ATMOSPHARE

· Composition of atmosphere:

O_2 (Oxygen)	→	21%	about 1/5th
N_2(Nitrogen)	→	78 %	about 4/5th
Other gases	→	1%	

Layers of the Earth's Atmosphere

The atmosphere is divided into five layers.
troposphere- is the first layer above the surface and contains half of the Earth's atmosphere. Weather occurs in this layer.
stratosphere-most a/c fly in this layer, because it is very stable. Also, the ozone layer absorbs harmful rays from the Sun.
mesosphere-Meteors or rock fragments burn up in the .
thermosphere is a layer with auroras. It is also where the space shuttleorbits.
exosphere-The atmosphere merges into space in the extremely thin. This is the upper limit of our atmosphere.

Layers of the Earth's atmosphere

troposphere -The troposphere is the lowest layer of Earth's atmosphere. Almost all weather occurs within this layer. Air is warmest at the bottom of the troposphere near ground level. Higher up it gets colder. Air pressureand the density of the air are also less at high altitudes. The layer above the troposphere is called the stratosphere.

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The boundary between the top of the troposphere and the stratosphere (the layer above it) is called the tropopause.

The Stratosphere

stratosphere is the second layer, most a/c fly in this layer, because it is very stable. Also, the ozone layer absorbs harmful rays from the

Sun. The stratosphere is above the troposphere and below the mesosphere.

The boundary between the stratosphere and the mesosphere above is called the stratopause. The boundary between the stratosphere and the troposphere below is called the tropopause

The thin ozone layer in the upper stratosphere has a high concentration of ozone, a particularly reactive form of oxygen. This layer is primarily responsible for absorbing the ultraviolet radiation from the Sun.

The Mesosphere

As you get higher up in the mesosphere, the temperature gets colder. The top of the mesosphere is the coldest part of Earth's atmosphere. The temperature there is around -90° C (-130° F). The mesopause is the boundary between the mesosphere and the thermosphere above it. The stratopause is the boundary between the mesosphere and the stratosphere below it.

ionosphere-Above the mesosphere is ionosphere , where many atoms are ionized (have gained or lost electrons so they have a net electrical charge). The ionosphere is very thin, and is responsible for absorbing the most energetic photons from the Sun, and for reflecting radio waves, thereby making long-distance radio communication possible.

The Thermosphere

The thermosphere is directly above the mesosphere and below the exosphere. Temperatures climb sharply in the lower thermosphere then level off and hold fairly steady with increasing altitude above that height. Solar activity strongly influences temperature in the thermosphere. The boundary between the thermosphere and the exosphere above it is called the thermopause. At the bottom of the thermosphere is the mesopause, the boundary between the thermosphere and the mesosphere below.

The space shuttle and the International Space Station both orbit Earth within the thermosphere!

exosphare

Very high up, the Earth's atmosphere becomes very thin. The region where atoms and molecules escape into space is referred to as the exosphere. The exosphere is on top of the thermosphere.

- **Humidity** is a term for the amount of water vapour in the air
- **Density of air** **Mass of air per unit volume.**
- **Law of inertia of air:** The air which is still will tend to remain still; the air which is moving will tend to remain moving and will resist any change of speed or direction.

If we wish to alter the state of rest or uniform motion of air, or to change the direction of airflow we must apply a force to the air. More sudden the change of speed or direction and the greater the mass of air affected, the greater must be the force applied.

The application of such a force upon the air will cause an equal and opposite reaction upon the surface which produces the force.

- **Pressure of atmosphere:** Weight of air per meter sq. of a surface is called the pressure of atmosphere on that surface.

Pressure of atmospheric and density of air decreases with the increase in altitude.

- As altitude increases temperature and pressure decreases.
- In most parts of the world, the atmospheric temperature falls off at a steady rate, is called lapse rate – 6.5^0 C per 1000 meter or 1.98℃ per 1000' increase in height up to 11000 meter,

Above 11000 M, the temperature remains nearly constant until the outer regions of the atmosphere are reached.

The portion of the atmosphere below the height, at which the change occurs, is called troposphere and the portion above is called stratosphere. The interface between the two is called tropopause.

- Lapse rate and height of tropopause vary with latitude.
- For aircraft performance calculations, standard set of condition are used called →International standard atmosphere (ISA).

ISA → defines precise values of lapse rate, height of the tropopause and sea level value of temperature, pressure and density.

For temperature regions → 6.5^{0}C / 1000 m and tropopause is at 11 KM

- The sea level std pressure is equal to 101.325 kPa or 101 KN/m^2, 760mmHg , 29.92 inHg, 14.7 psi, 1013.25 millibars,76 mHg, 01 atmp
- Sea level std temperature is 59^0 f,15^{0}c,288k
- Density → → 1.222 Kg/m^3
- RD → 1.000 →

ISA is based on US standard Atmosphere 1962 which was prepared under the sponsorship of NASA, the USAF and US Weather Bureau.

- It actual performance under the condition of standard atmosphere, it can be compared with the performance of some other aero plane.

Wind gradient: Even when the surface of ground is comparatively flat, as on the ground by the roughness of the surface and successive layers are held back by the layers below them- due to viscosity and so the wind velocity gradually increases from ground to upwards. This phenomenon is called wind gradient.

Air speed: The speed of the aircraft relative to the air.

Ground speed: The speed of a/c relative to the earth.

- 1 knot = 0.514 m/s = 1.85 kmph
- Altimeter is an instrument which is used to measure the height of a/c above mean sea level.
- density is directly proportional to pressure at constant temp.

In the atmosphere, both temperature and pressure decrease with altitude, and have conflict effects upon density. However, the fairly rapid drop in pressure as altitude is increased usually has the dominating effect. Hence density decrease with altitude.

The Bernoulli Principle

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bernoulli's principle states that when the velocity (speed) of a gas or liquid is increased, its pressure becomes lower. and as the velocity decreases ,pressure increases.the principle that total energy per unit of mass in the stream line flow of a movinr fluied is constant,being the sum of potential energy,kinetik energy and the energy due to pressure.as the velocity of fluid increases ,internal pr.decreases.

example

When air rushes over the curved top of an aircraft wing, it goes faster than when it passes over the flat bottom of the wing. Therefore, the pressure or force of the air pressing down on the top of the wing becomes less than the force of the air pressing up on the bottom of the wing. The result is lift, one of the Four Forces of Flight

Bernaulli's Principle. For constant height P + ½ ^{2} = constant

Static Press + Dynamic press.

