PRINCIPLES OF FLIGHT

MINTYFS

1: Basic Laws & Definitions

- Kts → m/s
  1 kt = 0·514 m/s
- Force / weight always in N. Mass kg / lbs.

- Wing loading → kg/m^2
  ↳ $\dfrac{\text{Total mass of the aircraft}}{\text{Total wing area of the aircraft}}$

- Thermal energy → total of all kinetic and potential energy of the atoms in an object
  - Degrees Celsius (°c) [0°c = 273k]
  - Kelvin (K)
    ↳ 0°k = molecular vibration stops = absolute 0

- Density → ρ (rho) → mass of air (kg) / unit of volume (m^3)

- Pressure → Force / Area → Pascal (pa) (N/m^2)

Aerodynamics

- **Static Pressure** - Result of the weight of the atmosphere pressing down on anything beneath it
  ↳ 100 Pa = 1 hPa
- **Dynamic Pressure** - Air in motion.
  ↳ q (dynamic pressure) $= \frac{1}{2} \times \rho \times V^2$
  rho/density
  velocity
- **Total Pressure** - Static pressure (p) + Dynamic pressure (q)

- Lower the density, faster we need to go to achieve pressure

volume

pressure

$$\frac{P \times V}{T} = \text{Constant}$$

temperature

pressure

$$\uparrow\rho = \frac{\uparrow p}{R \times T\downarrow}$$

density

temperature

constant

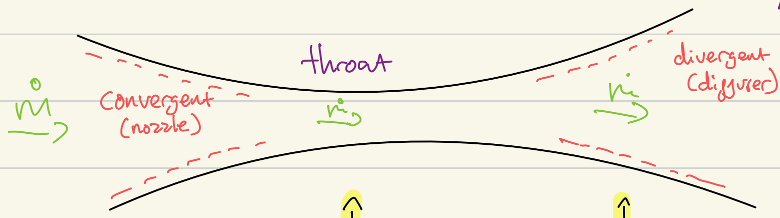
Continuity equation

$$\dot{m} = \rho \times a \times V$$

mass flow rate, density, area, velocity

ρ won't change
↳ Temp constant
↳ flow < 300kts
↳ incompressible

venturi



$\rho a V$

$\rho a \downarrow V \uparrow$
$P_d \uparrow$
$P_s \downarrow$

$\rho a \uparrow V \downarrow$
$P_d \downarrow$
$P_s \uparrow$

Bernoulli

$$P_T = P_s + P_d \uparrow$$

P_T must be constant.

$$= P_s \downarrow + \frac{1}{2} \rho V^2$$

Static port → Static Pressure

$P_{dynamic} = P_{total} - P_{static}$

Pitot Tube → Total Pressure

$P_s + P_d$

Airspeed Indicator (ASI) → Measures dynamic Pressure

↳ how much air is going over the aircraft. not how fast you are going.

↓

Errors: Instrument error, Position error

Calibrated Airspeed: Speed registered on A/S corrected for position & instrument errors

↓

Errors: Compressibility error

Equivalent Airspeed: Accurate measure of dynamic pressure when the aircraft is flying fast

$\frac{1}{2} \rho \underline{v}^2$ → IAS, CAS, EAS } measures dynamic pressure

↳ not a true speed

↓

TAS

True air speed

↓

EAS corrected for density

Memo!

IAS: I → CAS: C → EAS: E → TAS: T

I → C: Correct for: Instrument error, position error

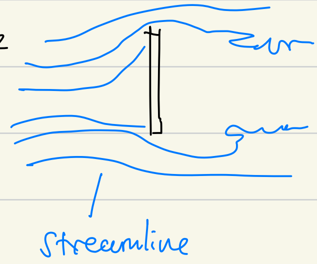
C → E: correct for: compressibility error

E → T: correct for: density error

Steady / Unsteady Airflow

Steady flow - fluid properties do not change
↳ aka laminar flow

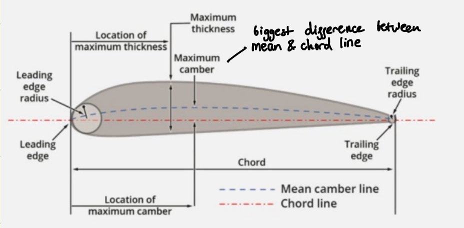
Unsteady flow - turbulent flow



Streamlines - a path traced by a particle of air in steady airflow.
- streamlines never cross
- closer the streamlines, the faster they are

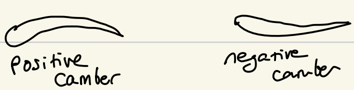
Aerofoils & Wings

- **Leading edge (radius)**
- **Trailing edge (radius)**

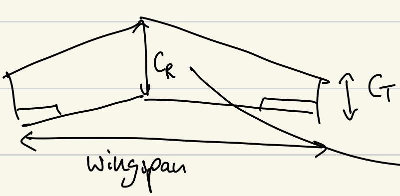


- **Chord line** - straight line between leading & trailing edge - the chord is the length of that line
- **Camber line** - line joining leading & trailing that is equidistant between upper & lower surfaces

Symmetrical aerofoil = no camber



Wing planform - layout of a wing viewed from above



Taper ratio = $\dfrac{\text{tip chord } C_T}{\text{root chord } C_R}$

Aspect Ratio = Wingspan / chord / $\frac{b}{c}$

AVERAGE $\left(\frac{\text{TIP/ROOT}}{2}\right)$

$\frac{\text{Wingspan}^2}{\text{area}}$ / $\frac{b^2}{c}$

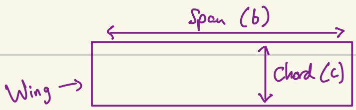
High AR:

- More stable, less induced drag

Low AR:

- More manueverable
- Less adverse yaw

Eg, glider AR 35
jet AR 3



Mean Aerodynamic Chord

↳ Rectangular wing that has the same span & area as the non rectangular wing

$$MAC = \frac{S}{b}$$

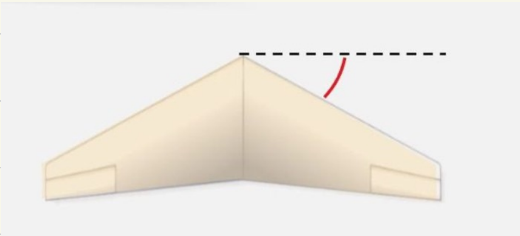
Area
Span

Dihedral Angle:

- Angle between wing tips & root
- Positive = upwards, negative = downwards

Sweep Angle:

Angle between leading edge & perpendicular to root chord



Angle of Incidence:

- Angle between the aeroplane longitudinal axis and the wing-root chord line

Angle of Attack:

- Angle between chord line & relative airflow
- Relative airflow will be the opposite direction from which the aircraft is moving (Flight Path Vector).

Wing twist:

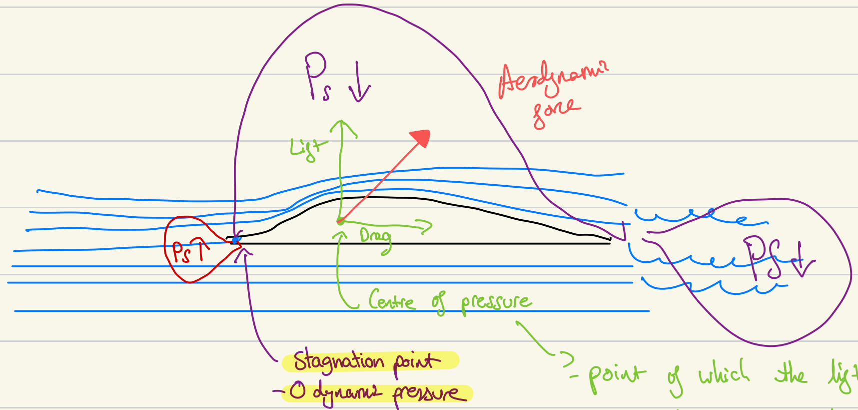
- A change in angle of incidence along the wingspan
- Improves lift characteristics across the wing
  - ↳ Wash out - decreasing angle from root to tip
  - ↳ Wash in - increasing ——— " ———

Aerodynamic wing twist - wing twist when under dynamic load

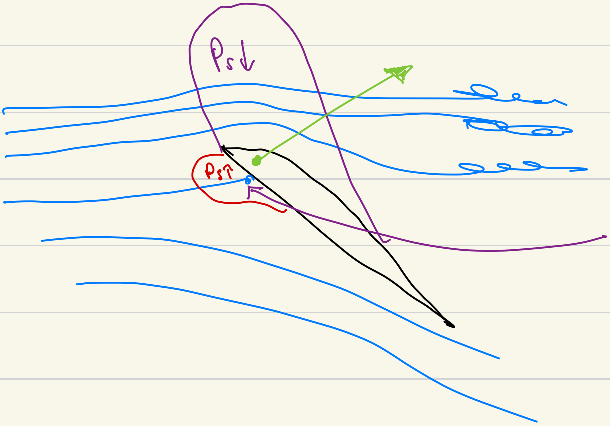
Aerodynamic Forces on Aerofoils

$P = \frac{F}{A}$

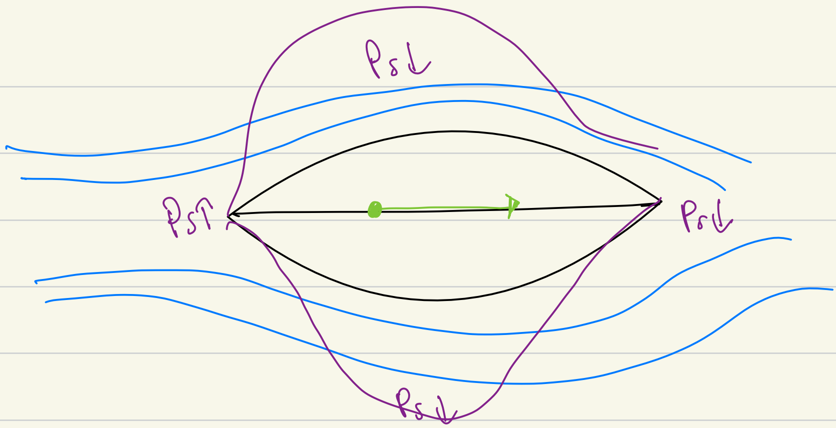
$F = P \times A \rightarrow$ Diff. in P acting over an A, I can generate a F.



- point of which the lift & drag act through
- average location of all the pressure acting on the aerofoil



As AOA increases, the stagnation point moves down the leading edge



- A symmetrical aerofoil does not produce lift at 0° AoA

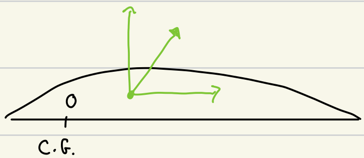
However, a positively cambered aerofoil does produce lift at 0° AoA

- Lift - Is the component of the total aerodynamic force that is perpendicular to the relative air flow.
- Drag - Is the component of the total aerodynamic force that is parallel to the relative airflow.
- Centre of pressure - for a symmetrical aerofoil, is at 25% of the chord regardless of AoA

For a positively cambered wing, it moves forward with increasing AoA.

Moments:

$\vec{M} = \vec{F} \times \vec{d}$



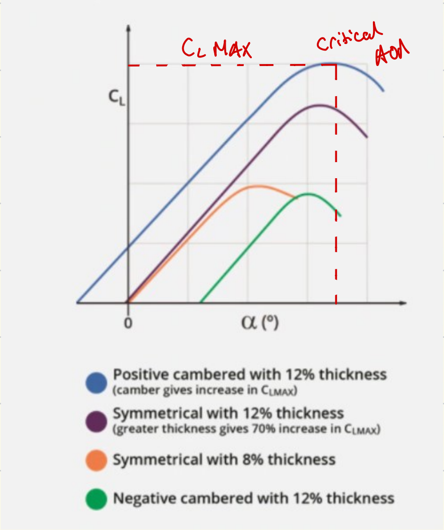
Moment between CP & CG = average pitch nose down

Aerodynamic Center: Fixed reference point used for the calculation of lift.

Zero-lift AoA:

- For a positively cambered aerofoil, to have zero lift we need to be at a negative AoA
- As AoA gets bigger, suction peak gets bigger & moves forwards. This means lift increases & CP moves forwards. (for a positively cambered wing)
- If we get too steep, ie 16 degrees, the airflow struggles to stay attached to the wing and may seperate off. This dramatically reduces the pressure differential (Lift) and causes something called a stall.
- CP/AC always behind CG → cause nose to pitch down

Lift coefficient (C_L) - Angle of Attack (α) graph



Coefficients

↳ Dimensionless number that adjusts our equations to express a degree of magnitude

- C_L (lift coefficient) • C_D (drag coefficient)

Factors :

- Airstream Velocity (V), air density (ρ)
- Shape or profile of the surface & AoA
- Surface area (S)
- Condition of surface

Coefficient of lift C_L - is influenced by shape of wing (positively cambered, symmetrical, wheelie bin?) and if you change the AoA

The Lift Equation

$$L = \overbrace{\boxed{\frac{1}{2} \times \rho \times V^2}}^{Q} \times C_L \times S$$

ρ absolute air density → 1.225 kg/m^3

V True air speed (TAS) → m/S

C_L Angle of Attack (lift coefficient)

S Fixed wing area m^2

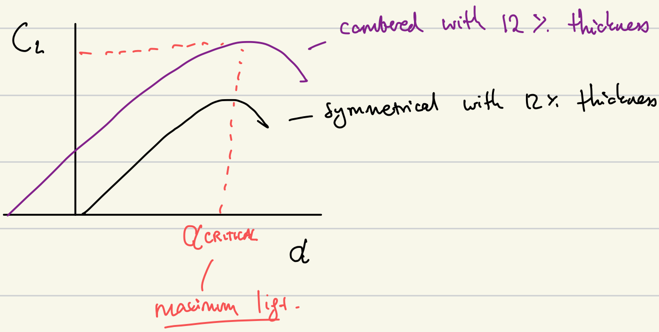
Q Dynamic pressure

$$L = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_L$$

re-arrange for V

$$\sqrt{\frac{L}{\frac{1}{2}\rho S C_L}} = V$$

- thick, rounded wing = ↑ lift



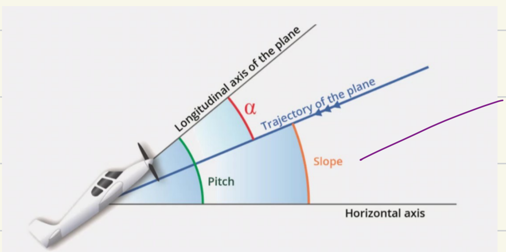
$$L = \frac{1}{2}\cdot\rho\cdot 2V^2 \cdot S \cdot C_L \frac{1}{4}$$

An aircraft maintains S&L flight but doubles its airspeed. What happens to the Cl?

$= 0.25$ or $\frac{1}{4}$

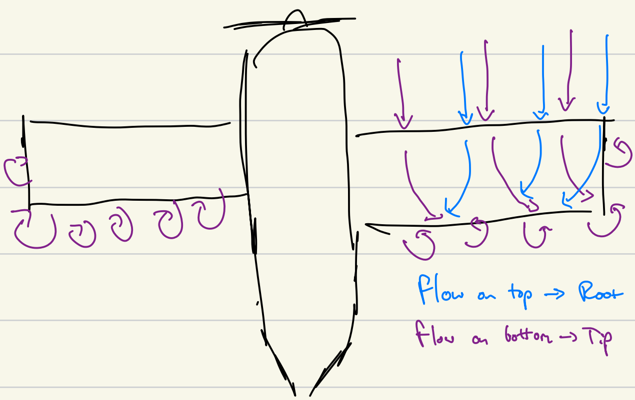
As speed increases we need to reduce C_L to maintain straight & level flight.

In 3D airflow, the AoA is between the longitudinal axis and the relative airflow



→ Also known as Flight Path Angle

air wants to be in low pressure. so air will spill around the tips.

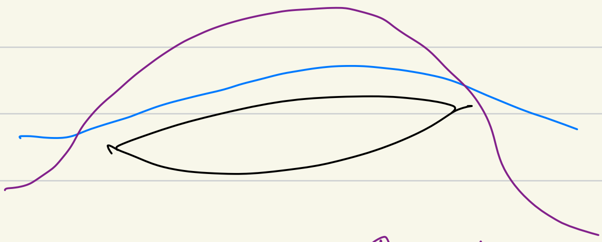


above wing
below wing

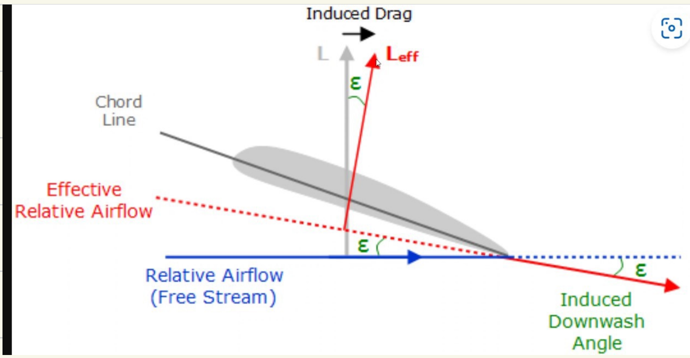
wing tip / trailing edge vortices

Flow on top → Root
Flow on bottom → Tip

3D



↑ up & down wash for 3D flow due to the increase in the trailing edge vortices



- Induced drag occurs due to the increased downwash
- Angle between relative airflow & effective airflow is called the induced angle of attack.

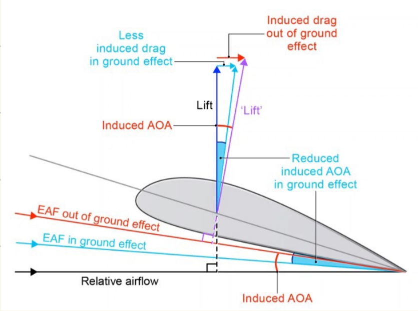
- The angle between the effective airflow and the chord line is called the effective angle of attack & creates our lift.

- ↑ wing tip vortices = ↑ downwash = ↑ induced drag
  ↳ Winglets change stalling / lift / drag characteristics
- Factors affecting strength of wing tip vortices:
  - Gross weight
  - Wingspan
  - Airspeed (lower speed, stronger vortices)
  - Attitude (higher AOA = stronger vortices)

the harder the wing is working the stronger the vortices

Ground effect & Induced Drag

Ground effect = reduction in downwash/vortices = EAF shallower = smaller induced AOA = Decreased induced drag



- You may start to feel ground effect 1 wingspan above the ground
- You will start to feel ground effect ½ wingspan above the ground
- Landing Threat: Ballooning & running out of runway
- Takeoff Threat: If aircraft overweight you may takeoff when you shouldn't = stall?
- As we enter ground effect the C_L ↑ because ↑ Effective AoA so stalling more sudden

Change in Pitch: Change in EAF across tailplane reduces tailplane downforce. On some aircraft this may cause a pitch down.

Influence on IAS: Airspeed indicator may under-read

Low wing = Increased ground effect (closer)

Ground effect

"Dont let dogs eat ice crystals"

	Enter	Leave
Drag	−	+
Lift	+	−
Downwash	−	+
Effective AoA	+	−
Induced AoA	−	+
Critical AoA	−	+

Induced Drag

Formulas: $D_i = \frac{1}{2} \times \rho \times V^2 \times C_{D_i} \times S$

$\therefore C_{D_i} = \frac{{C_L}^2}{AR}$ ~ aspect ratio $\left(\frac{\text{Wingspan}}{\text{Chord}} / \frac{\text{wingspan}^2}{\text{area}} \right)$

As aircraft speeds up, to maintain lift C_L is reduced (ie reduce AOA)

$\therefore D_i = \frac{1}{V^2}$

- ↑ IAS = ↓ Induced Drag

↑ Aspect Ratio = + less induced drag, more stable

- Stronger heavier spar needed, less maneuverable, more prone to tip strikes

Wing loading - Weight of the aeroplane / Wing area.

