

POF 1 – UNITS OF MEASUREMENT

FUNDAMENTAL SI UNITS

- **Mass** – Kg
- **Length** – m
- **Time** - s

DERIVED UNITS

- **Area** – m²
- **Volume** – m³
- **Velocity** – m/s
- **Acceleration** – m/s²
- **Momentum** – kg.m/s
- **Force** – N
- **Weight** – N
- **Work** – J (Joule)
- **Power** – W (Watt)
- **Energy** - J (Joule)
 - Capacity of doing work
 - Potential – due to position
 - Kinetic – due to motion
- **Pressure** – Pa (Pascal)
 - Bar used in aviation. 1 Bar = 105 Pa
 - Static pressure (P_S) – Stationary air exerts pressure in all directions.
 - Dynamic pressure (P_D) – Moving air is brought to rest on surface of a body.
 - Total Pressure: P_T = P_S + P_D
- **Density**– kg/m³
- **Temperature** – °C / K

VISCOSITY

- Measure of the **resistance to motion** between two layers of the same material.

WING LOADING

- $$\frac{\text{Aircraft Weight}}{\text{Wing Area}}$$
- Unit: N / m²

LOAD FACTOR

- $$\frac{\text{Lift}}{\text{Weight}}$$

POF 2 – THE FLIGHT ENVIRONMENT

THE ATMOSPHERE

- A region of air surrounding earth up to approximately 500 miles / 900 km.
- Higher temperature allows air to hold more **water vapour**.
- Air has weight and is also **compressible**.
- Pressure, density and temperature all **decrease** with altitude.

HUMIDITY & DENSITY

- Water vapour is **less dense** than dry air.
- **Water vapour (ISA MSL) = 0.760 kg/m³**
- **Dry air (ISA MSL) = 1.225 kg/m³**

UNIVERSAL GAS LAW

- $\frac{P}{\rho T} = \text{Constant}$
- P = Pressure (N/m²)
- ρ = Density (kg/m³)
- T = Temperature (K)
- Only applies to a perfect gas.

PRESSURE & DENSITY

- **Density $\propto$ Pressure**
- Pressure doubled then density is doubled.

TEMPERATURE & DENSITY

- **Density $\propto 1 / \text{Temperature}$**
- Temperature doubled then density halved.

POF 4 – AIRSPEEDS

INDICATED AND TRUE AIRSPEEDS

- **Indicated (IAS)** – Shown on the ASI
- **Calibrated (CAS / RAS)**– IAS corrected for:
 - Position error (due to location of pitot head and static)
 - Instrument error (due mechanical workings of ASI).
- **Equivalent (EAS)** – CAS corrected for:
 - Compressibility Error (airspeeds greater than 300 kts).
 - Not applicable less than 300 kts as air assumed incompressible.
- **True (TAS)** – EAS corrected for:
 - Density error
- **ICE - T**

POF 3 – AIRCRAFT COMPONENTS AND TERMINOLOGY

DIHEDRAL VS ANHEDRAL

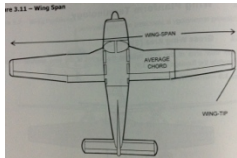
- **Dihedral** - Upwards
- **Anhedral** - Downwards
- **“Angle between the wing plane and the horizontal with the aeroplane in an unbanked level condition”** (Preferable answer)
- **“Angle between 0.25 chord line and the lateral axis”** (Next best answer if above not present)

WING AREA

- **Gross Wing Area** – Plan view area of the wing including the portion normally cut out to accommodate the fuselage.
- **Net Wing Area** – Area of the wing excluding the fuselage portion.

WING SPAN & AVERAGE CHORD

- **Wing Span (b)** – Straight line distance between the wing tips.
- **Average Chord (C_{AV})** – Mathematical average of the chord lengths.
- **Gross Wing Area (S) = Span (b) x C_{AV}**



MEAN GEOMETRIC CHORD

- Mean Geometric Chord = Wing Area / Span

ASPECT RATIO (AR)

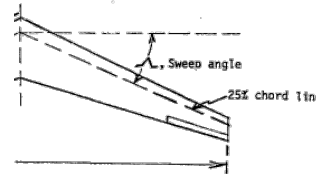
- High aspect ratio = Long and thin
- Low aspect ratio = Short and stubby
- **$AR = \text{Span} / C_{AV}$**
- **$AR = \text{Span}^2 / \text{Wing Area}$**
- **$AR = \text{Wing Area} / C_{AV}^2$**

TAPER RATIO

- C_T = Tip Chord
- C_R = Root Chord
- **Taper Ratio = C_T / C_R**

SWEEP ANGLE

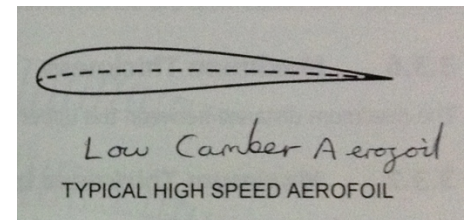
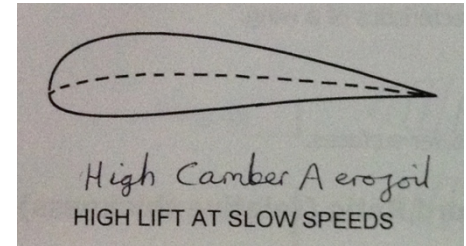
- **Angle between a line at 25% chord, root to tip, and a line perpendicular to the root chord.**



