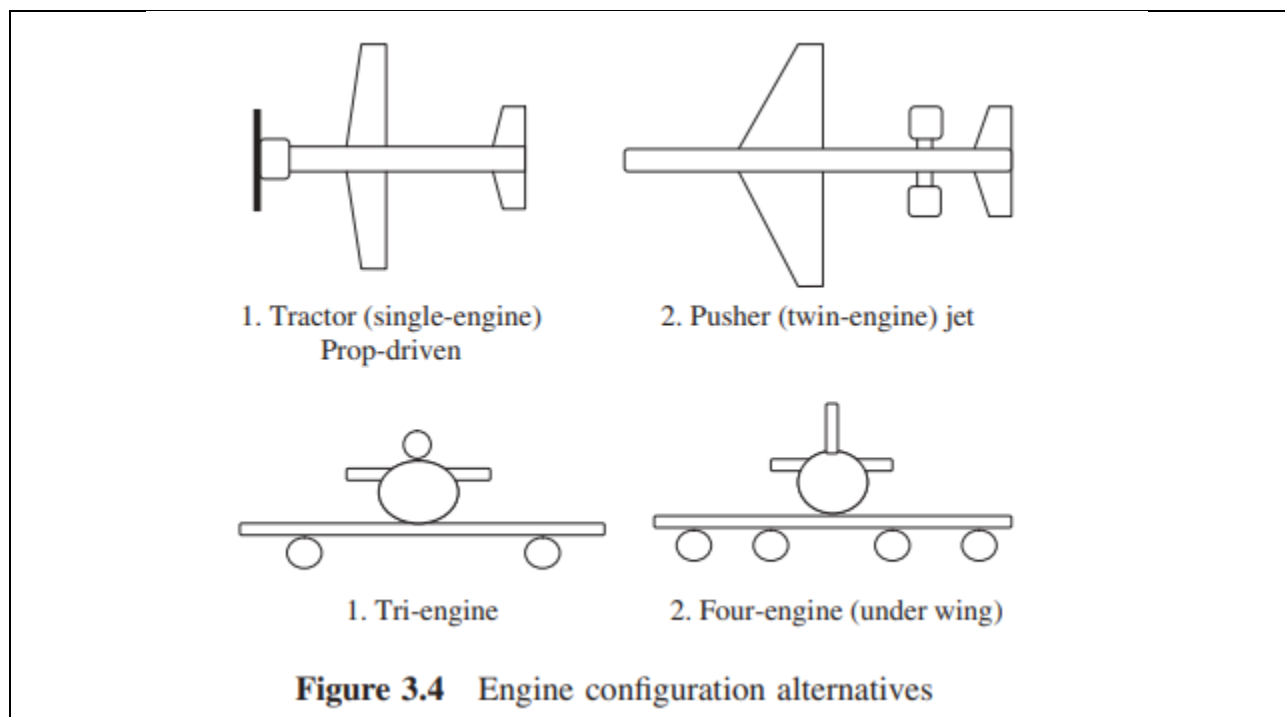
3. Number of engines

- a. Single-engine
- b. Twin-engine
- c. Tri-engine
- d. Four-engine
- e. Multi-engine

4. Engine location

- a. In front of nose (inside)
- b. Inside fuselage mid-section
- c. Inside wing
- d. Top of wing
- e. Under wing
- f. Inside vertical tail
- g. Side of fuselage at aft section
- h. Top of fuselage

Figure 3.4 illustrates several engine configuration alternatives.



Landing Gear Configuration

In general, the landing gear configuration alternatives from three different aspects are as follows:

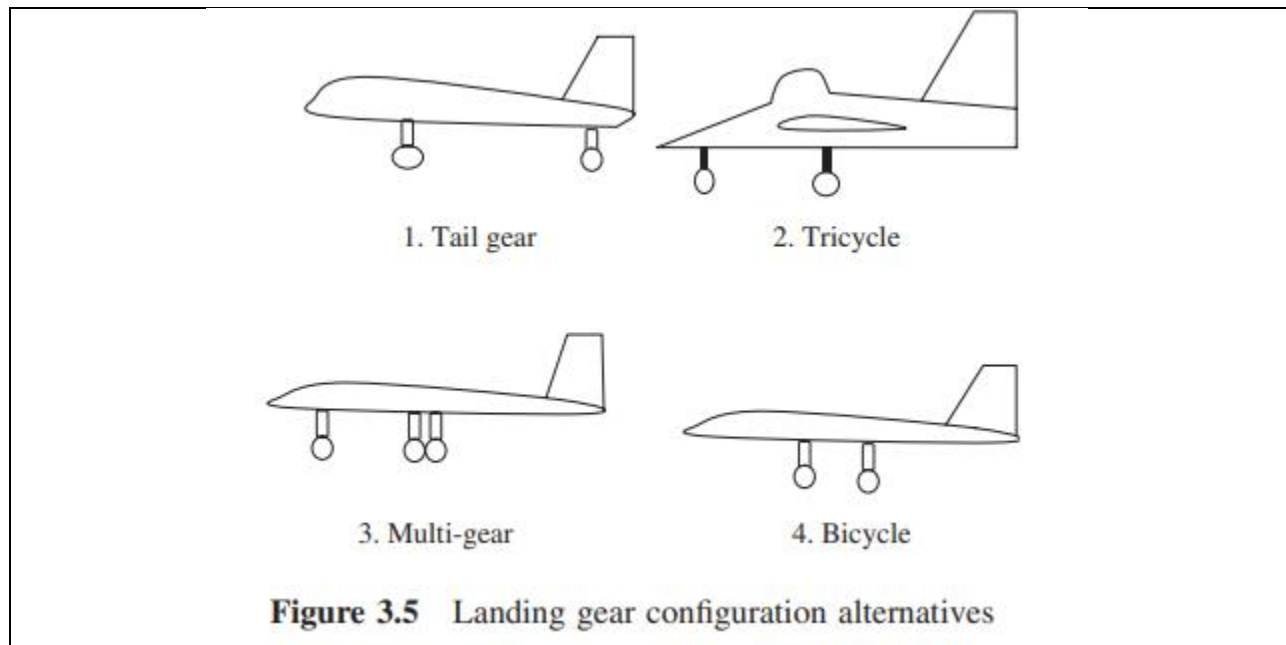
1. Landing gear mechanism

- a. Fixed ((i) faired and (ii) un-faired)
- b. Retractable
- c. Partially retractable

2. Landing gear type

- a. Tricycle (or nose gear)
- b. Tail gear (tail dragger or skid)
- c. Bicycle (tandem)
- d. Multi-wheel
- e. Bicycle (tandem)
- f. Float-equipped
- g. Removable landing gear.

Figure 3.5 shows several landing gear configuration alternatives. Another design requirement that influences the design of the landing gear is the type of runway. There are mainly five types of runway:

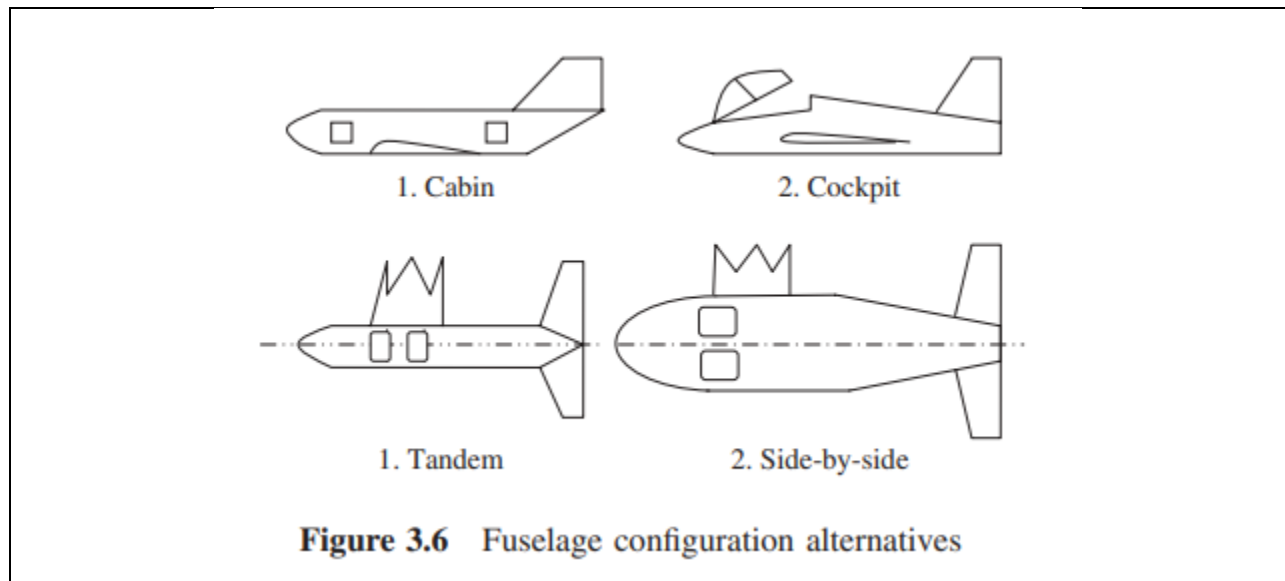


3. Runway

- a. Land-based
- b. Sea-based
- c. Amphibian
- d. Ship-based
- e. Shoulder-based (for small remote-controlled aircraft).

Fuselage Configuration

Figure 3.6 illustrates several fuselage configuration alternatives.



In general, the fuselage configuration alternatives from three different aspects are as follows:

1. Door

- a. Cabin
- b. Cockpit

2. Seat

- a. Tandem
- b. Side-by-side
- c. n Seats per row

3. Pressure system

- a. Pressurized cabin
- b. Pressurized hose
- c. Unpressurized cabin.

Manufacturing-Related Items Configuration

In general, the manufacturing configuration alternatives from four different aspects are as follows:

1. Materials for structure

- a. Metal (often aerospace aluminum)
- b. Wood and fabric Aircraft Conceptual Design 59
- c. Composite materials
- d. Metal and composite materials

2. Assembly technique

- a. Kit form (kit-plane rule: 51% amateur construction)
- b. Semi-kit form
- c. Modular

3. Metallic components manufacturing technique

- a. Welding
- b. Machining
- c. Casting
- d. Sheet metal work

4. Composite materials manufacturing technique

- a. Hand layup
- b. Machine layup
- c. Wet layup
- d. Filament winding
- e. Resin transfer molding
- f. Pultrusion
- g. Sandwich construction.

Subsystems Configuration

In general, the subsystems configuration alternatives from five different aspects are as follows:

1. Primary control surfaces

- a. Conventional (i.e., elevator, aileron, and rudder)
- b. Elevon/rudder
- c. Aileron/ruddervator
- d. Flaperon/rudder/aileron
- e. Cross (×) or plus (+) section

2. Secondary control surfaces

- a. High-lift device (e.g., flap, slat, and slot)
- b. Spoiler
- c. Tab

3. Power transmission

- a. Mechanical
- b. Hydraulic
- c. Pneumatic
- d. Fly-by-wire
- e. Fly-by-optic

4. Fuel tank

- a. Inside fuselage
- b. Inside wing (both sides) ((i) between two spars and (ii) in front of main spar)
- c. Wing tip-tank
- d. External tank

5. Store

- a. Camera
- b. Rocket

- c. Missile
- d. Gun
- e. External tank

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Chapter 2 Aircraft Structures

1. Introduction

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.

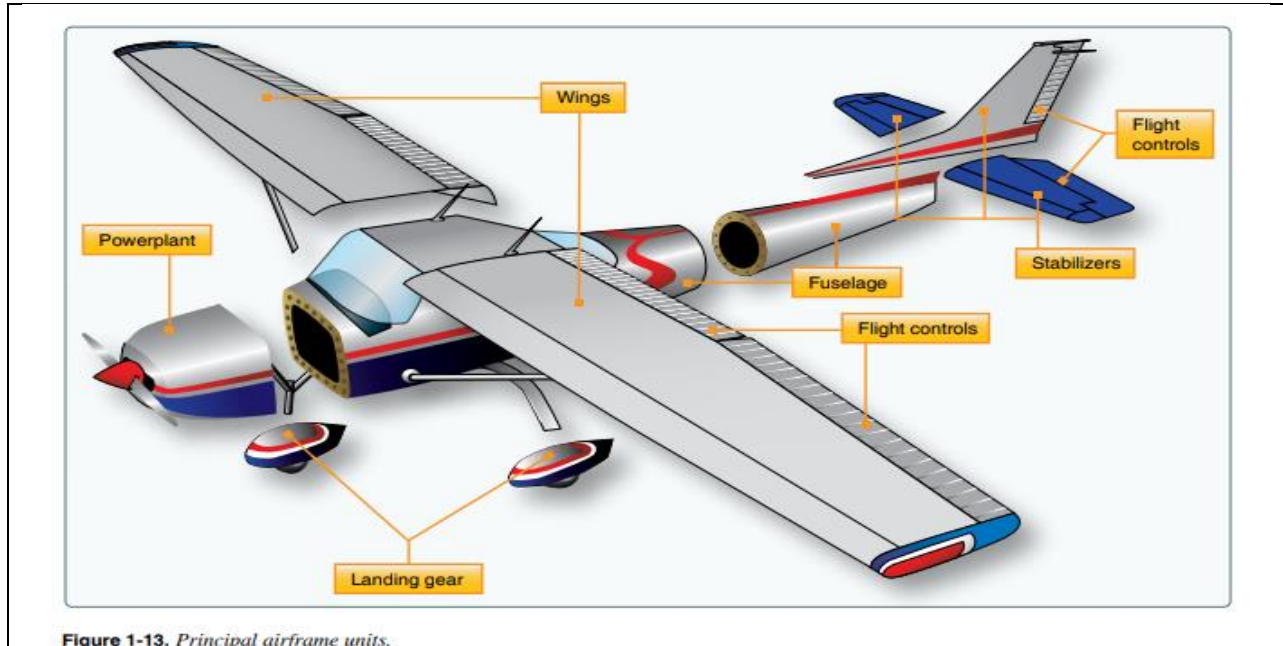


Figure 1-13. Principal airframe units.

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.