- Small wing relative to weight of aircraft = high wing loading
- High wing loading =

- Increasing mass increases induced drag
- Reducing aspect ratio increases induced drag
- Winglets / tip tanks reduce induced drag by minimizing the formation of wingtip vortices
  - ↳ But increase parasite drag due to increased surface area of the wing.

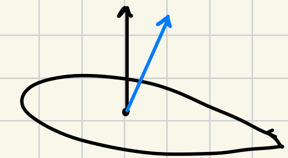
- Another method of reducing induced drag is washout.
  - ↳ Angle of incidence / wing twists as we go from root to tip. ∴ reduces induced drag
- Camber change - minimise lift at the tips to reduce vorticies generated

- Best wing shape for minimizing induced drag is the elliptical wing.
  - ↳ Produces an equal lift distribution / vorticies generation
    - ↳ Difficult & expensive to manufacture.

TOTAL DRAG

$$Drag = \frac{1}{2}\rho v^2 S C_D$$

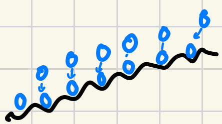
Total drag



Parasite drag

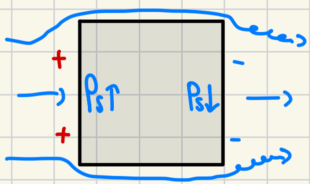
$\propto v^2$

Skin friction drag

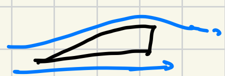


Form drag

Aka pressure drag

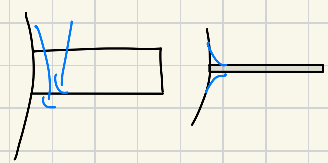


Laminar → turbulent



Fairing = less form drag

Interference drag



- Connection between surfaces (wings/fuselage)
- Reduced by filleting

Induced Drag

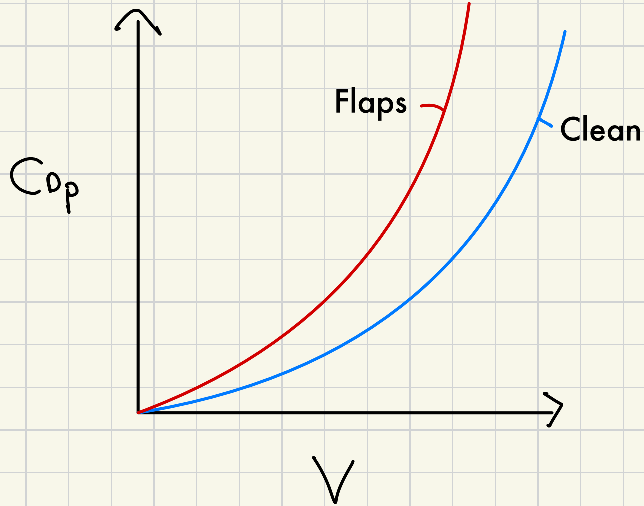
- Drag by wings
- Important at low speeds
- Wing tips
- Less Di (gliders)
  -> High aspect ratio(AR)
  -> Elliptical wing lowest Di

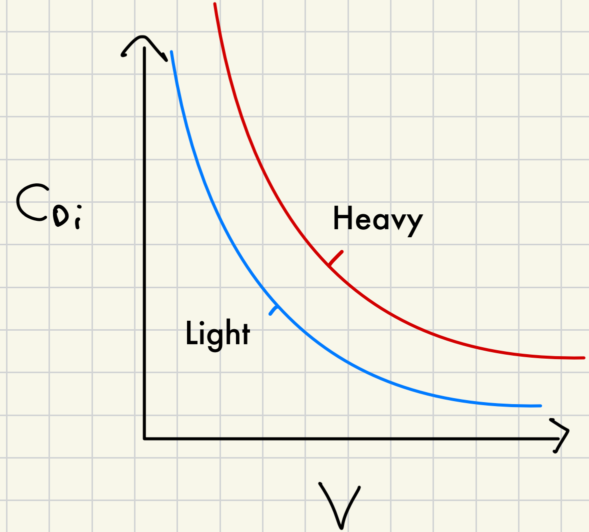
$$C_{Di} \propto \frac{1}{AR}$$

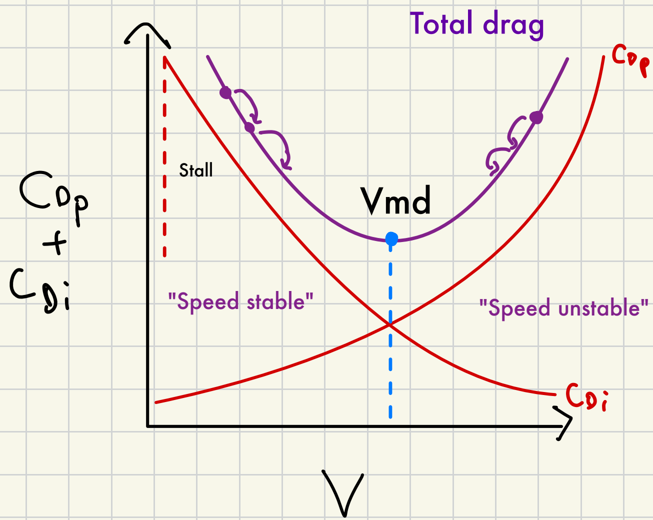
$$C_{Di} \propto C_L^2$$

$$C_{Di} \propto \frac{C_L^2}{AR}$$

PARASITE VS INDUCED DRAG



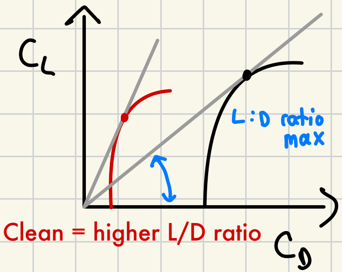




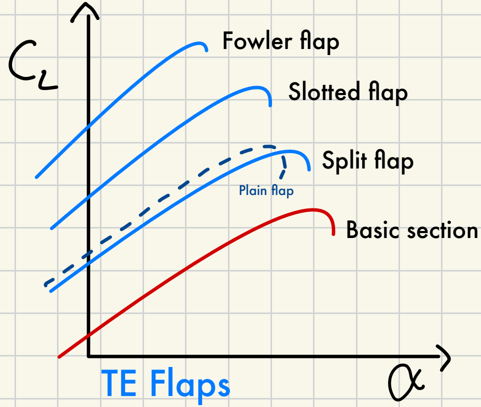
$$C_D = C_{D_i} + C_{D_p}$$

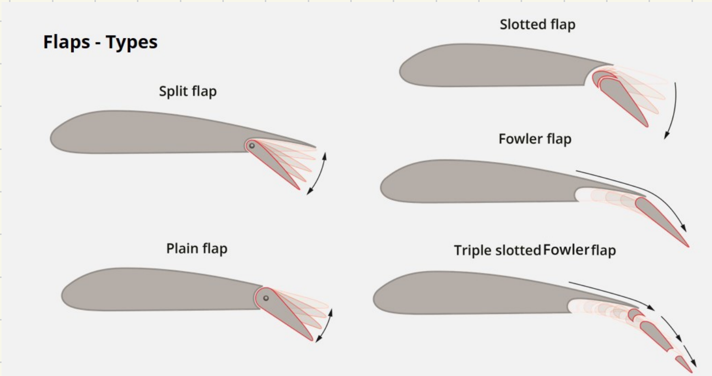
$$V_{md} = \quad C_{D_i} : C_{D_p} = 1$$

CLmax AUGMENTATION - Trailing edge flaps

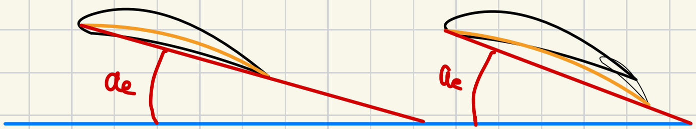


Clean = higher L/D ratio



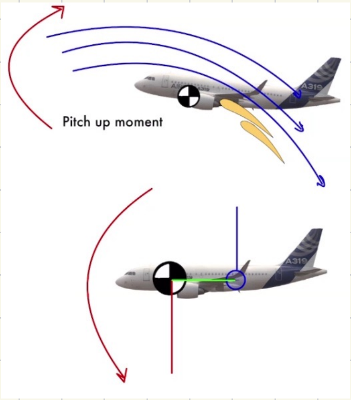


TE Flaps extended =
- ⬇️ Critical AOA
- ⬇️ Stall speed
- ⬆️ CLmax



Flaps extended = ⬆️ effective AOA
Flaps allow you to fly SLOWER with the SAME LIFT

<u>Initial</u> effect of TE flaps
Is a pitch up moment
- Due to downwash impinging on horizontal stabiliser

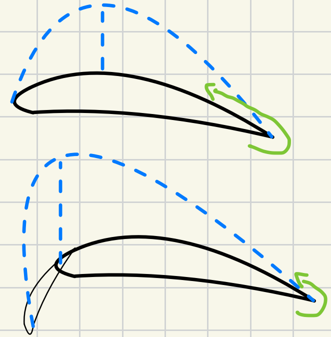


<u>Main</u> effect of flaps is a pitch down moment
- AFT movement of the CP/AC
- Increased moment of CG = pitch down

CLmax AUGMENTATION - Leading edge flaps

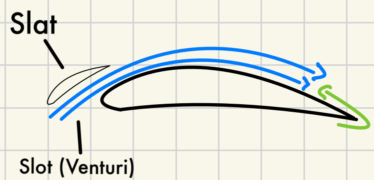
LE Devices can:

- Primarily increase aCrit
- Increase leading edge camber
  -> Leading-edge flap
- Re-energise the boundary layer
  -> Leading-edge slot or slat



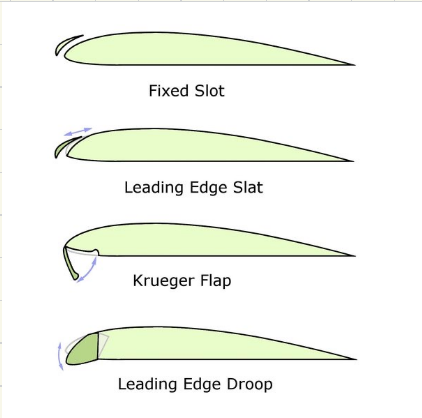
LE devices increase aCrit

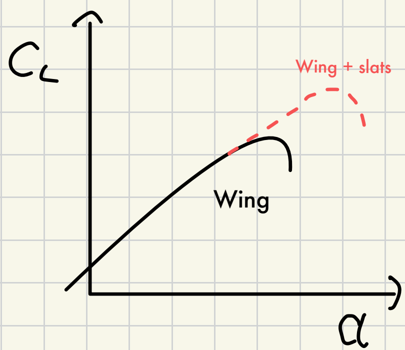
- Apart from the ‘slat’, LE devices work by moving the lowest Pstat forward reducing the strength of the adverse pressure gradient



Slot accelerates airflow

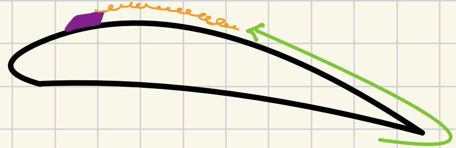
- Re-energises boundary layer
- Delays onset of separation





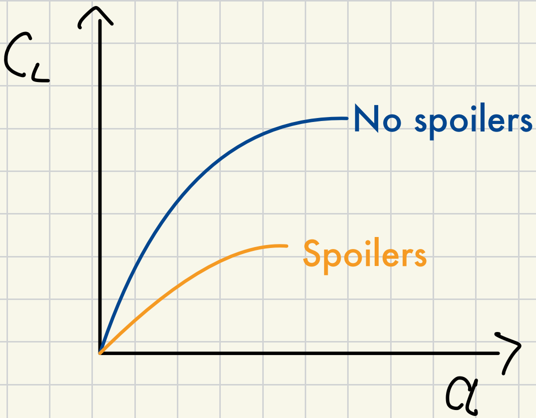
Slats increase CLmax more than flaps
LE Flaps decrease Vs more than flaps
And increase aCrit

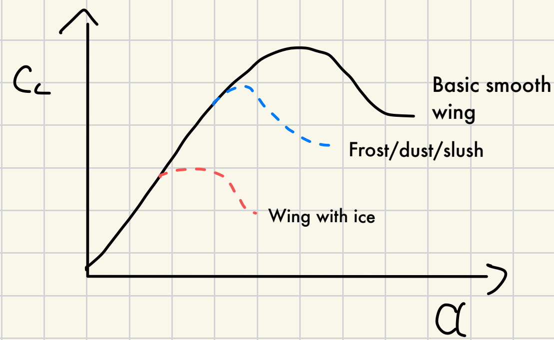
CLmax AUGMENTATION - Vortex generators, spoilers & contamination

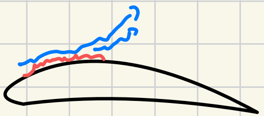


Vortex generators energise the boundary layer by introducing high energy free stream flow into lower layers of the boundary layers

- Increases aCrit
- Delays flow separation







Spoiler extension:

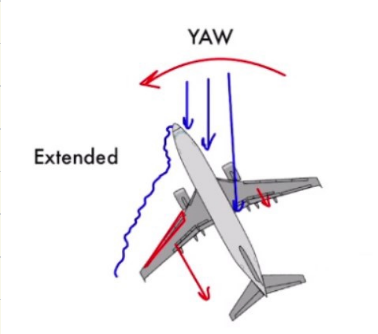
- ⬆️ Cd is increased
- ⬇️ CL is decreased
- Angle of attack is unaffected
- Margin to stall ⬇️

Icing/contamination

- Decreases critical angle of attack and can lead to absence of stall warning
- Reduction in CLmax

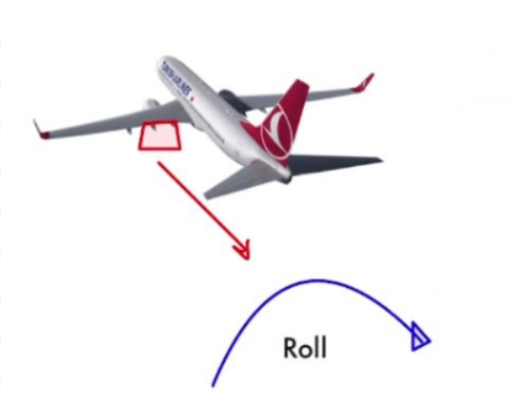
CLmax AUGMENTATION - Yaw Asymmetry

Flap asymmetry prevented via
- Flap interlock
- Senses if one flap is extending and one is not



LE asymmetry creates a YAWING moment towards extended device
- Wing with LE extended more likely to stall - due to 'fuselage blanking'

TE flaps primarily induce a roll away from extended flap
- May be un recoverable
- Wing without TE flap is likely to stall



Can recover by trimming ailerons to lower the wing with TE flap and opposite rudder

THE STALL

Boundary Layer (layer where the velocity is slower than the undisturbed stream):

<u>Laminar Layer</u>

- Laminar layer is thinner than the turbulent layer
- Friction drag is lower in the laminar layer
- No velocity component exists normal to the surface

<u>Turbulent Layer</u>

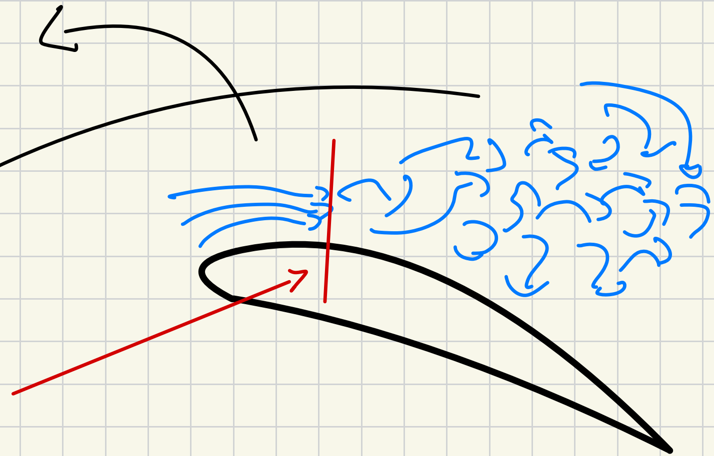
- More energy (stays attached for longer)
- Thicker
- More friction drag, consumes more energy

<u>Transition point</u>

- Turbulent between transition and separation point
- Behind the transition point the mean speed and friction drag ⬆️

<u>Airflow separation</u>

- Characteristic by airflow reversal on the surface body. Moves forward with increasing AOA.

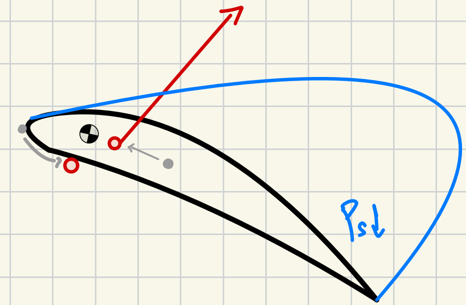


Stalling only depends on AOA. In order to get out of a stall we have to lower the nose.

INFLUENCE OF AOA

- As AOA increases, the CP moves forward, with most lift being produced at the LE of wing
- Acrit -> lift force dramatically reduces = unable to maintain weight = stall
- Stagnation point moves down the wing

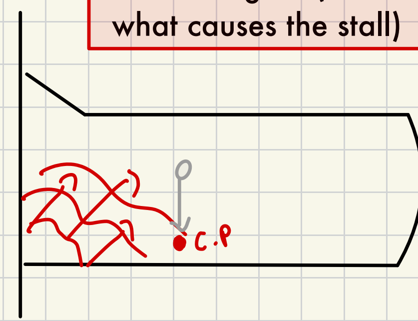
- AT the stall, the CP then moves rearwards = creates a nose down pitching moment = GOOD



RECTANGULAR WING

- Root directly in front of tail section. Creates natural warning buffet
- Reduced down wash and downforce on tail plane increases pitch down moment at the stall
- Rectangular wing greater down wash at wing tips and less down wash at root.
- Causes the ROOT to stall FIRST.

Where vortices are smallest, the induced AOA is lowest and effective AOA is higher (effective AOA is what causes the stall)



Wing Drop

One wing stalls before the other. Possible reasons:

- Slight manufacturing difference between each wing
- Small imbalances in lift production

-> Loss of lift close to root produces smaller rolling moment than lift at tips

-> So rectangular wing great for training aircraft

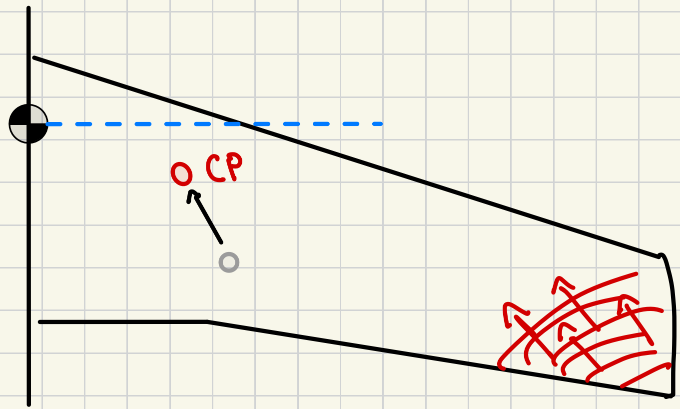
SWEPT WING

Designed to minimise TIP VORTICES.

- Stalls at TIPS FIRST.

