UNIT I
INTRODUCTION TO AIRCRAFT

International Standard Atmosphere

Aerospace vehicles can be classified into two categories: Atmospheric vehicles and space vehicles. Under Atmospheric vehicles we have aircrafts, airplanes, seaplanes, helicopters, gliders, UAVs etc that operate within the earth's sensible atmosphere and under space vehicles there are Rockets, satellites, deep space probes, interplanetary probes, interplanetary vehicles etc operate outside the sensible atmosphere. However the space vehicles encounter the earth's atmosphere both while blasting off from the surface and also during the re-entries as well as during recoveries after completing their missions. In case of planetary probes, then it may encounter the atmosphere of other planets like Venus, mars, Jupiter etc. Since all the aerospace vehicles are operating in some or the other atmosphere, their design and performance is influenced by the atmospheric properties of that particular atmosphere.

We know that the earth is completely surrounded by a thin blanket of air called atmosphere and it is retained by the earth's gravitational forces. The average mass of the atmosphere is found to be around 5.15×10^{18} kg. Out of this, around 50% of the mass is said to be concentrated below 5.6 km (18,000ft). Further 75% of the mass is found to be under 11km (33,000ft), next the 90% is below 16km (52,000ft), Lastly, 99.999997% is within 100km (3,30,000ft) from the ground. Beyond 100km, the effect of gravity almost vanishes and this marks the beginning of the outer space.

As the concentration of the mass of air is constantly varying with altitude, even the properties of air like the pressure, temperature, density and viscosity also vary with altitude. Since the atmosphere is dynamically changing with altitude, it will have a detrimental effect on the performance of all the air vehicles operating within the earth's atmosphere. It will negatively affect the efficiency of the airplane engine and also influence the aerodynamic capability of the aircraft. Further, they affect the total performance of the aircraft.

Let us consider an example of an aircraft taking off from a runway at sea level and climbing to attain an altitude of 10,000ft from the ground. The standard pressure and temperature at the sea level is 1bar and 15^0C. But when it reaches an altitude of 10,000ft, the pressure and temperature are around 0.0697bar. This decrease in pressure will affect the density to reduce which falls from 1.23kg/m^3 at sea level to 0.905 kg/m^3. Reduction in density or pressure will have the following effect:

1. Reduce the thrust generated by the engine
2. Reduction in the aircrafts lifting capability. Reduced atmospheric pressure alters the production of lift. Reduced density means lesser molecules of air flowing around the airplane's wings to generate lift. The aircraft's lifting capability is decreased.

Reduced atmospheric pressure alters the fuel/air ratio. Reduced density, in this case, is responsible for less number of molecules of air entering the cylinder. This upsets the optimum ratio required between aircraft fuel and air molecules, to maintain efficient flight.

Since the atmospheric properties are dynamically changing with altitude, the performance will also change with every altitude. In that case, it becomes mandatory for the pilot to know the conditions of the atmosphere before making any flight plan. For this, the pilot should have enough information regarding the possible values of the atmospheric variables which will be encountered in the direction of flight. This will enable the pilot to calculate the changes in the thrust of the engine at every altitude and this will help the pilot to maintain an optimum thrust settings at every altitude.

Not only to calculate the performance of aircrafts, atmospheric values are also required for the design and calibration of altimeters, transponders, encoders etc. In order to achieve this, we should have enough information regarding the values of pressure, temperature, density, viscosity etc at different altitudes right from the sea level. For this purpose, aviation and metrological authorities have come up with a standard atmospheric model which gives the information of temperature, density, pressure at different altitudes for sea level. In fact, many atmospheric models have been developed which provides a table with the values of atmospheric parameters like temperature, density, pressure at different altitudes. The models may be

1. The US Standard Atmosphere
2. The International Standard Atmosphere
3. Jet standard atmosphere
4. NRLMSISE-00 is a recent model from NRL often used in the atmospheric sciences

