Principle of flight

Amirhoseinsalme

Chapter 1

Laws
and
definitions

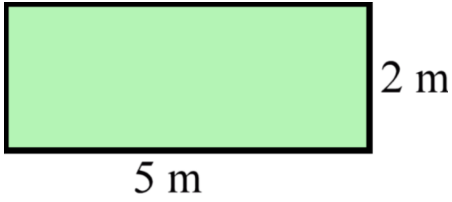
SI UNITS

- **Mass** The amount of matter in a body; measured in kilograms (kg).

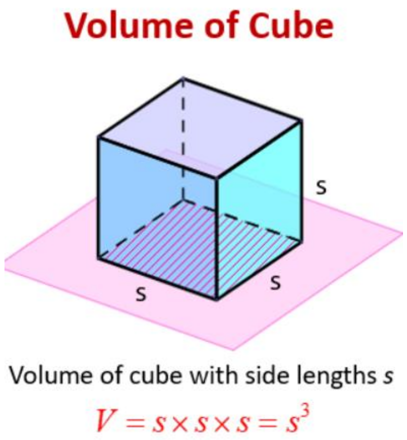
- **Length** The distance between two points; measured in metres (m).

- **Time** The duration of an event; measured in seconds (s).

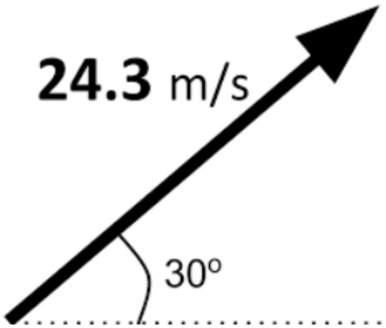
- **Area** A measure of a surface; measured in square metres (m2)

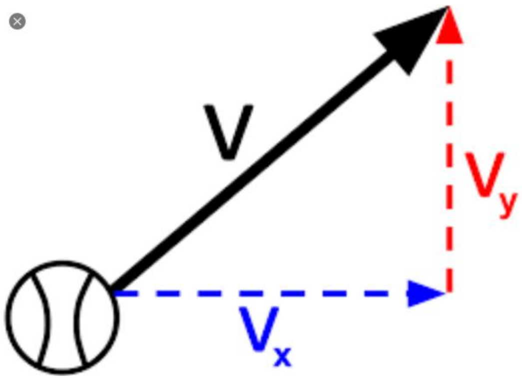


- **Volume** A measure of the bulk or space occupied by a body; measured in cubic metres (m3).



- **Velocity** A measure of motion in a specified direction; measured in metres per second (m/s)





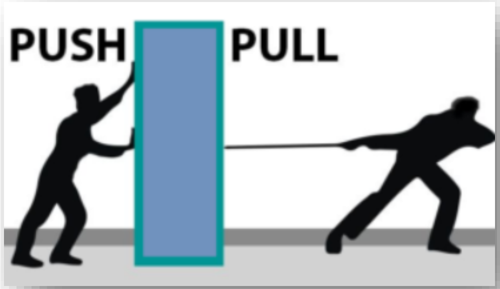
- **Acceleration** A measure of the change of velocity of a body; measured in metres per second per second (m/s2)

Principle of Flight

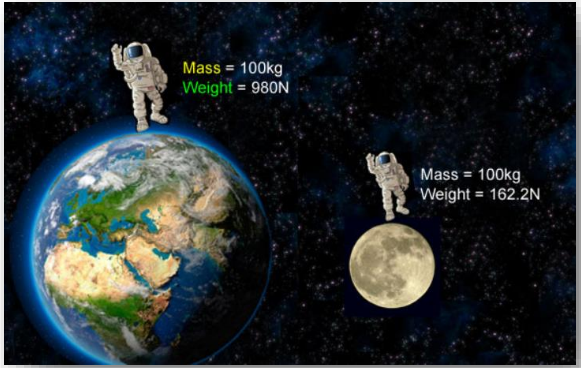
02

- **Force** An external influence capable of altering the state of rest or motion of a body, proportional to the rate of change of momentum of a body

Force = Mass x Acceleration



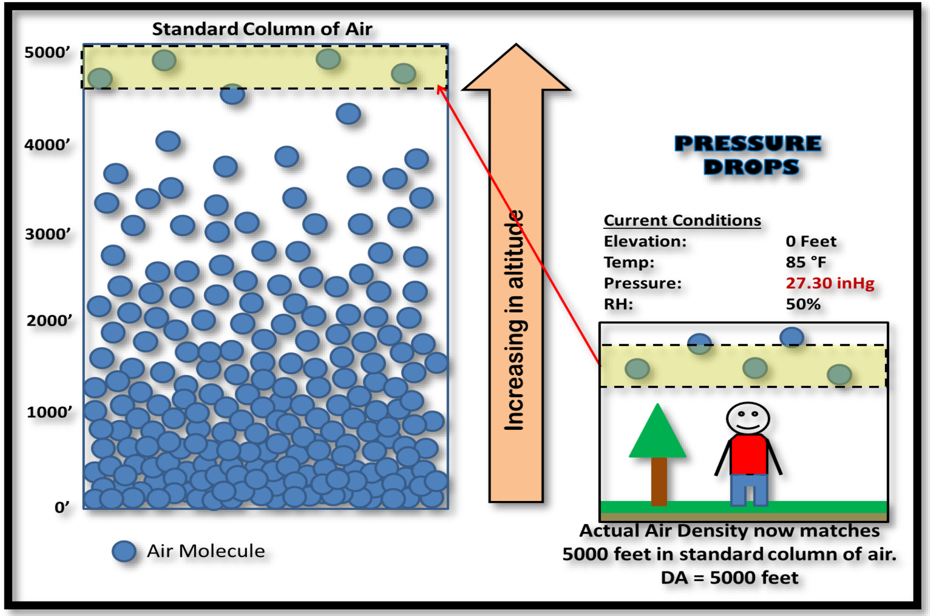
- **Weight**

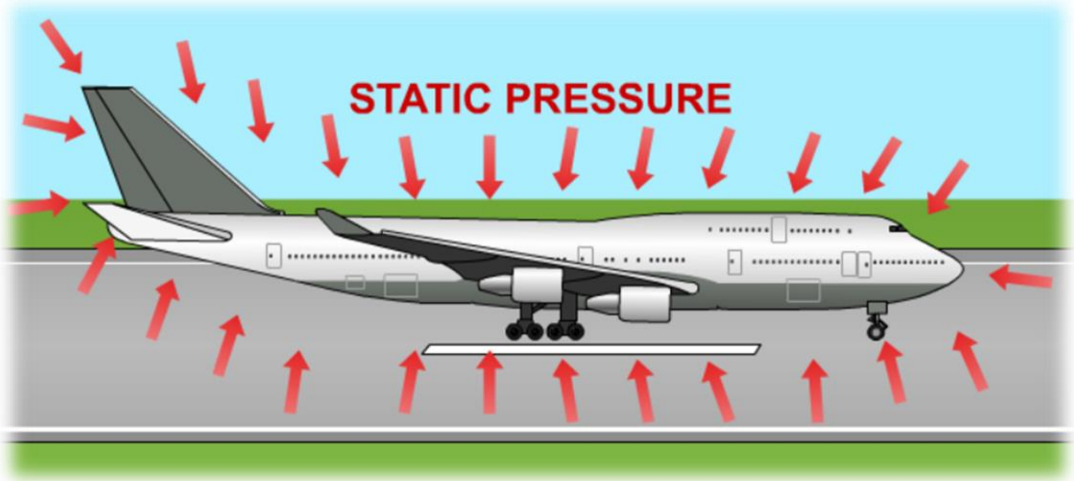


Mass vs weight

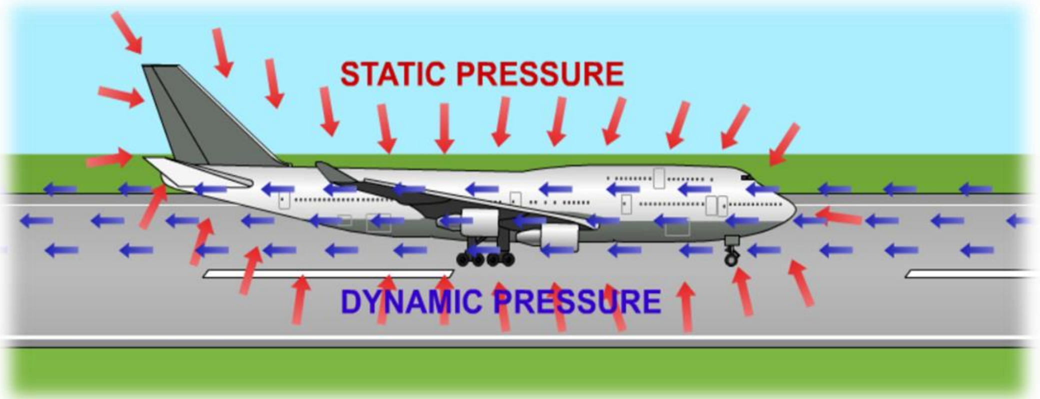
- **Pressure** The force per unit area acting on a surface; This is measured in Newtons per square metre (N/m2) and is called the Pascal (Pa). In aviation, the bar is more commonly used to measure pressure. 1 bar = 105 Pa, or 1 mb = 1 hPa. In aerodynamics three types of pressure exist:

1. **Static Pressure (PS)**




STATIC PRESSURE

2. Dynamic Pressure (PD)



$$Q = \frac{1}{2} \rho V^2$$

2. Total Pressure (PT) The sum of both the static and dynamic pressures; This is a very important term in aerodynamic formulae, as it is used in the calculation of lift, drag, and indicated airspeeds.

$$\text{Total Pressure} = \text{Static Pressure} + \text{Dynamic Pressure}$$

In aerodynamics, this is also referred to as Pitot Pressure.

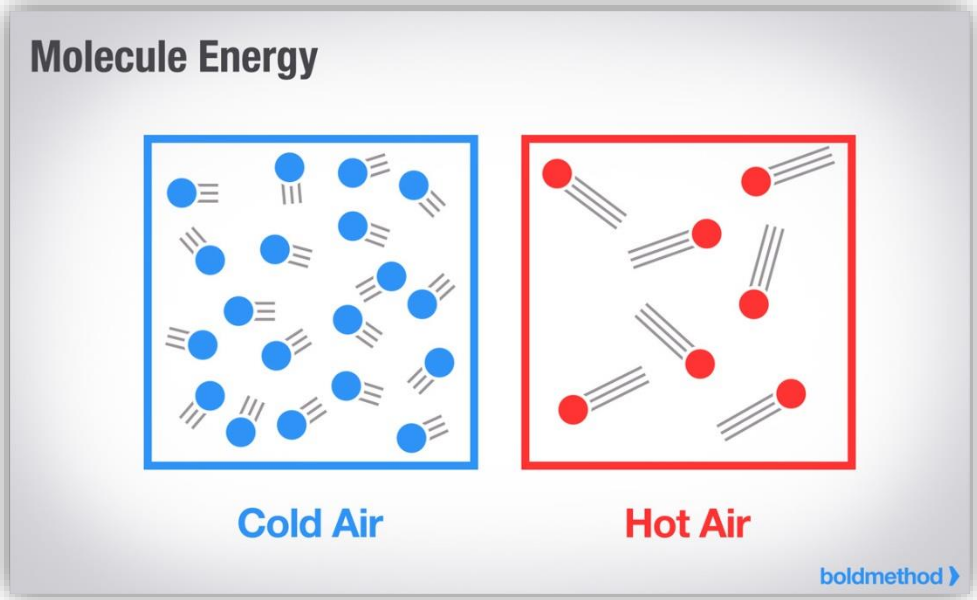
- **Density(ρ)** mass per unit volume(ρ =m/v)

density

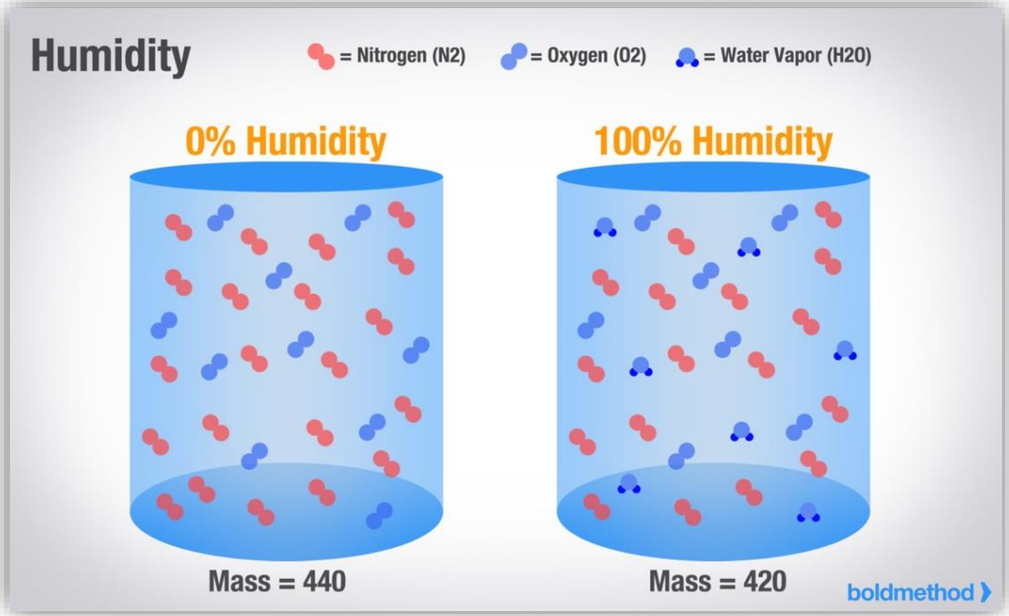
Factors affecting air density:

✓ **pressure**

✓ **Temperature**



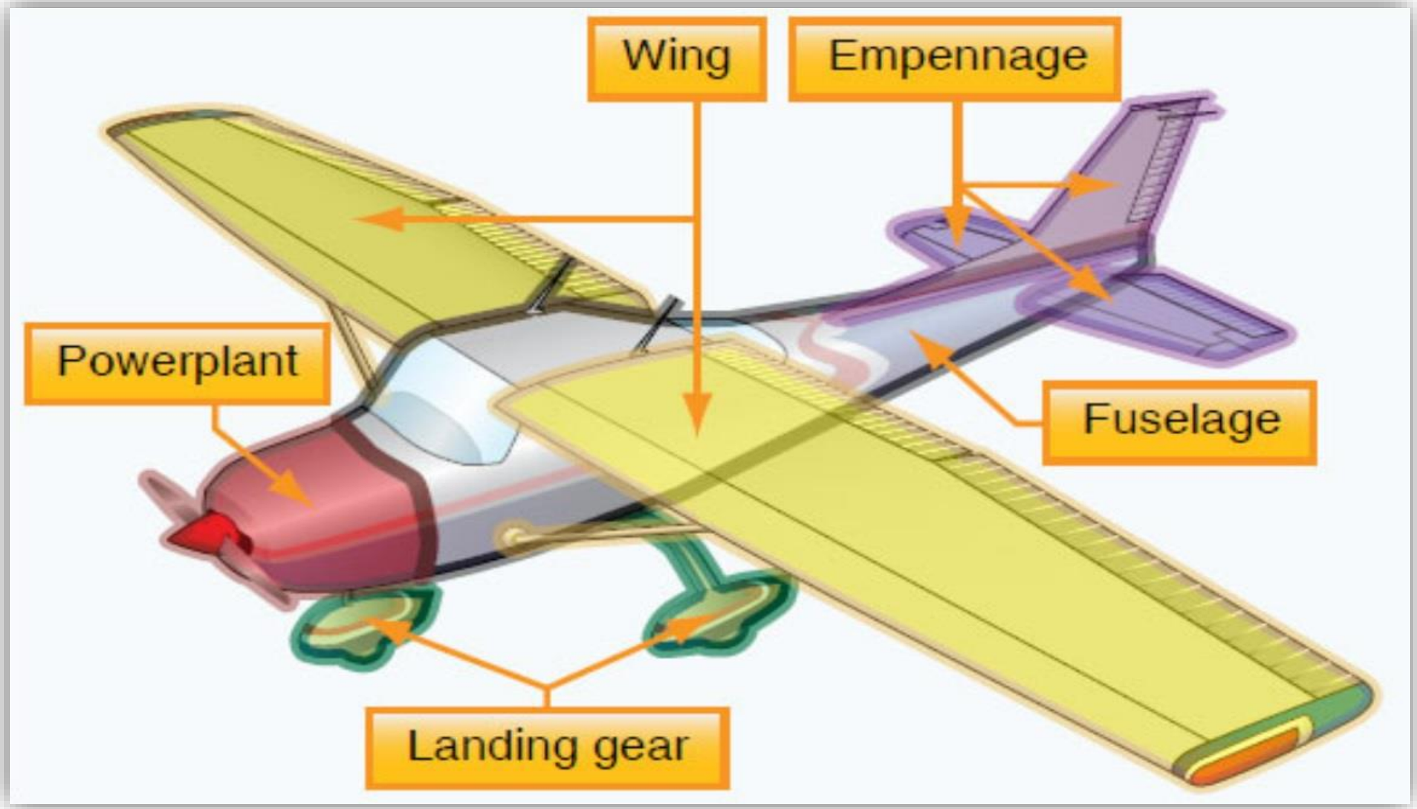
✓ **Humidity**

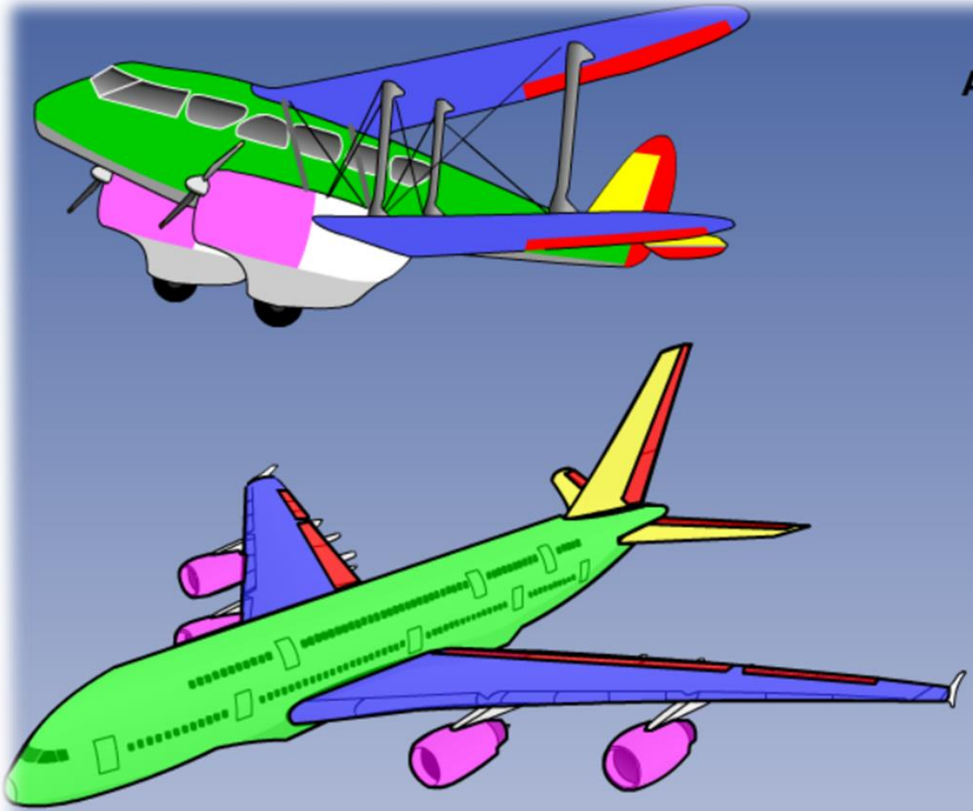

Humidity
= Nitrogen (N2)
= Oxygen (O2)
= Water Vapor (H2O)
0% Humidity
100% Humidity
Mass = 440
Mass = 420
boldmethod

Chapter 1

OVERVIEW

Major Components of an Aircraft





Aeroplane Primary Components

wings - to generate lift

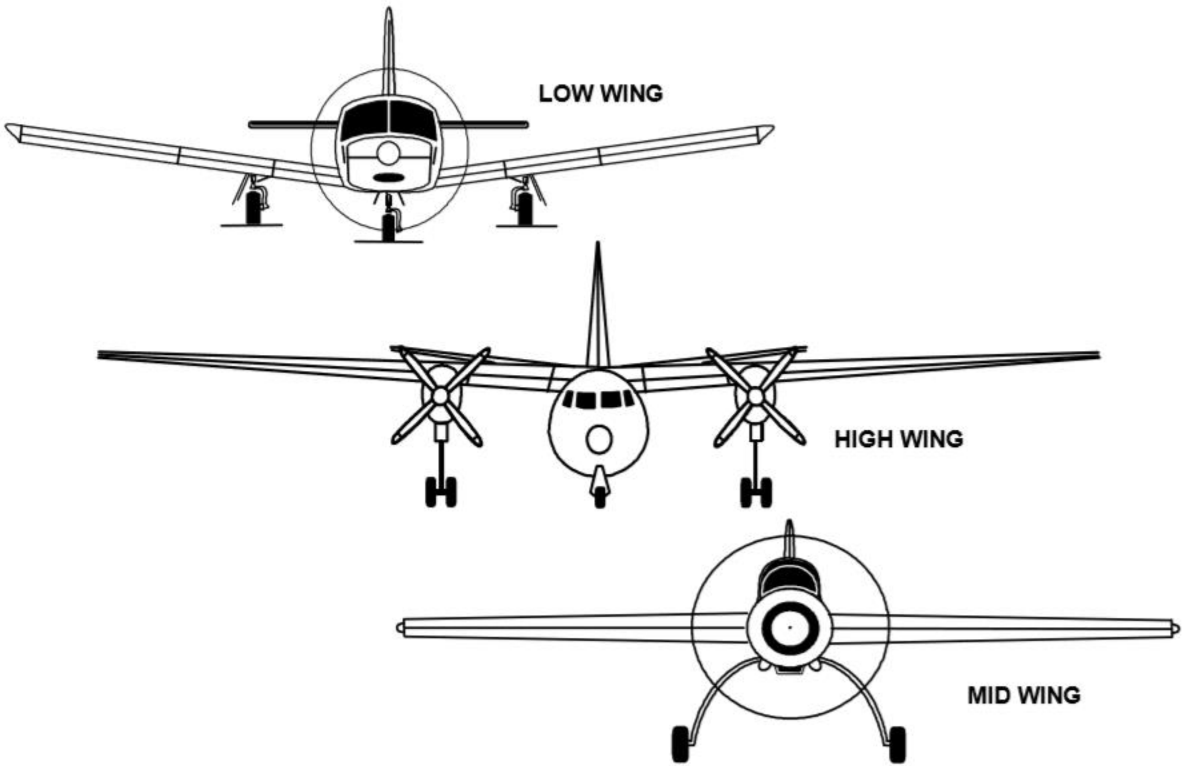
fuselage - to carry and protect the payload and crew

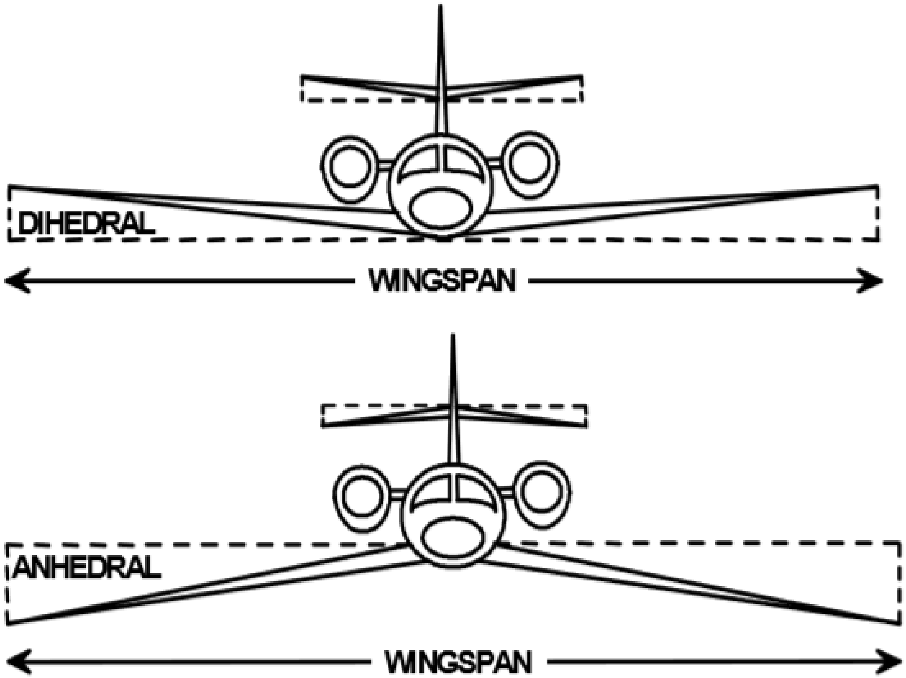
tail surfaces - to provide stability

control surfaces - to change the aeroplane's direction

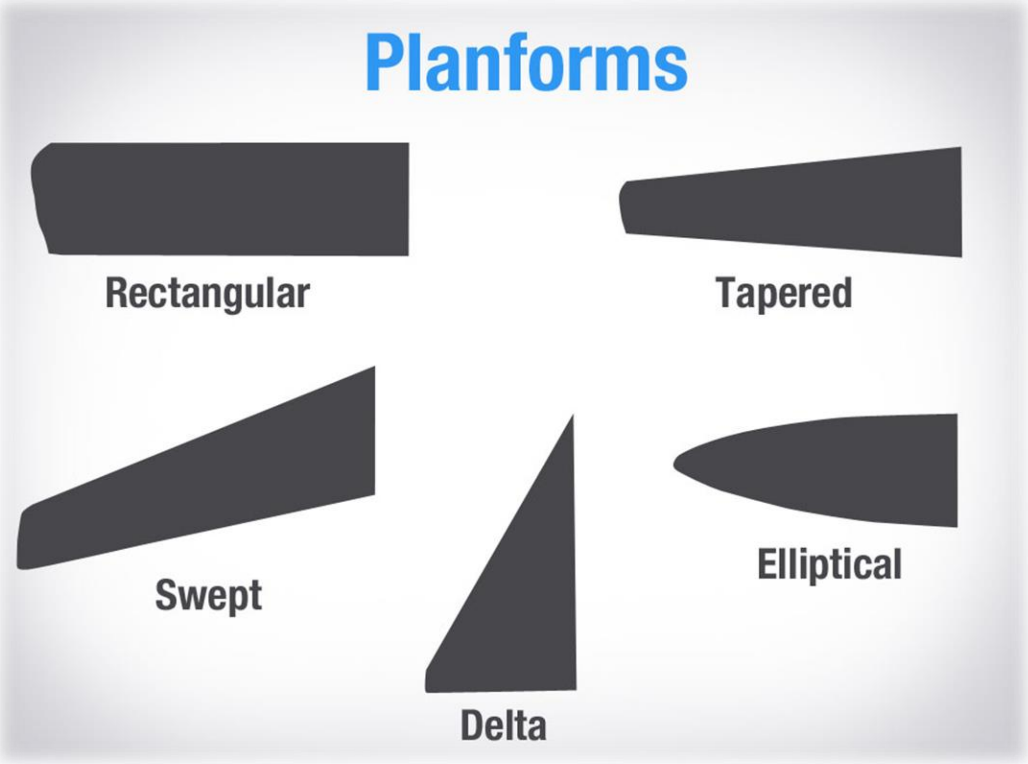
engines - to produce thrust and sustain flight

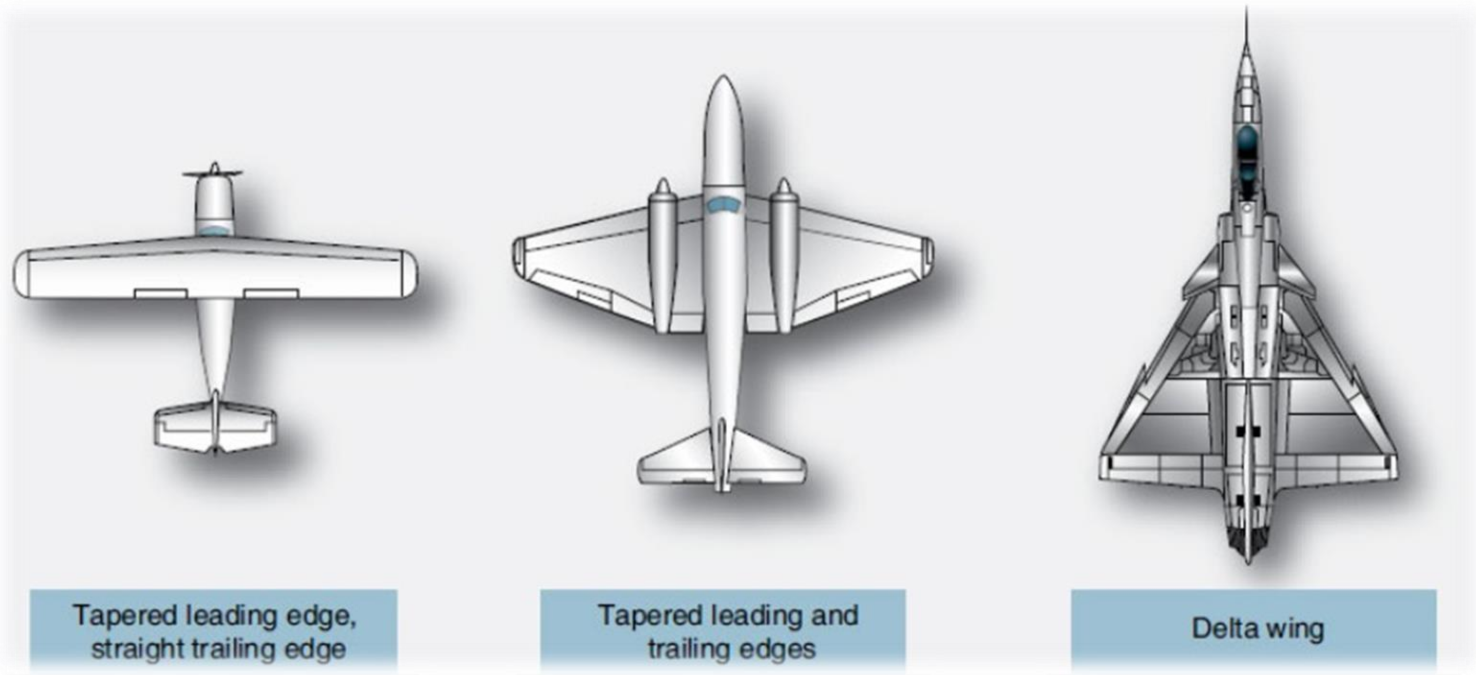
WING POSITION TERMINOLOGY

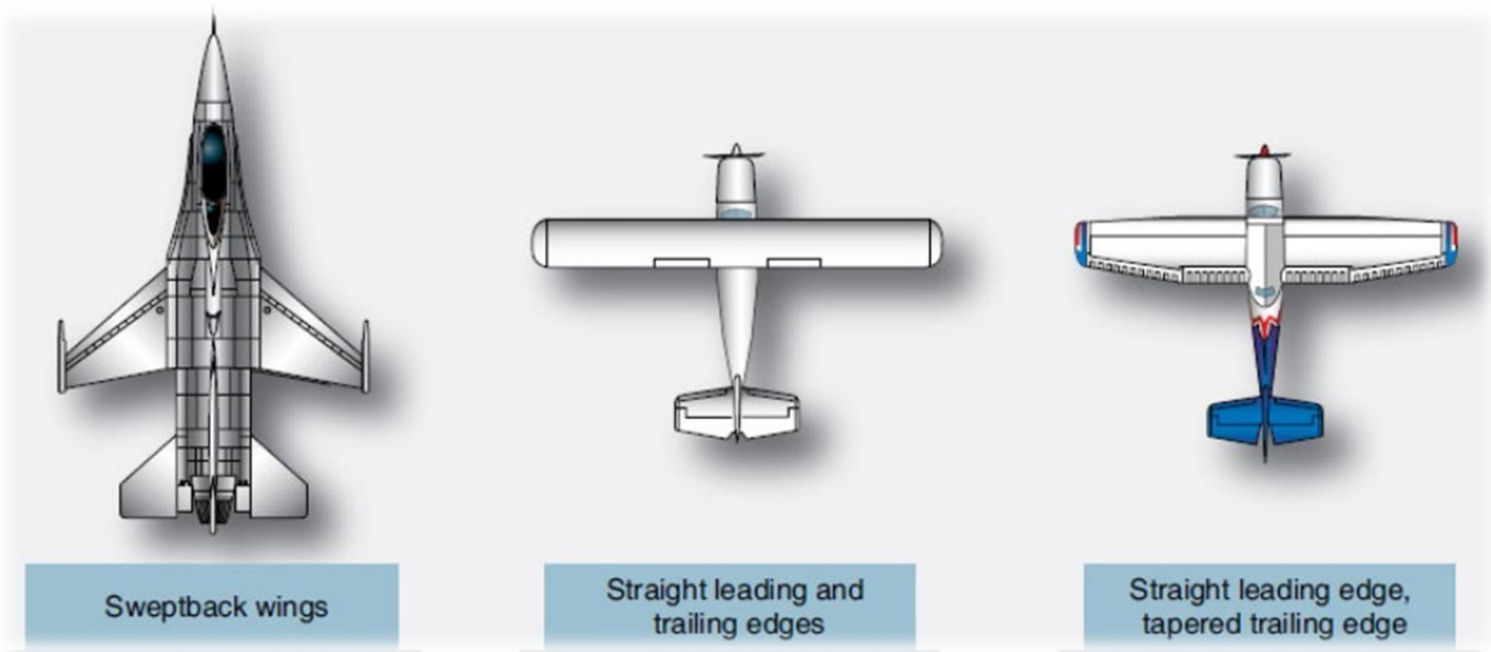


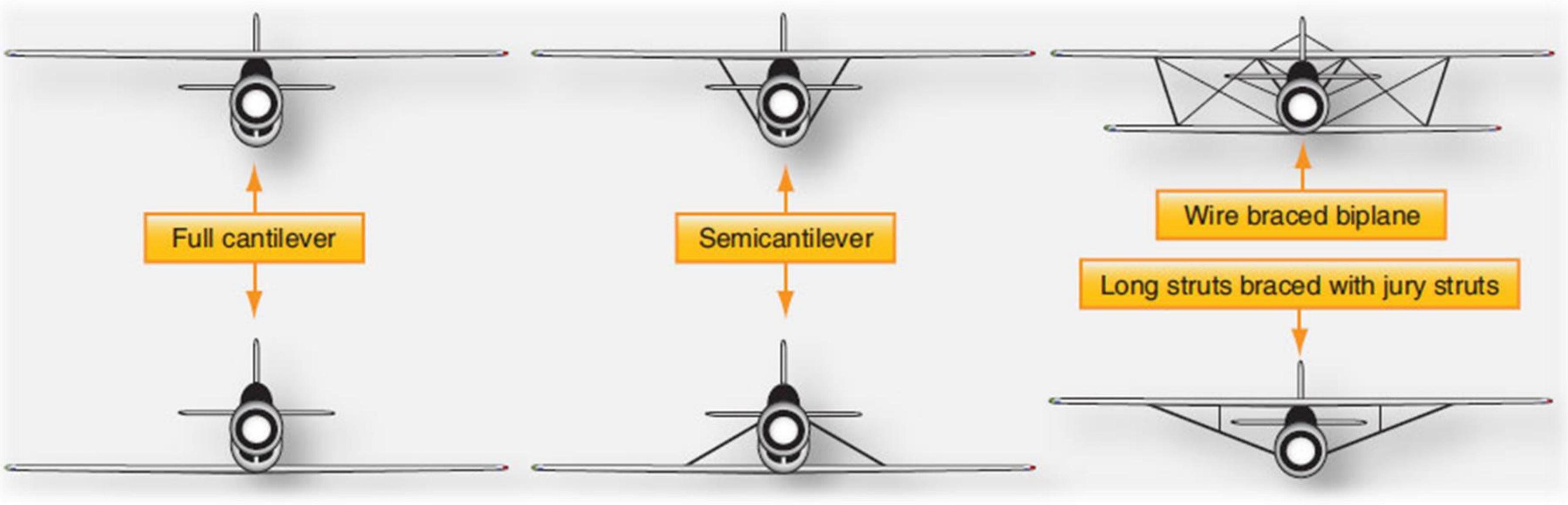

DIHEDRAL
WINGSPAN
ANHEDRAL
WINGSPAN

WING planforms

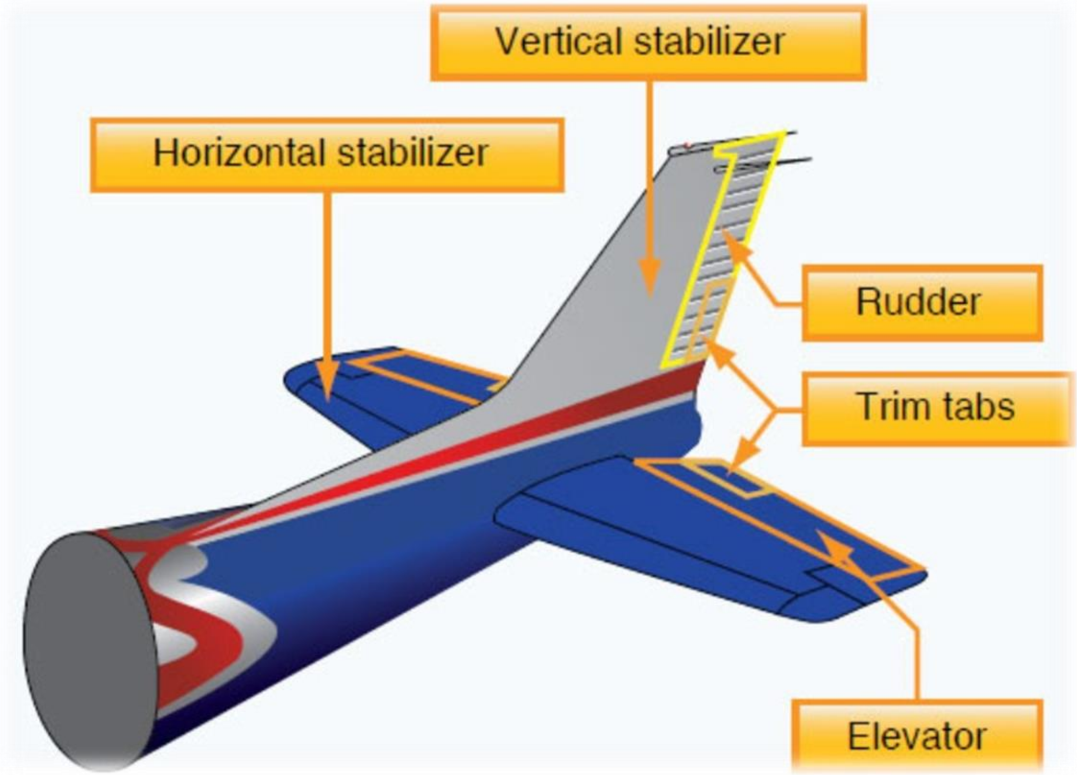


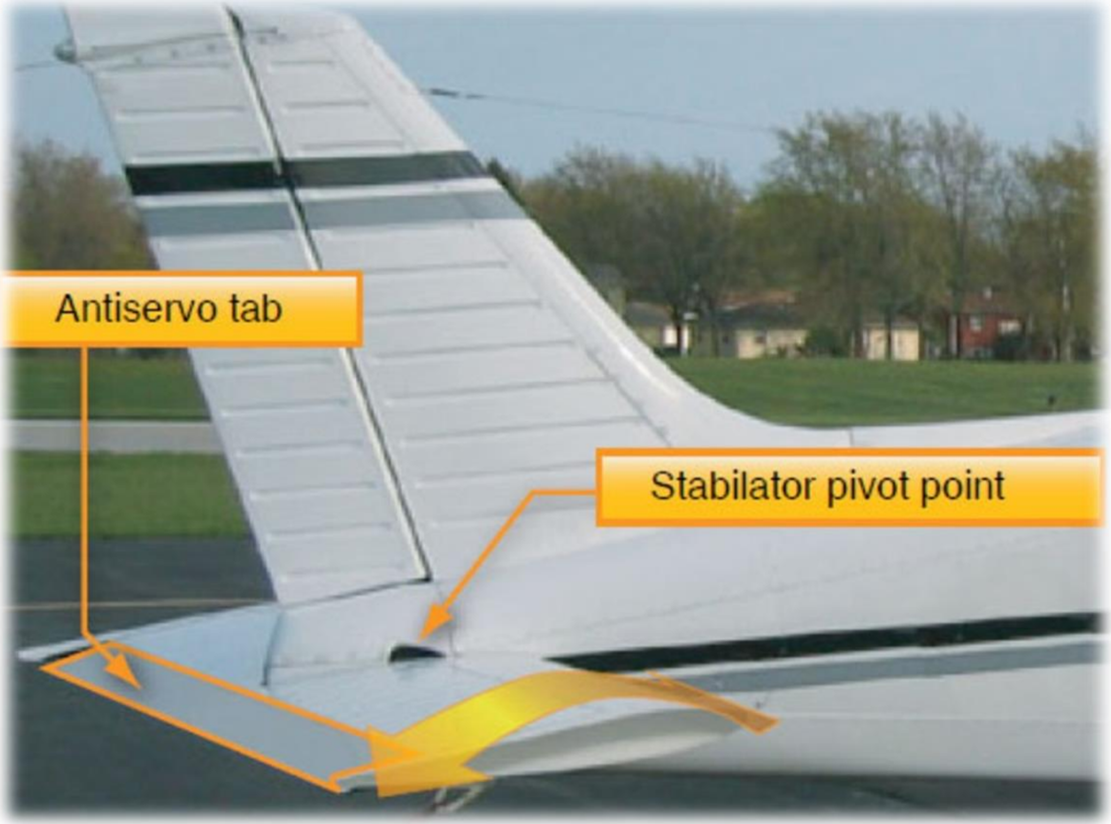

Tapered leading edge, straight trailing edge
Tapered leading and trailing edges
Delta wing

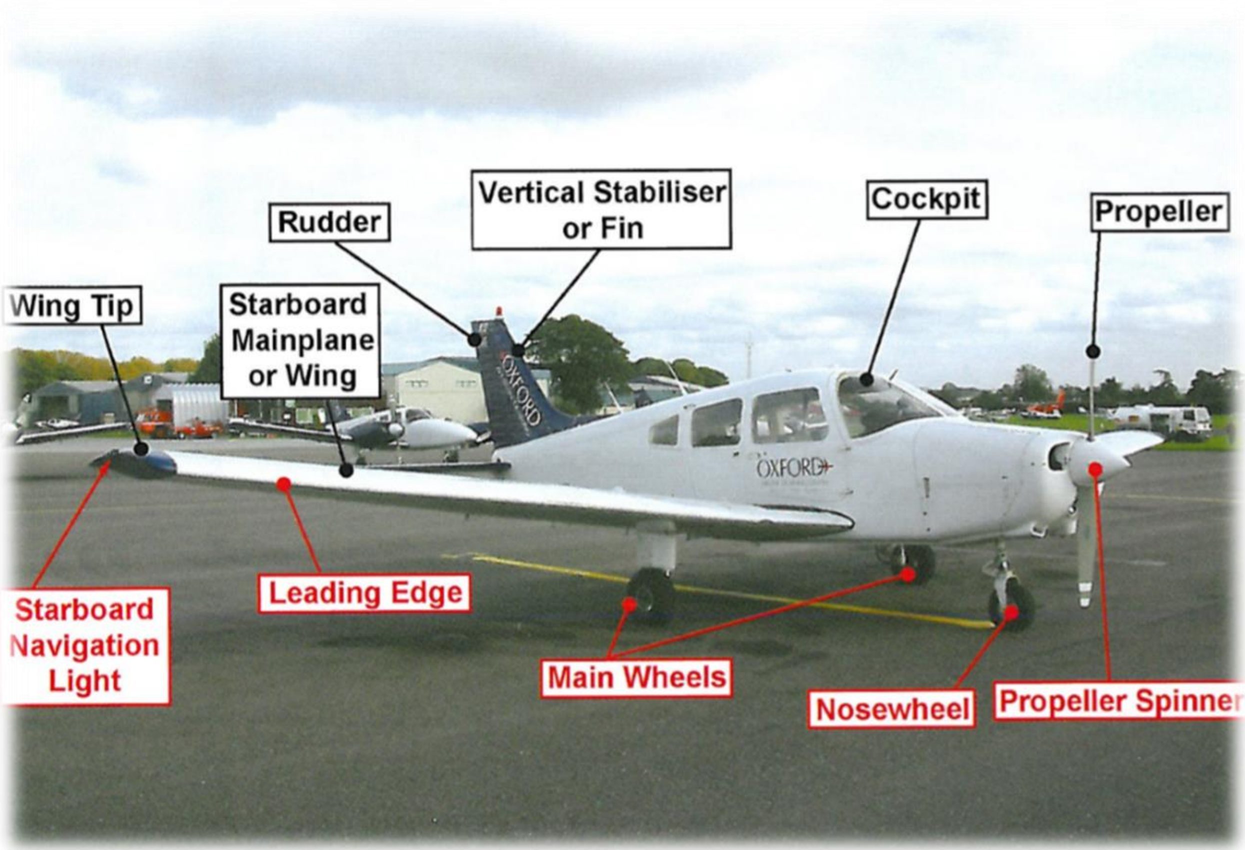

Sweptback wings
Straight leading and trailing edges
Straight leading edge, tapered trailing edge

