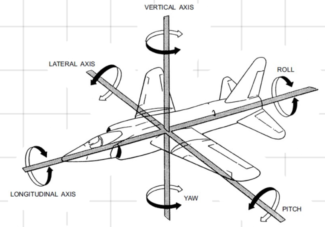
Principle of flight

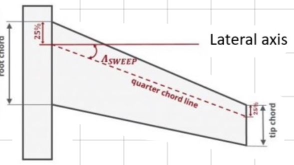
Eliott Johnson

1 Subsonic Aerodynamics

Basics, laws and definition

- Lift and drag → depend on pressure distribution around the wing
- Chord : line from leading edge to trailing edge / thickness = % chord
- AOA → angle between chord line and relative wind (undisturbed airflow)
- Maximum camber → max distance between chord and camber
- Angle of incidence → between longitudinal axis and the wing root chord line





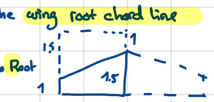
- Equation of continuity

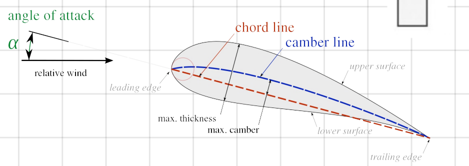
$$\boxed{\rho \cdot A \cdot v = C^{te}}$$

ρ is incompressible - constant
A is area
v is speed

$$\boxed{\frac{P}{\rho \cdot T} = C^{te}}$$

Taper ratio → Tip to Root $= \frac{1}{1.5}$

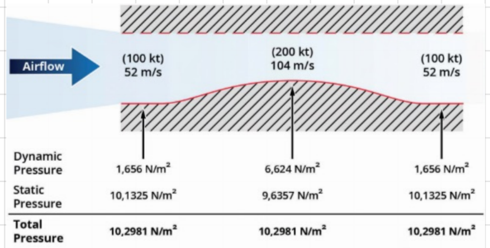




I C E - T

IAS → CAS → EAS → TAS

instrument position error — compressibility error — relative density error



- $\boxed{\text{Wing loading} = \frac{\text{weight aircraft [N]}}{\text{area of wing [m}^2\text{]}}}$

- Mean Aerodynamic Chord (MAC):
  - Chord equivalent untwisted, rectangular wing with same pitching moment and lift characteristics as actual wing

- $\boxed{\text{Mean geometric chord} = \frac{\text{wing area}}{\text{wingspan}}}$

- $\boxed{\text{Aspect Ratio} = \frac{\text{wingspan}}{\text{mean geometric chord}} = \frac{\text{wingspan}^2}{\text{wing area}}}$

Bernoulli's equation

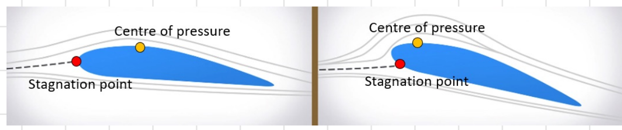
Total Pressure = Dynamic Pressure + Static Pressure

$$\boxed{\text{Total Pressure} = \underbrace{\tfrac{1}{2} \cdot \rho \cdot v^2}_{TAS} + C^{te}}$$

Two dimensional airflow around an aerofoil

Center of Pressure

- is a point where resultants of aerodynamic forces is applied
- does not move for symmetrical aerofoil
- affects pitch moment and stabiliser movement



At low AOA
- High speed
- Stagnation point is on the front of the wing
- CP moves aft

At high AOA
- Low speed
- Stagnation point moves to the back
- CP move forward

Aerodynamic centre of the wing

- Pitching moment coefficient does not vary with AOA
- Located at 25% chord

- Lift / Drag ratio → Max lift effort compared with drag obtained at the same AOA
- Max C_L / C_D at an AOA of 4°

  lift — Drag coefficient

- Total drag in 2D = Pressure drag + skin friction drag (dirt and other particles)
- Form drag
  - caused by pressure difference between leading edge and the trailing edge
- Reduction in induced drag
  - decreased upwash
  - decreased induced AOA

Coefficients

$$\boxed{\text{Lift} = C_L \cdot \tfrac{1}{2} \rho v^2 \cdot S}$$

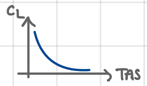
$$\boxed{\text{Drag} = C_D \cdot \underbrace{\tfrac{1}{2} \rho v^2}_{\text{dynamic pressure}} S}$$

[N]

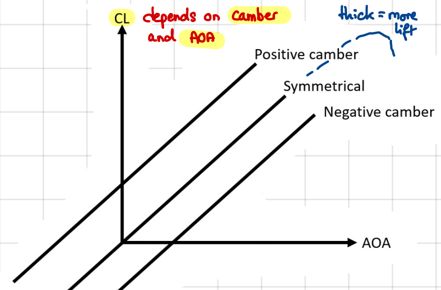
ρ = air density
v = speed
S = wing area [m²]

- Max C_L/C_D ratio at lowest drag
  → clean configuration

$$\boxed{C_L = \frac{2 W n}{\rho v^2 S}}$$



n = load factor
W = weight
S = surface

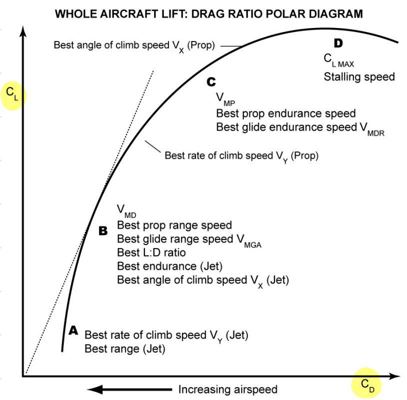


- C_L affected by camber and AOA only

  Change in stall speed given by $\boxed{\left(\frac{V_{old}}{V_{new}}\right)^2 = \Delta C_L}$

- Positevely cambered airfoil:
  $C_L = 0$
  ↳ pitching moment down
  ↳ negative AOA
- Negatively cambered airfoil:
  $C_L = 0$
  ↳ pitching moment up
  ↳ positive AOA
- Symmetric cambered airfoil:
  - pitching moment = 0
  - AOA = 0
  - there is only drag, no lift