2. Major Structural Stresses

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**

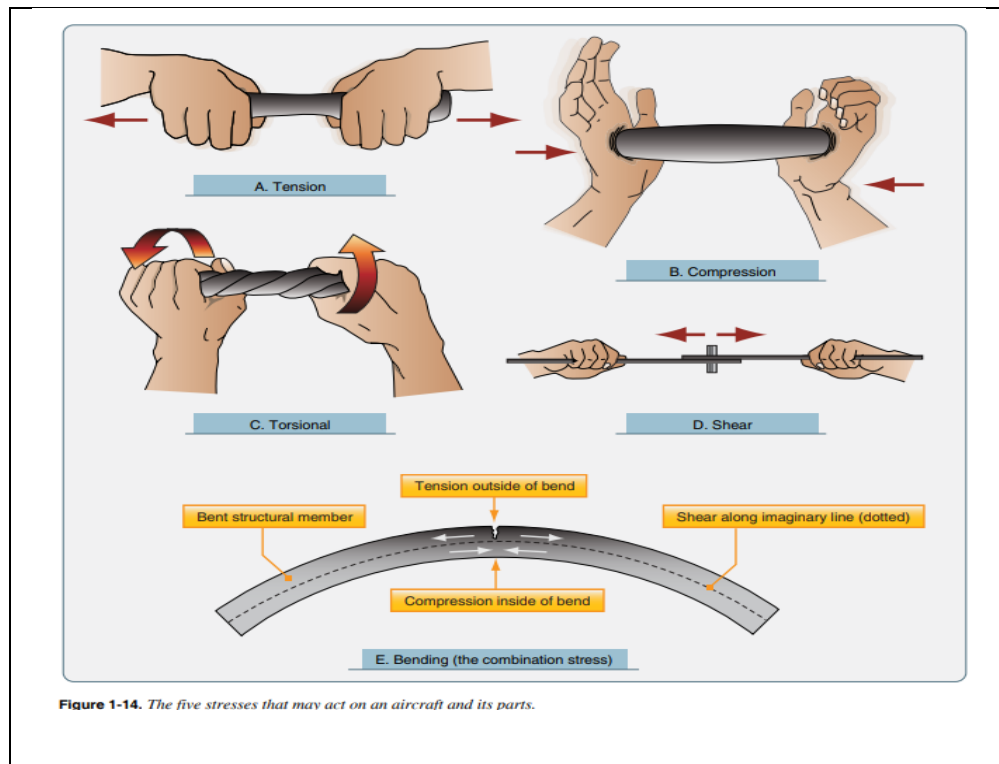


Figure 1-14. The five stresses that may act on an aircraft and its parts.

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.

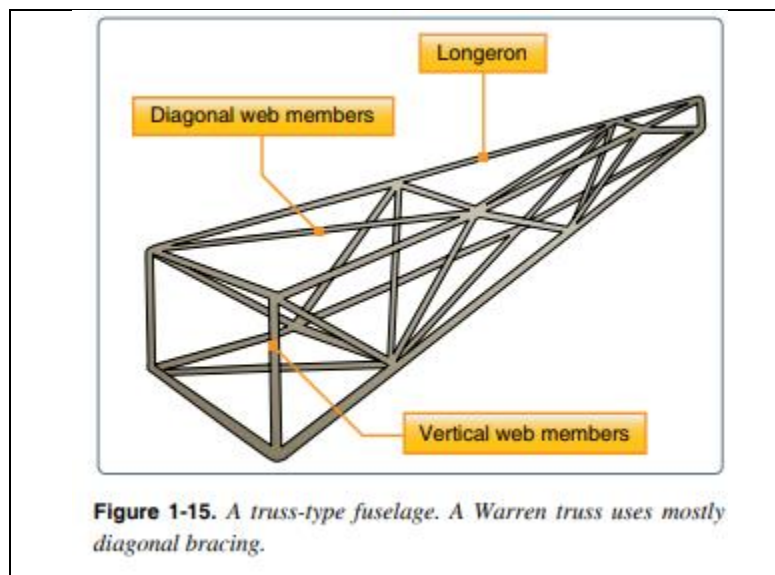
Shear is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer. [Figure 1-14D] Two riveted plates in tension subject the rivets to a shearing force. Usually, the shearing strength of a material is either equal to or less than its tensile or compressive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

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 [Figure 1-15].



Monocoque

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.

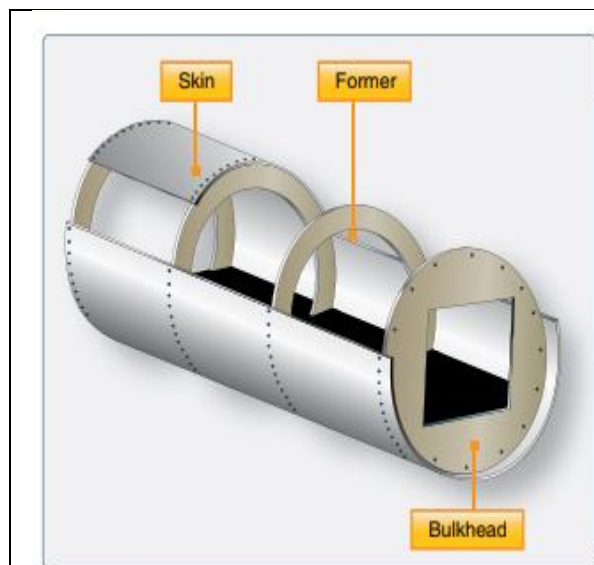


Figure 1-16. An airframe using monocoque construction.

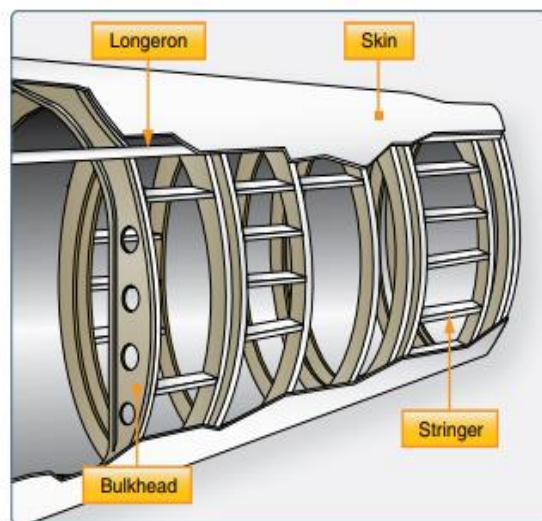


Figure 1-17. The most common airframe construction is semimonocoque.

Semimonocoque

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.

Pressurization

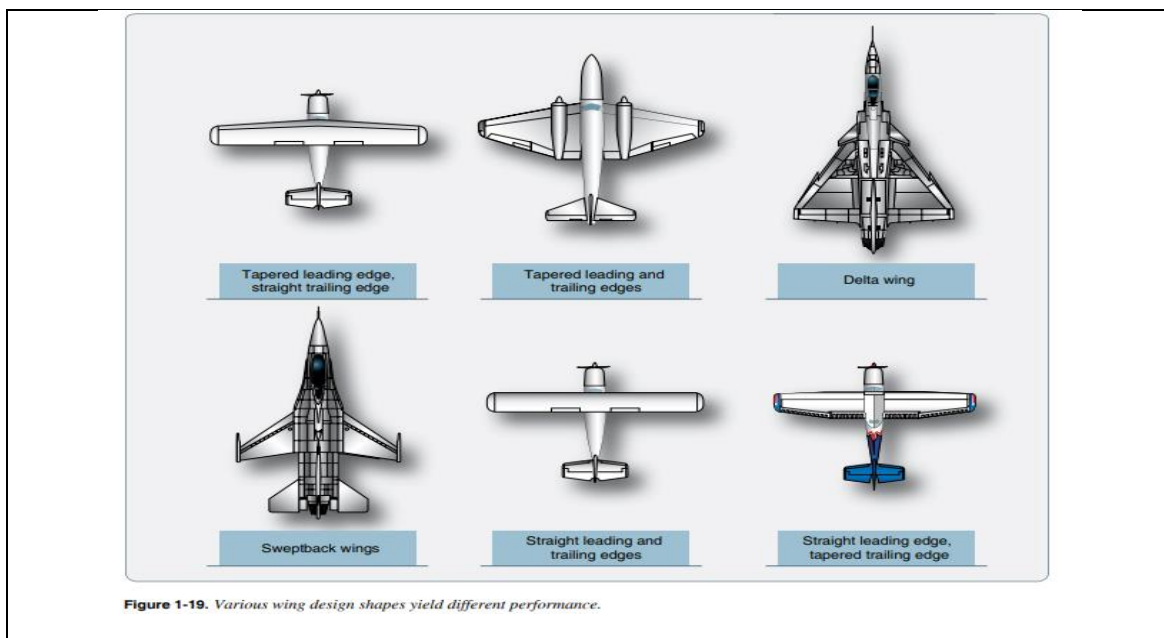
Many aircraft are pressurized. This means that air is pumped into the cabin after takeoff and a difference in pressure between the air inside the cabin and the air outside the cabin is established. This differential is regulated and maintained. In this manner, enough oxygen is made available for passengers 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.

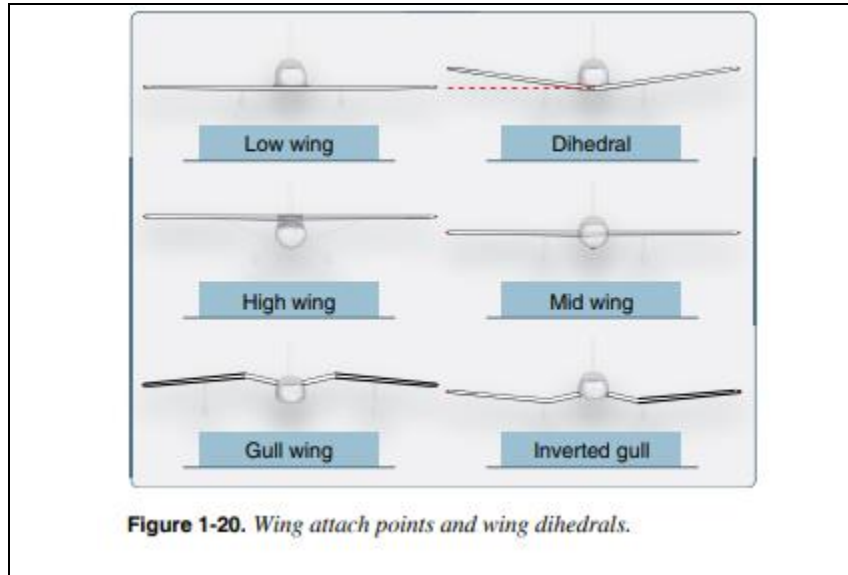
- **Wings**

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.

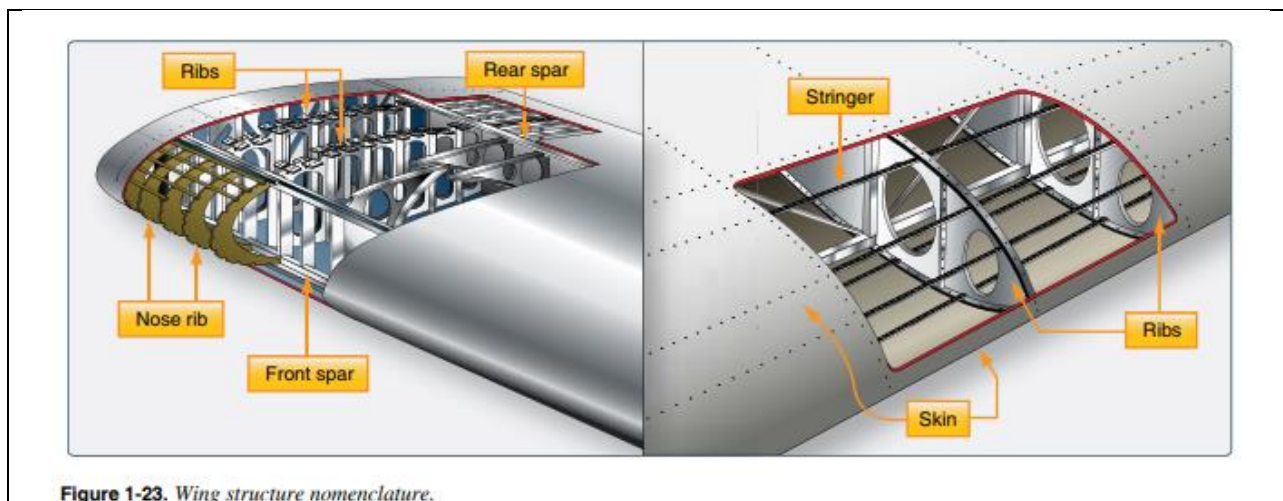


The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of the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



Wing Structure

The internal structures of most wings are made up of spars and stringers running spanwise and ribs. 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**

The **monospar** wing incorporates only one main spanwise or longitudinal member in its construction. Ribs or bulkheads supply the necessary contour or shape to the airfoil.

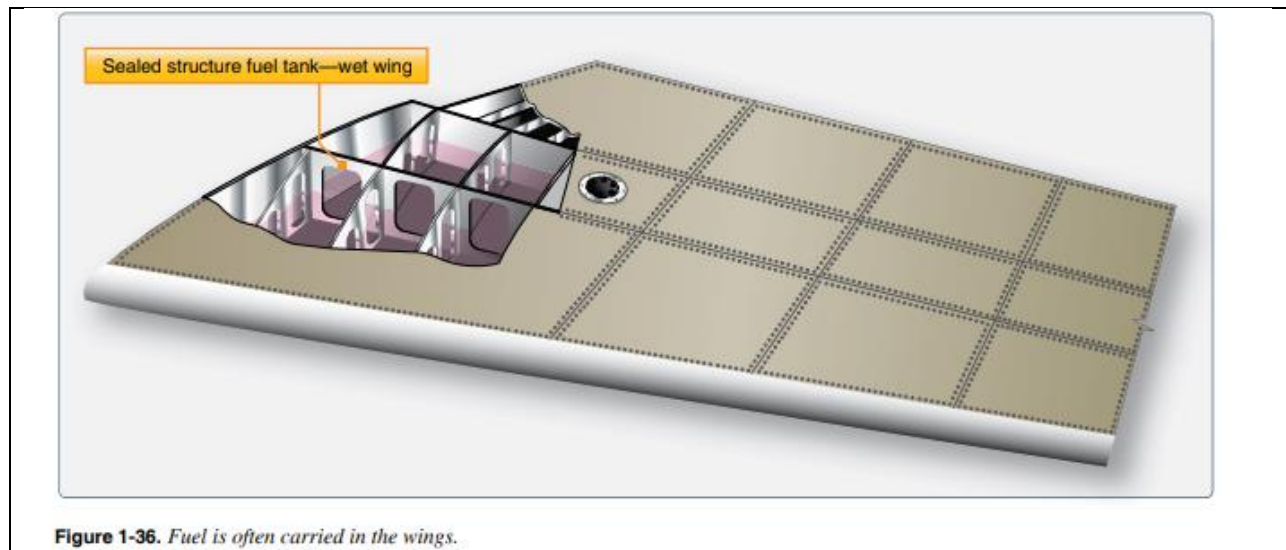
The **multispar** wing incorporates more than one main longitudinal member in its construction.

The **box beam** type of wing construction uses two main longitudinal members with connecting bulkheads to furnish additional strength and to give contour to the wing.