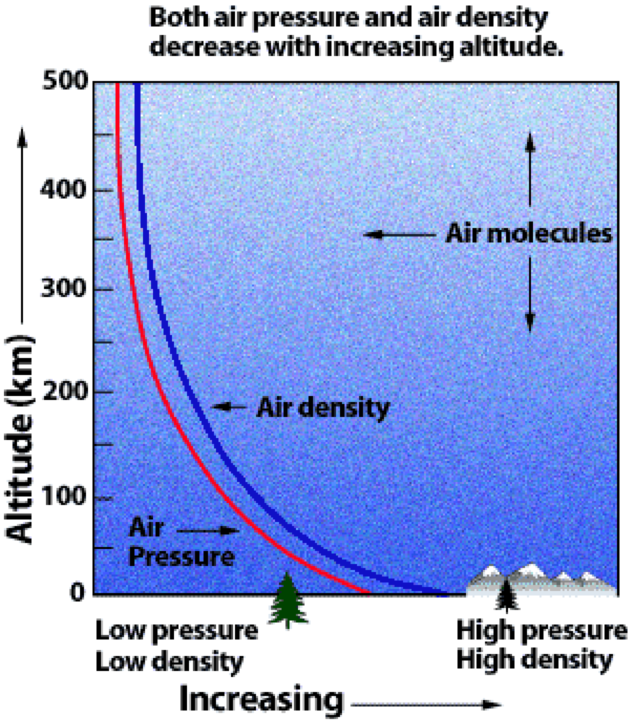
For aviation propose, International Civil Aviation Organization has recommended the use of **International Standard Atmosphere (ISA)** as a standard model to calculate the performance of aircrafts and other aviation instruments. ISA is an hypothetical atmospheric model which provides a table with average values of pressure, temperature, density, viscosity at various levels of altitude.

ISA is hypothetical model because it doesn't consider the effect of water vapour, wind, turbulence, season, wind, turbulence, moisture, water vapour, and even on solar sunspot activity. To take all these variations into account when considering the design and performance of the flight vehicle is impractical. These values are obtained by experiments conducted using experimental balloons and sounding rockets combined with mathematical model of the atmosphere.

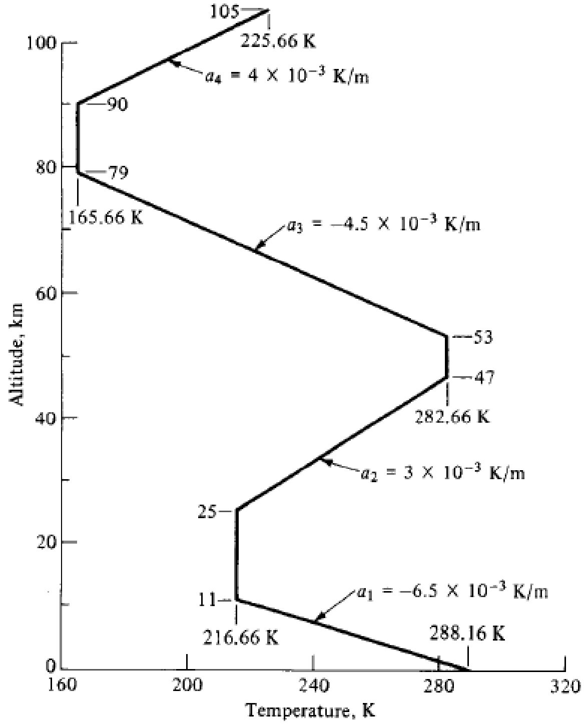
Along the altitude, all the parameters of atmosphere vary. Pressure and density decrease with altitude. But, temperature exhibits a very complicated variation profile as compared to the pressure and density. In certain regions, the temperature is constant and in some regions the temperature shows a gradual incline and declining profiles. This variation in temperature provides a useful metric to distinguish between layers. The parameters are usually measured using sounding balloons and sounding rockets. In this way, Earth's atmosphere can be divided (called atmospheric stratification) into five main layers. Excluding the exosphere, the atmosphere has four primary layers, which are the troposphere, stratosphere, mesosphere, and thermosphere. From highest to lowest, the five main layers are:

- Exosphere: 700 to 10,000 km (440 to 6,200 miles)
- Thermosphere: 80 to 700 km (50 to 440 miles)
- Mesosphere: 50 to 80 km (31 to 50 miles)
- Stratosphere: 12 to 50 km (7 to 31 miles)
- Troposphere: 0 to 12 km (0 to 7 miles)

Since the properties of the atmosphere are continuously varying with altitude and also to find the properties like p, T density, we have to first define the meaning of altitude and types of altitudes.



Variation of Pressure and Density with Altitude



Variation of Temperature with Altitude

The profile of the atmosphere is basically classified into different layers. This differentiation is caused due to the changes in the temperature with altitude. Based on the variation of the temperature the layers have been categorised.

Troposphere: This is the first layer of the atmosphere and often referred to as the Lower Atmosphere. Earth's surface is a major source of heat for the troposphere. Nearly all the heat comes from the sun, either directly or indirectly. Some incoming sunlight warms the gases in the atmosphere directly. But more sunlight strikes the Earth's rock, soil, and water, which radiate it back into the atmosphere as heat, further warming the troposphere. The temperature of the troposphere is highest near the surface of the Earth and declines with altitude. On average, the temperature gradient of the troposphere is 6.5°C per 1,000 m (3.6°F per 1,000 feet) of altitude.