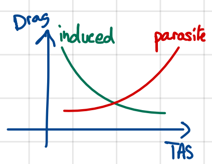
Aerofoil polar curve



Three-dimensional airflow around an aeroplane

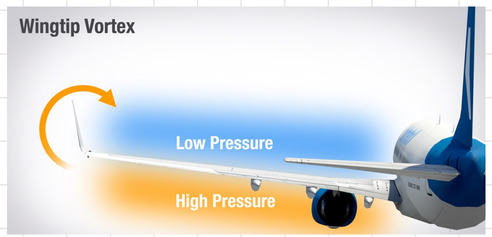
- Wing vortices
  - ↗ as AOA ↗
  - ↘ as Aspect Ratio ↗ (glider have high AR but less drag)
  - are stronger in clean configuration

- External wing tip-tank reduces induced drag (less wing vortices) but increase parasite drag
  ↳ caused by wing tip vortices and downwash
  ↳ inversely proportional to AR
  ↳ low speed = high induced drag
  → elliptical wings have lowest induced drag



$$\boxed{\text{Drag}_{\text{induced}} = C_{D_i} \tfrac{1}{2} \rho v^2 S}$$

$$\boxed{C_{D_i} = \frac{C_L^2}{\pi \cdot AR}}$$

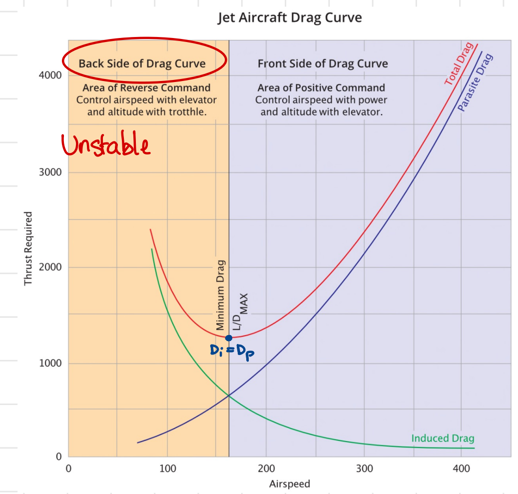


Total drag

Total drag
- Parasite drag
  - Dirt, particles
  - $\propto v^2$
  - Skin friction drag
  - Form drag — Pressure drag
  - (Skin friction drag + Form drag = Profile drag)
  - Interference drag
    - Connection between surfaces wing/fuselage
    - Reduce by fileting
- Induced drag D_i
  - Drag by wings
  - important at low speeds
  - Wing tips
  - less D_i (gliders)
    ↳ High Aspect Ratio (AR)
    ↳ elliptical wing
  - $\propto \frac{1}{v^2}$
  - Coefficient of induced drag
    - $C_{D_i} = \frac{C_L^2}{\pi \cdot AR}$

- to lower induced drag:
  - ↘ mass $D_i \propto lift^2$
  - ↗ speed $D_i \propto \frac{1}{v^2}$
  - ↗ AR $C_{D_i} \propto \frac{1}{AR}$
  - ↘ AOA
  - install winglet, tip tanks
  - Geometric washout
    → reduce angle of incidence at tip
  - Aerodynamic washout
    → reduce camber at tip
  - Deploy flaps + slats
    (because flaps = more lift ⇒ push nose down, less AOA ⇒ less induced drag)

V_{MP} - lower



Ground effect

- Effective AOA and lift coefficient ♥ ground, all the rest loves Air
- Entering ground effect
  - ↗ α_e (effective AOA)
  - ↗ C_L (lift coefficient)
  - ↘ α_i (induced AOA)
  - ↘ downwash angle
  - ↘ C_{D_i} (induced drag)
- Leaving ground effect
  - ↘ α_e (effective AOA)
  - ↘ C_L (lift coefficient)
  - ↗ α_i (induced AOA)
  - ↗ downwash angle
  - ↗ C_{D_i} (induced drag)
- Low wing and low tail plane will feel more the ground effect
- Hot day → add ground effect (thermals)

The relationship between lift coefficient and speed in steady, straight and level flight

$$\boxed{\text{Lift} = C_L \cdot \tfrac{1}{2} \cdot \rho \cdot v^2 \cdot S}$$

$C_L (200)^2 = (230)^2 \cdot 0.3$

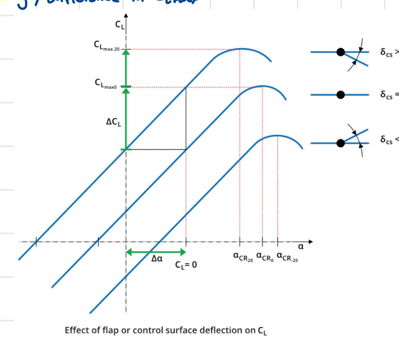
$C_L (1.8 V_S)^2 = (1 \cdot V_S)^2 C_{Lmax}$

- IAS same at different altitude
- TAS higher at higher altitude

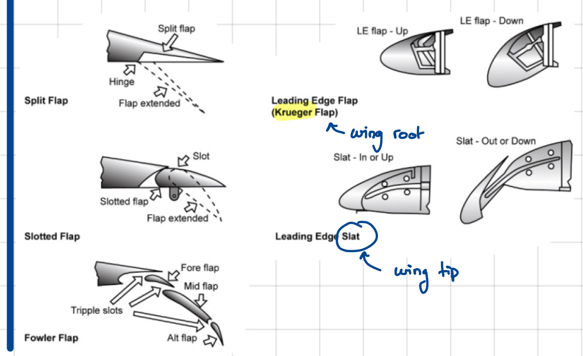
CLMAX augmentation

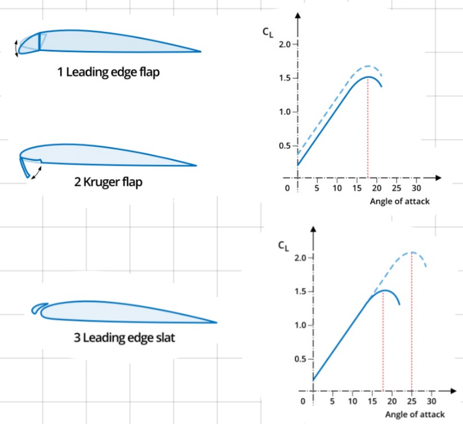
- Slats
  - increase C_{LMAX} more than flaps
  - ↗ critical angle of attack
- Clean configuration → higher L/D ratio
- Increasing critical AOA
  1) flaps only extended
  2) clean wing
  3) slats only extended
- Krueger flaps → leading edge (wing root)
- Fowler flaps → best system
- Trailing edge flap extension
  - ↘ critical angle of attack
  - ↗ C_{Lmax}