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.

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.

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Chapter 3 Aircraft Structures

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. 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.

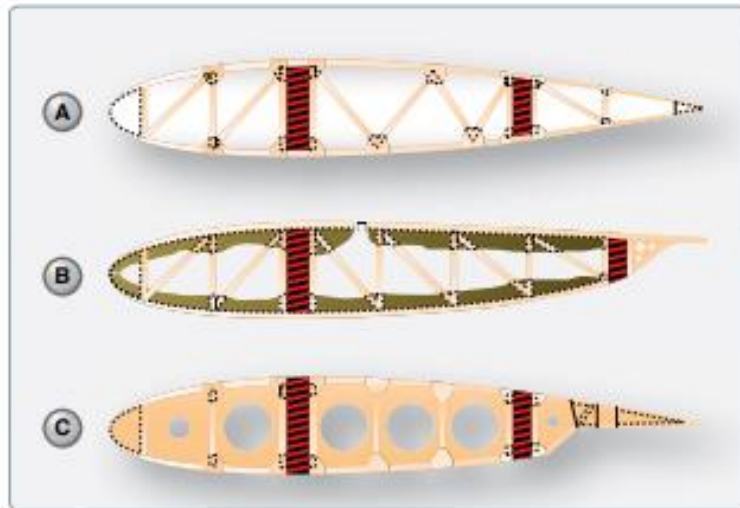


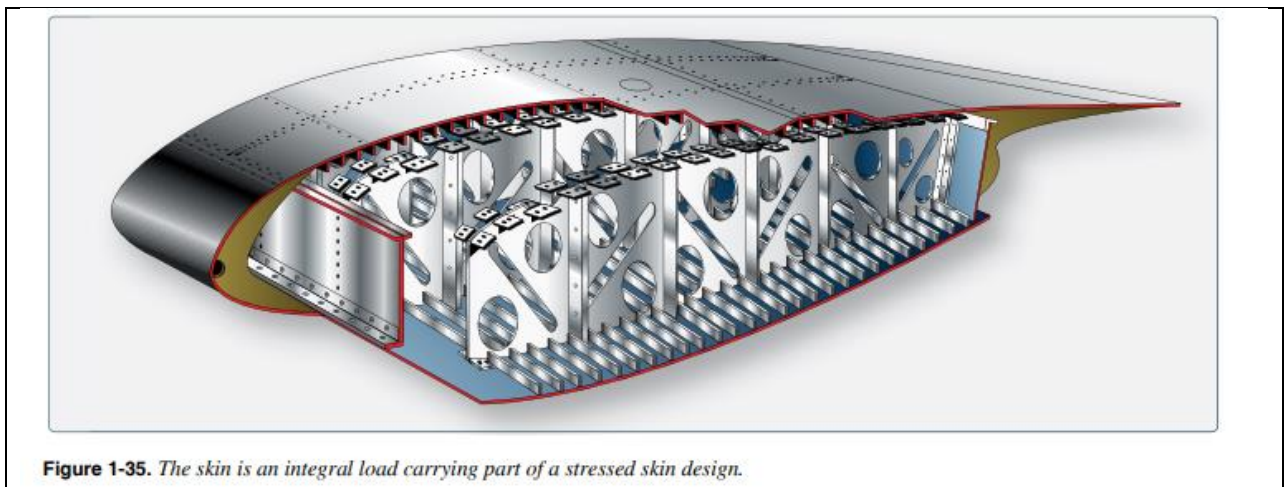
Figure 1-31. Examples of wing ribs constructed of wood.

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. Continuous gussets are also more easily handled than the many small separate

gussets otherwise required. Figure 1-31C shows a rib with a lighten plywood web. It also contains gussets to support the web/cap strip interface. The cap strip is usually laminated to the web, especially at the leading edge.

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.



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.

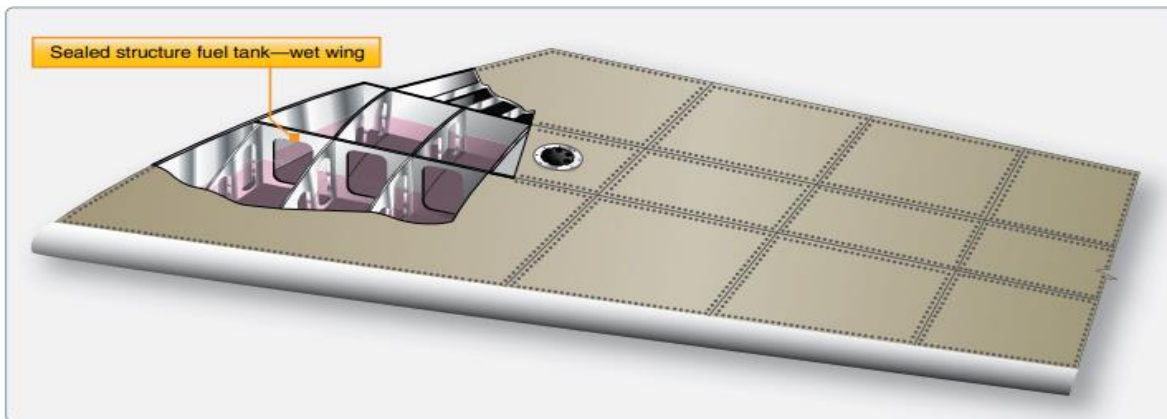


Figure 1-36. Fuel is often carried in the wings.

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 panes 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 1-39 shows an entire wing leading edge formed from honeycomb structure.

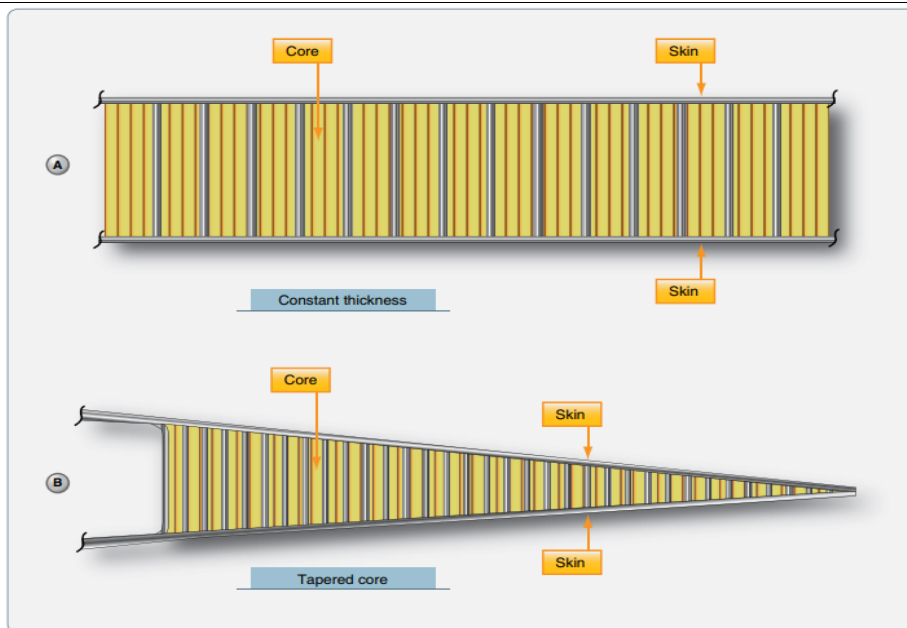


Figure 1-37. The honeycomb panel is a staple in aircraft construction. Cores can be either constant thickness (A) or tapered (B). Tapered core honeycomb panels are frequently used as flight control surfaces and wing trailing edges.

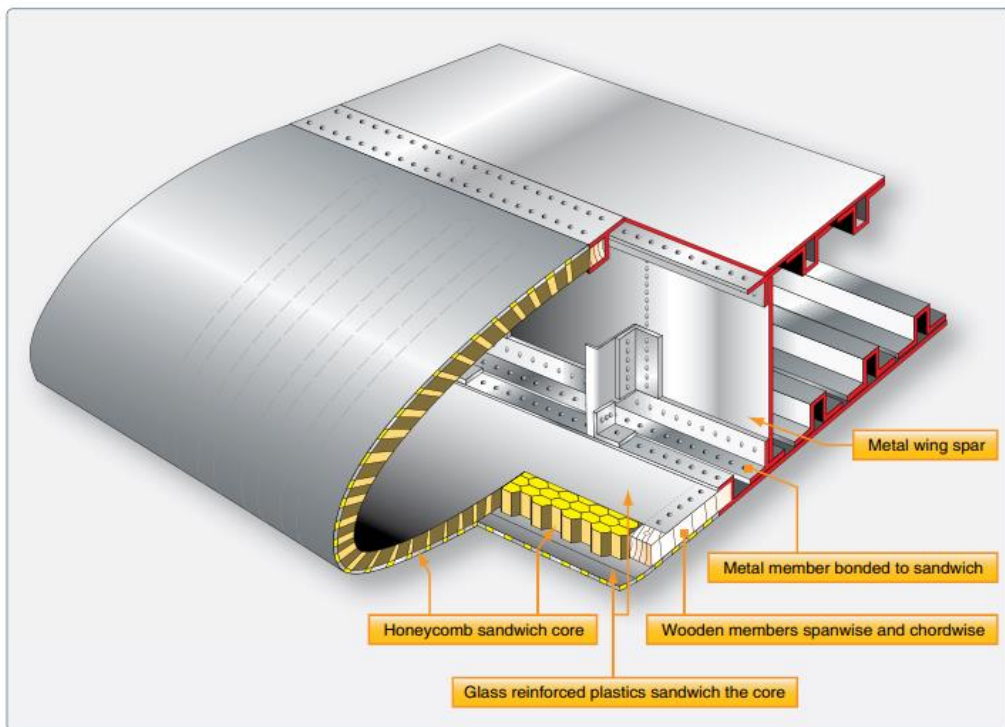


Figure 1-39. A wing leading edge formed from honeycomb material bonded to the aluminum spar structure.

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

Engine mounts are also found in the nacelle. These are the structural assemblies to which the engine is fastened.

The exterior of a nacelle is covered with a skin or fitted with a **cowling** 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.

There are many engine cowl designs. Figure 1-43 shows an exploded view of the pieces of cowling for a horizontally opposed engine on a light aircraft. It is attached to the nacelle by means of screws and/or quick release fasteners. 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.

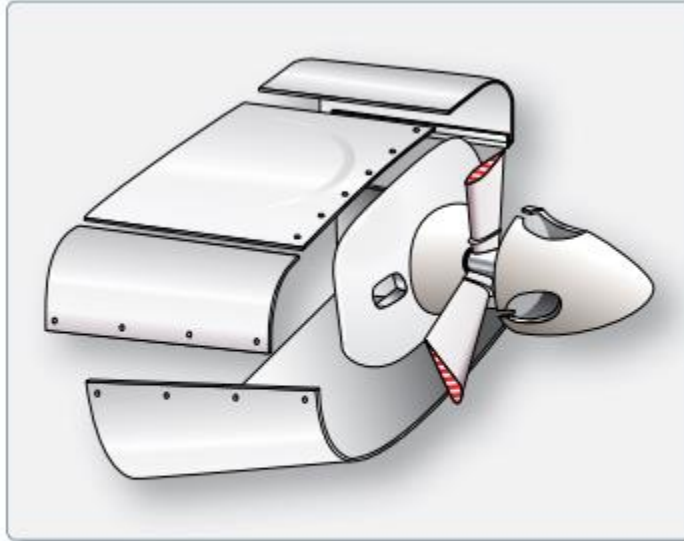


Figure 1-43. *Typical cowling for a horizontally opposed reciprocating engine.*



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

- **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. 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].

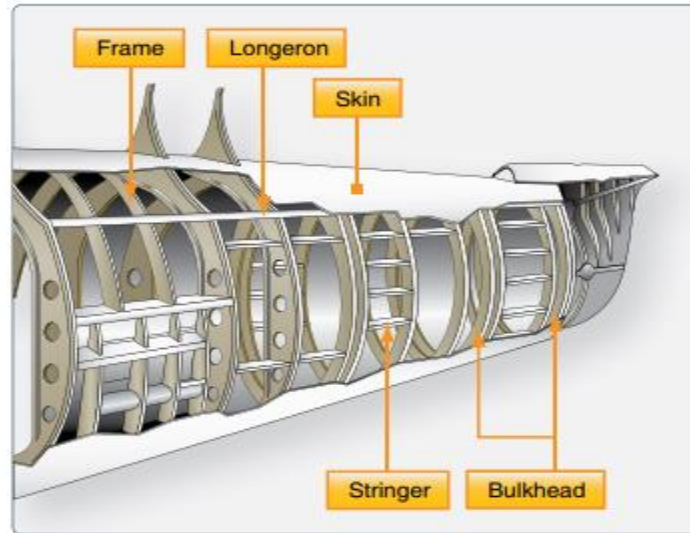


Figure 1-46. The fuselage terminates at the tail cone with similar but more lightweight construction.