May be dangerous during stall because:

- No natural buffet to warn of excess AOA
- Tip stall causes wing drop
- The CP moves FORWARD so aircraft pitches nose up at stall.
- Downwash at roots increase tail plane downforce = adding to pitch up moment



Post-stall behaviour

- AOA must be DECREASED to reduce the adverse pressure gradient
- Usually sufficient to LOWER THE NOSE, and apply maximum power to minimise height loss
- Pitching up too quickly after stall can cause secondary stall

Effect of controls at stall:

- Use of ailerons can exacerbate stall, due to increasing the AOA of the wing, stalling it
- Instead of rolling up, wing drops

CAUTION USING AILERONS AT OR NEAR THE STALL (SWEPT BETTER)

Indications prior to stall

- Stall warning system operating
- Buffeting (flow separation affecting control surfaces)
- Controls become less effective (ie elevator authority reduces from turbulent boundary layer coming off wing)
- Uncommanded pitch down
- Uncommanded pitch roll
- Rate of descent
- Visual or aural warnings

Stall speeds

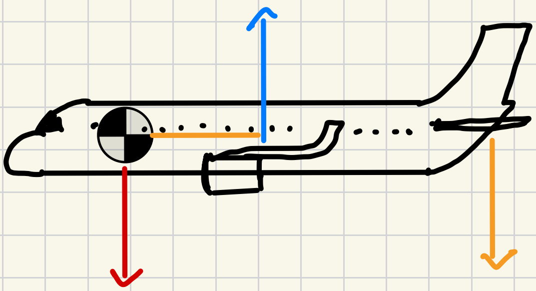
- Vs = Stall speed or minimum steady flight for which the aircraft is still controllable
- Vs0 = Stall speed/minimum steady flight speed in landing configuration
- Vs1 = Stall speed/minimum steady flight speed in specific configuration (takeoff/cruise)
- Vs1g = Min speed at which lift = weight (1g)
- VSR = reference calibrated stall speed and may be less than 1g stall speed

-> Stall speeds determined at the FWD CG limit (least favourable position)

Influence of different parameters on stall speed

CENTER OF GRAVITY (CG)

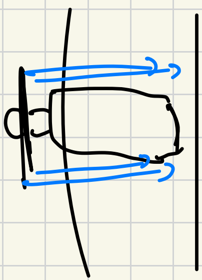
- Lift = Weight + Tail plane down force
- FWD CG = pitch down moment - extra tail plane downforce increases the need for lift to counter it
- More lift requirement = higher stall speed



FWD CG = Higher Stall Speed

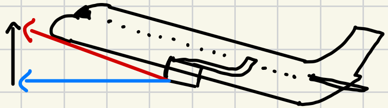
Thrust/Slipstream

- In prop aircraft, having prop on full RPM can reduce stall speed as prop increases velocity of air over wing



More thrust = Lower Stall Speed

- Jet aircraft does not induce flow on the wing BUT vertical component of thrust supports weight of aircraft so less lift required



WING LOADING & MASS

Wing loading: ratio of aircraft weight (or lift) to the wing area

Can be impacted by:

- More mass (wing works harder)
- Smaller wing (wing works harder)
- Steep turn (wing works harder)

More wing loading/Mass = Higher Stall Speed

CONTAMINATED WING

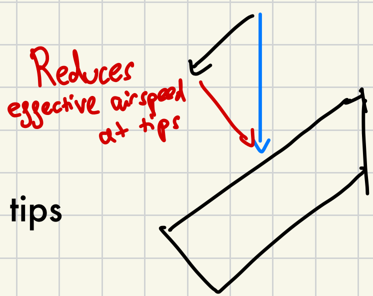
Contamination/ice can increase stall speed by:

- Increasing drag by causing a rough surface
- Increasing mass of the aircraft, causing wing to work harder
- Reduces acrit!

More contamination = Higher Stall Speed

INCREASED WING SWEEP (or forward sweep)

- Increased spanwise flow = tendency to stall at tips
- Less efficient at producing lift, lower CLmax



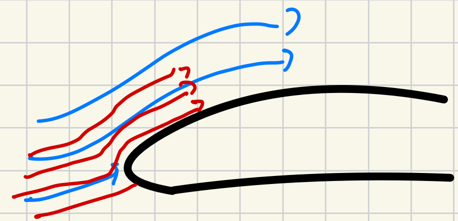
More sweep = Higher Stall Speed

ALTITUDE (compressibility effects)

- Air has less ‘warning’ of the incoming aircraft at higher altitudes

Modifies the way the air flows over the wing:

- Steep upwash
- Aircraft stalls much earlier



Higher Altitude = Higher Stall Speed

Load Factor (n)

- Load Factor = ratio of lift to weight. Also referred to as G force.

Load Factor (n) = $\frac{\text{Lift}}{\text{Weight}}$

Change in load factor during a turn

- In a turn, the load factor increases. So turn also susceptible to the 'accelerated stall'.

Stall speed is proportional to the load factor

In a turn:

- Load Factor = $\frac{1}{\text{Cos(bank angle)}}$

Accelerated stall = Occur during a sudden change in the flight path, ie steep turns or recovery from a previous stall. It is called accelerated because it occurs at a load factor greater than 1g.

Pull up/Push down manoeuvre

- Pull up = increased load factor
- Push down = decreased load factor

Limit LF = Vs^2

Stall Characteristics with Different Wing Planforms

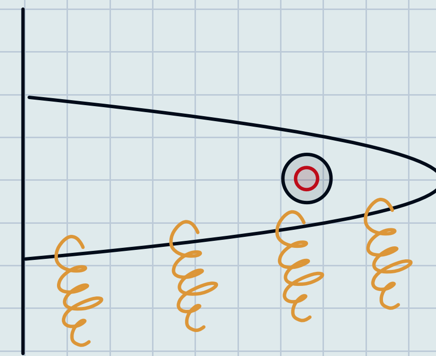
Elliptical wing:

- Downwash on elliptical wing mostly constant across its span
- Wing stalls simultaneously across its entire span

-> Undesirable because stall is sudden with only limited stall warning from light buffet on the tail plane

-> Ailerons become quickly ineffective

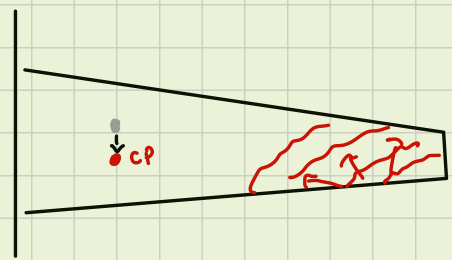
-> CP moves rearwards.



Taper Wing:

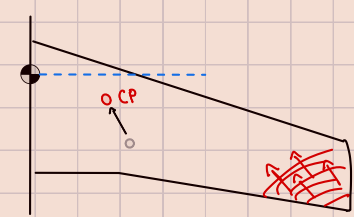
- Separation occurs first at the tips
- Stalling will create a light buffet on ailerons
- Perhaps violent wing drop
- Behaves similarly to swept wing

-> CP moves rearwards



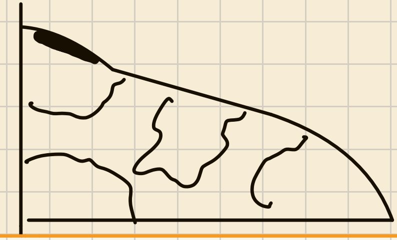
Sweepback wing:

- Tendency for tip stall
- Due to swept platform, overall wing CP moves forward creating a nose-up pitching moment



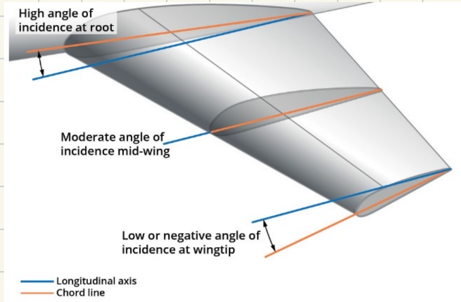
Delta Wing

- Very good at dealing with stalling
- Vortex runs down the leading edge, energising the boundary layer (delays flow separation)



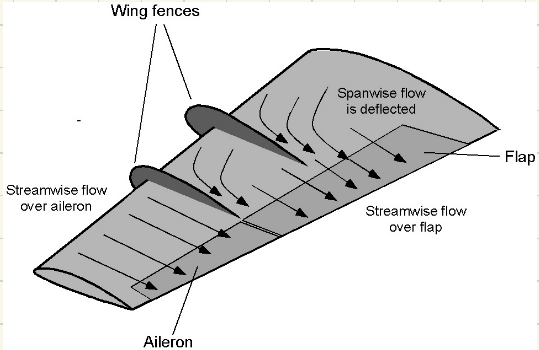
Geometric Washout

- Decreases angle of incidence towards the tip of a wing
- Better stall behaviour as the wing root tends to stall first



Fences, Vortilons, Saw Teeth, Vortex Generators, and Strakes on Engine Nacelles

- All of the above **restrict spanwise flow** and **improve low speed handling characteristics.**
- Prevent tips stalling first
- Fence on top of wing
- Vortilon underneath wing



Stall warning - aerodynamic or natural warning

Natural/Aerodynamic warnings:

- Buffet
- Low airspeed
- Sloppy controls
- High AOA

Artificial stall warning:

- Aural alert
- Stick shaker - simulates aerodynamic buffet
- Stick pusher

Deep stall

- Turbulent flow created over the horizontal stabiliser reducing authority
- Any aircraft prone to a deep stall will have a stick pusher (activate prior to the stall)
- Stall warner will go off 3kts or 3% before stall reference speed VSr
- Stall pusher will go off 2kts of 2% after the stall reference speed

- Audible stall warnings sense the movement of the leading stagnation point.

An aircraft with a stall warning device must go off 5kts or 5% faster than your stall speed, whichever is greater.

- Stall strip cause the inboard area of the wing to begin to stall first
- Angle of attack vane
- Angle of attack probe

-> In a light aircraft a stall is measured using the stagnation point

-> A large aircraft is actually measuring the angle of attack of the wing

STALL PHENOMENA & SPIN

Swept wing stall

- Stall at the wing tips causes centre of pressure to move forward - causes an unstable nose up pitching moment
- This can be improved through through a stall strip, utilisation of different flaps/slats

Absence of stall warning

- Malfunction
- Icing - a stall could occur at a lower AOA if wing is contaminated - can cause stall speed to increase by around 30°

Spin

- Stalled condition in which the aircraft pitches, rolls and yaws about a central spin axis without control axis

How to avoid the spin? Avoid stalling the aircraft!

Autorotation - recover by using standard stall recovery. In a spin both wings stalled but one more deeply than the other. This creates rolling moment. The down-going wing produces more drag, creating yaw. The way causes the outer wing to travel faster, creating more lift thus increasing the roll.
Fully developed spin - Rolling pitching and yawing at a stable low speed without any inputs.

Effect of CG position: The further forward the CG, the steeper the spin. The further after the GC, the flatter the spin. Steep spin easier to recover as smaller angle of attack. Flat spins have a very high AOA and a rapid rate of yaw.

Effect of mass distribution: The most dominant factor is the lateral distribution of mass.
Determined by the aspect ratio, position of engines and the amount of fuel in the wing tanks. High lateral mass distribution means the aircraft will spin with more roll, due to larger moments produced.

Avoid impending spin by reducing AOA, no aileron, no rudder.

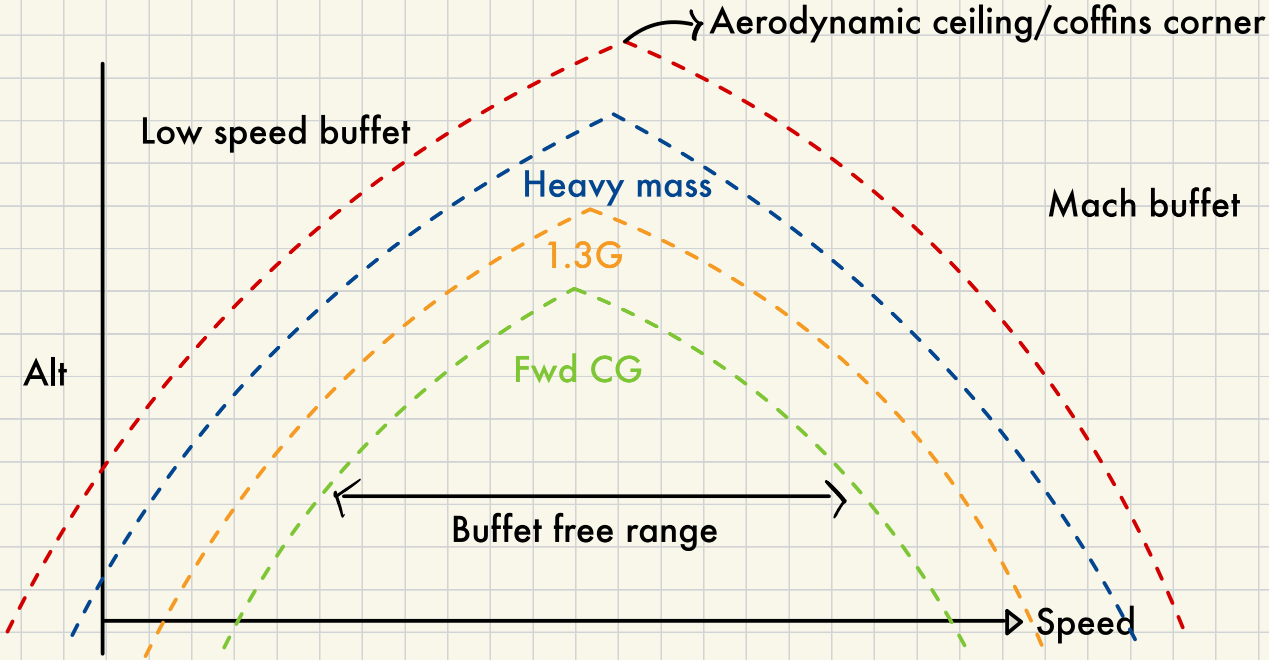
3 phases. 1) Incipient spin, 2) Fully developed spin, 3) spin recovery

Recovery from a spin

- Incipient spin recovery is to centralise the controls (standard stall recovery, reduce AOA)

To recover from a the fully developed spin:
1) Close power lever
2) Opposite the yaw with full opposite rudder
3) Unstall the wings by pushing the control column centrally forward until buffet stops
4) As soon as the spin stops, centralise the rudder and gently ease out of the dive

Buffet Onset Boundary



- Mach buffet occurs following boundary layer separation due to shockwave formation

High Speed Flight & Shockwaves

LSS (local speed of sound) = $39 \times \sqrt{K^{\circ}}$

(kts)

Remember °K = °C + 273

Mach = TAS / LSS

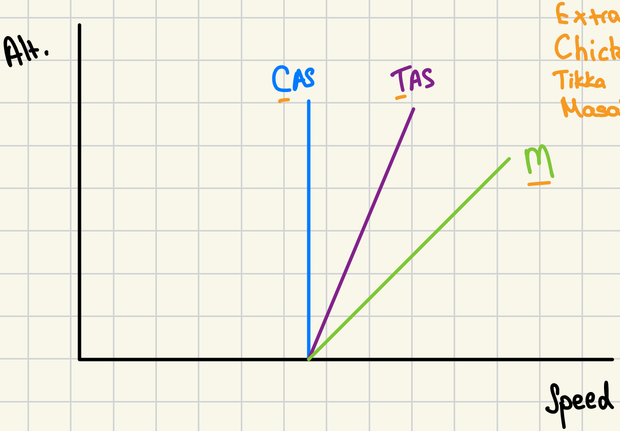
Ratio, no units

Average speed of sound at ground level = 340m/s

Indicated airspeed/cas = 1/2 p v^2

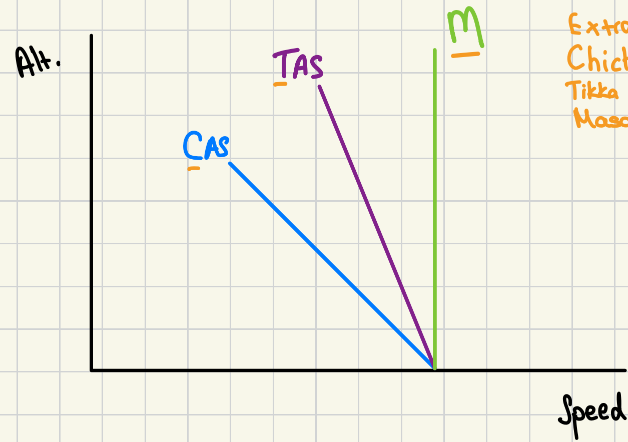
TAS

Mcrit = speed of the aircraft at which somewhere on the aircraft is forming shockwaves (> mach 1)



Extra Chicken Tikka Masala

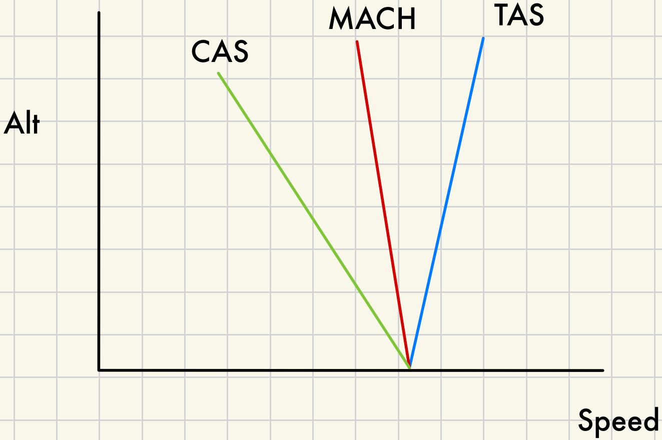
$M = \frac{TAS}{LSS}$



Extra Chicken Tikka Masala

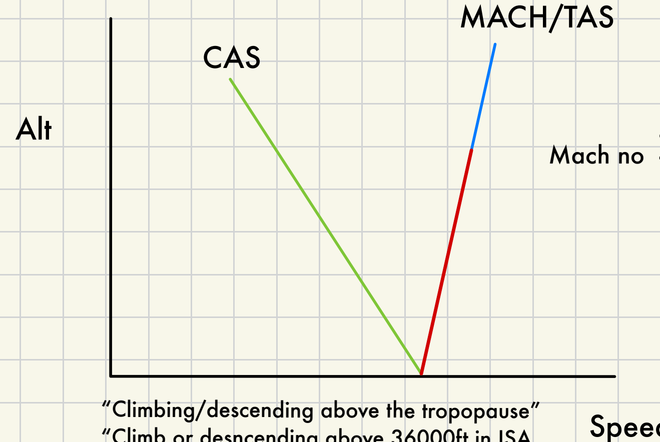
Inversion

Country Music Time



Isotherm

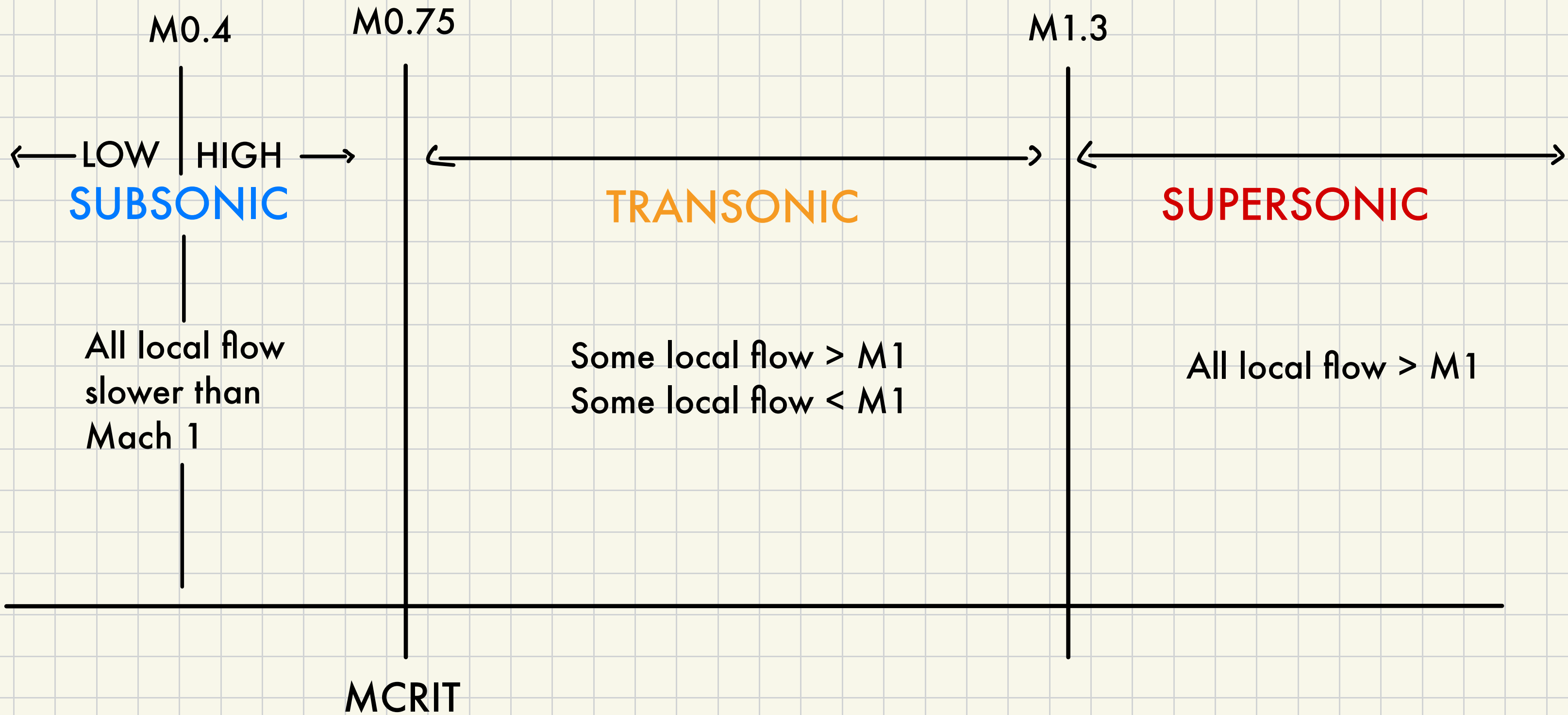
C. MT



Mach no $\frac{TAS}{LSS}$ Density Temp

"Climbing/descending above the tropopause"
"Climb or desncending above 36000ft in ISA atmosphere"