Notice that in the troposphere, warm air is beneath cold air. Since warm air is less dense and tries to rise, this condition is unstable. So the warm air at the base of the troposphere rises and cool air higher in the troposphere sinks. For this reason, air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. At the top of the troposphere is a thin layer called the tropopause. Temperature in the tropopause does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. So the tropopause is a barrier that keeps air from moving from the troposphere to the stratosphere. Sometimes breaks are found in the tropopause and air from the troposphere and stratosphere can mix.

Stratosphere : This the second layer in the atmosphere and referred as the upper atmosphere. Most of the important processes of the atmosphere occur place in either troposphere or the stratosphere. The **Stratosphere** has a layer of ozone, called the **ozone layer.** This layer absorbs most of the ultraviolet radiation from sunlight. This results in the stratosphere being warmer. Though the temperature increases, it still be freezing in nature.

Stratopause: Above the stratosphere is the thin **stratopause**, which is the boundary between the stratosphere below and the mesosphere above. The stratopause is at about 50 km above the Earth's surface.

The **Mesosphere,** like the troposphere layer, has a decrease in temperature with altitude because of the decreases in the density of the air molecules.

The **Thermosphere** is warmed by the absorption of solar X-rays by the nitrogen and oxygen molecules in this outer layer. Thus, the temperature of this layer increases with altitude.

DEFINITION OF ALTITUDE

Intuitively, we all know the meaning of altitude. We think of it as the distance above the ground. But to be used in engineering, it has to be precisely defined. There are 3 different altitudes. Geometrical Altitude, Absolute altitude and geopotential altitude.

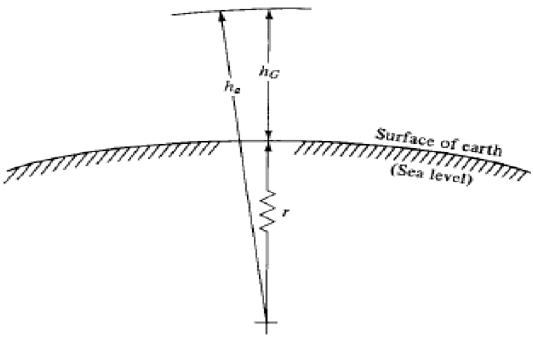


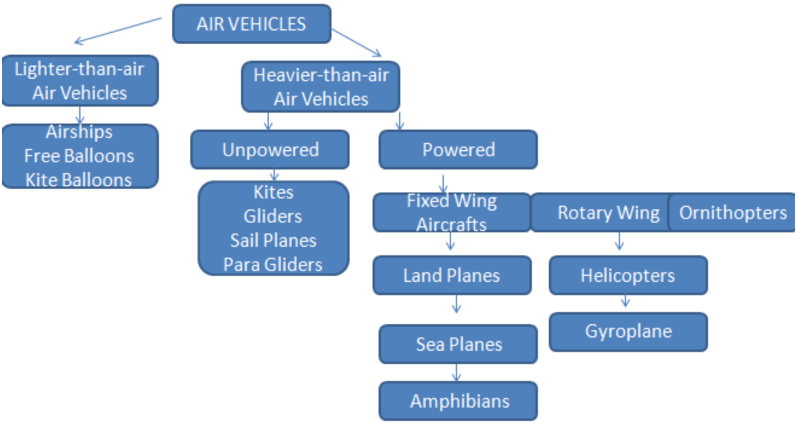
Fig : Definition of Altitude

Geometrical Altitude (h_G) - It is the geometric height measured above the ground from the sea level.

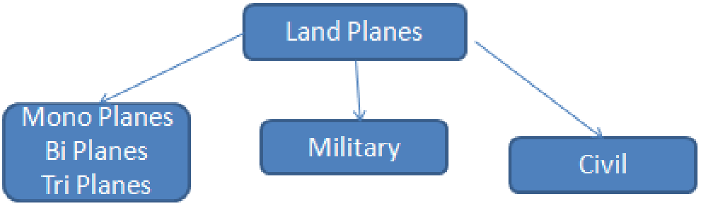
Absolute altitude (h_a) - It is the height measured from the centre of the earth to any point above the ground. If r is the radius of the earth, the $h_a = r + h_G$. Absolute height is important for space flights, because the local acceleration due to gravity changes with height h_a.

