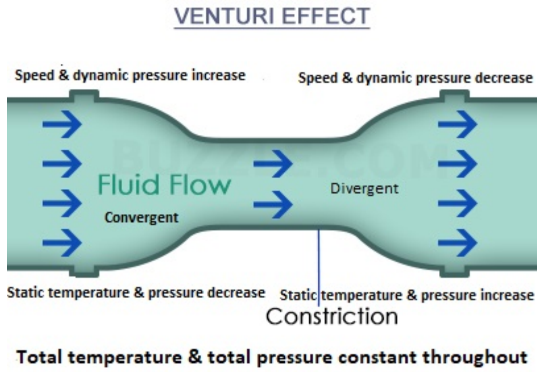
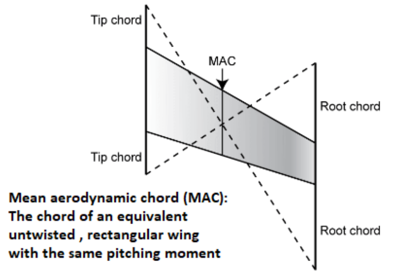
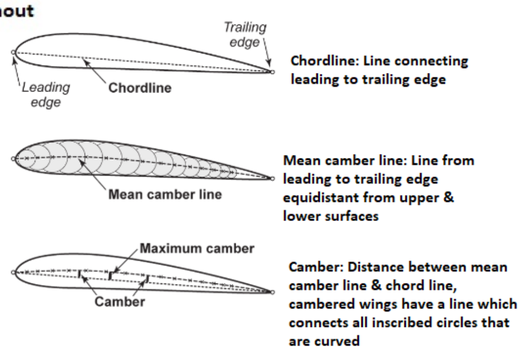
# POF

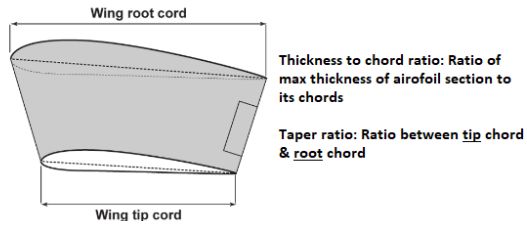
## General:

Bernoulli: Sum of all energy constant
Temperature ~ density(rho)[kg/m$^3$]
Density ∝ mass
Density ∝ pressure
Density does not vary in venturi
Density decrease as humidity increase
Temp ↑ mass flow ↓
Dynamic pressure [q]( N/m$^2$)
= $^1/_2\rho V(TAS)^2$
Dynamic press = 0 when speed = 0
Static + dynamic = constant
p/(rho*T) = Constant

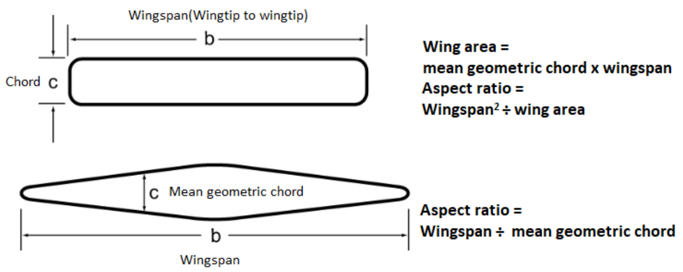


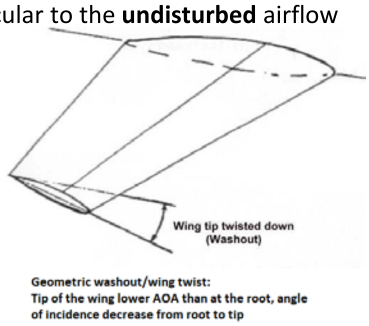



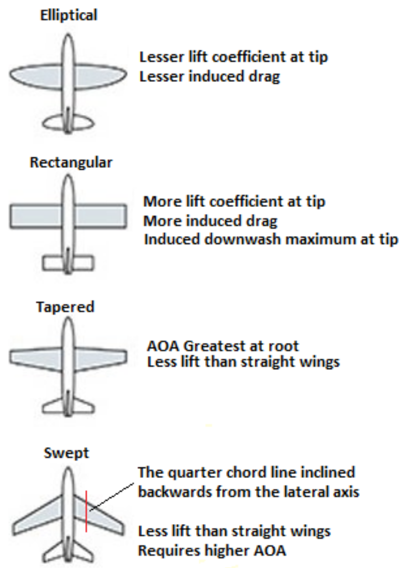




- SI units:
  - Weight (Newton) = Force = Mass(kg) x acceleration
  - Power (Nm/s) = Watts (W) Force x distance ÷ time (J/s) [There is time]
  - Work = Joule
  - Force [kg.m/s$^2$]= m x a
  - Wing loading[W/S](N/m$^2$): Weight of aircraft ÷ area of the wings
- Density decrease with increase in humidity (Dry air = better performance)
- Mean geometric chord: Wing area ÷ wing span
  **Difference** between **MAC** & **mean camber line**
  Relative thickness: Expressed in % chord
  Symmetrical airfoil: 0 camber, mean camber line = chord line
  & lift characteristics as the actual wing
- **Aeroplane** AOA: Angle between speed vector & longitudinal axis
  **Wing** AOA: Angle between longitudinal axis & wing root chord line
  Angle of incidence: Angle between wing root chord line & longitudinal axis
  Dihedral angle:
  - Angle between wing plane & the horizontal with aeroplane in an unbanked , level condition
  - Angle between the 0.25 chord line of the wing and the lateral axis
- Lift & drag forces depend on the pressure distribuition around the aerofoil cross section
- Lift = Component of total aerodynamic force perpendicular to the **undisturbed** airflow



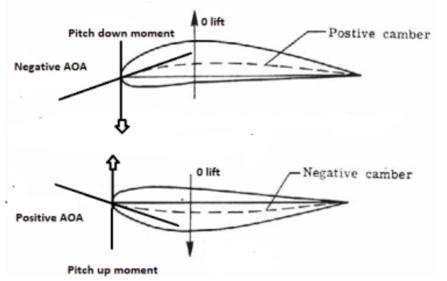




## 2D airflow over an aerofoil

- Typical $C_L/C_D$ ratio: Max at angle of attack of 4$^o$
- Lift:
  - Upwash ahead of the wing & downwash behind
  - Downwash increase: Lift generated by the aerofoil increases
  - Upper surface produces greatest proportion of lift at all speeds
  - Generated when the flow direction of a certain mass of air is changed
- Stagnation point:
  - Static pressure maximum value
  - Relative velocity = 0
- AOA
  - Decrease: Stagnation point moves forward /up, lowest pressure(CP) moves aft, COP moves aft
  - Increase: Stagnation point moves down, lowest pressure(CP) moves forward, COP moves forward until crit AOA
- Aerodynamic centre of an aerofoil:
  - Approx 25% chord irrespective/**independent of AOA**
  - Assume no flow separation, pitching moment coefficient does not change with carying angle of attack

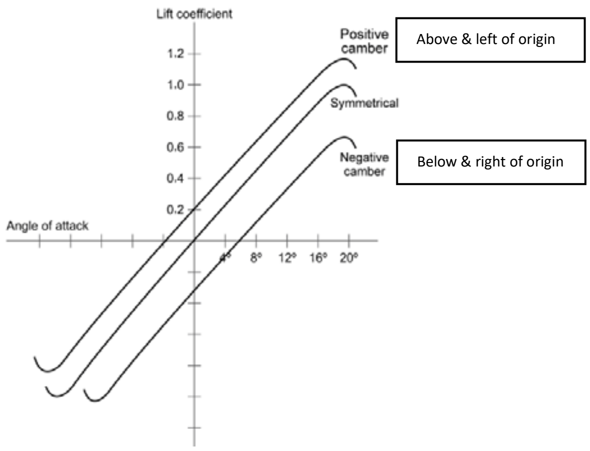
- Where instantaneous variation in wing lift acts
- Don't mix up aerodynamic centre with centre of pressure

- Centre of pressure:
  - Does not change on **symmetric** airfoils
  - Moves forward as AOA increase
- Streamlines:
  - Speed increases: Area of condensed streamlines moves to the back (In the direction of trailing edge), COP moves aft
  - Speed decreases: COP moves forward & total lift force is constant
  - Streamlines converge: Static pressure decreases & velocity increases
  - Streamlines diverge: Stati pressure increases & velocity decreases
  - Airflow accelerates over wing when generating lift
- Drag:
  - Total drag: Pressure drag & skin friction drag
  - Profile drag proportional to square of the relative velocity of the air & drag coefficient




**Coefficients:**

- Positively cambered airfoil: $C_L = 0$, pitching moment down, negative AOA
  Negatively cambered airfoil: $C_L = 0$, pitching moment up, positive AOA
  Symmetric airfoil: AOA = 0, pitching moment = 0, there is only drag but no lift
- Swept vs unswept: Swept has less lift at AOA
- Lift/aerodynamic force:
  - $^{1}/_{2}\rho V^2SC_L$
  - **q(dynamic pressure) x S x $C_L$**
  - $(V_S)^2C_{LMAX} = (V)^2C_L$ [V = actual speed & $C_L$ = actual lift coefficient]
  - When speed increases by a ratio = **Lift = ratio$^2$, $C_L$ = $^1/_{ratio}{}^2$**
  - **$C_L$** is directly affected by **AOA**
- Drag = $^{1}/_{2}\rho V^2SC_D$ [S = reference area, $C_D$ = Drag coefficient]
  - Minimum when $C_L/C_D$ ratio is maximum
- Coefficient of lifts & drag affected by **camber** & **AOA** only
- Parabolic curve: Minimum glide angle & parasite drag coefficient
- Aerofoil polar graph: $C_L$ /$C_D$, shows max ratio(Total drag lowest) & max $C_L$
- **AOA is unaffected by density**