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]

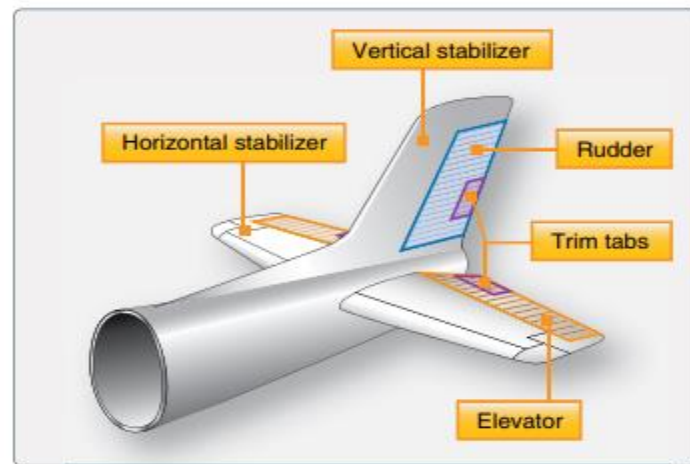
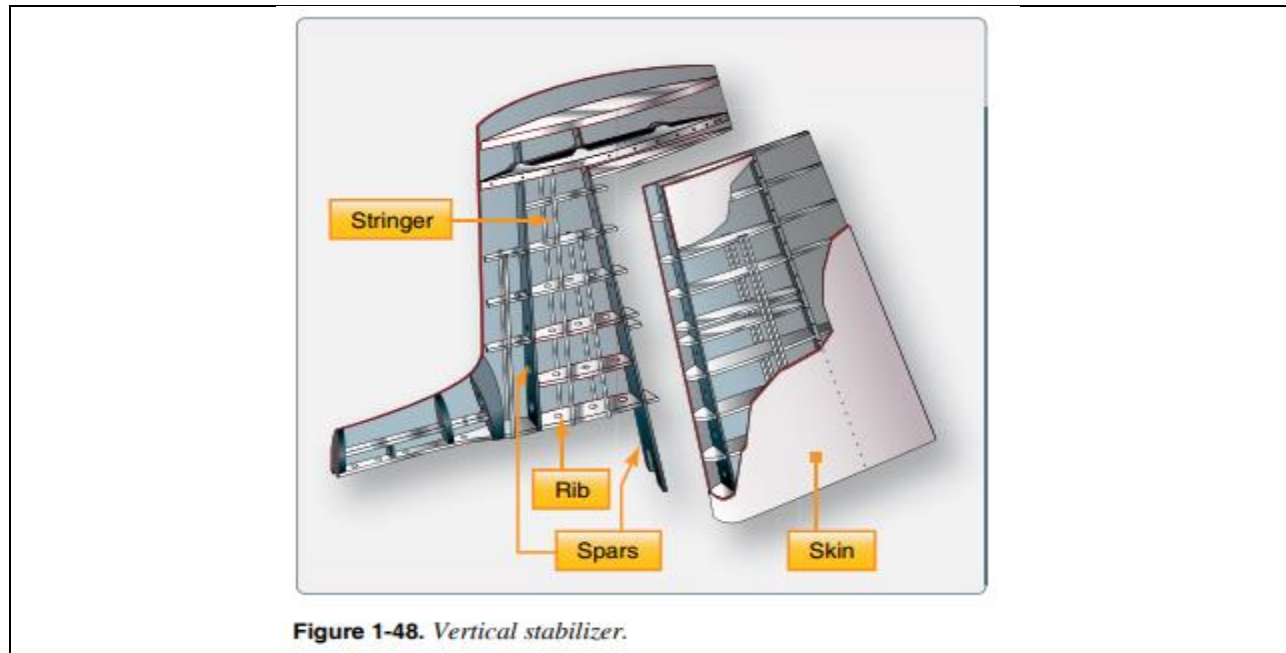


Figure 1-47. Components of a typical empennage.

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 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.



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.

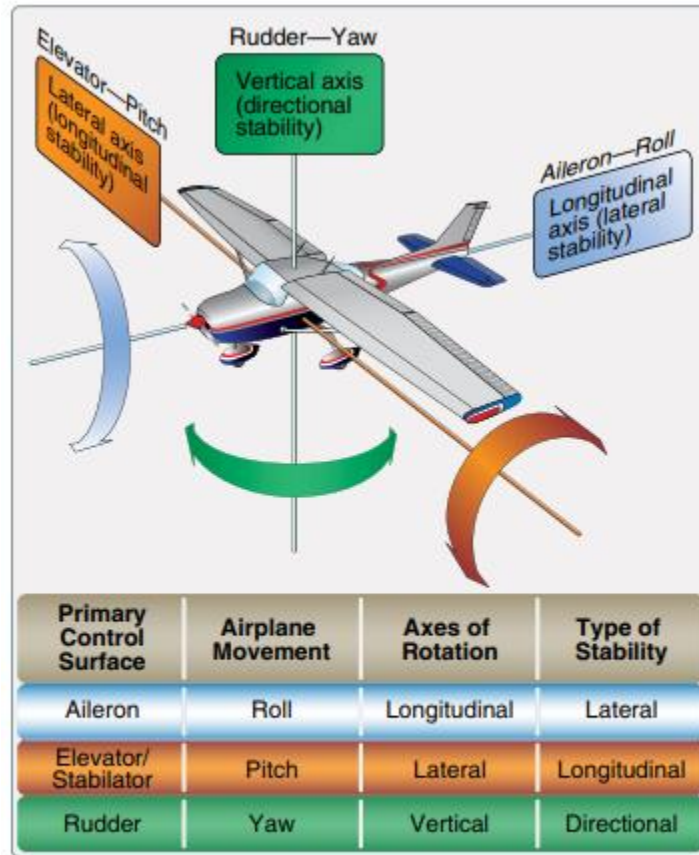


Figure 1-49. Flight control surfaces move the aircraft around the three axes of flight.

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

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.

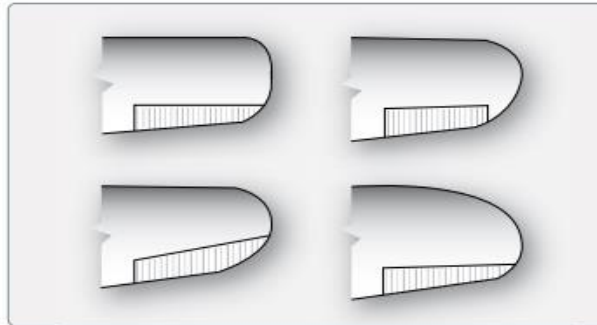


Figure 1-53. Aileron location on various wings.

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].

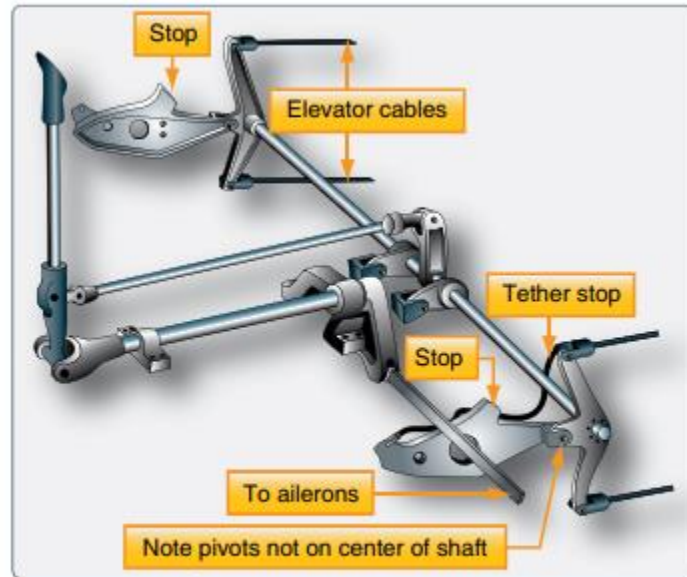


Figure 1-55. *Transferring control surface inputs from the cockpit.*

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.

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].

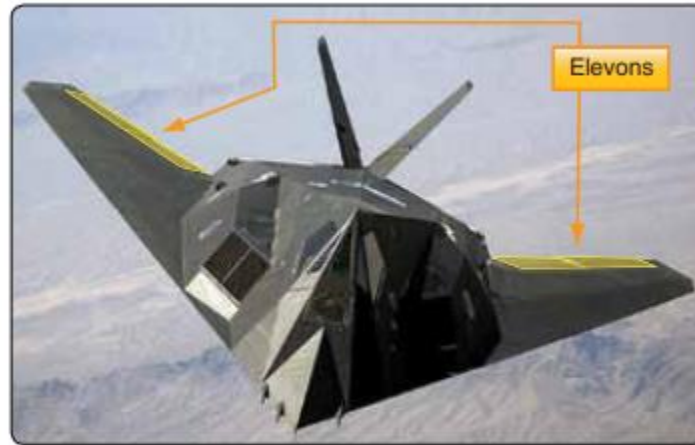


Figure 1-57. Elevons.

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 edge. Movement of the ruddervators can alter the movement of the aircraft around the horizontal and/or vertical axis.



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

Additionally, some aircraft are equipped with flaperons. [Figure 1-60] Flaperons are ailerons which can also act as flaps.



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.

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.

Al-Najaf Technical Institute
Aeronautical Technologies Department
Year One

Subject: - Configuration of Aircrafts
Lecturer Notes by Dr. Essam Al-Zaini

Source 1: - AIRCRAFT DESIGN A Systems Engineering Approach

Source 2: - Aviation Maintenance Technician Handbook—Airframe Volume 1, 2012, U.S.
Department of Transportation FEDERAL AVIATION ADMINISTRATION

Chapter 4 Aircraft Structures

- **Secondary or Auxiliary Control Surfaces**

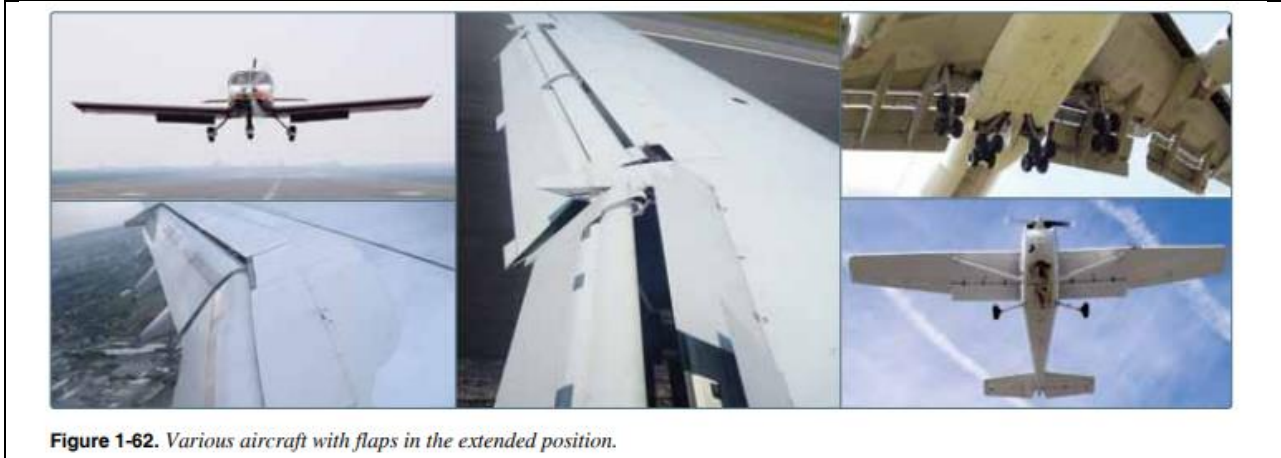
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NOTE: An aircraft may possess none, one, or a combination of the above control surfaces.

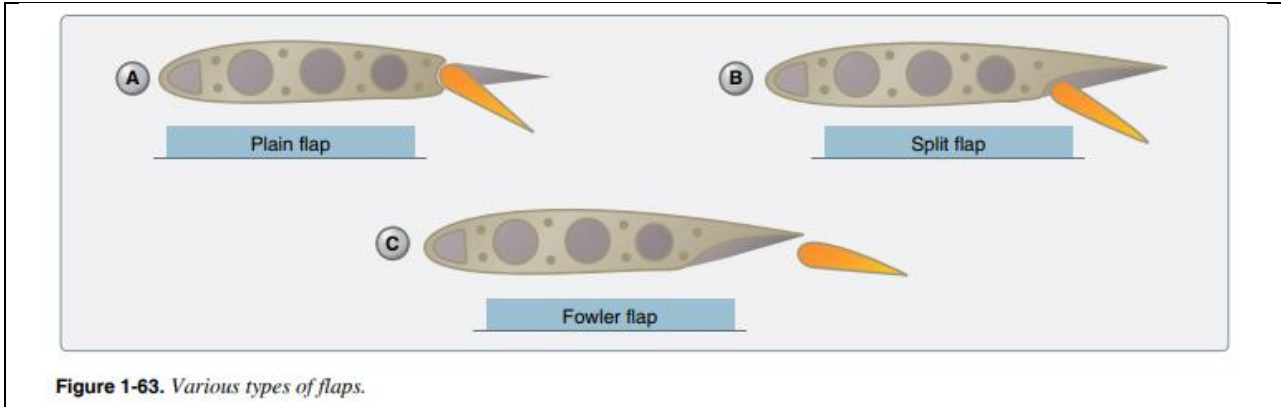
- **Flaps**

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.

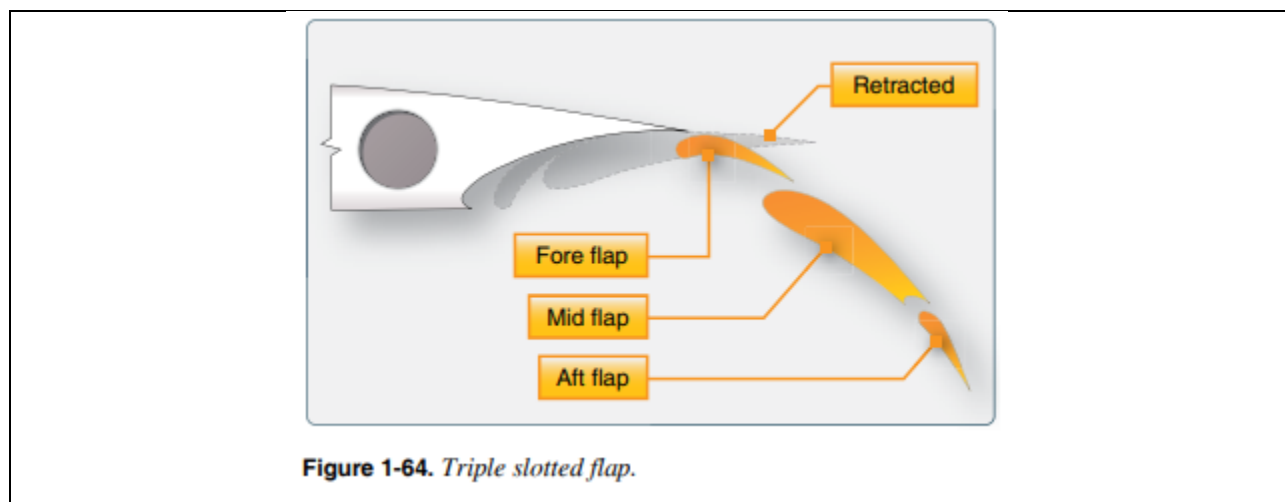
Plain flaps form the trailing edge of the wing when the flap is in the retracted position. [Figure 1-63A] The airflow over the wing continues over the upper and lower surfaces of the flap, making the trailing edge of the flap essentially the trailing edge of the wing. The plain flap is hinged so that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



- **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.



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.

- **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 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.



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

- **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.

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.

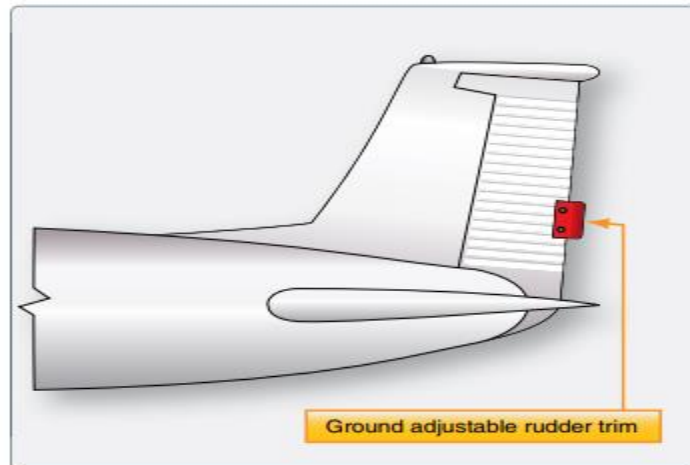


Figure 1-70. Example of a trim tab.