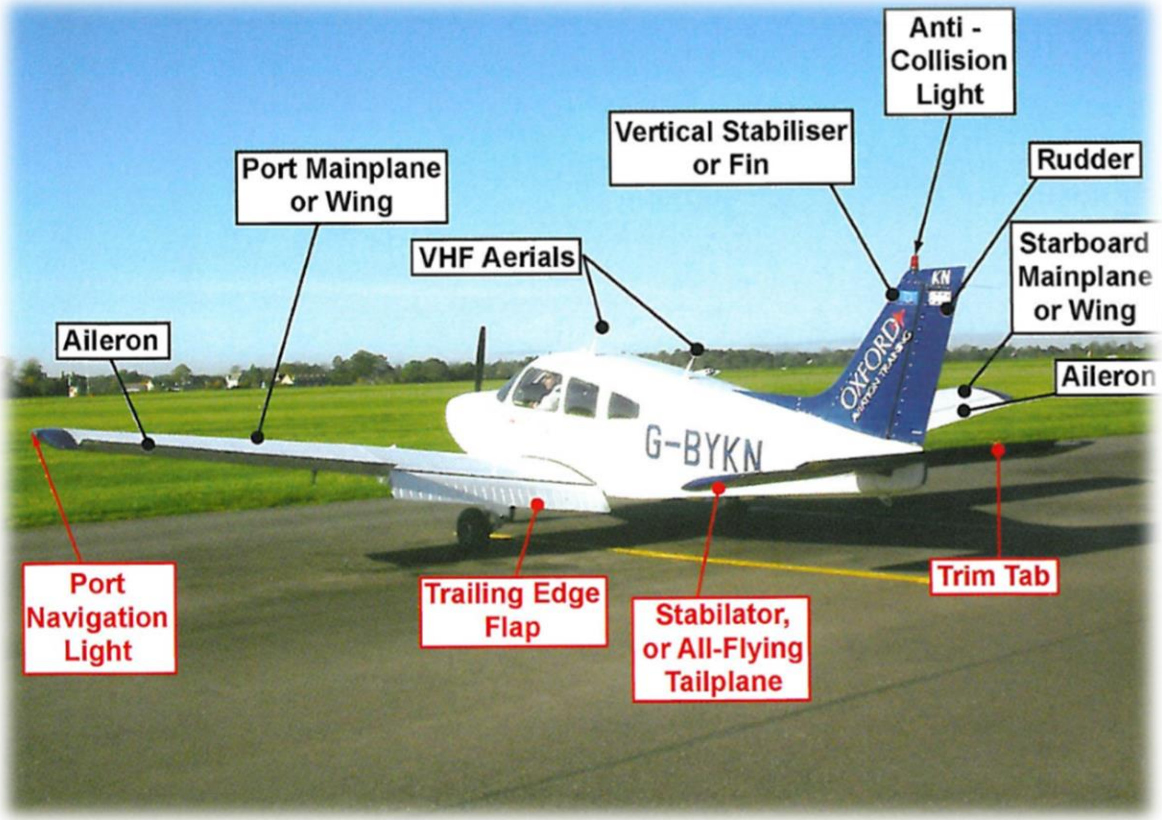

Full cantilever
Semicantilever
Wire braced biplane
Long struts braced with jury struts

Empennage


Vertical stabilizer
Horizontal stabilizer
Rudder
Trim tabs
Elevator

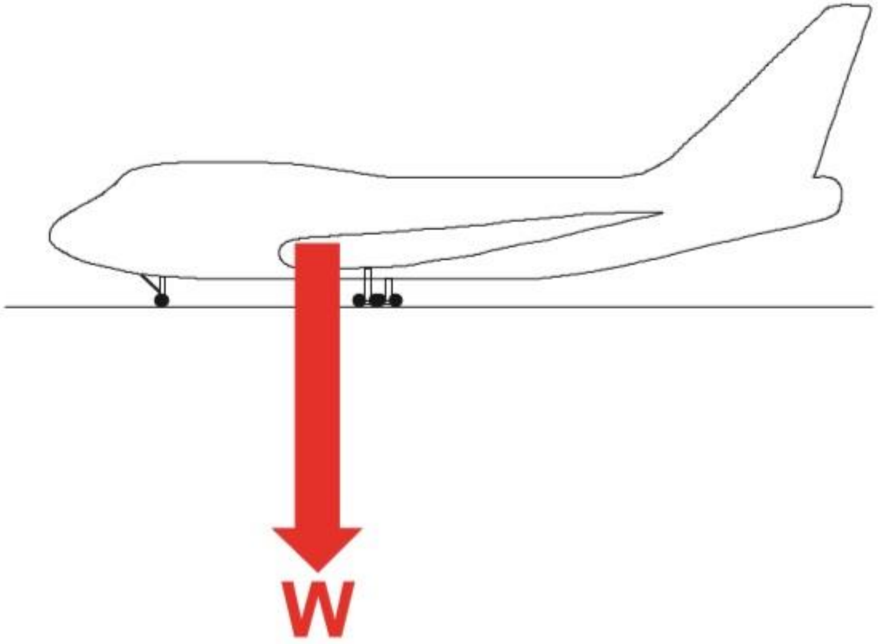

Antiservo tab
Stabilator pivot point


Vertical Stabiliser or Fin
Cockpit
Propeller
Rudder
Wing Tip
Starboard Mainplane or Wing
Starboard Navigation Light
Leading Edge
Main Wheels
Nosewheel
Propeller Spinner
OXFORD

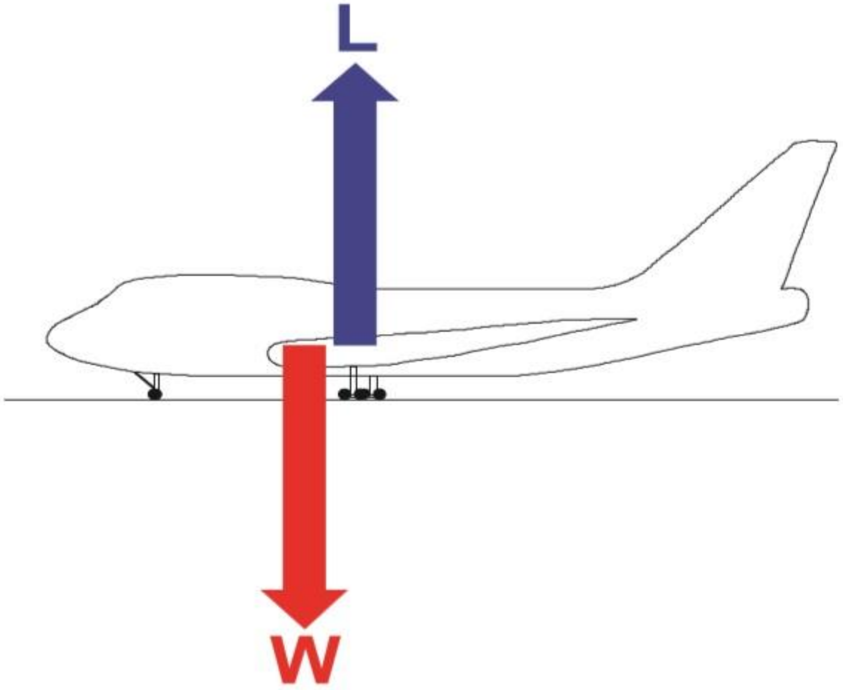

Anti - Collision Light
Vertical Stabiliser or Fin
Rudder
Port Mainplane or Wing
VHF Aerials
Starboard Mainplane or Wing
Aileron
Aileron
G-BYKN
Port Navigation Light
Trailing Edge Flap
Stabilator, or All-Flying Tailplane
Trim Tab

Overview of forces

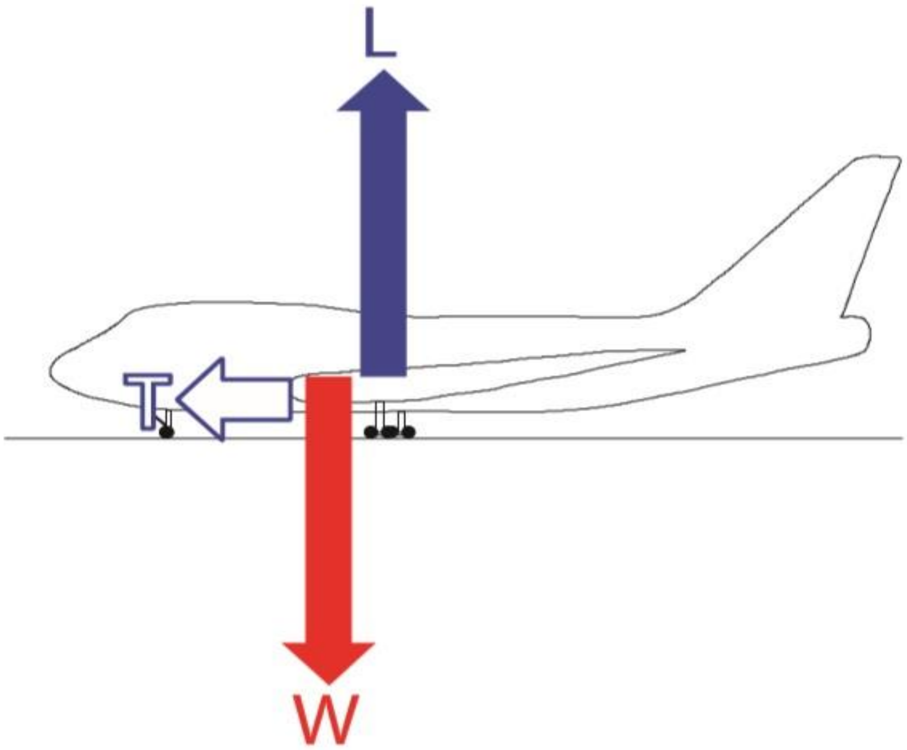
With the aircraft stationary on the ground it has only the force due to the acceleration of gravity acting upon it. This force, its WEIGHT, acts vertically downward at all times.



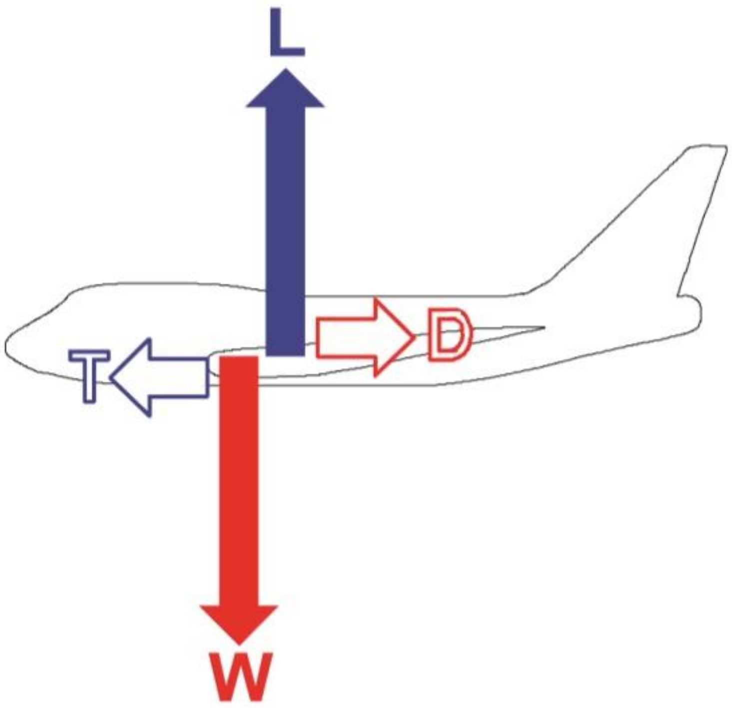
Before an aeroplane can leave the ground and fly, the force of weight must be balanced by a force which acts upwards. This force is called LIFT. The lift force must be increased until it is the same as the aeroplane's weight.

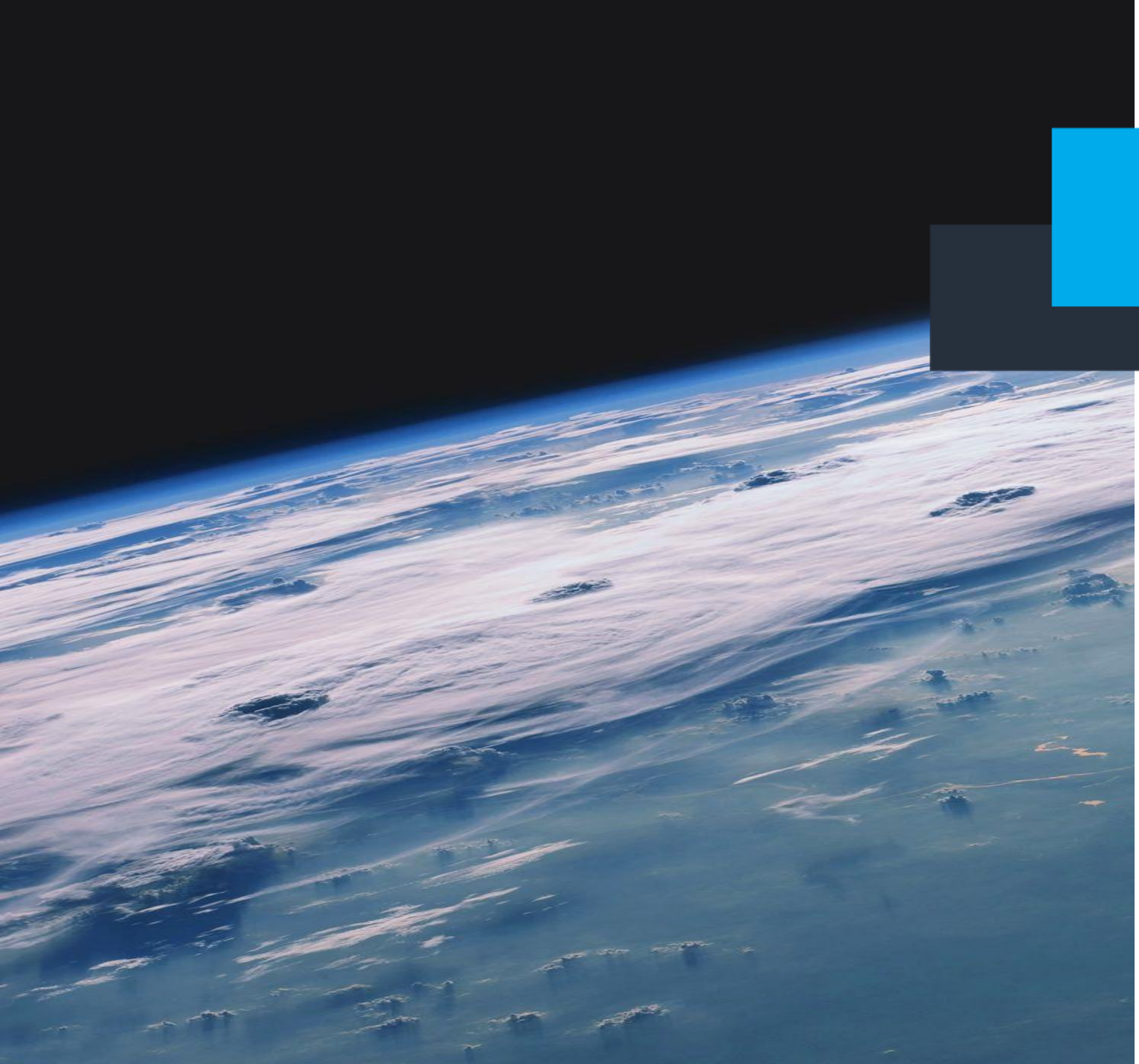


To generate a lift force, the aeroplane must be propelled forward through the air by a force called THRUST, provided by the engine(s).



From the very moment the aeroplane begins to move, air resists its forward motion with a force called DRAG.





Chapter 2

THE ATMOSPHERE

The Physical Properties of Air

• Air has mass and A mass of moving air has considerable kinetic energy.

• Air is a compressible and is able to flow or change its shape when subjected to even minute pressure Differences.

• The viscosity of air is so low that very small forces are able to move the molecules in relation to each other.

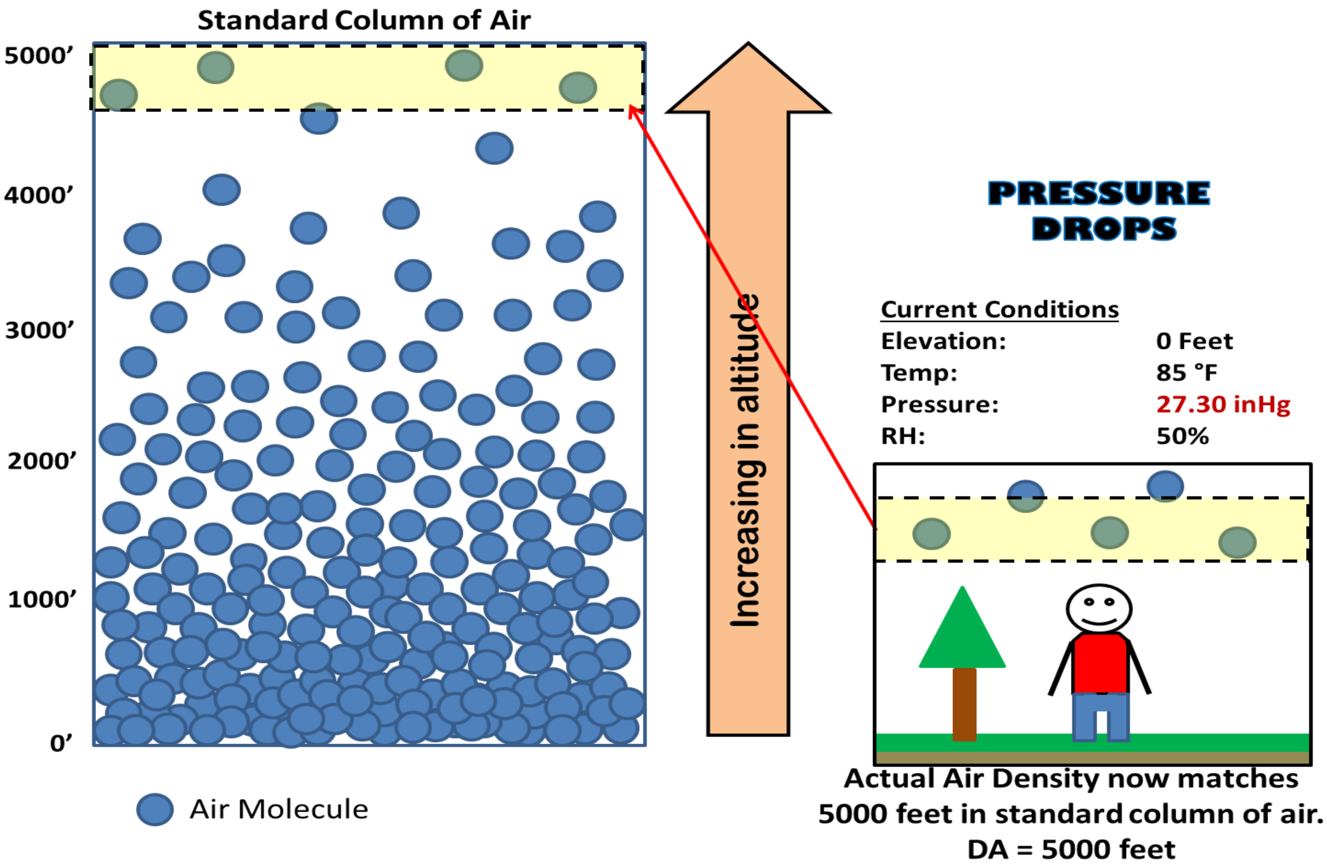
STATIC PRESSURE

Static pressure is the result of the weight of the atmosphere pressing down on the air beneath.

- Static pressure will exert the same force per square metre on all surfaces of an aeroplane. The lower the altitude the greater the force per square metre.

- It is called static pressure because of the air's stationary or static presence.

- An aircraft always has Static pressure acting upon it.


Standard Column of Air
5000’
4000’
3000’
2000’
1000’
0’
Air Molecule
Increasing in altitude
PRESSURE DROPS
Current Conditions
Elevation: 0 Feet
Temp: 85 °F
Pressure: 27.30 inHg
RH: 50%
Actual Air Density now matches 5000 feet in standard column of air.
DA = 5000 feet

AIR DENSITY

Density is ‘Mass per unit volume’ (The ‘number’ of air particles in a given space).
The unit for density is kg/m3 and the symbol is the Greek letter ρ .

- Density decreases if static pressure decreases.
- Density decreases if temperature increases.
- Density decreases if humidity increases.

DYNAMIC PRESSURE

• Because air has mass, air in motion must possess kinetic energy , and will exert a force per square metre on any object in its path. (KE = ½ m V2)

• It is called DYNAMIC pressure because the air is moving in relation to the object being considered, in this case an aircraft.

• Dynamic pressure is proportional to the density of the air and the square of the speed of the air flowing over the aircraft.

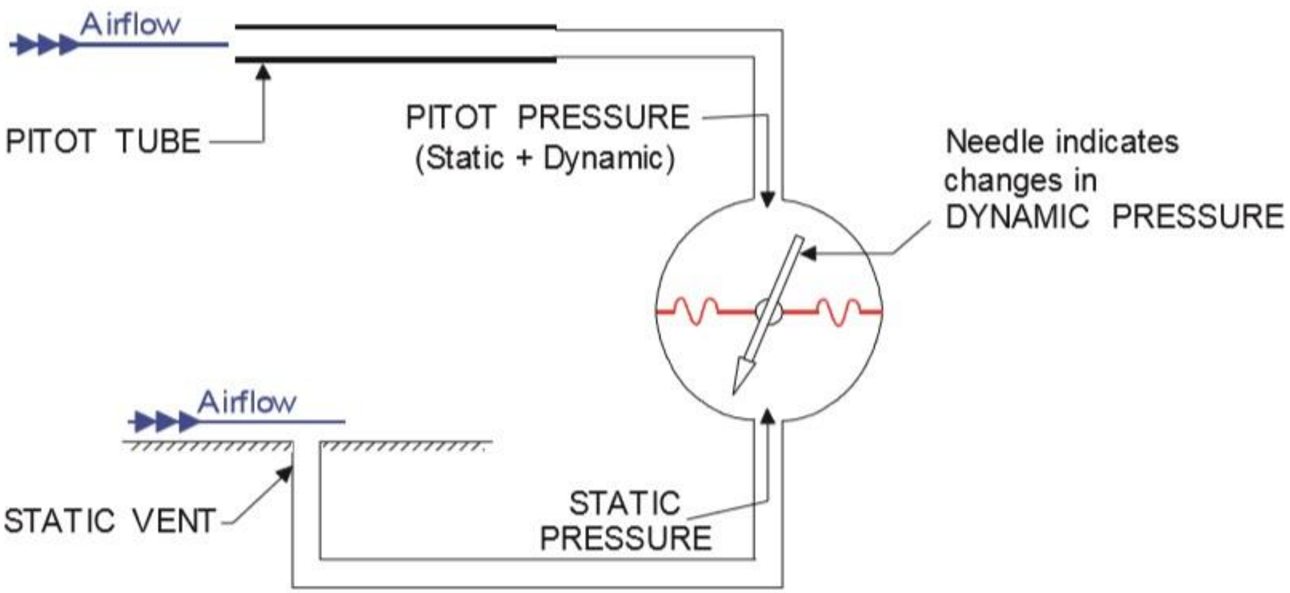
An aircraft immersed in moving airflow will therefore experience both Static AND Dynamic pressure. (Remember, static pressure is always present).

If speed is doubled, dynamic pressure will be four times greater

Total Pressure = Static Pressure + Dynamic Pressure

$$\boxed{Q = \tfrac{1}{2}\,\rho\,V^2}$$

MEASURING DYNAMIC PRESSURE



The Air Speed Indicator is a pressure gauge

International Standard Atmosphere (ISA)

The ICAO standard atmosphere assumes the following mean sea level values:

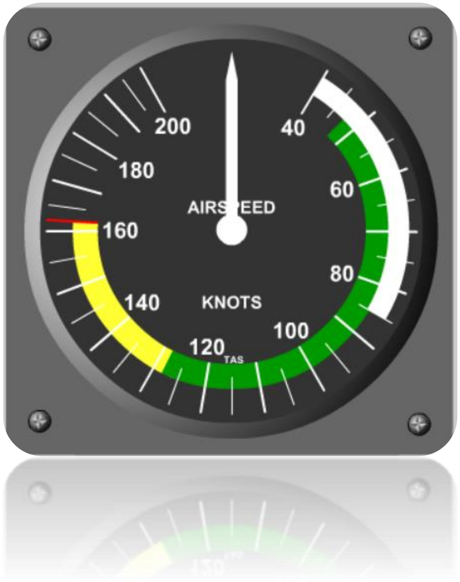
• Pressure of **1013.25** hpa or **29.92** in/hg .

• Temperature of +15 °C (59 F). Temperature falls at a rate of 2 °C per 1,000 feet until the tropopause is Reached which the temperature is assumed to be constant at -56.5 °C.

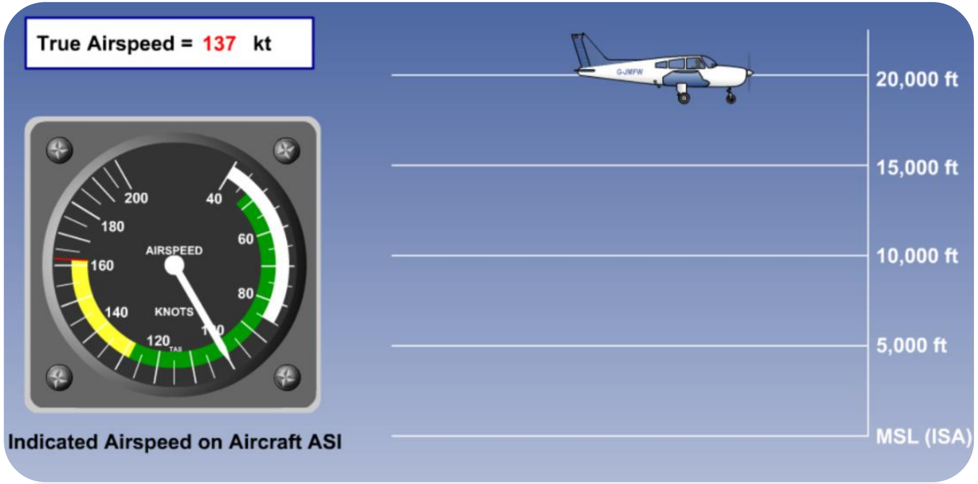
• Density of **1.225** kg/m3.

AIR SPEEDS

- **Indicated Air Speed**: (IAS) The speed registered on the Air Speed Indicator.



- **True Air Speed:** The actual speed of an aircraft through the air relative to the air that is uninfluenced by the aircraft. **TAS** is **IAS** corrected for density error.



Chapter 3

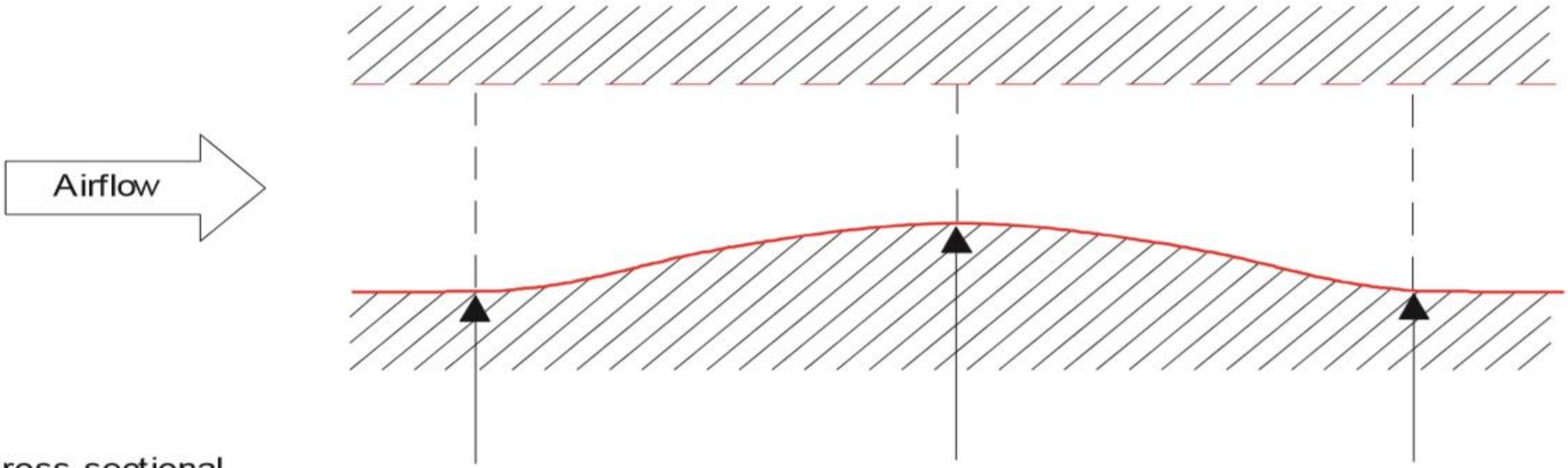
BASIC AERODYNAMIC THEORY

The Principle of Continuity

One of the fundamental laws of the universe is **ENERGY and MASS can neither be created nor destroyed,** only changed from one form to another.

The Principle of Continuity : $A \times V \times \rho$ = constant

Because air is a compressible fluid, any pressure change in the flow will affect the air density. However, at low subsonic speeds (< M 0.4) density changes will be insignificant and can be disregarded.



Cross-sectional Area (A)	1 m^3	½ m^3	1 m^3
Velocity (V)	52 m/s (100 kt)	104 m/s (200 kt)	52 m/s (100 kt)
Mass Flow (Constant)	52 m^3/s	52 m^3/s	52 m^3/s

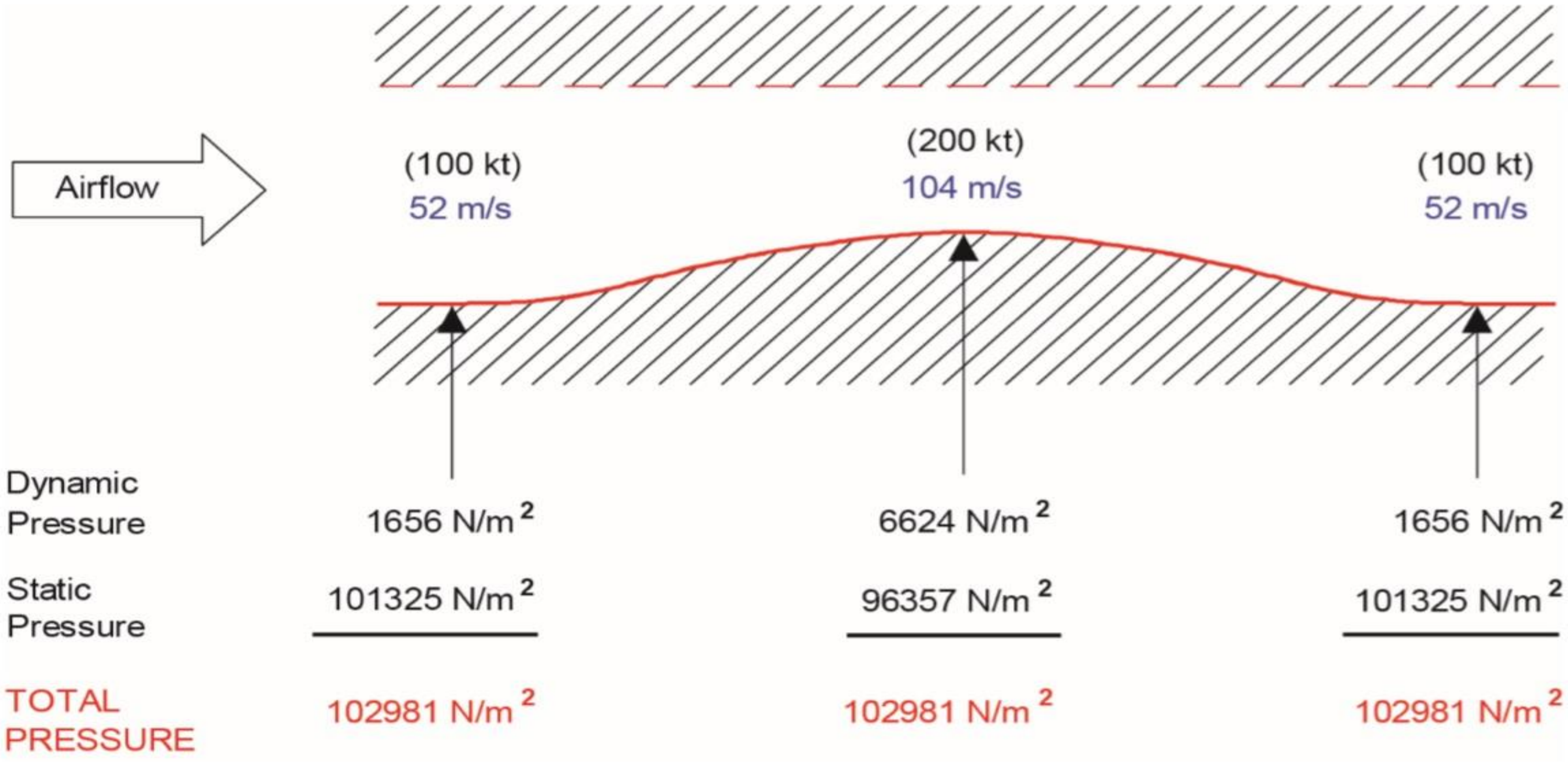
Bernoulli's Theorem

"In the steady flow of an ideal fluid the sum of the pressure energy and the kinetic energy remains constant".

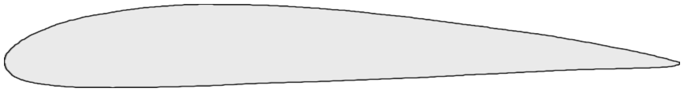
Static Pressure + Dynamic Pressure = constant

This constant can be referred to either as:

TOTAL PRESSURE, STAGNATION PRESSURE or PITOT PRESSURE.


Airflow
(100 kt)
52 m/s
(200 kt)
104 m/s
(100 kt)
52 m/s
Dynamic Pressure
1656 N/m²
6624 N/m²
1656 N/m²
Static Pressure
101325 N/m²
96357 N/m²
101325 N/m²
TOTAL PRESSURE
102981 N/m²
102981 N/m²
102981 N/m²

• The tubes illustrated above are used only to demonstrate the principle of continuity and Bernoulli's theorem and are of no practical use in making an aeroplane fly.
But an aerodynamic force to oppose the weight of an aircraft can be generated by using a specially shaped body called an aerofoil.

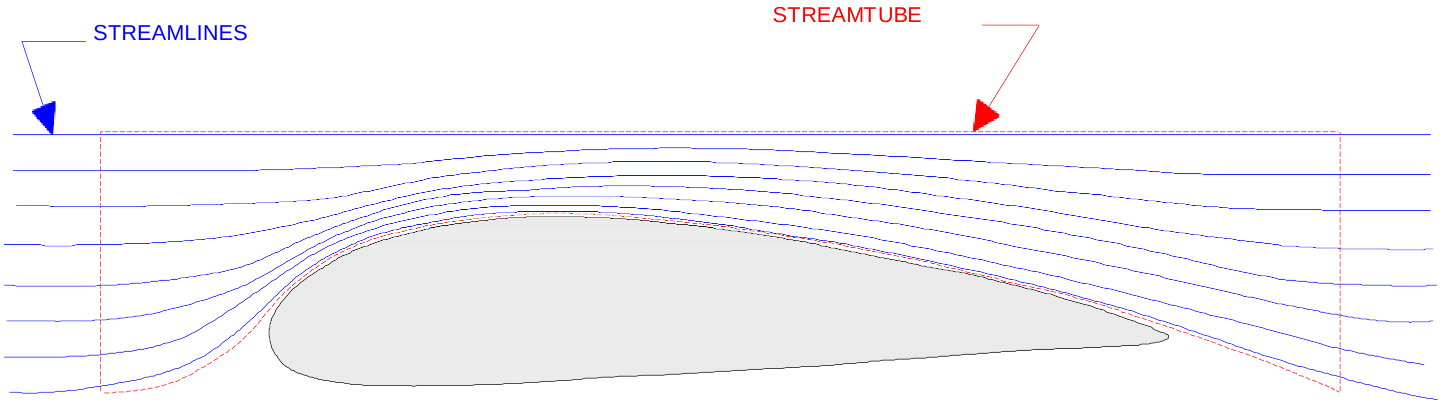


Typical Aerofoil Section

• The airflow velocity over the top surface of a lifting aerofoil will be greater than that beneath, so the pressure differential that results will produce a force per unit area acting upwards. The larger the surface area, the bigger the force that can be generated.

STREAMLINES AND THE STREAMTUBE

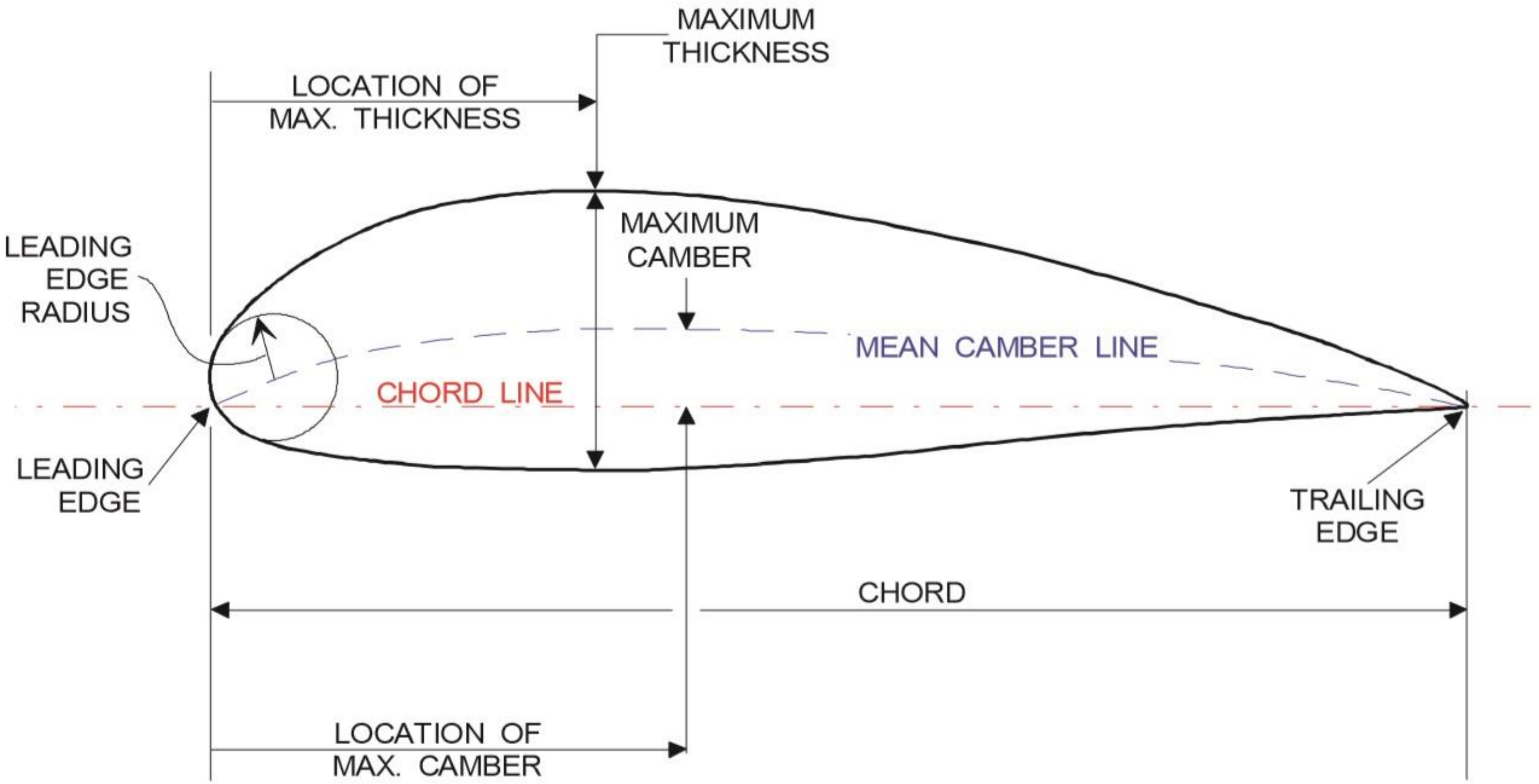
A streamline is the path traced by a particle of air in a steady airflow, and streamlines cannot cross. When streamlines are shown close together it illustrates increased velocity and vice versa.Diverging streamlines illustrate a decelerating airflow and resultant increasing pressure and converging streamlines illustrate an accelerating airflow, with resultant decreasing pressure.A streamtube is an imaginary tube made of streamlines. There is no flow into or out of the streamtube through the “walls”, only a flow along the tube. With this concept it is possible to visualise the airflow around an aerofoil being within a tube made-up of streamlines.



Chapter 4

SUBSONIC AIRFLOW

AEROFOIL TERMINOLOGY



- **Aerofoil:** A shape capable of producing lift with relatively high efficiency.

- **Chord Line:** A straight line joining the centres of curvature of the leading and trailing edges of an aerofoil.

- **Chord:** The distance between the leading and trailing edges measured along the chord line.

- **Mean Line or Camber Line:** A line joining the leading and trailing edges of an aerofoil,equidistant from the upper and lower surfaces.

- **Thickness/Chord ratio:** The maximum thickness or depth of an aerofoil section expressed as a percentage of the chord, with its location as a percentages of the chord aft of the leading edge.

- **Relative Air Flow :** (Relative Wind or Free Stream Flow): Relative Air Flow has three qualities.

DIRECTION - air parallel to, and in the opposite direction to the flight path of the aircraft, in fact the path of the CG; the direction in which the aircraft is pointing is irrelevant.

CONDITION - air close to, but unaffected by the presence of the aircraft; its pressure,temperature and velocity are not affected by the passage of the aircraft through it.

MAGNITUDE - The magnitude of the Relative Air Flow is the TAS. If air flow does not possess all three of these qualities, it is referred to as **EFFECTIVE AIRFLOW**.

- **Lift:** The aerodynamic force which acts at 90° to the Relative Air Flow**.**

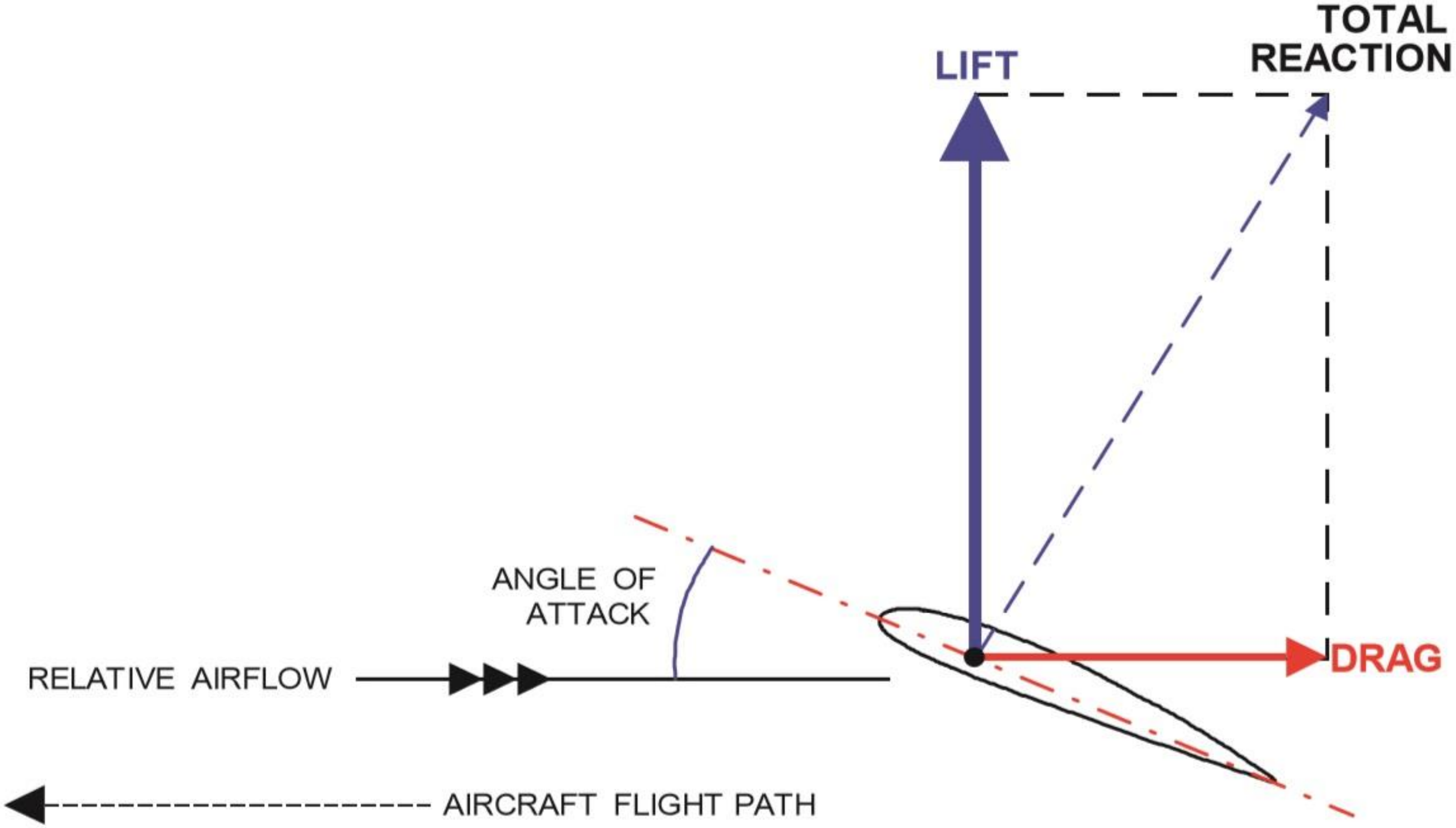
- **Drag:** The aerodynamic force which acts parallel to and in the same direction as the Relative Air Flow (or opposite to the aircraft flight path).