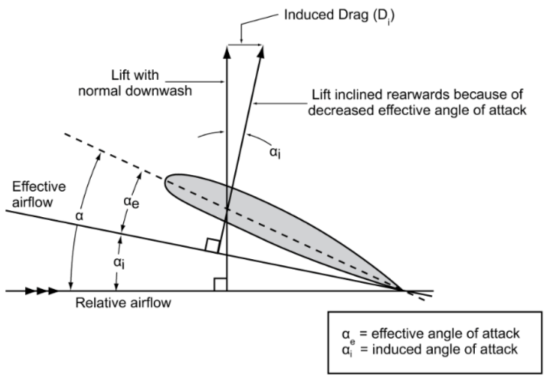



IAS & TAS:

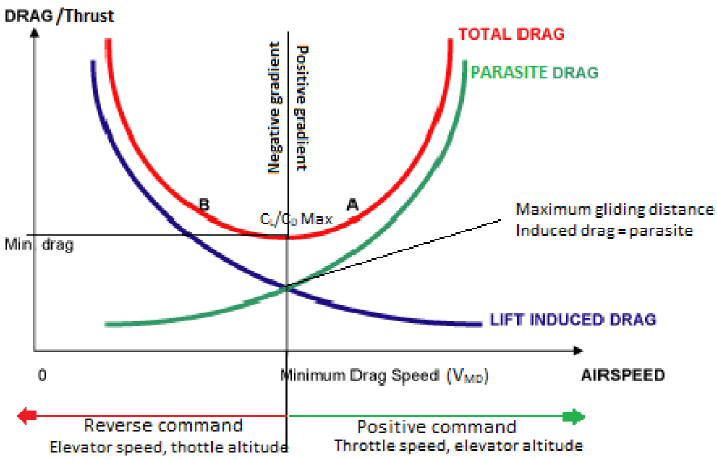
- Assuming no compressibility effects & straight & level flight with same AOA:
  - TAS is higher at higher altitudes
  - IAS is constant with altitude, $C_L$ must be constant as density is changed hence AOA the same

**3D airflow over an aeroplane**

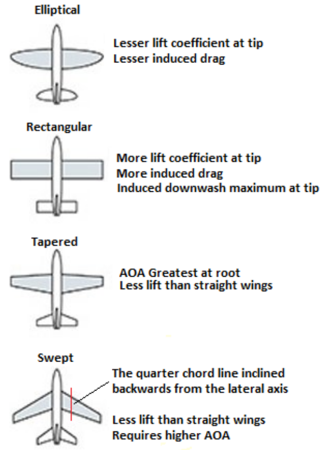
- Spanwise component
  - Added compared to 2D airflow
  - Airflow on the upper surface flows to root, lower surface to wingtip
- Wing tip vortices:
  - Increase as AOA increase
  - Descrease as aspect ratio increase
  - Highest at take-off
  - Vortex waves gradually descends to a lower level
  - Vortex forms on rotation & ends when noswheel touches down




- Aspect ratio:
  - Increase: Induced drag & crit AOA decrease
  - Increase: Max lift lift/drag ratio increase
  - Decreases: when flaps are deployed
- Induced drag:
  - **Induced AOA:** A result of **downwash** due to **tip vortices**
  - Caused by wing tip vortices & downwash
  - Reduced by installing wing tip tank
  - Strongest at wing tips
  - Increases as AOA increase
  - Increases airplane mass increase (Higher mass = higher AOA)
  - Decreases as speed increases (See curve)
  - Decreases when flaps are deployed
  - **$C_{Di} = (C_L)^2 \div \pi$ x AR**
  - **$C_{Di} = 1 \div V^2$**
  - **$D_i = {}^{1}/_{2}\rho V^2SC_{Di}$**

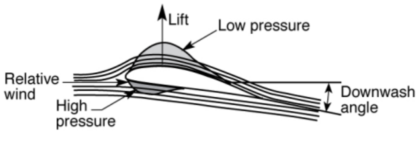


- Parasite drag:
  - Form + profile + skin friction + interference + pressure drag
  - Increases when wing tip tank installed
- Interference drag:
  - Aerodynamic interference between parts of the aeroplane
- Form drag:
  - Reduced by streamlining, however skin friction drag increases
- Speed stable:
  - Tendency to return to original speed after gust, speed is disturbed from its trimmed value tends to return to the original speed
  - Speed unstable: No tendency to return to original speed




**Ground effect:**

- Airborne before reaching recommended take-off speed, floating
- Height is less than half of the length of the wingspan above the surface
- Affects low wing & low tailplane aircraft most
- Enetering ground effect
  - Lift coefficient increases
  - Effective AOA increases
  - Induced AOA decreases
  - Downwash angle decreases
  - Induced drag coefficient $C_{Di}$ decreases

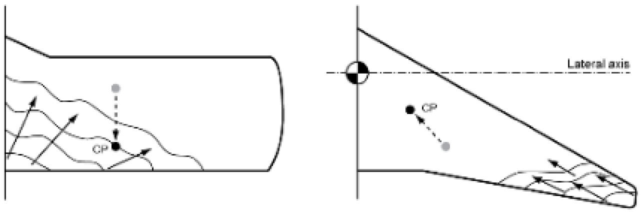



**downwash angle**

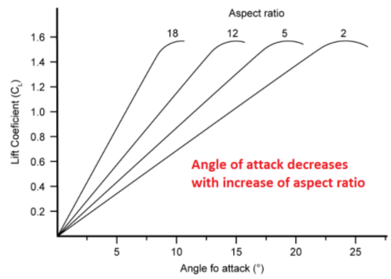
$V_S$ = Stall speed or minimum steady flight speed for which the aircraft is still controllable.
$V_{S0}$ = Stall speed or minimum flight speed in landing configuration.
$V_{S1}$ = Stall speed or minimum steady flight speed for which the aircraft is still controllable in a specific configuration.
$V_{S1g}$ = Minimum speed at which lift equals weight (1g or g = 1)
$V_{SR}$ = Reference stall speed.
$V_{SR0}$ = Reference stall speed in landing configuration.
$V_{SR1}$ = Reference stall speed in a specific configuration.
$V_{SW}$ = Speed at which the stall warning will occur.

**Stall:**

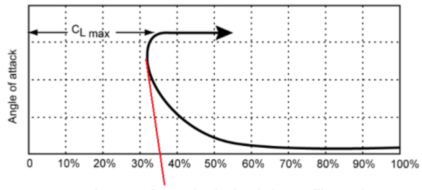
- Load factor(Lift ÷ weight):
  - Load factor >1, lift more than weight
  - Load factor <1, lift less than weight, steady climb
  - & AOA increases when pulling out from a dive
- Airflow characteristics:
  - Boundary layer: Layer of air on wing stream velocity lower than free stream velocity
  - Transition point: Transition from laminar to turbulent layer
  - Airflow seperation: Airflow reversal on the surface of the body



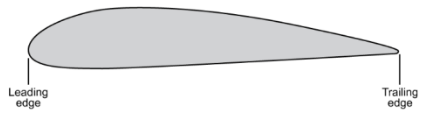

- Stall characteristics:
  - There is a large reduction in lift but it does not drop to zero
  - COG more forward: Stall speed higher, AOA unaffected
  - COG moves aft: More difficult for stall recovery
  - COP moves aft approaching stall on rectangular wings
  - COP moves fwd approaching stall on swept wings
  - Rectangular wings: Just before stall has a nose-down tendency
- Stall speed:
  - Stall speed increases with the **square root of load factor**,
  - Increases during turns, increase of **mass/weight**, forward CG location, icing conditions & decreasing thrust
  - Decrease with flaps
  - Wing with back sweep has higher tendency to stall, increasing sweep back increases stall speed
  - Determined by CG at forward limit, min control speeds determined when CG at aft limit
  - Does **not** change with IAS, but changes with TAS at altitude
  - **IAS stall speed constant at lower altitudes**, increases at higher altitudes due to **compressibility (More correct)**
  - **IAS stall speed increase at higher altitudes (More correct)**
- Stall formulas:
  - $V_s$ new = $V_s$ old x [√(1/cos ϕ new) ÷ (1/cos ϕ old)]
  - $V_s$ new = $V_s$ old x √(New weight ÷ old weight)
  - Stall speed increase by a factor of **√[1÷cos(bank angle)] = √n**
- Super/deep stall:
  - Stable stall with almost constant pitch attitude
  - Swept wings has highest probability of a super stall
  - Negative tail stall: Uncontrollable pitch down moment (Tailplane no longer producing down force)
  - Largest AOA
- Accelerated stall:
  - Stall at high load factors (Turning/dive), stalling at higher speeds
  - Stall speed increase with square root of load factor
  - Stall due to increase in load factor