Flap asymmetry:
- Flap → cause rolling
- Slat → yawing / difference in C_{Lmax}



Effect of flap or control surface deflection on C_L





Means to reduce C_L/C_D ratio

- Spoiler extension:
  - $\nearrow C_D$ is increased (more drag)
  - $\searrow C_L$ is decreased (except if load factor unaffected)
  - Angle of attack is unaffected
  - Margin to stall $\searrow$

Aerodynamic degradation

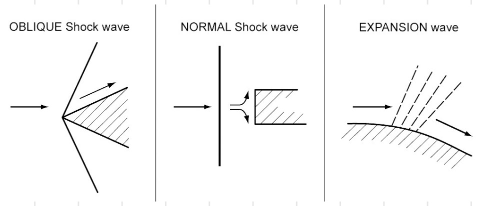
- Icing decreases critical angle of attack and can lead to absence of stall warning
- Reduction in $C_{L_{max}}$

02 High speeds Aerodynamics

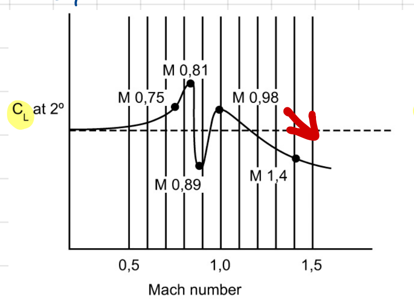
Speeds

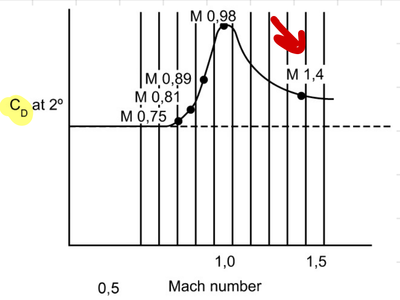
- Expected speed restriction during: Chicken Tikka Masalla
  - Climb: MMO
  - Descent: VMO
- Mach = $\frac{TAS}{LSS}$
- Subsonic speed:
  - up to M_{CRIT}
- Transonic speed:
  - Both supersonic and subsonic exist around the aircraft
  - Region around Mach 1
  - If compressibility comes into effect
    - Density = main cause
- Supersonic range:
  - From Mach 1.3 to 5
  - pressure distribution is rectangular

Shock waves



- Normal shockwave
  - Normal to the local airflow (perpendicular)
  - Separation of boundary layer at high M
- If Mach number in front of shockwave is small but still supersonic you can achieve high efficiency
  - ↳ just above Mach 1 → least energy lost
- Increasing mass increase shockwave intensity
- Behind shockwave
  - → Speed change from supersonic to subsonic (M<1)
  - → density increases
  - → Temperature increases ⇒ LSS Speed of Sound increases
- Shock wave on upper side of wing ⇒ CP will move to trailing edge
- Loss of total pressure in shock wave is due to kinetic energy changed to heat energy
- Shock wave speed = Ground speed of aeroplane
- If Mach number is increased beyond M>1:
  - $\searrow$ CL
  - $\searrow$ CD





Effect of exceeding the critical Mach number (MCRIT)

- MCRIT = somewhere on airframe Mach=1 is reached (local sonic flow)
- Tuck under:
  - Aft movement of the centre of pressure
  - $\searrow$ downwash angle at the horizontal stabiliser contributes to tuck under
  - Only occurs > MCRIT
- Mach trim:
  - Prevent tuck under (aircraft having nose down moment) → change in CP
  - Used to maintain the required stick force gradient
  - Corrects insufficient stick force stability at high Mach numbers

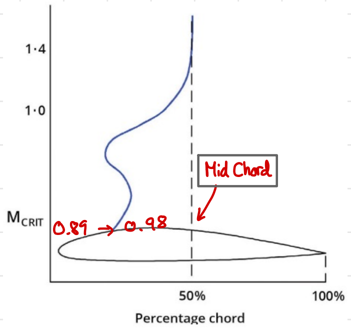
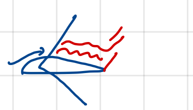
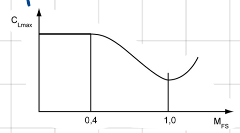


Figure 2.46 CP movement vs Mach number

- Shock stall
  - Lift decrease because of flow separation (boundary layer) behind the shock wave
  - Small AOA
  - occurs when lift coefficient, as a function Mach number reaches it's maximum value
- Drag divergence Mach number
  - Mach number at which the drag rises rapidly   MDR > MCRIT   below MCRIT, no shockwave
  - Depends on
    - → AOA
    - → Wing profile
- Other:
  - Additional drag is wave drag
  - Centre of pressure will move aft to mid chord (from 25% to 50%) → less stable (more stable in longitudinal)
  - Stall speed increases at higher altitude due to increasing compressibility effect as a result of increasing Mach number ↳ loss of lift wing root area
  - Lower mass = higher MCRIT due to smaller AOA
  - Aileron deflection partialy affect the pressure distribution because of shock wave

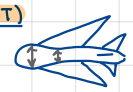


  - transonic region:
    - $C_{L_{MAX}}$ decreases
    - 1g stalling speed increases



Means to influence critical Mach number (MCRIT)

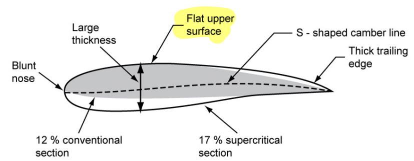
- Wing sweepback ↳ Area ruling



  - Delays appearance of shock waves due to decrease of the velocity of air, perpendicular to leading edge
  - $\nearrow$ sweepback $\nearrow$ MCRIT
  - $\nearrow$ sweepback $\nearrow$ Drag divergence number
  - Higher CD than a straight wing (counter intuitive)
  - Flaps are less effective as sweepback increases (ex 25° sweepback = bad)
  - poor low speed handling
  - 30° sweepback = Theory $\frac{1}{\cos(30°)}$ 1.15   practice $\frac{1}{2}$

Supercritical aerofoil

- Allows a wing of increased relative thickness for approx same cruise Mach number
- Will develop no noticeable shock waves when flying above MCRIT