- **Angle of Attack (α or alpha):**(can also be referred to as Aerodynamic Incidence) The angle between the chord line and the Relative Air Flow. The angle between the chord line and the effective airflow is referred to as the **EFFECTIVE ANGLE OF ATTACK**.

AOA

- **Angle of Incidence:** The angle between the wing root chord line and the longitudinal axis of the aircraft. (This angle is fixed for the wing)

AOA
vs
AOI


TOTAL
REACTION
LIFT
ANGLE OF
ATTACK
DRAG
RELATIVE AIRFLOW
AIRCRAFT FLIGHT PATH

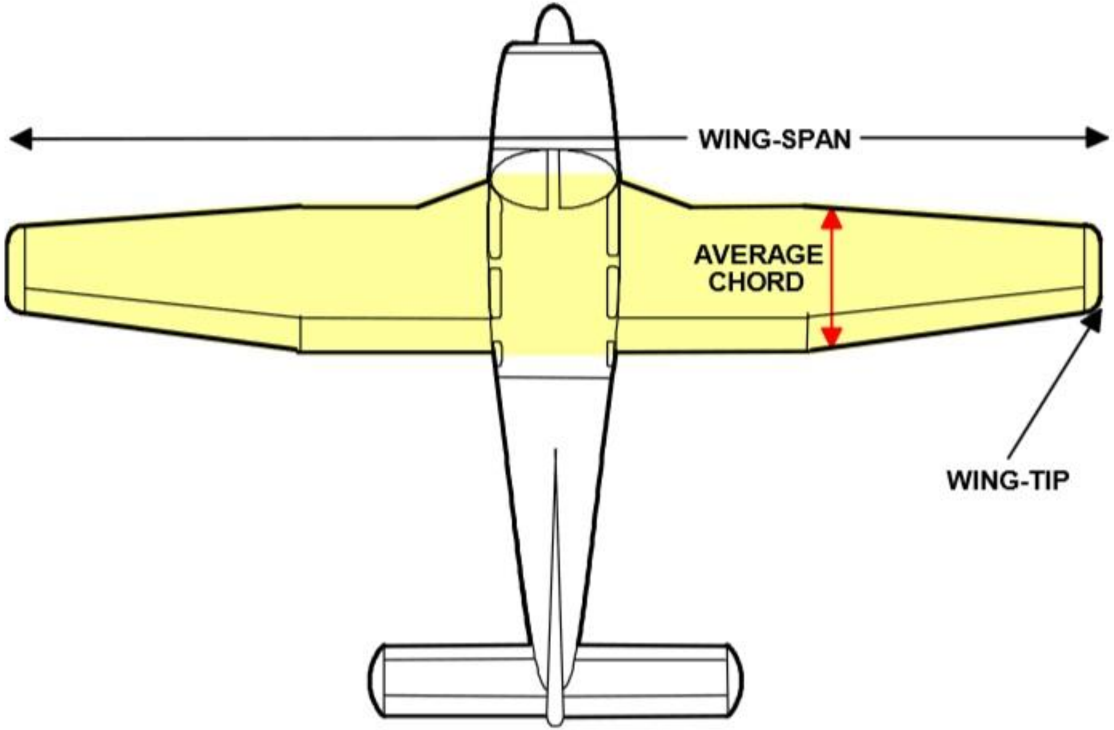
Chapter 5

LIFT

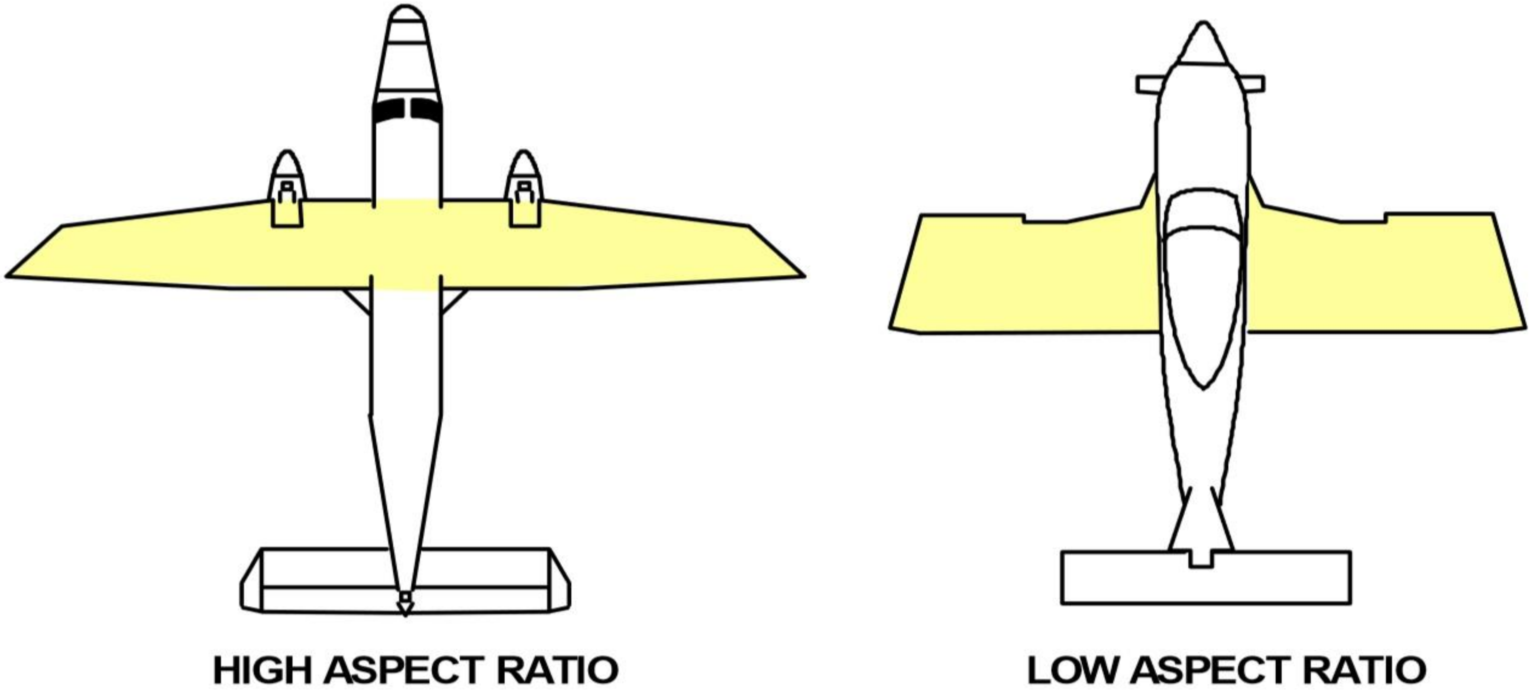
WING TERMINOLOGY

- **Wing Span (b)**
The distance from **tip to tip.**

- **Average Chord (c)**
The mean geometric chord.
The product of the span and the average chord is the **wing area** (b × c = S).

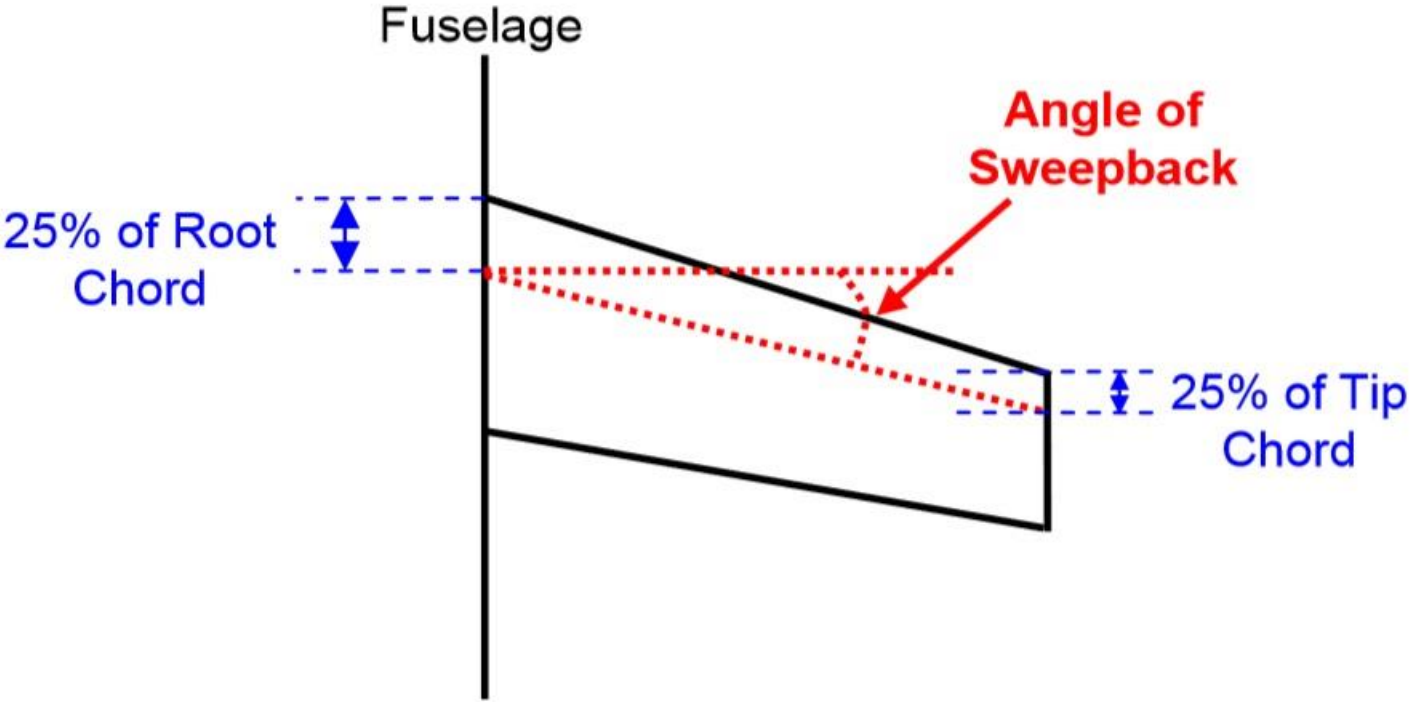


- **Aspect Ratio (AR) :** The ratio of wing span to average chord. Long narrow wings have a high aspect ratio, whilst short stubby wings have a low aspect ratio



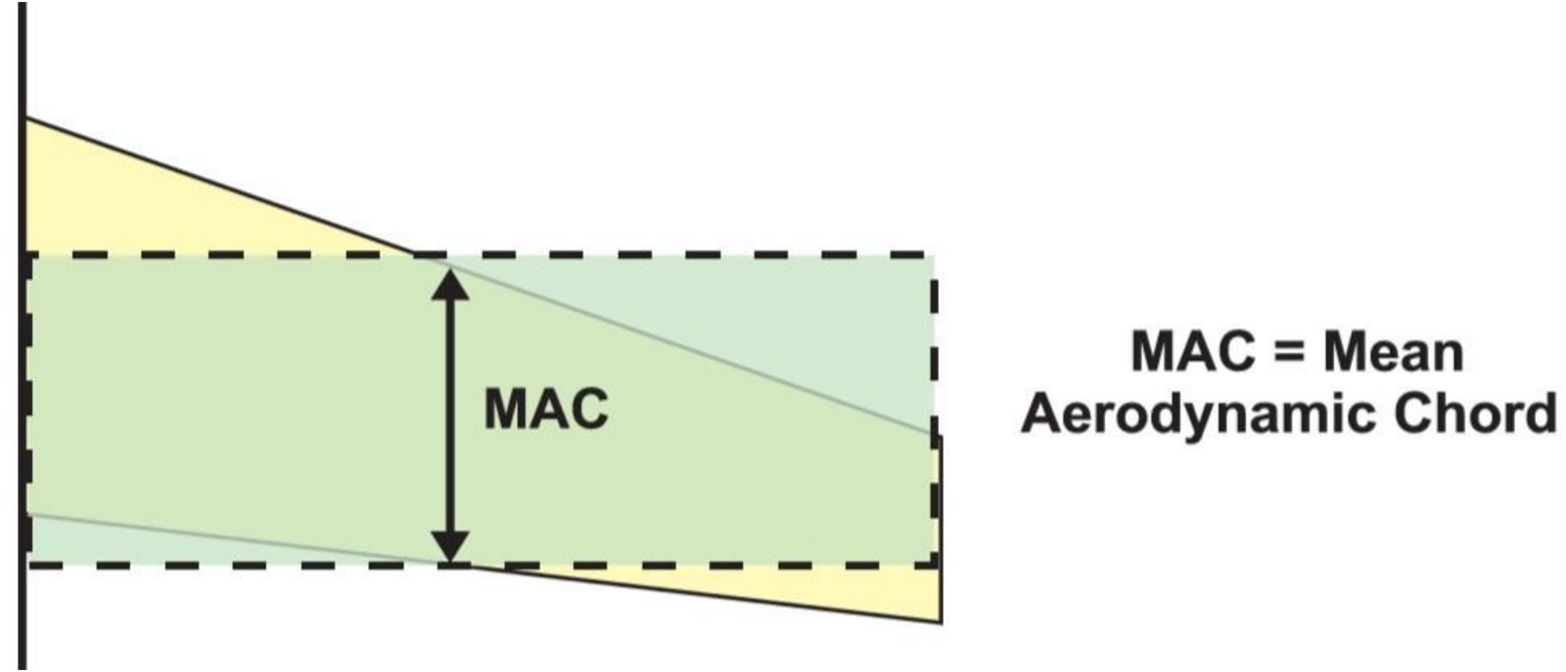
- **Sweep Angle**

The angle between the line of 25% chord and a perpendicular to the root chord.



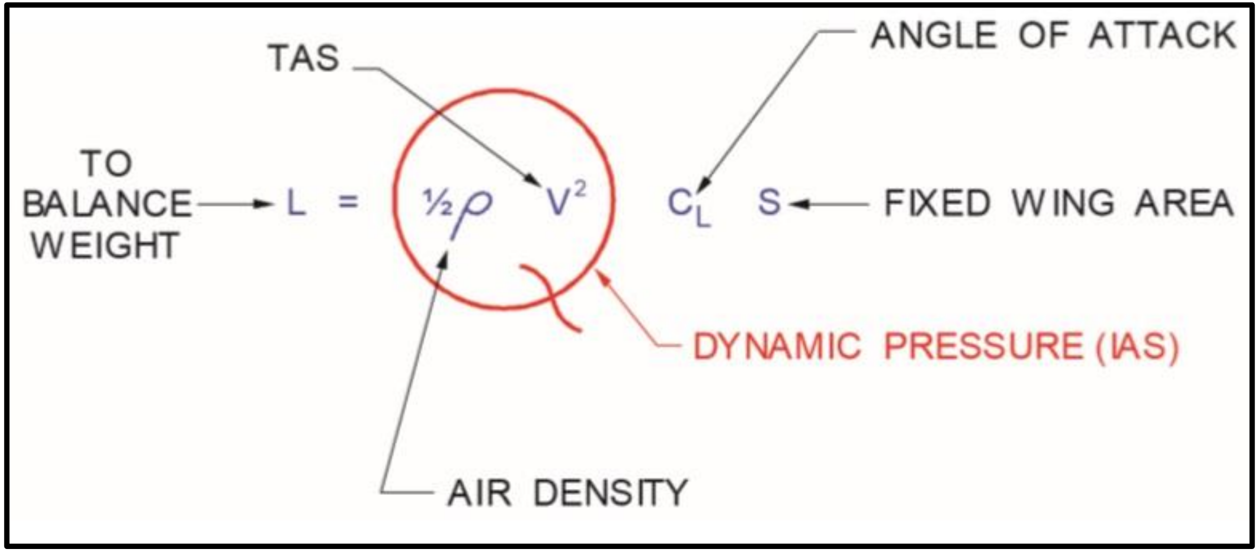
- **Mean Aerodynamic Chord (MAC)**

A rectangular wing of this chord and the same span. The chord drawn through the centroid (centre of area) of the halfspan area.



THE BASIC LIFT EQUATION

Lift is defined as the net force generated normal (at 90°) to the relative airflow or flight path of the aircraft.The aerodynamic force of lift results from the pressure differential between the top and Bottom surfaces of the wing. This lift force can be defined by the following equation:



AERODYNAMIC FORCE COEFFICIENT

The aerodynamic forces of both lift and drag depend on the combined effect of many variables. The important factors being:

- Airstream velocity (V)
- Air density (ρ)

} **Dynamic Pressure (½ ρ V2)**

- Shape or profile of the surface
- Angle of attack

} **Pressure Distribution** (C_L or C_D)

- Surface area (S)
- Condition of the surface
- Compressibility effects (to be considered in later chapters)

Note: For the sake of clarity; during this initial examination of the lift formula it is stated that CL is determined by angle of attack. This is true, but CL is also influenced by the shape or profile of the surface and other factors.

• An aircraft spends most of its time in straight and level flight.

• How much lift is required? The same as the weight.

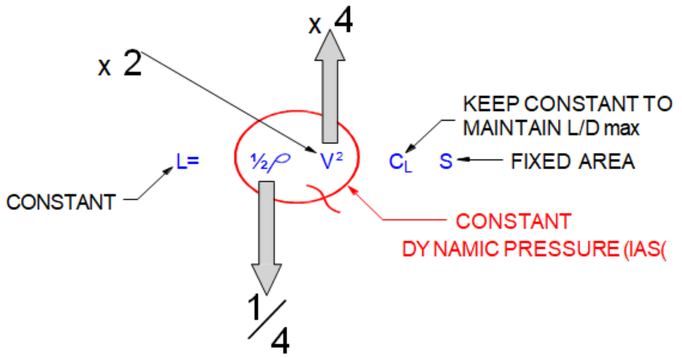
• Consider that at any moment in time weight is constant, so lift must be constant.

• While generating the required lift force the less drag the better, because drag has to be balanced by thrust and thrust costs money.

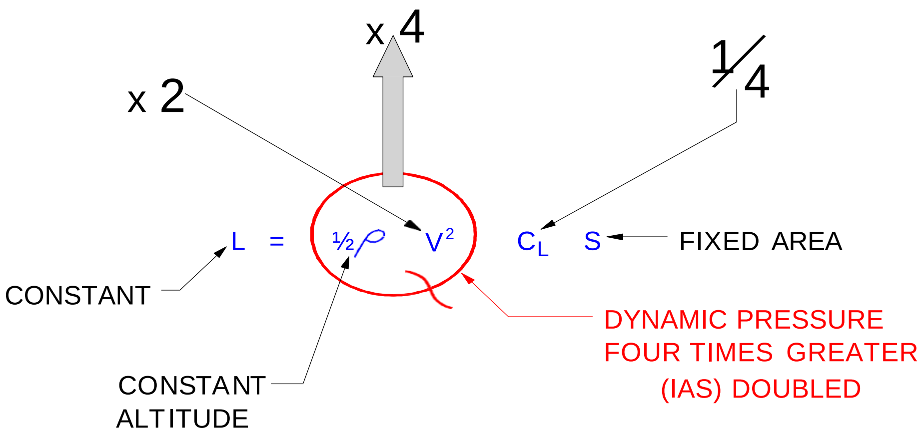
• Air gets thinner as altitude increases. If the speed of the aircraft through the air (TAS) is kept constant as altitude is increased, the amount of air flowing over the wing in a given time would Decrease and lift would decrease.

• For a constant Lift force as altitude is increased, a constant mass flow must be maintained. As air density decreases with altitude the speed of the wing through the air must be increased; the true airspeed (TAS).

TO KEEP LIFT CONSTANT AT 40,000 ft,(density is one quarter of sea level)
TAS MUST BE DOUBLED



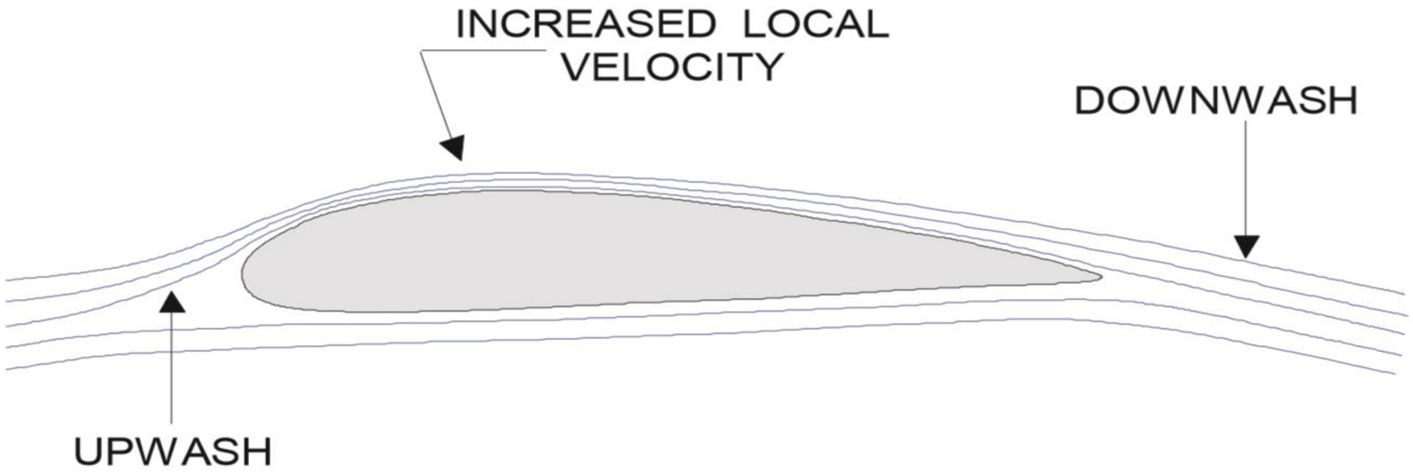
IF SPEED IS DOUBLED, C_L MUST BE REDUCED TO ¼ OF ITS PREVIOUS VALUE



Lift
Formula

TWO DIMENSIONAL AIRFLOW

As air flows towards an aerofoil it will be turned towards the lower pressure at the upper surface; this is termed **upwash.** After passing over the aerofoil the airflow returns to its original position and state; this is termed **downwash.**



Influence of Dynamic Pressure

- Figure 4.4 shows an aerofoil section at a representative angle of attack subject to a given dynamic pressure (IAS). “If the static pressure on one side of a body is reduced more than on the other side, a pressure differential will exist”.

- Figure 4.5 shows the same aerofoil section at the same angle of attack, but subject to a higher dynamic pressure (IAS). “If the dynamic pressure (IAS) is increased, the pressure differential will increase”.

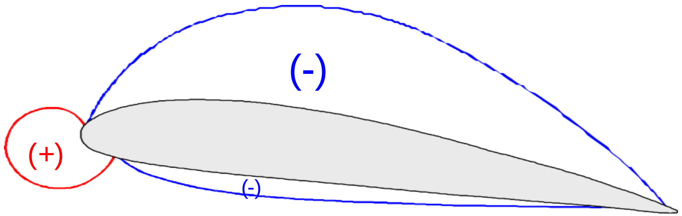


Figure 4.4

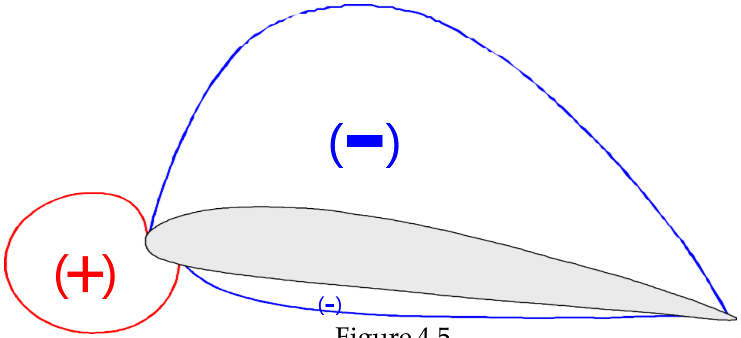


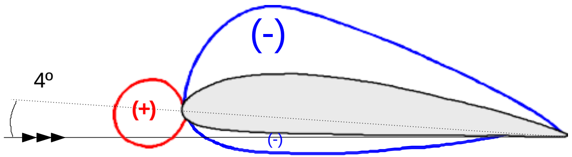
Figure 4.5

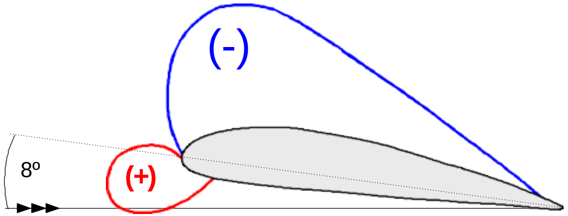
Influence of Angle of Attack

- At a constant dynamic pressure (IAS), increasing the angle of attack (up to about 16°) will likewise increase the pressure differential, but will also change the pattern of pressure distribution.

- The greatest positive pressure occurs at the stagnation point where the relative flow velocity is zero. This stagnation point is located somewhere near the leading edge.

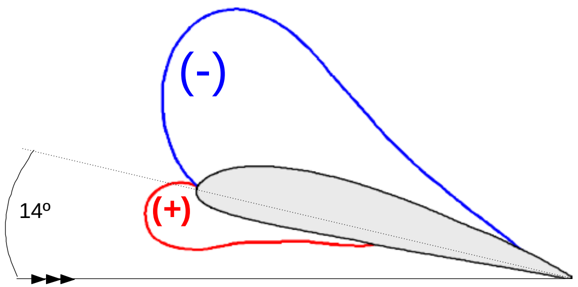
- As the angle of attack increases from -4° the leading edge stagnation point moves from the upper surface around the leading edge to the lower surface. It is at the front stagnation point where the flow divides to pass over and under the section. The pressure at the stagnation point is Static + Dynamic.





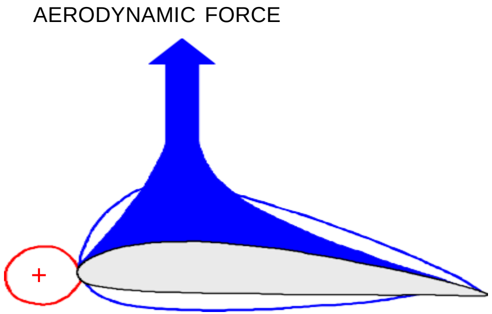
- The flow over the top of the section accelerates rapidly around the nose and over the leading portion of the surface - inducing a substantial decrease in static pressure in those areas.

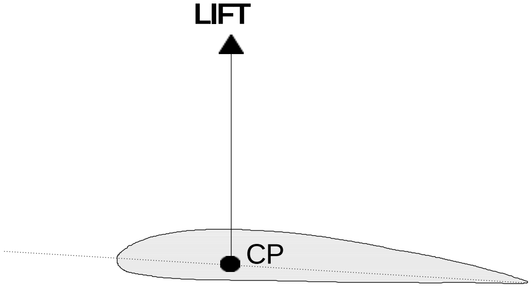
- The rate of acceleration increases with increase in angle of attack, up to about 16°. The pressure reduces continuously from the stagnation value through the free stream value To a position on the top surface where a peak negative value is reached. From there onwards the flow continuously slows down again and the pressure increases back to the free stream value in the region of the trailing edge.



Centre of Pressure (CP)

The whole surface of the aerofoil contributes to lift, but the point along the chord where the distributed lift is **effectively** concentrated is termed the Centre of Pressure.





Note that the CP is at its most forward location just before the stall (C L MAX)

- **Movement of the Centre of Pressure**

As the angle of attack increases from 0° to 16° the CP moves forward. The CP moves forward and the magnitude of the lift force increases with increase in angle of attack until the stall is reached when the lift force decreases abruptly and the CP generally moves back along the chord.

THE LIFT CURVE

Lift coefficient increases with angle of attack up to a maximum (CL MAX), which Corresponds to the "Critical" angle of attack. Continuing to increase the angle of attack beyond this point makes it impossible for the airflow to maintain its previous smooth flow over the contour of the upper surface, and lift will reduce. This phenomena, stall, will be discussed in detail later.

- To generate a constant lift force, any adjustment in dynamic pressure must be accompanied by a change in angle of attack. (At CL less than CL MAX).

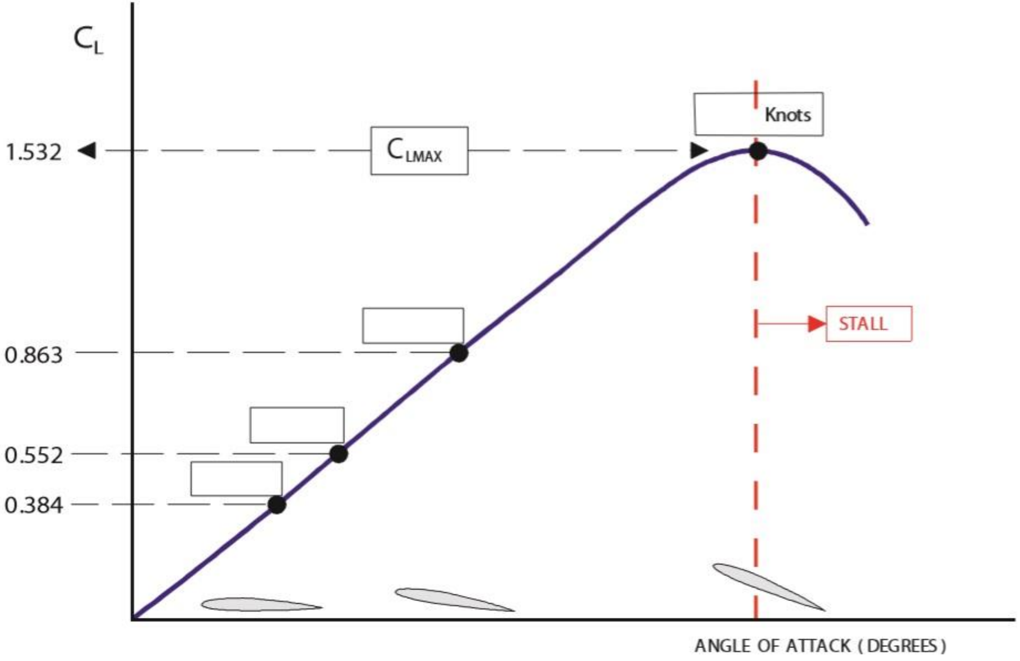
- For a constant lift force, each dynamic pressure requires a specific angle of attack.

- Minimum dynamic pressure is determined by the maximum lift coefficient (CL MAX),which occurs at a specific angle of attack (approximately 16°).

- The angle of attack for CL MAX is constant.

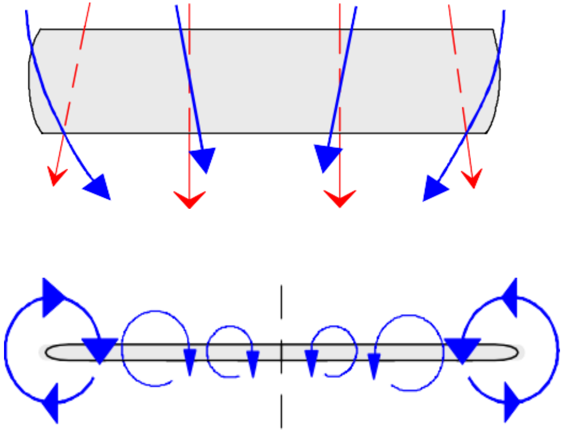
- If more lift is required due to greater operating weight, a greater dynamic pressure is required to maintain a given angle of attack.

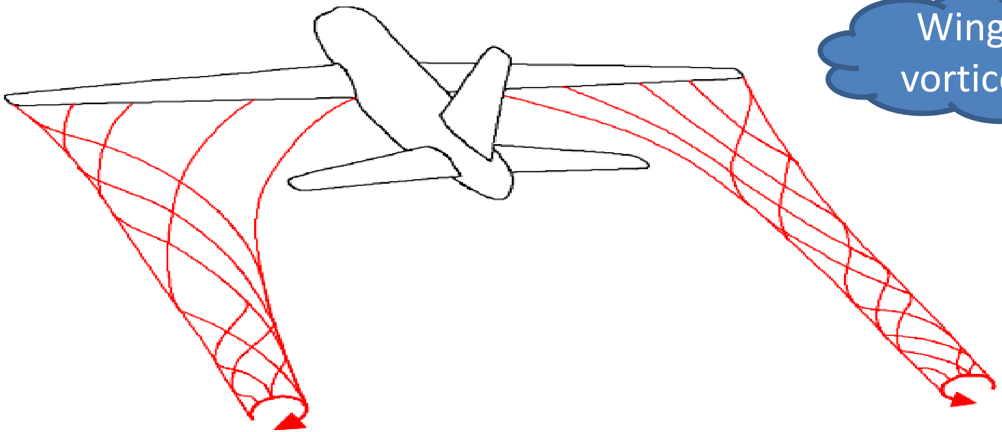
- The greater the operating weight, the higher the minimum dynamic pressure.

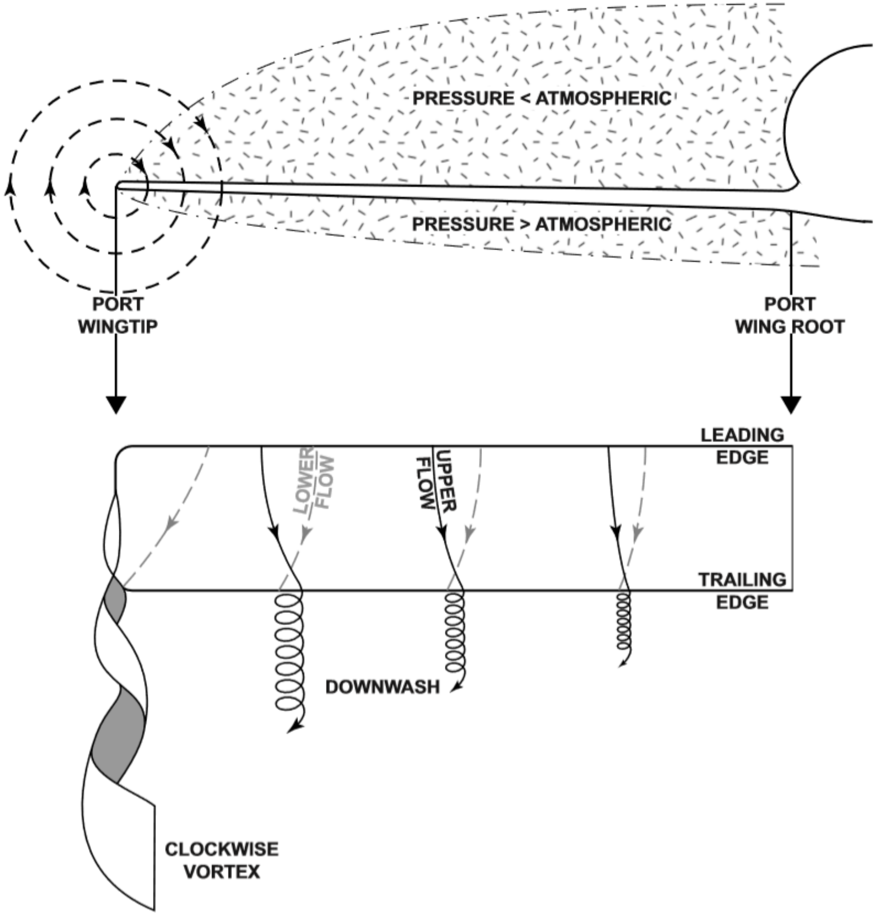


WING TIP VORTICES

Air flowing over the top surface of a wing is at a lower pressure than that beneath. The trailing edge and the wing tips are where the airflows interact. The pressure differential modifies the directions of flow, inducing a span-wise vector towards the root on the upper surface and generally, towards the tip on the lower surface. An anti-clockwise Vortex will be induced at the right wing-tip and a clockwise vortex at the left wing-tip. At higher angles of attack (Lower IAS) the decreased chordwise vector will increase the effect of the resultant spanwise flow, making the vortices stronger.

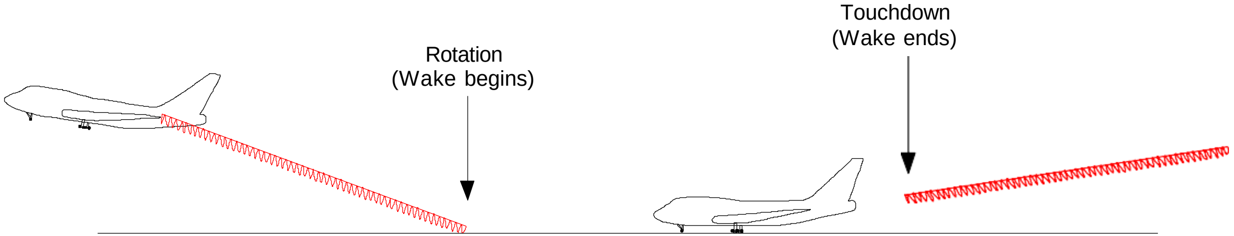





PRESSURE < ATMOSPHERIC
PRESSURE > ATMOSPHERIC
PORT
WINGTIP
PORT
WING ROOT
LEADING
EDGE
LOWER
FLOW
UPPER
FLOW
TRAILING
EDGE
DOWNWASH
CLOCKWISE
VORTEX

WAKE TURBULENCE

Trailing wingtip vortices extend behind aircraft for a considerable distance and can present An **extreme hazard** to any aircraft unfortunate enough to encounter them.Wake vortex generation begins when the nosewheel lifts off the runway on take-off and continues until the nosewheel touches down on landing.



Weight ↑

AOA ↑

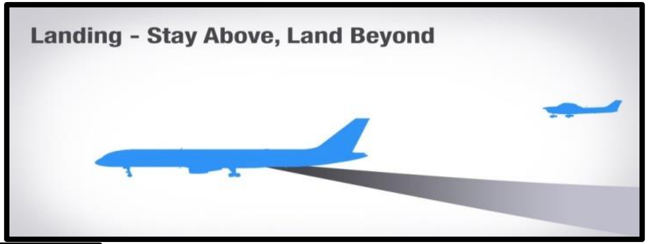
Air speed ↓

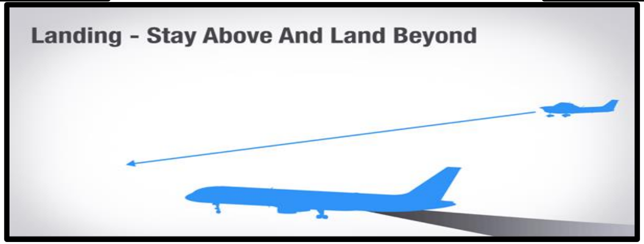
Clean config

→ stronger the vortices

Wake Turbulence Avoidance

If the location of wake vortices behind a preceding or crossing aircraft are visualised, appropriate flight path control will minimise the probability of a wake turbulence encounter. Staying above and/or upwind of a preceding or crossing aircraft will usually keep your aircraft out of the generating aircraft's wake vortex. Unfortunately, deviating from published approach and departure requirements in order to stay above/upwind of the flight path of a preceding aircraft may not be advisable. Maintaining proper separation remains the best advice for avoiding a wake turbulence encounter.

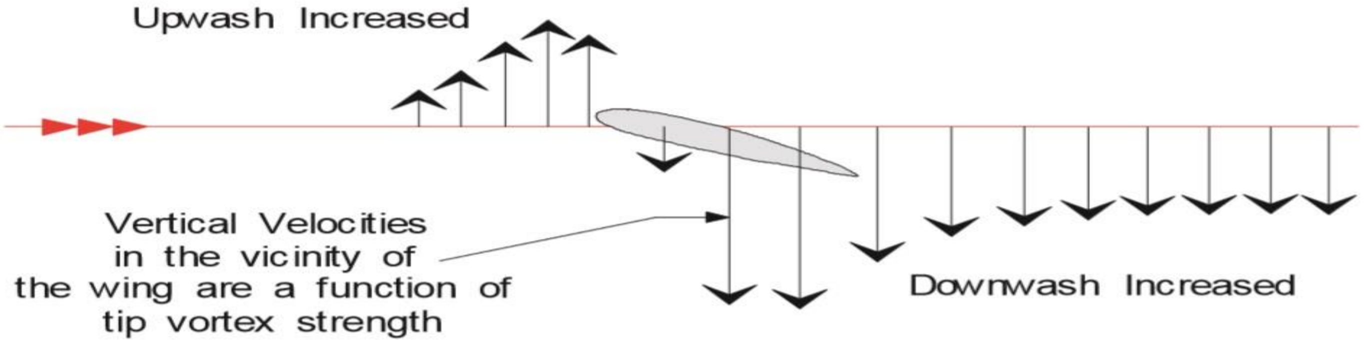


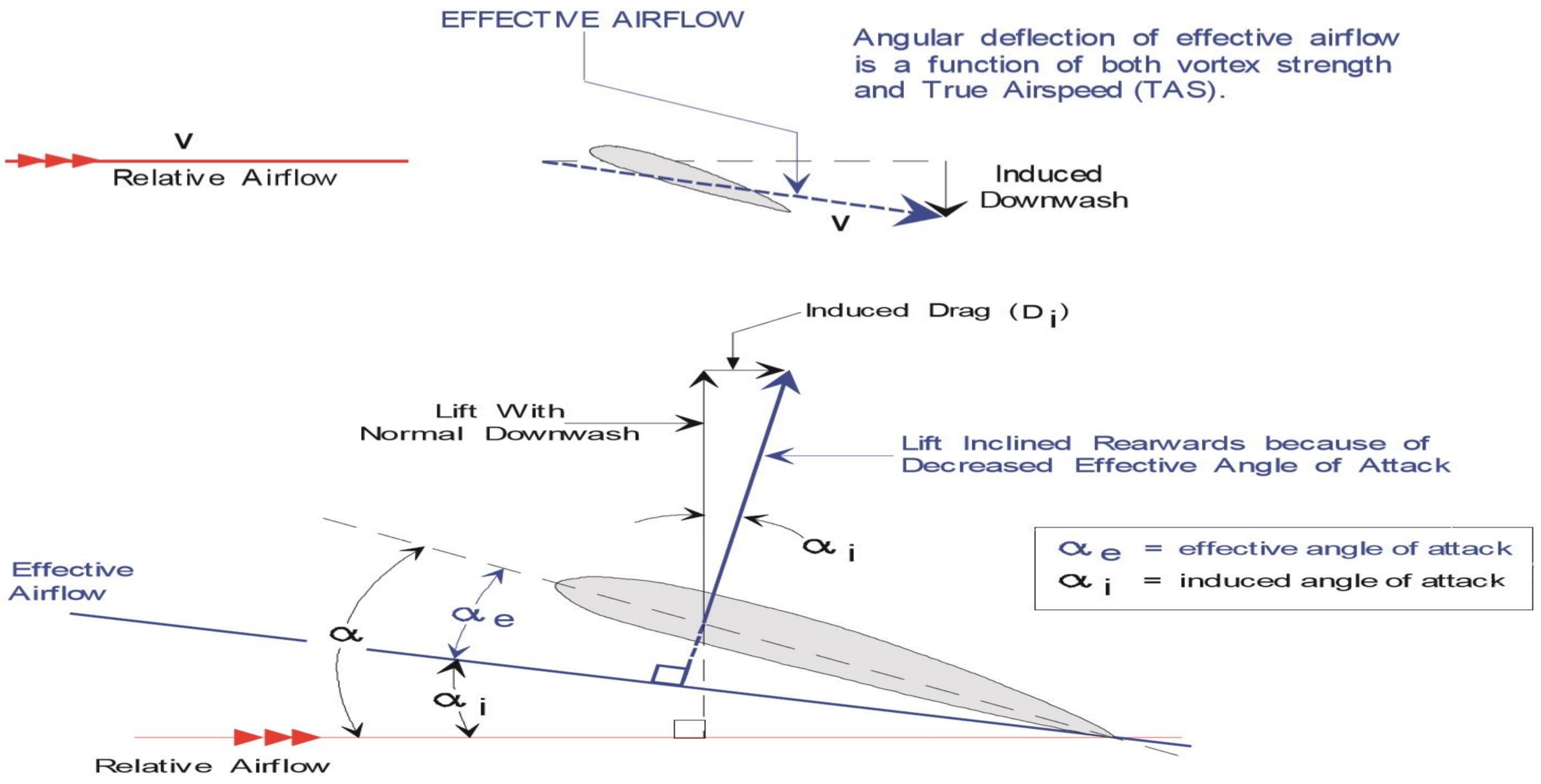


Wingtip vortices 2

Induced Downwash

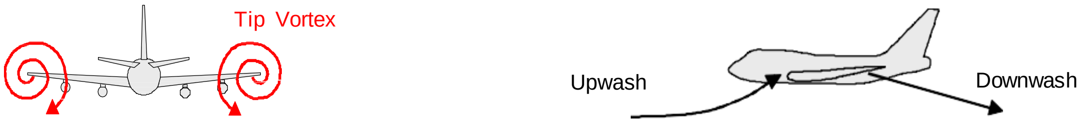
Trailing vortices create certain vertical velocity components in the airflow in the vicinity of the wing, both in front of and behind it. These vertical velocities cause a downwash over The wing resulting in a reduction in the effective angle of attack. The stronger the vortices,The greater the reduction in effective angle of attack. Because of this local reduction in effective angle of attack, the overall lift generated by a wing will be below the value that would be generated if there were no spanwise pressure differential. It is the production of lift itself which reduces the magnitude of the lift force being generated. To replace the lift lost by the increased downwash, the aircraft must be flown at a higher angle of attack. This increases drag. This extra drag is called **induced drag.** The stronger the vortices, the greater the induced drag.




EFFECTIVE AIRFLOW
Angular deflection of effective airflow is a function of both vortex strength and True Airspeed (TAS).
V
Relative Airflow
Induced Downwash
V
Induced Drag (D i)
Lift With Normal Downwash
Lift Inclined Rearwards because of Decreased Effective Angle of Attack
α i
α e = effective angle of attack
α i = induced angle of attack
Effective Airflow
α
α e
α i
Relative Airflow

GROUND EFFECT

When landing and taking off, the closeness of the wing to the ground prevents full Development of the trailing vortices and make them much weaker.(aircraft is one wing span or less above the surface). Upwash and downwash are reduced, causing the effective angle of attack of the wing to Increase. Therefore, when an aircraft is "**in ground effect**" lift will generally be increased and induced drag (CDi) will be decreased.