Flow Categories

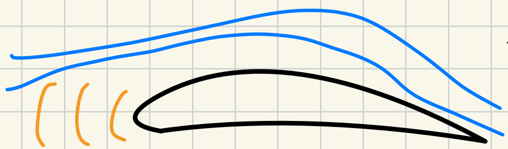


- In a low speed body, the leading edge creates pressure waves which propagate out from the leading edge at the speed of sound.
- At high speed, as the object approaches the speed of sound the pressure waves start to accumulate ahead of it -> pressure increases

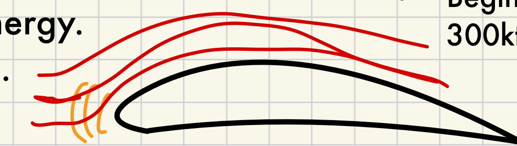
Compressibility effect -

- Alters the wings effective angle of attack. Increases the low-speed stall speed
- Alters the energy of the flow over the upper surface. It decreases alpha crit.
- Alters the density of the flow

- Stall Speed (Vs) increases at high altitude
- Acrit reduces at high altitude
- Begins at 300kts/M0.4

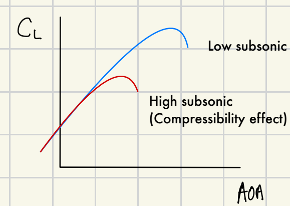


Air looses kinetic energy.
Flies at higher AOA.



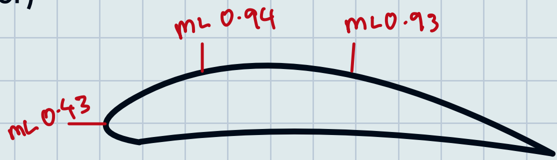
For an aerofoil at high speed, pressure waves are bunch up at the front of the leading edge. The airflow separates in a more abrupt way around the aerofoil, increasing the effective angle of attack.

> Compressibility means that **density** can changes along a streamline, and this occurs in high subsonic, transonic, and supersonic flow



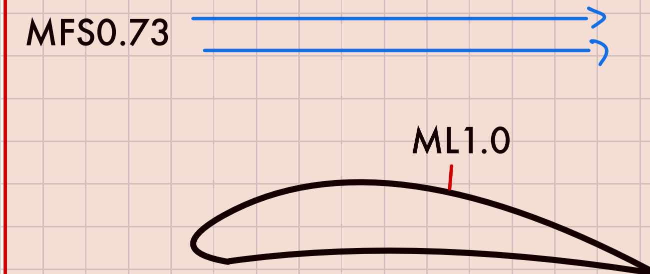
Local Mach Number

Free stream Mach no
- Mach no of air unaffected by the aircraft (Mach meter)



Local Mach no.
- Mach no of the flow or a given point of the aircraft

Critical Mach number
- The MFS where you first get shockwaves forming (M1.0+)



Factors affecting Mcrit

Smaller venturi

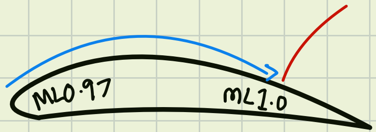
- Increased camber
- Increased mass
- Increased g-loading
- Forward Centre of Gravity

Increases AOA

Higher Mcrit = good
Anything increases lift requirement/local speed on the wing reduces Mcrit (bad)

Shockwaves

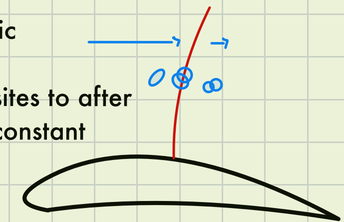
Normal shockwave
- Area of intense compression normal to the local flow direction



Before
Supersonic

- Opposites to after
- PTOT constant

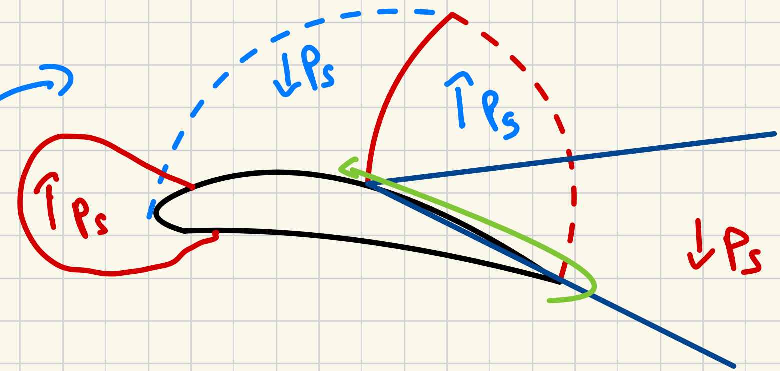
Remember like a
Car crash



After
Subsonic
- Density +
- Temperature +
- LSS +
- Pstat +
- PDYN -
- PTOT -
- Mach no -

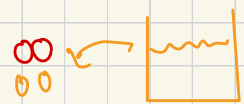
Ideal fluid
- Incompressible
- Pstat + Pdyn = Ptot

Wave Drag
- Thermal loss/energy drag
- Shock induced separation



BUT not an ideal fluid:
- Compression (increase in temperature)

Fuel



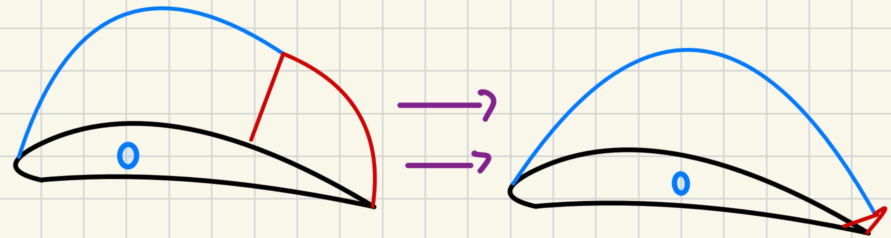
Pstat + Pdyn = Ptot

Thermal loss

$$L = \frac{1}{2}\rho v^2 C_L$$

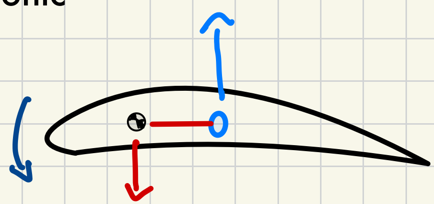
- Normal shockwave creates an APG
- Boundary layer separation creates a low pressure area behind aircraft
- High pressure at the front flow to the back - creating an increase in form drag

- In subsonic flight, the CP (Centre of Pressure) is at 25% of MAC (mean aerodynamic chord)
- Transonic flight it varies
- Supersonic flight CP 50% MAC

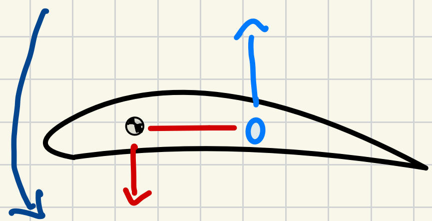


Mach Tuck

Subsonic



Transonic



- Aft movement of CP creates an increased pitch down moment
- Reduced down wash on the tail plane increases nose down moment

Mach Trimmer

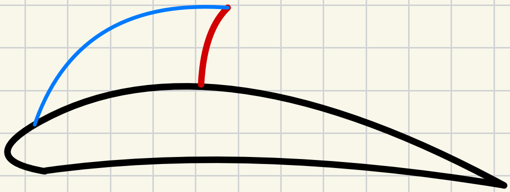
- Automatic system that reduces the tail plane angle of incidence to increase downforce
- Counteracts the nose down pitching moment (Mach tuck)
- Maintains stick force and stick position stability

If Mach Trimmer Inoperative

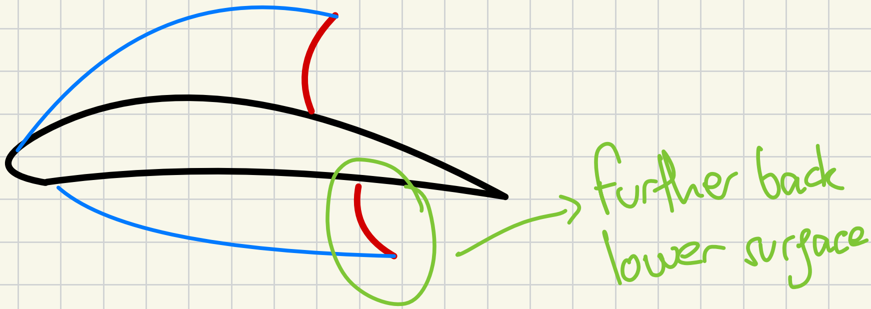
- Aircraft can be dispatched
- But Mach number must be limited well below Mcrit

Shockwave movement

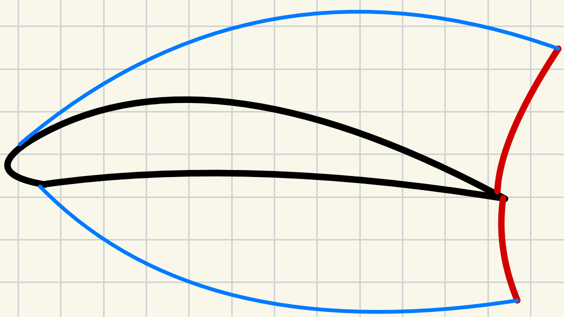
M0.75



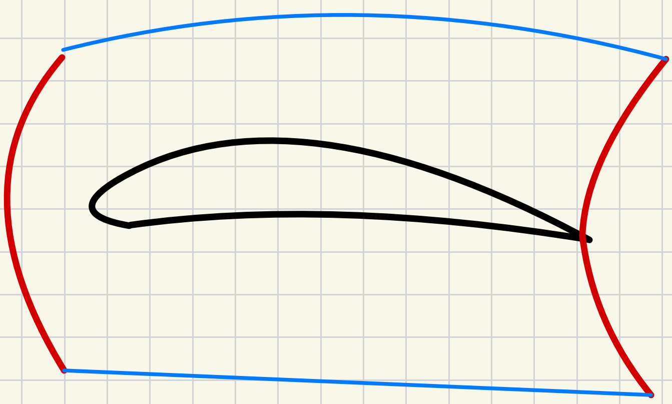
M0.85



M0.95



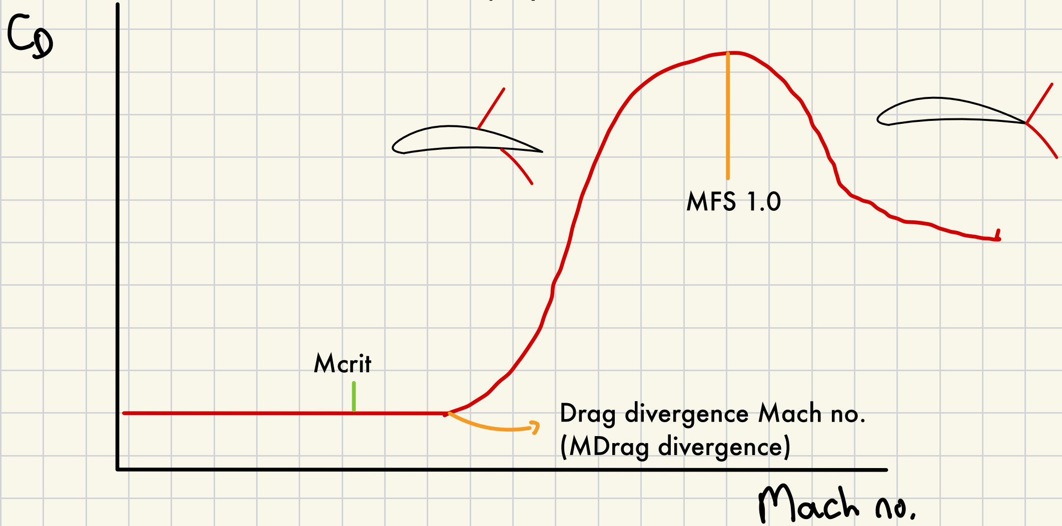
M1.05

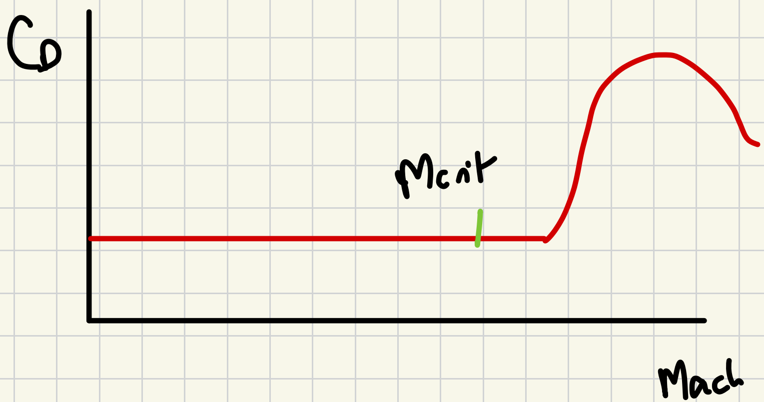


CD vs Mach

Drag divergence Mach no.

- Mach no. Where CD rises rapidly with further increase in Mach no.

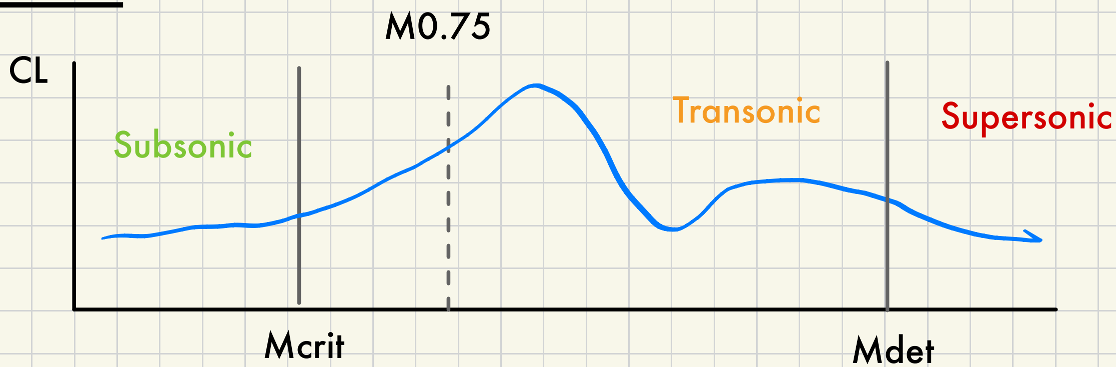


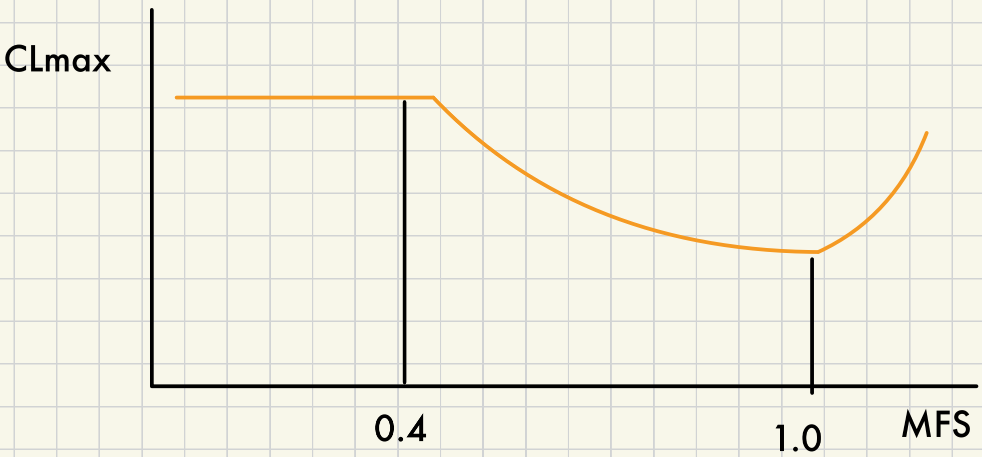


Increasing MCRIT

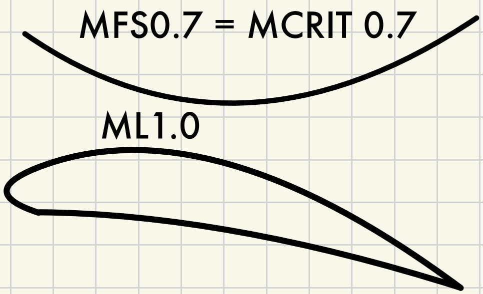
- Sweepback
- Thin wings
- Supercritical aerofoil