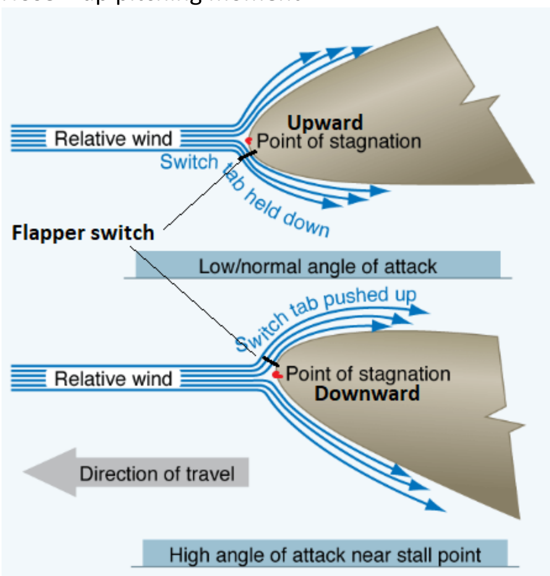


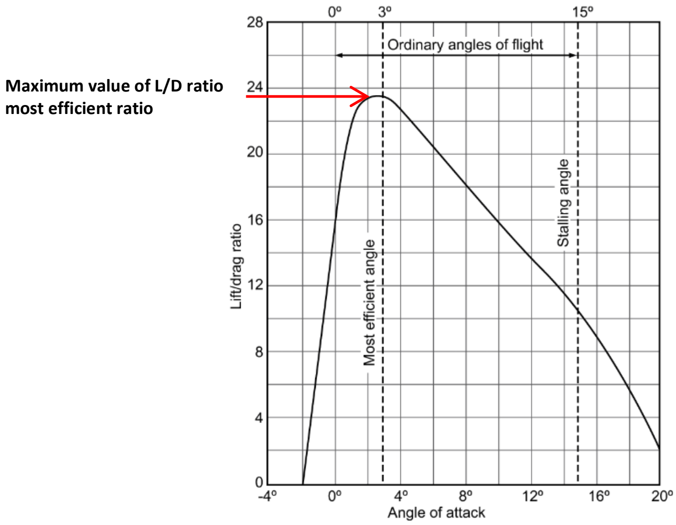
- Spin:
  - Spin recovery: PARE
  - Both wings are stalled
- Stall warning:
  - Vane flapper switch activated by change of stagnation point
  - Stagnation point moves downwards & flapper switch moves upwards
  - Installed just **<u>below</u>** the leading edge
- Stall protection:
  - Stick shakers activates at a lower AOA, before stick pushers, at speeds higher than $V_S$
  - Stick shaker input: AOA & rate of change of AOA
  - Stick pusher push the stick forward at or beyond a certain value of angle of attack
  - Wing fences reduce spanwise flow, low speed handling characteristics
  - Stall strip/**fixed spoiler**: On leading edge, induces **root** stall, ensures root of wing stalls before the tip
- Critical angle of attack(A fixed value):
  - Aspect ratio increases, critical angle of attack decrease
  - CP will reach its most forward point at the stalling angle
  - Affected by **design** of wing & aspect ratio only
- **Stall angle unaffected by turn**. Approximately 16°
- Low speed pitch:
  - Forward movement of CP (Wing tips stalls first),of **swept back** wings, outward drift of the boundary layer
  - Nose – up pitching moment




CP reaches most forward point just below stalling angle

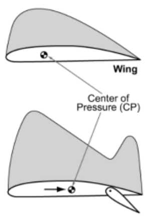


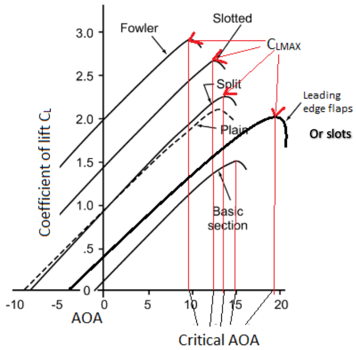



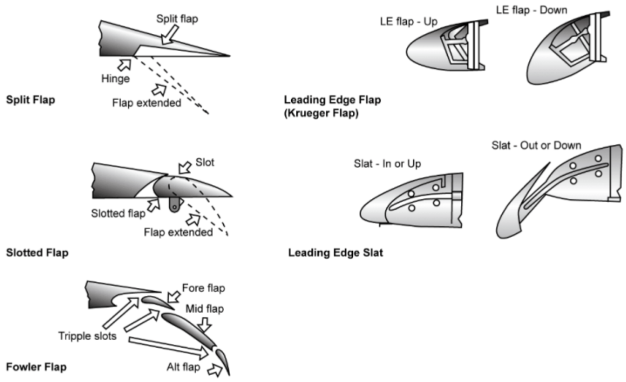

## <u>Augmentation/high lift devices:</u>

- Clean configuration: Highest $C_L/C_D$ ratio. 30° – 45° flaps adversely effects ratio
- Trailing edge flaps:
  - Critical AOA decreases when flap is deployed
  - Increases $C_{LMAX}$
  - Increase effective AOA, increase stall AOA
  - CP moves to the rear/aft (Inboard towards wing root)
  - When deployed creates a nose down tendency, aircraft tendency to climb
  - When retracted aircraft has tendency to sink
  - Flaps are installed inboard (Near root)
  - Increase lift at low AOA: L/D ratio decreases
  - Maximum glide distance decreases, degrades minimum glide angle
  - Deployed while keeping AOA constant: $C_L$ & $C_D$ increases
  - Maintaining level flight, constant IAS flaps deployed:
    - $C_L$ eventually remains the same
    - Nose must be lowered & thrust increased
  - Maintaining level flight, constant IAS flaps retracted:
    - AOA is increased
  - During approaches to land:
    - Provides same amount of lift at a slower speed



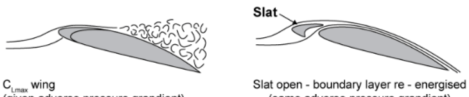

1. **Plain flap:**
   - Increase $C_{LMAX}$ by increasing camber
2. **Fowler flaps:**
   - Most effective



- Moves aft then turns down
- Increase wing area & camber

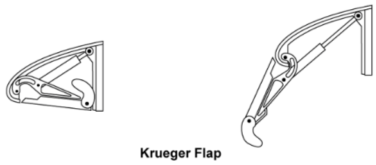
**3.** Slotted flaps:
- Increasing camber & re-energize flow through slots

- Krueger leading edge flap:
  - Part of the lower surface of the leading edge, hinged at its forward edge




$C_{Lmax}$ wing (given adverse pressure grandient)

Slat open - boundary layer re - energised (same adverse pressure grandient)



Krueger Flap

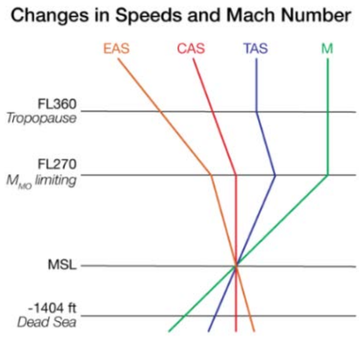
- Slat:
  - Critical AOA increases when slat is deployed
  - Increases $C_{LMAX}$ more than it causes yawing moment
  - Large decrease in stall speed with relatively less drag
  - Slats are installed outboard (Near tips)
  - Higher contribuition to $C_{LMAX}$ than flaps at any position, greater effect on stall speed than flaps
  - Increase boundary layer energy at the suction peak (fixed point), postponing stall to higher AOA using venturi effect
  - An auxiliary leading edge device cambered aerofoil positioned forward of the main aerofoil so as to form a slot
  - Automatically operated by aerodynamic forces acting on the leading edge, when a certain AOA is reached
- Vortex generators:
  - Delays stall by reducing boundary layer separation, installed near wing **leading** edge
  - Re-energize boundary layer
  - Transfer energy from the free airflow into the boundary layer
- Tailplane:
  - Increased downwash at tailplane = Increased negative lift (Downward lift of tailplane), producing a pitch up moment (Which opposes wing pitch down moment at wings upon flap deployment), and increasing effectiveness of the tailplane (More airflow over the tailplane & control surfaces)
- Asymmetric flaps:
  - Flap asymmetry causes rolling, slat asymmetry causes difference in $C_{LMAX}$ or yawing moment
  - Slightly asymmetric flaps: Causes a steady rate of roll which may be correctable with ailerons

- Spoilers:
  - Roll spoilers: Reduces lift on a part of wing, generating the desired rolling moment. There is a local increase in drag which supresses adverse yaw
  - Spoiler extension **increases the stall speed**, the **min rate of descent** (ROD) & **min angle of descent**
  - Symmetrically deflected spoilers: Decelerate aeroplane/decrease ROD, may be used as speed brakes during flight
  - Speed brakes increase drag in order to maintain a steeper gradient of descent, spoilers may be used as speed brakes
  - **AOA constant**, spoilers deployed: $C_D$ increases & **$C_L$ decreases**
  - Flight level & **speed constant**: $C_D$ increases & **$C_L$ unaffected (More correct)**
  - Air brakes reduce **min drag speed**
  - Wing spoiler extension causes an increase in drag & decrease in lift
- Boundary layers:
  - Laminar:
  - Less change in velocity close to surface
  - Lesser mean speed
  - Friction drag lower
  - Thinner
  - More tendency to separate from the surface
  - Less kinetic energy than turbulent layer
  - No velocity components exist normal to surface
  - Turbulent:
  - More change in velocity close to surface
  - More mean speed
  - Friction drag higher
  - Thicker
  - Less tendency to separate from the surface
  - More kinetic energy than laminer layer
  - Compared with laminar layer, a turbulent boundary layer is better able to resist a positive pressure gradient before it separates
- Skin friction drag:
  - Increases with age
  - Ageing causes the transition point to move forward & larger part is turbulent
- Icing:
  - Frost: Decrease in lift & an increase in drag
  - Increases landing distance up to 40 – 50%
  - Most critical during rotation
  - Ice accretion causes reduction in $C_{LMAX}$, increase of drag

- AOA & controllability are going to decrease stall speed is going to increase
- Decreased critical AOA

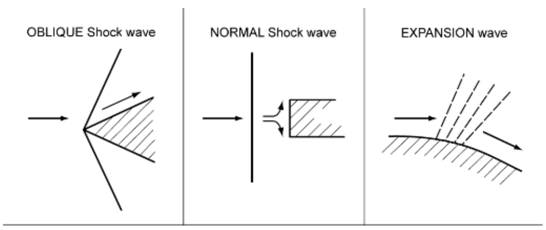
**<u>High speed aerodynamics:</u>**

- Speed of sound(a) = √(y x R x T) [y = specific heat, R = universal gas constant, T =Absolute temperature]
  Local speed of sound(LSS) = 38.95x √Absolute temp(K)
  Local speed of sound(LSS) estimate = 644 ÷ 1.2(TAT in $^{o}$C)
- Mach number: Ratio of TAS to LSS of the undisturbed flow, TAS ÷ LSS, affects compressibility
- Subsonic speed:
  - Up to $M_{CRIT}$
- Transonic speed:
  - Speed when both supersonic & subsonic speed exists around the aircraft
  - The region **around** mach 1, $M_{CRIT}$ – M1.3
  - Rearward shift of CP is M**0.89 – 0.98**
  - Aeroplane characteristic depends heavily on mach number
  - $C_D$ increases then decreases
  - $C_{LMAX}$ will decrease & 1G stalling speed increases
  - **Increased static longitudinal stability**
- Supersonic speed:
  - CP further aft during supersonic flight compared to subsonic
  - Aerofoil pressure distibuition is rectangular
  - M1.3 – M5
- Below tropopause: ECTM
- Above tropopause: Temperature constant so LSS/TAS/Mach is constant
- **Coefficient of lift ($C_L$) above & below tropopause has the same effect**:
  - Descending: $C_L$ decrease, **pitch angle & AOA decreasing** due to increasing IAS caused by increasing density
  - Climbing: $C_L$ increase, **pitch angle & AOA increasing** due to reducing IAS caused by decreasing density
- Operational limit: $M_{MO}$ (Mach exceeded when climbing at constant TAS/IAS)
  Operational speed limitation: $V_{MO}$ (TAS/IAS exceeded while descending at constant Mach)
- **Key point**: At **constant flight level**, temperature increase/decrease affects **TAS only**, Mach no. etc. is not affected