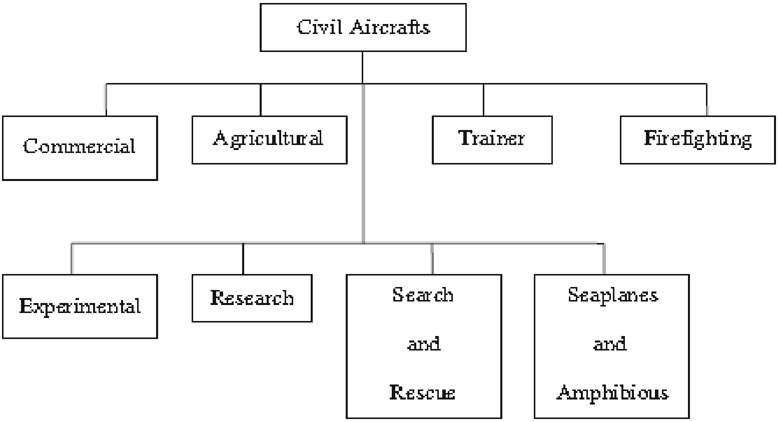
Geopotential Altitude (h) - It is a fictitious altitude corrected for acceleration due to gravity.

CLASSIFICATION OF AIRCRAFTS

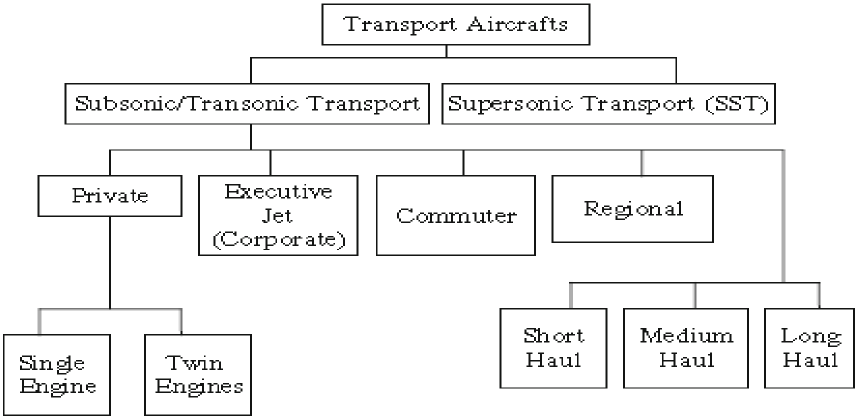


Classification of Air Vehicles

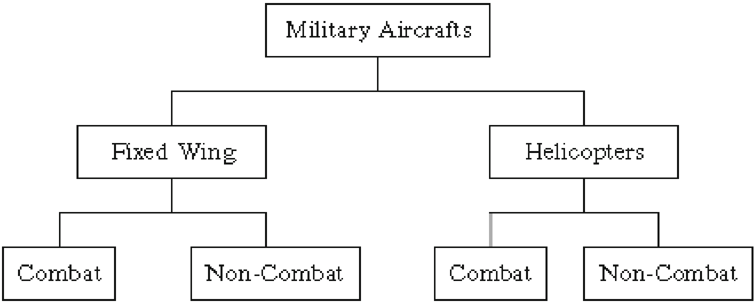




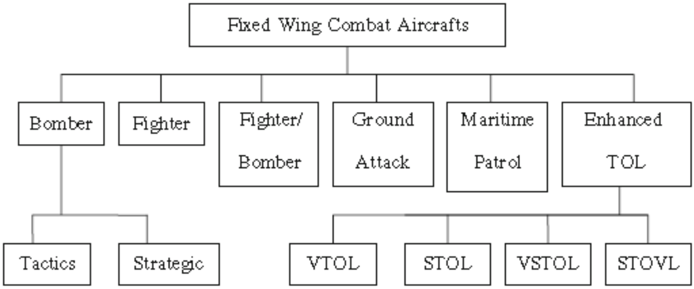
Classification of Commercial Air Vehicles