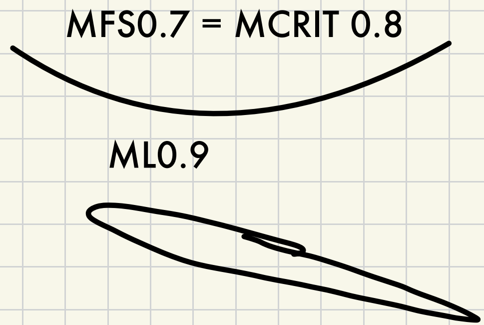
CL vs Mach


M0.75
CL
Subsonic
Transonic
Supersonic
Mcrit
Mdet


CLmax
0.4
1.0
MFS

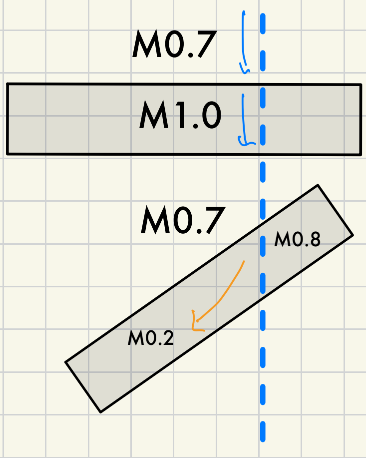
Increasing Mcrit - Thin wings





Thing wings disadvantages
- Impractical for fuel/system storage
- Dangerous stalling behaviour
- Very high landing/TO speeds
- They need re-inforcement (adds weight)

Increasing Mcrit - Sweepback

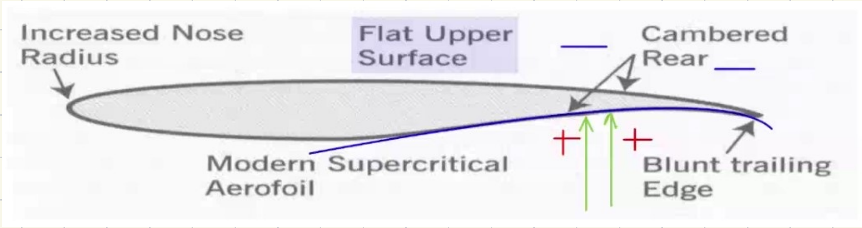


Spanwise flow
- Does not contribute to shockwave strength (good)
- Reduces strength of shockwave/wave drag (good)
- Increases Mcrit (good)
- Does not contribute to lift (bad)
- Faster To and landing speeds (bad)
- Dangerous stalling characteristics (tip stalling)

A320 25° sweep
777 35° sweep
-> long haul aircraft tend to have more sweepback (more time spent at transonic)

Supercritical aerofoil

- Flat top reduces flow acceleration
- Increases Mcrit
- Reduced wave drag
- Wing not super thin = room for fuel and systems
- Rounded leading edge - improved stall behaviour

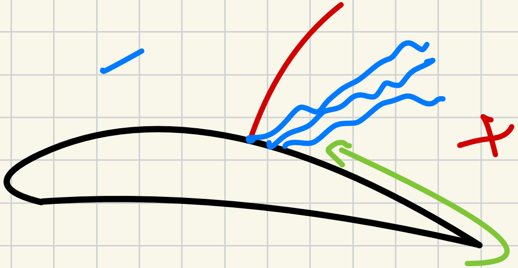


Fitted to most modern transonic jets

- Most lift is made in rear 30% - 40% chord = large pitching moments
- Unpredictable stall behaviour

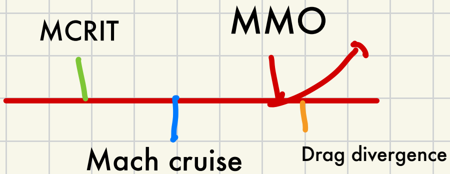
Shock stall

- Occurs when the lift coefficient, as a function of Mach number, reaches its maximum value
- Flow separation occurs behind the shock wave



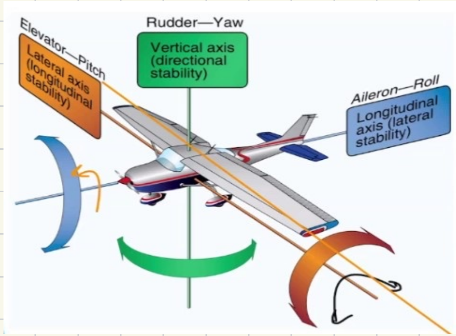
Mach buffet
- Shock induced flow separation hits the tail plane
- Creates buffeting

MMO - max operating Mach no
- Limiting at high altitudes
- Speeds above MMO expect Mach buffet



FLIGHT CONTROLS

Axes of control

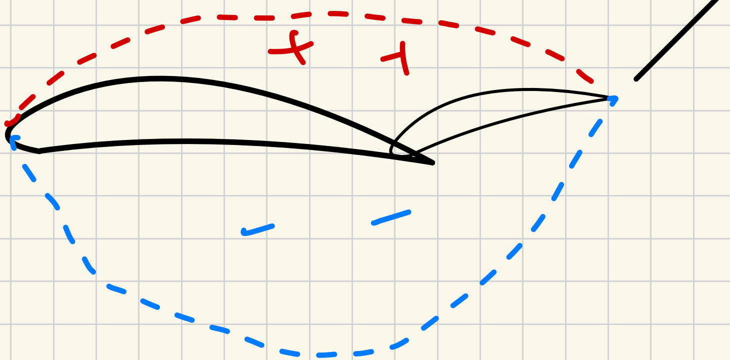


Pitch on the longitudinal   Pitch ABOUT lateral axis
Roll on the lateral   Roll ABOUT the Longitudinal
Yaw on normal axis

Pivots around CG

Principle of operation

- Primarily Camber changing devices
- Also influence AOA



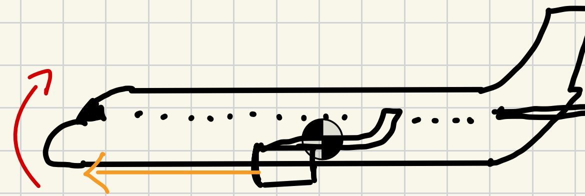
Upwards deflection - decreased camber, push wing down

Pitch (longitudinal control)

- Further forward CG = higher control forces -> manueverability decrease due to static longitudinal stability
- Higher Vref (1.3 Vs)
- Aft limit of CG, among other things, limited by MINIMUM acceptable
  Stick force

<u>Horizontal Stabiliser</u>

- May stall before the wing
- Necessary to balance total pitch moment of the plane



- Line of thrust below CG: if increase power -> nose up attitude + stabilising | Below line = nose down + stabilising
- Trimmable horizontal deflection: correct setting determined by CG position
- Variable incidence tailplane: better because less trim drag and maximum elevator authority retained

Yaw (directional) control

- A full rudder deflection could cause excessive load - variable stop/rudder ratio can prevent this

Roll (lateral) control

- Ailerons change wing camber.

Adverse Yaw

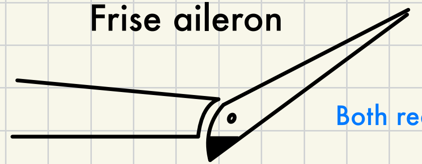
- When you roll right, you also have a yaw left
- Rudder deflection to help turn (roll left, deflect left)

Spoilers

- Help ailerons but only the one on the side of the turn (wing down) - OUTBOARD

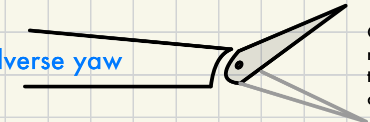
- Inboard aileron - used for high speed to reduce aero elastic effects

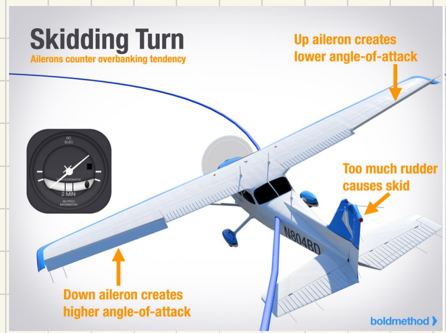
Frise aileron

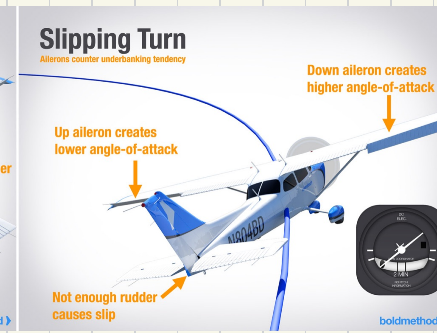


Both reduce adverse yaw

Differential Aileron







Drag

- Upwards aileron acts like a spoiler -> FORM drag
- Downwards aileron increases lift -> INDUCED drag

    -> up going wing = increased AOA

Control Hinge Moment

- When a flight control is deflected, it is forced onto the oncoming airflow
- The dynamic pressure attempts to neutralise the control back to its starting position
- To maintain a selected deflection, a continual force. Must be applied to the control yoke/stick
- The resistance felt through the controls is known as the hinge moment/'**control feel**'.

Hinge Moment = Force x Distance Arm

Altering the hinge moment

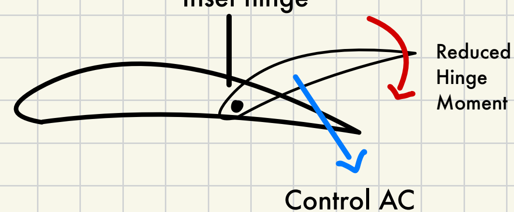
- If the controls feel too 'heavy' the pilot is likely to become fatigued
- If the controls feel too 'light' the pilot is likely to apply an inappropriate amount of input
- Designers must ensure controls have an appropriate level of feel throughout speed range

Aerodynamic 'Balances'

An *aerodynamic* balance reduces the hinge moment

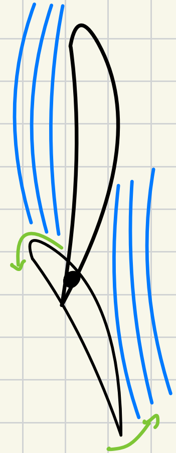
- Reduces control feel/makes the controls feel 'lighter'

1) Inset Hinge - less of a hinge moment



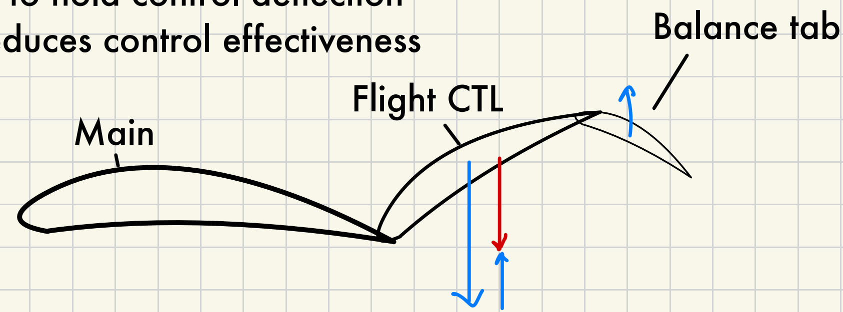
2) Control horn

Helps deflect the controls by forcing the air into the horn of the flight control



3) Balance tab moves in opposite direction to flight control

- Reduces control feel
- Helps to hold control deflection
- But reduces control effectiveness



4) Servo Tab

Pilot moves the balance tab

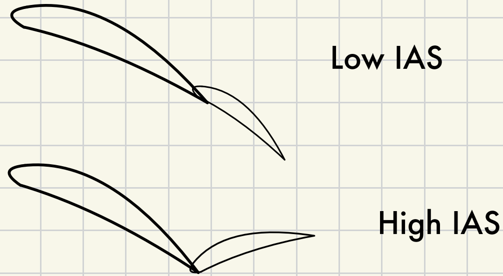
Balance Tab: Pilot input Control movement Tab movement

Servo Tab: Pilot input Tab movement Control movement

- Could get insufficient control authority at low IAS
- Controls could feel 'sloppy'

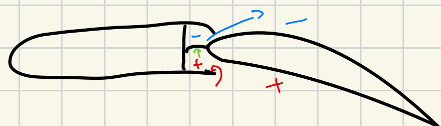
5) Spring tab

Combination of:
- No tab at low speed
- Servo tab at high speed



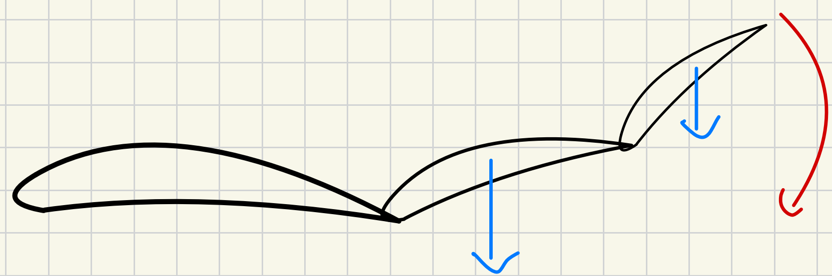
6) Internal Balance

- Sealed chambers separated by flexible rubber seal
- Pressure difference pushes against the seal helping to move the control, reducing control feel



7) Anti Balance - Anti Servo Tab

Anti balance increases feel (heavier controls)
Moves in same direction as control
- Increases control feel
- Increases control effectiveness

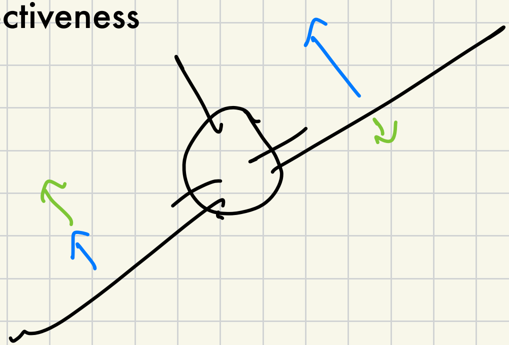


Aerodynamic Damping

Damping increases control feel
- Reduces control effectiveness

Up-going wing
- Wing with more CL
- Alpha reducing

Down-going wing
- Wing with less CL
- Alpha increasing



- Aerodynamic damping is increased at low altitude (low TAS)
- Aerodynamic damping is reduced at high altitude (high TAS)

Hydraulics

Fully powered flight controls
- Hydraulically operated, no feel!

Artificial Feel System (Q-feel)
- Based upon IAS - gives a set feedback resistance to controls

Partially powered controls
- Hydraulics provide most of the assistance
- Some of the hinge moment is fed to pilot

Displacement controls

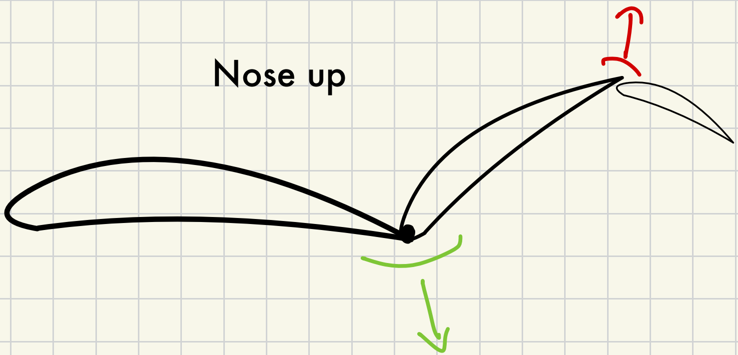
Controls which change the direction of the flight path
- Elevator
- Rudder

Rate controls

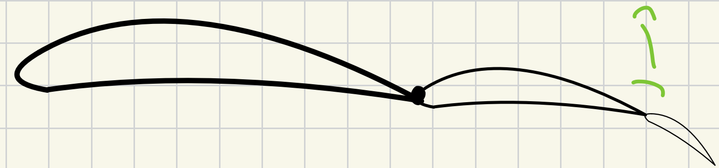
Controls which do not change the direction of the flight path
- Aileron

TRIMMING

- Trimming an aeroplane reduces the stick force to zero.



Jammed elevator = nose down

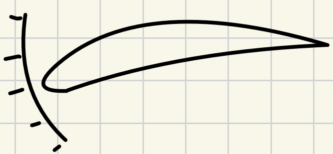


CG Position

Forward CG -> Pitch Trim Nose UP
Aft CG -> Pitch Trim Nose DOWN

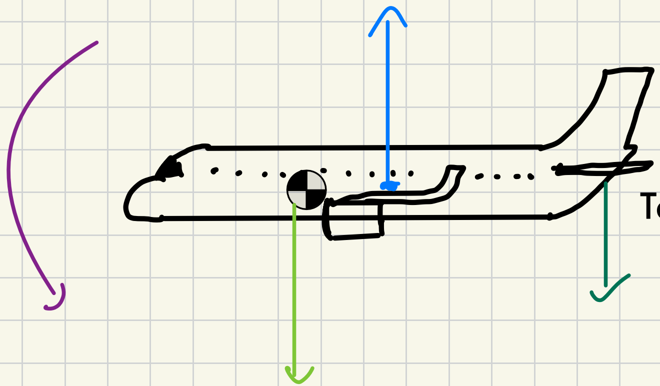
Trimmable Horizontal Stabiliser

- More powerful
- Less drag
- Bigger CG range
- Don't loose elevator authority



FORCES ACTING ON AN AIRCRAFT

- Lift has to counteract Weight + Tailplane downforce



Climbing flight

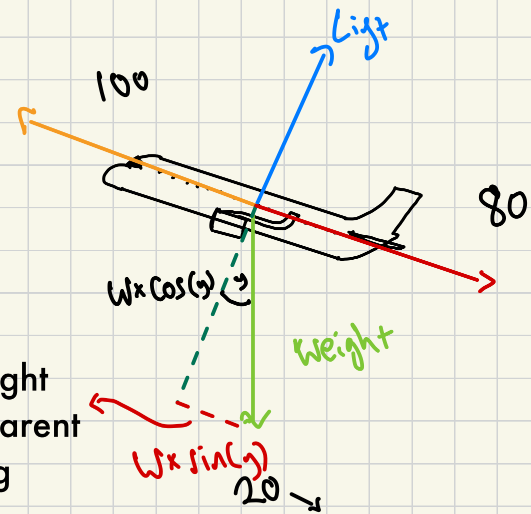
In a climb, F+A = P

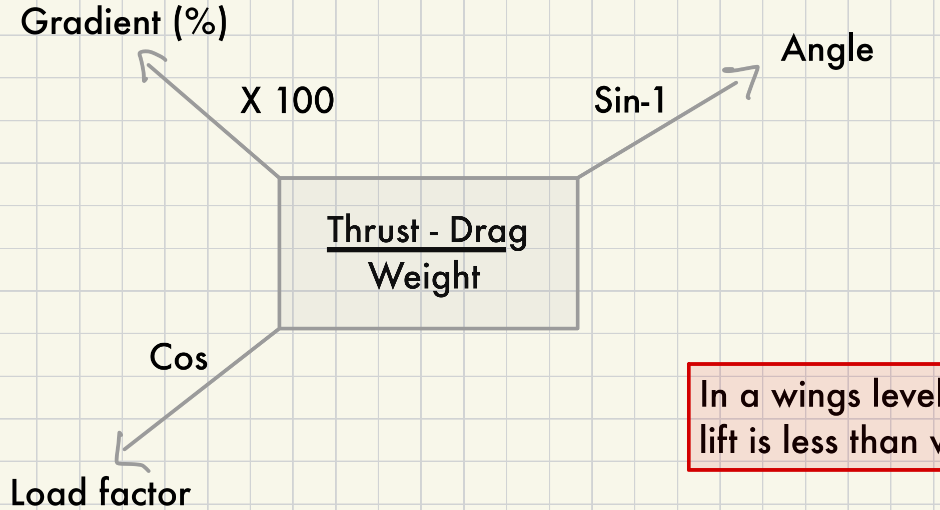
Lift = W x cos(y)

$$\text{Sin}(y) = \frac{\text{Thrust-Drag}}{\text{Weight}}$$

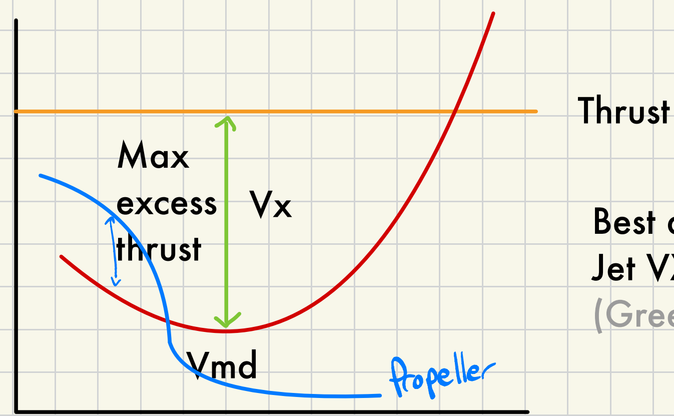
Flight path
Angle of attack
Pitch angle

Weight
apparent
drag





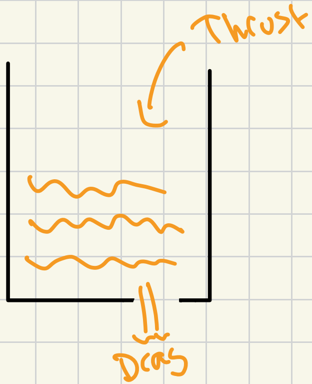
In a wings level, steady climb, lift is less than weight (n < 1g)