Aeroplane out of Ground Effect

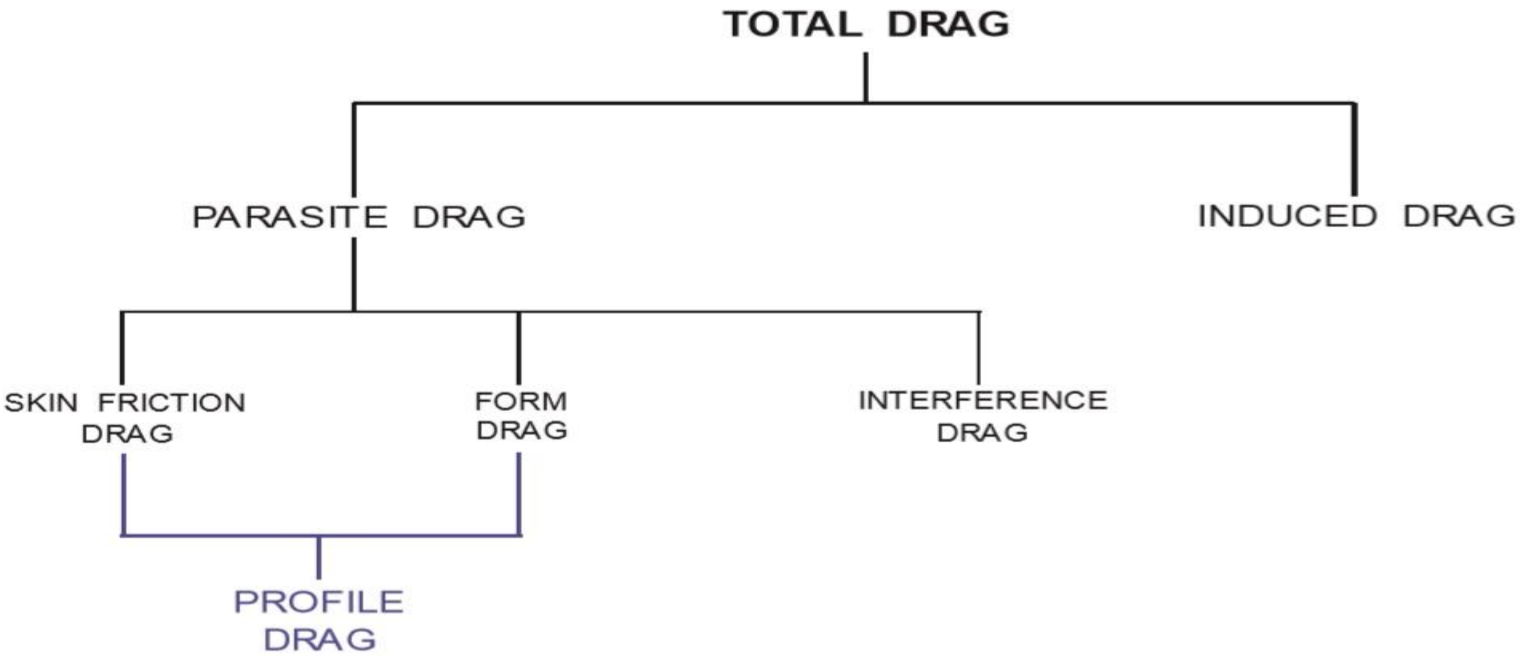
Aeroplane in Ground Effect

Chapter 6

DRAG

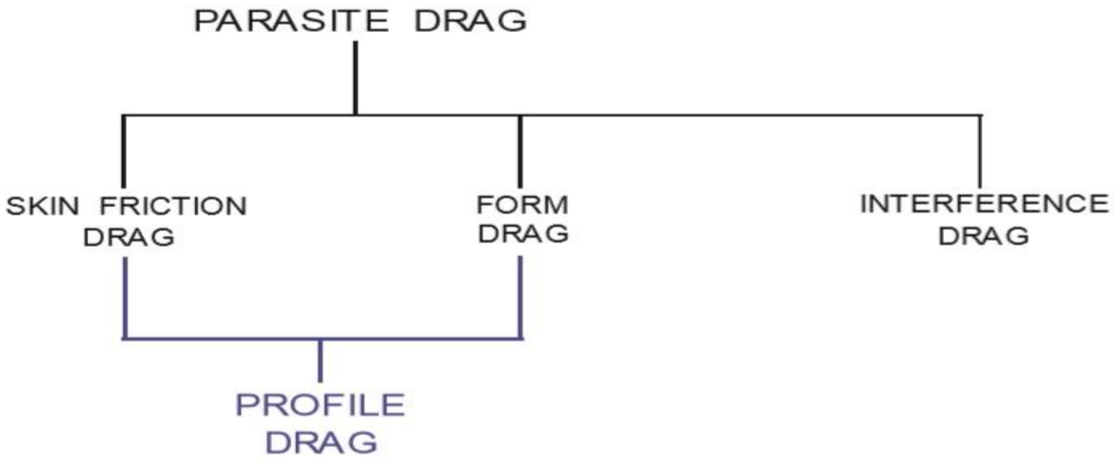
INTRODUCTION

Drag is the force which resists the forward motion of the aircraft. Drag acts parallel to and in the same direction as the relative airflow (in the opposite direction to the flight path).



PARASITE DRAG

If an aircraft were flying at zero lift angle of attack, the only drag present would be parasite drag. Parasite drag is made-up of ‘Skin Friction’,’Form’ and ‘Interference’ drag.

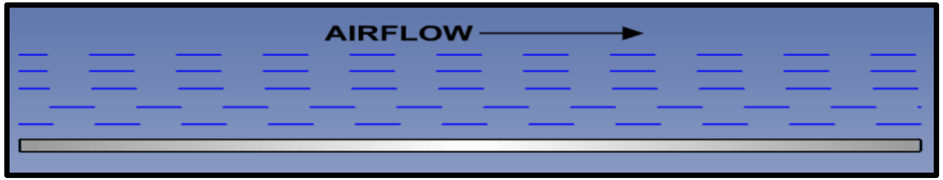


Skin Friction Drag

• Particles of air in direct contact with the surface are accelerated to the speed of the aircraft and are carried along with it.

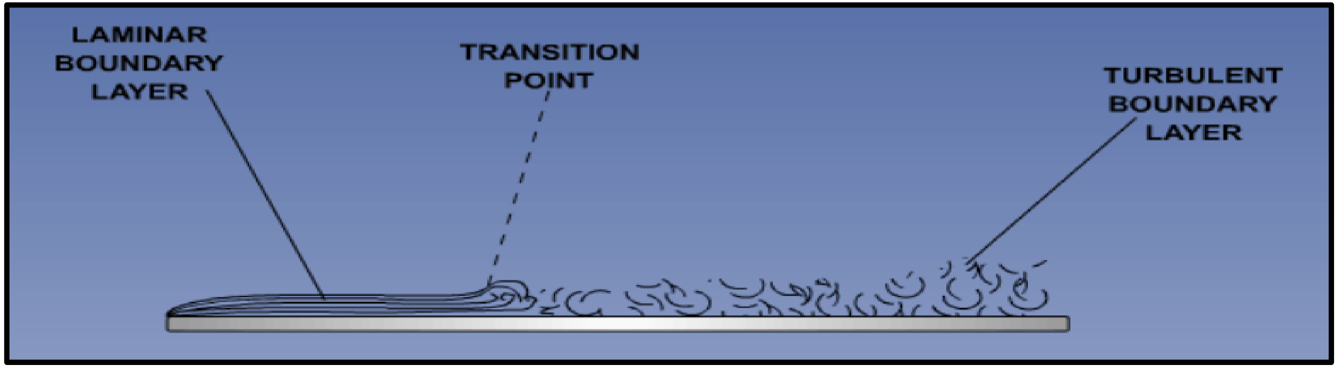
• Adjacent particles will be accelerated by contact with the lower particles, but their velocity will be slightly less than the aircraft because the viscosity of air is low.

• As distance from the surface increases, less and less acceleration of the layers of air takes place.



Therefore, over the entire surface there will exist a layer of air whose relative velocity ranges from zero at the surface to a maximum at the boundary of the air affected by the presence of the aircraft.

• The layer of air extending from the surface to the point where no viscous effect is detectable is known as the boundary layer.



Consider the flow of air across a flat surface. The boundary layer will exist in two forms, either laminar or turbulent. In general, the flow at the front will be laminar and become turbulent some distance back, known as the transition point. The increased rate of change in velocity at the surface in the turbulent flow will give more skin friction than the laminar flow. A turbulent boundary layer also has a higher level of kinetic energy than a laminar layer.

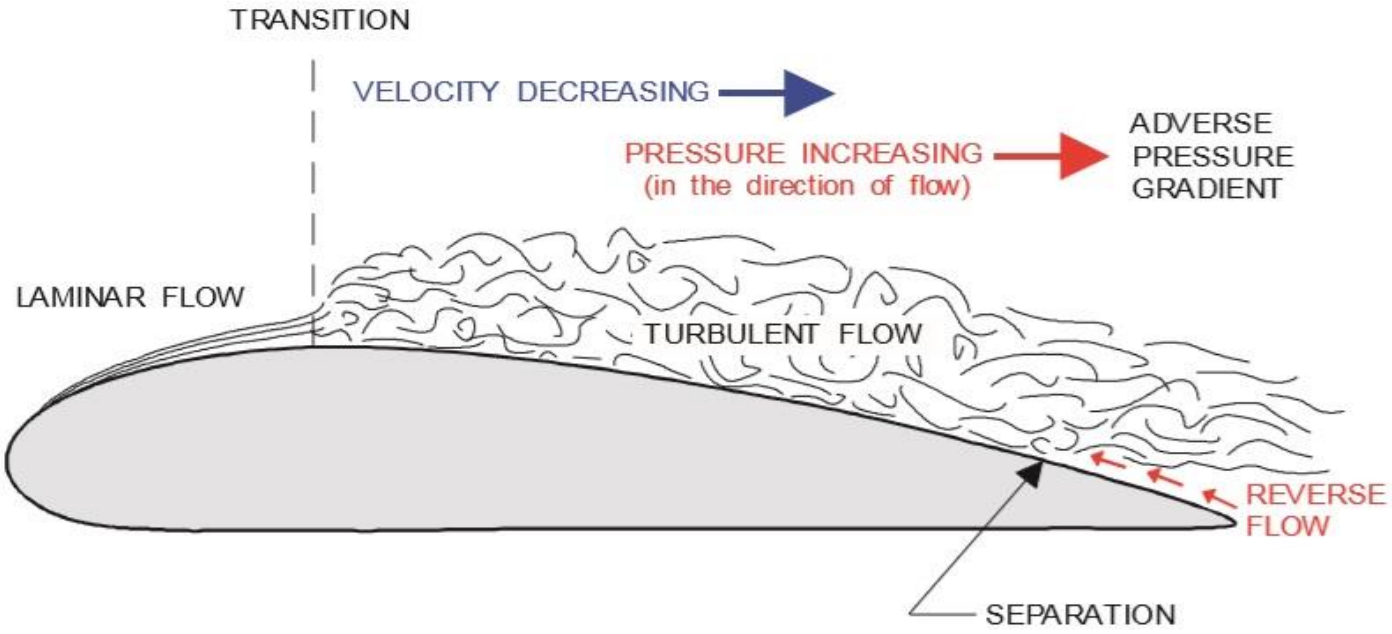
Forward movement of the transition point will increase skin friction because there will be a greater area of turbulent flow

The position of the transition point is dependent upon :

- **Surface condition** - The thin laminar layer is extremely sensitive to surface irregularities. Any roughness on the skin of a leading portion of an aircraft will cause transition to turbulence at that point and the thickening, turbulent boundary layer will spread out fanwise downstream causing a marked increase in skin friction drag.

- **Adverse pressure gradient** - A laminar layer cannot exist when pressure is rising in the direction of flow. On a curved surface, such as an aerofoil, the transition point is usually at, or near to, the point of maximum thickness. Because of the adverse pressure gradient existing on a curved surface, the transition point will be further forward than if the surface was flat.

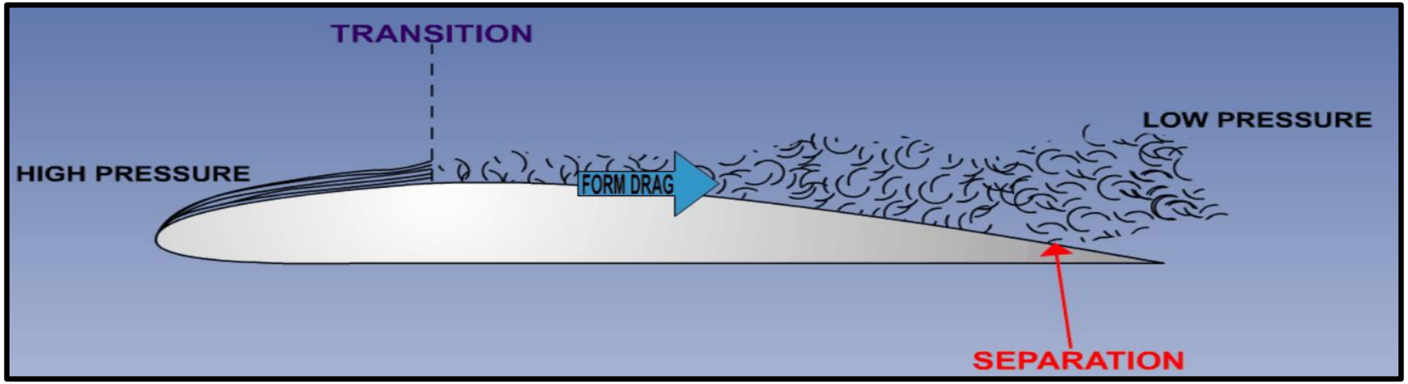
NOTE: Typically, boundary layer thickness is from 2 millimetres at the leading edge, increasing to about 20 millimetres at the trailing edge.

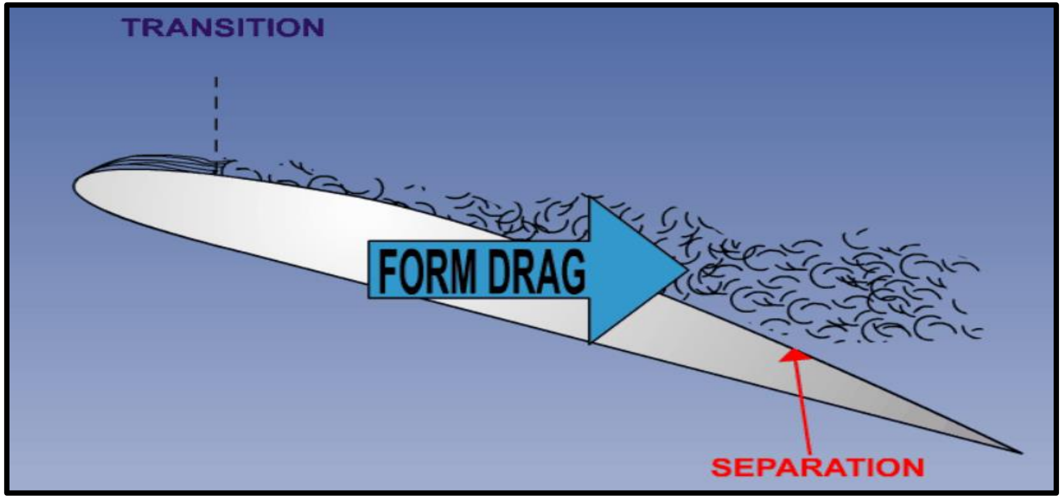

TRANSITION
VELOCITY DECREASING
PRESSURE INCREASING
(in the direction of flow)
ADVERSE
PRESSURE
GRADIENT
LAMINAR FLOW
TURBULENT FLOW
REVERSE
FLOW
SEPARATION

Form (Pressure) Drag

• Form (pressure) drag results from the pressure at the leading edge of a body being greater than the pressure at the trailing edge. the boundary layer will separate from the surface at the separation Point.

Because of separation, there will be a lower pressure at the trailing edge than the leading edge. An aerodynamic force will act in the direction of the lower pressure - form drag Separation will occur when the boundary layer does not have sufficient kinetic energy in the presence of a given adverse pressure gradient.



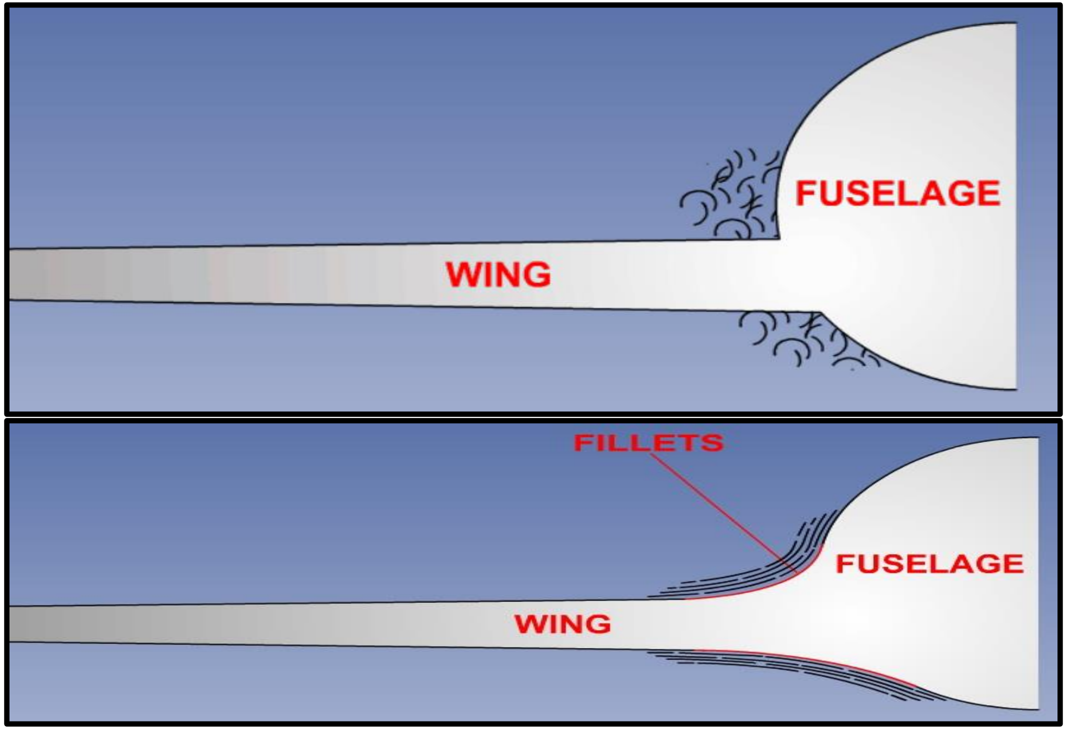


Profile Drag

The combination of skin friction and form drag is known as profile drag. It can be considered that these drags result from the "profile" (or cross-sectional area) of the aircraft presented to the relative airflow.

Interference Drag

- Interference Drag drag results from boundary layer ‘interference’ at wing/fuselage, wing/engine nacelle and other such junctions. Filleting is necessary to minimize interference drag.



Factors Affecting Parasite Drag

- Indicated Airspeed
  Parasite Drag varies directly with the square of the Indicated Airspeed (IAS).
  If IAS is doubled, the Parasite Drag will be four times greater - if IAS is halved, the Parasite Drag will be one quarter of its previous value.

- Configuration

- Airframe Contamination

Induced Drag

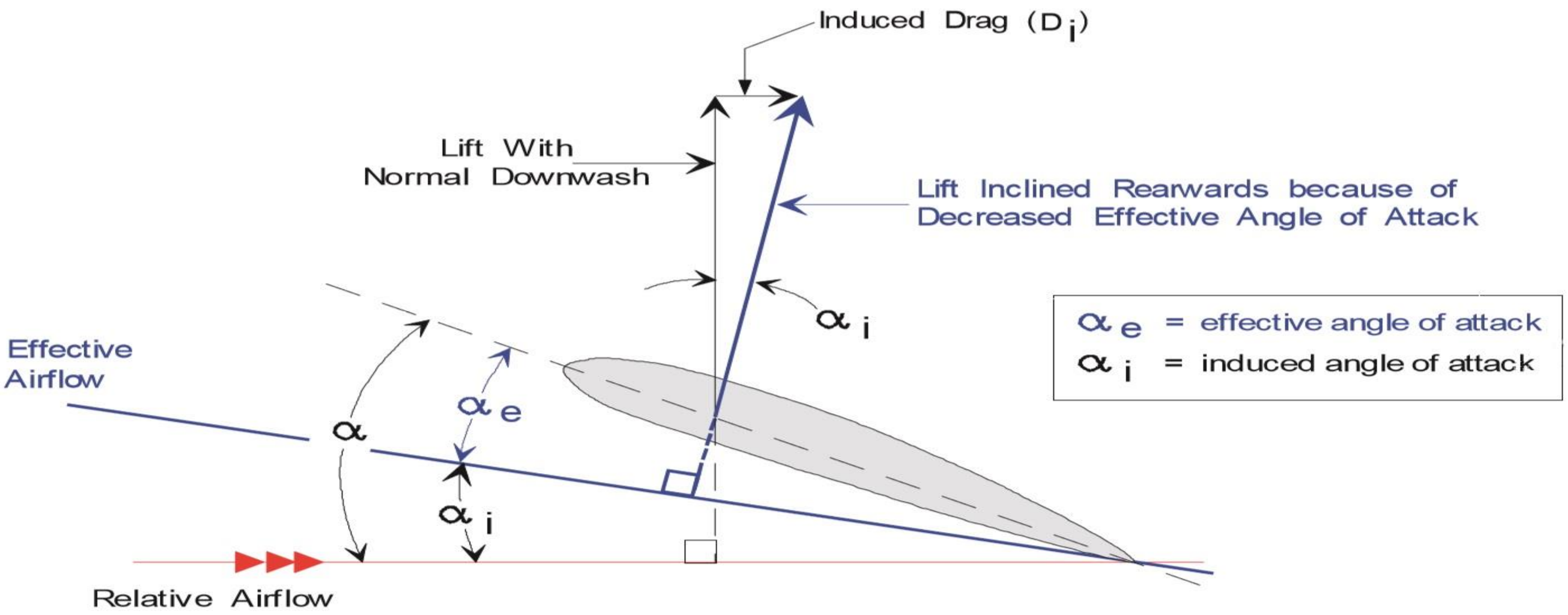
Induced drag is an undesirable by-product of lift. Wing tip vortices modify upwash and downwash in the vicinity of the wing which produces a rearward component to the lift vector known as induced drag.

**The lower the IAS, the higher the angle of attack - the stronger the vortices.
The stronger the vortices - the greater the induced drag.**

Factors that Affect Induced Drag

- **The size of the lift force**

Because induced drag is a component of the lift force, the greater the lift, the greater will be the induced drag. Lift must be equal to weight in level flight so induced drag will depend on the weight of the aircraft. Induced drag will be greater at higher aircraft weights.Certain require the lift force to be greater than the aircraft weight. The relationship of lift to weight is known as the ‘Load Factor’ (or ‘g’). For example, lift is greater than weight during a steady turn so induced drag will be higher during a steady Turn than in straight and level flight. Therefore, induced drag also increases as the Load Factor increases. Induced drag will increase in proportion to the square of the lift force.


Induced Drag (D_i)
Lift With
Normal Downwash
Lift Inclined Rearwards because of
Decreased Effective Angle of Attack
α_i
α_e = effective angle of attack
α_i = induced angle of attack
Effective
Airflow
α
α_e
α_i
Relative Airflow

- **The speed of the aircraft**

Induced drag decreases with increasing speed (for a constant lift force). This is because, as speed increases, the downwash caused by the tip vortices becomes less significant, the rearward inclination of the lift is less, and therefore induced drag is less. Induced drag varies inversely as the square of the speed. Maximum induced drag occurs at the highest possible angle of attack and at the lowest possible speed, which is the stalling speed in the landing configuation (VS0).

$$Di \propto \frac{1}{v^2}$$

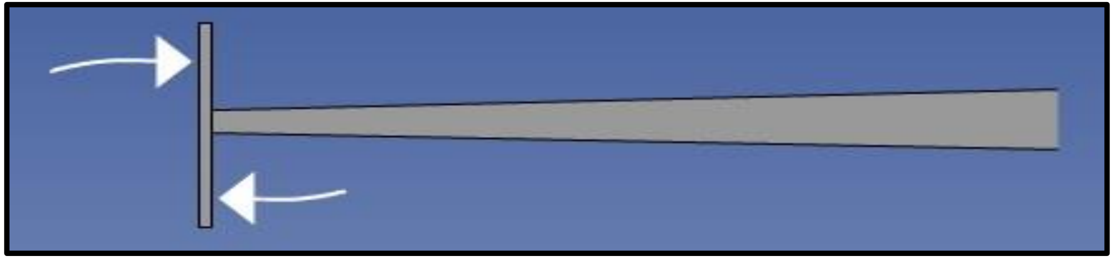
- **MASS**

Methods of Reducing Induced Drag

Induced drag is low at high speeds, but at low speeds it comprises over half the total drag.Induced drag depends on the strength of the trailing vortices, and it has been shown that a high aspect ratio wing reduces the strength of the vortices for a given lift force.

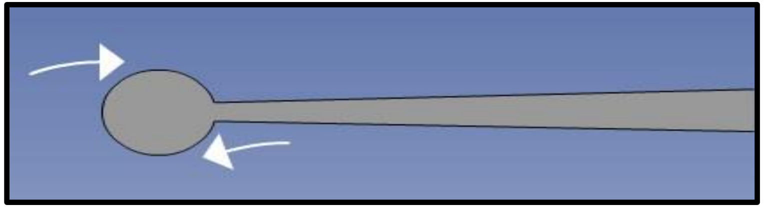
- **Wing end Plates**

A flat plate placed at the wing tip will restrict the tip vortices and have a similar effect to an increased aspect ratio but without the extra bending loads. However, the plate itself will cause parasite drag, and at higher speeds there may be no overall saving in drag.



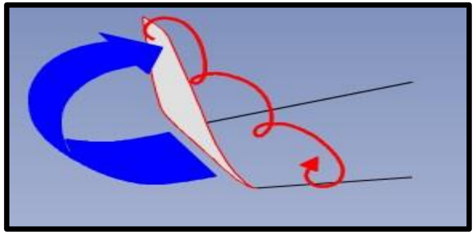
- **Tip tanks**

Fuel tanks placed at the wing tips will have a similar beneficial effect to an end plate, will reduce the induced drag and will also reduce the wing root bending moment.



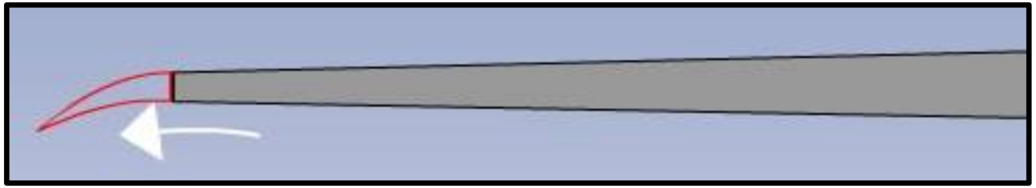
- **Winglets**

These are small vertical aerofoils which form part of the wing tip. Shaped and angled to the induced airflow, they generate a small forward force (i.e. "negative drag", or thrust). Winglets partly block the air flowing from the bottom to the top surface of the wing, reducing the strength of the tip vortex. In addition, the small vortex generated by the winglet interacts with and further reduces the strength of the main wing tip vortex.



- **Wing tip shape**

The shape of the wing tip can affect the strength of the tip vortices, and designs such as turned down or turned up wing tips have been used to reduce induced drag.



FACTORS AFFECTING ON PARASITE DRAG

- **Effect of Configuration**

Parasite drag, Dp , is unaffected by lift, but is variable with dynamic pressure and area. If all other factors are held constant, parasite drag varies significantly with frontal area. As an example, lowering the landing gear and flaps might increase the parasite area by as much as 80%. At any given IAS this aeroplane would experience an 80% increase in parasite drag.

- **Effect of Altitude**

In most phases of flight the aircraft will be flown at a constant IAS, the dynamic pressure and, thus, parasite drag will not vary. The TAS would be higher at altitude to provide the same IAS.

- **Effect of Speed**

The effect of speed alone on parasite drag is the most important. If all other factors are held constant, doubling the speed will give four times the dynamic pressure and, hence, four times the parasite drag.

Aeroplane Total Drag

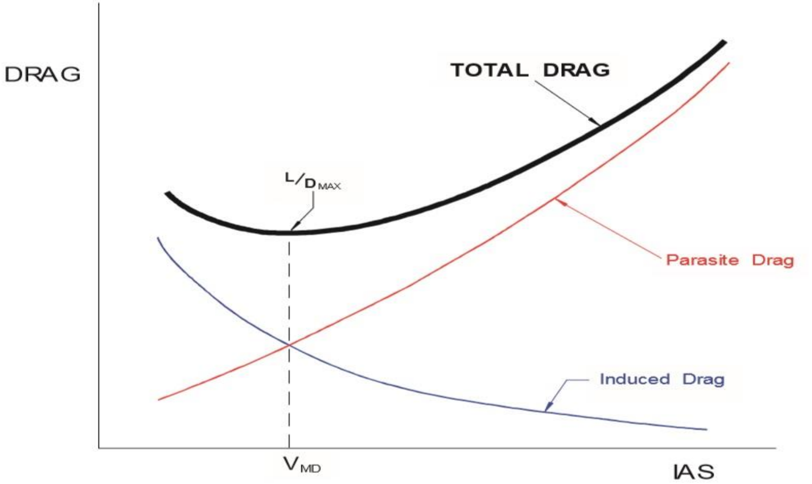
The total drag of an aeroplane in flight is the sum of induced drag and parasite drag.

The general drag formula is thus:

$$\text{Drag} = C_D \, \tfrac{1}{2} \rho V^2 S$$

• Figure shows the predominance of induced drag at low speed and parasite drag at high speed.

• Because of the particular manner in which parasite and induced drags vary with speed, the speed at which total drag is a minimum (VMD) occurs when the induced and parasite drags are equal.



• The speed for minimum drag is an important reference for many items of aeroplane performance.

• Range, endurance, climb, glide, manoeuvre, landing and take-off performance are all based on some relationship involving the aeroplane total drag curve.

• Since flying at VMD incurs the least total drag for lift-equal-weight flight, the aeroplane will also be at L/DMAX angle of attack (approximately 4°).

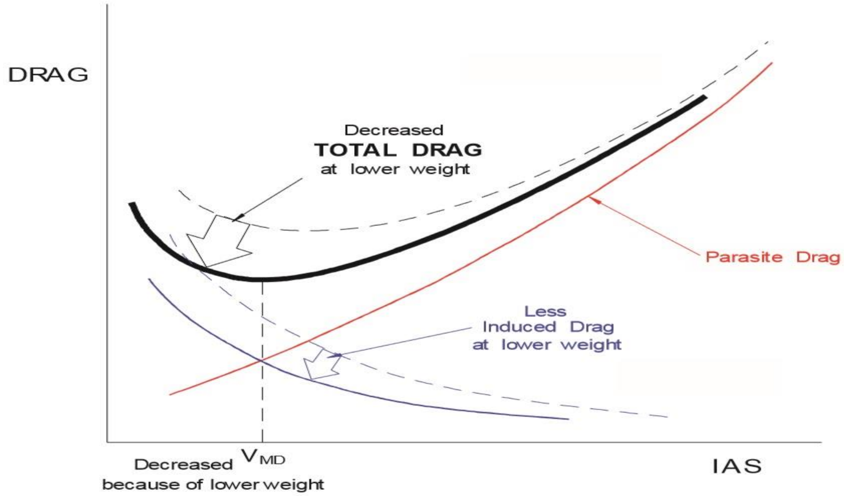
• If an aircraft is operated at the L/DMAX angle of attack, drag will be a minimum while generating the required lift force.

• Any angle of attack lower or higher than that for L/DMAX increases the drag for a given lift force; greater drag requires more thrust, which would be inefficient, and expensive. It must also be noted that if IAS is varied, L/D will vary.

FACTORS AFFECTING Total Drag

- **The Effect of Aircraft Gross Weight on Total Drag**

The effect of variation in aircraft gross weight on total drag can be seen from Figure. As fuel is consumed, gross weight will decrease. As the aircraft weight decreases,less lift is required (lower CL) which will reduce induced drag. Total drag will be less and VMD will occur at a lower IAS. If an aircraft is manoeuvred so that the load factor is increased, the result will be similar to that caused by an increase in gross weight, i.e. induced drag will increase.

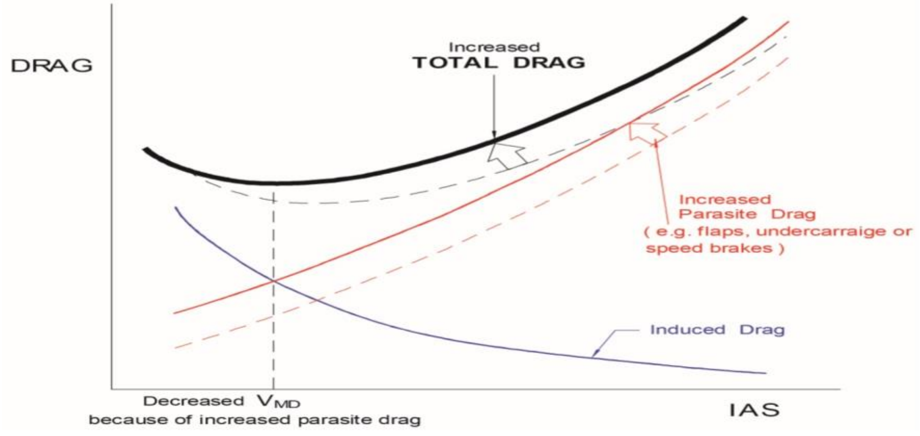


- **The Effect of Altitude on Total Drag**

Aircraft usually operate within limits of Indicated Airspeed (IAS), so it is relevant to consider the variation of drag with IAS. If an aircraft is flown at a constant IAS, dynamic pressure will be constant. As density decreases with increasing altitude, TAS must be increased to maintain the constant IAS (Q = ½ ρ V2). If the aircraft is flown at a constant IAS, drag will not vary with altitude.

- **The Effect of Configuration on Total Drag**

Extension of the landing gear, air brakes, or flaps will increase parasite drag but will not substantially affect induced drag. The effect of increasing parasite drag is to increase total drag at any IAS but to decrease the speed VMD compared to the clean aircraft.



Chapter 9

STALL

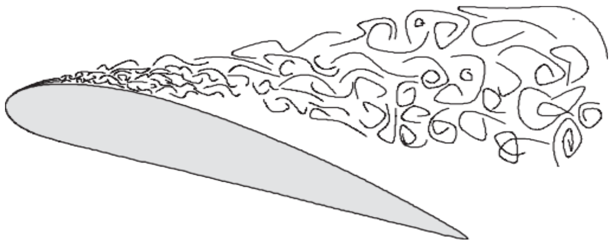
Cause of the Stall

The CL of an aerofoil increases with angle of attack up to a maximum (CLMAX). Any further increase above this stalling angle, or critical angle of attack, will make it impossible for the airflow to smoothly follow the upper wing contour, and the flow will separate from the surface, causing CL to decrease and drag to increase rapidly. A stall is caused by airflow separation. Separation can occur when either the boundary layer has insufficient kinetic energy or the adverse pressure gradient becomes too great.

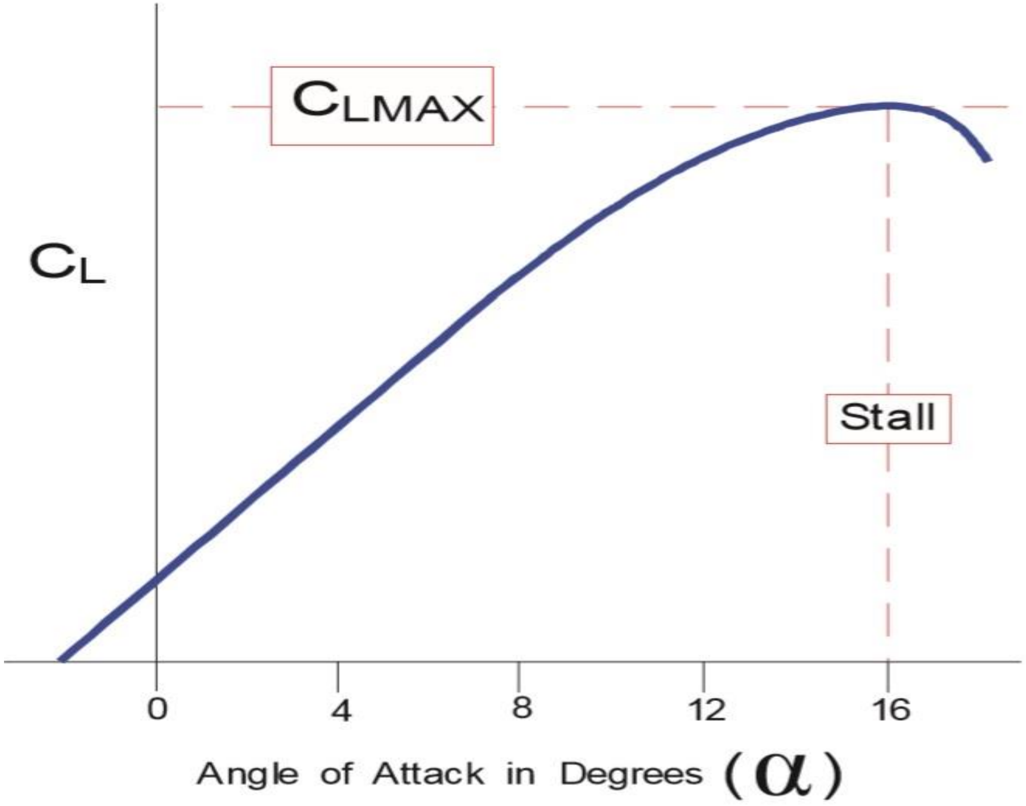
Figure shows that at low angles of attack virtually no flow separation occurs before the trailing edge, the flow being attached over the rear part of the surface in the form of a turbulent boundary layer.

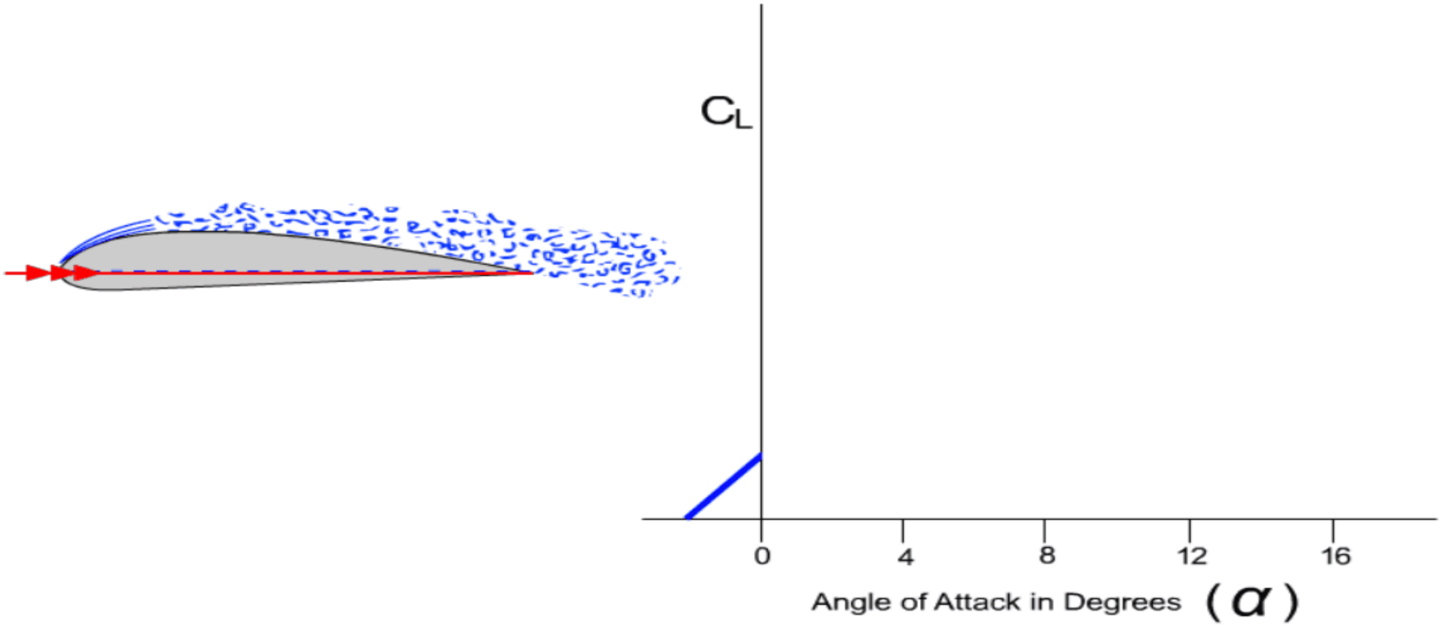
As angle of attack increases,the adverse pressure gradient increases, reducing the Kinetic energy, and the boundary layer will begin to separate from the surface at the trailing edge

stall



Further increase in angle of attack makes the separation point move forward and the wing area that generates a pressure differential becomes smaller. At angles of attack higher than approximately 16°, the extremely steep adverse pressure gradient will have caused so much separation that insufficient lift is generated to balance the aircraft weight





It is important to remember that the angle of attack is the angle between the chord line and the relative airflow. Therefore, if the angle of attack is increased up to or beyond the critical angle, an aeroplane can be stalled at any airspeed or flight attitude.

Stall Recovery

To recover from a stall or prevent a full stall, the angle of attack must be decreased to reduce the adverse pressure gradient. Allow airspeed to increase and recover lost altitude with moderate back pressure on The pitch control.
for a light single engine aeroplane stall recovery procedure is :
Full power and stick roll-neutral nose-down, correcting for angle of bank with rudder.

Aircraft Behaviour Close to the Stall

Stall characteristics vary with different types of aircraft. However, for modern aircraft during most normal manoeuvres, the onset of stall is gradual. The first indications of a stall may be provided by any or all of the following:

- unresponsive flight controls,
- a stall warning or stall prevention device, or
- aerodynamic buffet.

Stall Speed

It is necessary to fly at slow speeds (high angles of attack) during take-off and landing in order to keep the required runway lengths to a reasonable minimum. There must be an adequate safety margin between the minimum speed allowed for normal operations and the stall speed.

- “Small” aircraft use V_{S0} and V_{S1} on which to base the stall speed.

- “Large” aircraft use a reference stall speed, V_{SR} ,.

- 1g stall speed (V_{S1g}).

Stall warning Speed

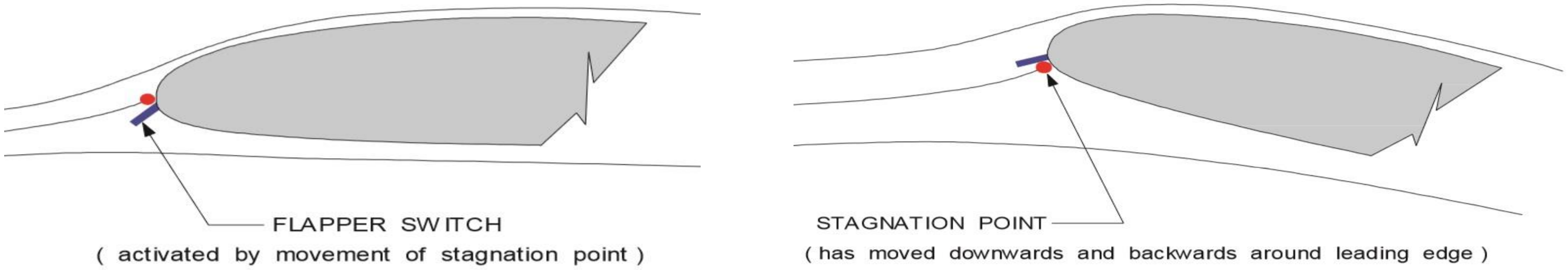
Having established a stall speed for each configuration, there must be clear and distinctive warning, sufficiently in advance of the stall, for the stall itself to be avoided.

- stall warning in light aircrafts normally activates 5 to 10 kt above the stalling speed.

detector switch

activated by changes in angle of attack.

• **Flapper Switch (Leading Edge Stall Warning Vane)**
As angle of attack increases, the stagnation point moves downwards and backwards around the leading edge. The flapper switch is so located that, at the appropriate angle of attack, the stagnation point moves to its underside and the increased pressure lifts and closes the switch.



The Effect of Aerofoil Section on stall

A given aerofoil section will always stall at the same angle of attack

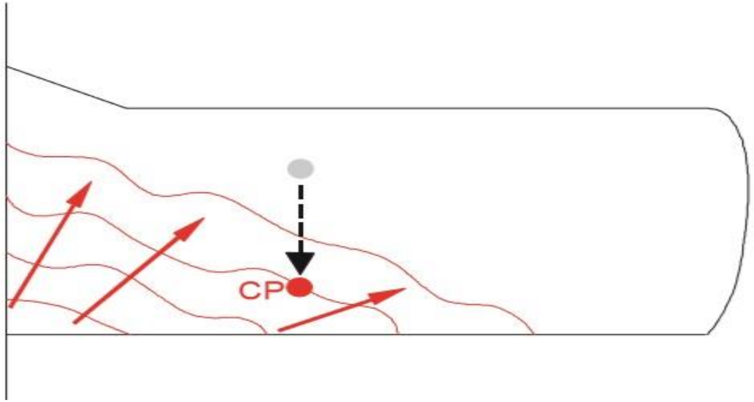
The Effect of Wing Planform on stall

The Rectangular Wing

The stall of an unswept rectangular wing does not occur over the whole wing simultaneously, it commences at one particular point usually at the wing root near the trailing edge and spreads outward and forward to the rest of the wing. This pattern of progression is caused by the lift coefficient being much greater at the wing root than at the wing tip.