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 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.

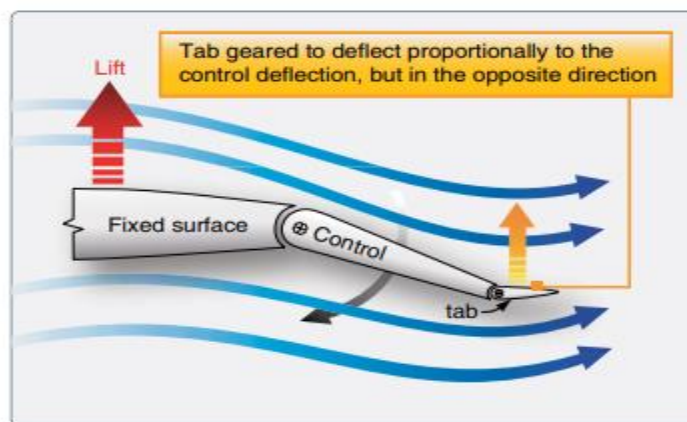


Figure 1-71. Balance tabs assist with forces needed to position control surfaces.

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.



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.

Other Wing Features

There may be other structures visible on the wings of an aircraft that contribute to performance. **1) Winglets, 2) vortex generators, 3) stall fences, and 4) 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 1-77. 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.

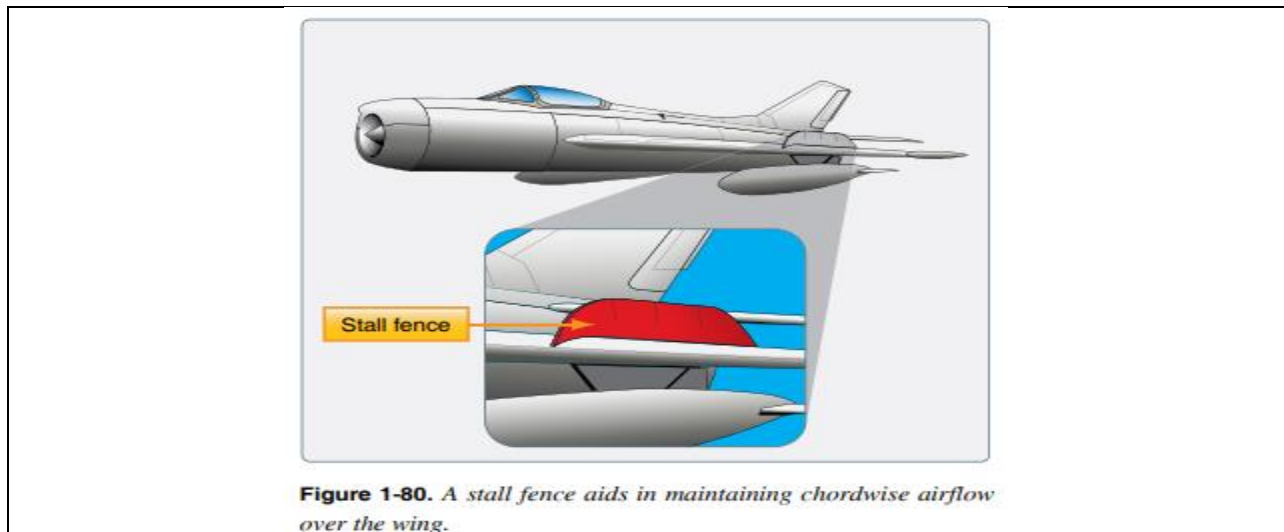


Figure 1-78. Vortex generators.

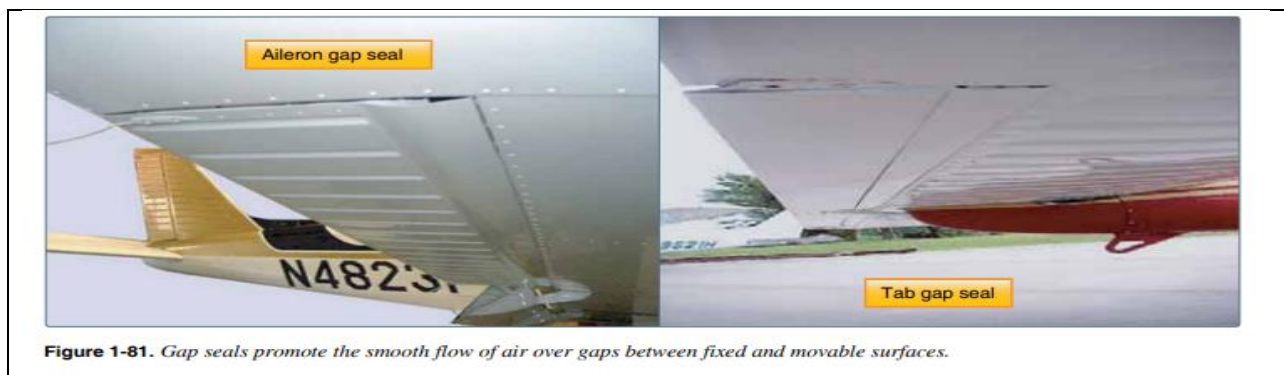


Figure 1-79. The Symphony SA-160 has two unique vortex generators on its wing to ensure aileron effectiveness through the stall.

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].



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 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.



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Chapter 5 Helicopter Structures

Introduction

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.

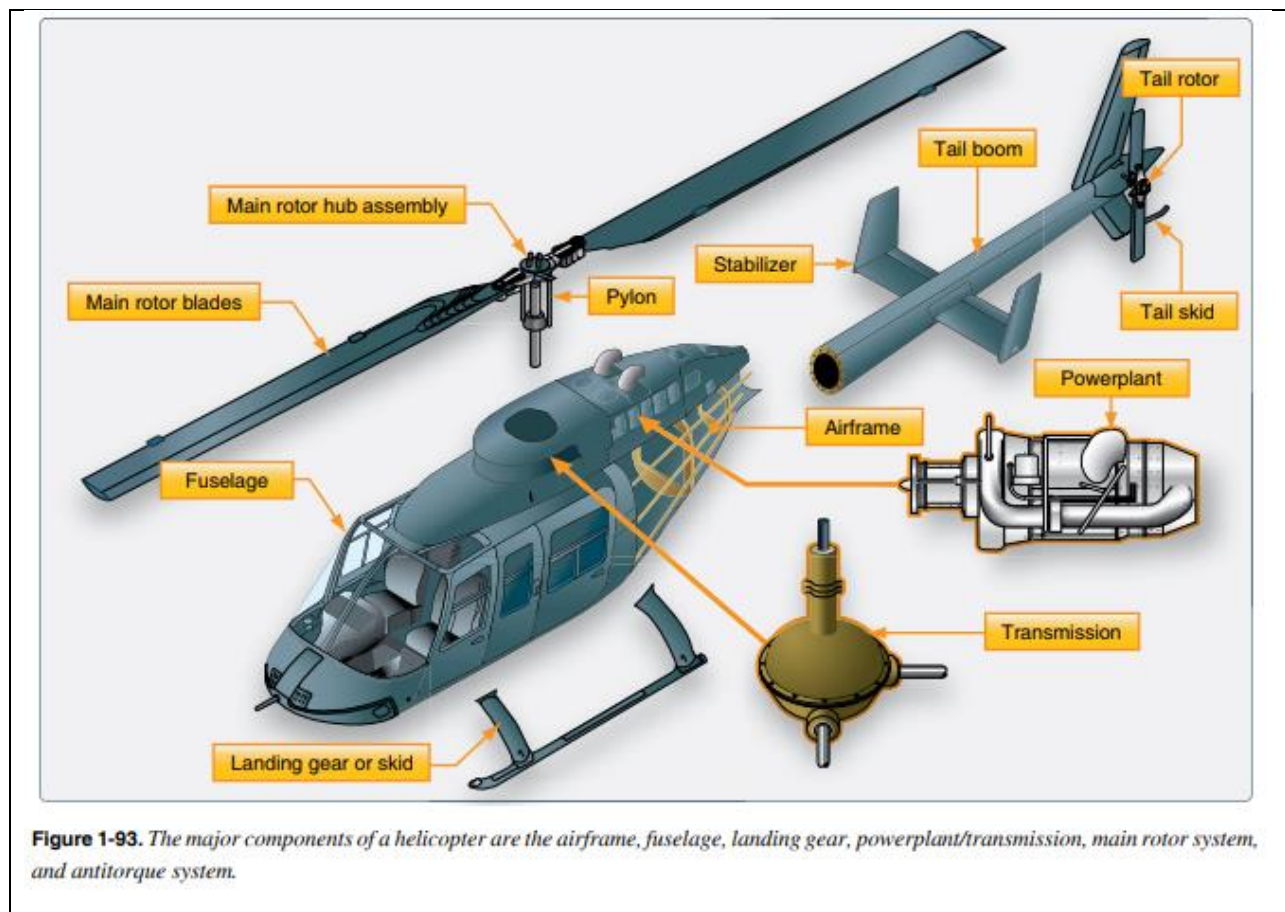


Figure 1-93. The major components of a helicopter are the airframe, fuselage, landing gear, powerplant/transmission, main rotor system, and antitorque system.

1. Airframe

The airframe, or fundamental structure, of a helicopter can be made of a **composite component** 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.

1. 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.

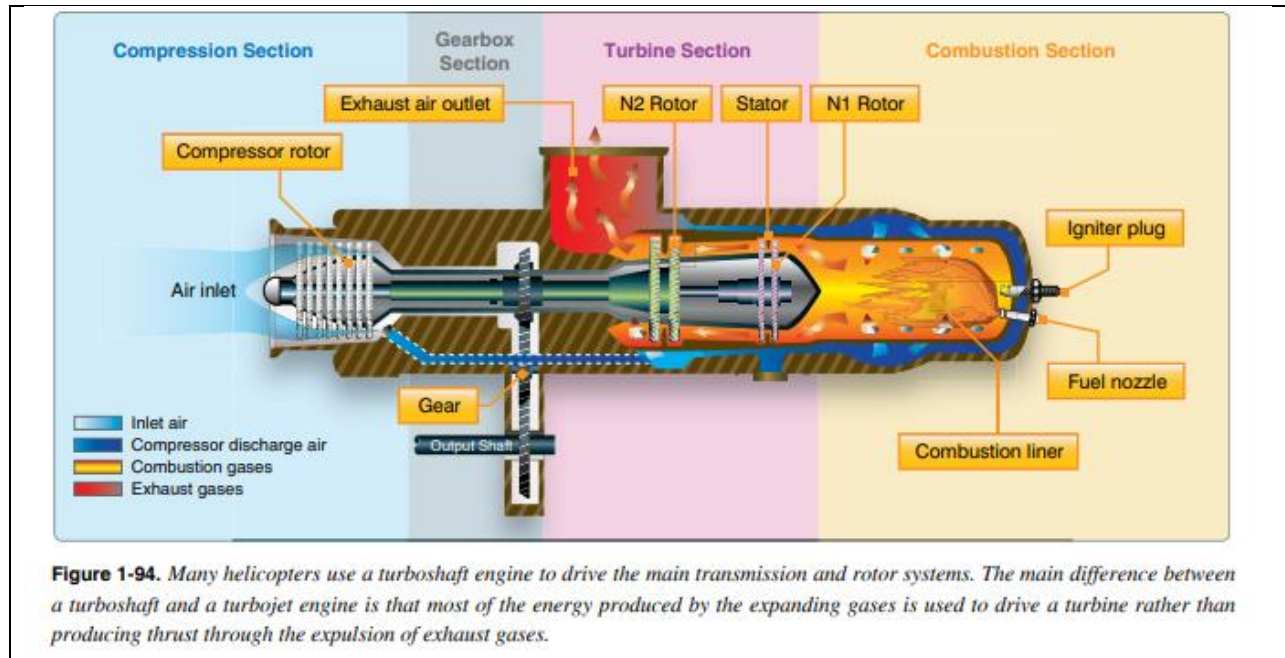
2. Landing Gear or Skids

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.

3. Powerplant (Turbine Engines)

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.

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 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 1) **compressor**, 2) **combustion chamber**, 3) **turbine**, and 4) **accessory gearbox assembly**.

- 1) 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).
- 2) 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.
- 3) 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**.
- 4) 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.

4) **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.

5) Main Rotor System

The rotor system is the rotating part of a helicopter which generates lift. The rotor consists of a **1) mast, 2) hub, and 3) 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: 1) rigid, 2) semirigid, or 3) fully articulated.**

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).