· If we bring the flow to rest at same points (e.g. L/G ,Nose etc.), the press must reach its highest possible value, because the dynamic pressure becomes zero, the max pressure will be called stagnation press

Stagnation press = Static press +Dynamic press.

It is the basis of air speed measurement in ASI (Air speed indicator).

Dynamic Press = ½ ^{2}

V = (stagnation (P) – Static P)

→ standard sea level air density

Reading of ASI

AIR speed Indicator reading
(instrument error)
Indicated air speed.
(Position error)
Calibrated air speed
(compressibility error)
Equivalent air speed
True air speed (TAS) = EAS/
σ → relative density.

- SUBSONIC AIRFLOW-BELOW SPEED OF SOUND
- SUPERSONIC-ABOVE SPEED OF SOUND
- CONVERGENT-AREA DECREASE
- DIVERGENT –AREA INCREASE

WHEN SUBSONIC AIR PAAS THROUGH CONVERGENT PASSAGE VELOCITY INCREASE PRESSURE DECREASE.
WHEN SUBSONIC AIR PAAS THROUGH DIVERERGENT PASSAGE VELOCITY DECREASE, PRESSURE INCREASE
WHEN SUPERSONIC AIR PAAS THROUGH DIVERERGENT PASSAGE VELOCITY INCREASE, PRESSURE DECREASE.
WHEN SUPERSONIC AIR PAAS THROUGH CONVERGENT PASSAGE VELOCITY DECREASE PRESSURE INCREASE

BOUNDARY LAYER

- A **boundary layer** is that layer of air adjacent of the airfoil surface. or The layer of air between the surface of wing and free air stream is called boundary layer. Boundary layer is of two types:

the air velocity in the **boundary layer** varies from zero on the surface of the airfoil to the velocity of free stream at the outer edge of **boundary layer** .the **boundary layer** is caused by the viscosity of the air sticking to the surface of wing and succeeding layers of air.

- Air flows around a body are of two types:

(i) Laminar flow
(ii) Turbulent flow

Laminar Flow

Airflow in which the air passes over the surface in smooth layers with min. turbulence. Laminar flow, sometimes known as streamline flow, occurs when a fluid flows in parallel layers, with no disruption between the layers. Laminar flow is the opposite of turbulent flow.it is most likely to occur where the surface is extreamly smooth and specially near the LE of an airfoil.under this condition boundary layer will be very thin.

turbulent flow

flow in a fluid characterized by const. change in direction and velocity at any particular point.air can flow in boundary layer in two ways the air particle can move in orderly path or in irregular path.the parallel flow is called laminar flow and irregular flow is called turbulent flow. In non-scientific terms laminar flow is "smooth", while turbulent flow is "rough."

transition point

The point at which the boundary layer changes from laminar to turbulent is called the transition point . Where the boundary layer becomes turbulent, drag due to skin friction is relatively high. As speed increases, the transition point tends to move forward. As the angle of attack increases, the transition point also tends to move forward.

Relative Airflow

Relative airflow is a term used to describe the direction of the airflow with respect to the wing. In other texts, it is sometimes called relative wind.a relative wind flows opposite the direction of object in motion. If a wing is moving forward and downward, the relative airflow is upward and backward. If the wing is moving forward horizontally, the relative airflow moves backward horizontally. The flight path and the relative airflow are, therefore, always parallel but travel in opposite directions.

Relative airflow is created by the motion of the airplane through the air. It is also created by the motion of air past a stationary body or by a combination of both. Therefore, on a take-off roll, an airplane is subject to the relative airflow created by its motion along the ground and also by the moving mass of air (wind). In flight, however, only the motion of the airplane produces a relative airflow. The direction and speed of the wind have no effect on relative airflow.

Upwash and downwash

Downward deflected air stream by an lifting surface is callad downwash.

The upward movement of air ahead of the leading edge of a subsonic wing, giving a positive lift called upwash.

As the air passes over the wing towards the trailing edge, the air flows not only rearward but downward as well. This flow is called downwash. At the same time, the airflow passing under the wing is deflected downward by the bottom surface of the wing. In exerting a downward force upon the air, the wing receives an upward counterforce. Remember Newton's Third Law—for every action there is an equal and opposite reaction. Therefore, the more air deflected downward, the more lift is created. Air is heavy; its weight exerts a pressure of 14.7 lbs per square inch at sea level. The reaction produced by the downwash is therefore significant.

Airfoils

An airfoil, or aerofoil section, may be defined as any surface designed to obtain a reaction(lift) from the air through which it moves, that is, to obtain lift. It has been found that the most suitable shape for producing lift is a curved or cambered shape.

The camber of an airfoil is the curvature of the upper and lower surfaces relative to chord line. mean camber is camber located midway between upper and lower camber. Usually the upper surface has a greater camber than the lower.

Airfoil terminology

Airfoil nomenclature

The various terms related to airfoils are defined below:

§ The *suction surface* (upper surface) is generally associated with higher velocity and thus lower static pressure.

§ The *pressure surface* (lower surface) has a comparatively higher static pressure than the suction surface. The pressure gradient between these two surfaces contributes to the lift force generated for a given airfoil.

§ The *leading edge* (LE)is the point at the front of the airfoil that has maximum curvature.

§ The *trailing edge (TE)* is defined similarly as the point of minimum curvature at the rear of the airfoil.

§ The *chord line* is a straight imaginary line connecting the leading and trailing edges of the airfoil.

§ The *chord length*, or simply **chord**, is the length of the chord line and is the characteristic dimension of the airfoil section.

§ The *mean camber line* is the points midway between the upper and lower surfaces.

Maximum thickness (expressed as a percentage of the chord), and the location of the maximum thickness point (also expressed as a percentage of the chord).

Finally, important concepts used to describe the airfoil's behaviour when moving through a fluid are:

- Characteristics of an ideal airfoil:

1. High max. lift co-efficient
2. Good Lift/Drag ratio
3. Small and stable movement of C of P.
4. Sufficient depth to enable good spars to be used.