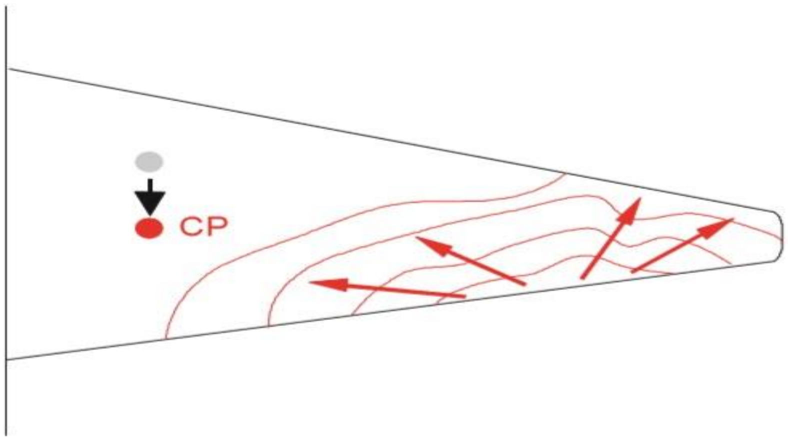
Loss of lift is felt ahead of the centre of gravity of the aircraft and the CP moves rearwards, so the nose drops and angle of attack is reduced.

- **Aileron effectiveness,**
- **nose drop,**
- **aerodynamic buffet, and**
- **absence of violent wing drop.**



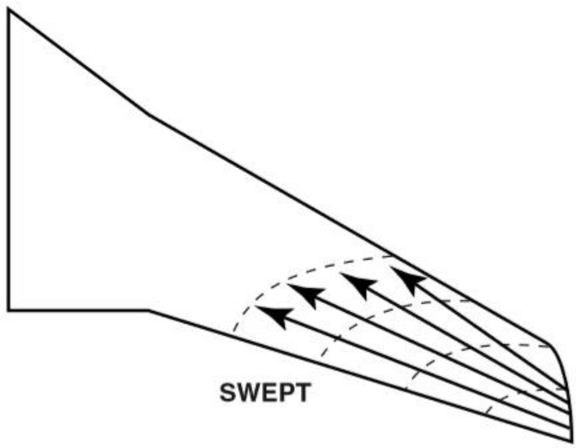
The Tapered Wing

Separation tends to occur first in the region of the wing tips, reducing lift in those areas. If an actual wing were allowed to stall in this way, stalling would give aileron buffet and perhaps violent wing drop. (Wing drop at the stall gives an increased tendency for an aircraft to enter a spin). There would be no buffet on the tail, no strong nose-down pitching moment and very little, if any, aileron effectiveness.



Swept wings

Of all wing shapes, swept wings have the greatest tendency to tip stall first because of the spanwise flow of the boundary layer . The three elements that combine to form the wing-tip vortex on swept-wing aeroplanes are leading-edge separation, flow around the wing tips and spanwise boundary layerflow.The greater the sweep back the greater is the boundary-layer spanwise flow and the magnitude of the vortex drag. Increased angle of attack also increases the spanwise flow of the boundary layer.



Modification of wing

• Geometric twist (washout)

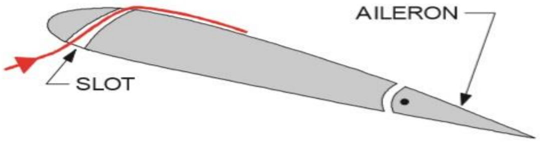
a decrease in incidence from root to tip. This decreases the angle of attack at the tip, and the root will tend to stall first.

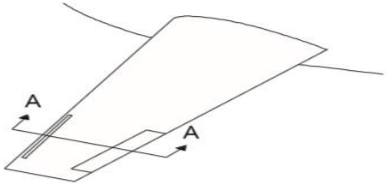
• Camber/thicknes variation

an increase in camber/thickness towards the wingtips will Delay the stall owning the higher CLmax. so that the root will tend to stall first.

• Leading edge slots

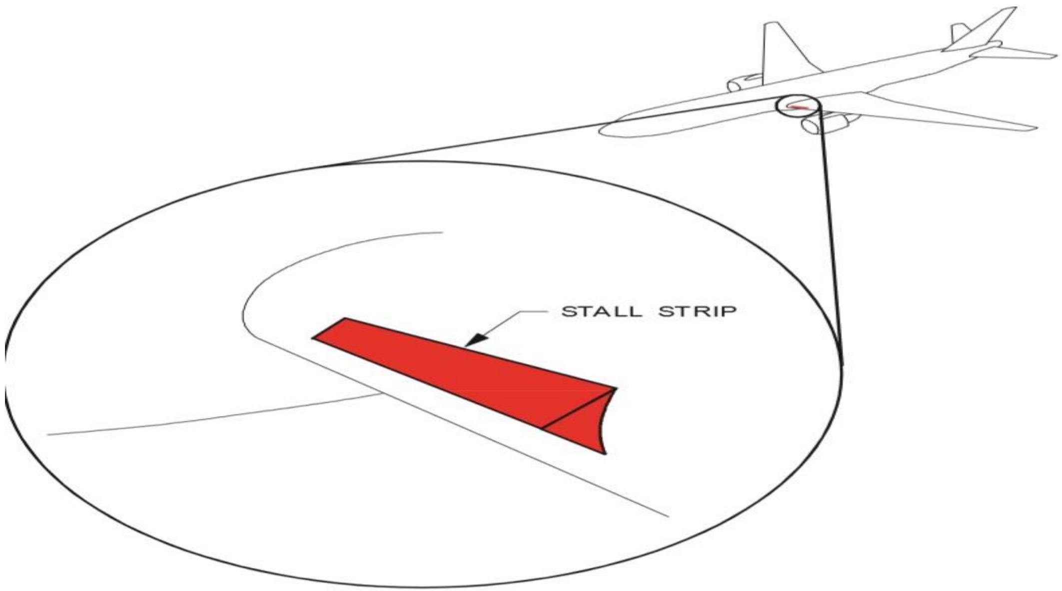
towards the tip re-energize (increase the kinetic energy of) the boundary layer. They increase local CLMAX and are useful, both for delaying separation at the tip and retaining aileron effectiveness.





- **stall strips**

Another method for improving the stall pattern is by forcing a stall to occur from the root. An aerofoil section with a smaller leading edge radius at the root would promote airflow separation at a lower angle of attack but decrease overall wing efficiency. The same result can be accomplished by attaching stall strips (small triangular strips) to the wing leading edge. At higher angles of attack, stall strips promote separation, but they will not effect the efficiency of the wing in the cruise.



Effect of Weight Change on Stall Speed

Weight ↑ → Stall Speed ↑

Increasing weight increases stall speed

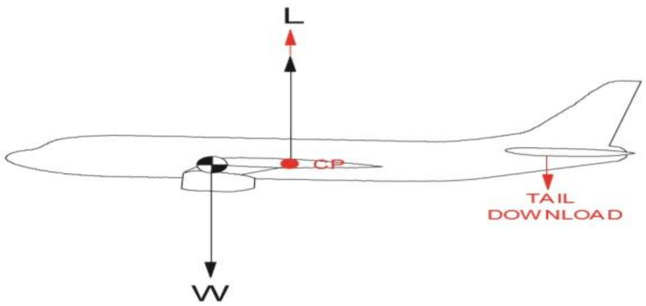
- **stall speed in a turn**

Bank angle ↑ ⟶ stall speed ↑

Increasing bank angle increases stall speed

Stall speed : vs = 150
45° bank : vs = 178 kt
60° bank : vs = 212 kt

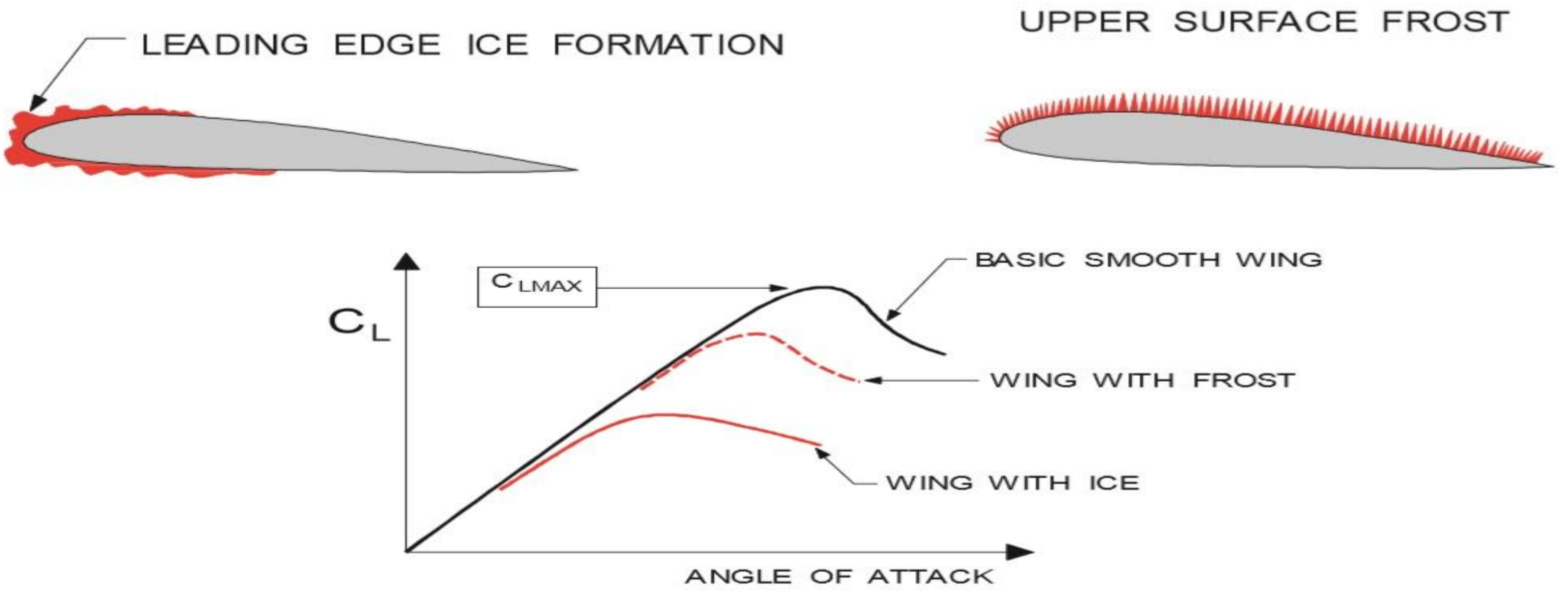
- **Effect of CG Position on Stall Speed**



Forward movement of the CG increases stall speed

• **Effect of Wing Contamination on Stall Speed**

Ice, frost and snow change the aerofoil section, decrease the stall angle and increase the stall speed



• Effect of Heavy Rain on Stall Speed

Weight

Heavy rain will form a film of water on an aircraft and increase its weight slightly, maybe as much as 1 - 2% this in itself will increase stall speed.

Aerodynamic Effect

The film of water will distort the aerofoil, roughen the surface and alter the airflow pattern on the whole aircraft. CLMAX will decrease causing stall speed to increase.

Drag

The film of water will increase interference drag, profile drag and form drag. In light rain, drag may increase by 5%, in moderate by 20% and in heavy rain by up to 30%. This obviously increases thrust required.

Impact

An additional consideration, while not affecting stall speed, is the effect of the impact of heavy rain on the aircraft. heavy rain will also be driving the aircraft downwards. The volume of rain in any given situation will vary, but an aircraft on final approach which suddenly enters a torrential downpour of heavy rain will be subject to a loss of momentum and a decrease in altitude, similar to the effect of microburst windshear.

Special Phenomena of Stall

- **power on stall**
- **power off stall**
- **Accelerated Stall**
- **Secondary Stall**

Spinning

When an aircraft is accidentally or deliberately stalled, the motion of the aircraft may in some cases develop into a spin. The important characteristics of a spin are:

- the aircraft is descending along a steep helical path about a vertical spin axis,
- the angle of attack of both wings is well above the stall angle,
- the aircraft has a high rate of rotation about the vertical spin axis,
- viewed from above, the aircraft executes a circular path about the spin axis, and the radius of the helix is usually less than the semi-span of the wing,
- the aircraft may be in the "erect" or "inverted" position in the spin.

During the spin, the wings remain unequally stalled.

stall

TYPES OF SPIN

ERECT SPIN

INVERTED SPIN

FLAT SPIN

Roll and yaw
In same direction

Roll and yaw
In opposite direction

Yaw only

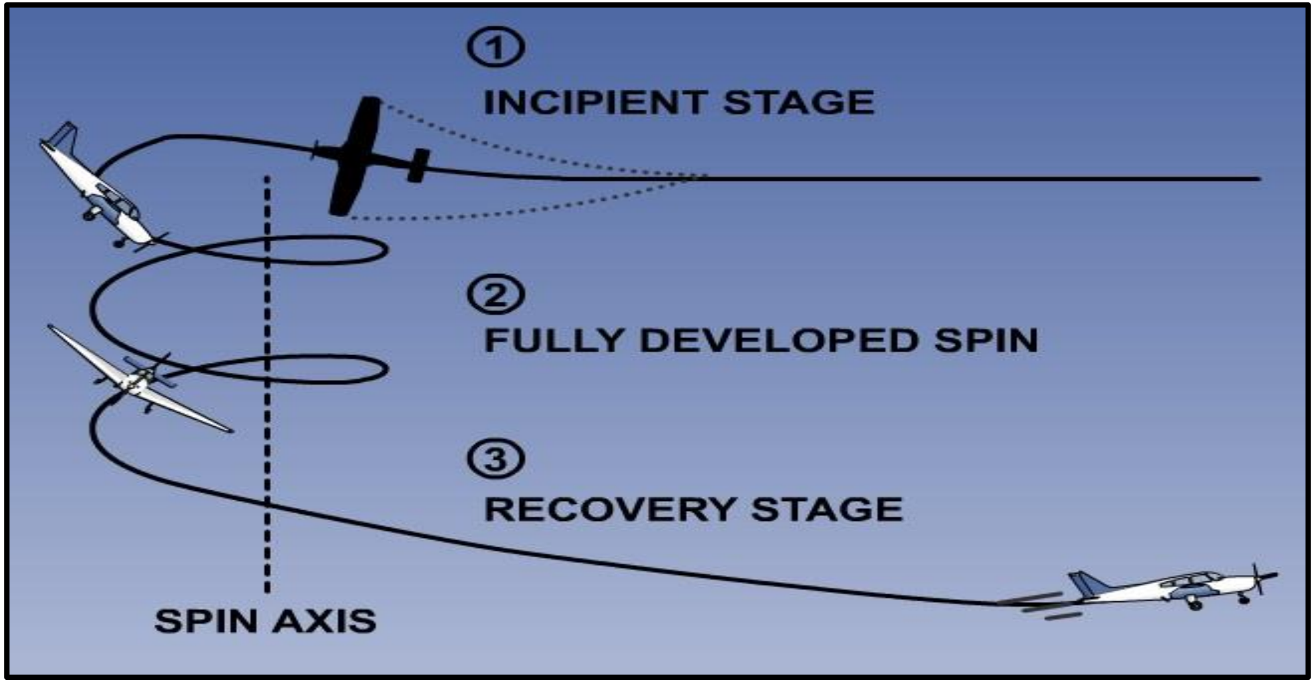
Primary Causes of a Spin

- A stall must occur before a spin can take place.
- A spin occurs when one wing stalls more than the other.
- The wing that is more stalled will drop and the nose of the aircraft will yaw in the direction of the lower wing.
- The cause of an accidental spin is exceeding the critical angle of attack while performing a manoeuvre with either too much or not enough rudder input for the amount of aileron being used (crossed-controls).
- If the correct stall recovery is not initiated promptly, the stall could develop into a spin.

Phases of a Spin

1. The incipient spin is the first phase, and exists from the time the aeroplane stalls and rotation starts until the spin is fully developed.
2. A fully developed spin exists from the time the angular rotation rates, airspeed and vertical descent rate are stabilized from one turn to the next.

3. The third phase, spin recovery, begins when the anti-spin forces overcome the pro-spin forces.



Chapter 10

High Lift Devices

Purpose of High Lift Devices

Aircraft are fitted with high lift devices to reduce the take-off and landing distances. This permits operation at greater weights from given runway lengths and enables greater payloads to be carried.

Take-off and Landing Speeds

The take-off and landing distances depend on the speeds required at the screen, and these are laid down in the performance regulations. For both take-off and landing, one of the requirements is for a safe margin above the stalling speed .The stalling speed is determined by the CLMAX of the wing, and so to obtain the lowest possible distances, the CLMAX , must be as high as possible.

CLMAX Augmentation

There are three main types of device that may be used to improve the value of Clmax. They are:
a. slats;
b. built-in slots;
c. flaps either leading edge or trailing edge;

Leading Edge High Lift Devices

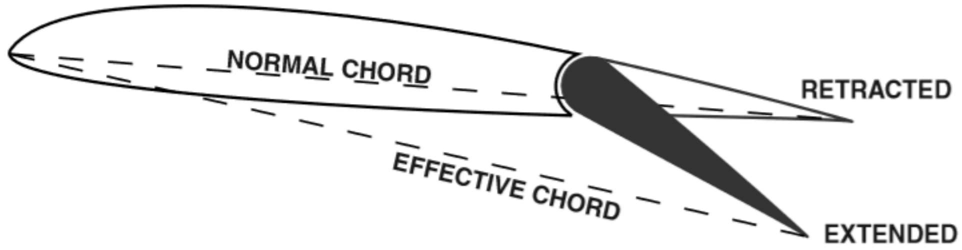
There are two forms of leading edge high lift device commonly in use:
• leading edge slot or slat
• the leading edge flap

Trailing Edge Flaps

The more commonly used types of trailing edge flap are considered below :

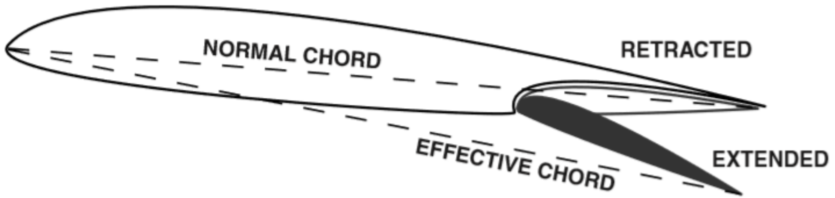
• **Plain Flap**

The plain flap, has a simple construction and gives a good increase in CLMAX, although with fairly high drag.This flap increases the wing's effective camber and alters the curvature of the wing's upper surface. The increase in curvature causes earlier separation of the boundary layer and increases form drag. It is used mainly on low speed aircraft and where very short take-off and landing is not required.



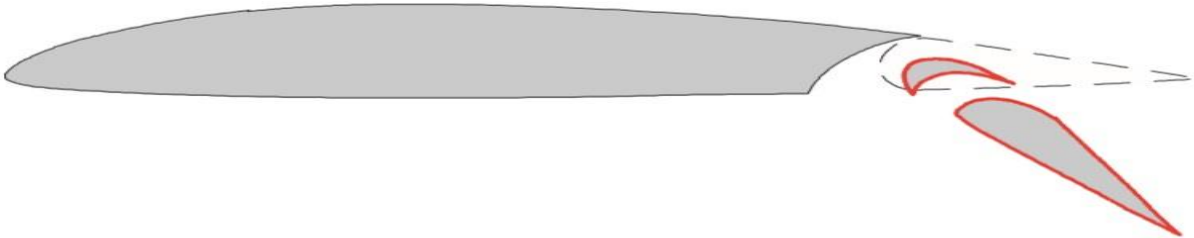
- **Split Flap**

The flap forms part of the lower surface of the wing trailing edge. Deflecting the split flap increases the wing's effective camber but the curvature of the upper surface remains unchanged. This produces a large turbulent wake at low angles of attack and hence drag, but provides better lift performance than the plain flap at high angles of attack. This is because the less curved upper surface delays the separation of the boundary layer.



- **Slotted and Multiple Slotted Flaps**

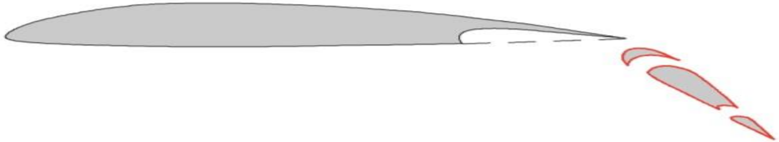
When the slotted flap is lowered, a slot or gap is opened between the flap and the wing.The purpose of the slot is to direct higher pressure air from the lower surface over the flap and re-energize the boundary layer. This delays the separation of the airflow on the upper surface of the flap. The slotted flap gives a bigger increase in CLMAX than the plain or split flap and much less drag, but it has a more complex construction.



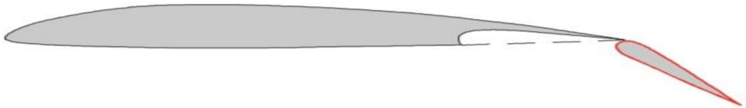
- **The Fowler Flap**

The Fowler flap,moves rearwards and then down, initially giving an increase in wing area and then an increase in camber. The Fowler flap may be slotted.

Because of the combined effects of increased area and camber, the Fowler flap gives the greatest increase in lift of the flaps considered and also gives the least drag because of the slot and the reduction of thickness : chord ratio. However, the change of pitching moment is greater because of the rearward extension of the chord.

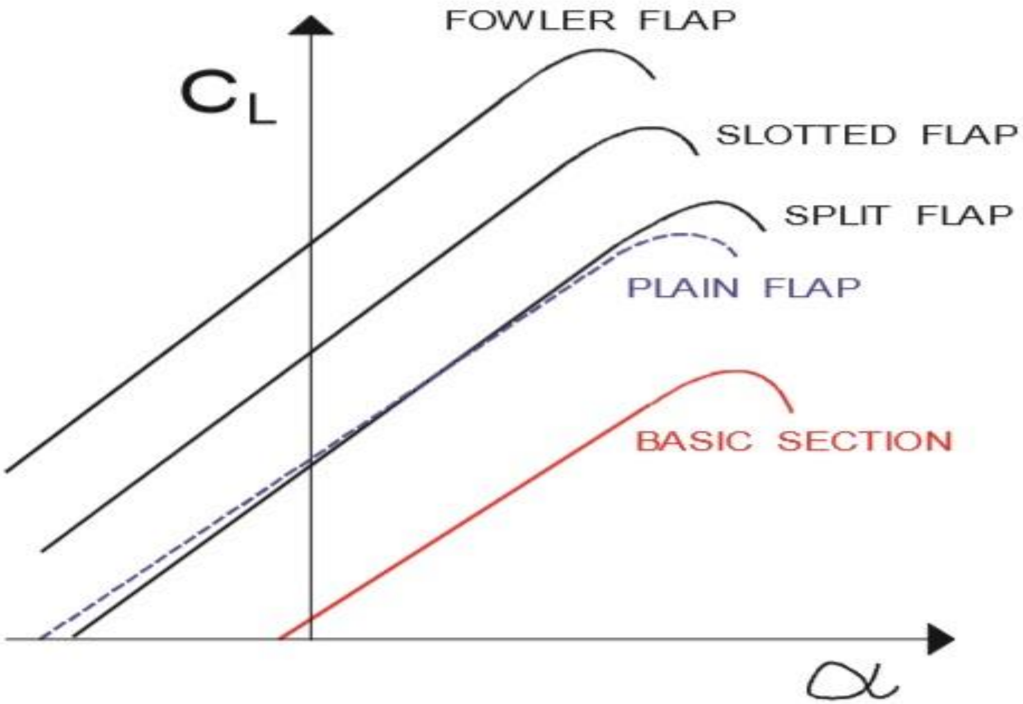


Triple Slotted Fowler Flap

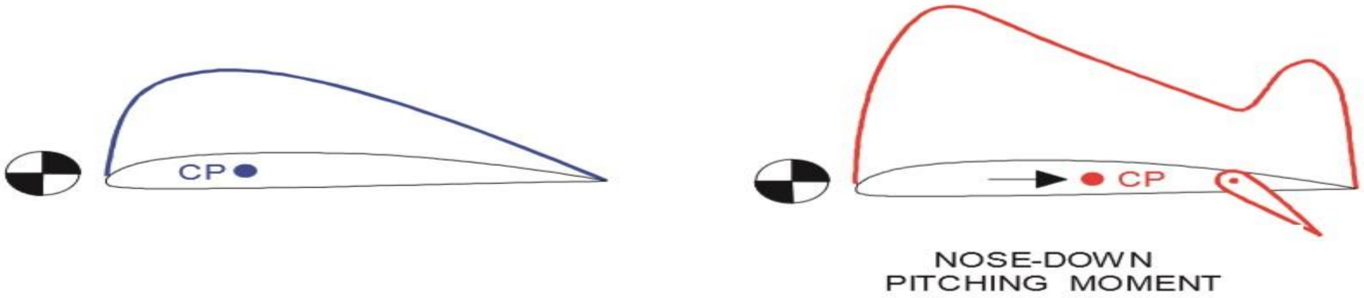


Fowler Flap

Comparison of Trailing Edge Flaps



Centre of Pressure Movement



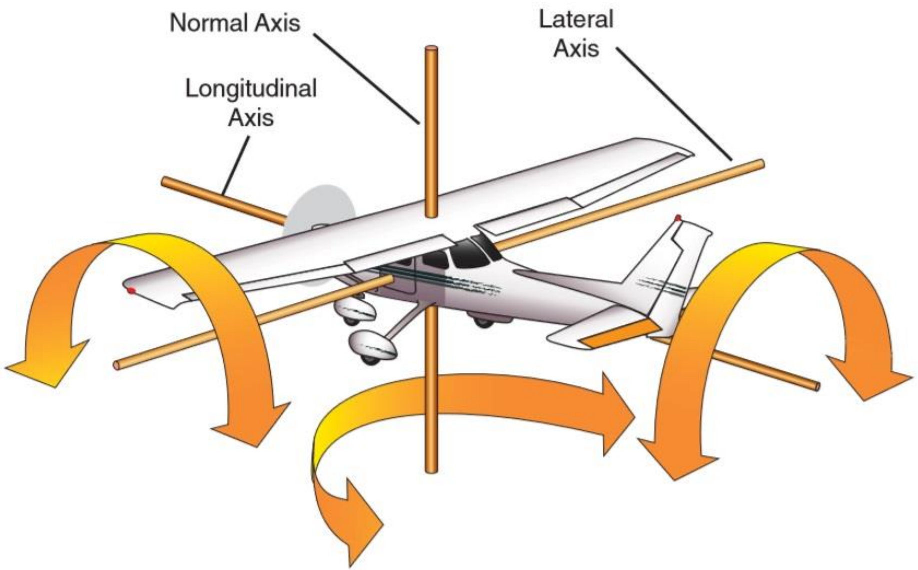
Chapter 7

Controls

Introduction

• In flight, an aircraft can rotate about any one, or any combination of, its three axes.

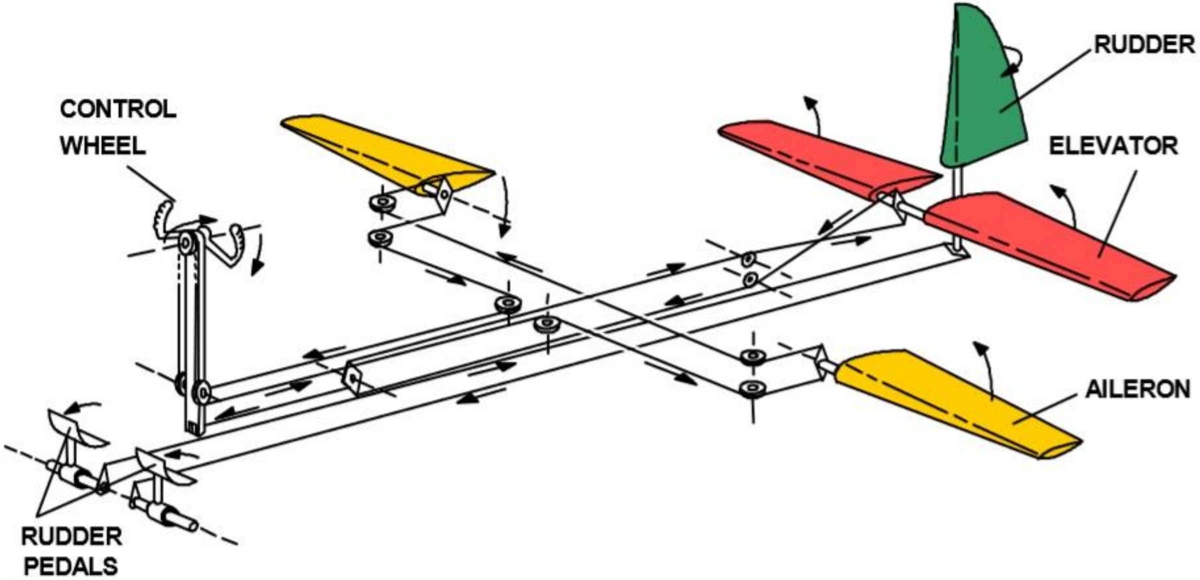
• These axes are at right angles to each other and all pass through the aircraft’s centre of gravity In flight, an aircraft can rotate about any one, or any combination of, its three axes.



axis

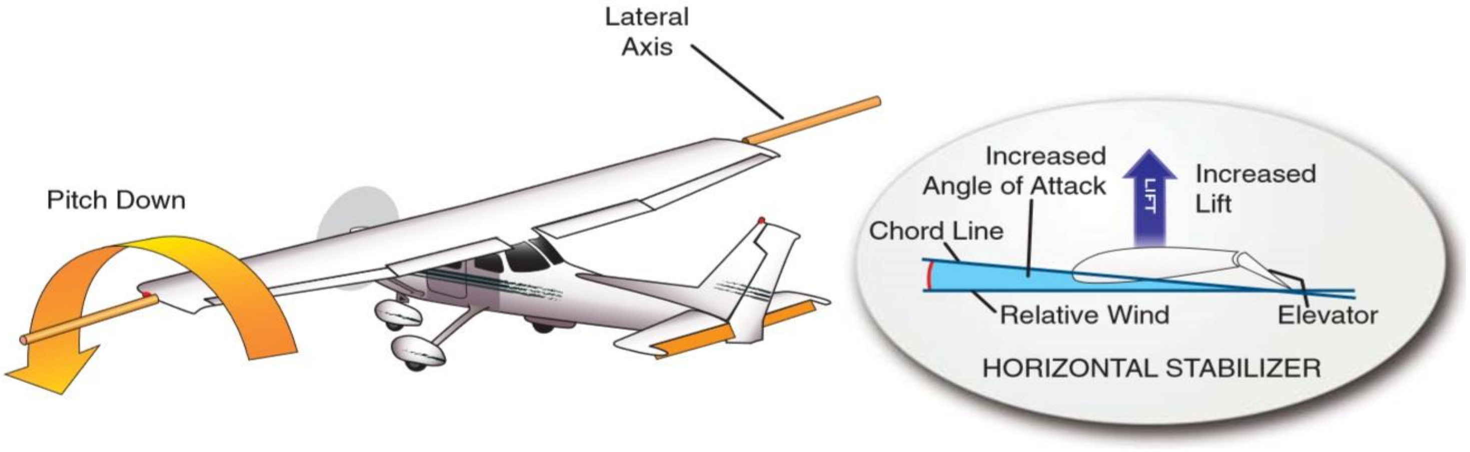
Principle of Flight

- Movement about the lateral axis is pitch.
- Movement about the longitudinal axis is roll.
- Finally, movement about the normal axis is yaw.
- The primary control surfaces are the elevators, ailerons, and rudder.



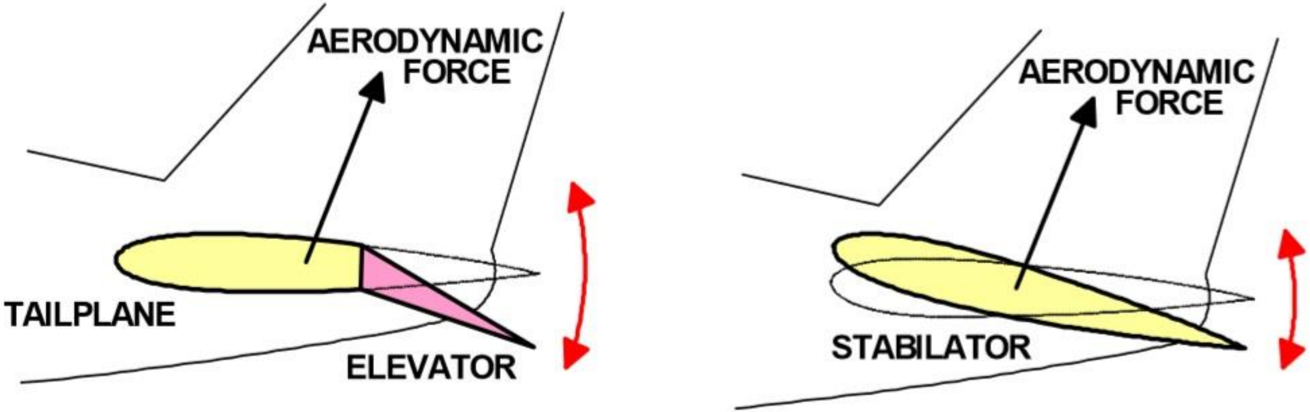
ELEVATORS

• The primary effect of elevators is to provide pitch control about the lateral axis.
• Pushing the control column forward causes the elevator to move downward. This produces an aerodynamic force acting on the tailplane in an upward direction causing the aircraft to pitch nose-down.
• Pulling the control column rearward has the reverse effect, and causes the aircraft to pitch nose-up.
• The elevators produce no real secondary effect on an aircraft, although changes in pitch attitude change the angle of attack and thus airspeed.



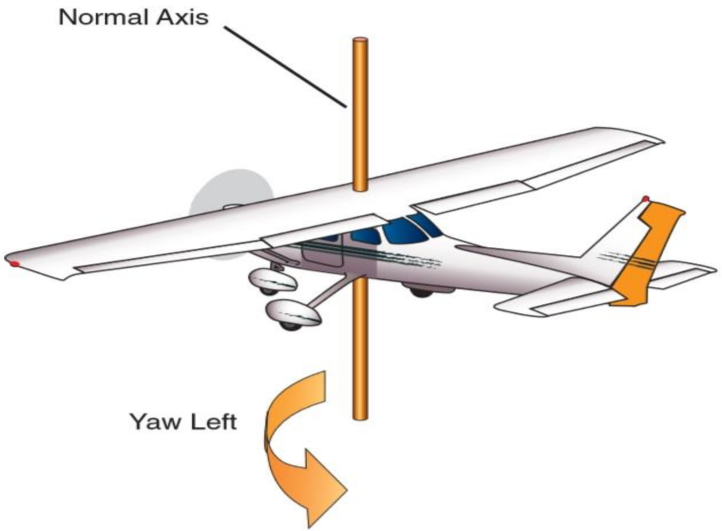
STABILATOR

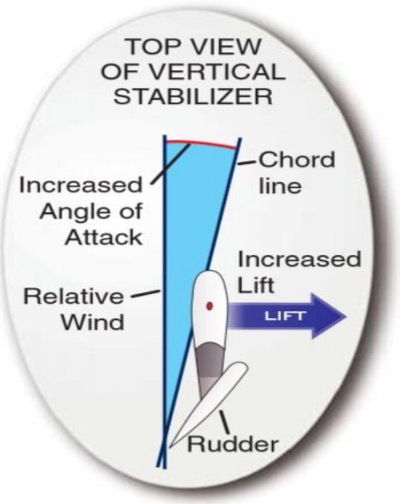
• On some aircraft, the tailplane and elevator are combined into one surface, known as a stabilator, or an all-moving tailplane .



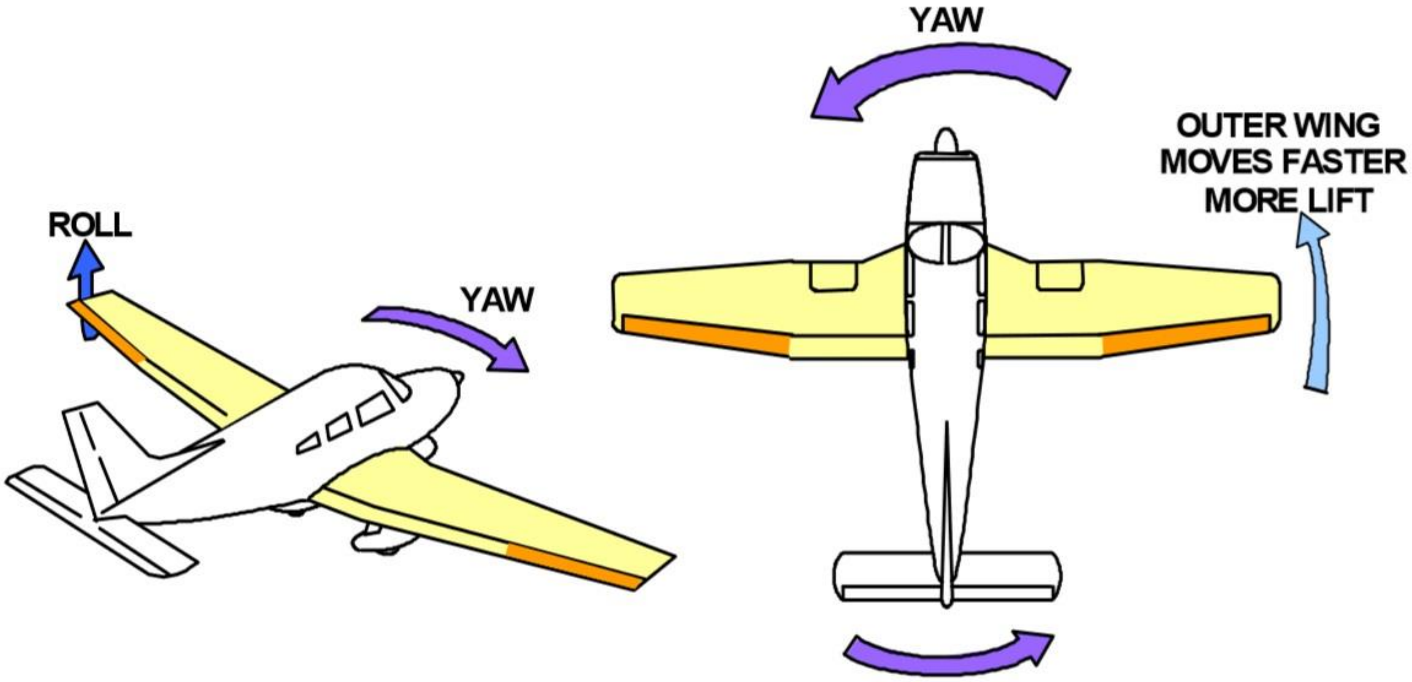
THE RUDDER

- The primary effect of the rudder is to provide yaw control about the normal axis.
- Moving the left rudder pedal forward moves the rudder to the left. In flight, this produces an aerodynamic force on the fin and the aircraft yaws to the left. Moving the right rudder pedal forward reverses the action, and the aircraft yaws to the right.



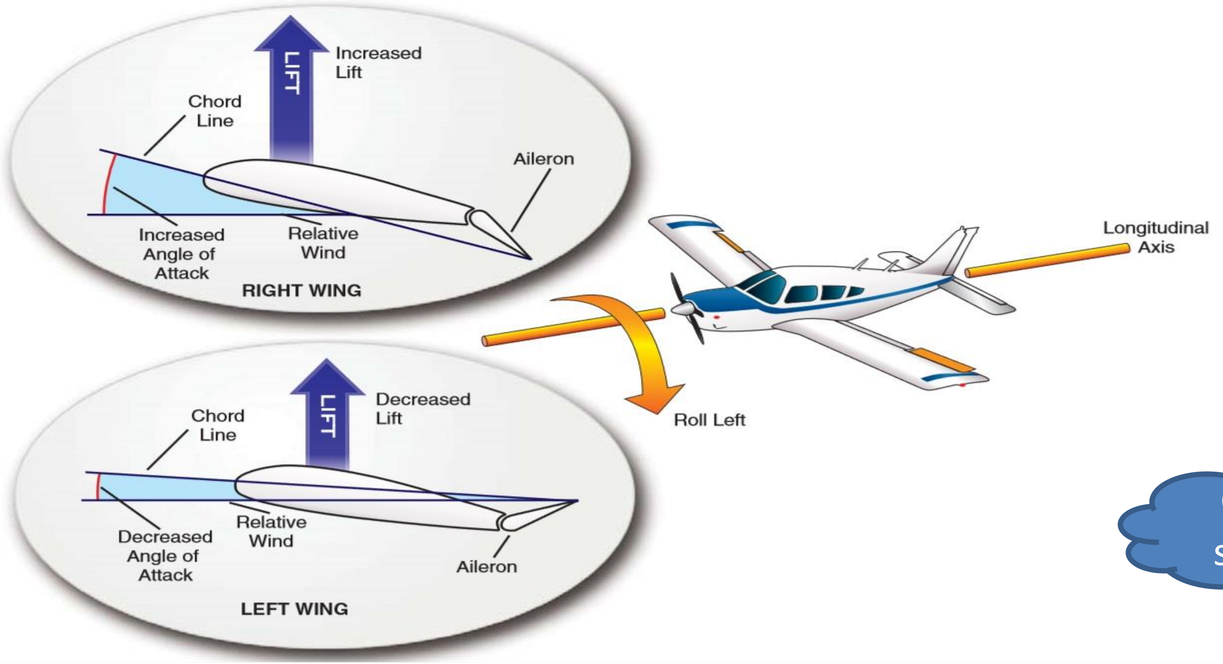


• The secondary effect of rudder is roll in the same direction as yaw.This occurs because the outer wing travels faster than the inner wing, thereby generating more lift.



AILERONS

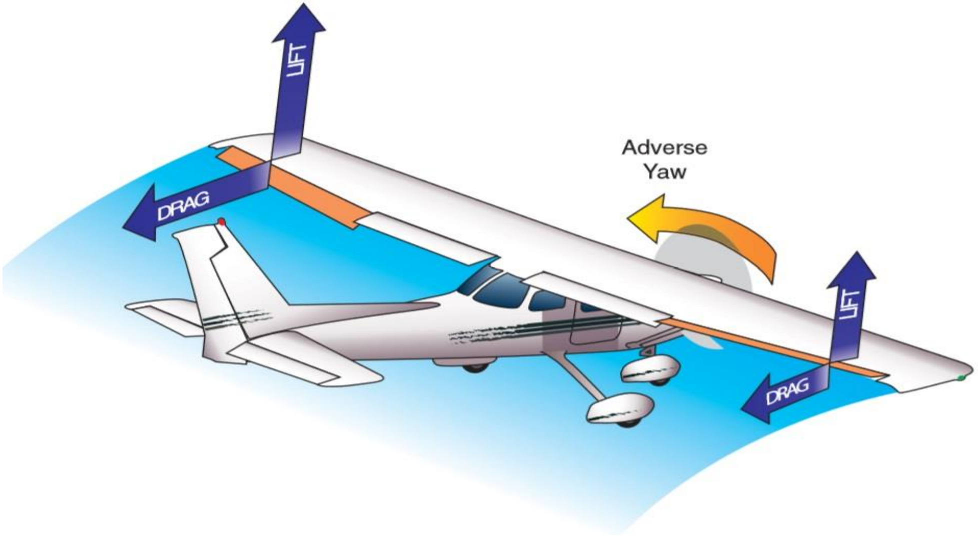
• The primary effect of ailerons is to provide roll control about the longitudinal axis .



Control surfaces

Adverse Aileron Yaw

• The ailerons produce a rolling moment by increasing the lift on one wing and decreasing it on the other.
• The increased lift on the up-going wing gives an increase in the induced drag, whereas the reduced lift
on the down-going wing gives a decease in induced drag.
• The difference in drag on the two wings produces a yawing moment which is opposite to the rolling
moment, that is, a roll to the left produces a yawing moment to the right. This is known as adverse
aileron yaw.