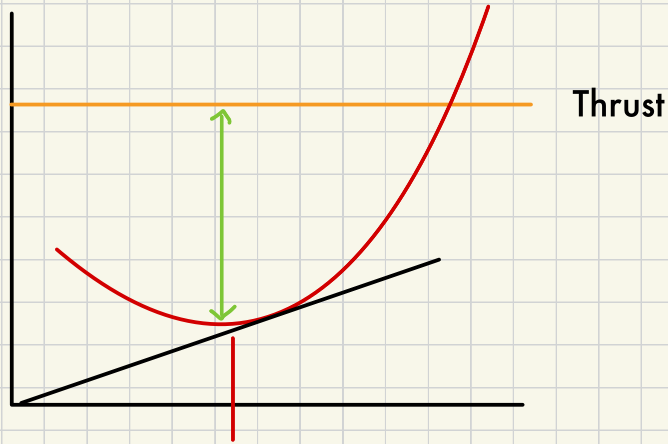


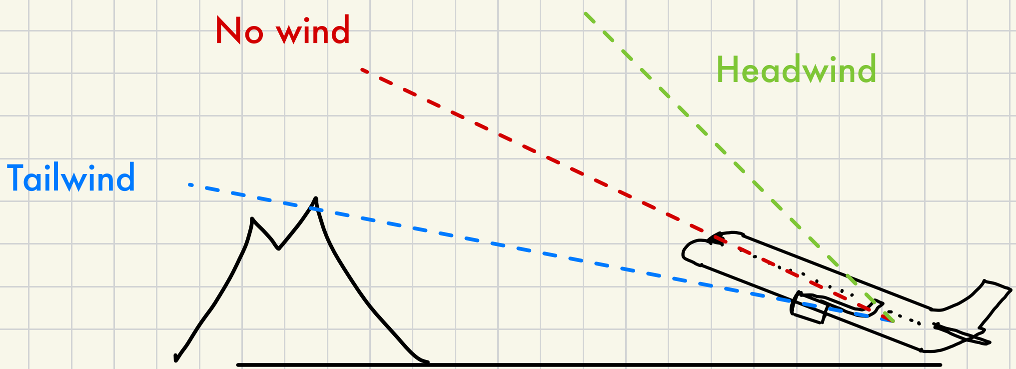
Best angle of climb = Vx
Jet VX = Vmd
(Green dot speed)

Rate of climb

VY = best rate of climb
Tangent of drag curve
1.32 x VMD



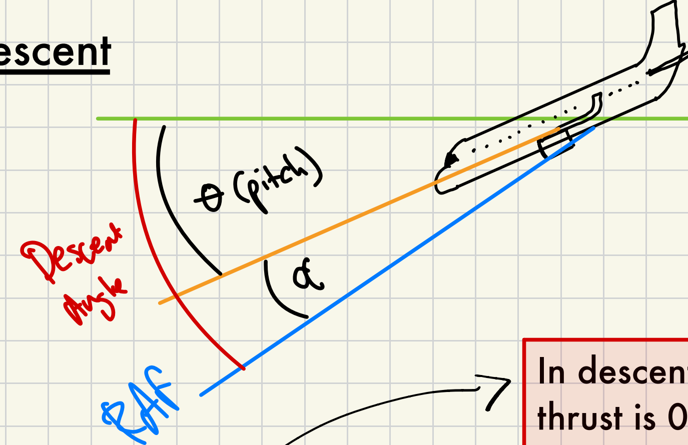




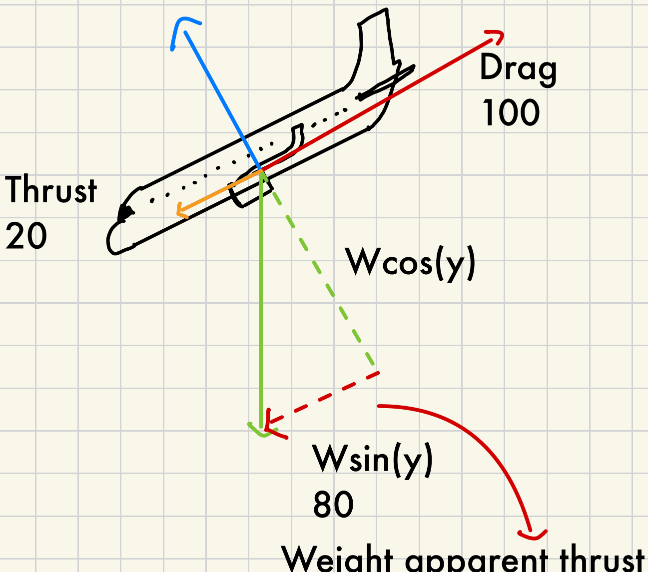
- Wind has no effect on Rate Of Climb
- Tailwind decreases climb angle
- Headwind increases climb angle

Descent

- Descending nose down: F = P+A
- Descending nose up: A = F+P



In descent assume thrust is 0!!



$$\boxed{\text{Drag} = \text{Thrust} + W\sin(y)}$$

$$\boxed{\sin(y) = \frac{\text{Drag} - \text{Thrust}}{\text{Weight}}}$$

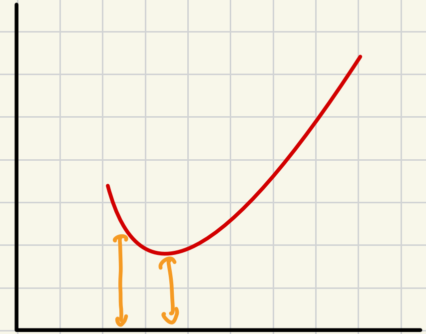
Max descent rate:

- Highest speed (Vmo/Mmo)
- Speedbrakes

- The MINIMUM descent angle for all aircraft is VMD

- VMD is the speed for:
  - Best glide range
  - Minimum glide angle
  - Minimum descent angle

Any speed faster or slower will result in a **steeper** descent angle and a **reduced** glide range



"Don't stretch the glide"

Above ground

Glide Range = Height x L:D Ratio

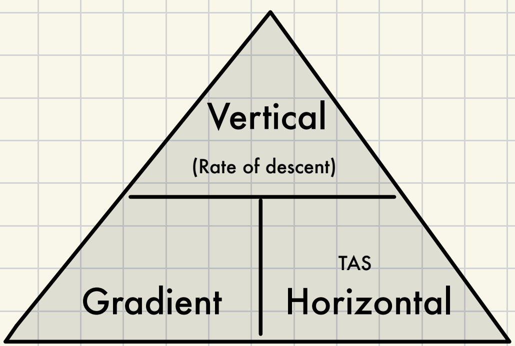
$\boxed{nm = ft / 6080}$!

"Very Good Hobnobs"

Height = AGL
Altitude = MSL

Increase Mass:

- **No effect** on **glide angle**!
- Rate of descent increases!
- Endurance reduces (have to fly at faster speed so less time in air)

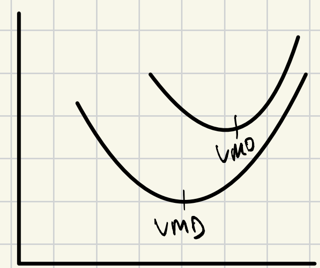


NM -> FT/Same time metric

G% or TAS x$\left(\dfrac{6000}{6080}\right)$

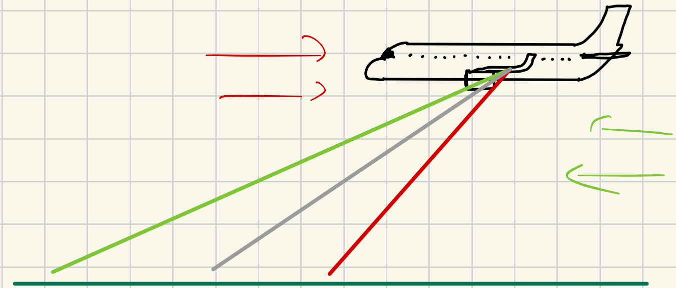
ROD x$\left(\dfrac{6080}{6000}\right)$

Increased VMD when heavier



Wind in descent

- Headwind glide range is reduced
  - increased glide angle
- Tailwind glide range is increased
  - reduced glide angle



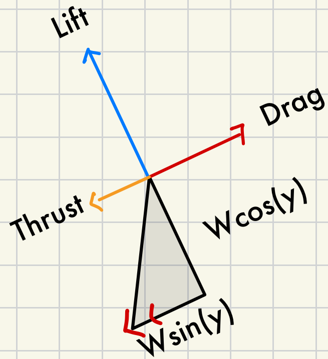
Heavier aircraft glide further in a headwind

Lighter aircraft glide further in a tailwind

Wind Summary:

Headwinds increase glide angles (Bad)
Headwinds increase climb angle (good)

Tailwinds reduce climb angle (good)
Tailwinds reduce climb angle (bad)

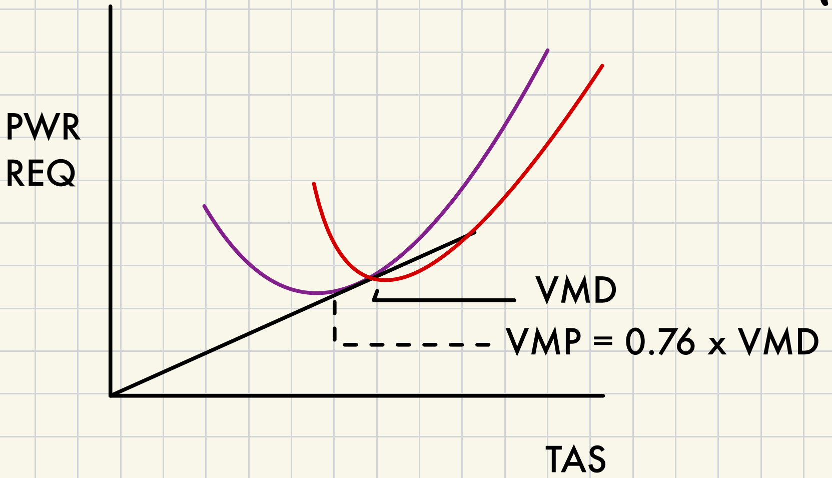


Still air gradient
SAG

Wind adjusted gradient
WAG

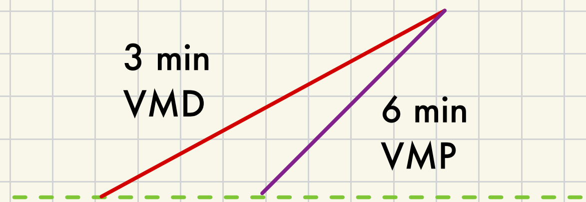
$$WAG = SAG \times \frac{TAS}{GS}$$

<u>Rate of descent</u>

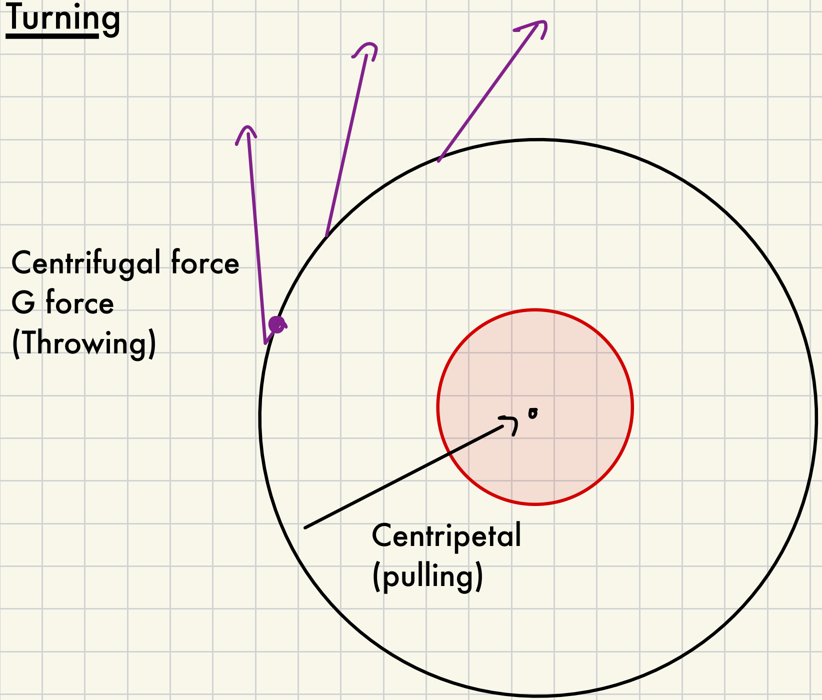


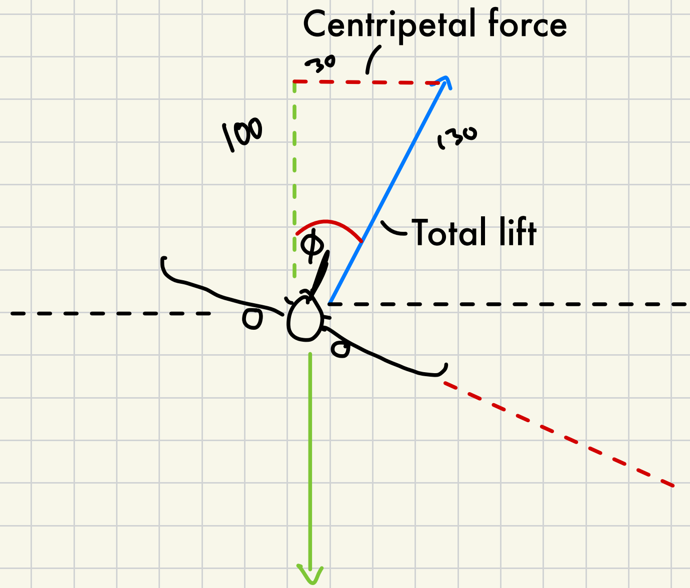
Propellor aircraft only.

VMP = max glide endurance
(Minimum sink rate) - Minimum ROD



Turning





Load factor (n) = $\frac{1}{\text{Cos}(y)}$

W = L cos(y)

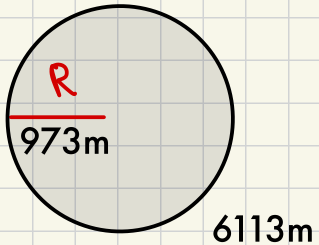
Mass of aircraft has no effect on the radius of the turn!

Centripetal force = L sin(y)

! m/s (kts × 0.514) !

1) $$\text{Radius} = \frac{TAS^2}{G \times \tan(\Phi)}$$

2) Distance flown (circumference): $2\pi r$

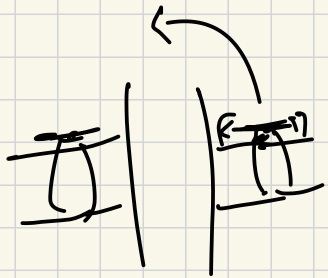


3) Time taken (s) = Distance (C) / Speed (m/s)

Rate 1 turn is standard
3° / second

ASYMMETRIC FLIGHT

One engine inop:



Favourable:

- Hot
- High
- Forward CG

-> Less density better for asymmetric thrust recovery
(Low) "density altitude"! = high density

Failure to stop yaw:

- If the yaw and roll from asymmetric thrust is not stopped, plane will enter tightening spiral dive.

Achieve equilibrium - banking:

- Reduces the drag generated by the rudder
- A slight amount (up to 5°) of bank applied towards live engine
- Creates horizontal component of lift - compensates for side force

Critical Engine

- The critical engine is the engine that, if it fails, results in the largest yaw moment produced by the remaining engine.

- **Heavier aircraft** = greater induced slideslip = **better** rudder effectiveness

- Counter rotating = propellor on one wing turns in the opposite direction to the other wing

Vmc, Vmca, Vmcg, Vmcl

Vmc
- Minimum control speed with critical engine inop
- Bank angle not more than 5° and max power

Vmca
- Minimum control speed in **TO config** with **gear up**
- VMC determination:
  - Bank angle ⬇️, VMCA ⬆️
  - If bank angle **> 5**° = increased risk of **fin stall**
  - You need to obtain equilibrium of moment about normal axis (provided by rudder deflection)
  - Equilibrium of forces along the lateral axis requires either bank angle or sideslip or combination of both
  - Max TO thrust and 5° bank angle

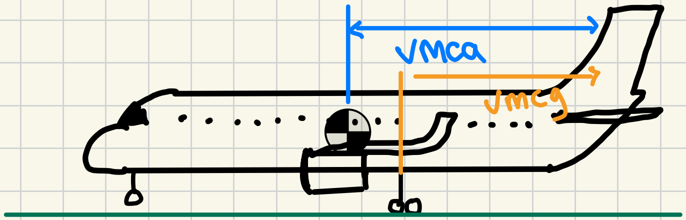
Vmcg
- Minimum control speed **on ground**
- Main variables -> Airport **elevation** and **temperature**
- Parameters -> Rudder
- Must be determined using rudder control alone
- **Highest** value is at **low pressure altitude** and **low temperature**
- Decreasing with increasing field elevation and temp

Vmcg determination:
- Lateral deviation from centerline **LESS than 30ft**
- To simulate wet runway -> **nose wheel steering** may **not** be used
- CG should be **aft limit** (shorter arm from CG thus less manueverability -> fwd CG decreases Vmcg

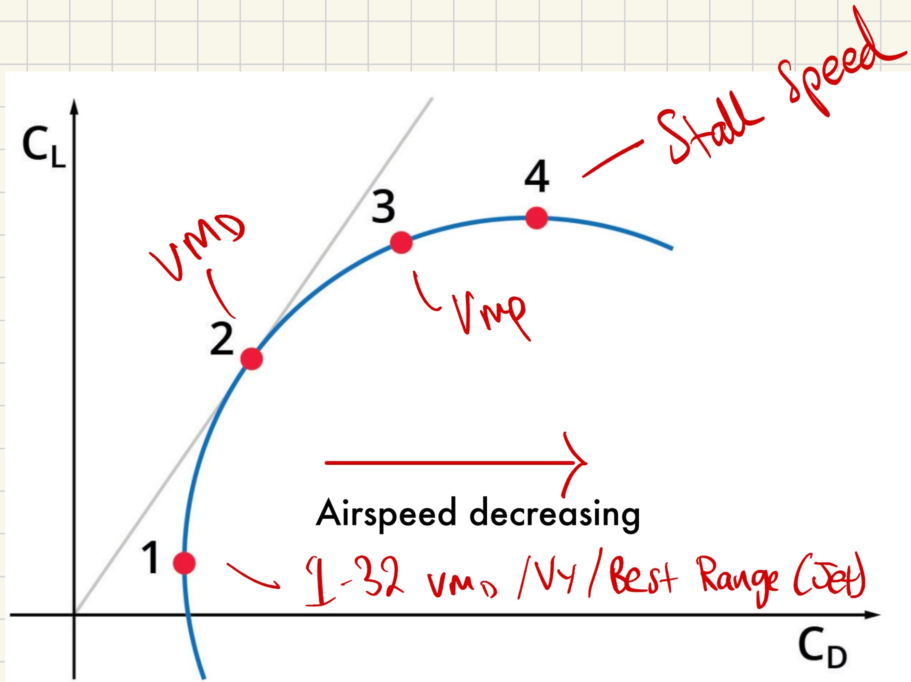
Vmcl
- Minimum control speed in **landing/approach config** (with all engines operating)
- Limited by the available maximum roll rate/aileron deflection