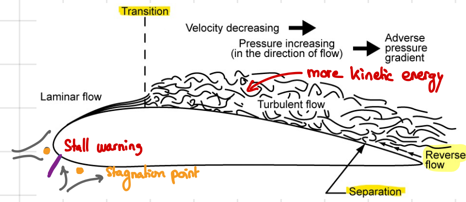


Vortex generator

- decrease wing drag

03 Stall, Mach Tuck and Upset Prevention and Recovery

The Stall



Load factor

$n = \frac{Lift}{Weight}$

- Load factor < 1
  - during climb (thrust replaces lift)
  - lift < weight
  - During a steady wings level descent
- load factor > 1
  - lift > weight
- Load factor (LF) in a turn

$$LF = n = \frac{1}{\cos(\alpha)}$$

- Stall speed in a turn is increased by $\sqrt{n}$

$$V_{S_{turn}} = V_S \cdot \sqrt{\frac{1}{\cos(\alpha)}} = V_S \cdot \sqrt{n}$$

$$V_{S_{new\ mass}} = V_S \sqrt{\frac{new\ mass}{old\ mass}}$$

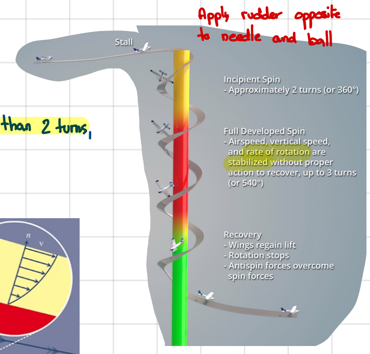
Deep stall

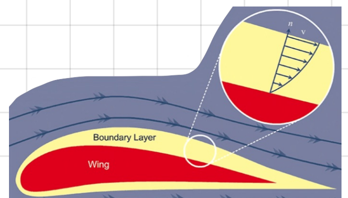
- Swept back wing (and T-tail)
- Big AOA

Incipient Stall

- Flight condition post-stalled
- Initial rotation of not more than 2 turns, forces unbalanced

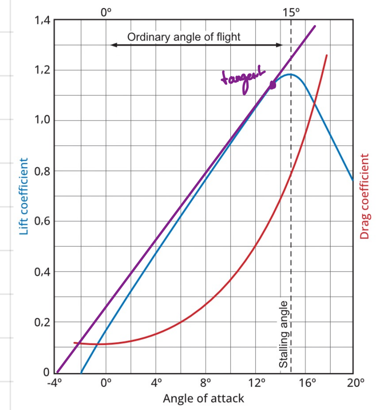
Apply rudder opposite to needle and ball





Boundary layer

- Laminar layer
  - no velocity component exists normal to the surface
  - Friction drag is lower in laminar layer
  - laminar is thinner than turbulent layer
- Transition point
  - Turbulent between transition and separation point
  - Behind the transition point the mean speed and friction drag $\nearrow$
  - Turbulent boundary layer has more kinetic energy than laminar
- Airflow separation
  - characteristic by airflow reversal on the surface body



Stall characteristics

Deterrent buffet

- caused by high AOA (shaking of flight controls)
- Pilot will feel need to react to leave conditions

But minimum control speeds with CG at aft limit

Speeds

- Determined with CG at forward limit (need more force/lift on tail)
- V_S = Stall speed or minimum steady flight for wich the aircraft is still controllable
- V_{S0} = Stall speed or min flight speed in landing configuration
- V_{S1} = Stall speed or minimum steady flight for wich the aircraft is still controllable in specific configuration
- V_{S1g} = Min speed at wich lift = weight (1g or g=1)
- V_{SR} = Reference stall speed
- V_{SR0} = Reference stall speed in landing config
- V_{SR1} = Reference stall speed in specific config
- V_{SW} = Stall warning
- Stall speeds (IAS)
  - initially remain constant and then increase with altitude, Compressibility effects

Accelerated stall

- Stall at high load factor n>1
  Turning/dive, stalling at higher speed

Stick shaker

- doesn't prevent pilot from pushing stick further
- input from AOA and sometimes AOA rate of change
- not for deep stalls

Stick pusher

- installed on aeroplanes prone to
  - excessive wing drop
  - deep stall
- actuates at higher AOA (after) stick shaker

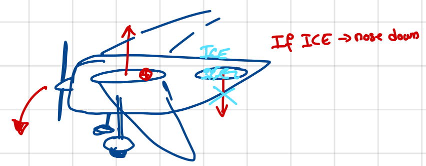
Critical AOA (stalling angle)

- Doesn't change in a turn (fixed value)
  - ↳ regardless of gross weight
- After critical AOA CP moves
  - → Aft for straight wing
  - → Forward for sweptback wing

Wing sweepback

- wing-tip stalls first
  - ↳ nose up pitching moment
- at low speed → pitch up (because of spanwise flow)

- Big aspect ratio stall at low AOA (fighter jets have small AR and do crazy AOA)



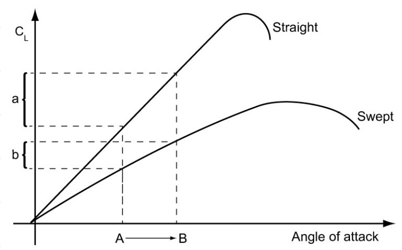
↳ improved low speed handling

Buffet onset boundary

- High speed buffet
  - Mach buffet occurs following boundary layer separation due to shockwave formation
- Buffet free range
  - ↘ with mass ↗
  - ↘ as altitude ↗
  - ↘ during a pull manoeuvre (load factor ↗)
  - ↗ during a push manoeuvre (↘ AOA)
  - When CG moves aft, buffet free range ↗
  - When the speed / Mach number changes the buffet free range does not change

Situations in which buffet or stall could occur

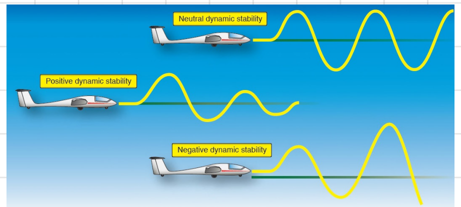
- If buffeting due to Clear Air Turbulence ⇒ descend at lower altitudes and fly turbulence penetration speed
- In strong wind shear, tailwind can make you stall
- Swept wings:
  - are less affected by turbulence
  - have a shallow C_L vs AOA curve w/r straight wings