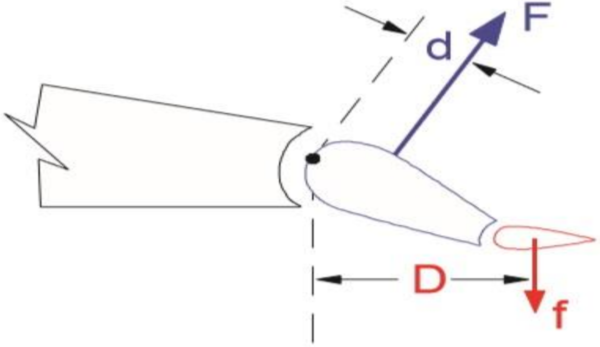


Trimming

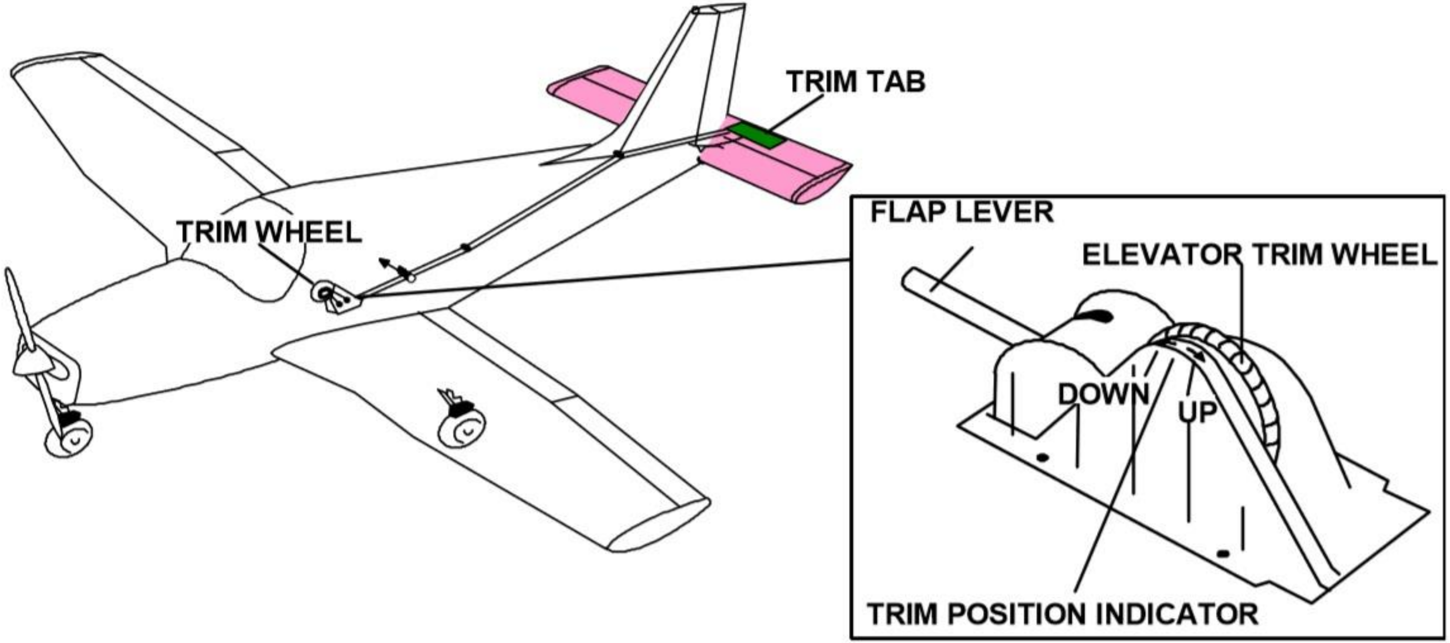
The trimming control system principally reduces the stick forces or control forces to zero. This allows an aircraft to maintain any yaw, pitch, or roll attitude set by the pilot without further control input.

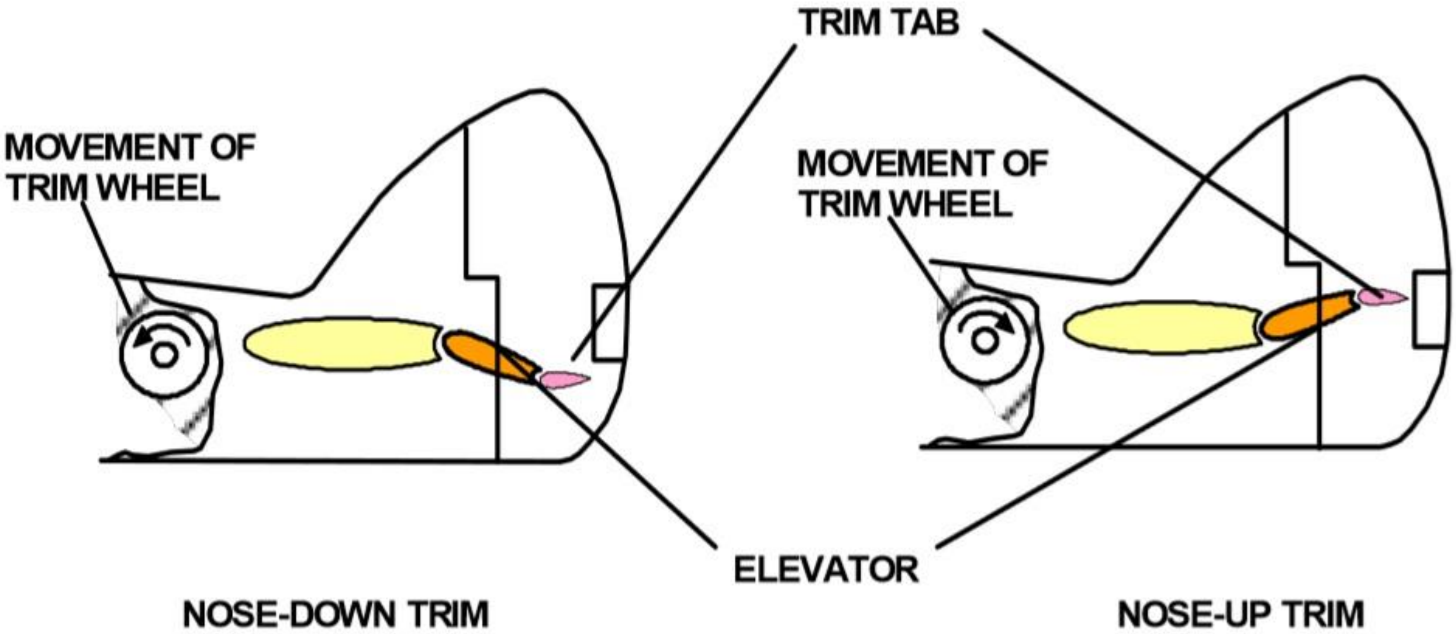
Trim Tab

• A trim tab is a small adjustable surface set into the trailing edge of a main control surface.
• Its deflection is controlled by a trim wheel or electrical switch in the cockpit, usually arranged to operate in an instinctive sense.
• To maintain the primary control surface in its required position, the tab is moved in the opposite direction to the control surface until the tab moment balances the control surface hinge moment.



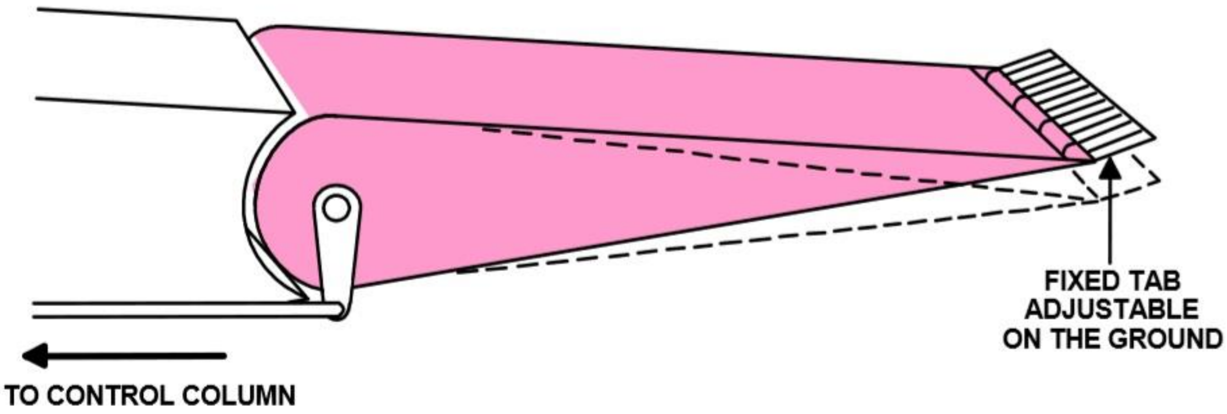
- **Moveable trim tabs**




TRIM TAB
MOVEMENT OF TRIM WHEEL
MOVEMENT OF TRIM WHEEL
ELEVATOR
NOSE-DOWN TRIM
NOSE-UP TRIM

- **Fixed Tabs**

Some trim tabs are not adjustable in flight but can be adjusted on the ground, to correct a permanent out of trim condition. They are usually found on ailerons and rudder. They operate in the same manner as the adjustable trim tab.



SECONDARY EFFECTS OF CONTROLS

YAWING MOMENT DUE TO ROLL

• A rolling moment is normally produced by deflecting the ailerons, and it has been seen that they can also produce an adverse yawing moment due to the difference in drag on the two ailerons. Induced drag is increased on the wing with the down going aileron, making the aircraft, for instance, roll left and at the same time, yaw right.

• If the aircraft is rolling, the down-going wing experiences an increased angle of attack and the up-going wing a decreased angle of attack, increasing the adverse yawing moment.

ROLLING MOMENT DUE TO YAW

• If the aircraft is yawing to the left, the right wing has a higher velocity than the left wing and so will give more lift. The difference in lift will give a rolling moment to the left.

• If the rudder is deflected to the left (to give yaw to the left) the force on the fin is to the right. This will give a small rolling moment to the right because the fin CP is above the aircraft CG. This effect is usually very small, but a high fin may give an adverse roll.
One way to counteract this effect is to interconnect the ailerons and rudder so that when the rudder is moved the ailerons move automatically to correct the adverse roll.

Chapter 8

Flight Mechanics

Introduction

Flight Mechanics is the study of the forces acting on an aircraft in flight and the response of the aircraft to those forces.

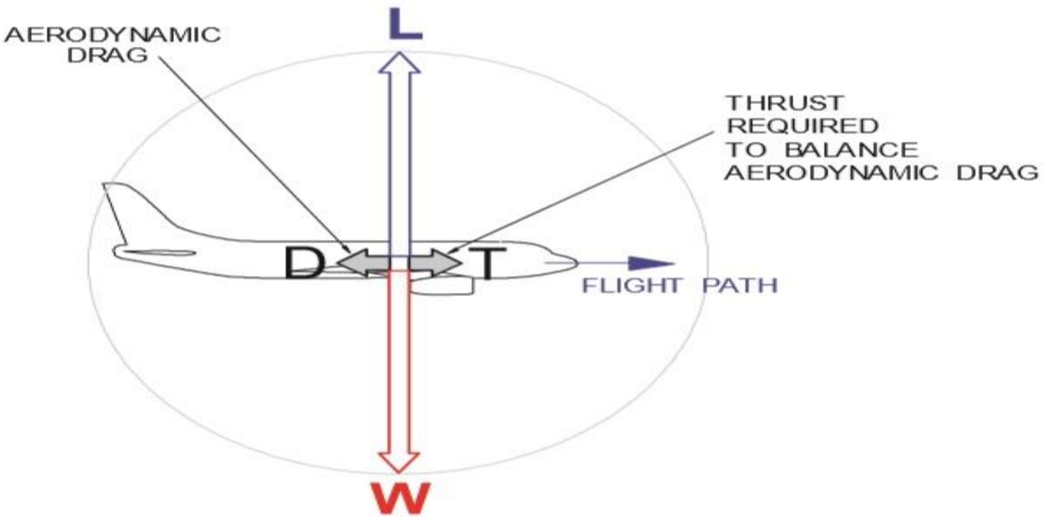
For an aircraft to be in steady (unaccelerated) flight, the following conditions must exist:

- the forces acting upward must exactly balance the forces acting downward,
- the forces acting forward must exactly balance the forces acting backward, and
- the sum of all moments must be zero.

This condition is known as equilibrium.

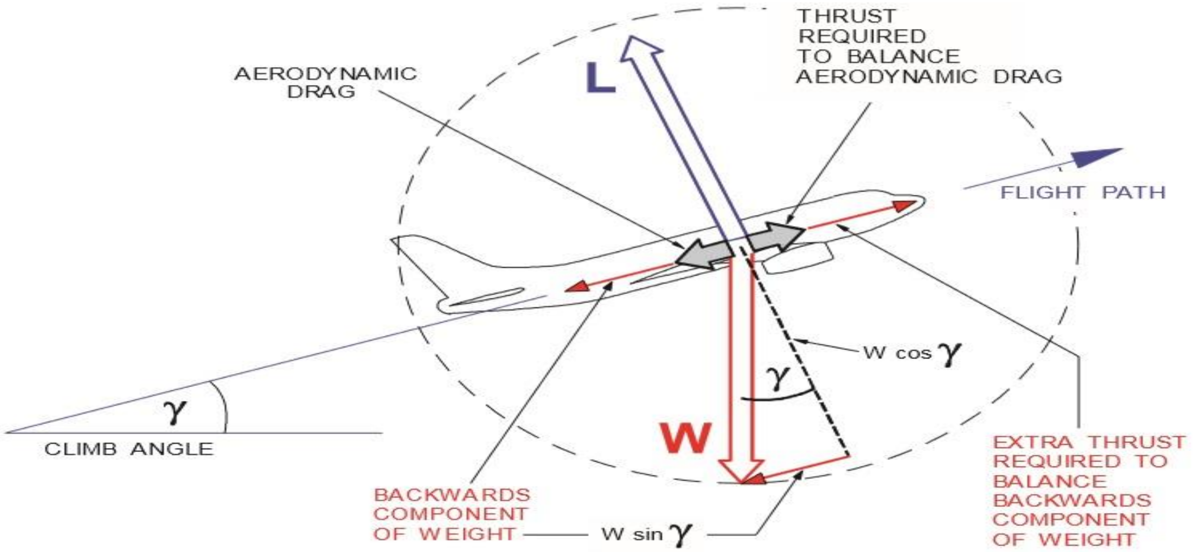
Straight Horizontal Steady Flight

In straight and level flight there are four forces acting on the aircraft: LIFT, WEIGHT, THRUST and DRAG.
Weight acts through the aircraft centre of gravity (CG), vertically downwards towards the centre of the earth. Alternatively, weight can be defined as acting parallel to the force of gravity.
Lift acts through the centre of pressure (CP), normal (at 90°) to the flight path.



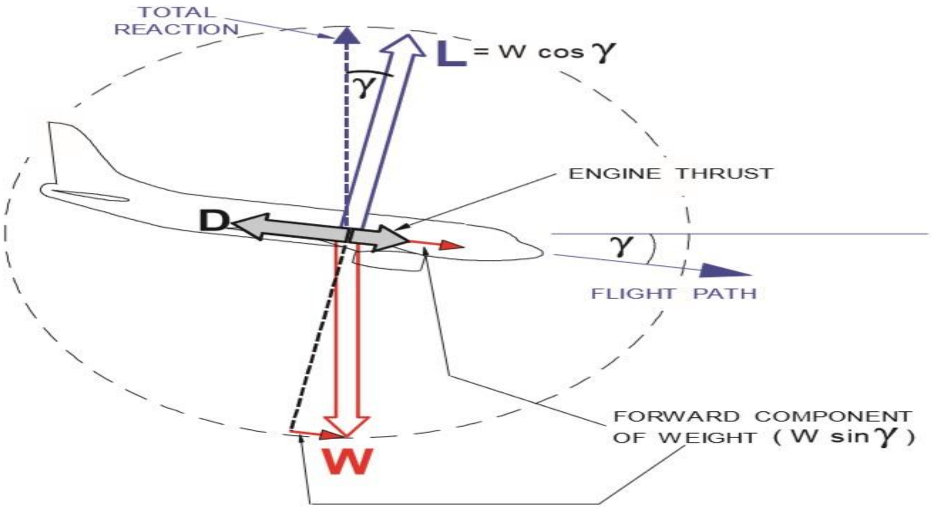
Straight Steady Climb

• Consider an aircraft in a straight steady climb along a straight flight path inclined at an angle (γ) to the horizontal. γ (gamma) is the symbol used for climb angle.
• The forces on the aircraft consist of Lift, normal to the flight path; Thrust and Drag, parallel to it; and Weight, parallel to the force of gravity.



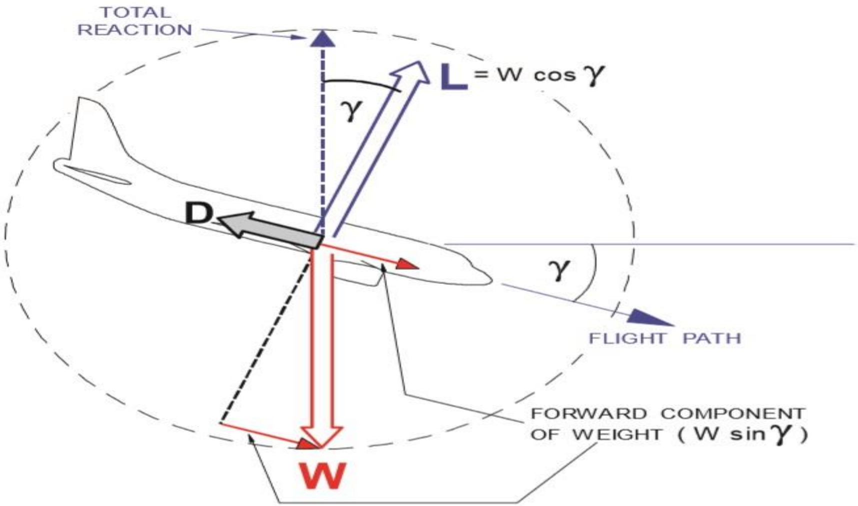
Power-on Descent

• The force of Weight is split into two components. One component (W cos γ) acts perpendicular to the flight path and is balanced by Lift, while the other component (W sin γ) acts forward along the flight path and 'adds' to the Thrust to balance Drag.
• If the nose of the aircraft is lowered with a constant Thrust setting, the increased component of Weight acting forward along the flight path will cause an increase in IAS.



Glide

• In a glide without Thrust , the Weight component along the flight path must supply the propulsive force and balance Drag. In a glide there are only three forces acting on the aircraft: Lift, Weight and Drag.



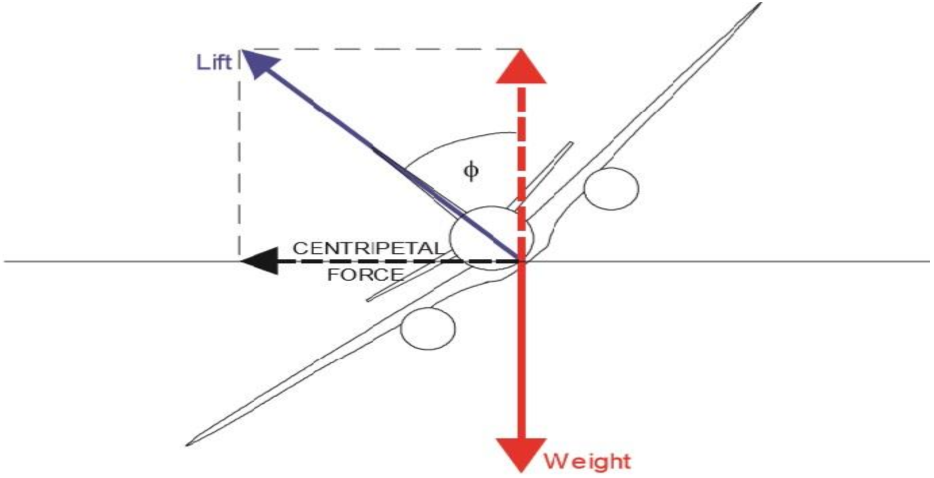
Turning

- For an aircraft to change direction, a force is required to deflect it towards the centre of the turn.

- This is called the centripetal force.

- Banking the aircraft inclines the lift.

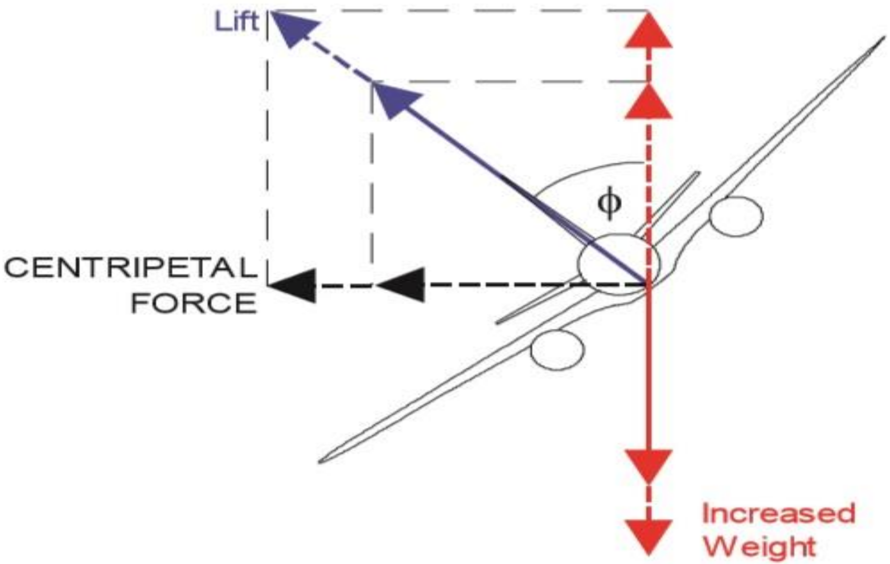
- It is the horizontal component of lift which causes the aircraft to turn. If the aircraft is banked and the angle of attack kept constant, the vertical component of lift will be too small to balance the weight and the aircraft will start to descend.



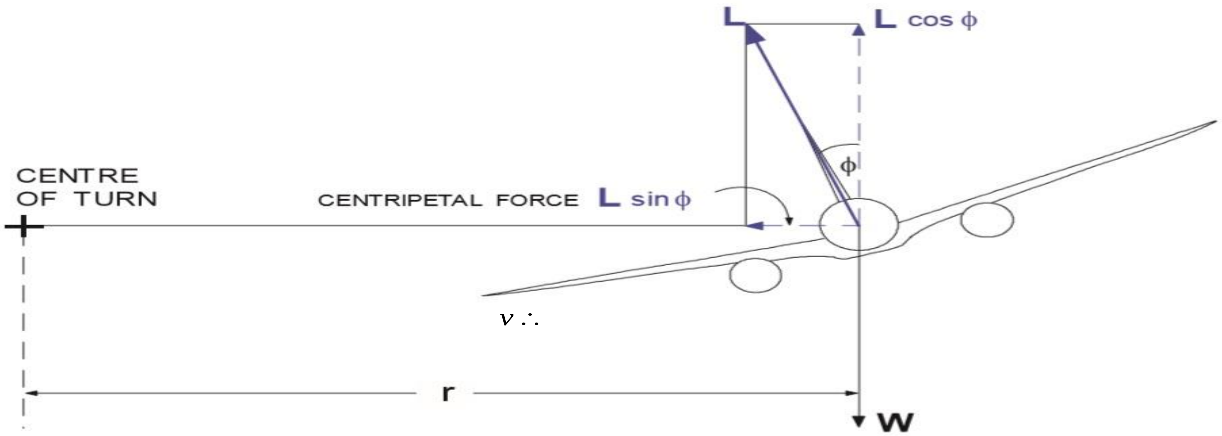
Effect of Weight on Turning

• In a steady level turn, if thrust is ignored, lift provides a force to balance weight and centripetal force to turn the aircraft.

• **If the same TAS and angle of bank can be obtained, the radius of turn is basically independent of weight or the aircraft type.**



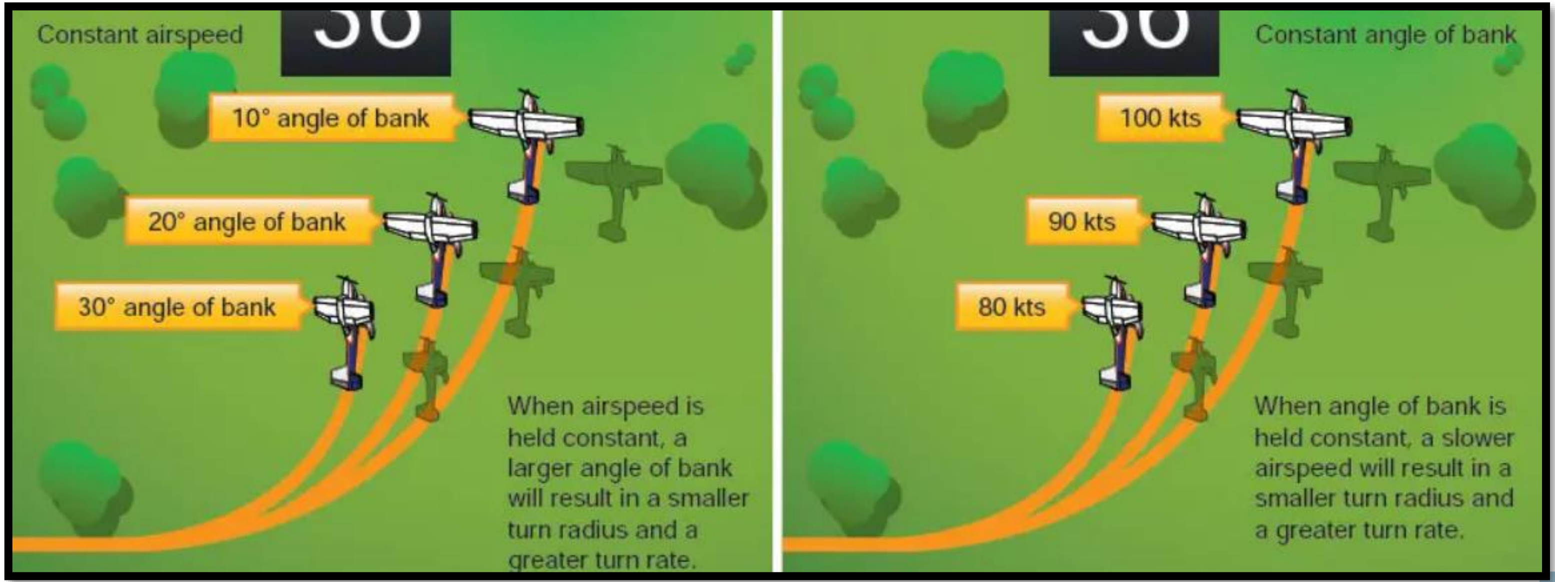
Radius and Rate of Turn



Turn Radius = $\frac{V2}{B.A}$

Rate of Turn = $\frac{B.A}{v}$

- **In a Constant Rate Turn The Angle of Bank is Dependent Upon TAS.**
- **If speed is doubled, the turn radius will be four times greater, at a constant bank angle.**
- **If speed is doubled, the rate of turn will be half of its previous value, at a constant bank angle.**



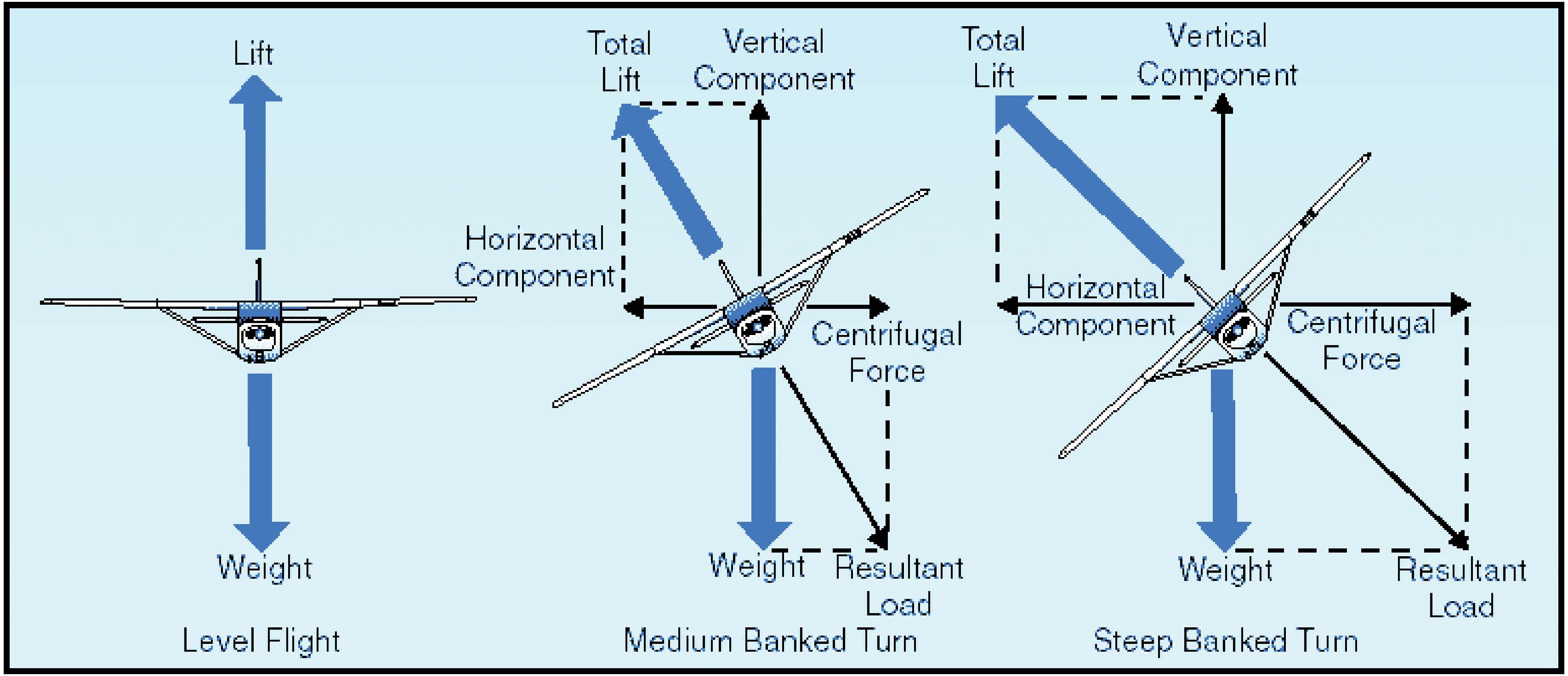
Load Factor in the Turn

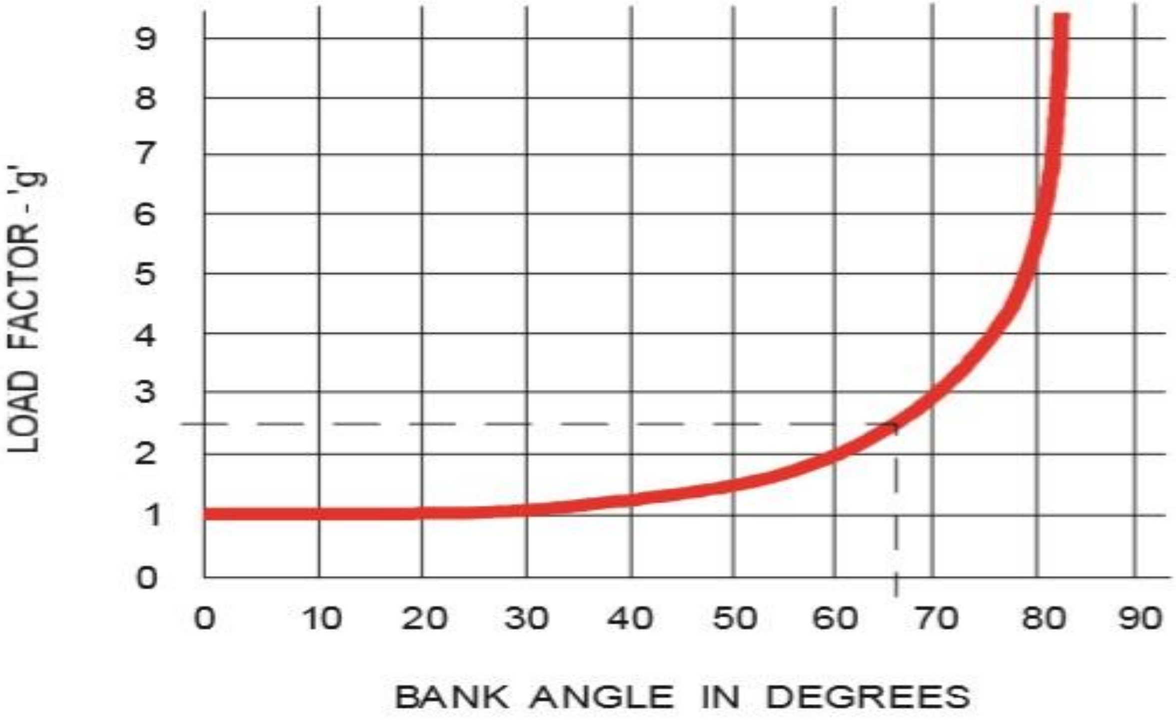
Load factor is directly related to bank angle, so the load factor for a given bank angle is the same at any speed.

Load factor in the turn is a function ONLY of bank angle
Constant Bank Angle, Constant Load Factor

$$\text{LOAD FACTOR 'g'} = \frac{\text{LIFT}}{\text{WEIGHT}}$$

(a) Increasing lift in a turn, increases the load factor.
(b) As bank angle increases, load factor increases.

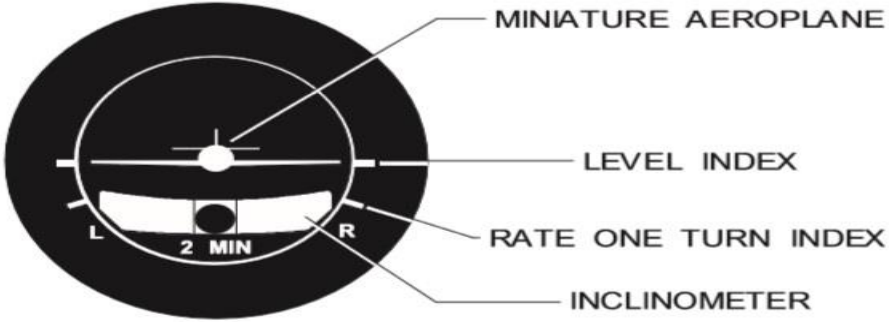

Lift
Weight
Level Flight
Total Lift
Vertical Component
Horizontal Component
Centrifugal Force
Weight
Resultant Load
Medium Banked Turn
Total Lift
Vertical Component
Horizontal Component
Centrifugal Force
Weight
Resultant Load
Steep Banked Turn


LOAD FACTOR - 'g'
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
BANK ANGLE IN DEGREES

Turn Co-ordination

• If the turn is unbalanced, an aircraft either **slips into**, or **skids out** of the turn, thereby reducing the aerodynamic efficiency of the aircraft.

• Co-ordinated flight is maintained by keeping the ball centred between the reference lines with rudder.
To do this, apply rudder pressure on the side where the ball is deflected.
The simple rule, "step on the ball," is a useful way to remember which rudder to apply.

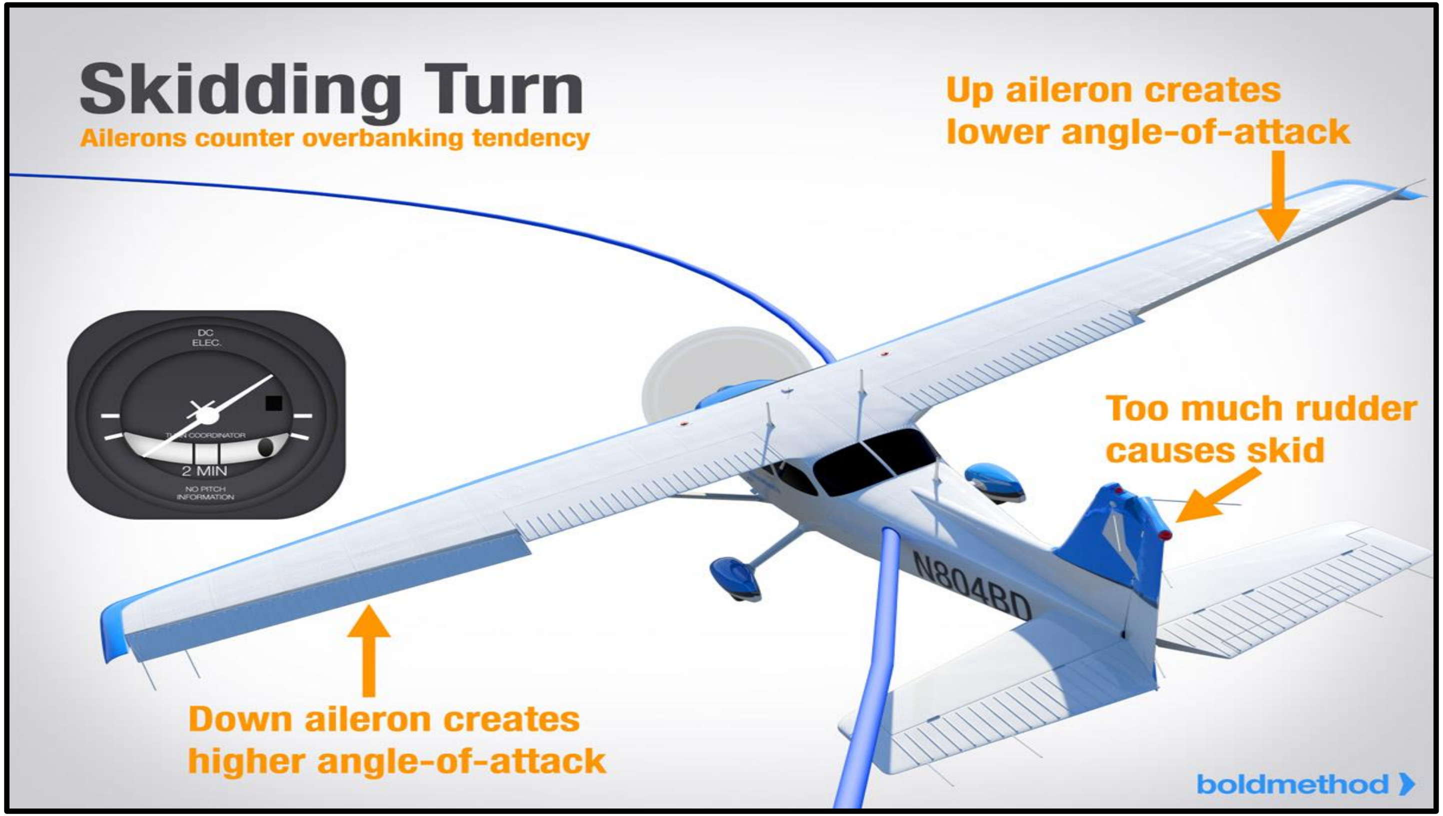


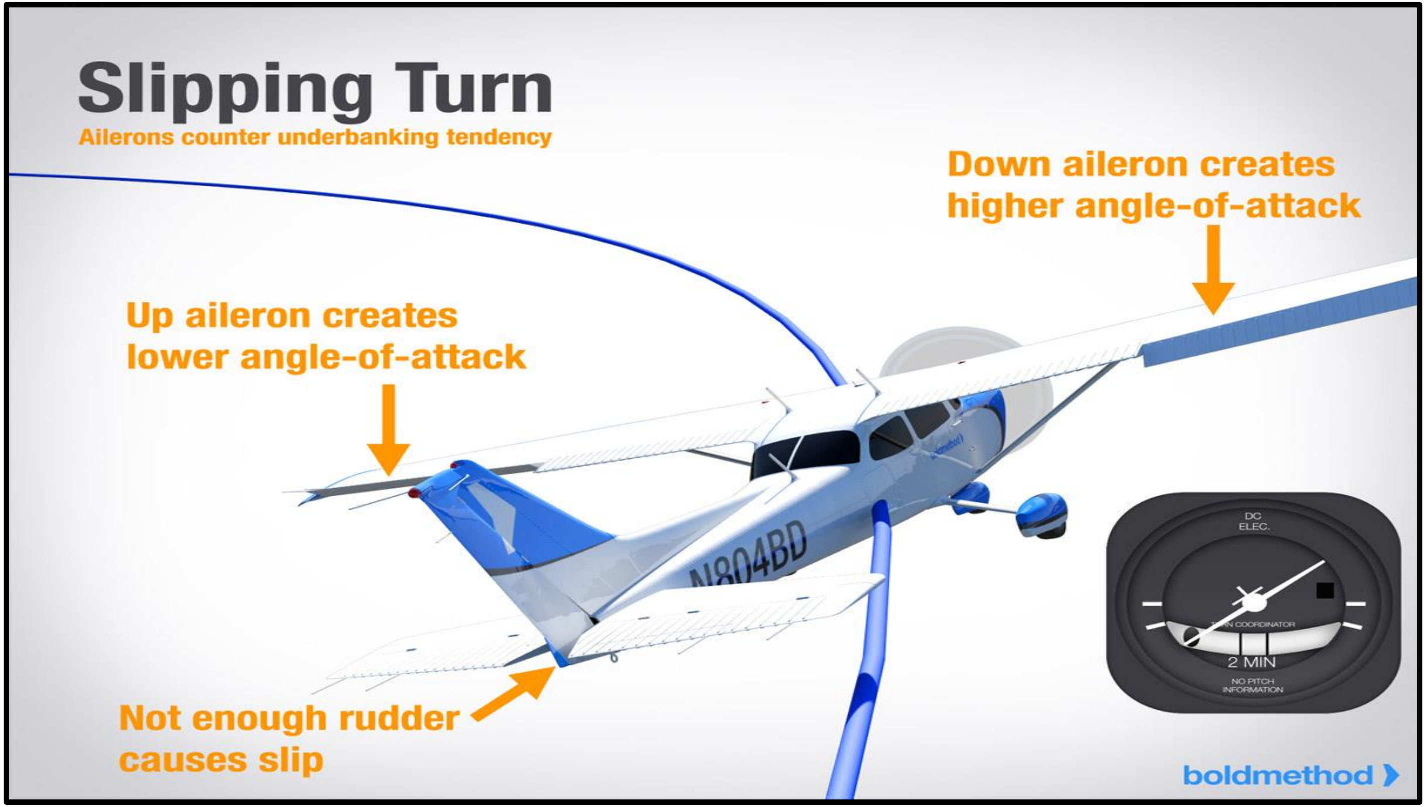
Slipping turn

• Figure shows the aircraft in an unco-ordinated turn to the right; it will be sideslipping towards the centre of the turn (**slipping turn**).
• A slipping turn occurs if the angle of bank is too large for a given rate of turn (i.e. the aircraft is over-banked).
• Using "step on the ball," the turn can be coordinated by applying right rudder pressure to centre the ball.

Skidding turn

• Figure shows the aircraft in an unco-ordinated turn to the right; it will be sideslipping towards the outside of the turn (**skidding turn**).
• A skidding turn occurs if the angle of bank is too small for the rate of turn (i.e. the aircraft is underbanked).
• Using "step on the ball," the turn can be coordinated by applying right rudder pressure to centre the ball.


Skidding Turn
Ailerons counter overbanking tendency
Up aileron creates lower angle-of-attack
Too much rudder causes skid
Down aileron creates higher angle-of-attack
DC ELEC.
2 MIN
NO PITCH INFORMATION
N804BD
boldmethod


Slipping Turn
Ailerons counter underbanking tendency
Down aileron creates higher angle-of-attack
Up aileron creates lower angle-of-attack
Not enough rudder causes slip
N804BD
DC ELEC.
2 MIN
NO PITCH INFORMATION
boldmethod

Chapter 11

Stability and Control

Introduction

Stability is the tendency of an aircraft to return to a steady state of flight without any help from the pilot, after being disturbed by an external force.
An aircraft must have the following qualities:

- Adequate stability to maintain a uniform flight condition.
- The ability to recover from various disturbing influences.
- Sufficient stability to minimize the workload of the pilot.
- Proper response to the controls so that it may achieve its design performance with adequate manoeuvrability.

There are two broad categories of stability, **static and dynamic**.

Static Stability

The type of static stability an aircraft possesses is defined by its initial tendency, following the removal of some disturbing force.

- **Positive static stability (or static stability)**

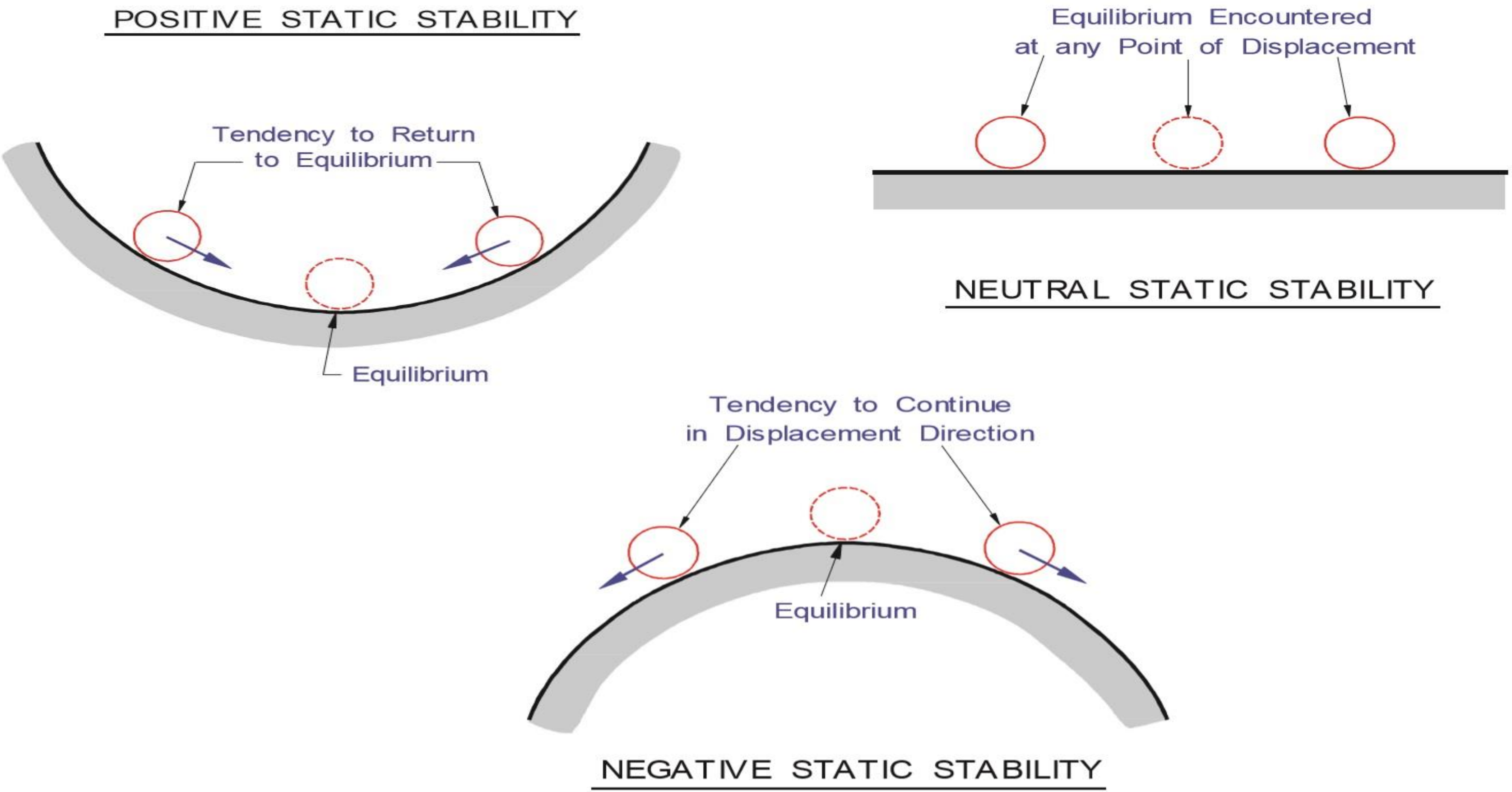
exists if an aircraft is disturbed from equilibrium and has the tendency to return to equilibrium.