§ **Aerodynamic centre:** Point on the chord about which there is no change in the pitching moment as the AOC is increased, about which the moment remains at the small -ve nose down value that it had at zero lift angle. This point is called aerodynamic centre of the wing.

§ Centre of gravity-the point with in an a/c ,the total force due to gravity is concentrated.

How Is Lift Created

Air flowing around an airfoil is subject to the Laws of Motion discovered by Sir Isaac Newton. Air, being a gaseous liquid possesses inertia and, therefore, according to Newton's First Law, when in motion tends to remain in motion. The introduction of an airfoil into the streamlined airflow alters the uniform flow of air. Newton's Second Law states that a force must be applied to alter the state of uniform motion of a body. The airfoil is the force that acts on the body (in this case, the air) to produce a change of direction. The application of such a force causes an equal and opposite reaction, in compliance with Newton's Third Law, called, in this case, lifts.

Angle of Attack and Center of Pressure

Acute angle between the chord line and relative wind is called Angle of attack.

Generally higher the AOA higher will be the lift

AOA is a variable angle which change during flight.

As the angle of attack is increased, the changes in pressure over the upper and lower surfaces and the amount of downwash, that is air deflected downward, increase up to a point (the stalling angle). Beyond this angle, these changes in pressure decreases.

If we consider all the distributed pressure on the wing to be equivalent to a single force, this force will act through a straight line. The point where this line cuts the chord of an airfoil is called the **center of pressure.** Thus, it will be seen that as the angle of attack of an airfoil is increased up to the point of stall, the center of pressure will move forward. Beyond this point of stall, the center of pressure will move back. The movement of the center of pressure causes an airplane to be unstable.

§ **The point at which resultant of aerodynamic force intersects the chord line of an airfoil is called *center of pressure*(CP).lift acts from cp so also called as center of lift.cp moves forward**

as AOA increases and backward as AOA decreases.the cp is generally located at app. 25% of chord position for most aerofoil.

§ **The *center of pressure*, which is the chord-wise location about which the pitching moment is zero.**

angle of incidence

The angle of incidence is the angle formed by the wing chord line and the aircraft longitudinal axis. The wing chord line extends from the leading edge of the wing to the trailing edge of the wing. The ***longitudinal axis*** is an imaginary line that extends from the nose of the aircraft to the tail.[1]

The angle of incidence is measured by the angle at which the wing is attached to the fuselage and in general, the angle of incidence is fixed and cannot be changed by the pilot.

The angle of incidence is usually set at a small positive angle in order to allow the fuselage to maintain level during normal cruising flight. The angle of incidence varies on different aircraft, but on most light general aviation aircraft the angle is normally set at 6°.

Relation between angle of attack and lift

AS AOA increases lift increases within certain limit.

- If we tilt the airfoil downward until it produces no lift at the time of no lift. If we draw a straight line, through the air foil parallel to the airflow, this will be called the line of zero lift and the corresponding angle is called angle of zero lift. Or (zero AOA) Normally → 3^0 to 4^0
- The decrease in pressure on the upper surface is greater than the increase on the lower surface.

4L/5 Upper surface

Lift---------------------------

1L/5 Lower surface

· Stalling angle: The AOA at which the lift co-efficient of an airfoil is a maximum and beyond which it beings to decrease owing to the airflow becoming separated.

A typical lift coefficient curve.

The lift coefficient of a fixed-wing aircraft varies uniquely with angle of attack. Increasing angle of attack is associated with increasing lift coefficient up to the maximum lift coefficient, after which lift coefficient decreases.

As the angle of attack of a fixed-wing aircraft increases, separation of the airflow from the upper surface of the wing becomes more pronounced, leading to a reduction in the rate of increase of the lift coefficient. The figure shows a typical curve for a cambered straight wing. A symmetrical wing has zero lift at 0 degrees angle of attack. The lift curve is also influenced by wing planform. A swept wing has a lower flatter curve with a higher critical angle.

Critical angle of attack

The **critical angle of attack** is the angle of attack which produces maximum lift coefficient. This is also called the "stall angle of attack". Below the critical angle of attack, as the angle of attack increases, the coefficient of lift (Cl) increases. At the same time, below the critical angle of attack, as angle of attack increases, the air begins to flow less smoothly over the upper surface of the airfoil and begins to separate from the upper surface. On most airfoil shapes, as the angle of attack increases, the upper surface separation point of the flow moves from the trailing edge towards the leading edge. At the critical angle of attack, upper surface flow is more separated and the airfoil or wing is producing its maximum coefficient of lift. As angle of attack increases further, the upper surface flow becomes more and more fully separated and the airfoil/wing produces less coefficient of lift.

Above this critical angle of attack, the aircraft is said to be in a stall. A fixed-wing aircraft by definition is stalled at or above the critical angle of attack rather than at or below a particular airspeed. The airspeed at which the aircraft stalls varies with the weight of the aircraft, the load factor, bank angle, the center of gravity of the aircraft and other factors. However the aircraft always stalls at the same critical angle of attack. The critical or stalling angle of attack is typically around 15° for many airfoils.

Stalls

Stalls occur at the critical angle of attack, at which point the airflow over the wing becomes chaotic and the wings can no longer produce sufficient lift to counteract weight.

As the airfoil approaches the stalling speed, the point of transition, or separation point, moves forward enough to exceed the design factor of the wing.

The stalling angle is usually 18°. Since most aircraft lack angle-of-attack indicators, airfoil angle is measured by indicated airspeed (IAS).

FOUR FORCES ACTING ON AIRCRAFT

Lift-upward force

Thrust-forward moving force

Weight-downward force

Drag-backward force

LIFT

Lift is the component right angle or perpendicular to the relative wind.

- Generated through the wings.
- Lift is exerted through the *centre of pressure*.
- Opposes weight: during level cruise, lift equals weight; during climb, lift is greater than weight; and during descent, weight is greater that lift.

$L=CL*1/2\rho v^2 s$

CL-coefficent of lift

ρ-density(kg/m^3)

v-velocity(m/s)

s-surface area(m^2)

Coefficient-number that is constant for a given substance,body, or process under certain specified conditions, servingas a measure of one of its properties

$CL = L/1/2\rho v^2 s$

AS AOA increases lift increases within certain limit.