04 Stability

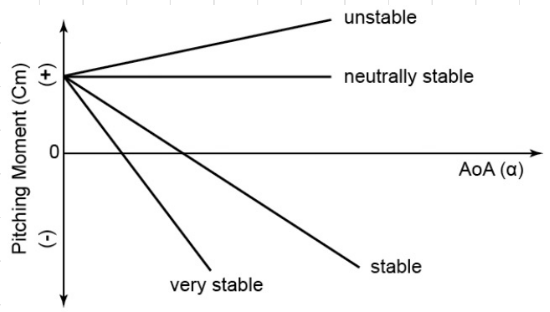
Static and dynamic stability

- Positive stability
  - initial tendency to return towards equilibrium condition
  - Can be dynamically stable, neutral or unstable
  - Dynamic stability:
    - You need static stability and sufficient damping
  - ↗ stability ↘ manoeuvrability
  - Transonic range → stability increases



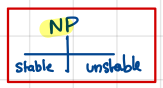
Static and dynamic longitudinal stability

- It is the stability in pitch up or down



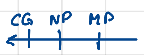
- Phugoid
  - Long term oscillation around the lateral axis
  - Dynamic longitudinal stability
  - Speed and Altitude varies significantly (long oscillations)
  - No observation of pitch (or AOA) change because it's very slow
  - Damping very weak
- Centre of gravity

  - Fwd CG:
    - very stable, requires large stick force (more stick force stability)
  - Aft CG:
    - not stable, require little stick force
    - limited by the minimum value of the stick force per g
- Neutral point: → CG fwd of neutral point, it's stable
  → aft of neutral point ⇒ unstable



- Contribution to static longitudinal stability
  - positive or negative camber has no effect on longitudinal stability
  - wing downwash: negative
    ⚠ don't get tricked by question about CG in front of aerodynamic center
- Negative contribution
  → fuselage

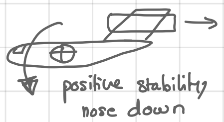
Manoeuvre point



- Is the CG position where the moment from the wing lift and the tail lift are equal
- Always behind the neutral point

Highest value of lift

- Forward CG (because aircraft stable so need more tail force)
- Low thrust (no lift from engine, only from wings)

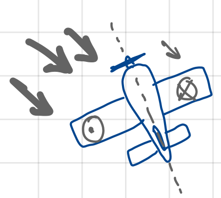


Static directional stability

- Yaw axis
- Tendency of an aeroplane to recover from a skid without control input from the pilot
- Contribution to directional stability
  - Dorsal fin
  - Ventral fin (longitudinal - no effect, lateral negative)
  - wing sweep back
  - Straight wing with high AR is negligible

Sideslip angle = angle between · speed vector
· plane of symmetry

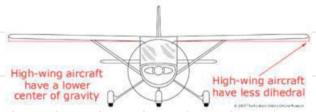
- Sideslip with airflow from left
  - Nose move to the left (in the wind direction)
  - Left wing moves up (because lift is increased on that side)

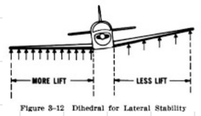


Static lateral stability

about the longitudinal axis

- Roll axis
- Dihedral wing
  - increases stability by increasing lift on the upper wing (in a side slip)
  - The down going wing gets a greater AOA than the upgoing wing thus has more lift
  - You don't want too much lateral stability otherwise you don't have enough roll/aileron control





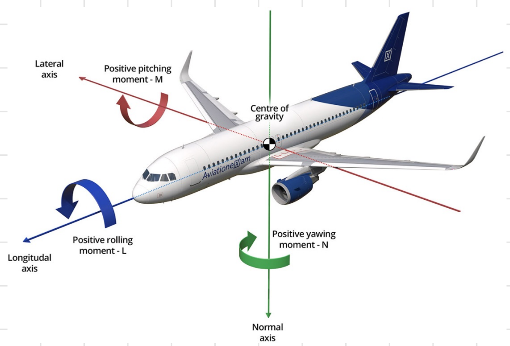
Positive contribution to lateral stability	Negative contribution to lateral stability
Dihedral	Anhedral
Sweepback	Forward-swept
High wing	Low wing
Large and high vertical fin (big AR)	Ventral fin
	flaps extended

Dynamic lateral / directional stability

- Dutch roll
  - Result of strong static lateral stability and a weak static directional stability
  - Usually at high Mach number
  - Rolling and yawing motions
  - Corrected by yaw damper
- Spiral dive
  - Result of weak static lateral stability and a strong static directional stability
  - Aperiodic
- Lateral and directional stabilities interact through sideslip, which is created using aileron or rudder alone

05 Control

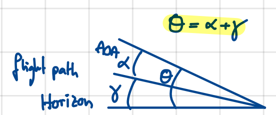
- Spring tabs → reduces pilot effort to move controls
- Servo tabs
- Horizontal trimmable stabilizer
  - less drag
  - Larger C.G. because the whole stabilizer moves
- Trim tab opposite to control surface



General

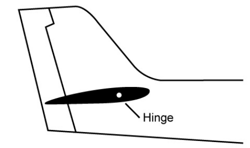
- Aeroplane manoeuvrability ↗ IAS ↗
- Pitch angle: angle between longitudinal axis and horizontal plane
- Bank angle: angle between longitudinal axis and horizontal plane

$\theta = \alpha + \gamma$



Pitch (longitudinal) control

- Too much stability (forward CG)
  - High control forces because fwd CG aircraft appear heavier
  - Higher V_{REF} ($1.3 \cdot V_S$)
    ↳ manoeuvrability decrease due to Static longitudinal stability
- Horizontal stabilizer (tail)
  - Contributes to the total lift of the airplane
  - May stall before the wing
  - Is necessary to balance the total pitch moment of the plane



All flying tail

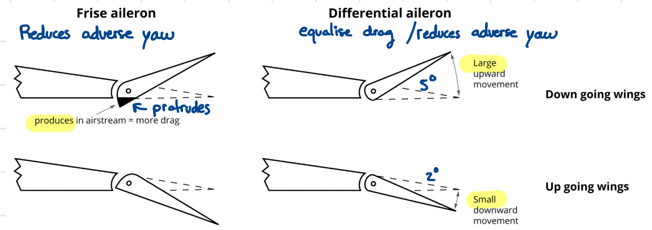
- Line of thrust below CG: if increase power ⇒ nose up altitude + stabilizing
- Elevator deflection:
  - CG fwd: requires large elevator deflections
  - Smaller deflection needed at high IAS
- Trimmable horizontal deflection: correct setting determined by CG position
- Variable incidence tailplane:
  ⇒ better because less trim drag and maximum elevator authority retained