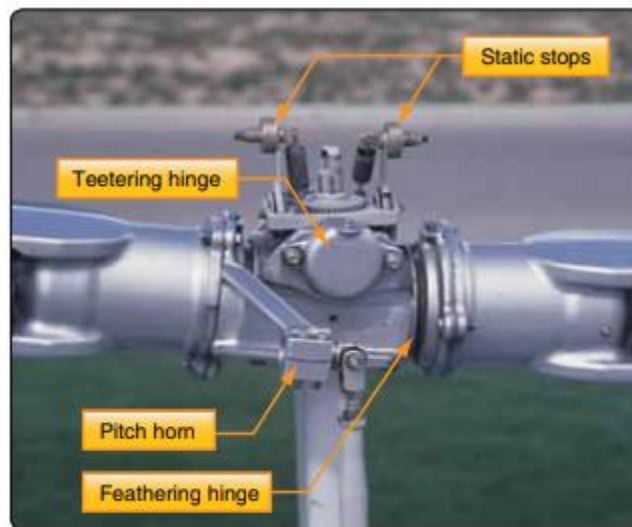
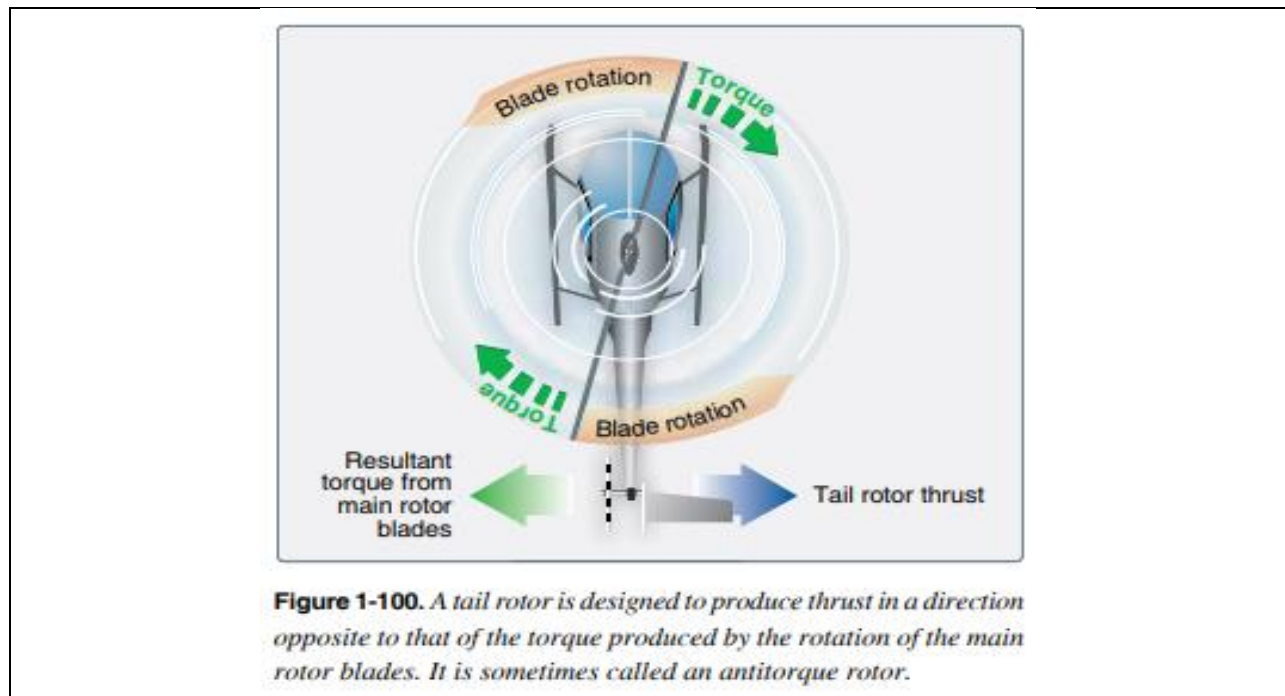


Figure 1-95. *The teetering hinge allows the main rotor hub to tilt, and the feathering hinge enables the pitch angle of the blades to change.*

6) 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 counter torque of the tail rotor must be modulated as engine power levels are changed. This is done by changing the pitch of the tail rotor blades. This, in turn, changes the amount of counter torque, and the aircraft can be rotated about its vertical axis, allowing the pilot to control the direction the helicopter is facing.



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.

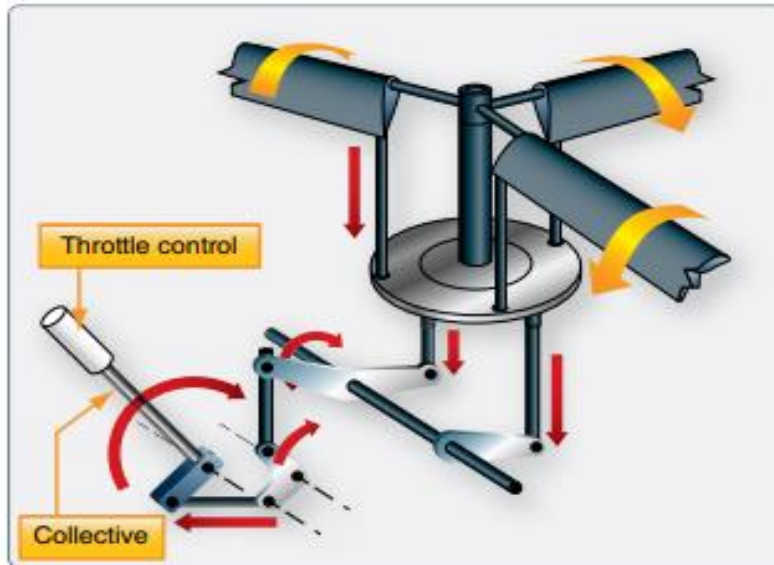


Figure 1-103. The collective changes the pitch of all of the rotor blades simultaneously and by the same amount, thereby increasing or decreasing lift.

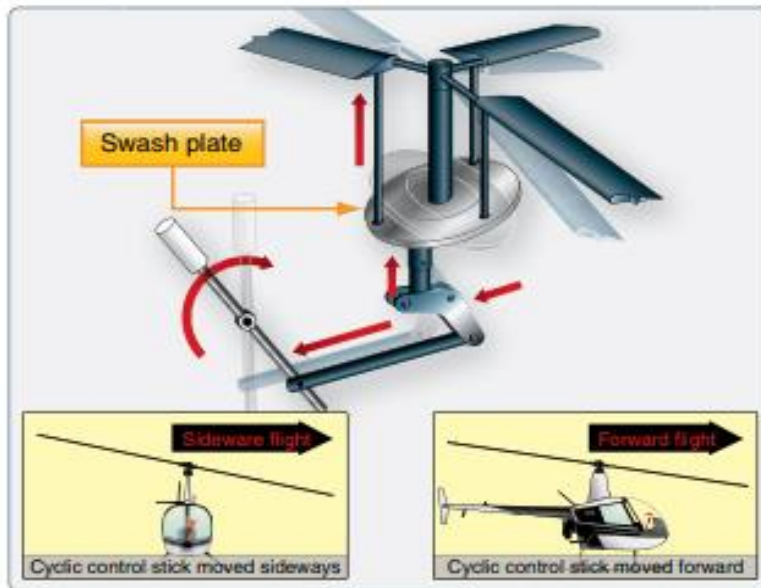


Figure 1-104. The cyclic changes the angle of the swash plate which changes the plane of rotation of the rotor blades. This moves the aircraft horizontally in any direction depending on the positioning of the cyclic.

Al-Najaf Technical Institute
Aeronautical Technologies Department
Year One

Subject: - Configuration of Aircrafts
Lecturer Notes by Dr. Essam Al-Zaini

Source 1: - AIRCRAFT DESIGN A Systems Engineering Approach

Source 2: - Aviation Maintenance Technician Handbook—Airframe Volume 1, 2012, U.S.
Department of Transportation FEDERAL AVIATION ADMINISTRATION

Chapter 6 Aerodynamics

Introduction

Aerodynamics is the study of the dynamics of gases, the interaction between a moving object and the atmosphere. Aerodynamically, an aircraft can be defined as an object traveling through space that is affected by the changes in atmospheric conditions. To state it another way, aerodynamics covers **the relationships between the aircraft, relative wind, and atmosphere.**

The Atmosphere

Before examining the fundamental laws of flight, several basic facts must be considered, namely that an aircraft operates in the air. Therefore, those properties of air that affect the control and performance of an aircraft must be understood.

Pressure

Atmospheric pressure is usually defined as the force exerted against the earth's surface by the weight of the air above that surface. Weight is force applied to an area that results in pressure. Force (F) equals area (A) times pressure (P), or $F = AP$. Therefore, to find the amount of pressure, divide area into force ($P = F/A$). A column of air (one square inch) extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds; therefore, atmospheric pressure is stated in pounds per square inch (psi). Thus, atmospheric pressure at sea level is **14.7 psi.**

Atmospheric pressure is measured with an instrument called a barometer, composed of mercury in a tube that records atmospheric pressure in inches of mercury ("Hg). [Figure 2-1] The standard measurement in aviation altimeters and U.S. weather reports has been "Hg. However, world-wide weather maps and some non-U.S. manufactured aircraft instruments indicate pressure in millibars (mb), a metric unit.

At sea level, when the average atmospheric pressure is 14.7 psi, the barometric pressure is 29.92 "Hg, and the metric measurement is 1013.25 mb.

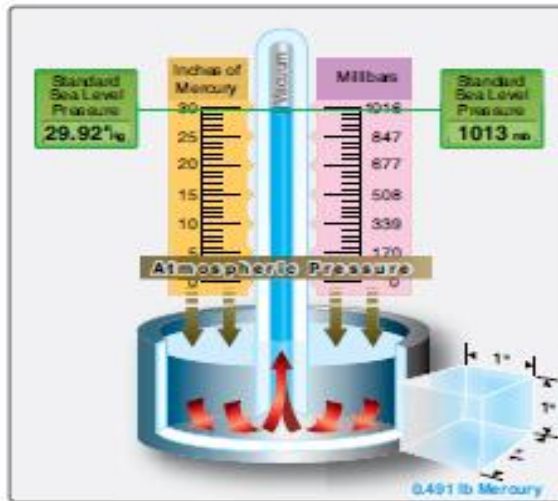


Figure 2-1. Barometer used to measure atmospheric pressure.

Density

Density is weight per unit of volume. Since air is a mixture of gases, it can be compressed. If the air in one container is under half as much pressure as an equal amount of air in an identical container, the air under the greater pressure weighs twice as much as that in the container under lower pressure.

The air under greater pressure is twice as dense as that in the other container. For the equal weight of air, that which is under the greater pressure occupies only half the volume of that under half the pressure.

The density of gases is governed by the following rules:

- 1. Density varies in direct proportion with the pressure.**
- 2. Density varies inversely with the temperature.**

Thus, air at high altitudes is less dense than air at low altitudes, and a mass of hot air is less dense than a mass of cool air.

Changes in density affect the aerodynamic performance of aircraft with the same horsepower. An aircraft can fly faster at a high altitude where the density is low than at a low altitude where the density is greater. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit of volume.

Humidity

Humidity is the amount of water vapor in the air. The maximum amount of water vapor that air can hold varies with the temperature. **The higher the temperature of the air, the more water vapor it can absorb.**

1. **Absolute humidity** is the weight of water vapor in a unit volume of air.
2. **Relative humidity** is the ratio, in percent, of the moisture actually in the air to the moisture it would hold if it were saturated at the same temperature and pressure.

Assuming that the temperature and pressure remain the same, the density of the air varies inversely with the humidity. On damp days, the air density is less than on dry days. For this reason, an aircraft requires a longer runway for takeoff on damp days than it does on dry days.

By itself, water vapor weighs approximately five-eighths as much as an equal amount of perfectly dry air. Therefore, when air contains water vapor, it is not as heavy as dry air containing no moisture.

Aerodynamics and the Laws of Physics

The law of conservation of energy states that energy may neither be created nor destroyed. Motion is the act or process of changing place or position. An object may be in motion with respect to one object and motionless with respect to another. For example, a person sitting quietly in an aircraft flying at 200 knots is at rest or motionless with respect to the aircraft; however, the person and the aircraft are in motion with respect to the air and to the earth.

Air has no force or power, except pressure, unless it is in motion. When it is moving, however, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect then, whether an object is moving with respect to the air or the air is moving with respect to the object. The flow of air around an object caused by the movement of either the air or the object, or both, is called the relative wind.

Velocity and Acceleration

The terms “speed” and “velocity” are often used interchangeably, but they do not have the same meaning. **Speed is the rate of motion in relation to time, and velocity is the rate of motion in a particular direction in relation to time.**

An aircraft starts from New York City and flies 10 hours at an average speed of 260 miles per hour (mph). At the end of this time, the aircraft may be over the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, or, if its flight were in a circular path, it may even be back over New York City. If this same aircraft flew at a velocity of 260 mph in a southwestward direction, it would arrive in Los Angeles in about 10 hours. Only the rate of motion is indicated in the first example and denotes the speed of the aircraft. In the last example, the particular direction is included with the rate of motion, thus, denoting the velocity of the aircraft.

Acceleration is defined as the rate of change of velocity. An aircraft increasing in velocity is an example of **positive acceleration**, while another aircraft reducing its velocity is an example of **negative acceleration, or deceleration.**

Newton’s Laws of Motion

The fundamental laws governing the action of air about a wing are known as **Newton’s laws of motion.** **Newton’s first law is normally referred to as the law of inertia. It simply means that a body at rest does not move unless force is applied to it. If a body is moving at uniform speed in a straight line, force must be applied to increase or decrease the speed.**

According to Newton’s law, since air has mass, it is a body. When an aircraft is on the ground with its engines off, inertia keeps the aircraft at rest. An aircraft is moved from its state of rest by the thrust force created by a propeller, or by the expanding exhaust, or both. When an aircraft is flying at uniform speed in a straight line, inertia tends to keep the aircraft moving. Some external force is required to change the aircraft from its path of flight.

Newton's second law states that if a body moving with uniform speed is acted upon by an external force, the change of motion is proportional to the amount of the force, and motion takes place in the direction in which the force acts.

This law may be stated mathematically as follows:

Force = mass × acceleration ($F = ma$)

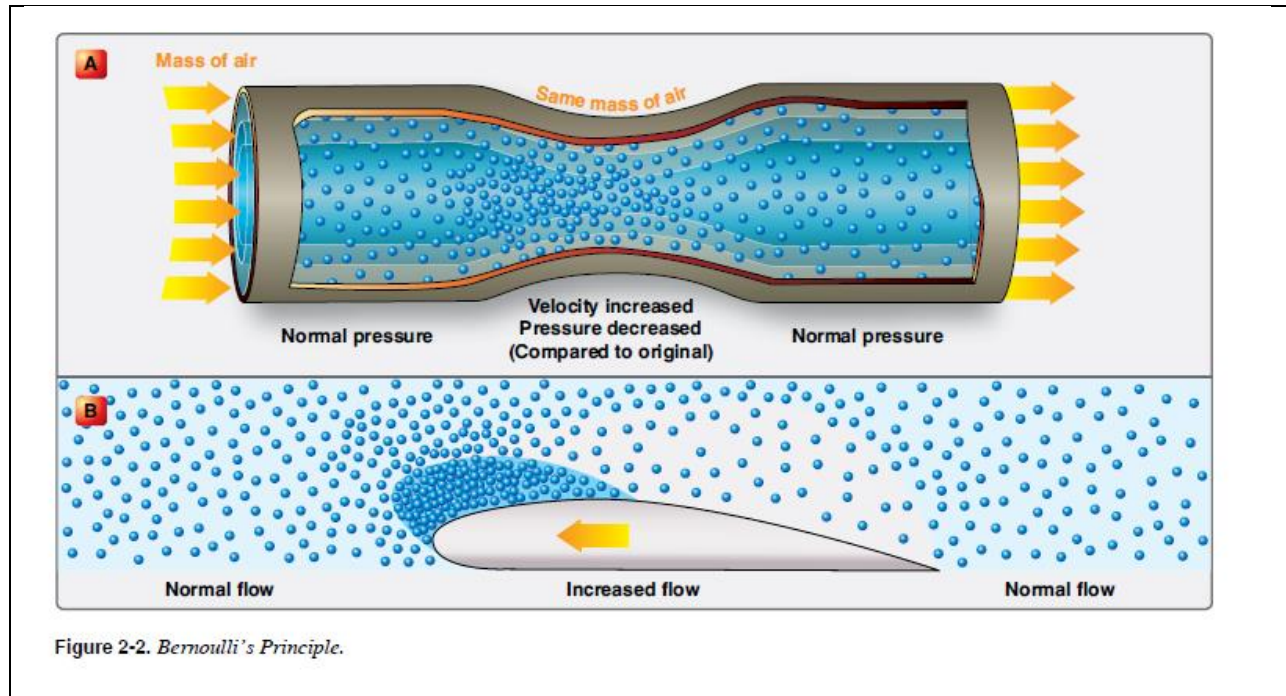
If an aircraft is flying against a headwind, it is slowed down. If the wind is coming from either side of the aircraft's heading, the aircraft is pushed off course unless the pilot takes corrective action against the wind direction.