**<u>Shock waves:</u>**

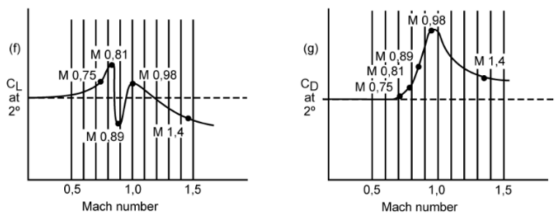
- General:
  - Mach = 1 ÷ sin(angle)
  - Increasing **mass increases** shockwave intensity
  - Shockwave moves slightly aft in front of a downward deflecting aileron
  - Shockwave moves aft towards trailing edge on upper surface as mach no. increases
  - Centre of pressure moves aft to 20% -50% **mid chord** towards direction of the trailing edge
  - Loss of pressure in a shock wave is due to **kinetic energy** in the flow is changed to **heat energy**
  - The first evidence of a shockwave appears in the upper side of the wing, at the wing root, near to the point of maximum wing **thickness**
  - Perpendicular to the local airflow, it is **normal** to the local airflow (**90$^{o}$**)
  - The front of a shockwave travels at the speed of the **ground** speed of the airplane
- Normal shock wave:
  - Higher **compression**
  - Highest efficiency when shock wave is small but supersonic
  - Least energy lost is when the mach is **just above** mach 1
  - Can occur at different points on the airplane in transonic flight
  - Changes from supersonic to subsonic < Mach 1
  - Higher loss in total pressure compared to oblique
- Oblique shock waves:
  - Velocity decreases but airflow remains supersonic
- Expansion wave:
  - Velocity ncreased to supersonic (M)
- Mach conical cone:
  - Cone angle decreases as mach number increases
  - All disturbances produced by an airplane are within this zone depending on mach number
- Bow wave:
  - Appears **just above** Mach = 1



| | | Total temperature & pressure | Mach & speed | Static temperature & pressure | Density | LSS |
|---|---|---|---|---|---|---|
| Oblique wave | In front | Higher | **Higher** | Lower | Lower | Lower |
| | Behind | Lower | **Lower** | Higher | Higher | Higher |
| Expansion wave | In front | - | **Lower** | Higher | Higher | Higher |
| | Behind | - | **Higher** | Lower | Lower | Lower |

**Effects of exceeding $M_{CRIT}$**

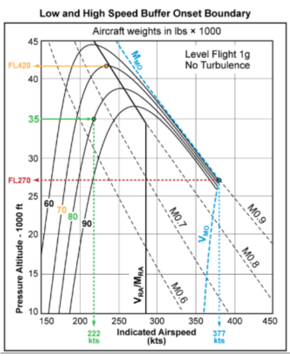
- Tuck under:
  - Nose down pitching tendency when entering the transonic range
  - **Reduction** in downwash at the horizontal stabiliser
  - Occurs only above the $M_{CRIT}$
- Mach trim:
  - Required as at transonic speeds airplane has decrease in longitudinal stick force stability
  - **CAUSE:** Stick force stablity decreases but static longitudinal stability increases
  - **EFFECT:** Mach trim **maintains** the required stick force gradient
  - Mach trimmer system failure: Mach number must be reduced
  - Adjusted by pitch up input of the stabilizer according to mach number
  - Adjusted by decreasing incidence of trimmable airplane (Stabilizer), [**NOT** elevator trim tab]
  - Adjusted by **trim tank**, moving fuel towards the tail
- $M_{CRIT}$ Critical mach number:
  - Local sonic speed (Not a shockwave) M1 is first reached on the upper surface of the wing
  - Above which, locally, supersonic flow exists somewhere over the aeroplane
  - L/D ratio decreases
  - $M_{CRIT}$ increases when mass decreases, as a result of lower AOA
  - $M_{CRIT}$ decreases when mass increases, when deflecting control surface down (Aileron, increased camber accelerate upper flow)
  - No shockwaves < $M_{CRIT}$
  - Above $M_{CRIT}$, stick force stability decreases due to the loss of lift in the wing root area
  - Above $M_{CRIT,}$ buffeting occurs with a tendency to pitch down
- $M_{CDR}$ Critical drag rise/ drag divergence mach number:
  - Greater than $M_{CRIT}$
  - Determined by angle of attack & profile of the aerofoil
  - $C_D$ increases rapidly after $M_{CDR}$
  - Increased drag is due to wave drag

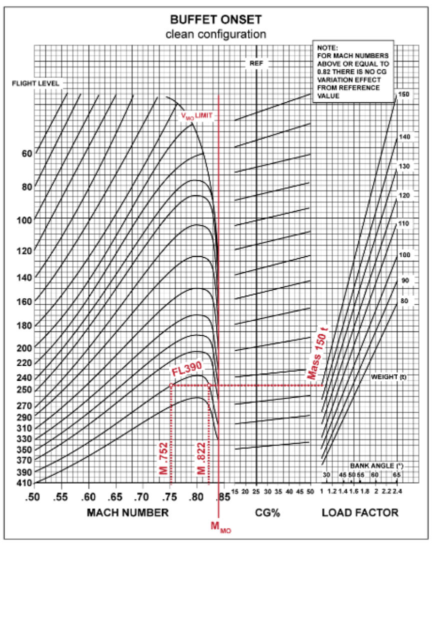



- Stall:
  - Stall speed increases at higher altitudes due to increasing compressibility effects as a result of increasing mach number Shock stall: Separation of the boundary layer at the shock waves
  - Shock stall has lowest AOA
  - Shock stall occurs when the lift coefficient, as a function of mach number reaches its maximum value
  - Shock induced separation results in decreasing lift, can occur behind a strong normal shockwave ranging from low to high AOA
- Effect on control surfaces:
  - Aileron deflection less effective during transonic flight: It only partly affects the pressure distribuition around the wing
  - Rapid fluctuation of hinge moments causing high frequency **buzz**

**Buffet:**

- High speed buffet:
  - Induced by interaction between shock wave motion & flow separation
  - Boundary layer separation due to shock wave formation
- Graph: Values at which low speed & mach buffet occurs at different weights & altitudes
- Buffet free ranges: Speed range between low & high buffet
  - Decreases as altitude increases
  - Decreases as mass increases
  - Decreases as load factor increases
  - Decreases in a pull manouvre (Higher load factor)
  - Increases in a push manouvre (Lower AOA)
  - **Not affected by speed**
- 1.3g load safety margin:
  - A manouvre with load factor 1.3g will cause buffet onset
  - Max cruise alt limited to 1.3g as exceeding that will cause: Turbulence induced high/low speed buffet
- $V_A$ less significant at high cruising altitudes as buffet onset limitations become limiting

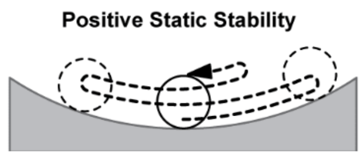


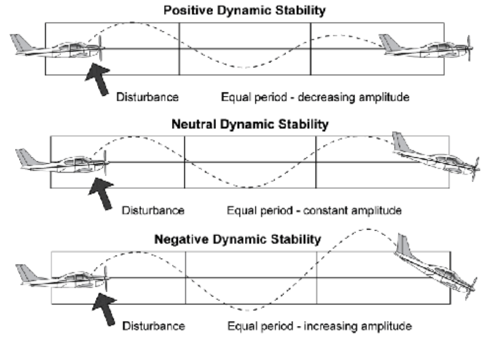



- Coffin corner: Stall speed = critical mach number, speed is too low & too high at the same time

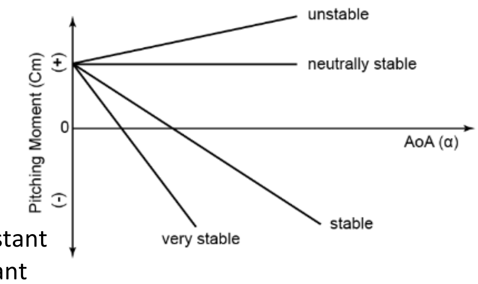
**<u>$M_{CRIT}$ influence</u>**
- Sweepback:
  - Appearance of shockwaves: Decreased velocity of air perpendicular to the leading edge
  - $M_{CRIT}$ Increases with sweepback
  - $M_{CDR}$(Drag divergence mach number) increases with sweepback
  - Straight wing vs sweepback: 1.154 times increase of $M_{CRIT}$ theoretically but half that value practically
  - Slower onset of transonic drag rise
  - **Higher $C_D$ in-flight**
  - Lesser effectiveness of high life devices (Flaps etc.) as sweepback is increased
- Thickness/chord ratio:
  - **Reduced**: Delays onset of shock wave, reduces transonic variations in lift & drag coeffcients $C_L/C_D$
  - Thin aerofoils increases $M_{CRIT}$
  - Thick aerofoil & high AOA decreases/lowers $M_{CRIT}$
- Area ruling:
  - Gives aircraft smooth cross-sectional area distribuition
  - Decreases wave drag
  - Gives “waist” or “coke bottle” shape
- Camber: Larger camber gives lower $M_{CRIT}$
- Supercritical aerofoil:
  - Larger nose radius, flatter upper surface & with negative as well as positive camber
  - Allows a wing of relative thickness to be used for approximately the same cruise Mach number
  - Shows no noticeable shockwaves when flying just above $M_{CRIT}$
- Vortex generators
  - Decrease wave drag
  - Decrease shockwave induced separation
  - Reduce boundary layer separation drag when shockwaves form