- If we tilt the airfoil downward until it produces no lift at the time of no lift. If we draw a straight line, through the air foil parallel to the airflow, this will be called the line of zero lift and the corresponding angle is called angle of zero lift. Or (zero AOA)

Normally → 3^0 to 4^0

- The decrease in pressure on the upper surface is greater than the increase on the lower surface.

4L/5 Upper surface

Lift--------------------------

1L/5 Lower surface

- Center of pressure : The point (position) on the chord at which the resultant force acts is called C of P.
- Within normal flight AOA range C of P moves forwards with increase in AOA.
- The lift drag and pitching movement depends on the following factors.

1. Shape of airfoil
2. Plan area of the airfoil
3. Square of the velocity
4. Density of air.

L = C_L ½ ^{2}S

D = C_D ½ ^{2}S

M_P = C_M ½ ^{2}SC

C_L = Co-efficient of lift

C_D = Co-efficient of drag

C_M = Co-efficient of pitching moment

C Chord

Density of air

V Velocity of airfoil

S Plan area (in case of lift)

Frontal area (in case of drag)

M_P +ve (Nose up tendency)

M_P -ve (Nose down tendency)

- **Factors affecting the airfoil characteristics:**

1. Co-efficient of lift
2. Co-efficient of drag
3. Ratio of lift to drag
4. Position of C of P and co-efficient pitching moment.

- Wing Geometry: The distance between L/E and trailing edge of the wing measured parallel to the normal, airflow over the wing, is known as the chord. If the L/E and T/E are parallel, the chord of the wing is constant along the wing length.

Most commercial transport airplanes have wing that are both tapered and swept with the result that the width of the wing changed along its entire length. Width of the wing is greatest where it meets the fuselage at wing root and progressively decreases toward the tip chord also changes along the span of wing, the average length of the chord is also known as mean aerodynamic chord (MAC).

- The distance from one wing tip to another wing tip is called span.
- Shape of the wing when viewed from the above looking down on to the wing is called a plane form
- Total surface area includes both upper and lower surface. Wing area is almost half of the total surface area.

DRAG

- Drag is the enemy of flight.
- Drag is the resistance of air on a body when it move through the air.
- Drag is the backward moving force parallel to the direction of airflow.
- The shape of body which causes the least possible resistance is called stream lined shaped.

The **drag coefficient** is a number that aerodynamicists use to model all of the complex dependencies of shape, inclination,and flow conditions on aircraft drag.

Types of drag

1. Parasite drag
2. Induced drag

Parasite drag

- it is the combination of different drag force.
- Created by those part of aircraft whose does not contribute in lift.
- Any exposed object on an aircraft offers some resistance to the air, and the more object in the airstream, the more parasite drag.
- Parasite drag can be reduced by reducing the number of exposed part and streamlining their shape.

Parasite Drag = Form Drag + Skin Friction Drag+ Interference drag

Skin friction drag(type of parasite drag)

Skin friction drag The drag due to the friction between surface (skin) and layer of air flow, is called skin friction drag, or surface drag, It is entirely due to the area of contact where the fractioning action takes place.

- It can be reduced by using glossy finish and eliminating protruding rivets heads, roughness and other irregularities.

Profile drag (type of parasite drag)

- Wing drag,Form drag, profile drag, or pressure drag, arises because of the forward facing part of the body
- **Form drag is entirely due to the pressure difference between the front and rear face.**
- The general size and shape of the body is the most important factor in form drag - bodies with a larger apparent cross-section will have a higher drag than thinner bodies

Interference drag (type of parasite drag)

- Produced where parts are joined to the aircraft.
- Interference drag can be minimized by use of proper fairing and filleting, which provide smooth mixing of air past the components.

Generally, interference drag will add to the component drags but in a few cases, for example, adding tip tanks to a wing, total drag will be less than the sum of the two component drags because of the reduction of induced drag.

Induced drag

- Drag produced by lifting surface is called induced drag
- As AOA increases induced drag increases and vice-versa
- The high pressure underneath the wing causes the airflow at the tips of the wings to curl around from bottom to top in a circular motion. This results in a wing tip vortices. Induced drag increases in direct proportion to increases in the angle of attack.
- Induced drag can be reduced by increasing the aspect ratio

ASPECT RATIO

Aspect ratio-span /chord(for rectangular wing)

Span^2/area(for nonrectangular wing)

Total drag=parasite drag +induced drag

induced drag tends to be greater at lower speeds because a high angle of attack is required to maintain lift, creating more drag. However, as speed increases the induced drag becomes much less, but parasitic drag increases because the fluid is flowing faster around protruding objects increasing friction or drag.

FINENESS RATIO

- Skin friction and turbulence can also be controlled by fineness ratio.
- it is the ratio of the chord of the airfoil to the maximum thickness

=CHORD/MAX.THICKNESS

		Skin f	Form drag/turbulence

		riction drag	
		High	Low
		Low	High

· So, the best wing is the compromise between these two extreme to hold both Skin friction and turbulence to a minimum.

Weight

- Natural (uncontrollable) force generated by gravity (g force) that acts perpendicular to earth's surface.
- Weight is exerted through the ***centre of gravity***.
- Opposes lift

Thrust

- Artificial force manipulated by pilot and generated through engine(s) that acts horizontally, parallel to flight path.
- Opposes drag:

when airspeed constant, thrust equals drag; when airspeed accelerating, thrust is greater than drag; and when decelerating, drag is greater than thrust.

Straight and Level flight

Various phase of flight

- Take-off-aircraft is transferred from one medium to another (lift >weight, thrust>drag)
- Climb-aircraft gains the height at which level flight will made (lift>weight, thrust>drag)
- Cruise-steady flight at a constant height(lift=weight, thrust=drag)
- Approach-back towards the earth
- Landing(lift <weight, thrust<drag)

The four forces

1. Lift of the main plane (L) acting vertically upward through centre of pressure.
2. Weight of aeroplane(W) acting vertically downward through centre of gravity.
3. Thrust of engine(T) pulling horizontally forward.
4. Drag(D) acting horizontally backwards.