Vmcl determination:
- Landing configuration
- Full power

- Fwd CG decreases Vmcl (most stable)



Polar Curve



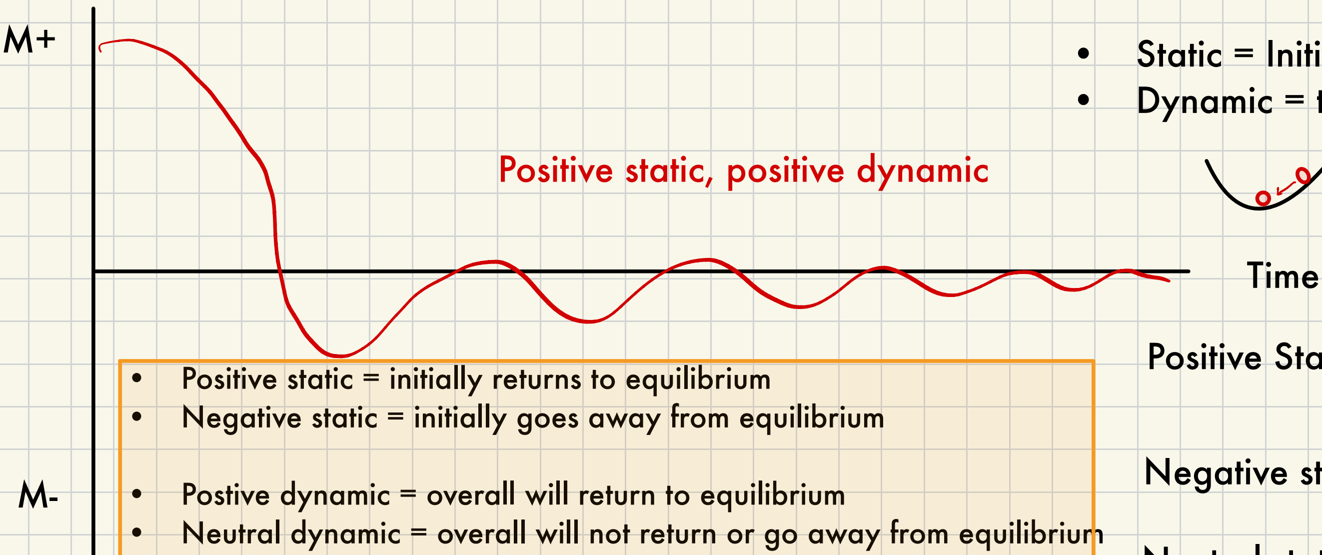
1 Minimum CD
2 Best glide (L/D)
3 Minimum sink rate
4 CL_{MAX} or critical alpha

STABILITY

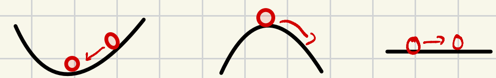
Manueverability vs Stability

- Stability is the natural tendency to return to equilibrium following a disturbance without any input from the pilot
- Manueverability is how easy it is to displace the aircraft OUT of equilibrium

More stability = Less manueverability/controlability



- Static = Initial tendency
- Dynamic = tendency over time



- Positive static = initially returns to equilibrium
- Negative static = initially goes away from equilibrium

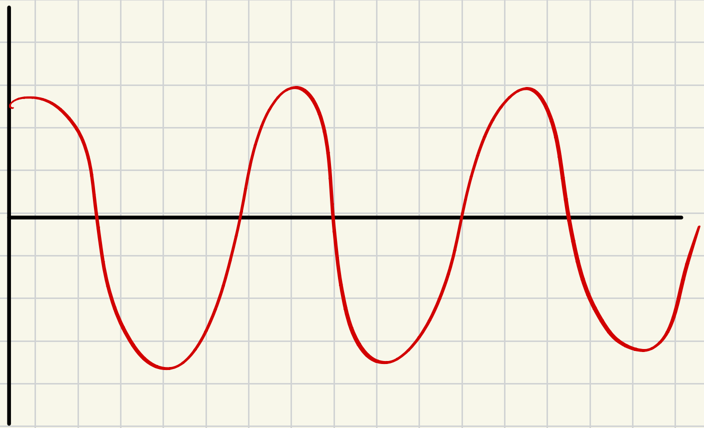
- Postive dynamic = overall will return to equilibrium
- Neutral dynamic = overall will not return or go away from equilibrium
- Negative dynamic = overall will go away from equilibrium

Positive Static
- Negative dynamic
- Neutral Dynamic
- Positive dynamic

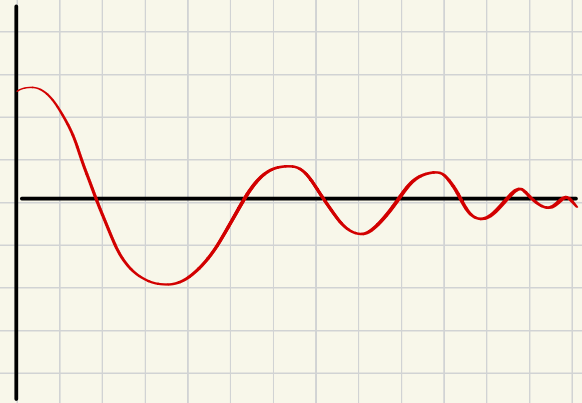
Negative static — Negative dynamic

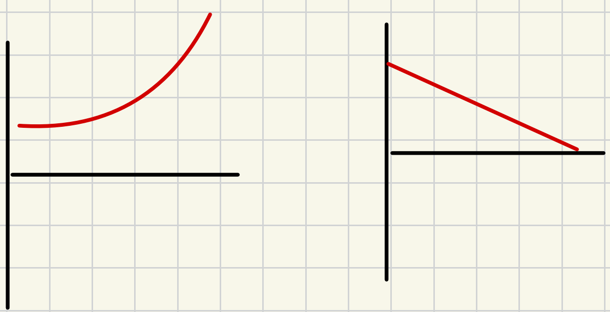
Neutral static — Neutral dynamic

Periodic motion (phugoid) - oscillatory motion



Damped fugoid



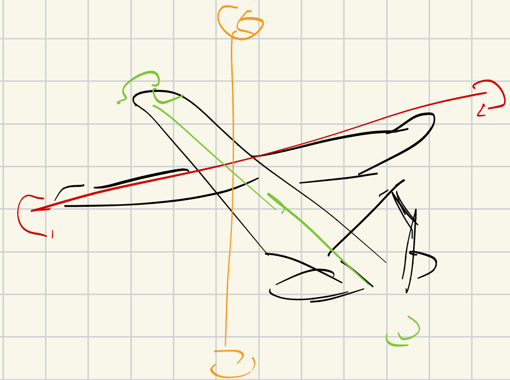


Aperiodic Motion (deadbeat motion)

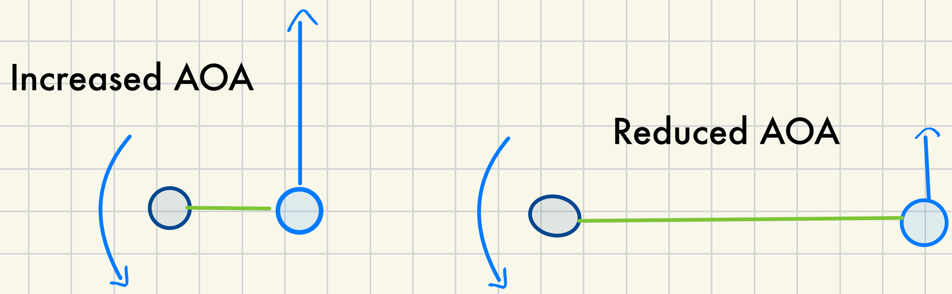
Longitudinal Stability (pitch)
- Acts on Longitudinal axis (about lateral axis)

Lateral stability (roll)
- Acts on Lateral axis (about longitudinal axis)

Directional stability (yaw)
- Normal axis

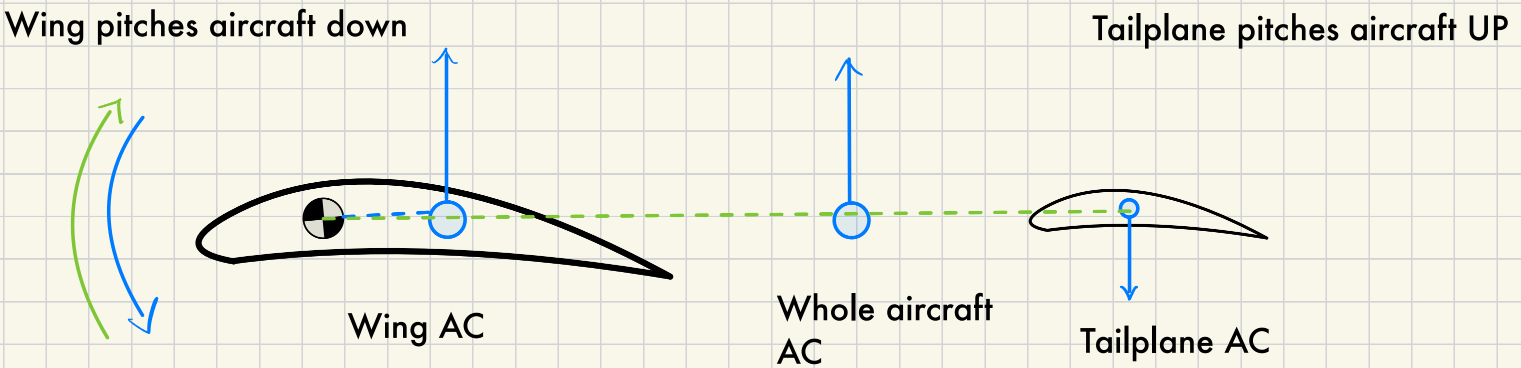


<u>Aerodynamic Centre</u>
- A point where pressure acts (not CP)
- Its position does not change when normal AOA changes (unlike CP)



Lift is actually the same (moments vs force) = AC

Longitudinal Stability



FWD CG: - **Increases** longitudinal **stability**

- Increases the arm from tailplane (more nose up)
- Increases arm between Wing AC and CG (more nose down)

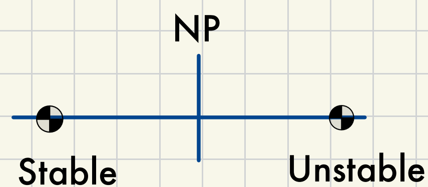
CG positioning

When CG moves forward:

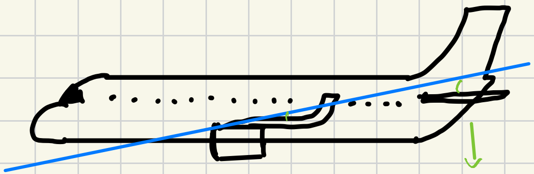
- Stability increases
- Stick force increase
- Increase fuel consumption

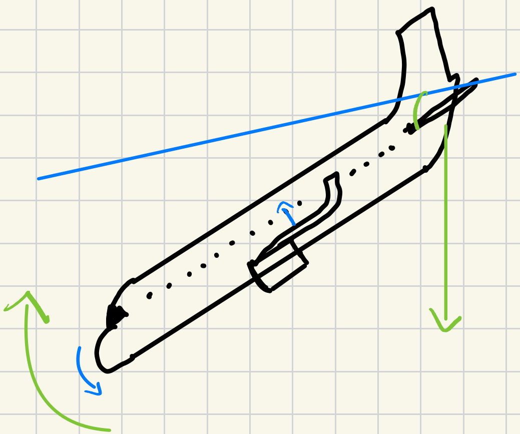
Neutral Point:

- Point where wing and tail moments are equal

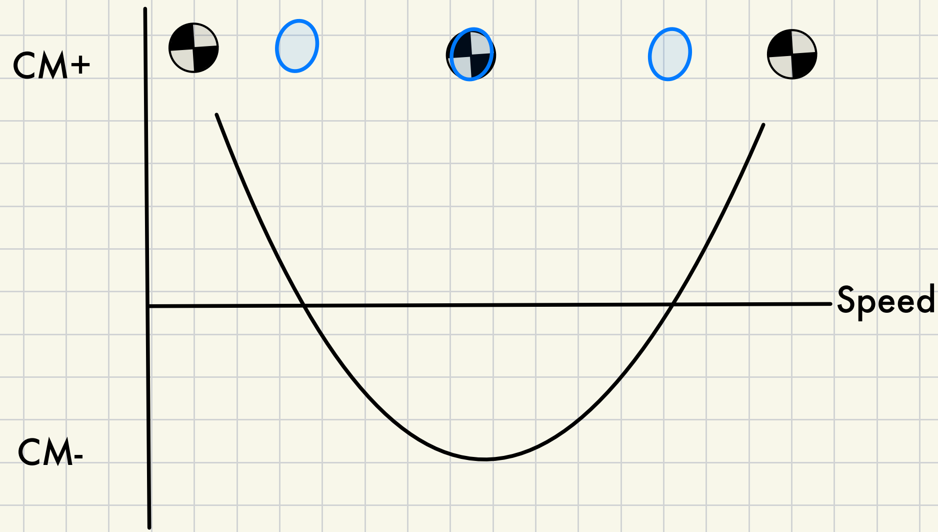


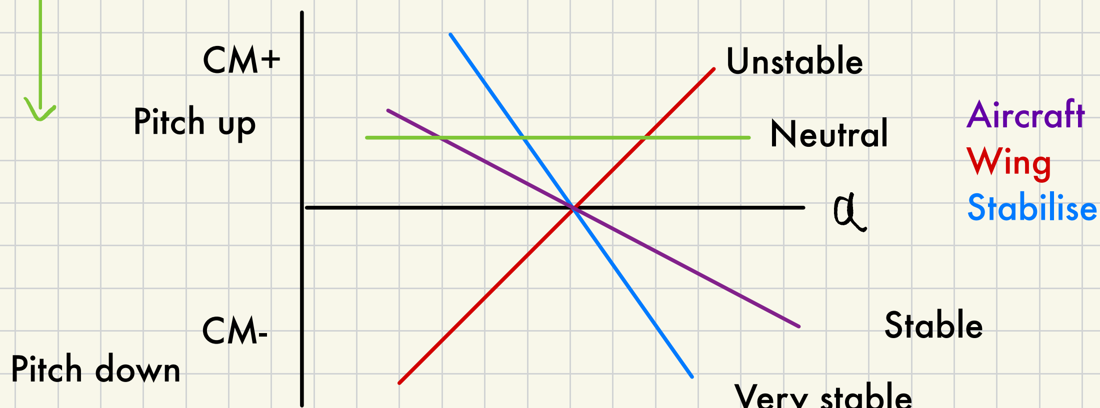
Equilibrium

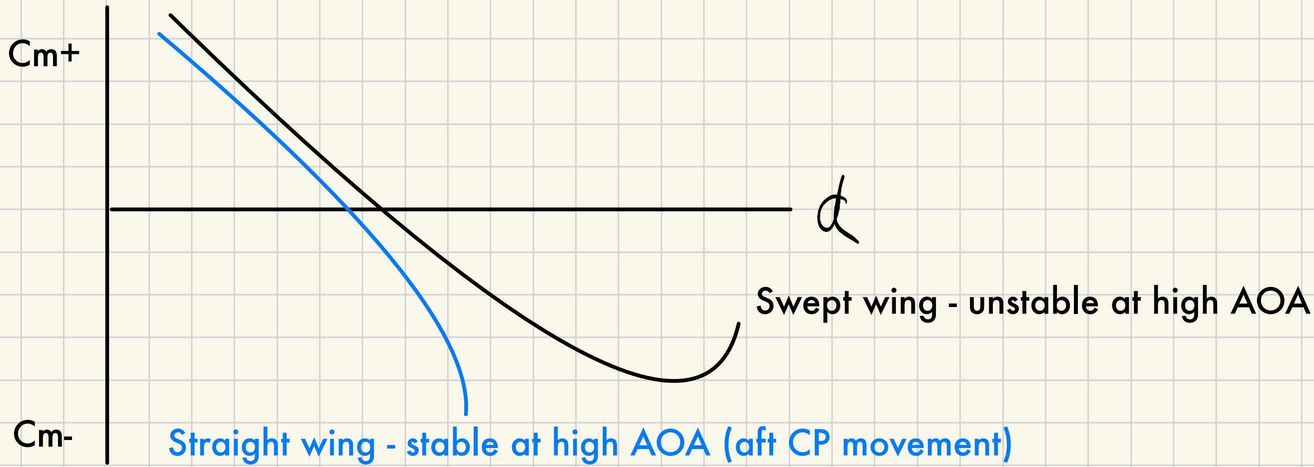




Swept wing







- The elevator or trim does not impact the horizontal stability.
- Only the horizontal stabiliser/CG/Speed impact the horizontal stability.

<u>Fuselage</u>

- The fuselage of the aircraft is de-stabilising

<u>Stick force stability</u>

- Required stick force and the required movement both act in the same direction
- Aircraft with don't have enough stick force stability must be equipped with artificial feel

Altitude

- At higher altitude we get less aerodynamic damping

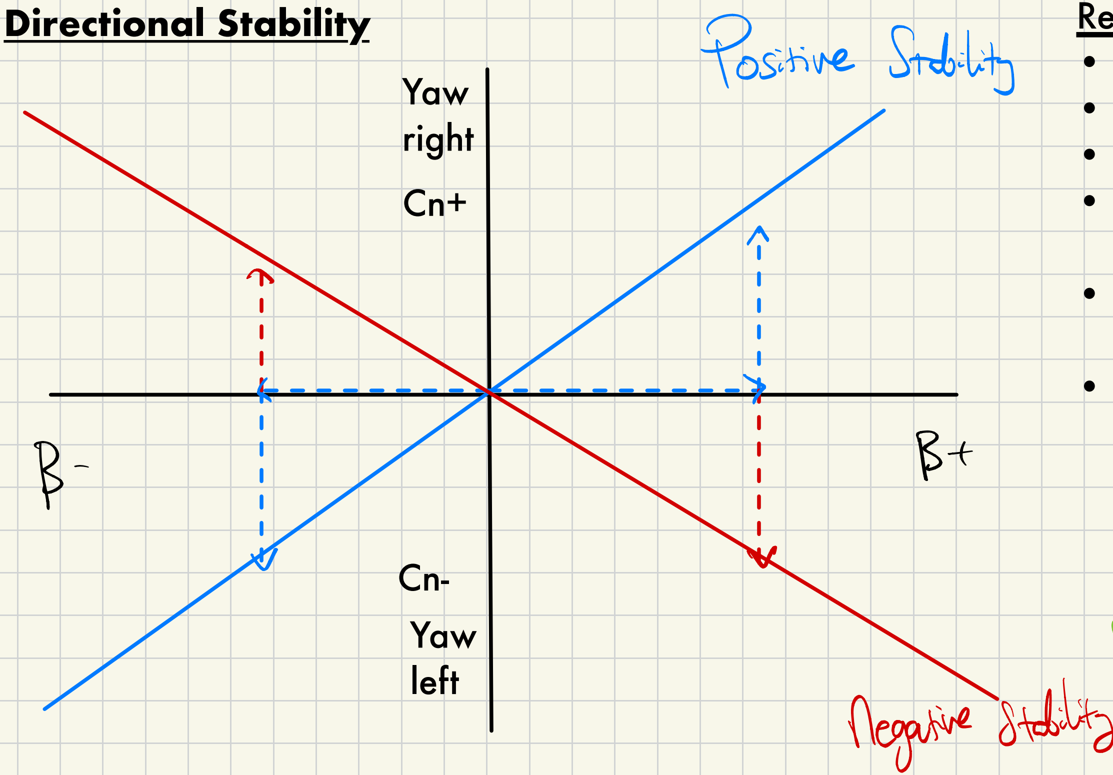
Longitudinal Dynamic Stability

- Dynamic stability cannot exist unless the aircraft has static stability
- Two types:
  - The short period oscillation - little change in height and airspeed - big change in load factor - more dangerous, could exceed load factor.
  - The long period oscillation also known as phugoid oscillation - large change in altitude, height, and airspeed - but little change in load factor

Stick Force

- Increases with forward CG
- Decreases with altitude
- Below/Above trim speed -> Requires pull/push force - think like glide slope. Above, push, below, pull.