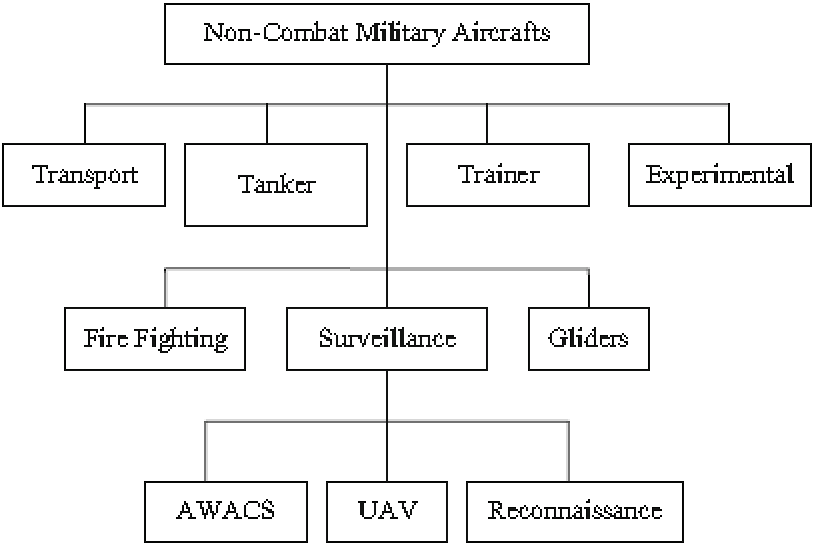
Classification of Transport Aircrafts



Classification of Military Vehicles



Classification of Fixed Wing Combat Military Vehicles



Classification of Non Combat Military Vehicles

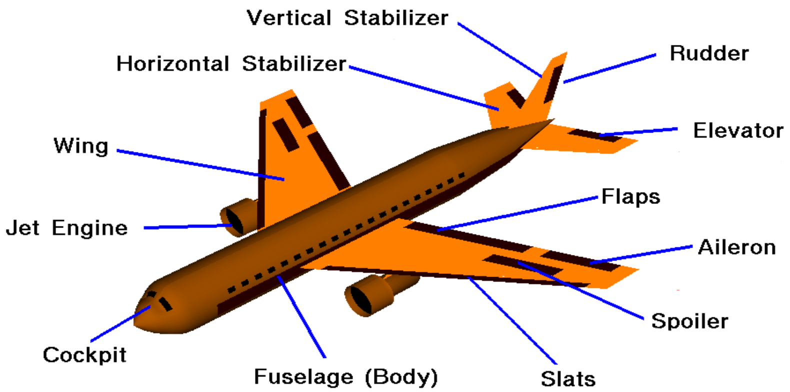
DESIGN REQUIREMENTS FOR A CONVENTIONAL TRANSPORT AIRCRAFT

The conventional aircraft design will have following features:

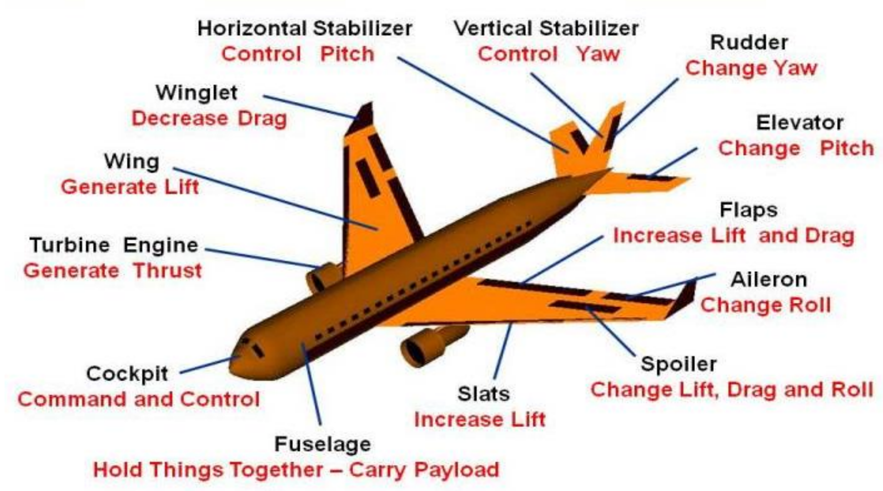
- Cantilevered monoplane wing
- Separate horizontal and vertical tail surfaces
- Control via ailerons, elevators and rudder
- Discrete fuselage to provide volume and continuity to fuselage
- Retractable landing gear
- Minimum number of power plants to meet power and operational needs

Examples of Typical Commercial Transport Aircrafts

ANATOMY OF A TYPICAL AIRCRAFT



AIRCRAFT COMPONENTS AND THEIR FUNCTIONS

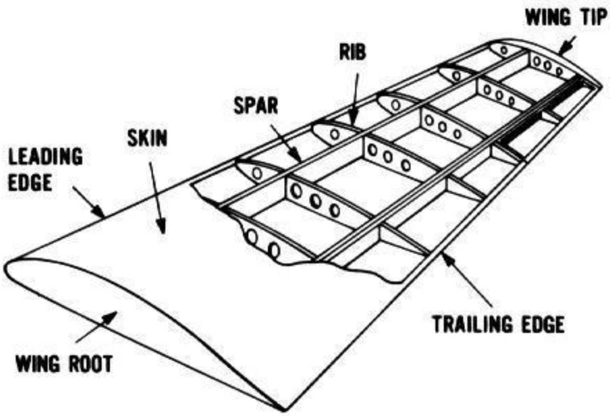


Major components of any typical aircraft are:

Fuselage: The fuselage is the main structure, or body, of the aircraft. It provides space for personnel, cargo, controls, and most of the accessories. The power plant, wings, stabilizers, and landing gear are attached to it.