Condition of Equilibrium

Travelling of object at steady height at uniform velocity in a fixed direction. Equilibrium simply means that the existing state of affairs is remaining unchanged or the plane is obeying Newton's law of motion.

- In order to maintain the equilibrium position the four forces must be balanced-the lift must be equal to weight(constant height) and thrust must be equal to drag(constant velocity).
- The another condition of equilibrium to maintain straight and level flight, we must prevent aeroplane from rotating, and this depend not only on magnitude of the a/c but also on the position at which they act.

Arrangement of four forces

Notice in the above fig, that four forces do not all line up with each other. Therefore, they create rotational moments(couples).

centre of pressure is behind the centre of gravity, and line of thrust is lower than line of drag.
Lift(CP) and weight(CG) create a nose-down tendency. There is an advantages of placing C.G ahead of CP because this arrangement give a nose down pitching tendency, which in event of failure of engine automatically put the aircraft in a position ready of glide where as if lift were in front of weight, there would be a tendency to stall.

Thrust and drag create a nose-up tendency.

Therefore they cancel each other out, to some degree. Any residual rotational moments are compensated for by the horizontal stabilizer; the pilot will use the trim to set the force produced by the stabilizer to maintain straight and level.

Now as long as nothing changes, and ignoring things like wind or turbulence, the aircraft will stay balanced all day long. In reality, however, we will from time to time change our thrust, or speed, or lift, and weight will change as we burn fuel (or drop payload) etc. Whenever any of these changes, the balance of the aircraft will be upset, and it will have to be re-trimmed (re-balanced). In the below example, thrust is increased, which will cause a nose-up moment. This has been compensated for by reduced down-force by the stabilizer.

MANOEUVERS

Stability and control

Stability-characteristic of an aircraft which tends to cause it to fly (hands off)in straight and level flight path
Maneuverability-is the ability of an a/c to be directed along a desired flight path and to withstand the stress imposed.
Controllability-is the quality of a/c to response of an a/c to the pilot's command while maneuvering the aircraft.

Axis of an aircraft

Axis-the imaginary line passing through centre of a/c.
At centre all the axis is perpendicular to each other.
Motion of aircraft take place about three axis

1. Longitudinal axis(roll axis)--length wise through the fuselage from nose to tail
2. Lateral axis(pitch axis) -from wing tip to wing tip
3. Vertical axis(yaw axis or normal axis) from top to bottom

MOTION

Roll-motion about Longitudinal axis
Pitch- motion about Lateral axis(nose up or down)
Yaw- motion about Vertical axis
Forward and backward motion- motion along Longitudinal axis
Skidding or side slipping- motion along Lateral axis
Upward and downward motion- motion along vertical axis

Stability

Lateral-stability of aircraft about longitudinal axis
Longitudinal- stability of aircraft about lateral axis
Vertical or yaw stability- stability of aircraft about vertical axis

FIXED SURFACE	PRIMARY CONTROL SURFACE	AIRPLANE MOVEMENT	AXIS OF ROTATION	TYPE OF STABILITY
Wing	Aileron	Roll	Longitudinal	Lateral
Horizontal stabilizer	Elevator	Pitch	Lateral	Longitudinal

Vertical stabilizer	Rudder	Yaw	Vertical	Directional

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 three major groups: 1) primary or main flight control surfaces and 2) secondary 3) auxiliary control surfaces.

Primary Flight Control Surfaces

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

Primary control surfaces are usually similar in construction to one another and vary only in size, shape, and methods of attachment. On aluminum light aircraft, their structure is often similar to an all-metal wing. This is appropriate because the primary control surfaces are simply smaller aerodynamic devices. They are typically made from an aluminum alloy structure built around a single spar member or torque tube to which ribs are fitted and a skin is attached. The lightweight ribs are, in many cases, stamped out from

flat aluminum sheet stock. Holes in the ribs lighten the assembly. An aluminum skin is attached with rivets. *Figure 1-50* illustrates this type of structure, which can be found on the primary control surfaces of light aircraft as well as on medium and heavy aircraft Performed to manufacturer's instructions, balancing usually consists of assuring that the center of gravity of a particular device is at or forward of the hinge point. Failure to properly balance a control surface could lead to catastrophic failure. *Figure 1-52* illustrates several aileron configurations with their hinge points well aft of the leading edge. This is a common design feature used to prevent flutter

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 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. 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]*

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

Elevator

The elevator is the primary flight control surface that moves the aircraft around the horizontal or lateral axis. This causes the nose of the aircraft to pitch up or down. The elevator is hinged to the trailing edge of the horizontal stabilizer and typically spans most or all of its width. It is controlled in the cockpit by pushing or pulling the control yoke forward or aft.
Light aircraft use a system of control cables and pulleys or push pull tubes to transfer cockpit inputs to the movement of the elevator. High performance and large aircraft typically employ more complex systems. Hydraulic power is commonly used to move the elevator on these aircraft. On aircraft equipped with fly-by-wire controls, a combination of electrical and hydraulic power is used.

Rudder

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

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

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

Dual Purpose Flight Control Surfaces

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

A movable horizontal tail section, called a stabilator, is a control surface that combines the action of both the horizontal stabilizer and the elevator. *[Figure 1-58]* Basically, a stabilator is a horizontal stabilizer that can also be rotated about the horizontal axis to affect the pitch of the aircraft. A ruddervator combines the action of the rudder and elevator. *[Figure 1-59]* This is possible on aircraft with V–tail empennages where the traditional horizontal and vertical stabilizers do not exist. Instead, two stabilizers angle upward and outward from the aft fuselage in a “V” configuration.

Each contains a movable ruddervator built into the trailing edge. Movement of the ruddervators can alter the movement *[Figure 1-60]* Flaperons are ailerons which can also act as flaps. Flaps are secondary control surfaces on most wings, discussed in the next section of this chapter.

Secondary or Auxiliary Control Surfaces

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

Flaps

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

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

There are various kinds of flaps.