Yaw (directional) control

- A full rudder deflection could cause excessive load

Roll (lateral) control

- Aileron change wing camber
- Left roll, left aileron moves up
- Adverse yaw
  - When you roll right, you also have a yaw left (adverse yaw)
  - Rudder deflect to help turn (roll left, deflects left)



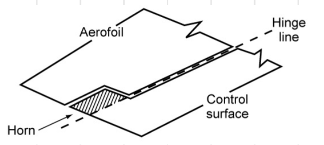
- Spoilers
  - Help ailerons but only the one on the side of the turn (wing down)
- Drag
  - Upwards aileron acts like a spoiler ⇒ FORM drag
  - Downwards aileron increases lift ⇒ induced drag
    ↳ up going wing has increased AOA

Roll/yaw interaction

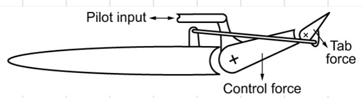
- If you yaw left, you also roll left because the right wing picks up more wind and has more lift

Means to reduce control forces

- Aerodynamic balance
  - Purpose: reduce the load required to move the controls
  - An internal balance
    ↳ seal
  - Balance tab
    - Reduce control force
  - Horn balance
    - Decrease stick force
    - A part of control surface is behind the hinge line to protrude into airflow

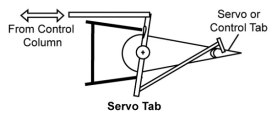


- Anti-balance tab
  - increases manoeuvring stick forces
  - protects from overstress
  - moves in the same direction as the control surface
  - increases control effectiveness

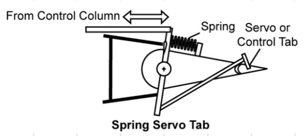


Aerodynamic means to decrease manoeuvring stick forces:

- Servo tab → in fully powered, moves the servo valve
  - Position is undetermined during taxiing
  - Reduces stick forces. Big control surface change/movement with small forces
  - Used in case of manual reversion of fully powered flight controls
  - Tab moves opposite to control surface
  - If elevator jam, tab acts like mini elevator with reverse pitch direction

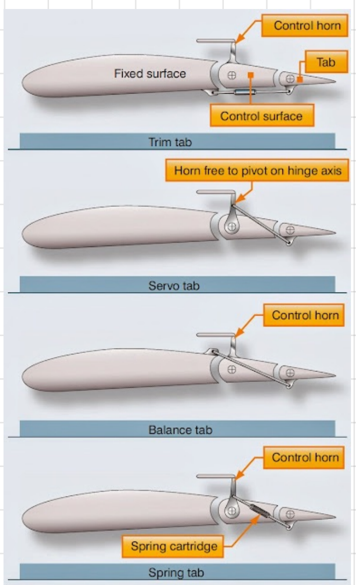


- Spring tab
  - decrease stick force
  - at high IAS behaves like a servo tab



- Offset hinge
- Internal balance/seal

- Trim tab
  - does not reduce stick force in general but only in one direction
  - Purpose is to reduce continuous stick force to zero



- Mass balance
  - Not an aerodynamic mean
  - Used to reduce flutter
- Bobweight
  - Not an aerodynamic mean
  - Used to increase stick force as g-force increase
  - Reduce likelihood to overstress aircraft

Trimming

- Movable stabiliser/trimmable horizontal stabilizer (THS)
  - Advantages:
    - less drag when trimmed for zero elevator stick force
    - Enables a larger CG than an elevator trim tab
    - Able to compensate large changes in pitching moments
  - Disadvantages
    - The effect of a stab trim rwy are more serious because the whole elevator moves
    - jammed stab trim causes more control difficulty
  - General
    - Power assisted ACFT
      position depends on speed, slats, flaps position and CG position
    - Fully hydraulic operated: elevator deflection = 0
    - Speed increase → no change in neutral position
- Trim tab
  - Reduce or cancel control forces
  - Remains fixed for control surface movement unless when using trim wheel
  - Move in the inverse direction of the elevator so if it's jammed → act like mini elevator in reversed direction
  - Speed increase → trim tab moves aft
  - reduces hinge moment and control surface efficiency

06 Limitations

Operating limitations

- Flutter
  - caused by structure stiffness
  - To reduce flutter → high stiffness
    ↳ mass balance in front of hinge moment

- Limiting speeds
  - M_{MO} applicable to CS-23 and CS-25
  - V_{NE} applies only to CS-23

- Aileron reversal
  - Low speed
  - High speed: wing twisting and reducing incidence when aileron is lowered

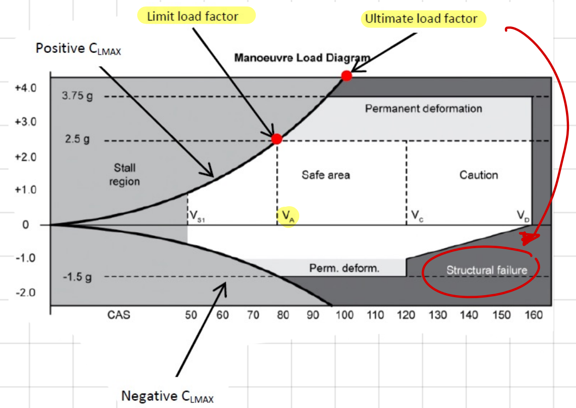
Manoeuvring envelope

- $V_{MO} < V_C$
- $V_{NE} < 0.9\ V_D$
- V_A Speed above which, full deflection cause damage
  ↳ Stall speed at manoeuvring limit load factor
  - V_A calculation for utility aeroplane
    - $\boxed{V_A \geq V_{S1} \cdot \sqrt{\text{limiting load}}}$ ↖ 4.4g
    - $\frac{V_{A_{new}}}{V_{A_{old}}} = \sqrt{\frac{m_{new}}{m_{old}}}$

$\boxed{\frac{V_{S_{new}}}{V_{S_{old}}} = \sqrt{\frac{C_{L_{old}}}{C_{L_{new}}}}}$