Wings: The wings are attached to the fuselage on either side. Wings develop the major portion of the lift of a heavier-than-air aircraft. Wing structures carry some of the heavier loads found in the aircraft structure. The particular design of a wing depends on many factors, such as the size, weight, speed, rate of climb, and use of the aircraft. The wing must be constructed so that it holds its aerodynamics shape under the extreme stresses of combat maneuvers or wing loading.

Wings may be attached at the top, middle, or lower portion of the fuselage. These designs are referred to as high, mid, and low-wing, respectively. The number of wings can also vary. Airplanes with a single set of wings are referred to as monoplanes, while those with two sets are called biplanes. The wing is held together and supported by metal spars, ribs, and stringers, and covered by a fabric, aluminum or composite shell. On the rear part of the wing (the trailing edge), you can find the aileron and flaps, which change the shape of the wing to create more or less lift for different phases of flight.



Structure of a Wing

Wing construction is similar in most modern aircraft. In its simplest form, the wing is a framework made up of spars and ribs and covered with metal. The construction of an aircraft wing is shown in figure above. Spars are the main structural members of the wing. They extend from the fuselage to the tip of the wing. All the load carried by the wing is taken up by the spars. The spars are designed to have great bending strength. Ribs give the wing section its shape, and they transmit the air load from the wing covering to the spars. Ribs extend from the leading edge to the trailing edge of the wing. In addition to the main spars, some wings have a false spar to support the ailerons and flaps. Most aircraft wings have a removable tip, which streamlines the outer end of the wing.

Most aircrafts are designed with a wing referred to as a wet wing. This term describes the wing that is constructed so it can be used as a fuel cell. The wet wing is sealed with a fuel-resistant compound as it is built. The wing holds fuel without the usual rubber cells or tanks. A complete wing assembly consists of the surface providing lift for the support of the aircraft. It also provides the necessary flight control surfaces.

Stabilizers: The stabilizing surfaces of an aircraft consist of vertical and horizontal airfoils. They are called the vertical stabilizer (or fin) and horizontal stabilizer. These two airfoils, along with the rudder and elevators, form the tail section. For inspection and maintenance purposes, the entire tail section is considered a single unit called the empennage. The main purpose of stabilizers is to keep the aircraft in straight-and-level flight. The vertical stabilizer maintains the stability of the aircraft about its vertical axis. This is known as directional stability. The vertical stabilizer usually serves as the base to which the rudder is attached. The horizontal stabilizer provides stability of the aircraft about its lateral axis. This is known as longitudinal stability. The horizontal stabilizer usually serves as the base to which the elevators are attached. On many newer, high-performance aircraft, the entire vertical and/or horizontal stabilizer is a movable airfoil. Without the movable airfoil, the flight control surfaces would lose their effectiveness at extremely high altitudes.

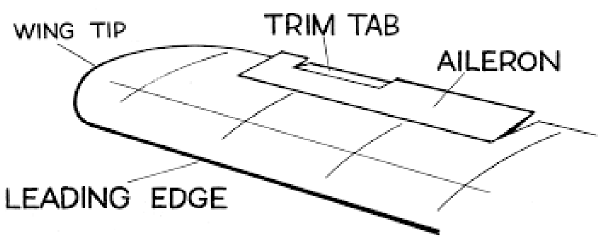
Empennage: The empennage (also called tail) is the rear part of the aircraft. The empennage consists of the vertical stabilizer (the "tail" of the airplane) and the horizontal stabilizer or stabilator.

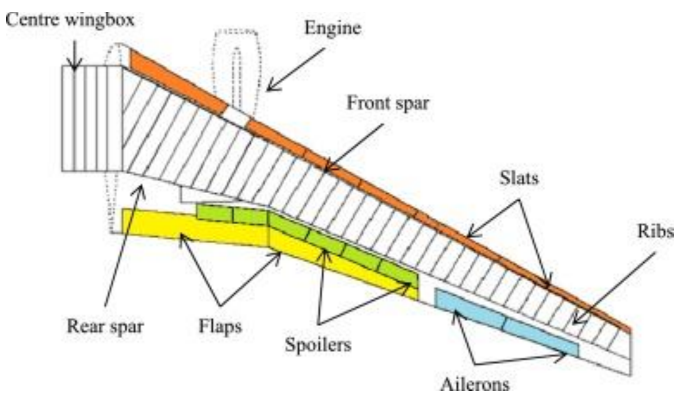
- Rudder: The rudder is a movable piece of the vertical stabilizer that allows the airplane to turn left or right about the airplane's vertical axis when activated. The rudder is connected to the foot pedals in the cockpit of the airplane.
- Elevator: The elevator is located on the rear part of the horizontal stabilizer. It moves up and down in order to make the airplane's nose move up or down. The elevator

is connected to the yoke. If you were to pull back on the yoke in the cockpit, the elevator would be moved upward, forcing the horizontal stabilizer to go down and the aircraft's nose to go up.