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

Heavy aircraft often have leading edge flaps that are used in conjunction with the trailing edge flaps. *[Figure 1-65]* They can be made of machined magnesium or can have an aluminum or composite structure. While they are not installed or operate independently, their use with trailing edge flaps can greatly increase wing camber and lift. When stowed, leading edge flaps retract into the leading edge of the wing. The differing designs of leading edge flaps essentially provide the same effect. Activation of the trailing edge flaps automatically deploys the leading edge flaps, which are driven out of the leading edge and downward, extending the camber of the wing. *Figure 1-66* shows a Krueger flap, recognizable by its flat mid-section.

Slats

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

Spoilers and Speed Brakes

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

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

Spoilers are unique in that they may also be fully deployed on both wings to act as speed brakes. The reduced lift and increased drag can quickly reduce the speed of the aircraft in flight. Dedicated speed brake panels similar to flight spoilers in construction can also be found on the upper surface of the wings of heavy and high-performance aircraft. They are designed specifically to increase drag and reduce the speed of the aircraft when deployed. These speed brake panels do not operate differentially with the ailerons at low speed. The speed brake control in the cockpit can deploy all spoiler and speed brake surfaces fully when operated. Often, these surfaces are also rigged to deploy on the ground automatically when engine thrust reversers are activated.

Tabs

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

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

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

The aerodynamic phenomenon of moving a trim tab in one direction to cause the control surface to experience a force moving in the opposite direction is exactly what occurs with the use of balance tabs. *[Figure 1-71]* Often, it is difficult to move a primary control surface due to its surface area and the speed of the air rushing over it. Deflecting a balance tab hinged at the trailing edge of the control surface in the opposite direction of the desired control surface movement causes a force to position the surface in the proper direction with reduced force to do so. Balance tabs are usually linked directly to the control surface linkage so that they move automatically when there is an input for control surface movement. They also can double as trim tabs, if adjustable in the flight deck.

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

On heavy aircraft, large control surfaces require too much force to be moved manually and are usually deflected out of the neutral position by hydraulic actuators. These power control units are signaled via a system of hydraulic valves connected to the yoke and rudder pedals. On fly-by-wire aircraft, the hydraulic actuators that move the flight control surfaces are signaled by electric input. In the case of hydraulic system failure(s), manual linkage to a servo tab can be used to deflect it. This, in turn, provides an aerodynamic force that moves the primary control surface.

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

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

stability and handling of aircraft

• Stability—The inherent quality of an airplane to correct for conditions that may disturb its equilibrium, and to return or to continue on the original flightpath. It is primarily an airplane design characteristic.
• Maneuverability—The quality of an airplane that permits it to be maneuvered easily and to withstand the stresses imposed by maneuvers. It is governed by the airplane's weight, inertia, size and location of flight controls, structural strength, and powerplant. It too is an airplane design characteristic.
• Controllability—The capability of an airplane to respond to the pilot's control, especially with regard to flightpath and attitude. It is the quality of the airplane's response to the pilot's control application when maneuvering the airplane, regardless of its stability characteristics.

Basic concepts of stability

The flightpaths and attitudes in which an airplane can fly are limited only by the aerodynamic characteristics of the airplane, its propulsive system, and its structural strength. These limitations indicate the maximum performance and maneuverability of the airplane. If the airplane is to provide maximum utility, it must be safely controllable to the full extent of these limits without exceeding the pilot's strength or requiring exceptional flying ability. If an airplane is to fly straight and steady along any arbitrary flightpath, the forces acting on it must be in static equilibrium. The reaction of any body when its equilibrium is disturbed is referred to as stability.

There are two types of stability; static and dynamic.

Static stability

Stability of an airplane in flight is slightly more complex than just explained, because the airplane is free to move in any direction and must be controllable in pitch, roll, and direction. When designing the airplane, engineers must compromise between stability, maneuverability, and controllability; and the problem is compounded because of the airplane's three-axis freedom. Too much stability is detrimental to maneuverability, and similarly, not enough stability is detrimental to controllability. In the design of airplanes, compromise between the two is the keyword.

Static will be discussed first, and in this discussion the following definitions will apply:

• Equilibrium—All opposing forces acting on the airplane are balanced; (i.e., steady, unaccelerated flight conditions).

• Static Stability—The initial tendency that the airplane displays after its equilibrium is disturbed.

• Positive Static Stability—The initial tendency of the airplane to return to the original state of equilibrium after being disturbed.

• Negative Static Stability—The initial tendency of the airplane to continue away from the original state of equilibrium after being disturbed.

• Neutral Static Stability—The initial tendency of the airplane to remain in a new condition after its equilibrium has been disturbed.

Dynamic stability

Static stability has been defined as the initial tendency that the airplane displays after being disturbed from its trimmed condition. Occasionally, the initial tendency is different or opposite from the overall tendency, so distinction must be made between the two. Dynamic stability is the overall tendency that the airplane displays after its equilibrium is disturbed. The curves of figure 2 represent the variation of controlled functions versus time. It is seen that the unit of time is very significant. If the time unit for one cycle or oscillation is above 10 seconds' duration, it is called a "long-period" oscillation (phugoid) and is easily controlled. In a longitudinal phugoid oscillation, the angle of attack remains constant when the airspeed increases and decreases. To a certain degree, a convergent phugoid is desirable but is not required. The phugoid can be determined only on a statically stable airplane, and this has a great effect on the trimming qualities of the airplane. If the time unit for one cycle or oscillation is less than one or two seconds, it is called a "short-period" oscillation and is normally very difficult, if not impossible, for the pilot to control. This is the type of oscillation that the pilot can easily "get in phase with" and reinforce.

Longitudinal stability (pitching)

stability about the lateral axis is longitudinal stability
Longitudinal stability is the quality that makes an airplane stable about its lateral axis. It involves the pitching motion as the airplane's nose moves up and down in flight. A longitudinally unstable airplane has a tendency to dive or climb progressively into a very steep dive or climb, or even a stall. Thus, an airplane with longitudinal instability becomes difficult and sometimes dangerous to fly. horizontal stabilizer control longitudinal stability.

Static longitudinal stability or instability in an airplane, is dependent upon three factors:

1. Location of the wing with respect to the center of gravity;

2. Location of the horizontal tail surfaces with respect to the center of gravity; and
3. The area or size of the tail surfaces.