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

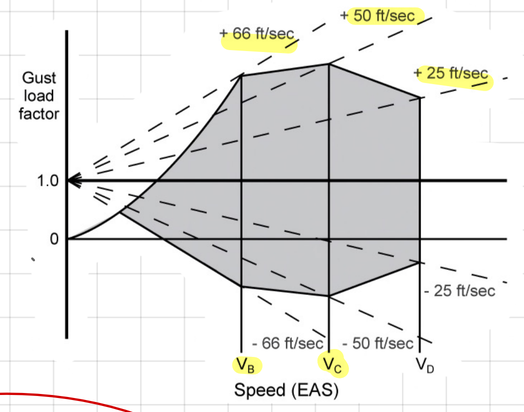
  - depends on mass and pressure altitude
- V_C: design cruise speed



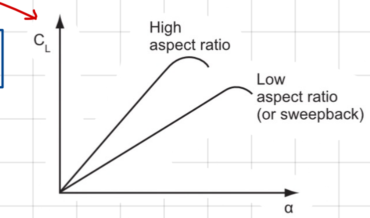
Gust envelope

- V_B is the design speed for maximum gust intensity
- Gust load factor
  - ↗ when wing loading ↘
  - ↗ when mass ↘ $\left(n = \frac{L}{W}\right)$
  - ↗ when altitude ↘ (higher altitude you have lower density so a gust is less effective)

  - ↗ when lift vs AOA curve ↗
  - ↗ when wing area ↗
  - ↗ when Aspect Ratio ↗ (slope of C_L vs AOA)
  - ↗ EAS ↗
  - ↗ with upward gust



$\boxed{V_{S_{new}} = V_{S_{old}} \sqrt{n}}$

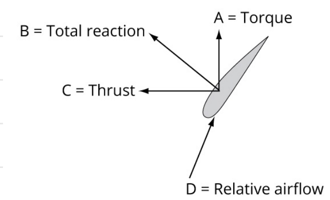


- Sudden updraft: AOA ↗ Drag ↗
- V_{RA} (Rough air) is the recommend turbulence penetration speed
- Can be higher than manoeuvring limit load factor
- Calculation technique
  1. Verify: $V_{S1} \geq V_{S0} \cdot \sqrt{n}$
  2. New n $\frac{V_{new}}{V_{old}} = \frac{n_{new} - 1}{n_{old} - 1}$

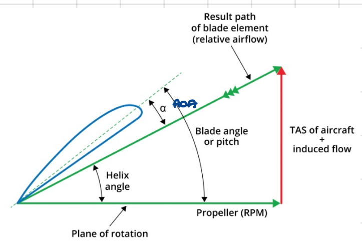
07 Propellers

Conversion of engine torque to thrust

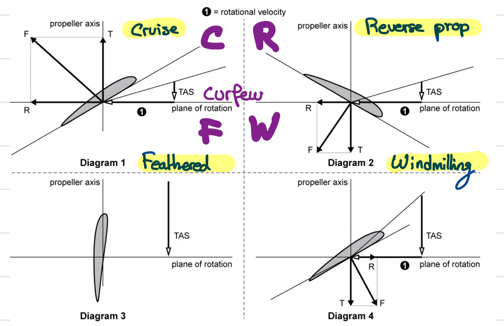
- Propeller runaway
  → reduce throttle



- Reference radius = 0.75R 2/3 prop length
- Coarse propeller
  - more efficient in cruise
  - cruise propeller has larger geometric pitch
  - less efficient during take-off and in climb



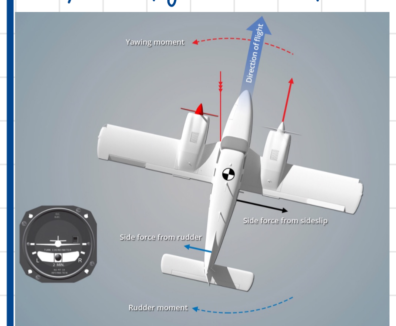
- LLLarge blade angle and LLLittle twist = coarse pitch
- SSSmall blade angle and SSSignificant twist = fine pitch (take-off)
- AOA fixed pitch propeller
  - ∝ to RPM
  - $\propto \frac{1}{TAS}$



- efficiency $= \frac{\text{power available (output)}}{\text{Shaft power (input)}} = \frac{\text{Thrust} \cdot \text{TAS}}{\text{Torque} \cdot \text{RPM}}$
- increasing camber increases power absorbtion capability
  - Effective pitch of a propeller is the actual distance a propeller advances in one revolution
  - Geometric pitch: theoretical distance
  ↳ Difference is propeller slip
- Prop chord ↗ : efficiency ↘, power absorption increase

Engine failure

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

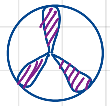


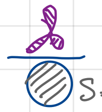
- pitch decrease, rate of descent increase, more drag
- pitch increase, rate of descent decreases, less drag
- feathered = 90°

Design features for power absorption

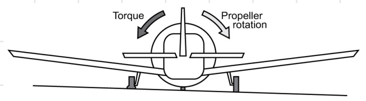
- ↑ number of propeller blades ↓ noise
- ↑ number of propeller blades ↑ solidity
- ↑ number of propeller blades ↑ max power absorption
- ↑ mean chord of blades ↑ max power absorption

Prop Aspect Ratio

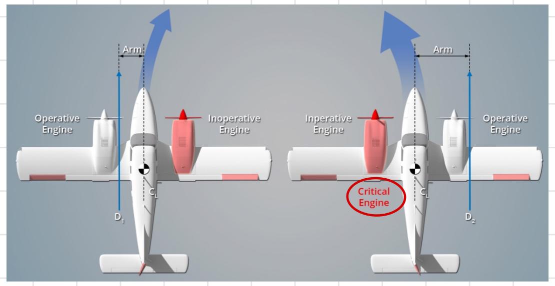




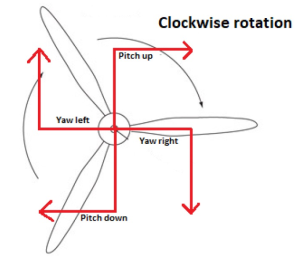
Secondary effect of propellers



- Clockwise rotating prop → Left yaw, left roll
- Assymetric blade effect ↑ engine power ↑
- Assymetric blade effect ↑ when angle (prop axis, airflow) ↑
- Left engine is critical engine (creates more yaw)
- Flaps increase roll from engine failure
- Go Around with clockwise prop:
  - Asymmetric thrust (P-factor) = left yaw
    ↳ Blade spinning down has more thrust
  - Gyroscopic effect = right yaw (when pitching up)