THICKNESS & MAC

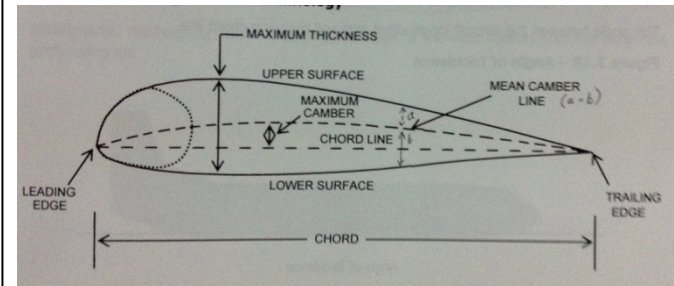
- **Thickness** of an aerofoil is expressed in % chord.
- **Thickness : Chord ratio** is the ratio of maximum thickness to the chord.
- **Mean Aerodynamic Chord** – Chord of a rectangular wing with same moment and lift

CAMBERED AEROFOILS



WING SECTION TERMINOLOGY

- **Chord Line** – Straight line joining leading and trailing edges of wing.
- **The Chord** – The length of the chord line.
- **Mean Camber Line** – Line equidistant between the upper and lower surface of an aerofoil.



POF 5 – LIFT

PRINCIPLE

- “Lift is generated when the **flow direction** of a certain mass of air is changed”

STREAMLINE / LAMINAR AIRFLOW

- Streamline flow exists when succeeding molecules follow a steady path.
- At any given point, the molecules will experience **the same velocities and pressure** as the preceding molecules.
- Narrow streamline spacing indicated an increase in velocity.

TURBULENT AIRFLOW

- When there is a sharp change in the direction of airflow and streamline airflow breaks down.
- At any given point, the molecules will experience **different velocities and pressure** compared to the preceding molecules.
- A.K.A **Unsteady / Eddying Flow**
- Results in **wasted energy**.
- Adds **drag**

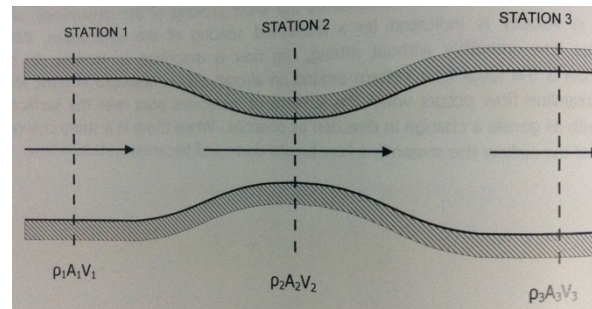
FREE STREAM AIRFLOW (FSA)

- Airflow that is far enough away from an aircraft to be unaffected by its presence.

EQUATION OF CONTINUITY

- Only applies to streamlined flow.
- Assumes airflow at speeds below M0.4 / 300 kts where air is **incompressible and density constant**.
- The mass of air entering the pipe in a given time will equal the mass of air leaving the pipe in the same time.**

$$\text{Mass Airflow} = A_1 V_1 = A_2 V_2 = A_3 V_3$$



EFFECT ON VELOCITY

- When cross sectional area reduces, the only way for the equation of continuity to hold true is if **velocity increases**.

DENSITY, PRESS AND TEMP RELATIONSHIP

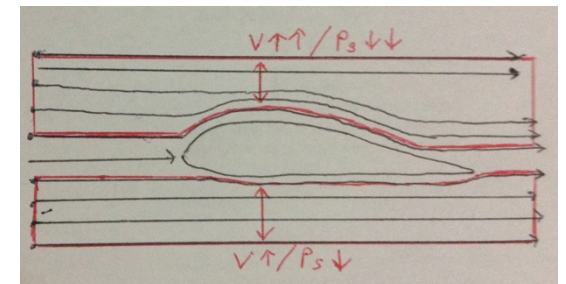
$$\frac{P}{\rho T} = \text{CONSTANT}$$

BERNOULLI'S THEOREM

- When fluid flows at a steady rate through a pipe, its total energy remains constant since energy cannot be created or destroyed.**
- Total Energy = Potential + Pressure + Kinetic
In terms of pressure (and negating potential)...
Total Pressure = Static + Dynamic
$$P_T = P_S + \frac{1}{2} \rho v^2$$
- As total pressure must remain constant, an **increase in velocity means static pressure must decrease**.

STATIC PRESSURE DIFFERENCE

- An aerofoil resembles a venturi either side with a smaller cross section on top compared with the bottom.
- Velocity decreases more on the top of the wing than on the bottom.
- Therefore, **static pressure drops more on the top of the wing**.
- Upwards force of lift** created by static pressure difference.