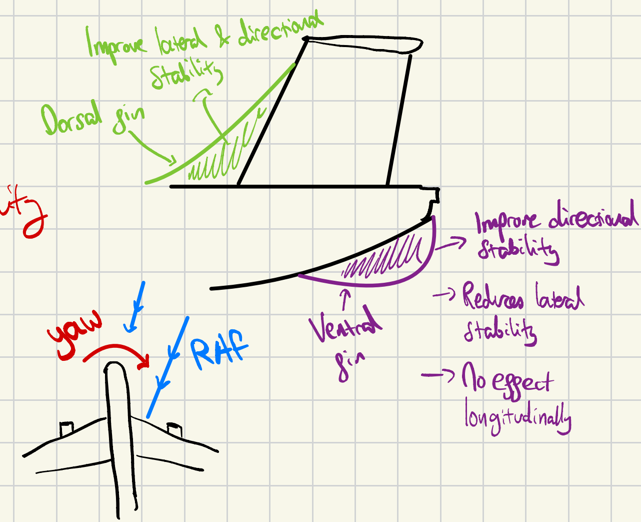
Directional Stability



Restoring moment will be greater:

- CG further forwards
- Fin area larger
- Higher IAS
- Size of sideslip angle

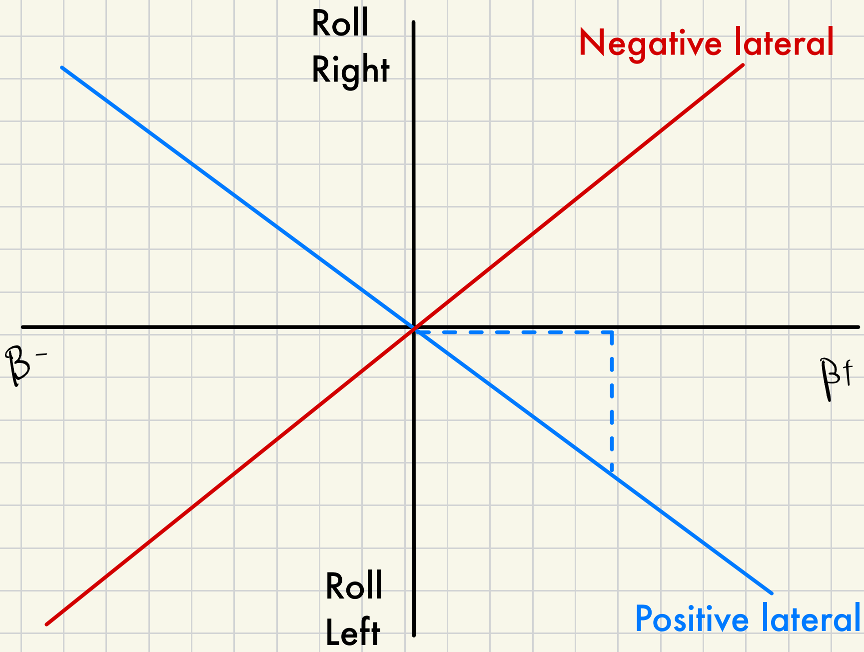
- Fin sweep back - less likely to stall at low AoA
- Swept back wings have weak stabilising effect (roll left, yaw right)



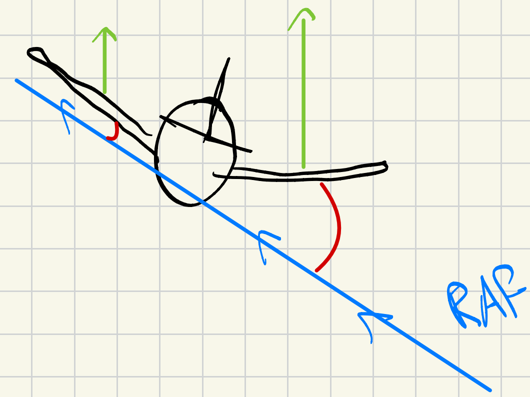
- Directional stability - aircraft yaws into wind (controlled by fin/vertical stabiliser)
- All aircraft must, as a minimum, have static directional stability at small and moderate sideslip angles

Lateral Stability

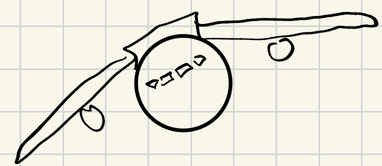
- Tendency to return to wings level condition
- Recovering from sideslip



Dihedral Wing



Anhedral



- On high wing stabilising

- Spiral instability occurs when directional stability is strong and lateral stability is weak

<u>Dutch roll</u>

- When the lateral stability is strong and the directional stability is weak
- Yaw damper - creates rudder inputs to oppose the yaw

OPERATING LIMITATIONS

- Flutter - aero elastic phenomenon due to the interaction of aerodynamic, elastic, and intertidal loads on a component (NOT friction)
- Flutter is bad and caused by too high speed
- Can be fixed by slowing down, mass balancing, stiffer structure

- **VLO** - Landing gear operating (in transit) speed
  - VLO (ext) - Maximum landing gear extension speed <u>Faster</u>
  - VLO (ret) - Maximum landing gear retraction speed <u>Slower</u>
- **VLE** - Maximum landing gear extended speed <u>Fastest</u>
- **VFE** - Maximum flap extended speed

CS25 aircraft:
- **VMO** - Maximum operating speed
- **MMO** - Maximum operating Mach number

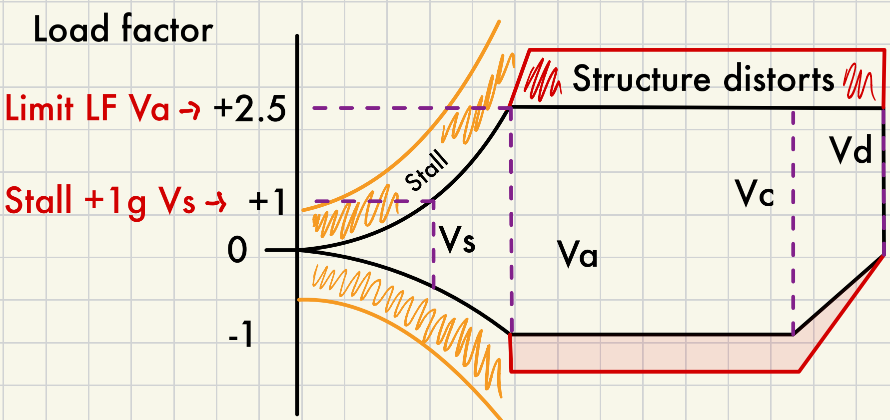
-> VMO & MMO can also be CS23

CS23 aircraft:
- **VNO** - Normal operating speed
- **VNE** - Never exceed speed

Manoeuvring Envelope

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

- **Va** -> Design manoeuver speed
- Va -> highest speed at which sudden, full up elevator deflection can be made without exceeding the limit load factor
- Speed below which there is some natural protection against stalling the aircraft
- Higher Mass = higher Va



- **Vb -** Design speed at which the aeroplane can withstand the greatest expected vertical **gust** +/- 66 feet per second at 20,000 feet
- **Vc** - Design **cruise** speed - greater than Vb to coupe with severe atmospheric turbulence.
- **Vd** - Design **Dive** Speed - expect **flutter** above Vd

- VMO < VC
- VNE < 0.9 VD

- Va calculation for utility aeroplane

$$\hookrightarrow V_a = V_{s_1} \times \sqrt{\text{Limiting load}}$$

4.4g

Gust Envelope

- VRA (rough air) = Recommended turbulence penetration speed

Gust load factor:

$$\downarrow n \downarrow = \frac{\frac{1}{2}\rho\downarrow S V^2 S C_L}{\uparrow mg}$$

(lift)

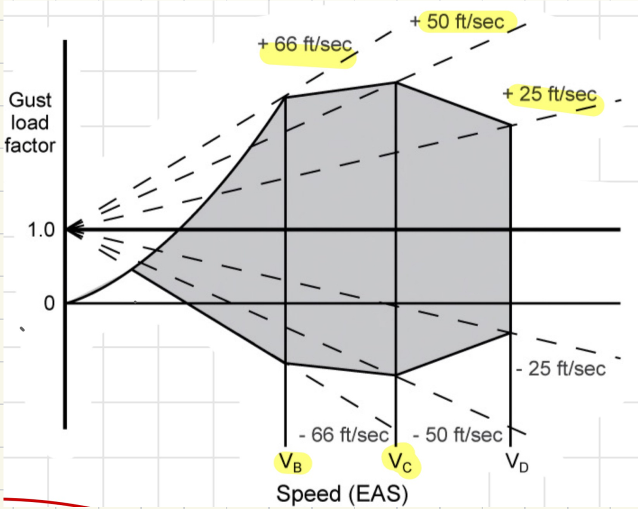
(weight)

E.g. an increase in altitude = decrease in density (p). = decrease in gust load factor (n)

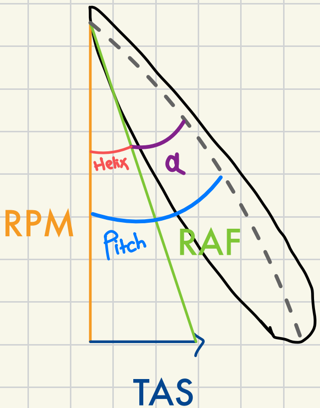
Gust load factor envelope:

The gust load factor diagram:

- Is centered about a load factor of 1
- Vb ensures the aeroplane can withstand a vertical gust of 66ft/sec
- Vc ensures the aeroplane can withstand a vertical gust of 50ft/sec
- Vd ensures the aeroplane can withstand a vertical gust of 25ft/sec

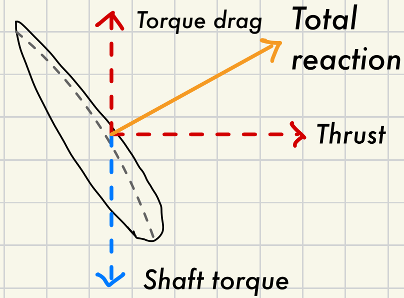


PROPELLERS



Coarse Propellor

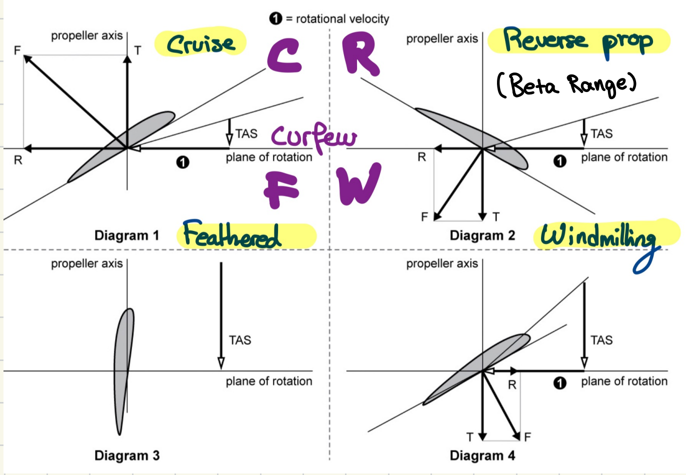
- More efficient in cruise
- Cruise propeller has larger geometric pitch
- Less efficient during takeoff and climb



- Geometric pitch: Theoretical distance a propellor advances in one revolution
- Effective Pitch: Actual distance a propellor advances in one revolution

Difference is propeller slip

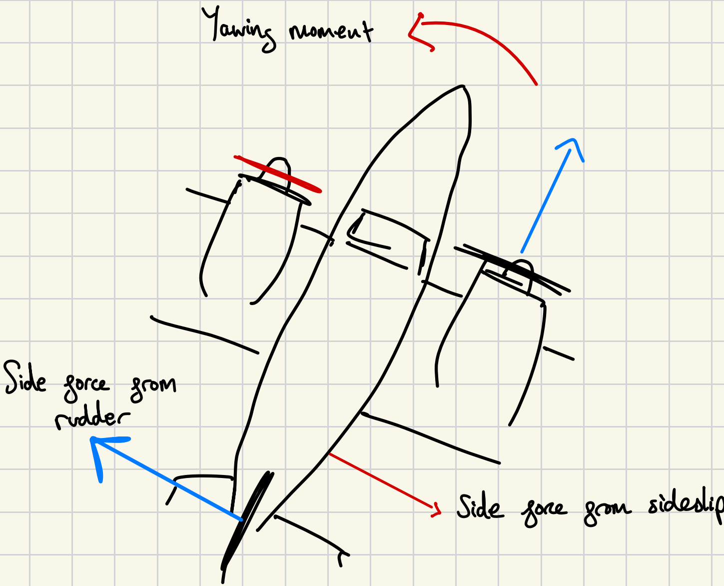
- Reference radius = 0.75R that actually produce thrust (2/3 prop length)
- **L**arge blade angle and **L**ittle twist = coarse pitch
- **S**mall blade angle and **S**ignificant twist = fine pitch
- Climb propellor, fine pitch / Cruise propellor, coarse pitch



$$\text{Propeller efficiency} = \frac{\text{Power available (output)}}{\text{Shaft power (input)}}$$

Engine Failure

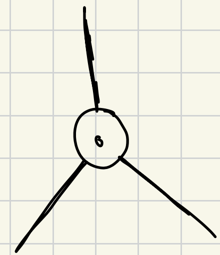
- Asymmetric flight, side slip force is aft of CG and in the opposite direction as the rudder force



In windmilling condition:

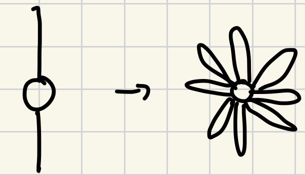
- Relative airflow approaches prop from blade back
- Total reaction creates large amount of drag and a small torque force (spins the engine)
- So a windmilling propeller degrades climb performance

- Pitch decrease, rate of descent increase, more drag
- Pitch increase, rate of descent decrease, less drag
- Feathered = 90°



Design features for power absorption

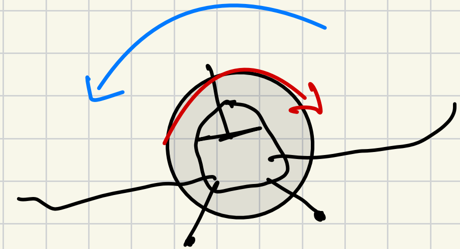
- $\uparrow$ number of propeller blades $\downarrow$ noise
- $\uparrow$ blade tip speed $\uparrow$ noise
- $\uparrow$ number of propeller blades $\uparrow$ solidity $\rightarrow$



  - More blades
  - Increase width

- $\uparrow$ number of propeller blades $\uparrow$ Max power absorption
- $\uparrow$ mean chord of blades $\uparrow$ max power absorption

Secondary Effects of Propellers

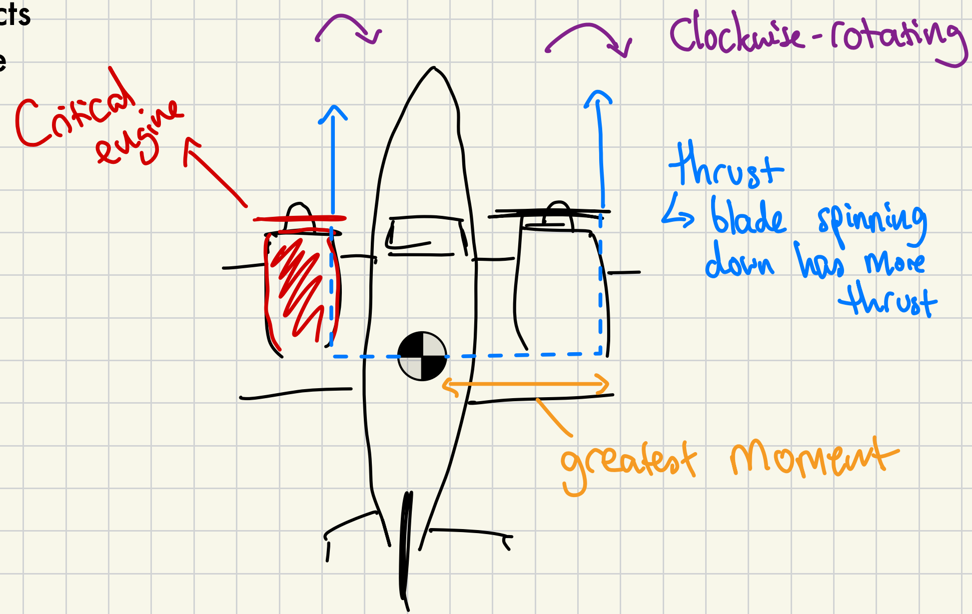


Torque Reaction

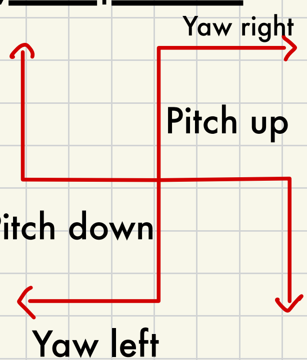
- Clockwise rotating prop -> Left yaw, Left Roll
- Worse on sudden power changes

Countra/Counter rotating

- Counter rotating: 2 engines spinning in oposite direction -> cancels torque and gyro effects
- Contra rotating: 2 blades on same engine spinning in opposite direction



Gyroscopic Effect



- Propeller effects WORSE & HIGH RPM, LOW SPEED

FORMULAS!

Subsonic

- $\dot{m} = \rho A V$
- $P_T = P_S + q$
- $q = \frac{1}{2} \rho V^2$
- $L = \frac{1}{2} \rho V^2 S C_L$
- $C_D = C_{DI} + C_{DP}$
- $C_{DI} = \frac{C_L^2}{\pi \times AR \times e}$
- $V_{stall} = \sqrt{\frac{W}{\frac{1}{2} \rho S C_L}}$

Supersonic

- $M = \frac{TAS}{LSS}$

  ↳ $LSS = 39 \times \sqrt{K}$

Climbing

- $\sin \gamma = \frac{T-D}{W}$
- $L = W \cos(\gamma)$
- $Grad\ (\%) = \left(\frac{T}{D} - \frac{1}{L:D}\right) \times 100$

Descent

- $\sin \gamma = \frac{D-T}{W}$
- $L = W \cos(\gamma)$

Turn

- $r = \frac{V^2}{g \tan\theta}$
- $n = \frac{1}{\cos\theta} = \frac{L}{W}$
- $C.P.F = W \tan\theta$
- $R.O.T = \frac{TAS}{Radius}$

Load Factor

- $n = \frac{L}{W}$
- $n = \frac{C_L\ new}{C_L\ old}$
- $V_a = V_{S1g} \times \sqrt{LLF}$
- $V_{S\,new} = V_{S\,old} \times \sqrt{n}$

(can use 3 step) $\times \sqrt{\frac{new\ weight}{old\ weight}}$