To obtain static longitudinal stability, the relation of the wing and tail moments must be such that, if the moments are initially balanced and the airplane is suddenly nosed up, the wing moments and tail moments will change so that the sum of their forces will provide an unbalanced but restoring moment which, in turn, will bring the nose down again.

Similarly, if the airplane is nosed down, the resulting change in moments will bring the nose back up.

The center of lift, sometimes called the center of pressure, in most unsymmetrical airfoils has a tendency to change its fore and aft position with a change in the angle of attack. The center of pressure tends to move forward with an increase in angle of attack and to move aft with a decrease in angle of attack. This means that when the angle of attack of an airfoil is increased, the center of pressure (lift) by moving forward, tends to lift the leading edge of the wing still more. This tendency gives the wing an inherent quality of instability.

Figure 3 shows an airplane in straight-and-level flight. The line CG-CL-T represents the airplane’s longitudinal axis from the center of gravity (CG) to a point T on the horizontal stabilizer. The center of lift (or center of pressure) is represented by the point CL.

Figure 3: Longitudinal stability.

Most airplanes are designed so that the wing’s center of lift (CL) is to the rear of the center of gravity. This makes the airplane “nose heavy” and requires that there be a slight downward force on the horizontal stabilizer in order

to balance the airplane and keep the nose from continually pitching downward.
Compensation for this nose heaviness is provided by setting the horizontal stabilizer at a slight negative angle of attack i.e longitudinal dihedral,which is the difference in AOI of main plain and tail plane(2degree)The downward force thus produced, holds the tail down, counterbalancing the "heavy" nose.
Even though the horizontal stabilizer may be level when the airplane is in level flight, there is a downwash of air from the wings. This downwash strikes the top of the stabilizer and produces a downward pressure, which at a certain speed will be just enough to balance the "lever." The faster the airplane is flying, the greater this downwash and the greater the downward force on the horizontal stabilizer (except "T" tails).
Figure 4: Effect of speed on downwash.
In airplanes with fixed position horizontal stabilizers, the airplane manufacturer sets the stabilizer at an angle that will provide the best stability (or balance) during flight at the design cruising speed and power setting.
Figure 5: Reduced power allows pitch down.
If the airplane's speed decreases, the speed of the airflow over the wing is decreased. As a result of this decreased flow of air over the wing, the downwash is reduced, causing a lesser downward force on the horizontal stabilizer. In turn, the characteristic nose heaviness is occoured, causing the airplane's nose to pitch down more. This places the airplane in a nose-low attitude, lessening the wing's angle of attack and drag and allowing the airspeed to increase.
A similar effect will be noted upon closing the throttle. The downwash of the wings is reduced and the force at T

in figure 3 is not enough to hold the horizontal stabilizer down. It is as if the force at T on the lever were allowing the force of gravity to pull the nose down. This, of course, is a desirable characteristic because the airplane is inherently trying to regain airspeed and reestablish the proper balance.

Power or thrust can also have a destabilizing effect in that an increase of power may tend to make the nose rise. The airplane designer can offset this by establishing a "high thrustline" wherein the line of thrust passes above the center of gravity.

Figure 6: Thrust line affects longitudinal stability.

Figure 7: Power changes affect longitudinal stability.

In this case, as power or thrust is increased a moment is produced to counteract the down load on the tail. On the other hand, a very "low thrust line" would tend to add to the nose-up effect of the horizontal tail surface.

It can be concluded, then, that with the center of gravity forward of the center of lift, and with an aerodynamic tail-down force, the result is that the airplane always tries to return to a safe flying attitude.

A simple demonstration of longitudinal stability may be made as follows: Trim the airplane for "hands off" control in level flight. Then momentarily give the controls a slight push to nose the airplane down. If, within a brief period, the nose rises to the original position and then stops, the airplane is statically stable. Ordinarily, the nose will pass the original position (that of level flight) and a series of slow pitching oscillations will follow. If the oscillations gradually cease, the airplane has positive stability; if they continue unevenly, the airplane has neutral stability; if they increase, the airplane is unstable.

Lateral stability (rolling)

stability about the aircraft's longitudinal axis, which extends from the nose of the aircraft to its tail, is called lateral stability. This helps to stabilize the lateral or "rolling effect" when one wing gets lower than the wing on the opposite side of the aircraft. There are four main design factors that affect an aircraft's lateral stability are as follows: dihedral, sweepback, keel effect, and weight distribution.wing give lateral stability.

Dihedral

The most common procedure for producing lateral stability is to build the wings with an angle of one to three degrees above perpendicular to the longitudinal axis. The wings on either side of the aircraft join the fuselage to form a slight V or angle called "dihedral." The amount of dihedral is measured by the angle made by each wing above a line parallel to the lateral axis.

Dihedral involves a balance of lift created by the wings' AOA on each side of the aircraft's longitudinal axis. If a momentary gust of wind forces one wing to rise and the other to lower, the aircraft banks. When the aircraft is banked without turning, the tendency to sideslip or slide downward toward the lowered wing occurs. [Figure 4-25] Since the wings have dihedral, the air strikes the lower wing at a much greater AOA than the higher wing. The increased AOA on the lower wing creates more lift than the higher wing. Increased lift causes the lower wing to begin to rise upward. As the wings approach the level position, the AOA on both wings once again are equal, causing the rolling tendency to subside. The effect of dihedral is to produce a rolling tendency to return the aircraft to a laterally balanced flight condition when a sideslip occurs.

Figure 4-25. Dihedral for lateral stability.

The restoring force may move the low wing up too far, so that the opposite wing now goes down. If so, the process is repeated, decreasing with each lateral oscillation until a balance for wings-level flight is finally reached.

Conversely, excessive dihedral has an adverse effect on lateral maneuvering qualities. The aircraft may be so stable laterally that it resists an intentional rolling motion. For this reason, aircraft that require fast roll or banking characteristics usually have less dihedral than those designed for less maneuverability.

Sweepback

Angle between a line perpendicular to the fuselage center line and quarter chord of each wing. A sweptback wing is one in which the leading edge slopes backward.

Sweepback is an addition to the dihedral that increases the lift created when a wing drops from the level position. When a disturbance causes an aircraft with sweepback to slip or drop a wing, the low wing presents its leading edge at an angle that is perpendicular to the relative airflow. As a result, the low wing acquires more lift, rises, and the aircraft is restored to its original flight attitude.