- **Neutral static stability**

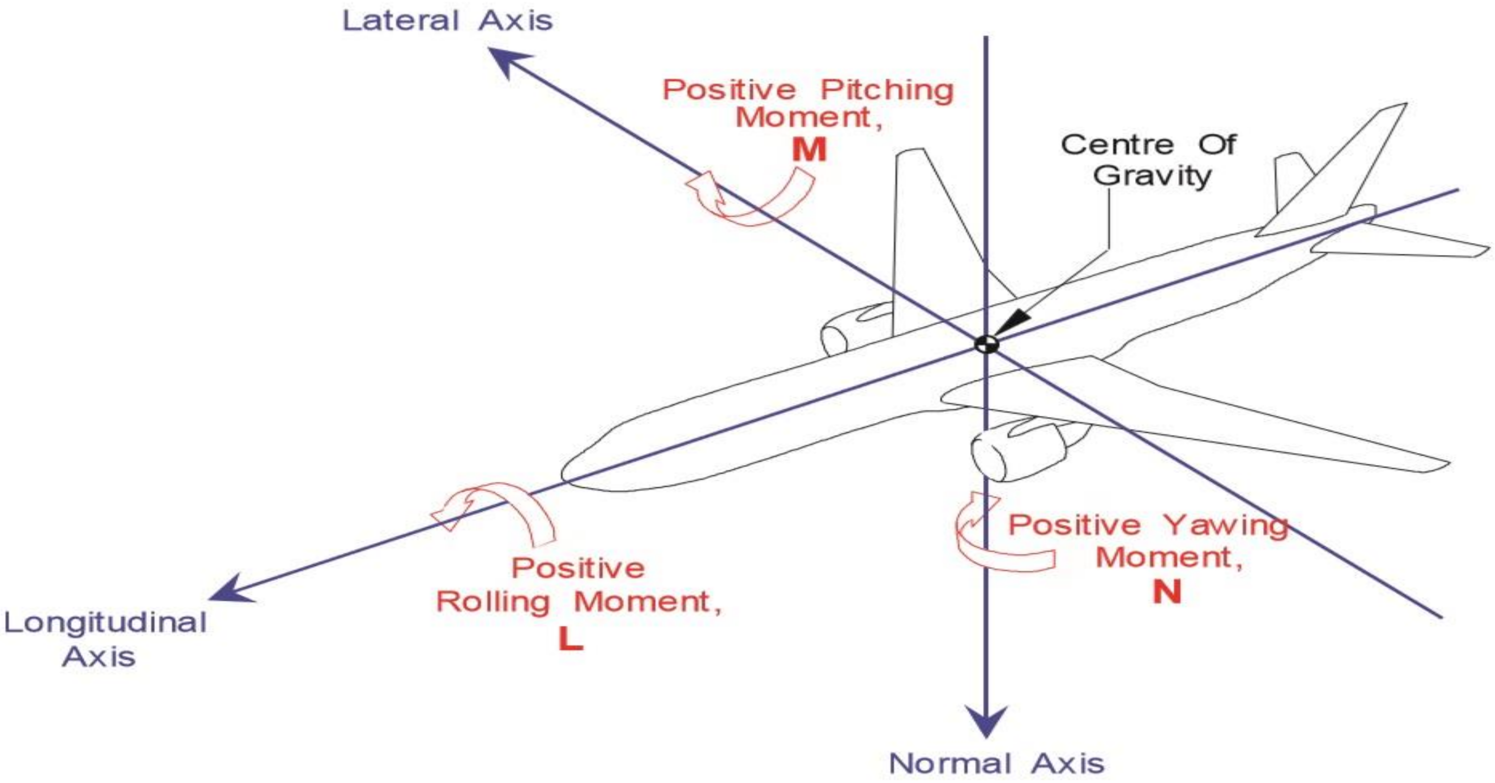
exists if an aircraft is subject to a disturbance and has neither the tendency to return nor the tendency to continue in the displacement direction.

- **Negative static stability (or static instability)**

exists if an aircraft has a tendency to continue in the direction of disturbance.


POSITIVE STATIC STABILITY
Tendency to Return to Equilibrium
Equilibrium
Equilibrium Encountered at any Point of Displacement
NEUTRAL STATIC STABILITY
Tendency to Continue in Displacement Direction
Equilibrium
NEGATIVE STATIC STABILITY

Aeroplane Reference Axes



Trim and Controllability

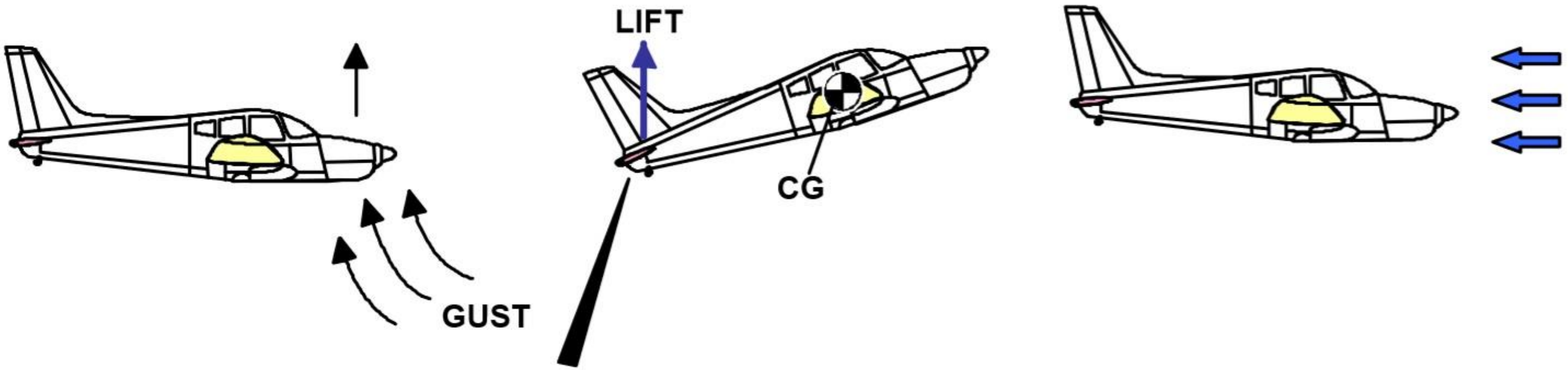
• An aircraft is said to be trimmed (in trim) if all moments in pitch, roll, and yaw are equal to zero.
• The term controllability refers to the ability of the aircraft to respond to control surface displacement and achieve the desired condition of flight.
• Adequate controllability must be available to perform take-off and landing and accomplish the various manoeuvres in flight.
• Manoeuvrability is the quality of an aircraft that permits it to be manoeuvred easily and to withstand the stresses imposed by those manoeuvres.

Increasing stability about any axis:

- decreases manoeuvrability and controllability, and
- increases stick (or pedal) forces.

Static Longitudinal Stability

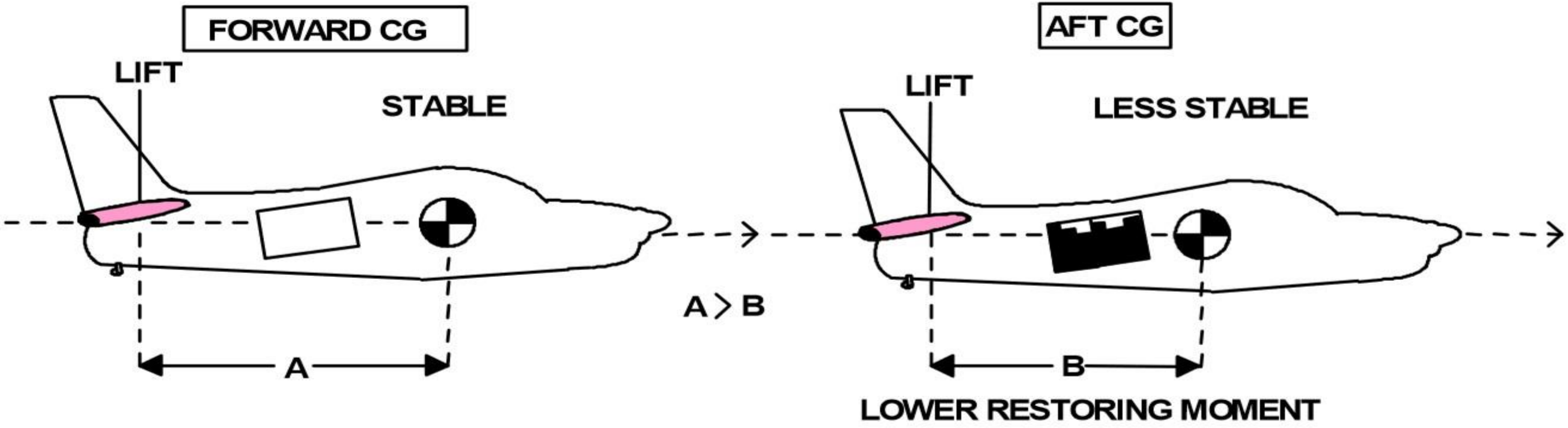
• Longitudinal stability is motion about the lateral axis.
• An aircraft will exhibit static longitudinal stability if it tends to return towards the trim angle of attack when displaced by a gust OR a control input.
• If the aircraft is neutrally stable, it tends to remain at any displacement to which it is disturbed.
• The aircraft which is unstable will continue to pitch in the disturbed direction until the displacement is resisted by opposing control forces.



FACTORS AFFECTING STATIC LONGITUDINAL STABILITY

- **Position of the Centre of Gravity**

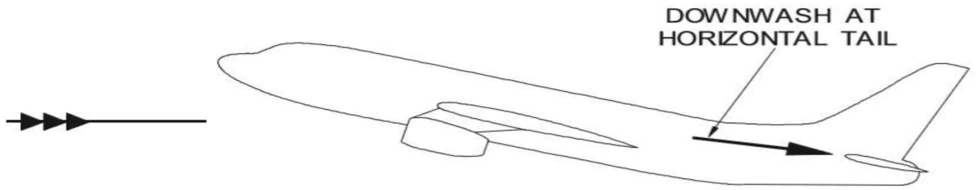
Generally, the further forward the centre of gravity the greater the stability , the greater the stick force and the greater the effort required to manoeuvre the aircraft. Positioning the centre of gravity too far forward results in excessive stick forces, making the aircraft extremely tiring to fly.
Conversely, moving the centre of gravity progressively aft steadily decreases the degree of stability, as well as the stick forces, and the aircraft returns less quickly to trimmed flight.



- **Downwash**

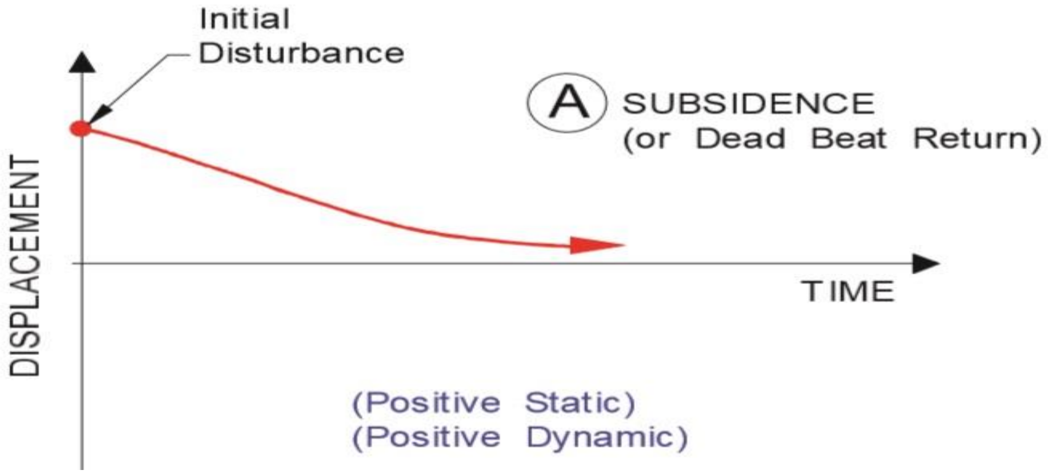
Any factor which alters the rate of change of downwash at the horizontal tail (e.g. flaps or propeller slipstream) will directly affect the tail contribution and aeroplane stability.

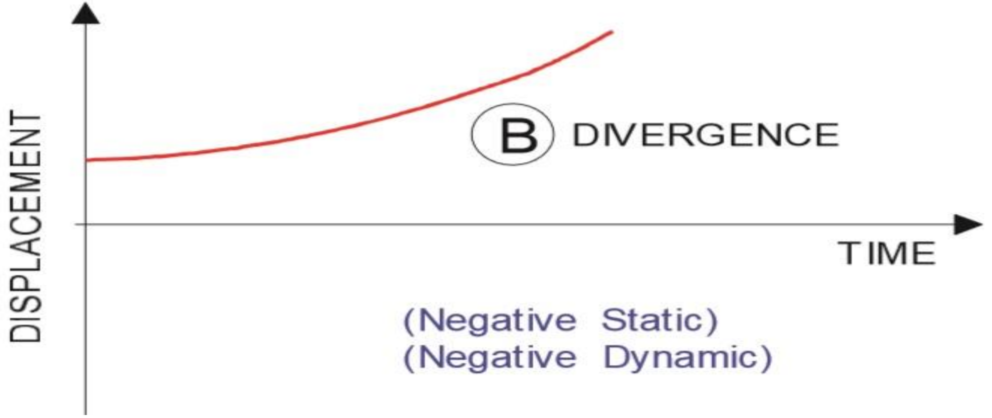
Downwash decreases static longitudinal stability.

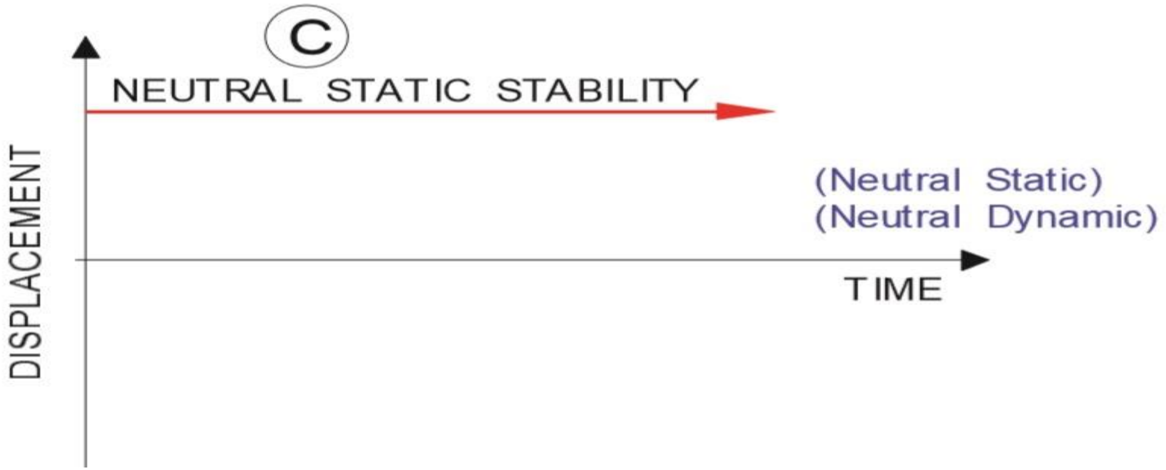


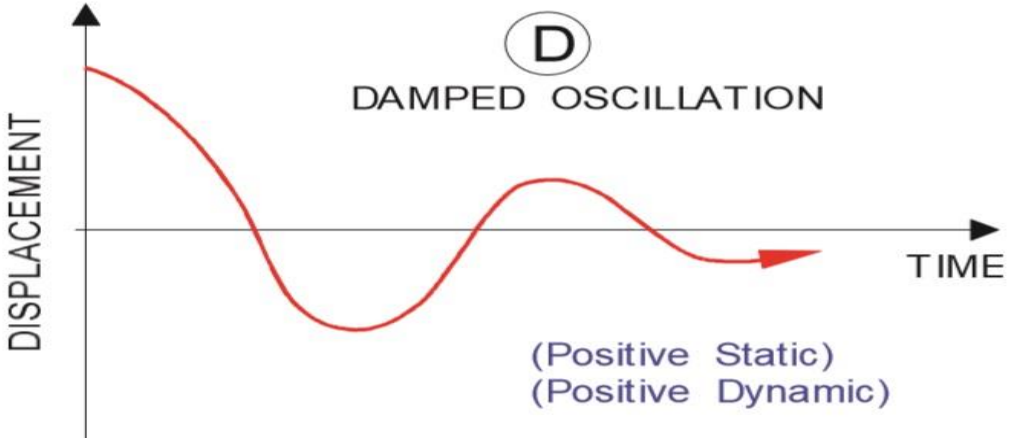
Dynamic Stability

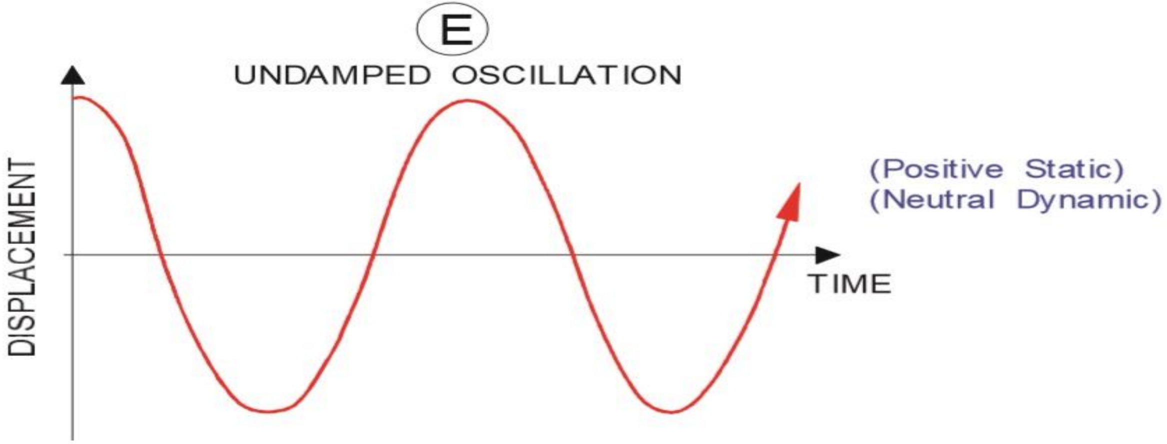
While static stability is concerned with the initial tendency of an aircraft to return to equilibrium, dynamic stability is defined by the resulting motion with time.

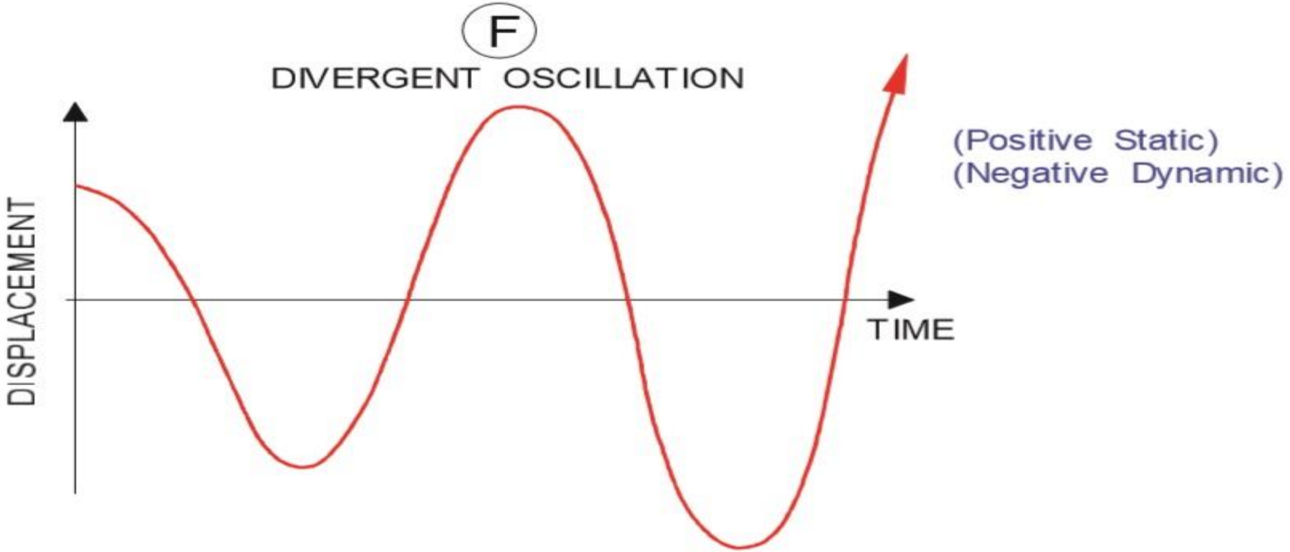



DISPLACEMENT
B DIVERGENCE
TIME
(Negative Static)
(Negative Dynamic)


C
NEUTRAL STATIC STABILITY
DISPLACEMENT
(Neutral Static)
(Neutral Dynamic)
TIME


D
DAMPED OSCILLATION
DISPLACEMENT
TIME
(Positive Static)
(Positive Dynamic)


E
UNDAMPED OSCILLATION
DISPLACEMENT
TIME
(Positive Static)
(Neutral Dynamic)

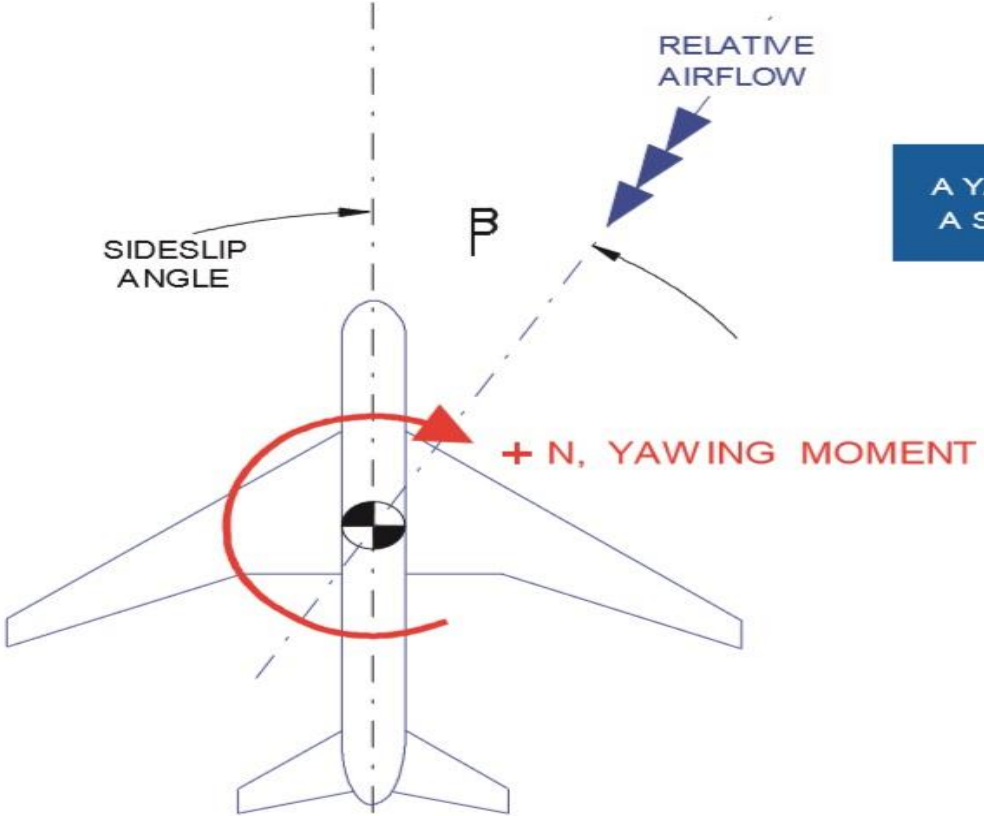


IF AN AIRCRAFT IS STATICALLY UNSTABLE, IT CANNOT BE DYNAMICALLY STABLE

Directional Stability and Control

directional stability would be the development of yawing moments which tend to restore the aeroplane to equilibrium.

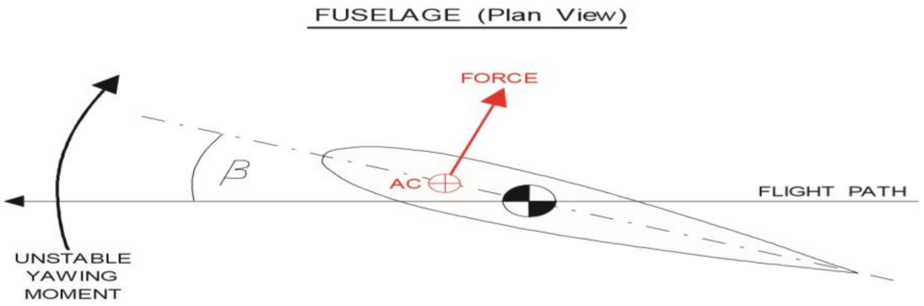
Sideslip Angle



A YAW TO THE LEFT GIVES
A SIDESLIP TO THE RIGHT

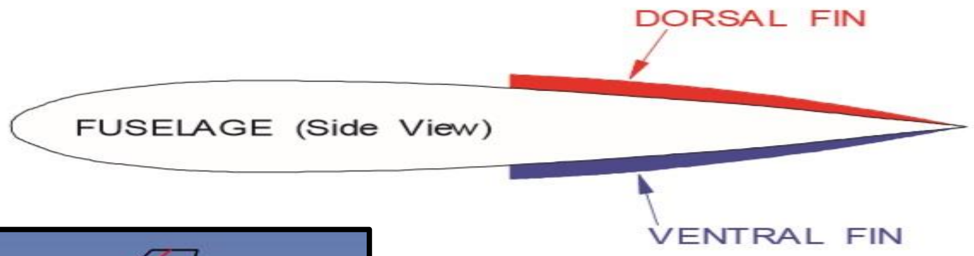
Contribution of the Aeroplane Components

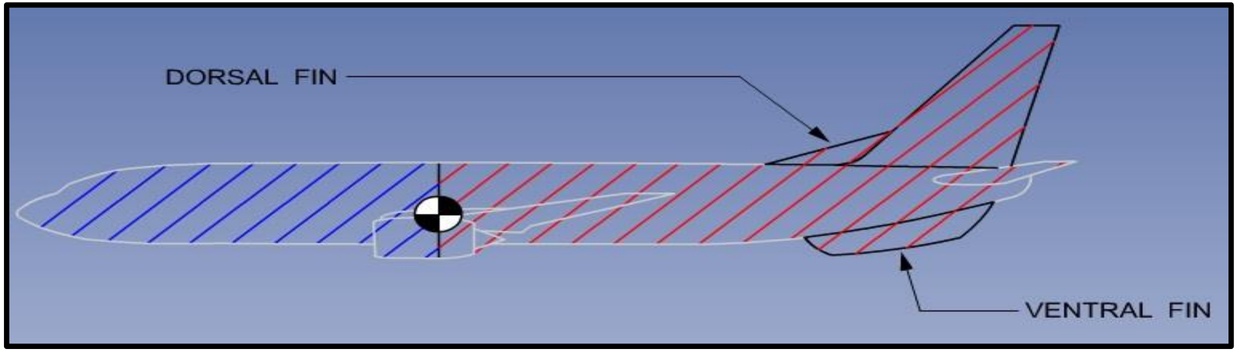
- **Fuselage**

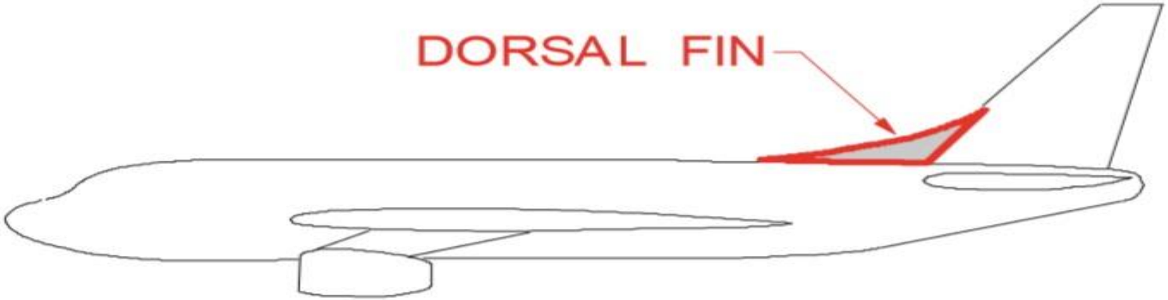


• **Dorsal and Ventral Fins**

To overcome the instability in the fuselage it is possible to incorporate into the overall design dorsal or ventral fins. A dorsal fin is a small aerofoil, of very low aspect ratio, mounted on top of the fuselage near the rear. A ventral fin is mounted below. If the aircraft is yawed to the right, the dorsal and ventral fins will create a side force to the right. The line of action of this force is well aft of the aircraft CG, giving a yawing moment to the left (a stabilizing effect).However, at small angles of yaw they are ineffective.

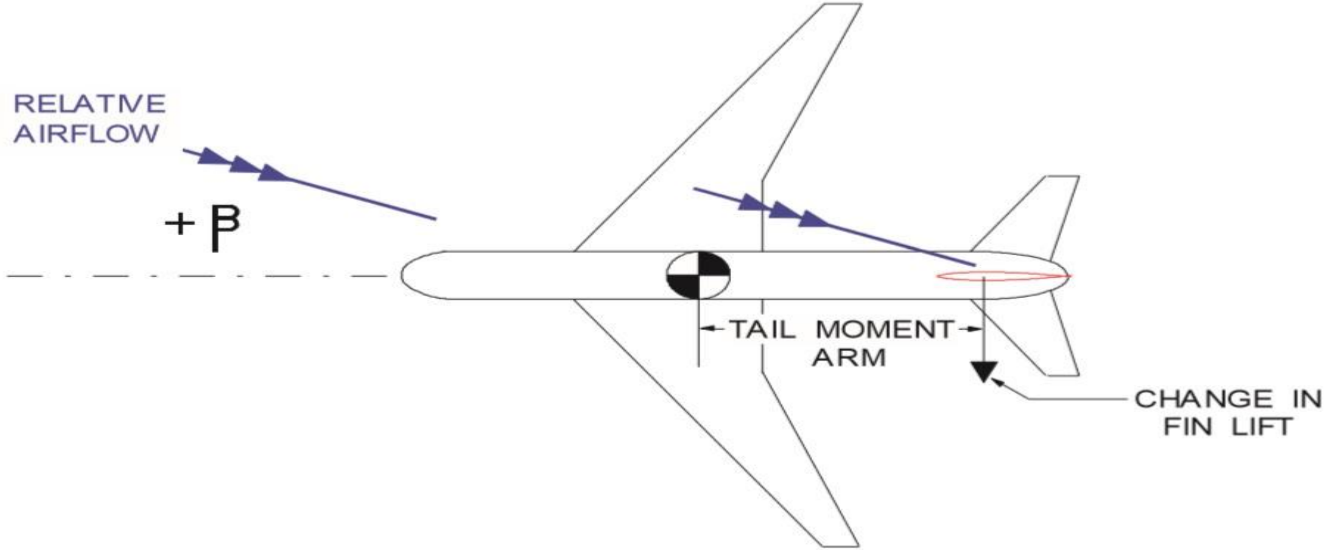





DORSAL FIN

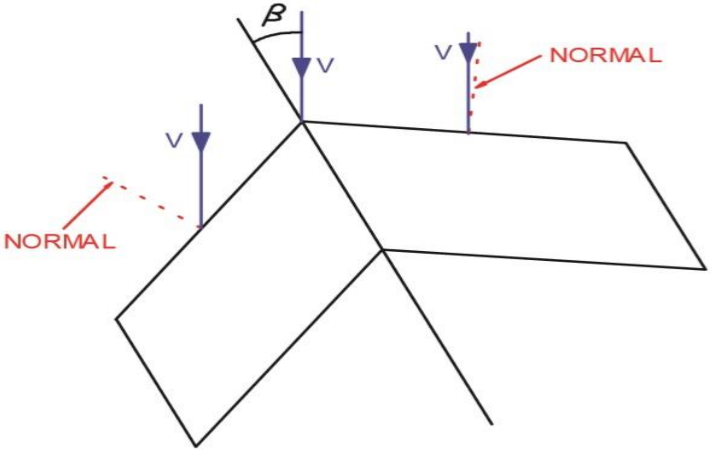
- **Fin**

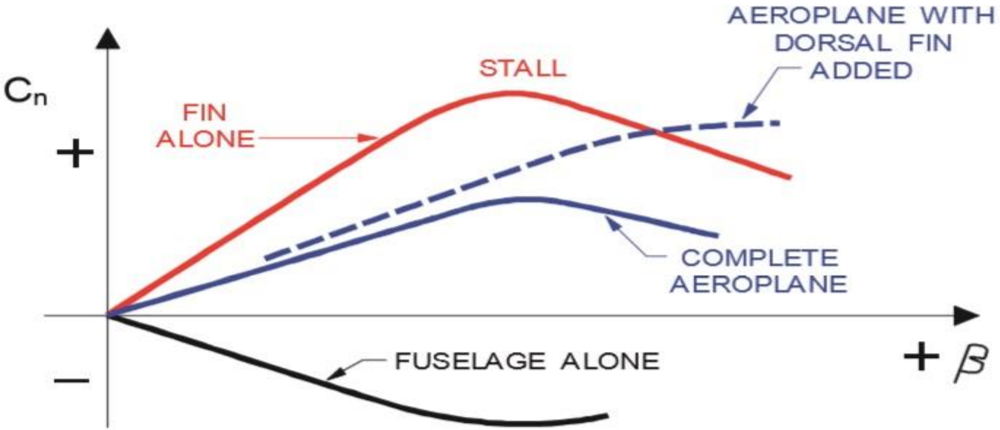
The fin (vertical stabilizer) is the major source of directional stability for the aeroplane.in a sideslip the fin will experience a change in angle of attack. The change in lift (side force) on the fin creates a yawing moment about the centre of gravity which tends to yaw the aeroplane into the relative airflow.
The contribution of the fin is a direct function of its area. A high mounted tailplane ('T' - tail) makes the fin more effective by acting as an "end plate".



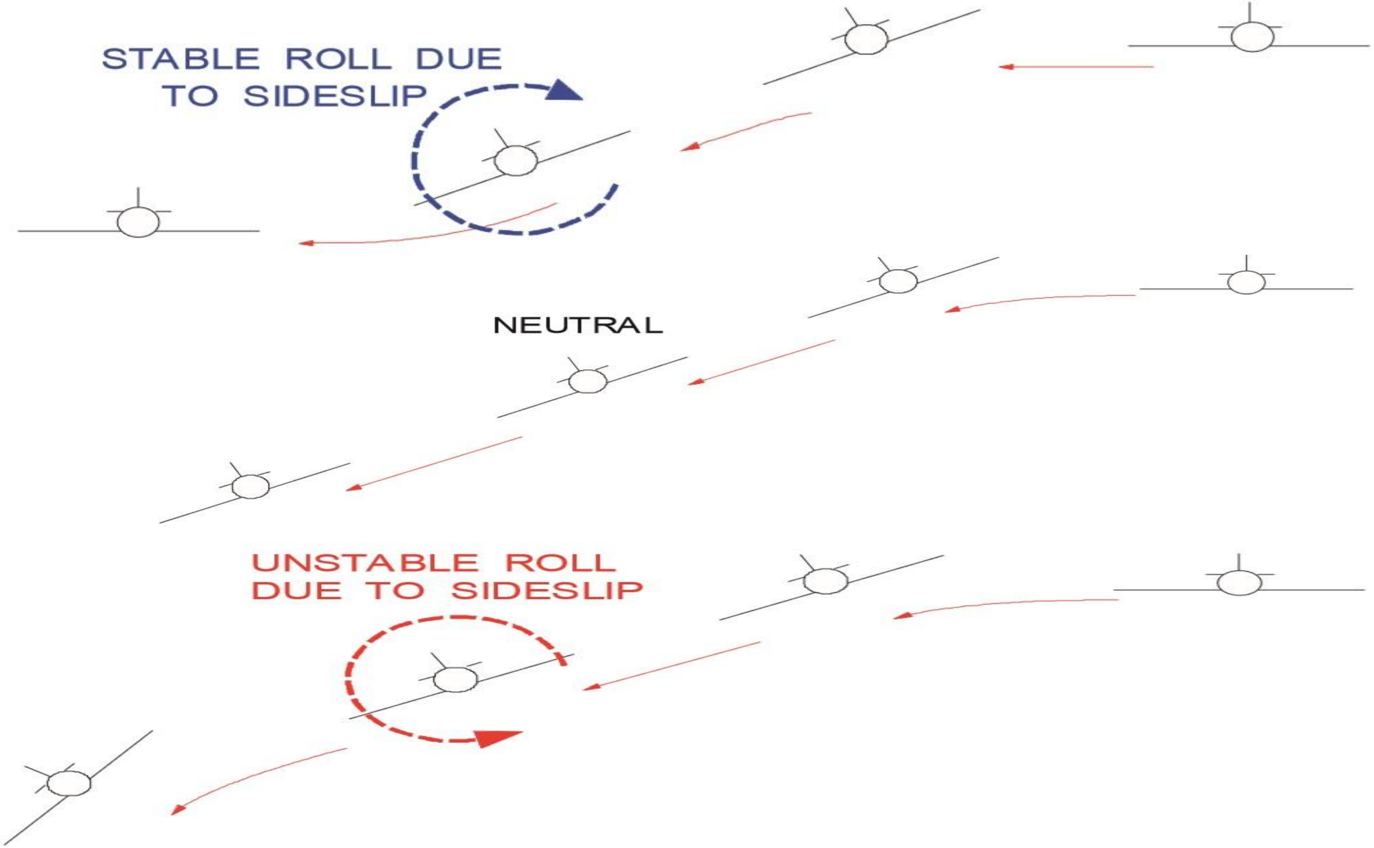
- **Wing**

Sweepback produces a stabilizing effect, which increases with increase in CL. The contribution of a straight wing alone is usually negligible.





Lateral Stability and Control



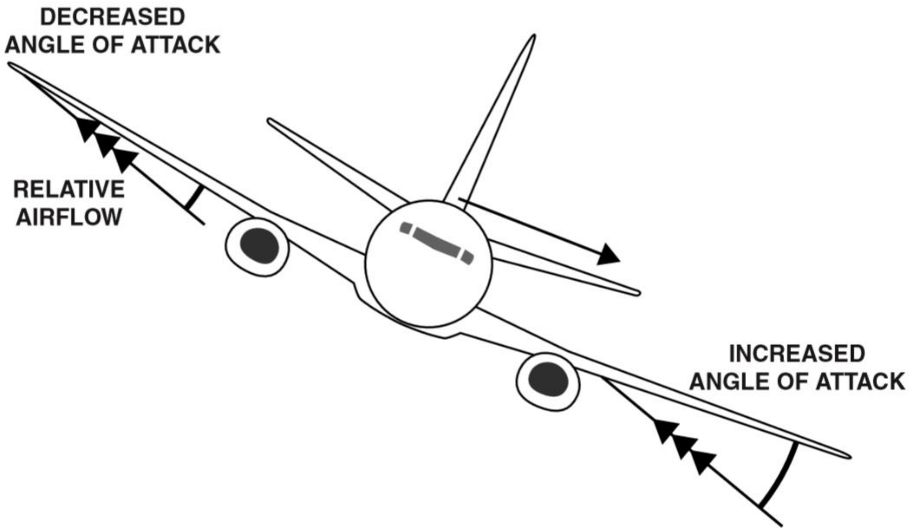
The aeroplane design features that increase the lateral static stability are:

a. dihedral;
b. sweepback;
c. high-wing mounting;
d. increased effective dihedral;
e. large, high vertical fin;

Contribution of the Aeroplane Components

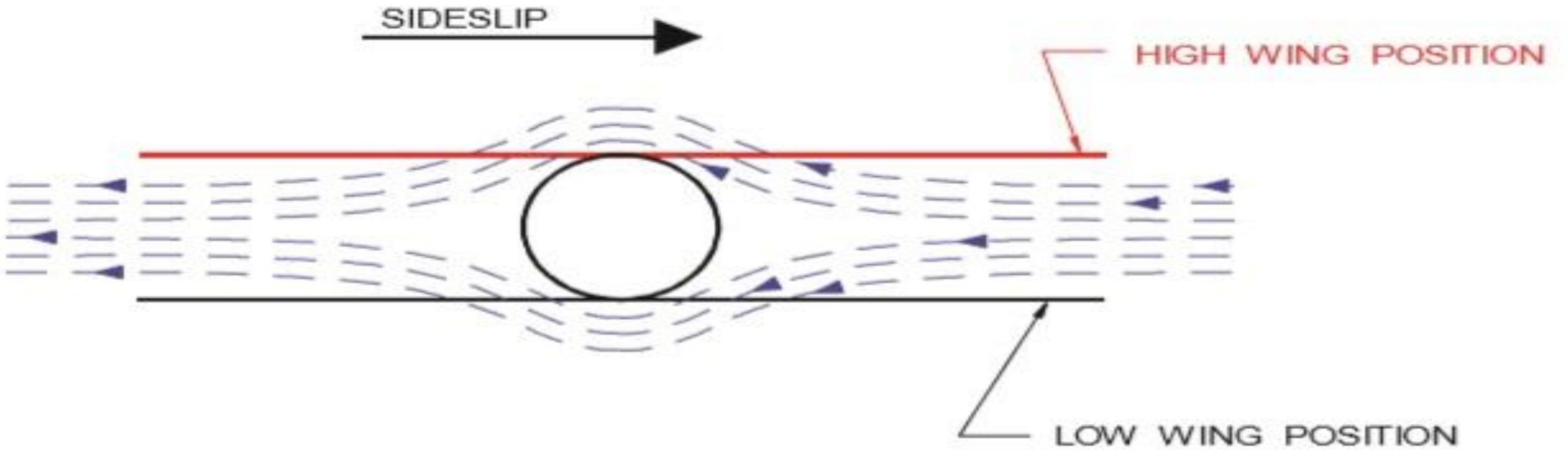
- **Wing**

The principal surface contributing to the lateral stability of an aeroplane is the wing. The effect of *geometric dihedral is a powerful contribution to lateral stability.Generally, the contribution of wing , is expressed as "DIHEDRAL EFFECT".



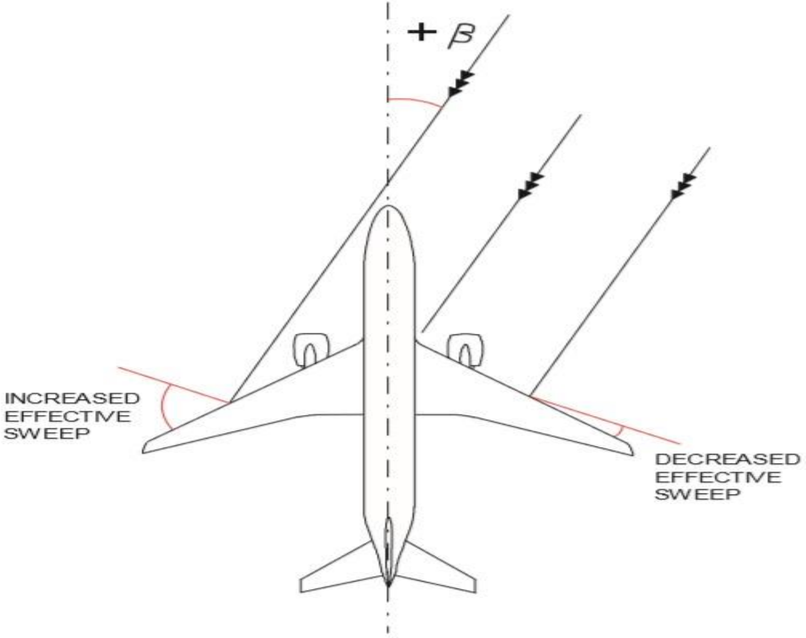
- **Wing Position**

A low wing position gives an unstable contribution. The direction of relative airflow decreases the effective angle of attack of the wing into wind and increases the effective angle of attack of the wing out of wind - tending to increase the rolling moment.A high wing location gives a stable contribution. The direction of relative airflow increases the effective angle of attack of the wing into wind and decreases the effective angle of attack of the wing out of wind, tending to decrease the rolling moment.