- Stabilator: A stabilator is similar to a horizontal stabilizer but doesn't include an elevator. The stabilator is one large piece of material with an anti-servo tab that doubles as a trim tab.

- Trim Tab: Trim tabs are small rectangle-shaped pieces of material on the trailing edge of the horizontal stabilizer. They're meant to be moved gradually, as set by the pilot, to ease control pressure and make the aircraft easier to handle.





Parts of a Wing

Ailerons: Ailerons can be used to generate a rolling motion for an aircraft. Ailerons are small hinged sections on the outboard portion of a wing. Ailerons usually work in opposition: as the right aileron is deflected upward, the left is deflected downward, and vice versa. The ailerons are used to bank the aircraft; to cause one wing tip to move up and the other wing tip to move down. The banking creates an unbalanced side force component of the large wing lift force which causes the aircraft's flight path to curve. (Airplanes turn because of banking created by the ailerons, not because of a rudder input.

Flaps: During takeoff and landing the airplane's velocity is relatively low. To keep the lift high airplane designers try to increase the wing area and change the airfoil shape by putting some moving parts on the wings' leading and trailing edges. The part on the leading edge is called a slat, while the part on the trailing edge is called a flap. The flaps and slats move along metal tracks built into the wings. Moving the flaps aft (toward the tail) and the slats forward increases the wing area. Pivoting the leading edge of the slat and the trailing edge of the flap downward increases the effective camber of the airfoil, which increases the lift. In addition, the large aft-projected area of the flap increases the drag of the aircraft. This helps the airplane slow down for landing.

Flaps are a type of high-lift device used to increase the lift of an aircraft wing at a given airspeed. Flaps are usually mounted on the wing trailing edges of a fixed-wing aircraft. Flaps are used for extra lift on takeoff. Flaps also cause an increase in drag in mid-flight, so they are retracted when not needed. Extending the wing flaps increases the camber or curvature of the wing, raising the maximum lift coefficient or the upper limit to the lift a wing can generate. This allows the aircraft to generate the required lift at a lower speed, reducing the stalling speed of the aircraft, and therefore also the minimum speed at which the aircraft will safely maintain flight.

Powerplant: The powerplant consists of the engine and all engine components, the propeller, and electrical system. It can be located on the front of the aircraft fuselage or toward the rear of the airplane. In multi-engine aircraft, the engines are typically located under the wings on each side. The engines generate the thrust required for the aircraft to move forward.

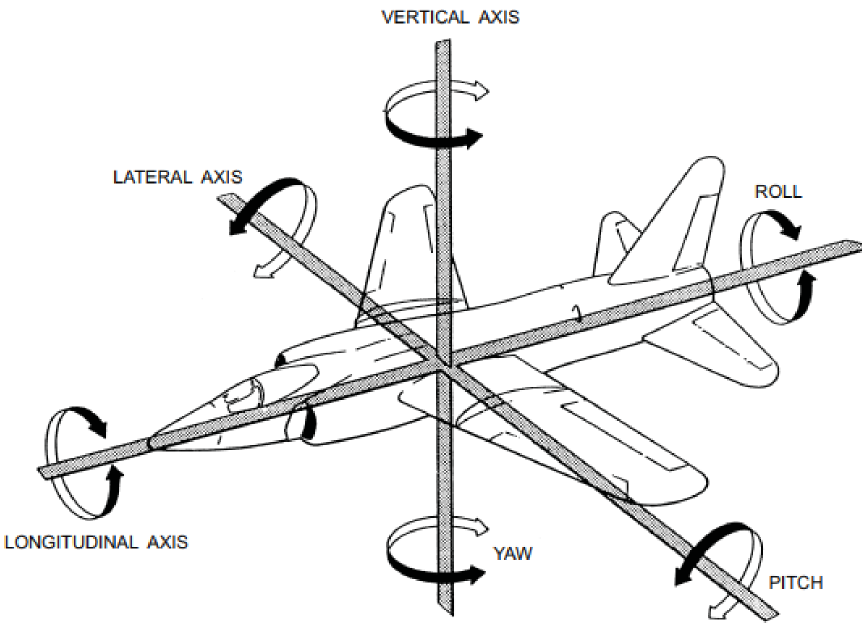
Landing Gear: The landing gear on most aircraft consists of wheels and struts. Some aircraft have skis or floats in order to land on snow or water, respectively. A typical single-ending land airplane will have either tricycle landing gear or conventional landing gear. Tricycle gear means that there are two main wheels with a nose wheel in front. On aircraft with conventional gear, there are two main wheels with a single wheel in back, under the tail. Aircraft with conventional type gear is often called tailwheel airplanes or taildraggers.