**<u>Stability:</u>**
- For there to be a condition of dynamic stability (Positive/neutral/negative), it must have positive static stability first
- For a plane to have dynamic stability it needs static stability & sufficient damping
- **Tends** to return: Positive static stability, initial **tendency** to return to equilibrium
- Returns: Positive dynamic stability
- Less stability = more manoeuvrability & vice versa
- Sum of moments about one axis is not = 0:
  - An angular acceleration about that axis exists
  - Aeroplane starts to rotate about its centre of gravity



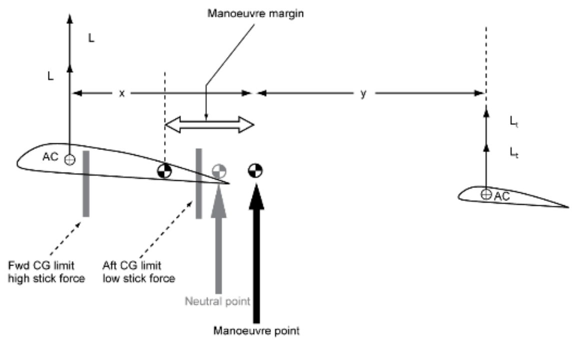




**<u>Longitudinal stability(Around lateral axis):</u>**
- Transport aircraft load factor limit: 2.5G
- Positive static longitudinal stability: Nose down moment occurs after an upgust
- Phugoid:
  - Slow changes in speed & altitude
  - Dynamic longitudinal stability
  - Altitude varies significantly
  - Speed varies significantly
  - Can be easily controlled by the pilot
  - Long period of weak damping
- Short period oscillation:
  - Altitude remains approximately constant
  - Speed remains approximately constant
  - Should always be heavily dampened

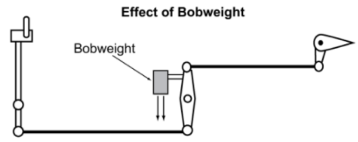


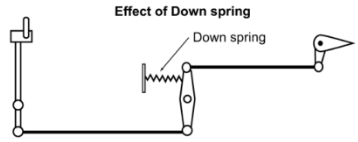

- Directly influenced by centre of gravity (CG):
  - Aft CG limit: Determined by minimum acceptable static longitudinal stability, minimum value of the stick force per G
  - Fwd CG limit: Limited by insufficient flare capability & insufficient in-flight manouevrability, minimum control response
  - Neutral point: Aircraft become longitudinally unstable when CG is shifted beyond this point
  - CG static margin: Distance between CG datum & CG neutral point
  - Magnitude of stick force determined by distance the CG is forward of the neutral point
- Contribuitions to static longitudinal stability :
  - Engine nacelles aft of CG have **positive** contribution to static longitudinal stability
  - Wing contribuition depends on CG location relative to the wing aerodynamic centre
    **May be** negative, also with flaps

- Wing downwash: **Negative**
- Fuselage: **Negative** contribution to static longitudinal stability
- Horizontal stabilizer surface area increase: Increased longitudinal stability
- Tailplane: Greatest contribuition to longtudinal stability (Positive effect)
  - CG location ahead of CP, gives downward vertical load
  - CG location behind CP, gives upwards tail loading
- Trim tabs have no effect on longitudinal stability
- Positive/negative camber has no effect




- Centre of pressure:
  - Always aft of CG when **tailplane is producing down load**
  - AOA increase changes total aeroplane lift aft of CG
  - CP moves fwd: Pitch up moment
  - **CP aft of CG**, tailplane has **downward load**
  - **CP fwd of CG**, taiplane has **upward load**
- Manouevre stability/stick force per G:
  - **Increases** as **CG moves fwd**
  - It is **not** manouevrability, it is stick force per G, **reduced as CG moves aft**
  - Manouvre point (Where wing lift = tail lift) is aft of neutral point
- Stick force gradient: Force required to change the load factor of the aircraft a given amount




- Stick **force** stability:
  - Affected by bob weights & down spring
  - Bob weights: Pulls the stick forward when there is sufficient stick force per G
  - **Increases as CG moves fwd**
  - Static stick force stability: Maintain a speed above the trim speed requires a push force
  - Static stick force stability: Maintain a speed below the trim speed requires a pull force
  - High limit load factor allows lower stick force per G
  - Stick force per G is **not** a limitation on an aircraft, it is dependent on CG location
  - Stick force per G is **dependent on altitude** (**Higher force at lower altitudes**) & CG location
  - Stick force per G **must have an upper & lower limit** in order to assure acceptable control characteristics
- Stick **position** stability:
  - Is always constant irregardless of trim
- Damping:
  - Damping in all axes is reduced as altitude gets higher
  - Slows down the rate or diminishes the amplitude of vibrations or cycles
- Flight phases:
  - During slow flight,
    - Least lift created to keep plane flying level occurs at an aft CG (High AOA) & high thrust settings
    - Most lift created to keep plane flying level occurs at an fwd CG (Low AOA) & low thrust setting
  - During landing max elevator deflection required when flaps are down and CG is at fwd limit
- Effective angle of attack:
  - Nose up pitch displacement: Effective AOA changes & causes the tail plane to apply a nose down moment

**Directional stability(Around normal axis):**
- Tendency of an aeroplane to recover from a skid without control input from the pilot
- Contribuitions:
  - Positive: Mainly by the fin
  - Positive: Swept back wings
  - Positive: Dorsal fins maintains static directional stability at large sideslip angles
  - Positive: Ventral fin (Negative effect on lateral, no effect on longitudinal)
  - Negligible: Straight wings with high aspect ratio
- Sideslip angle:
  - Angle between speed vector & the plane of symmetry
- Sideslip with relative airflow from the left
  - Initial tendency of nose to move left (Yaw left)
  - Initial tendency of right wing to move down

**Lateral stability(Around longitudinal axis):**
- Determined by aircrafts **response to sideslip** (Tendency to roll left with airplane nose pointing left of incoming flow)
- Sideslip: Banking in one directon & rudder in opposite direction. (Right sideslip = right wing down & left rudder)
- Effective dihedral on an airplane component: Contribution of that component to the static lateral stability
- Neutral lateral stability: Following a wing drop, wing would remain in its displaced position
- Excessive lateral stability is undesirable as:

- It would impose excessive demands on roll control during a sideslip
- Too much aileron deflection is required during a crosswind landing
- Increased by:
  - Wing sweepback, main function is to increase $M_{CRIT}$, but has a positive contribuition to lateral stability
  - Dihedral, to increase dihedral is to increase the stick force, required lateral control force increases
  - Increasing aspect ratio
  - Having high wing
- Decreased by:
  - Anhedral
  - Forward sweep
  - Flap extension
  - Low wing mounting
  - Ventral fin
- Advantage of horizontal stabilizer on top of vertical fin (T-tail): Improved aerodynamic efficiency of the vertical fin
- When lateral stability is increased, **lateral control force should increase** to counter stability

**Lateral & directional:**
- Dutch roll:
  - Combined lateral & directional **periodic** motion
  - Sensitivity increased: Lateral stability increase
  - Reduced by increasing anhedral angle of the wings (Decreasing lateral stability)
- Spiral dive:
  - Combined lateral & directional **aperiodic** motion
  - Directional stability positive/more excessive & lateral stability weak
  - Spirally unstable: A condition when, during a level turn, bank steadily increases
- Increasing altitude:
  - Constant IAS: Lateral stability increase, directional stability decrease
  - Constant Mach: Lateral stability the same, directional stability decrease
- Yaw damper failure: Counteract dutch roll by reducing altitude & mach number

**Control:**
- Aeroplane manouevrability decreases for a given control surface deflection when IAS decreases
  Aeroplane manouevrability increases for a given control surface deflection when IAS increases
- Control surface deflection decreases when IAS increases, when load factor decreases
  Control surface deflection increases when IAS decrease, when load factor increases
- Pitch angle: Angle between longitudinal axis & the horizontal plane (Flight path angle + AOA)
- Bank angle: Angle between lateral axis & horizontal plane

**Pitch control:**
- Thrust line is below CG when increase in power has a nose up tendency
- Lowering of landing gear, due to increased nose down moment, down load on tailplane needs to be increased
- During flare too much longitudinal stability = Higher control forces & higher $V_{REF}$(1.3 stalling speed)
- Low speed pitch up: Possible with podded engines located beneath a low mounted wing
- Trimmable horizontal stabiliser: Correct setting determined by CG position
- Variable incidence tailplane(Not fixed):
  - Advantage: Less trim drag & maximum elevator authority retained
  - Backward movement = Decrease in tail incidence & nose up pitch
- Engines rear of fuselage:
  - Compared to engines beneath wing: Less influence on longitudinal control of thrust changes
  - Fairings of tail mounted engines give positive pitching moment (Pitch up)
  - Longitudinal trim is less affected by changes in thrust
- Elevator deflection:
  - Smaller at high IAS compared to low IAS
  - Larger at lower IAS compared to high IAS
  - Decreases with decrease in load factor
  - Increases with increase in load factor
- Stabilizer:
  - Contributes to the total lift of the plane
  - May stall before the wing
  - Is necessary to balance the total pitch moment of the plane
  - When ice is present stabilizer may stall & induce a **vertical dive**

**Yaw:**

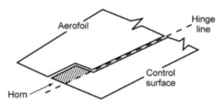
- Vertical fin could stall if fin AOA is too great
- Full rudder deflection limited as IAS increases as a full rudder deflection could cause an excessive load