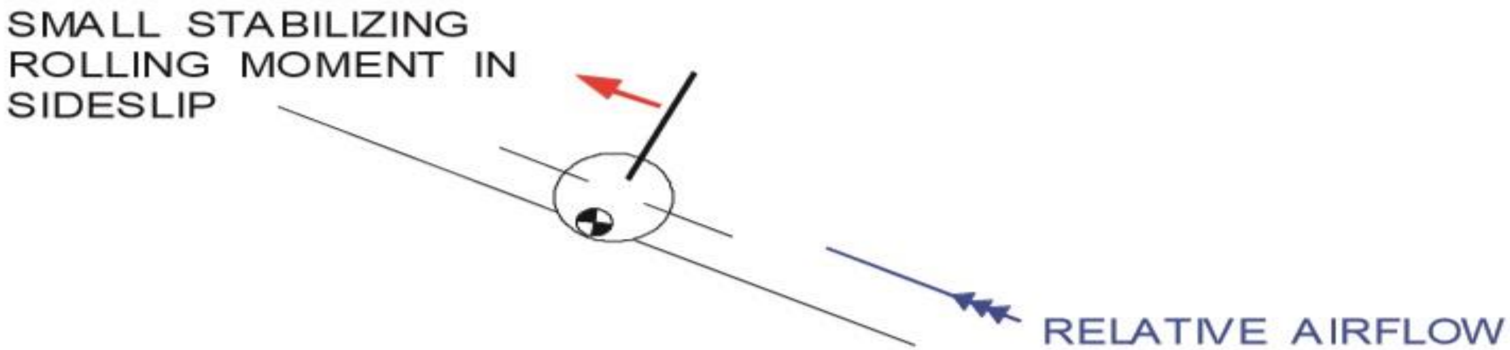
- **Sweepback**

The contribution of sweepback to "dihedral effect" is important . the wing into the wind has less sweep and an increase in lift, and the wing out of the wind has more sweep and a decrease in lift; a negative rolling moment will be generated, tending to roll the wings towards level. In this manner the swept-back wing contributes a **positive "dihedral effect".**



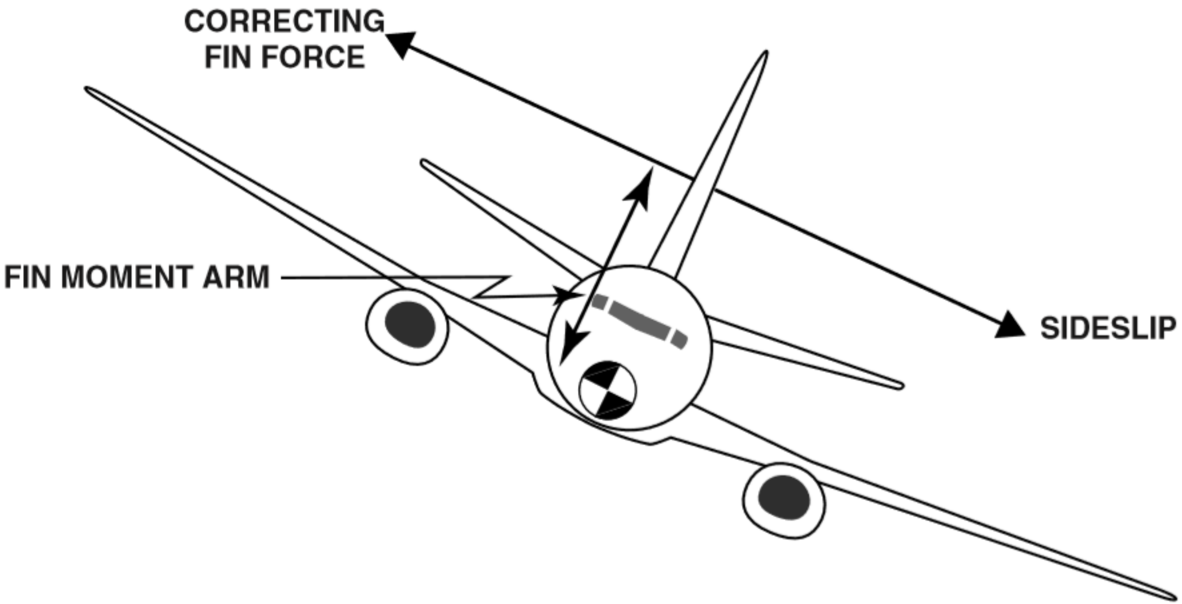
- **FIN**

If the fin is large, the side force produced by sideslip may produce a rolling moment as well as the important yawing moment contribution. The fin contribution to purely lateral static stability is usually very small.



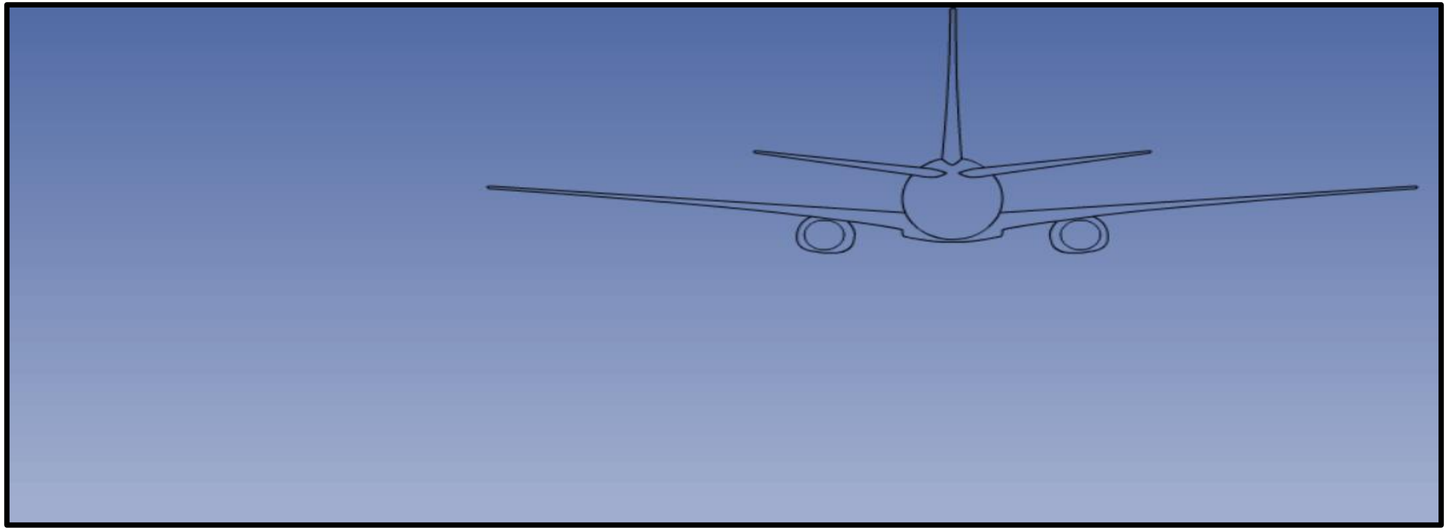
• **ventral fin**

Because the relative airflow during a sideslip produces a correcting moment it is advantageous for aeroplane designers to use a large fin area with the centre of pressure as far above the CG as possible. This engenders a large correcting rolling moment and it therefore creates a high degree of lateral static stability.



Spiral Divergence

$$DIRECTIONAL \succ LATERAL$$

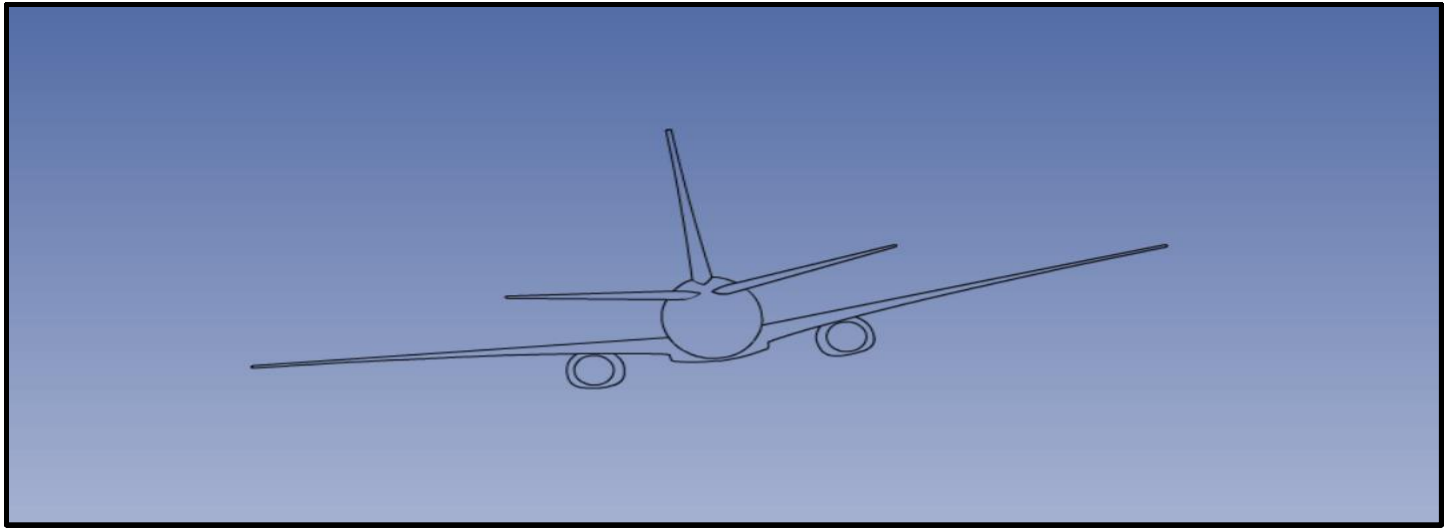


The character of spiral divergence is not violent. When a small sideslip is introduced, the strong directional stability tends to restore the nose into the wind while the relatively weak “dihedral effect” lags in restoring the aeroplane laterally. The rate of divergence in the spiral motion is usually so gradual that the pilot can control the tendency without difficulty.

Dutch Roll

$$LATERAL \succ DIRECTIONAL$$

When a yaw is introduced, the strong “dihedral effect” will roll the aircraft due to the lift increase on the wing into wind. The increased induced drag on the rising wing will yaw the aircraft in the opposite direction, reversing the coupled oscillations.
Aircraft with a tendency to Dutch roll are fitted with a Yaw Damper. This automatically displaces the rudder proportional to the rate of yaw to damp-out the oscillations.



Chapter 13

limitations

Operational Rough-air Speed (VRA)

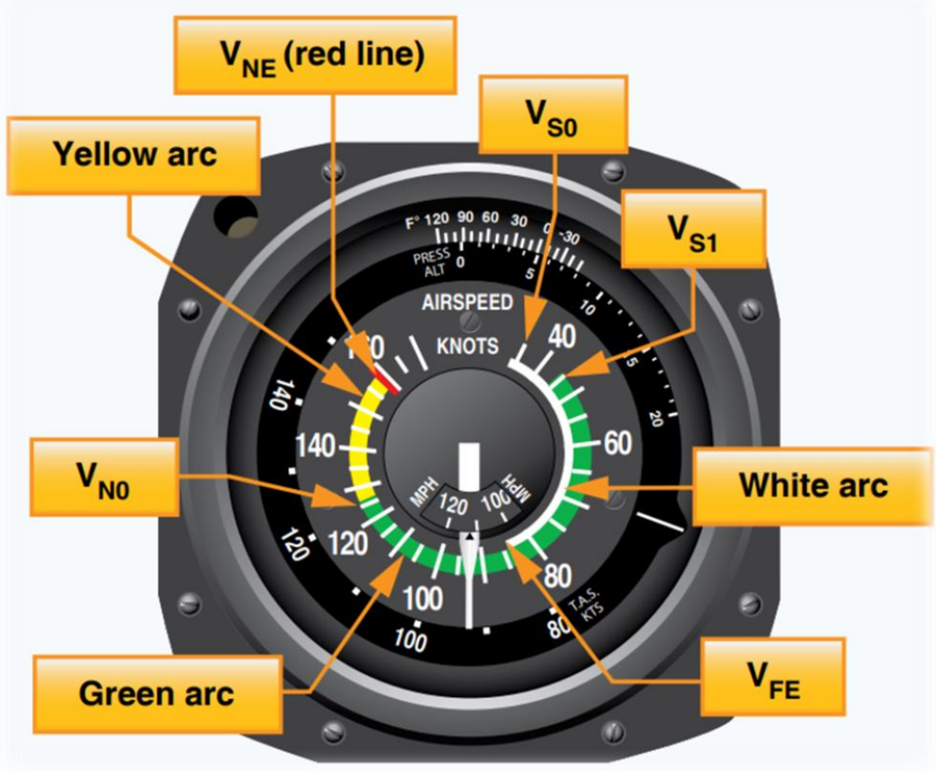
For flight in turbulence an airspeed must be chosen to give protection against two possibilities: stalling and overstressing the aircraft structure. Turbulence is defined by a gust of a defined value. If this defined gust is encountered, the aircraft speed must be:

- high enough to avoid stalling.
- low enough to avoid damage to the structure.

Design Manoeuvring Speed, VA

The highest speed at which sudden, full elevator deflection (nose-up) can be made without exceeding the design limit load factor.

Operational Speed Limits



Chapter 14

Propellers

Introduction

• A propeller converts shaft power from the engine into thrust.

• It does this by accelerating a mass of air rearwards.

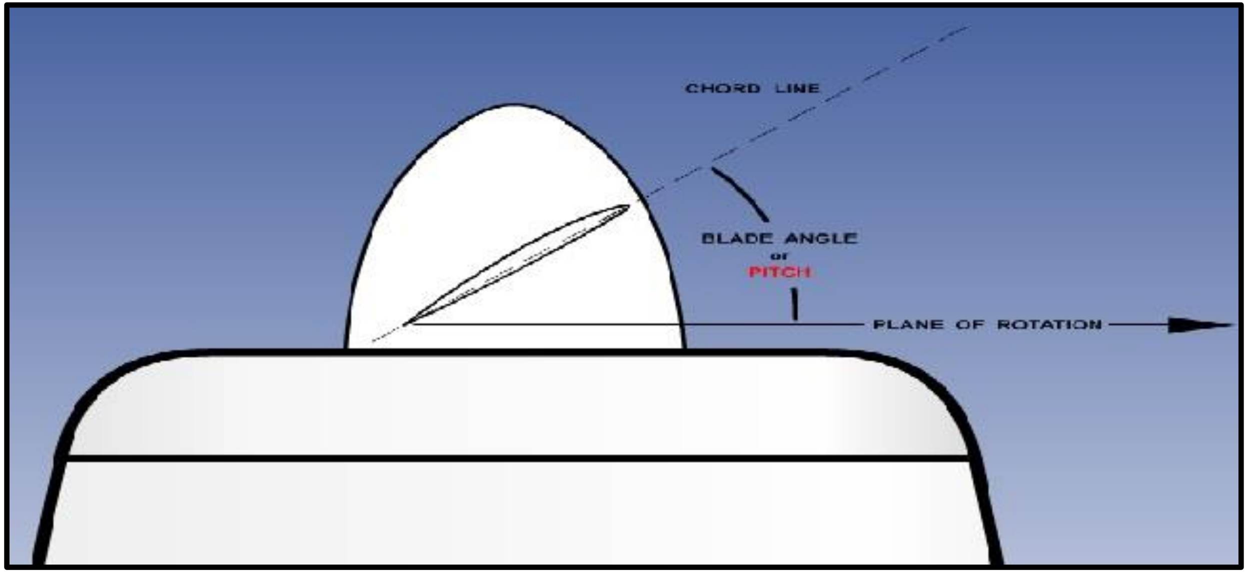
• Thrust from the propeller is equal to the mass of air accelerated rearwards multiplied by the acceleration given to it.

• A mass is accelerated rearwards and the equal and opposite reaction drives the aircraft forwards.

Definitions

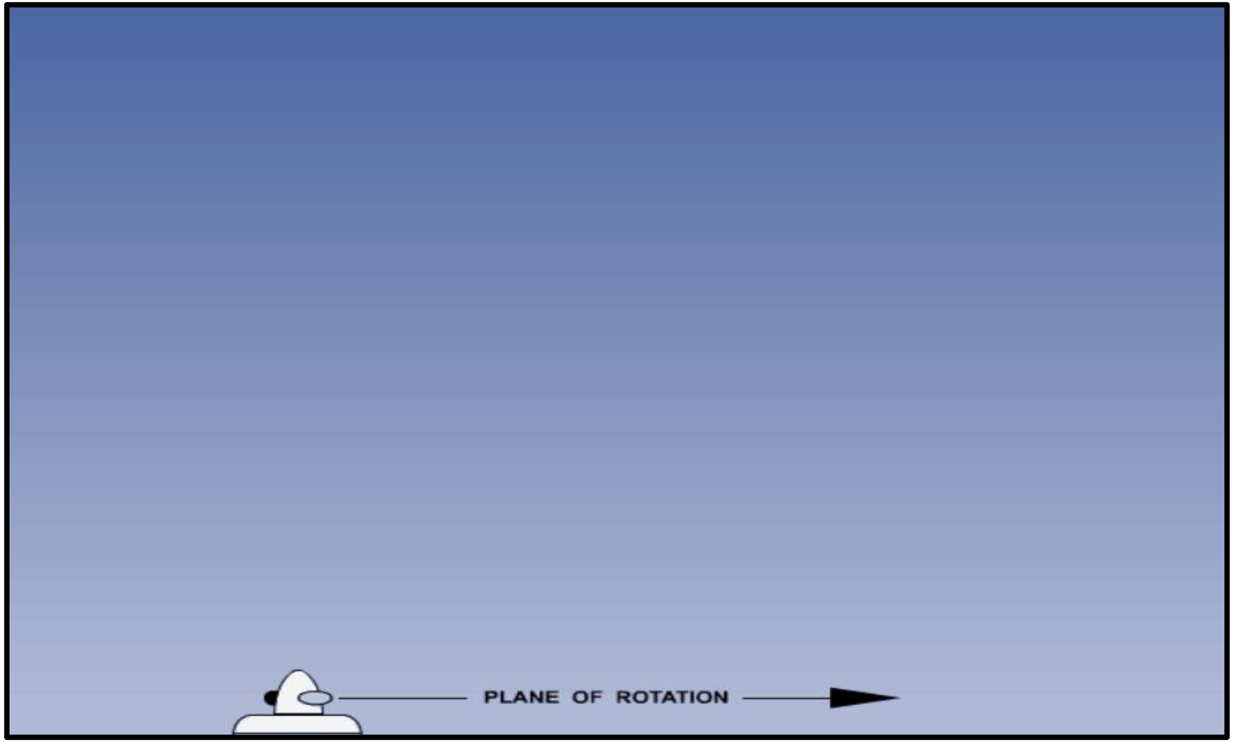
- **Blade Angle or Pitch**

The angle between the blade chord and the plane of rotation.



• **Geometric Pitch**

The geometric pitch is the distance the propeller would travel forward in one complete revolution if it were moving through the air at the blade angle.



- **Blade Twist**

Sections near the tip of the propeller are at a greater distance from the propeller shaft and travel through a greater distance. Tip speed is therefore greater. The blade angle must be decreased towards the tip to give a constant geometric pitch along the length of the blade.The blade angle determines the geometric pitch of the propeller. A small blade angle is called “fine pitch”, a large blade angle is called “coarse pitch”.

- **Effective Pitch**

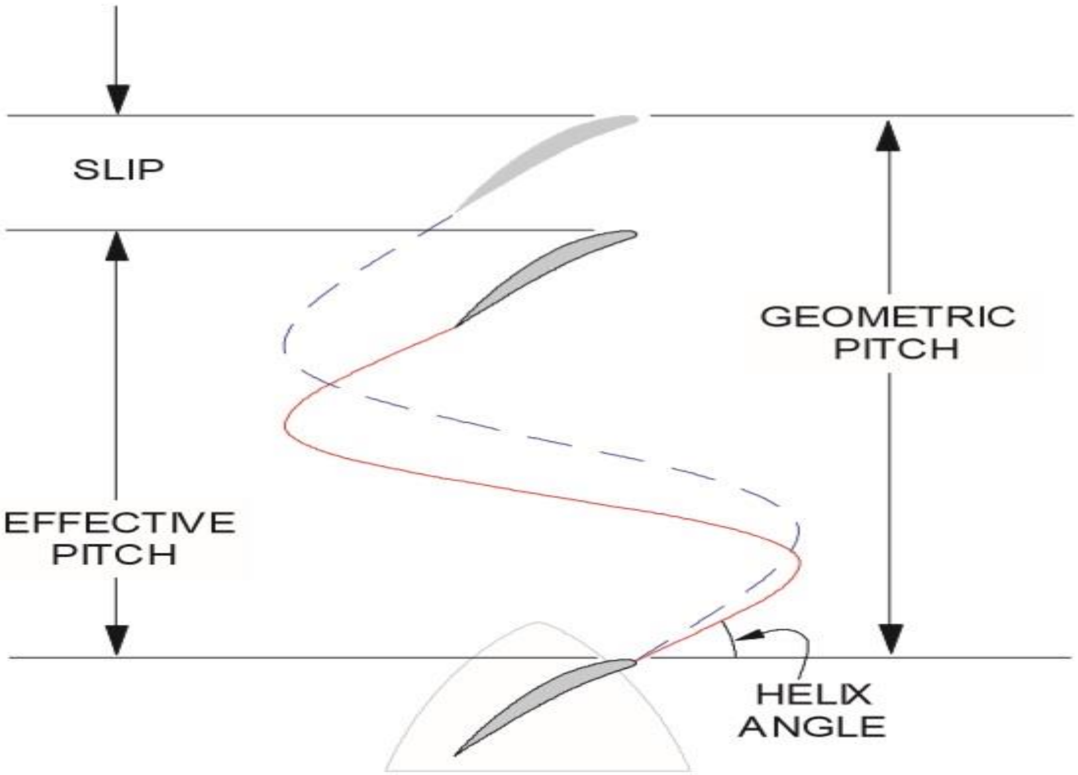
In flight the propeller does not move through the air at the geometric pitch; the distance it travels forward in each revolution depends on the aircraft’s forward speed. The distance which it actually moves forward in each revolution is called the “effective pitch” or “advance per revolution”.

- **Propeller Slip**

The difference between the Geometric and the Effective Pitch is called the Slip.

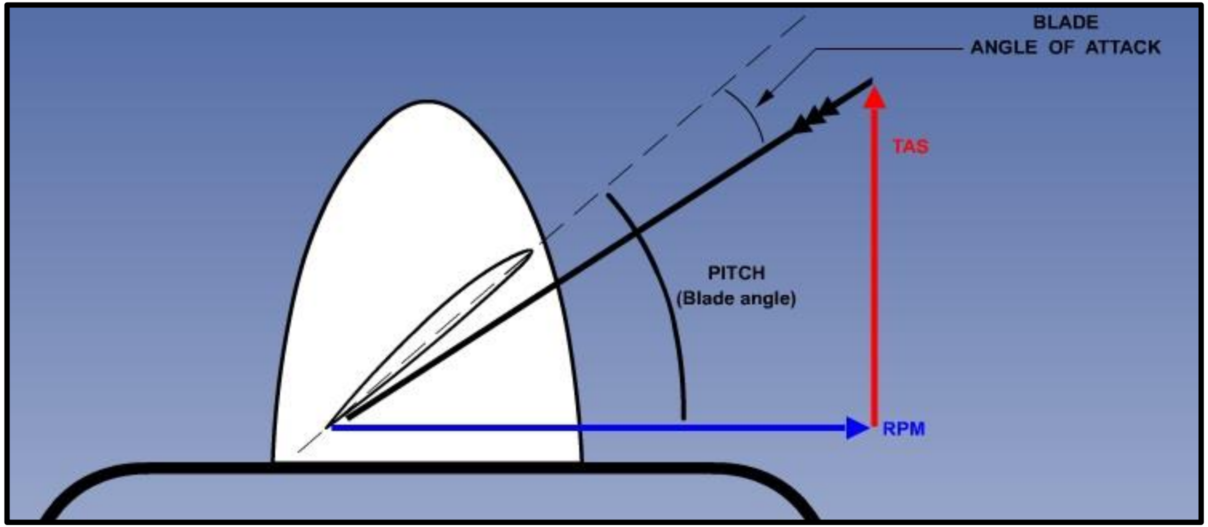
- **The Helix Angle**

The angle that the actual path of the propeller makes to the plane of rotation.


SLIP
GEOMETRIC PITCH
EFFECTIVE PITCH
HELIX ANGLE

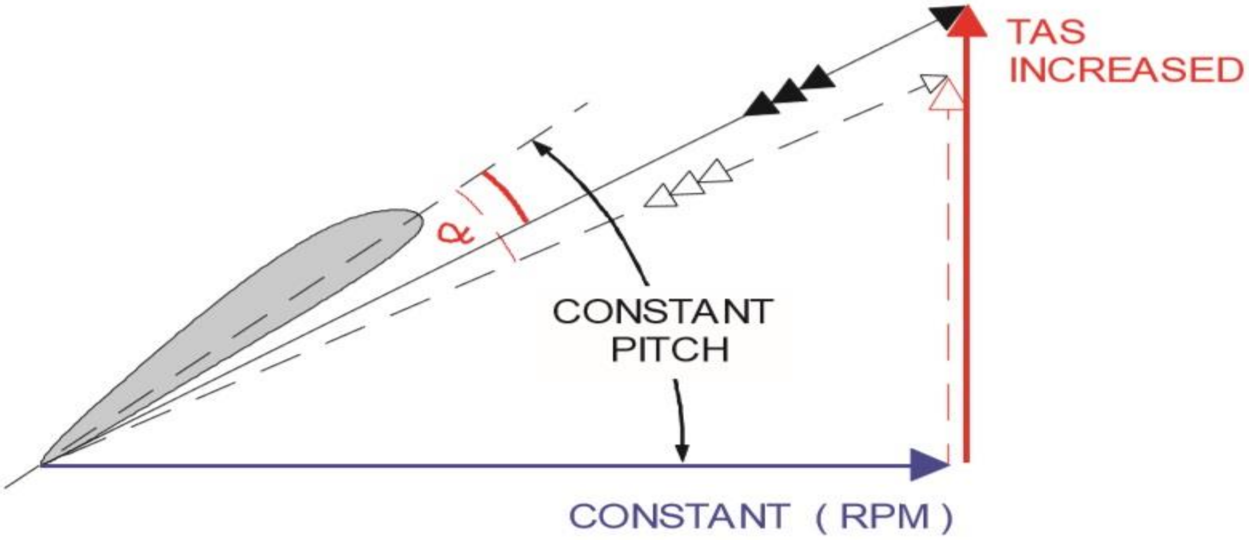
- **Angle of Attack**

The path of the propeller through the air determines the direction of the relative airflow. The angle between the blade chord and the relative airflow is the angle of attack (α). The angle of attack (α) is the result of propeller rotational velocity (RPM) and aircraft forward velocity (TAS).



Fixed Pitch Propeller

Figure shows a “fixed pitch” propeller at constant RPM. Increasing TAS decreases the angle of attack of the propeller. Increasing RPM increases the angle of attack of the propeller.

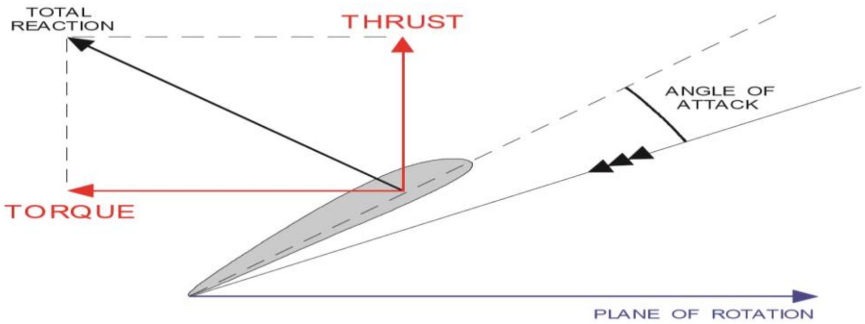


Thrust

A component at right angles to the plane of rotation. The thrust force will vary along the length of each blade, reducing at the tip where the pressures equalize and towards the root where the rotational velocity is low. Thrust will cause a bending moment on each blade, tending to bend the tip forward.

Torque (Propeller)

Torque is the equal and opposite reaction to the propeller being rotated, which generates a turning moment about the aircraft longitudinal axis. Propeller torque also gives a bending moment to the blades, but in the opposite direction to the plane of rotation.

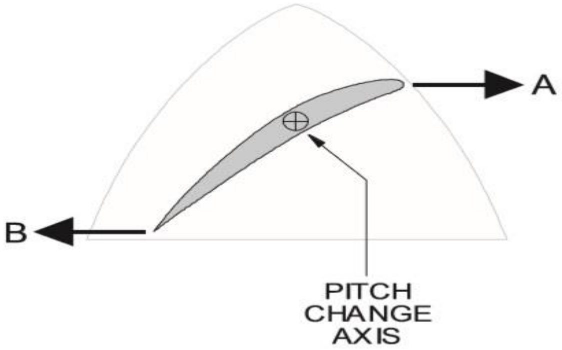


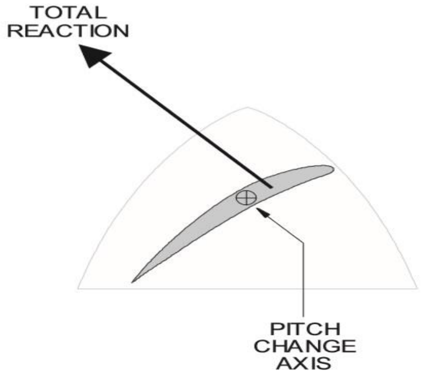
Centrifugal Twisting Moment (CTM)

Components 'A' and 'B', of the centrifugal force acting on the blade, produce a moment around the pitch change axis which tends to 'fine' the blade off.

Aerodynamic Twisting Moment (ATM)

Because the blade CP is in front of the pitch change axis, aerodynamic force generates a moment around the pitch change axis acting in the direction of coarse pitch.





Propeller Efficiency

- The efficiency of the propeller can be measured from the ratio, Power out / Power in.

- The power extracted (out) from a propeller, “Thrust Power”, is the product of Force (Thrust) × Velocity (TAS).

- The power into the propeller, “Shaft Power” is engine torque (Force) × Rotational Velocity (RPM).

- The efficiency of the propeller can be expressed as:

$$\text{Propeller Efficiency} = \frac{\text{Thrust Power}}{\text{Shaft Power}}$$

Variation of Propeller Efficiency with Speed

for a fixed pitch propeller, increasing TAS at a constant RPM reduces the blade angle of attack. This will decrease thrust. The effect of this on propeller efficiency is as follows:

• At some high forward speed the blade will be close to zero lift angle of attack and thrust, and therefore Thrust Power, will be zero. From the above 'equation' it can be seen that propeller efficiency will also be zero.

• There will be only one speed at which a fixed pitch propeller is operating at its most efficient angle of attack and where the propeller efficiency will be maximum.

• As TAS is decreased, thrust will increase because blade angle of attack is increased. Thrust is very large, but the TAS is low so propeller efficiency will be low. Thus no useful work is being done when the aircraft is, for instance, held against the brakes at full power prior to take-off. The efficiency of a fixed pitch propeller varies with forward speed.

Variable Pitch Propellers

- **Adjustable pitch propellers**

These are propellers which can have their pitch adjusted on the ground by mechanically resetting the blades in the hub. In flight they act as fixed pitch propellers.

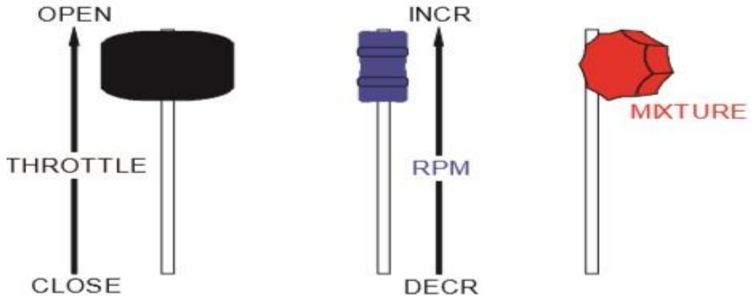
- **Two pitch propellers**

These are propellers which have a fine and coarse pitch setting which can be selected in flight. Fine pitch can be selected for take-off, climb and landing and coarse pitch for cruise. They will usually also have a feathered position.

- **(Variable pitch) Constant speed propellers**

Modern aircraft have propellers which are controlled automatically to vary their pitch (blade angle) so as to maintain a selected RPM. A variable pitch propeller permits high efficiency to be obtained over a wider range of TAS, giving improved take-off and climb performance and cruising fuel consumption.

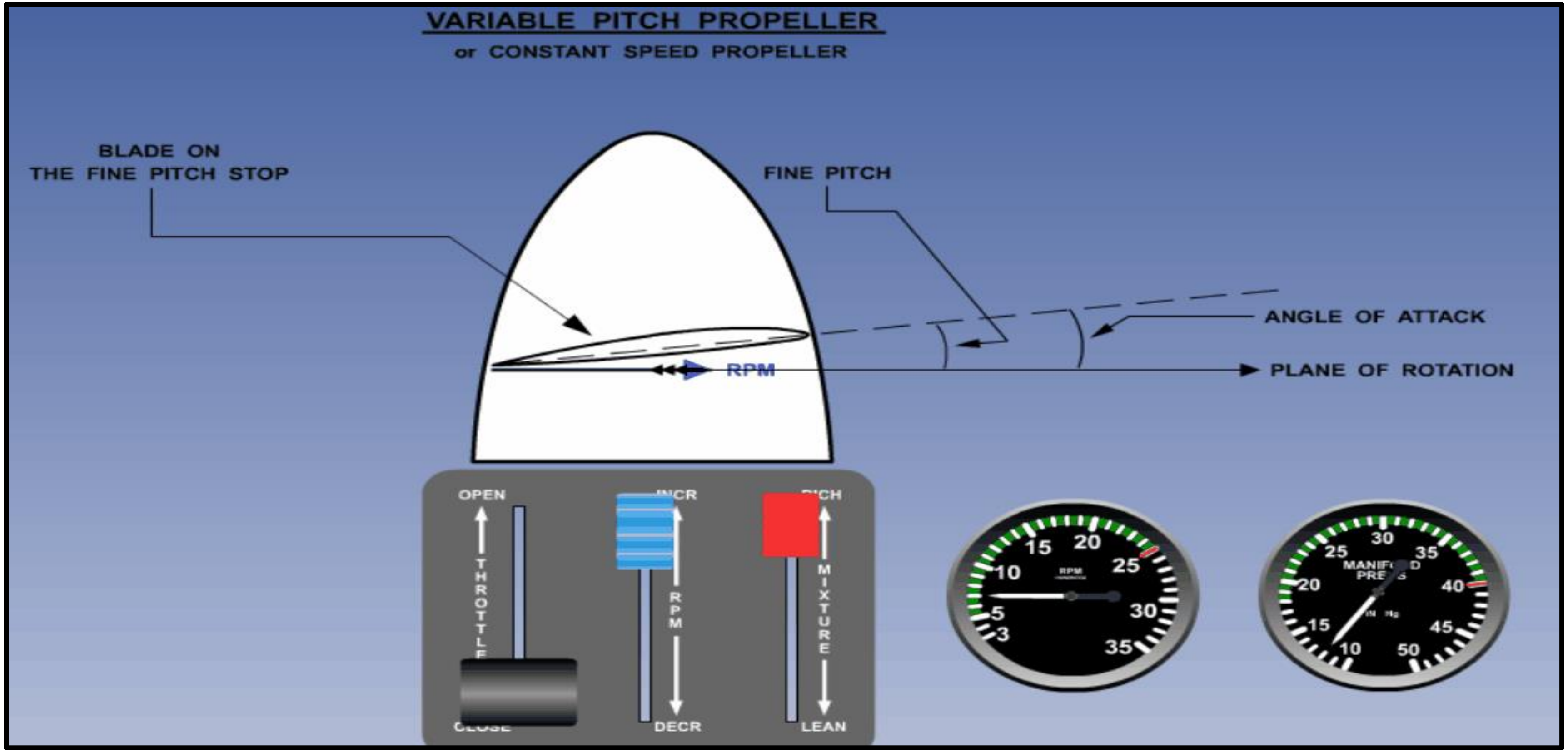
Constant Speed Propeller



- Throttle, prop' and mixture are shown in the take-off (all forward) position.

- **"Pulling back" on the prop' control will decrease RPM.** Back (decrease RPM) is fifth gear

- **"Pushing forward" on the prop' control will increase RPM.** Forward (increase RPM) is first gear

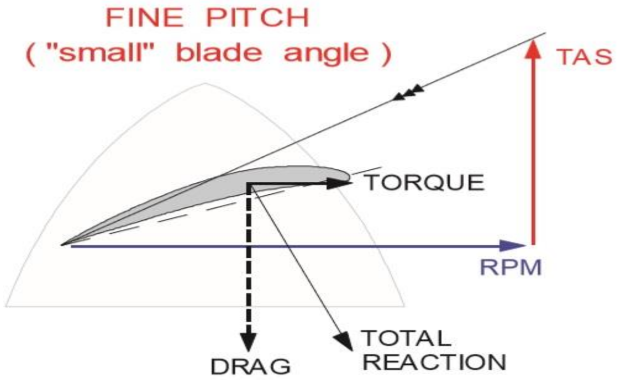

VARIABLE PITCH PROPELLER
or CONSTANT SPEED PROPELLER
BLADE ON
THE FINE PITCH STOP
FINE PITCH
ANGLE OF ATTACK
RPM
PLANE OF ROTATION
OPEN
THROTTLE
INCR
RPM
DECR
MIXTURE
LEAN
15
20
25
10
RPM
5
3
30
35
30
25
35
20
40
15
45
10
50

Windmilling

• If a loss of engine torque occurs (the throttle is closed or the engine fails), the prop' will "fine off" in an attempt to maintain the set RPM.

• The relative airflow will impinge on the front surface of the blade and generate drag and "negative propeller torque".

• **The drag generated by a windmilling propeller is very high.**

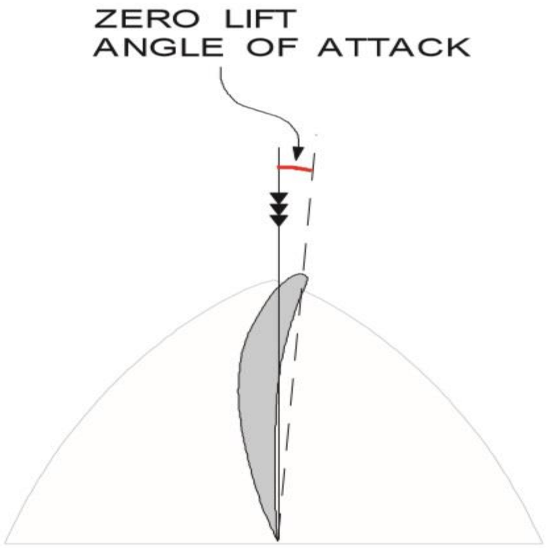


Feathering

By turning the blades to their zero lift angle of attack, no propeller torque is generated and the propeller will stop, reducing drag to a minimum.

In a steady glide with no shaft power from the engine (throttle closed), if the propeller pitch is increased by pulling back the prop' lever, the aircraft Lift/Drag ratio will increase. This will decrease the rate of descent. The RPM would decrease because of the reduction in negative propeller torque.

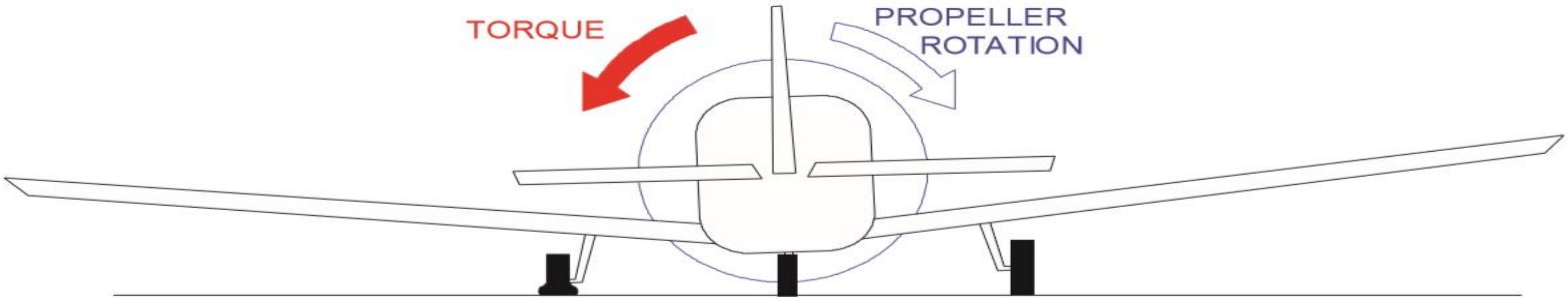
The opposite will be true if the propeller pitch is decreased.



Moments and Forces Generated by a Propeller

- **Torque Reaction**

Because the propeller rotates clockwise, the equal and opposite reaction (torque) will give the aircraft an anti-clockwise rolling moment about the longitudinal axis.
Torque reaction will be greatest during high power, low airspeed (IAS) flight conditions.
Low IAS will reduce the power of the controls to counter the “turning” moment due to torque.



- **Gyroscopic Effect**

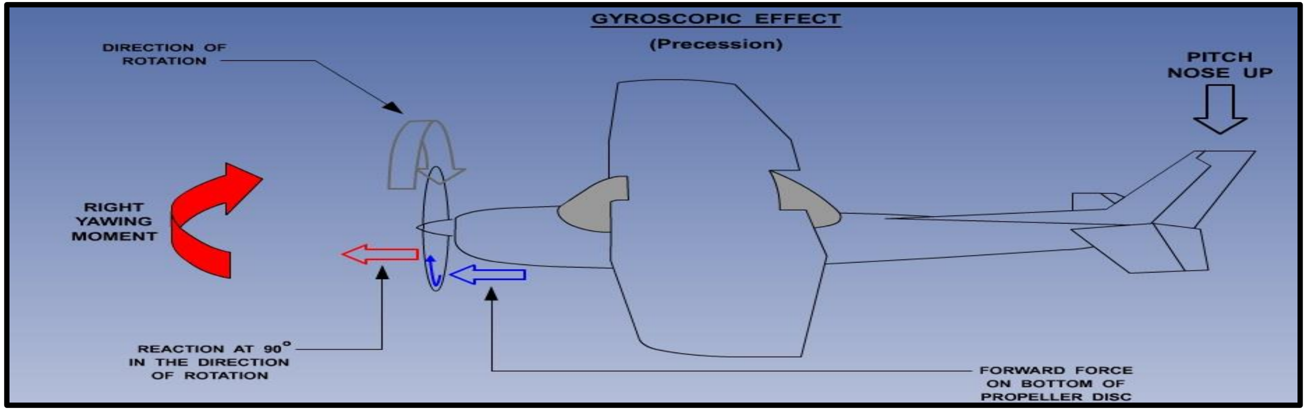
A rotating propeller has the properties of a gyroscope - rigidity in space and precession. The characteristic which produces "gyroscopic effect" is precession.When a force is applied to the rim of a propeller, the reaction occurs 90° ahead in the direction of rotation and in the same direction as the applied force.

Gyroscopic effect only occurs when the aircraft pitches and/or yaws.

Pitch down - forward force on the top, force emerges 90° clockwise, left yaw.

Left yaw - forward force on the right, force emerges 90° clockwise, pitch up.

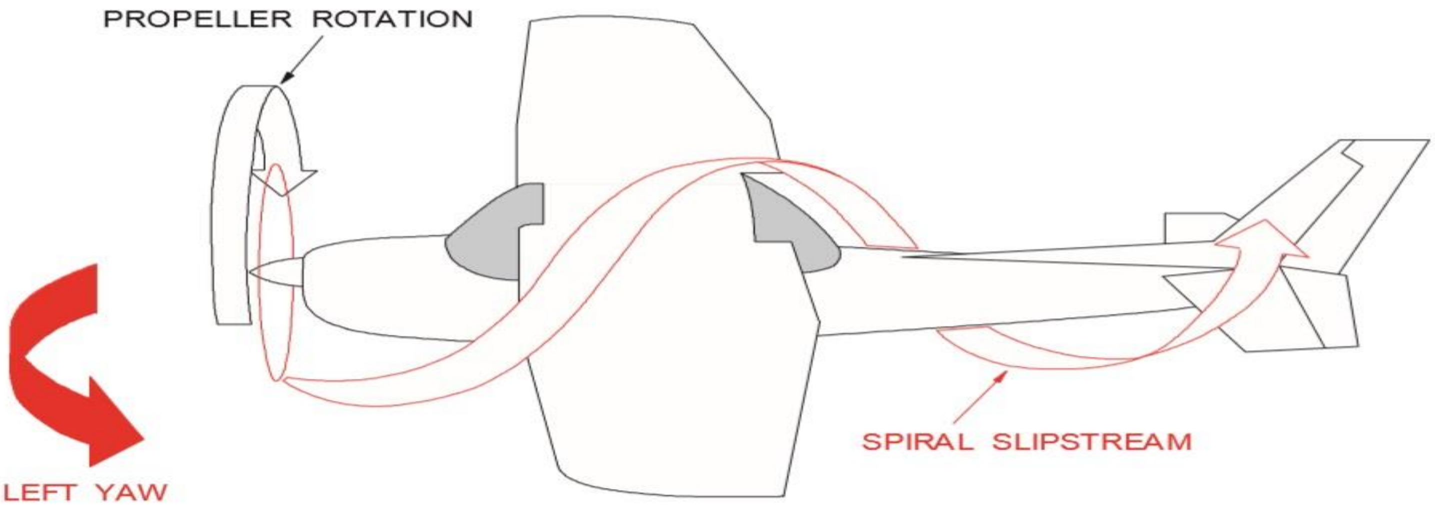
Right yaw - forward force on the left, force emerges 90° clockwise, pitch down.



- **Spiral Slipstream Effect**

As the propeller rotates it produces a backward flow of air, or slipstream, which rotates around the aircraft. This spiral slipstream causes a change in airflow around the fin (vertical stabilizer). Due to the direction of propeller rotation (clockwise) the spiral slipstream meets the fin at an angle from the left, producing a sideways force on the fin to the right.

Spiral slipstream effect gives the aircraft a yawing moment to the left.



- **Asymmetric Blade Effect**

In general, the propeller shaft will be inclined upwards from the direction of flight due to the angle of attack of the aircraft. This gives the down-going propeller blade a greater effective angle of attack than the up-going blade. The down-going (right) blade will generate more thrust. The difference in thrust on the two sides of the propeller disc will give a yawing moment to the left with a clockwise rotating propeller in a nose-up attitude.

Asymmetric blade effect will be greatest at full power and low airspeed (high angle of attack).