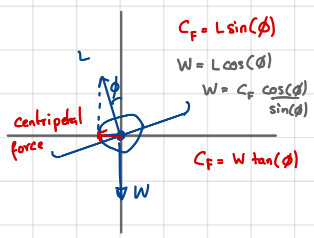
- Counter rotating: 2 engines spinning in opposite direction
  ↳ cancels torque and gyro effects
- Contra rotating: 2 blades on same engine spinning in opposite direction



08 Flight Mechanics

Forces acting on an aeroplane

- Coordinated turn:
  - $\boxed{t = \frac{2\pi r\,[m]}{TAS\,[m/s]}}$ [s]
  - $\boxed{r = \frac{TAS^2\,[m^2/s^2]}{g \cdot \tan(\phi)}}$ [m] — ϕ = bank angle
  - $\boxed{n = \frac{1}{\cos\phi} = \frac{L}{W}}$ ⚠ in climb $n < 1$ because thrust pulls up
  - $\boxed{V_{S\,in\,turn} = V_S \cdot \sqrt{n}}$
- $\frac{TAS\,[kts]}{2} = TAS\,[m/s]$
- 3° per second turn
- Climb and load factor:
  - $\boxed{n = \cos(\gamma)}$ — climb angle
  - $\tan(\gamma) = \frac{\text{Vertical}}{\text{Horizontal}}$ = climb gradient
  - For small angles $\cos(\gamma) \cong 1$



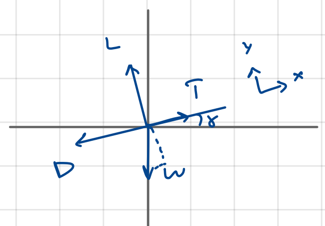
- $V_{min\,sink\,rate} < V_{min\,glide\,angle}$
  - In a glide, I want to glide as far as possible at higher speed (TAS)
  - In a sink, I want to get to the ground as slow as possible V_{MP}
- Minimum glide angle
  - Is the best distance to change in height ratio
- Glide:
  - Lift/drag ratio: determines distance
  - Wind: determines distance
  - Weight: determines speed

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

Climb



in x:
① $T = \sin(\gamma)W + D$

in y:
$L = W\cos(\gamma)$
$W = \frac{L}{\cos(\gamma)}$

① $\frac{T-D}{W} = \sin(\gamma)$

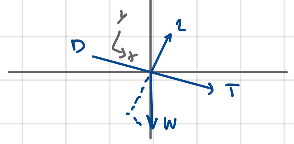
$\boxed{\gamma = \sin^{-1}\left(\frac{T-D}{W}\right)}$

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

Small angles $\cos(\gamma) \approx 1 + \dots$

$\boxed{\frac{T}{W} - \frac{D}{L} = \sin(\gamma)}$ — climb gradient

Descent



in x:
$T + \sin(\gamma)W = D$

in y:
$L = \cos(\gamma)W$

$T = D - W\sin(\gamma)$

Asymmetric thrust

- CG forward will reduce yaw
- Directional controllability with OEI favorably affected by
  - High temperature
  - Forward CG location
  - High altitude

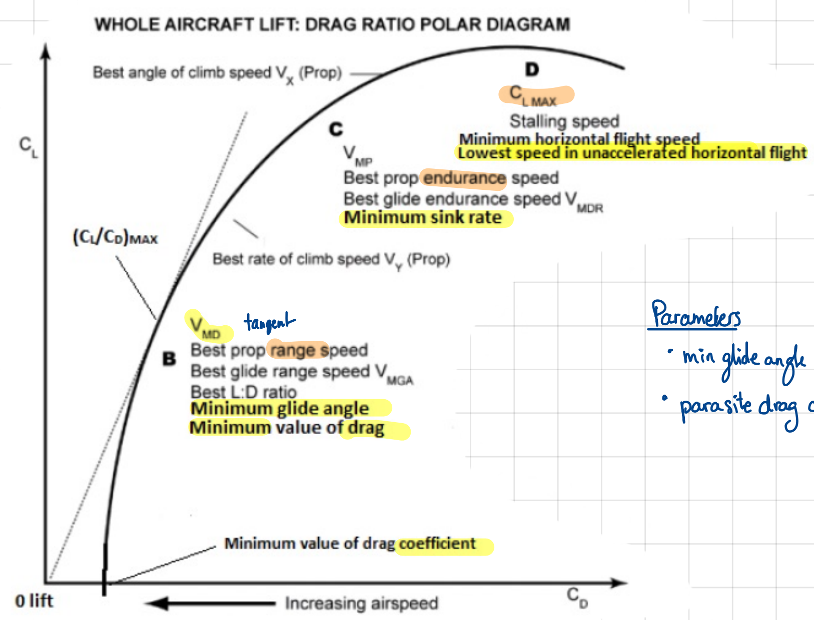
  } engine less performant → less asymmetric thrust

$\boxed{\text{Decrease in } V = \text{good!}}$

- VMC
  - Minimum control speed with critical engine inoperative
  - Bank angle not more than 5° and maximum power
- VMCA
  - Minimum control speed in take-off configuration with gear up
  - VMC determination:
    - Bank angle ↓ VMCA ↑
    - If bank angle > 5° → increasing risk of fin stall. But with bank angle VMCA ↓, better because helps with adverse yaw
    - 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 a combination of both
    - Max T-O 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 temperature because engine thrust decreases
  - VMCG determination:
    - Lateral deviation from centerline should be less than 30ft
    - To simulate wet runway → nose wheel steering may not be used
    - CG should be aft limit (shorter arm from CG and thus less manoeuvrability)
      ↳ fwd CG decreases VMCA
- VMCL
  - Minimum control speed in landing/approach configuration — with all engines operating
    - not limited by engine failure
    - not limited by rudder deflection
  - Limited by the available maximum roll rate/aileron deflection
  - VMCL determination:
    - Landing configuration
    - Full power

    } Go Around scenario
- Fwd CG decreases VMCL (most stable)

Polar curve



Parameters
- min glide angle
- parasite drag coefficient