Newton's third law is the law of action and reaction. This law states that for every action (force) there is an equal and opposite reaction (force). This law can be illustrated by the example of firing a gun. The action is the forward movement of the bullet while the reaction is the backward recoil of the gun.

The three laws of motion that have been discussed apply to the theory of flight. In many cases, all three laws may be operating on an aircraft at the same time.

Bernoulli's Principle and Subsonic Flow

Bernoulli's principle states that when a fluid (air) flowing through a tube reaches a constriction, or narrowing, of the tube, the speed of the fluid flowing through that constriction is increased and its pressure is decreased. The cambered (curved) surface of an airfoil (wing) affects the airflow exactly as a constriction in a tube affects airflow. *[Figure 2-2] Diagram A of Figure 2-2 illustrates the effect of air passing through a constriction in a tube. In B, air is flowing past a cambered surface, such as an airfoil, and the effect is similar to that of air passing through a restriction.*



As the air flows over the upper surface of an airfoil, its velocity increases and its pressure decreases; an area of low pressure is formed. There is an area of greater pressure on the lower surface of the airfoil, and this greater pressure tends to move the wing upward. The difference in pressure between the upper and lower surfaces of the wing is called lift. Three-fourths of the total lift of an airfoil is the result of the decrease in pressure over the upper surface. The impact of air on the under surface of an airfoil produces the other one-fourth of the total lift.

Airfoil

An airfoil is a surface designed to obtain lift from the air through which it moves. Thus, it can be stated that any part of the aircraft that converts air resistance into lift is an airfoil. The profile of a conventional wing is an excellent example of an airfoil. [Figure 2-3] Notice that the top surface of the wing profile has greater curvature than the lower surface.

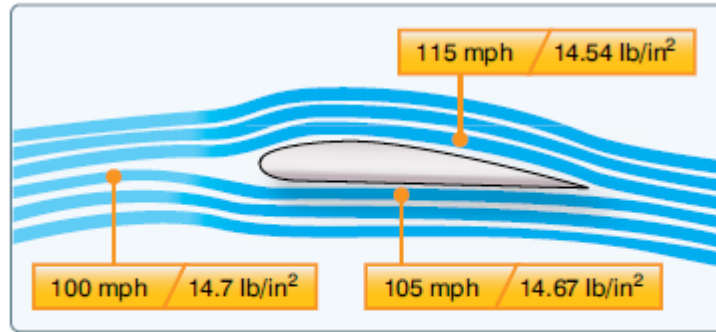


Figure 2-3. Airflow over a wing section.

The difference in curvature of the upper and lower surfaces of the wing builds up the lift force. Air flowing over the top surface of the wing must reach the trailing edge of the wing in the same amount of time as the air flowing under the wing. To do this, the air passing over the top surface moves at a greater velocity than the air passing below the wing because of the greater distance it must travel along the top surface. This increased velocity, according to Bernoulli's Principle, means a corresponding decrease in pressure on the surface. Thus, a pressure differential is created between the upper and lower surfaces of the wing, forcing the wing upward in the direction of the lower pressure.

Within limits, lift can be increased by increasing the angle of attack (AOA), wing area, velocity, density of the air, or by changing the shape of the airfoil. When the force of lift on an aircraft's wing equals the force of gravity, the aircraft maintains level flight.

Shape of the Airfoil

Individual airfoil section properties differ from those properties of the wing or aircraft as a whole because of the effect of the wing planform. A wing may have various airfoil sections from root to tip, with taper, twist, and sweepback.

The resulting aerodynamic properties of the wing are determined by the action of each section along the span. The shape of the airfoil determines the amount of turbulence or skin friction that it produces, consequently affecting the efficiency of the wing. Turbulence and skin friction are controlled mainly by the **fineness ratio, which is defined as the ratio of the chord of the airfoil to the maximum thickness.**

If the wing has a high fineness ratio, it is a very thin wing. A thick wing has a low fineness ratio.

A wing with a high fineness ratio produces a large amount of skin friction. A wing with a low fineness ratio produces a large amount of turbulence. The best wing is a compromise between these two extremes to hold both turbulence and skin friction to a minimum.

The efficiency of a wing is measured in terms of the lift to drag ratio (L/D). This ratio varies with the AOA but reaches a definite maximum value for a particular AOA. At this angle, the wing has reached its maximum efficiency. The shape of the airfoil is the factor that determines the AOA at which the wing is most efficient; it also determines the degree of efficiency.

Research has shown that the most efficient airfoils for general use have the maximum thickness occurring about one-third of the way back from the leading edge of the wing.

High-lift wings and high-lift devices for wings have been developed by shaping the airfoils to produce the desired effect. The amount of lift produced by an airfoil increases with an increase in wing camber. **Camber refers to the curvature of an airfoil above and below the chord line surface.**

Angle of Incidence

The acute angle the wing chord makes with the longitudinal axis of the aircraft is called the angle of incidence, or the angle of wing setting. [Figure 2-4] The angle of incidence in most cases is a fixed, built-in angle. When the leading edge of the wing is higher than the trailing edge, the angle of incidence is said to be positive. The angle of incidence is negative when the leading edge is lower than the trailing edge of the wing.

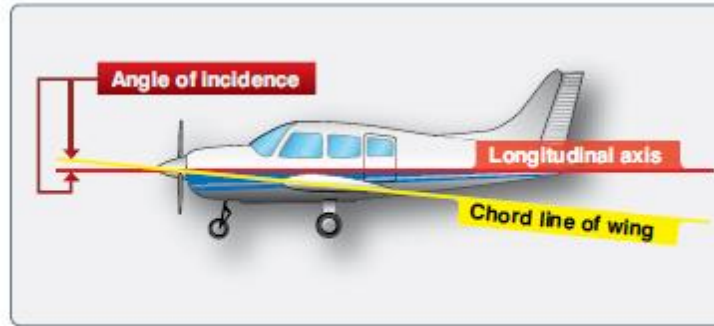


Figure 2-4. Angle of incidence.

Angle of Attack (AOA)

Before beginning the discussion on AOA and its effect on airfoils, first consider the terms chord and center of pressure (CP) as illustrated in *Figure 2-5*.

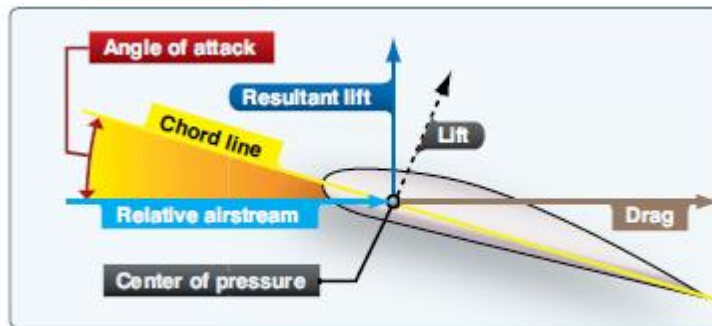
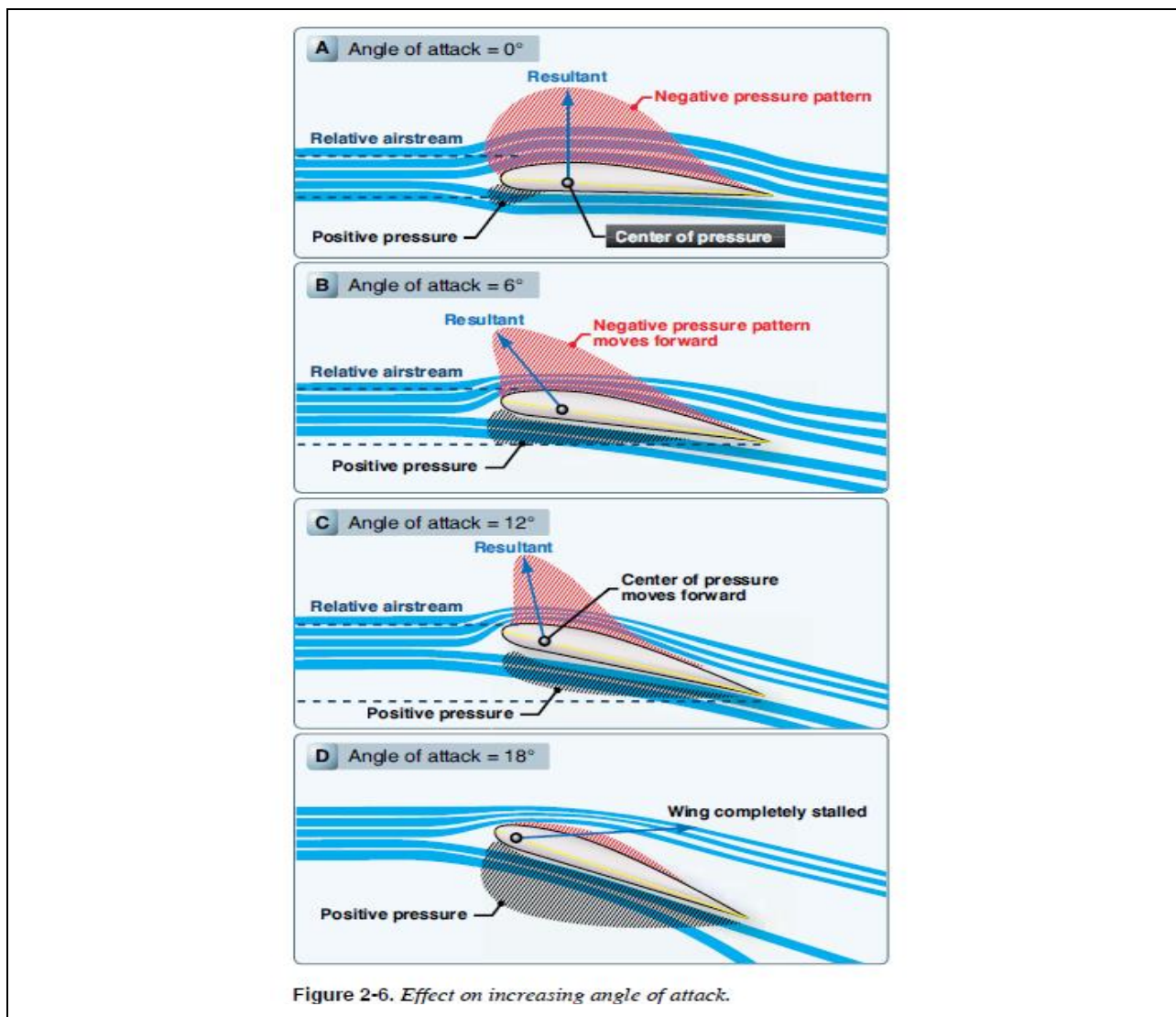


Figure 2-5. Airflow over a wing section.

The chord of an airfoil or wing section is an imaginary straight line that passes through the section from the leading edge to the trailing edge, as shown in *Figure 2-5*. The chord line provides one side of an angle that ultimately forms the AOA. The other side of the angle is formed by a line indicating the direction of the relative airstream. Thus, **AOA is defined as the angle between the chord line of the wing and the direction of the relative wind**. This is not to be confused with the **angle of incidence**, illustrated in *Figure 2-4*, which is the angle between the chord line of the wing and the longitudinal axis of the aircraft.

On each part of an airfoil or wing surface, a small force is present. This force is of a different magnitude and direction from any forces acting on other areas forward or rearward from this point. It is possible to add all of these small forces mathematically. That sum is called the “resultant force” (lift).

This resultant force has magnitude, direction, and location, and can be represented as a vector, as shown in *Figure 2-5*. The point of intersection of the resultant force line with the chord line of the airfoil is called the center of pressure (CP). The CP moves along the airfoil chord as the AOA changes. Throughout most of the flight range, the CP moves forward with increasing AOA and rearward as the AOA decreases. The effect of increasing AOA on the CP is shown in *Figure 2-6*.



The AOA changes as the aircraft's attitude changes. Since the AOA has a great deal to do with determining lift, it is given primary consideration when designing airfoils. In a properly designed airfoil, **the lift increases as the AOA is increased**. When the AOA is increased gradually toward a positive AOA, the lift component increases rapidly up to certain point and then suddenly begins to drop off. During this action the drag component increases slowly at first, then rapidly as lift begins to drop off. When the AOA increases to the angle of maximum lift, the **burble point** is reached. This is known as **the critical angle**. When the critical angle is reached, the air ceases to flow smoothly over the top surface of the airfoil and begins to burble or eddy. This means that air breaks away from the upper camber line of the wing. What was formerly the area of decreased pressure is now filled by this burbling air. When this occurs, the amount of lift drops and drag becomes excessive. The force of gravity exerts itself, and the nose of the aircraft drops. This is a stall. Thus, the burble point is **the stalling angle**.

Thrust and Drag

An aircraft in flight is the center of a continuous battle of forces. Actually, this conflict is not as violent as it sounds, but it is the key to all maneuvers performed in the air. There is nothing mysterious about these forces; they are definite and known. The directions in which they act can be calculated, and the aircraft itself is designed to take advantage of each of them. In all types of flying, flight calculations are based on the magnitude and direction of four forces: weight, lift, drag, and thrust. *[Figure 2-7]*

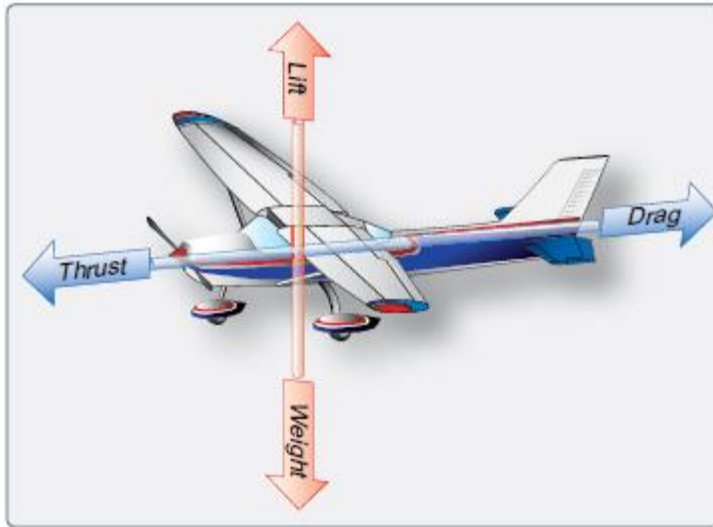


Figure 2-7. Forces in action during flight.