**Roll control:**

- Ailerons:
  - Form drag increases when aileron deflected upwards
  - Changing wing camber & two wings producing different lift values resulting in a moment around the longitudinal axis
  - Rolling out: Lowered aileron creates more drag as the AOA of the wing being raised is greater as the rollout is started
  - Rolling with ailerons & spoilers, right turn: Right spoiler & aileron up, left spoiler not moved & left aileron down
  - Altitude increases = rate of roll increases
- Spoliers:
  - Assists ailerons
  - Upper wing surface devices & deflection can be symmetrical or asymmetrical
  - Spoiler deflection downward on up going wing & upward on the down going wing
  - Operated asymmetrically for roll control
- Outboard ailerons:
  - Locked out during cruise (deactivated after flaps/slats retracted or above a certain speed)
  - Typically used when flaps are extended, in low speed flight only
- Inboard ailerons:
  - & roll spoilers are used during cruise
  - Reduce wing twist at high speed
- Frise ailerons:
  - Leading edge protrudes below wing when aileron is raised but not above it when lowered
  - Reduces adverse yaw
- Adverse yaw:
  - Tendency to yaw in the opposite direction of turn mainly due to difference in induced drag on each wing
  - Caused by decreased induce drag on the lowered wing & increased induced drag on the raised wing
  - Compensated by differential aileron deflection
  - Rudder cross coupling: Rudder deflected to roll direction
- Differential aileron:
  - Decreased deflection of down going aileron
  - Reduce drag on upgoing wing
  - Equalises drag on the left & right aileron
- Turbulent gusts: Up going wing experiences an increase in AOA
- Yaw causes roll:
  - Yawing left causes roll to the left & vice versa
  - Yawing motion generated by rudder deflection causes a speed increase of the outer wing which increases the lift on that wing so that the aeroplane starts to roll in the same direction of yaw

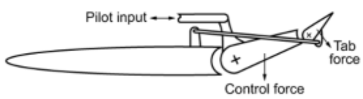
**Means to reduce control forces:**

- Aerodynamic force on a control surface: Increases as speed increases
- Aerodynamic balance:
  Purpose: Reduce load required to move the control

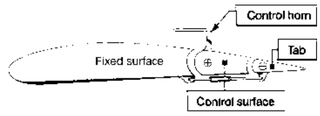



  1) An internal balance:
  - Leading edge of aileron in a box inside trailing edge, vented to atmosphere with a seal between wing & control surface

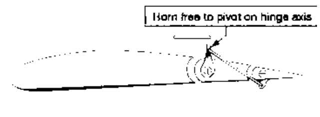
  2) Horn balance:
  - Decrease stick forces
  - Inset hinge, sets the hinge line back and any mass ahead of hinge will deflect oppositely
  - Gives assistance to the pilot to move the controls, leading edge of control surface potruding out
  - Prevents over balance resulting from excess balance at high speeds
  - Hinge cannot be too far back as it might cause overbalance, CP moves fwd
- Balance tabs:
  - Moves opposite of control surfaces & same direction as trim tabs
- Anti-balance tabs:
  - Moves in the same direction as control surfaces & increases control effectiveness
- Servo tabs:
  - Position undetermined during taxiing
  - Control surface moved by aerodynamic forces, servo tabs moved directly by pilot
  - Tab is always opposite direction to control surface
  - Rudder servo tabs moves as rudder pedals are moved
  - Used in case of manual reversion of fully powered flight controls
  - External locks: Prevent movement of control surfaces but not control wheel or servo tabs
  - Elevator jams: Pitch control reverses direction



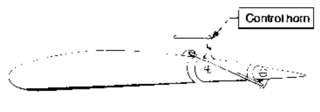
Anti-balance tab



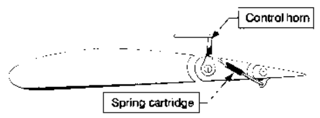
Trim tab



Servo tab



Balance tab



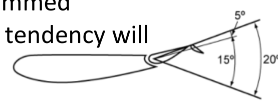
Spring tab

- Artificial feel system:
  - Main input: IAS
  - Inputs: Pitot & static pressure
  - Required with fully powered flight controls
- Spring tabs:
  - Reduces pilots effort to move the controls against high air loads
  - At high IAS it behaves like a servo tab
- Stick forces:
  - Determined by elevator deflection & dynamic pressure
- Power assisted controls:
  - A part of the aerodynamic forces is still felt on the column
- Mass balance:
  - Avoids flutter of control surface
  - There is a need for mass balancing on fully hydraulic powered flight controls
  - Weights located in front of hinge line

**Trimming:**

- Trim tabs:
  - Purpose: To reduce **continuous** stick force, a servo tab only reduces stick force
  - Reduces hinge moment & reduces control surface efficiency
  - Do **not** necessarily decrease manoeuvring **stick** forces
  - Reduces or cancels **control forces**
  - **Stick position stability never changes**
  - Not required on fully hydraulic powered flight controls
  - **Only** directly affected by trim wheel, not the control column/control surface
  - To **zero** loads on control column
  - Remains in line with elevator when it is neutral
  - Remains fixed for all control surface movements unless when using trim wheel
  - Neutral position on control column **changes** (Speed decreases neutral position moves aft)
  - Cause more drag than THS
  - Elevator trim more sensitive to flutter
  - Trim wheel moves forward = nose down trim
  - Speed
    - Increase: Tailplane should create more negative lift, AOA lowered & elevator down(nose down) & trim tab up
    - Reduce: Tailplane should create more downforce, AOA raised & elevator up(nose up) & trim tab down
  - Cockpit trim indicator: Elevator up, trim tab down = Indicator shows nose up

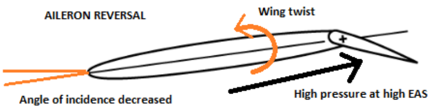

  - Pitch authority in a direction (nose down/up) is reduced in the corresponding direction the aircraft is trimmed
  - Jammed trim tab: Trim tab will act as a small elevator & respond oppositely, trying to decrease nose up tendency will increase it




- Movable stabilizer/trimmable horizontal stabilizer(THS):
  - Advantages:
    - It is a more powerful means of trimming, more power to generate tail loads for power assisted controls
    - Enables a larger CG range
    - Stabilizer trim more suitable for jet transport because of their large speed range
    - Able to compensate larger changes in pitching moments
    - When trimmed for 0 elevator stick force, it creates less drag
    - Less supceptible to control flutter
  - Disadvantages:
    - Effect of stabilizer trim runaway is more serious than trim tab runaway
    - Jammed stabilizer causes more control difficulty
  - Jammed at high IAS: Higher than normal landing speed, use lower flaps settings
  - Airplane with forward CG: Stabiliser leading edge **lower** (More negative lift, giving nose up moment on tail)
  - Airplane with aft CG: Stabiliser leading edge **higher** (Less negative lift, giving nose down moment on tail)
  - Take-off:
    - CG max fwd, THS max nose down = Rotation requires extra stick force
    - CG max aft, THS max nose down = Rotation normal
    - CG max fwd, THS max nose up = Rotation normal
    - CG max aft, THS max nose up = Early nose wheel raising takes place
  - For power assisted controls: Position of elevator depends on position of flaps, slats & **CG**(Main factor)
  - For fully operated hydraulic controls: Position of elevator deflection = 0
  - Neutral position on control column **does not** change for fully powered controls
  - Variable incidenct tailplane: Trimmed by changing the angle of incidence of the entire tailplane

**Operating limitations:**

- Wing flutter:
    - It is a destructive vibration that must be damped out within the flight envelope
    - A rapid oscillation of control surface in flight
    - Cyclic deformation generated by aerodynamic , inertial & elastic loads on the wing
    - A divergent oscillatory motion of a control surface by interaction of aerodynamic, inertia forces & stiffness
    - Caused by combination of bending & torsion of the wing structure
    - Prevented by locating mass in front of torsion axis of wing
    - Prevented by ensuring the wing CG is ahead of the torsional axis
    - Prevented by mas balancing
    - Reduced by mounting engines ahead of wing
    - Excessive free play/backlash (Clearance/tolerance) **decrease** flutter speed
    - Aeroelastic coupling affects flutter characteristics
    - IAS increase flutter risk increases
    - Resistance to flutter increases as wing stiffness increases
- Aileron reversal:
    - Twisting of the wing above reversal speed
    - Wing twisting & reducing incidence when the aileron is lowered
    - The down going aileron increasing the semi-span AOA beyond the critical

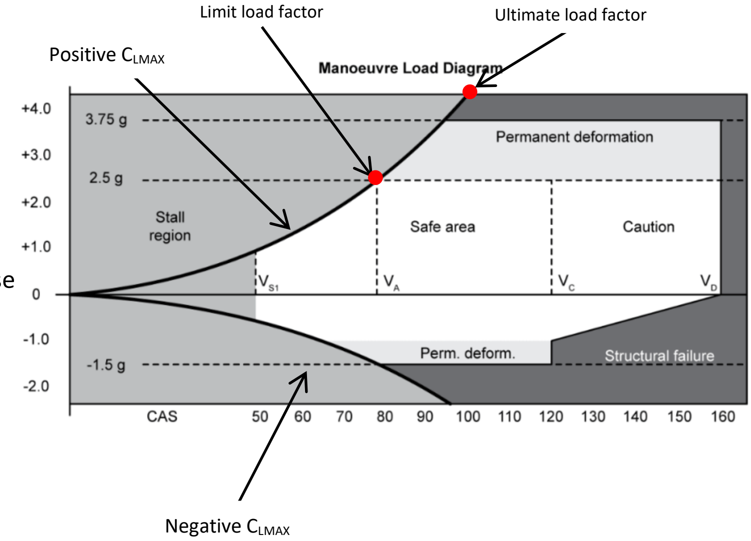



- Limiting speeds:
    - $V_{MO}$(Max operating speed):
        - CS-25 aeroplane speed that may not be deliberately exceeded in any phase of flight, unless higher speed is authorized for flight test/training operations
        - Climbing at $V_{MO}$ might exceed $M_{MO}$
        - $V_{MO}$ should not be greater than $V_C$
    - $M_{MO}$ can be exceeded in flight because maintaining a constant IAS requires an increase in TAS
    - $V_{FE}$: Above this speed flap movement prevented by flap load relied system
    - $V_{RA}$: Recommended turbulence penetration speed (Below structural limit speeds & above stall speeds determined by load factor graphs)
    - $V_A$ (Maximum design manouevring speed):
        - Above it, elevator deflection could cause structural damage/permanent deformation
        - Depends on aeroplane mass & pressure altitude
        - Speed at which aeroplane stalls at the manoeuvring limit load factor at MTOW
        - $V_A >= V_s \times \sqrt{(\textbf{limit} \text{ load factor})}$ **May not be less equates to symbols (>=)*
        - $V_A >= V_s \times \sqrt{(\mathbf{2.5})}$
        - $V_{A(NEW)} = V_{A(OLD)} \times \sqrt{(\text{New weight} \div \text{old weight})}$
        - Determined by **manouevring limit** load factor