Sweepback also contributes to directional stability. When turbulence or rudder application causes the aircraft to yaw to one side, the right wing presents a longer leading edge perpendicular to the relative airflow. The airspeed of the right wing increases and it acquires more drag than the left wing. The additional drag on the right wing pulls it back, turning the aircraft back to its original path.

Keel Effect and Weight Distribution

An aircraft always has the tendency to turn the longitudinal axis of the aircraft into the relative wind. This "weather vane" tendency is similar to the keel of a ship and exerts a steadying influence on the aircraft laterally about the longitudinal axis. When the aircraft is disturbed and one wing dips, the fuselage weight acts like a pendulum returning the airplane to its original attitude.

Laterally stable aircraft are constructed so that the greater portion of the keel area is above and behind the CG. [Figure 4-26] Thus, when the aircraft slips to one side, the combination of the aircraft's weight and the pressure of the airflow against the upper portion of the keel area (both acting about the CG) tends to roll the aircraft back to wings-level flight.

Figure 9: Keel area for lateral stability.

Vertical stability (yawing)

Stability about the airplane's vertical axis (the sideways moment) is called yawing or directional stability. The aircraft should be designed so that when it is in straight and level flight it remains on its course heading even though the pilot takes his hand and feet off the controls. If an aircraft recovers automatically from a skid, it has been ell designed and possesses good directional balance. The vertical stabilizer is the primary surface which controls directional stability.

As shown in figure 2-13, when an aircraft is in a sideslip or yawing, the vertical tail experiences a change in angle of attack with a resting change in lift (not to be confused with the lift created by the wing). The change in lift, or side force, on the vertical tail creates a yawing moment about the center of gravity which tends to return the aircraft to its original flight path.

Sweptback wings aid in directional stability. If the aircraft yaws from its direction of flight, the wing which is farther ahead offers more drag than the wing which in aft. The effect of this drag is to hold back the wing which is farther ahead, and to let the other wing catch up.

Directional stability is also aided by using a large dorsal fin and a long fuselage.

The high Mach numbers of supersonic flight reduce the contribution of the vertical tail to directional stability. To produce the required directional stability at high Mach numbers, a very large vertical tail area may be necessary. Ventral (belly) fins may be added as an additional contribution to directional stability.

Figure 10: Fuselage and fin for vertical stability.

Free directional oscillations (Dutch roll)

Dutch Roll is a coupled lateral/directional oscillation that is usually dynamically stable but is objectionable in an airplane because of the oscillatory nature. The damping of the oscillatory mode may be weak or strong depending on the properties of the particular airplane.

Unfortunately all air is not smooth. There are bumps and depressions created by gusty updrafts and downdrafts, and by gusts from ahead, behind, or the side of the airplane.

The response of the airplane to a disturbance from equilibrium is a combined rolling/yawing oscillation in which the rolling motion is phased to precede the yawing motion. The yawing motion is not too significant, but the roll is much more noticeable.

When the airplane rolls back toward level flight in response to dihedral effect, it rolls back too far and sideslips the other way. Thus, the airplane overshoots each time because of the strong dihedral effect. When the dihedral effect is large in comparison with static directional stability, the Dutch Roll motion has weak damping and is objectionable. When the static directional stability is strong in comparison with the dihedral effect, the Dutch Roll motion has such heavy damping that it is not objectionable. However, these qualities tend toward spiral instability.

The choice is then the least of two evils—Dutch Roll is objectionable and spiral instability is tolerable if the rate of divergence is low. Since the more important handling qualities are a result of high static directional stability and minimum necessary dihedral effect, most airplanes demonstrate a mild spiral tendency. This tendency would

be indicated to the pilot by the fact that the airplane cannot be flown “hands off” indefinitely.
In most modern airplanes, except high-speed swept wing designs, these free directional oscillations usually die out automatically in a very few cycles unless the air continues to be gusty or turbulent. Those airplanes with continuing Dutch Roll tendencies usually are equipped with gyro stabilized yaw dampers. An airplane that has Dutch Roll tendencies is disconcerting, to say the least. Therefore, the manufacturer tries to reach a medium between too much and too little directional stability. Because it is more desirable for the airplane to have “spiral instability” than Dutch Roll tendencies, most airplanes are designed with that characteristic.

Spiral instability

Spiral instability exists when the static directional stability of the airplane is very strong as compared to the effect of its dihedral in maintaining lateral equilibrium. When the lateral equilibrium of the airplane is disturbed by a gust of air and a sideslip is introduced, the strong directional stability tends to yaw the nose into the resultant relative wind while the comparatively weak dihedral lags in restoring the lateral balance. Due to this yaw, the wing on the outside of the turning moment travels forward faster than the inside wing and as a consequence, its lift becomes greater. This produces an overbanking tendency which, if not corrected by the pilot, will result in the bank angle becoming steeper and steeper. At the same time, the strong directional stability that yaws the airplane into the relative wind is actually forcing the nose to a lower pitch attitude. Then, the start of a slow downward spiral which has begun, if not counteracted by the pilot, will gradually increase into a steep spiral dive.

Usually the rate of divergence in the spiral motion is so gradual that the pilot can control the tendency without any difficulty.

All airplanes are affected to some degree by this characteristic although they may be inherently stable in all other normal parameters. This tendency would be indicated to the pilot by the fact that the airplane cannot be flown "hands off" indefinitely.

Much study and effort has gone into development of control devices (wing leveler) to eliminate or at least correct this instability. Advanced stages of this spiral condition demand that the pilot be very careful in application of recovery controls, or excessive loads on the structure may be imposed.

Of the in-flight structural failures that have occurred in general aviation airplanes, improper recovery from this condition has probably been the underlying cause of more fatalities than any other single factor. The reason is that the airspeed in the spiral condition builds up rapidly, and the application of back elevator force to reduce this speed and to pull the nose up only "tightens the turn," increasing the load factor. The results of the prolonged uncontrolled spiral are always the same; either in-flight structural failure, crashing into the ground, or both. The most common causes on record for getting into this situation are: loss of horizon reference, inability of the pilot to control the airplane by reference to instruments, or a combination of both.