An aircraft in flight is acted upon by four forces:

- 1. Gravity or weight—the force that pulls the aircraft toward the earth. Weight is the force of gravity acting downward upon everything that goes into the aircraft, such as the aircraft itself, crew, fuel, and cargo.**
- 2. Lift—the force that pushes the aircraft upward. Lift acts vertically and counteracts the effects of weight.**
- 3. Thrust—the force that moves the aircraft forward. Thrust is the forward force produced by the powerplant that overcomes the force of drag.**
- 4. Drag—the force that exerts a braking action to hold the aircraft back. Drag is a backward deterrent force and is caused by the disruption of the airflow by the wings, fuselage, and protruding objects.**

These four forces are in perfect balance only when the aircraft is in straight-and-level un-accelerated flight.

The forces of lift and drag are the direct result of the relationship between the relative wind and the aircraft. The force of lift always acts perpendicular to the relative wind, and the force of drag always acts parallel to and in the same direction as the relative wind. These forces are actually the components that produce a resultant lift force on the wing. [Figure 2-8]

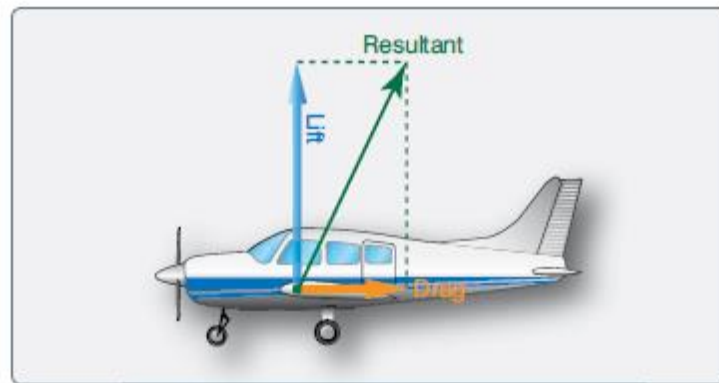


Figure 2-8. Resultant of lift and drag.

Weight has a definite relationship with lift, and thrust with drag. These relationships are quite simple, but very important in understanding the aerodynamics of flying. As stated previously, lift is the upward force on the wing perpendicular to the relative wind. Lift is required to counteract the aircraft's weight, caused by the force of gravity acting on the mass of the aircraft. This weight force acts downward through a point called **the center of gravity (CG)**.

The CG is the point at which all the weight of the aircraft is considered to be concentrated. When the lift force is in equilibrium with the weight force, the aircraft neither gains nor loses altitude. If lift becomes less than weight, the aircraft loses altitude. When the lift is greater than the weight, the aircraft gains altitude.

Wing area is measured in square feet and includes the part blanked out by the fuselage. Wing area is adequately described as the area of the shadow cast by the wing at high noon. Tests show that lift and drag forces acting on a wing are roughly proportional to the wing area. This means that if the wing area is doubled, all other variables remaining the same, the lift and drag created by the wing is doubled. If the area is tripled, lift and drag are tripled.

Drag must be overcome for the aircraft to move, and movement is essential to obtain lift. To overcome drag and move the aircraft forward, another force is essential. This force is thrust. Thrust is derived from jet propulsion or from a propeller and engine combination. Jet propulsion theory is based on Newton's third law of motion. The turbine engine causes a mass of air to be moved backward at high velocity causing a reaction that moves the aircraft forward.

In a propeller/engine combination, the propeller is actually two or more revolving airfoils mounted on a horizontal shaft. The motion of the blades through the air produces lift similar to the lift on the wing, but acts in a horizontal direction, pulling the aircraft forward. Before the aircraft begins to move, thrust must be exerted.

The aircraft continues to move and gain speed until thrust and drag are equal. In order to maintain a steady speed, thrust and drag must remain equal, just as lift and weight must be equal for steady, horizontal flight. Increasing the lift means that the aircraft moves upward, whereas decreasing the lift so that it is less than the weight causes the aircraft to lose altitude. A similar rule applies to the two forces of thrust and drag.

If the revolutions per minute (rpm) of the engine is reduced, the thrust is lessened, and the aircraft slows down. As long as the thrust is less than the drag, the aircraft travels more and more slowly until its speed is insufficient to support it in the air. Likewise, if the rpm of the engine is increased, thrust becomes greater than drag, and the speed of the aircraft increases. As long as the thrust continues to be greater than the drag, the aircraft continues to accelerate. When drag equals thrust, the aircraft flies at a steady speed.

The relative motion of the air over an object that produces lift also produces drag. Drag is the resistance of the air to objects moving through it. If an aircraft is flying on a level course, the lift force acts vertically to support it while the drag force acts horizontally to hold it back. The total amount of drag on an aircraft is made up of many drag forces, but this lecture note considers **three: parasite drag, profile drag, and induced drag.**

Parasite drag is made up of a combination of many different drag forces. Any exposed object on an aircraft offers some resistance to the air, and the more objects in the airstream, the more parasite drag. While parasite drag can be reduced by reducing the number of exposed parts to as few as practical and streamlining their shape, skin friction is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces have a ragged uneven appearance when inspected under magnification.

These ragged surfaces deflect the air near the surface causing resistance to smooth airflow. Skin friction can be reduced by using glossy smooth finishes and eliminating protruding rivet heads, roughness, and other irregularities.

Profile drag may be considered the parasite drag of the airfoil. The various components of parasite drag are all of the same nature as profile drag.

The action of the airfoil that creates lift also causes **induced drag**. Remember, the pressure above the wing is less than atmospheric pressure, and the pressure below the wing is equal to or greater than atmospheric pressure.

Since fluids always move from high pressure toward low pressure, there is a spanwise movement of air from the bottom of the wing outward from the fuselage and upward around the wing tip.

This flow of air results in spillage over the wing tip, thereby setting up a whirlpool of air called a “vortex.” [Figure 2-9]

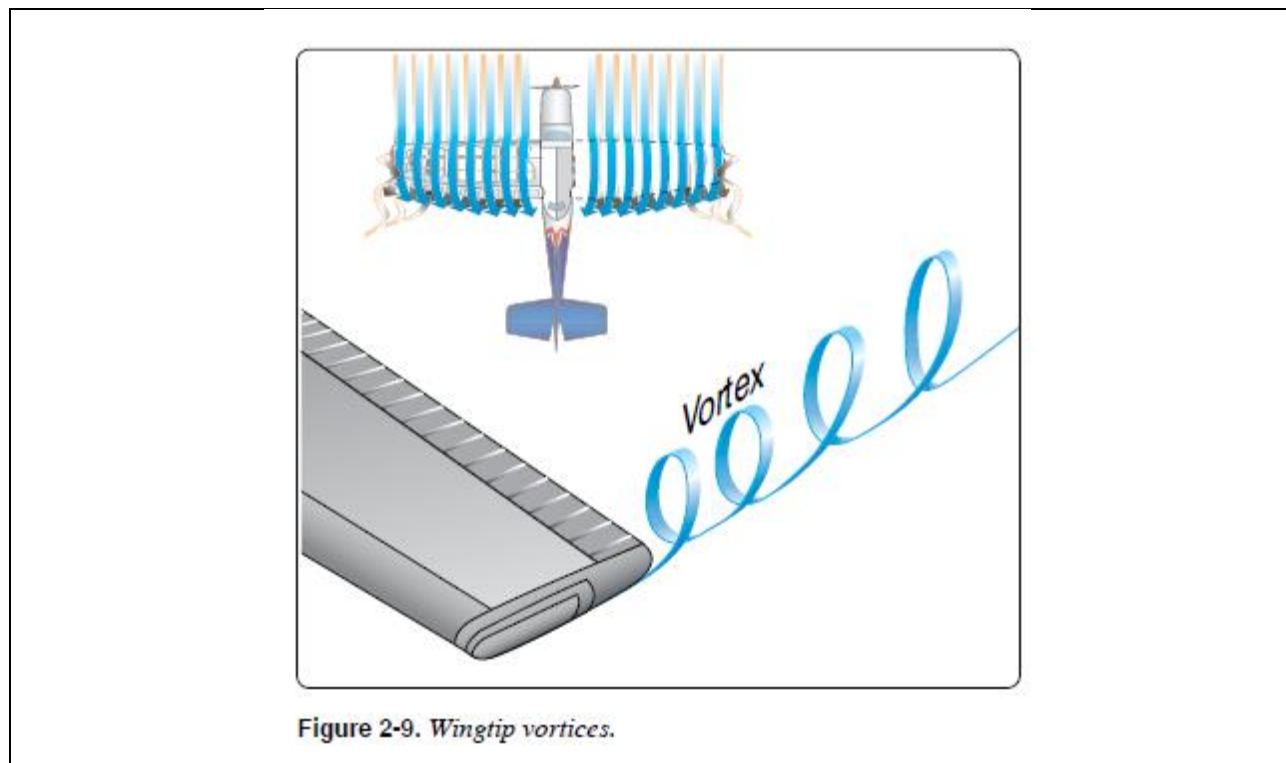


Figure 2-9. Wingtip vortices.

The air on the upper surface has a tendency to move in toward the fuselage and off the trailing edge. This air current forms a similar vortex at the inner portion of the trailing edge of the wing. These vortices increase drag because of the turbulence produced, and constitute **induced drag**.

Just as lift increases with an increase in AOA, induced drag also increases as the AOA becomes greater. This occurs because, as the AOA is increased, the pressure difference between the top and bottom of the wing becomes greater. This causes more violent vortices to be set up, resulting in more turbulence and more **induced drag**.

Center of Gravity (CG)

Gravity is the pulling force that tends to draw all bodies within the earth's gravitational field to the center of the earth. The CG may be considered the point at which all the weight of the aircraft is concentrated. If the aircraft were supported at its exact CG, it would balance in any position. CG is of major importance in an aircraft, for its position has a great bearing upon stability.

The CG is determined by the general design of the aircraft. The designers estimate how far the CP travels. They then fix the CG in front of the CP for the corresponding flight speed in order to provide an adequate restoring moment for flight equilibrium.

The Axes of an Aircraft

Whenever an aircraft changes its attitude in flight, it must turn about one or more of three axis. *Figure 2-10* shows the three axes, which are imaginary lines passing through the center of the aircraft.

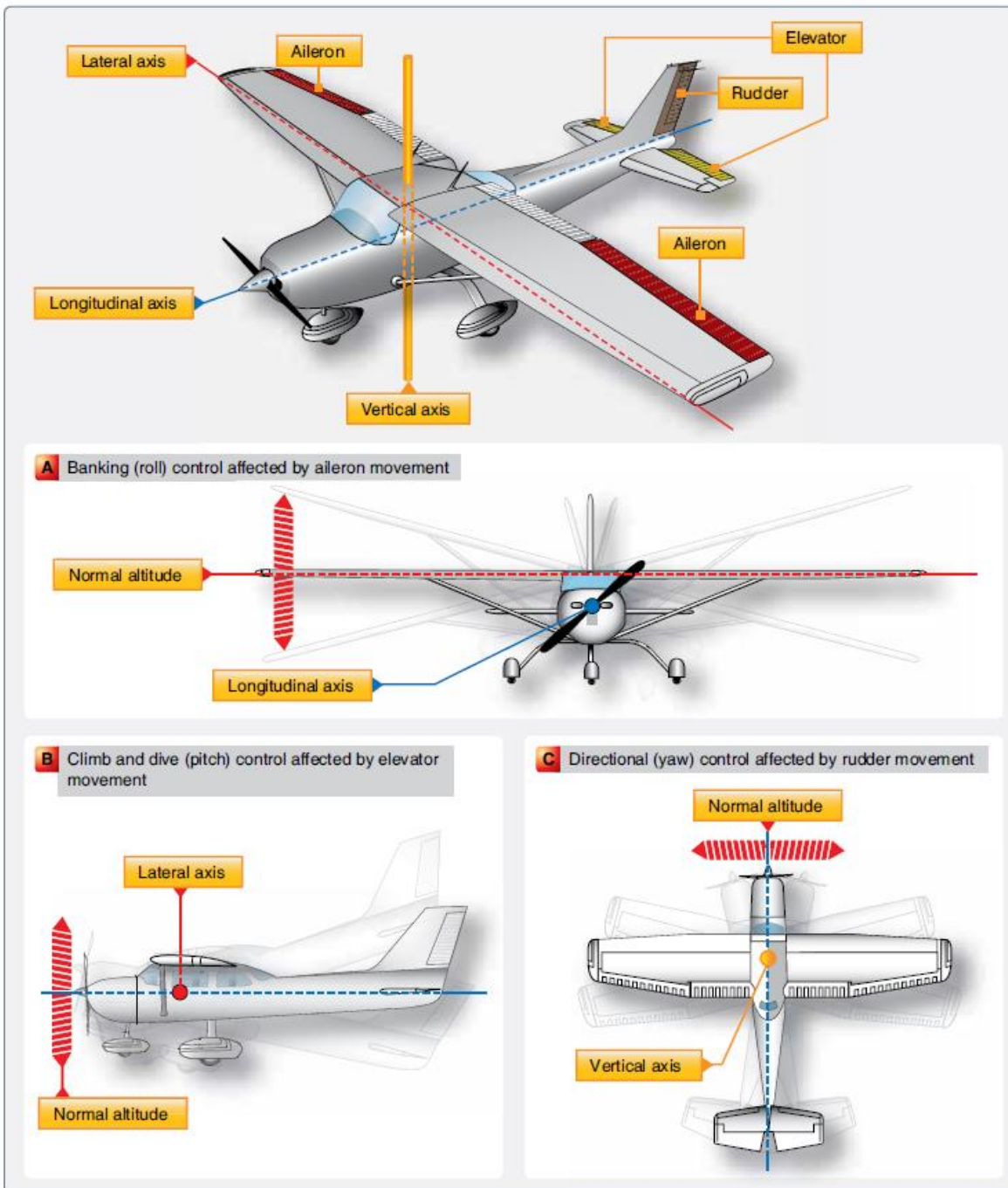


Figure 2-10. Motion of an aircraft about its axes.

The axes of an aircraft can be considered as imaginary axles around which the aircraft turns like a wheel. At the center, where all three axes intersect, each is perpendicular to the other two. **The axis that extends lengthwise through the fuselage from the nose to the tail is called the longitudinal axis. The axis that extends crosswise from wing tip to wing tip is the lateral, or**

pitch, axis. The axis that passes through the center, from top to bottom, is called the vertical, or yaw, axis. Roll, pitch, and yaw are controlled by three control surfaces. Roll is produced by the ailerons, which are located at the trailing edges of the wings. Pitch is affected by the elevators, the rear portion of the horizontal tail assembly. Yaw is controlled by the rudder, the rear portion of the vertical tail assembly.