**Manouevring envelope:**

- Exceeding ultimate load factor = Structural failure
- Manouvre load diagram:
    - Stall speed:
        - Reaches a point $V_S$ load factor = +1
        - Originates from Speed = 0 & load factor = 0
        - Speed = $V_A$, Load factor = limit load factor
    - $V_B$: Design speed for maximum gust intensity
    - $V_C$: Design cruise speed, strength requirements during cruise
    - $V_D$: Design dive speed (Most limiting speed)

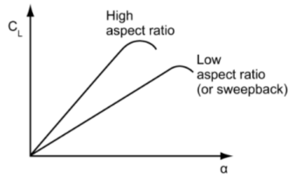
| Category | Load factor |
|---|---|
| Large/transport aircraft | -1 to 2.5g (2.0 flaps) |
| Normal | -1.52 to 3.8g |
| Utility | -1.76 to 4.4g |
| Acrobatic | -3 to 6g |

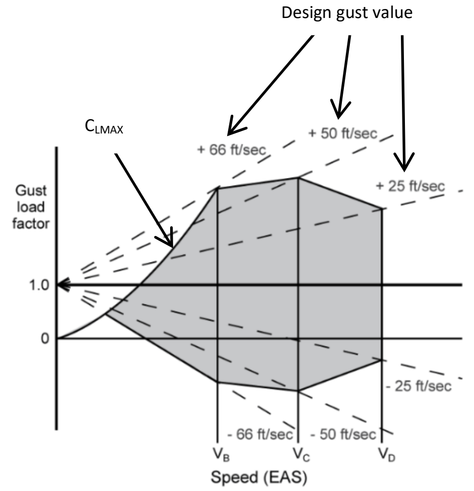



**Gust envelope:**

- Gust limit load factor:
    - Load factor created when aircraft penetrates horizontal/vertical gusts
    - Higher than manouevring limit load factor as gusts affects a small part of aircraft

- Manouevring limit load factor:
  - Load factor created by turning/pulling pushing aircraft
  - Lower than gust limit load factor as it affects entire aircraft
- Gust load factor:
  - Increase with upward gusts
  - Increase with wing area increase
  - Increase with EAS increase
  - Increase with slope of lift vs AOA increase
  - Increase with mass decrease
  - Increase with altitude decrease
  - Increase with wing loading decrease
  - Higher on high aspect ratio aircraft

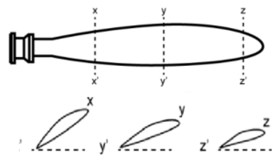


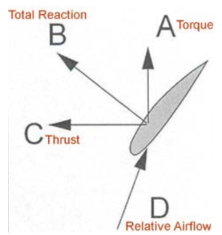




- Flaps extension **reduces stall speed** but will reduce margins to structural limitations
- Swept wings least sensitive to turbulence
- When AOA is constant, √Load factor = New airspeed ÷ old airspeed
- Load factor $= C_{LNEW} \div C_{LOLD}$
- $\sqrt{n} = V_{NEW} \div V_{OLD}$
- Gust load diagram:
  - B – C – D : 66 – 50 – 25
  - All lines originate from 0 speed & 1G gust load factor
- Gust stall questions:
  1. Check if gust will make the airplane stall:
  - $V_{S1} = V_{S0} \times \sqrt{n}$
  - If gust load factor < normal flight load factor it won't stall
  2. Calculate new load factor
  - New speed ÷ old speed = (new n - 1) ÷ (old n - 1)

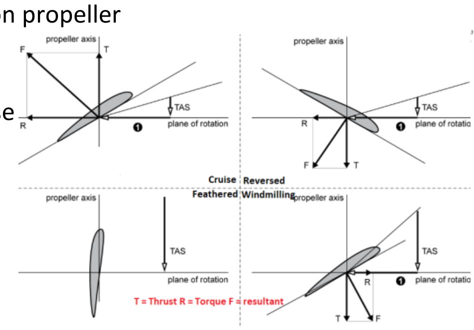
**<u>Propellers:</u>**

- Propeller efficiency =
  - Thrust power ÷ shaft power
  - Power available(Thrust x TAS) ÷ shaft power(Torque x RPM)
  - Power output ÷ power output
- Propeller blade twist: Varying of blade angle from root to tip of a propeller blade
- Propeller blade twisted root to tip: To maintain constant AOA along whole length of the blade
- Propeller reference section: 75%
- Helix angle: Blade pitch/angle – blade AOA
- Geometric pitch: Theoretical distance prop moves forward in one revolution at 0 AOA
- Effective pitch: Actual distance a propeller advances in one revolution
- Propeller slip = Geometric pitch – effective pitch
- Thrust: Component of aerodynamic force parallel to rotational axis
- Propeller torque: Forces caused by airflow on propeller

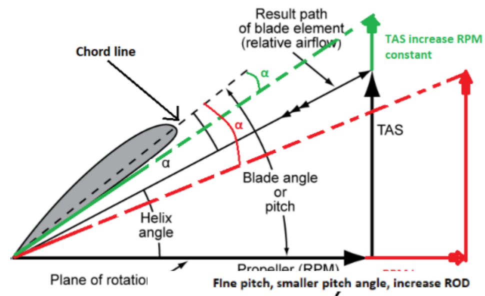


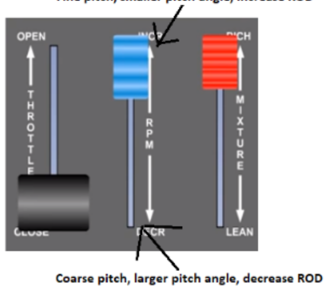

- RPM lever forward during takeoff:
  - Finer pitch for maximum power
  - More drag, L/D decrease & ROD increase



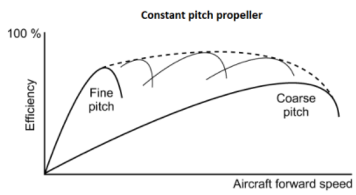

- Icing:
  - Reduces propeller efficiency by 20%
  - Increase blade drag & reduce blade lift
  - Occurs at low RPM
  - Occurs at thicker sections first (root)
  - Wing icing more critical than prop icing




- Cruise/coarse fixed pitch propellers:
  - Larger/coarser pitch compared to climb propeller
  - Greater geometric pitch compared to climb propeller
  - Less efficient during take-off & climb, more efficient in cruise
- Propeller runaway (overspeed): First action is to close throttle
- Blade AOA may become negative during high speed idle descent(Increasing TAS & decreasing RPM)



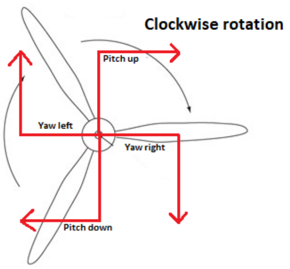

- Constant speed propellers:
  - Operate at a higher propeller efficiency over a wider speed range than a fixed pitch propeller
  - Reduces fuel consumption
  - Small blade angle/significant blade twist: Fine pitch
  - Large blade angle/little blade twist: Coarse pitch
  - Pitch angle alters slightly in medium horizontal turbulence
- Aerodynamic load: Bends tip forward

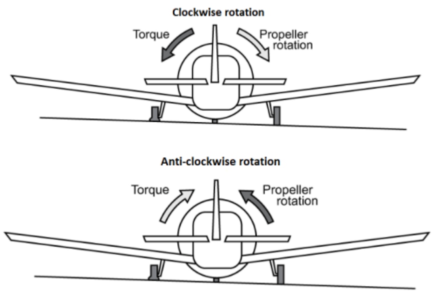


Centrifugal load: Bends tip backward

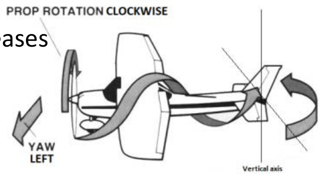
- Windmilling:
    - Produce drag instead of thrust, greatest drag condition
    - Drag higher than feathered propeller
    - Drag higher than non-rotating propeller
    - Pitch decrease, drag increase & ROD increase
    - Pitch increase, drag decrease & ROD decrease
- Feathered:
    - Minimum drag on propeller, less drag than windmilling
    - Compared to windmilling, feathered improves handling of multi engine airplane with one engine inoperative
    - Blade angle approximately $90^{o}$
- Limitation on number of blades:
    - Loss of efficiency of one blade if it follows to the path of the preceding blade too close
    - Due to decreased propeller efficiency
- Area ratio:
    - Area of all propeller blades to the circular surface
    - Solidity: ratio of total frontal area of all blades to frontal area of propeller disc
- Number of blades increase:
    - Power absorption increase
    - Efficiency decrease
    - Noise reduces
    - Solidity of the propeller increases
- Mean chord/camber increase:
    - Power absorption increase
    - Efficency **decrease**
- Tip speed increase to supersonic:
    - Noise increase
    - Efficiency decrease

<u>**Propeller effects:**</u>

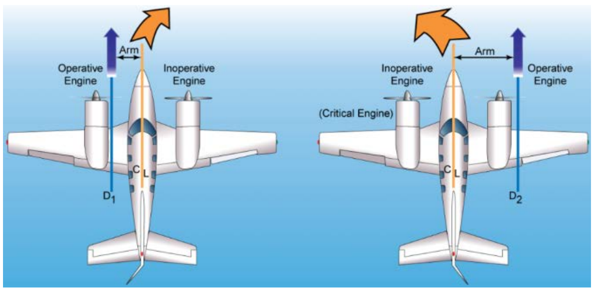



- Gyroiscopic effect:
    - Most noticeable during low speed flight & **high RPM**
    - Increase with RPM increase
    - Induced by pitching & yawing
- Torque effect:
    - Highest during low speed & max engine power
    - Produces roll about longitudinal axis
- Assymetric blade effect(P-factor):
    - Inclination of propeller axis to the relative airflow
    - Cause left yaw on clockwise rotating propellers
    - Increases when angle between propeller axis & airflow increases
    - Increases when engine power increases