Flight Control Surfaces

Flight control surfaces are hinged (movable) airfoils designed to change the attitude of the aircraft during flight. These surfaces are divided into three groups—primary, secondary, and auxiliary control surfaces.

primary flight control surfaces

The primary group of flight control surfaces includes ailerons, elevators, and rudders. The ailerons are attached to the trailing edge of the outboard wings. They control the rolling (or banking) motion of the aircraft. This action is known as longitudinal control. The elevators are attached to the horizontal stabilizer and control the climb or descent (pitching motion) of the aircraft. This action is known as lateral control. The rudder is attached to the vertical stabilizer. It determines the horizontal flight (turning or yawing motion) of the aircraft. This action is known as directional control. The ailerons and elevators are operated from the cockpit by a control stick on single-engine aircraft. A yoke and wheel assembly operates the ailerons and elevators on multiengine aircrafts and finally, the rudder is operated by foot pedals on all types of aircraft.

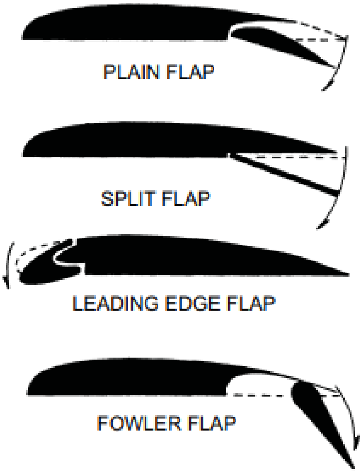


Axes and fundamental movements of the aircraft

Secondary Flight Control Surfaces:
The secondary group includes the trim tabs and spring tabs. Trim tabs are small airfoils recessed into the trailing edges of the primary control surface. Each trim tab hinges to its parent primary control surface, but operates by an independent control. Trim tabs let the pilot trim out an unbalanced condition without exerting pressure on the primary controls. Spring tabs are similar in appearance to trim tabs but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators. They aid the pilot in moving a larger control surface, such as the ailerons and elevators.

Auxiliary Flight Control Surfaces:
The auxiliary Flight Control Surfaces includes the wing flaps, spoilers, speed brakes, and slats.

Wing Flaps :Wing flaps give the aircraft extra lift. Their purpose is to reduce the landing speed. Reducing the landing speed shortens the length of the landing rollout. Flaps help the pilot land in small or obstructed areas by increasing the glide angle without greatly increasing the approach speed. The use of flaps during takeoff serves to reduce the length of the takeoff run. Some flaps hinge to the lower trailing edges of the wings inboard of the ailerons. Leading edge flaps are used on the F-14 Tomcat and F/A-18 Hornet. Four types of flaps are shown in figure below. The plain flap forms the trailing edge of the airfoil when the flap is in the up position. In the split flap, the trailing edge of the airfoil is split, and the lower half is hinged and lowers to form the flap. The fowler flap operates on rollers and tracks, causing the lower surface of the wing to roll out and then extend downward. The leading edge flap operates like the plain flap. It is hinged on the bottom side. When actuated, the leading edge of the wing actually extends in a downward direction to increase the camber of the wing. Landing flaps are used in conjunction with other types of flaps.



Types of Flaps

Spoilers: Spoilers are used to decrease wing lift. The specific design, function, and use vary with different aircraft. On some aircraft, the spoilers are long narrow surfaces, hinged at their leading edge to the upper surfaces of the wings. In the retracted position, they are flush with the wing skin. In the raised position, they greatly reduce wing lift by destroying the smooth flow of air over the wing surface.

Speed Brakes: Speed brakes are movable control surfaces used for reducing the speed of the aircraft. Some manufacturers refer to them as dive brakes; others refer to them as dive flaps. On some aircraft, they're hinged to the sides or bottom of the fuselage. Regardless of their location, speed brakes serve the same purpose—to keep the airspeed from building too high when the aircraft dives. Speed brakes slow the aircraft's speed before it lands.

Slats: Slats are movable control surfaces that attach to the leading edge of the wing. When the slat is retracted, it forms the leading edge of the wing. When the slat is open (extended forward), a slot is created between the slat and the wing leading edge. High-energy air is introduced into the boundary layer over the top of the wing. At low airspeeds, this action improves the lateral control handling characteristics. This allows the aircraft to be controlled at airspeeds below normal landing speed. The high-energy air that flows over the top of the wing is known as boundary layer control air. Boundary layer control is intended primarily for use during operations from carriers. Boundary layer control air aids in catapult takeoffs and arrested landings. Boundary control air can also be accomplished by directing high-pressure engine bleed air across the top of the wing or flap surface.