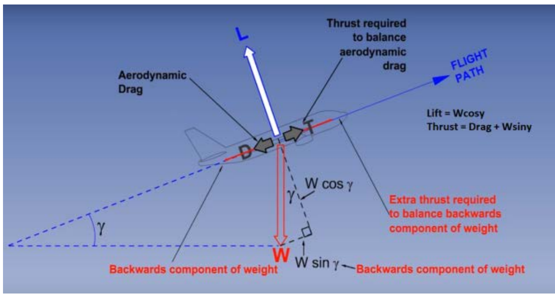



- Slipstream effect:
    - Countered by placing fin as far as possible from propeller
    - Produces yaw about vertical axis
- **Counter** rotating propellers: 2 engines, one spinning clockwise & one anti-clockwise cancels out torque & gyroscopic effects
- **Contra** rotating propellers: 2 blades on one engine, one spinning clockwise & one anticlockwise cancels out torque & gyroscopic effects
- Airplanes fitted with propellers have **more roll tendency** after engine failure compared to jet engines
- Tail wheel aircraft have a gyroscopic effect induced when taking off (Due to pitching up) when tailwheel is airborne
- Left engine is the critical engine as left engine failure creates **more yaw** moments

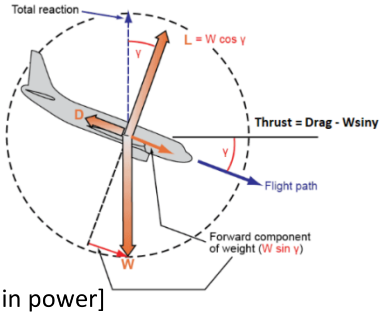


## Forces acting on an aeroplane:

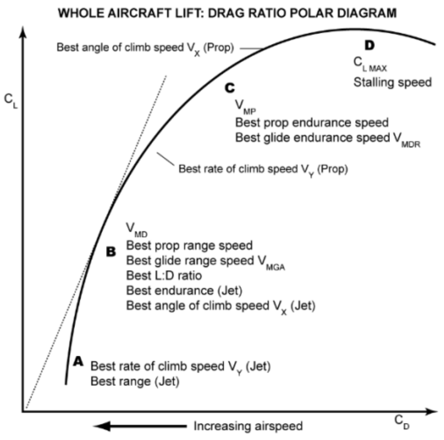
- General:
  - Forces of lift & drag are normal($90^o$) & parallel to the **relative airflow**
  - Weight is parallel to gravitational force g
  - All four forces act through CG
  - Steady = not accelerated, sum of forces = 0
  - y = flight path angle, angle between **speed vector** & **horizontal plane**
  - ϕ = bank angle
  - 1kt = $0.5144m/s^2$
- Straight & level flight:
  - Drag = Thrust & lift = weight
  - Opposing forces are equal
- Straight steady climb:
  - Lift = Wcosy
  - Thrust = Drag + Wsiny(Weight)
  - Up forces = down forces
  - Thrust greater than drag because it must also balance a component of weight
  - Lift less than weight because weight is compensated by the thrust
  - Altitude increase
    - Power available decreases, causing gamma to decrease
    - AOA increases as density decreases
    - IAS decreases as power decreases & also due to drag as AOA increases




- Straight steady descent:
  - Lift = Wcosy
  - Thrust = Drag – Wsiny(weight)
  - Thrust less than drag
  - Lift less than weight because it only needs to balance weight component perpendicular to flight path
  - Sum of forward forces equal to sum of all rearward forces
- Gliding:
  - Max gliding distance: Induced drag = parasite drag, determined by L/D ratio
  - Max gliding distance acheived when using gliding speed that gives the lowest drag
  - Max gliding duration: Decreased mass increases **duration,** does **not** affect **distance**
  - Max glide range: Depends on **wind** & **L/D ratio** which varies with AOA
    - Headwind: Glide range reduced
    - Tailwind: Glide range increased
  - Glide ratio = L/D ratio = Distance over ground ÷ height loss [Feet to NM: ÷ 6080]
  - Airspeed for minimum glide angle($V_{MD}$)[Min drag] is greater than minimum sink rate ($V_{MP}$)[Min power]
  - Descent angle: Fixed value for a certain combination of configuration & AOA




- Min glide angle: Achieved at $(C_L/C_D)_{MAX}$ Climb gradient:
  - [Thrust per engine (N) x number of engines] ÷ [Mass(kg) x gravitational force(g)] – [Drag ÷ lift] x 100%
  - Climb gradient = tany(Climb angle)
- Rate one turn:
  - $3^o/s$
  - (g x tan ϕ) ÷ V (Inversely proportional to speed)
  - Flying at ROT,
    - Airspeed decrease = Bank angle & radius decrease
    - Airspeed increase = Bank angle & radius increase




- Coordinated turns:
  - Radius = $[TAS(m/s)]^2$ ÷ [$9.81m/s^2$(gravitational force, g) x tan ϕ (Bank angle)]
  - Time to fly a circle: Circumference(2πr) ÷ TAS(m/s)
  - To deduce lift from coordinated turns:
    1. Load factor = L ÷ W, also load factor in a turn = 1 ÷ cos ϕ
    2. L/W = 1/cos ϕ (bank angle)
    3. L = Weight(N) ÷ cos ϕ
  - 2 aircraft at different speeds, same mass & bank angle
    - Turn radius greater with faster aircraft [Radius = $TAS^2$ ÷ (g x tan ϕ)]
    - ROT greater with slower aircraft [ROT = 1/TAS]
    - Lift coefficient greater with slower aircraft [According to lift formula (L = $\frac{1}{2}pV^2C_L$) To remain with same lift, if V is lower $C_L$ must be higher]
  - To maintain altitude & airspeed: AOA & thrust must be increased
  - To maintain altitude & thrust: Speed will decrease
  - Mass does not affect turn radius with constant bank & TAS, but determines whether it will stall or not at said speed **BUT <u>minimum</u> possible radius** of turn is smaller with smaller airplanes

- For a specific angle of bank & airspeed, ROT & radius does not vary
- It is when the longitudinal axis of the aeroplane at the CG is tangential to the flight path
- AOA has to be increased to compensate for the reduction of the vertical component of lift
- The **horizontal** component of **lift** makes the aircraft **turn**
- Lift force provides centripetal force & a force that opposes the weight of the aircraft
- Thrust = drag because there is equilibrium of forces along the direction of flight
- Centripetal force = weight at $45^o$ bank
    - $<45^o$: Centripetal force < weight
    - $>45^o$: Centripetal force > weight

- Load factor:
    - General:
        - Load factor = L ÷ W
        - Steady level flight load factor = 1
    - In a turn:
        - Load factor = 1 ÷ cos ϕ
        - Does not change with a constant bank angle
    - During climb & descent
        - Load factor < 1
        - Load factor = L ÷ W = Wcosγ (Lift) ÷ W = cosγ(climb angle)


**Coordinated right turn**

**Skidding right turn**
**Nose pointing inwards**
**Too little bank angle**
**Too much right rudder**
**Too little left rudder**

**Slipping right turn**
**Nose pointing outwards**
**Too much bank angle**
**Too much left rudder**
**Too little right rudder**

**<u>Assymetric thrust:</u>**

- General:
    - Directional controllability with one engine inoperative adversely affected by:
      (Due to increased thrust from other engine = more adverse yaw moments to counteract)
        - Low temperature
        - Aft CG location
        - Low altitude
    - Directional controllability with one engine inoperative favourably affected by:
      (Due to decreased thrust from other engine = less adverse yaw moments to counteract)
        - High temperature
        - Fwd CG location
        - High altitude
- $V_{MC}$:
    - Minimum control speed with criticial engine inoperative
    - Decrease with increasing altitude & temperature
- $V_{MCA}$:
    - Minimum control speed in the take-off configuration
    - Equilibrium about normal axis provided by rudder
    - Equilibrium along lateral axis requires banking/sideslipping
    - Determined by using **max thrust** & $5^o$ bank angle
    - Not more than $5^o$: Although more bank reduces $V_{MCA}$, too much bank may lead to fin stall
    - Bank angle reduces, $V_{MCA}$ increases
    - $V_{MCA}$ does **not** reduce at **any(keyword)** bank angle above $5^o$
    - Depends on airport density altitude & location of engine on the aeroplane (Aft, fuselage or wing)
    - Directional control ensured when:
        - Maximum take-off thrust was set & maintained on the remaining engines
        - Sudden engine failure occurs on most critical engine
        - **Not** with flaps, gear or in/out of ground effect
- $V_{MCG}$:
    - Minimum control speed on the ground
    - Speed at which directional control can be maintained at engine failure on take-off using primary flying controls
    - Determined without nose wheel steering (Incase of **slippery runways** or nosewheel ineffectiveness)
    - Determined with CG fully aft. When CG is aft, there is shorter arm from CG to tailplane causing less manouvrability
    - Determined using directional control/rudder **only** (No lateral)
    - Determined by **airport elevation** & **temperature**
    - Lateral deviation should not be more than 30ft
    - Decreases with increasing field elevation & temperature. Because engine thrust decreases
    - Crosswind **not** taken into account
- $V_{MCL}$:
    - Minimum control speed in the landing/approach configuration
    - Limited by the available maximum roll rate, limited by maximum **aileron** deflection
    - It is trimmed for **approach with all engines operating**
    - **NOT** for take-off

- Critical engine:
  - Engine failure with left crosswind, left outboard engine failure causes greatest problem
  - Engine failure with right crosswind, right outboard engine failure causes greatest problem
  - Engine failure: Bank & input rudder towards live engine, banking raises dead engine wing higher increasing it's lift, & rudder to counteract yawing moment caused by live engine

**Polar diagram:**