POF 5 – LIFT

WING ANGLE OF ATTACK

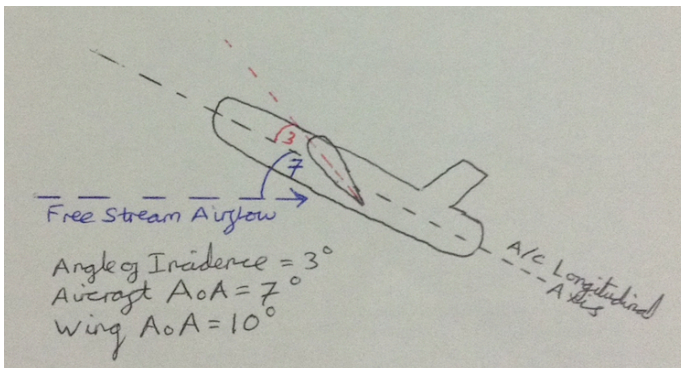
- Angle between the relative airflow and the chord line of an aerofoil.
- As the AoA increases, the cross sectional area between wing and FSA decreases, creating a bigger static drop and more lift.
- $\text{Wing AoA} = \text{A/C AoA} + \text{Incidence Angle}$

AIRCRAFT ANGLE OF ATTACK

- Angle between the longitudinal axis of the aircraft and the FSA.
- A.K.A. Angle between the speed vector and longitudinal axis.

ANGLE OF INCIDENCE

- Angle between the aircraft longitudinal axis and the wing chord line.
- This is fixed and will not vary.
- Allows the fuselage to remain level so less drag is generated.

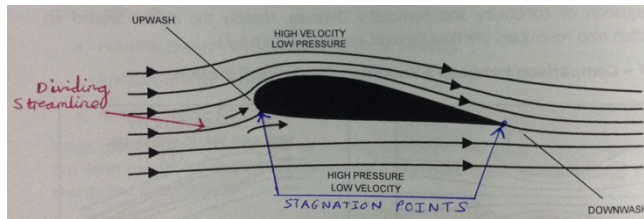


PITCH ANGLE

- Angle between the longitudinal axis of the aircraft and the horizontal.
- Can have the same AoA but difference pitch angles and vice versa.

DIVIDING STREAMLINE

- Separates the flow going over the top from the flow going underneath.
- Two stagnation points are created.
- Velocity at these points is zero.
- Static pressure is at its maximum which is equal to the total pressure (as total pressure must remain constant and dynamic = 0).

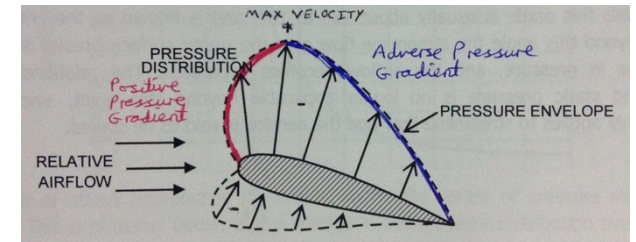


UPWASH AND DOWNWASH

- **Upwash** is where the air is deflected upwards before reaching the wing.
 - Due to pressure differential drawing the air locally upwards.
- **Downwash** is always a consequence of producing lift.
 - Faster moving airflow on top forces the lower streamlines downwards.

CHORDWISE PRESSURE DISTRIBUTION

- **Positive Pressure Gradient**
 - Velocity is increasing and static pressure getting larger.
 - Air is accelerated towards the point of max velocity.
- **Adverse Pressure Gradient**
 - Velocity decreasing and static pressure reducing.
 - Air wants to flow towards the point of max velocity due to pressure diff.
- Increasing AoA will move point of max velocity forwards towards leading edge.



ANGLE OF ATTACK (ASYMETRIC)

- $-4^\circ = \text{No Lift}$
- $16^\circ = \text{Stall}$

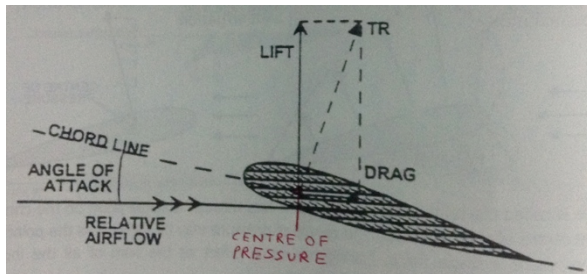
PROPRTION OF LIFT PRODUCTION

- The upper surface of the wing produces the greatest proportion of lift at all speeds.

POF 5 – LIFT

CENTRE OF PRESSURE

- The overall effect of the changes in static pressure can be shown by the **total reaction (T_R)**
- T_R acts through a single point on the chord line called the **centre of pressure (C_P)**
- Lift** – Component of T_R perpendicular to relative airflow.
- Drag** – Component of T_R parallel to relative airflow.
- As angle of attack increases (asymmetric):
 - C_P moves towards leading edge
 - T_R increases in magnitude



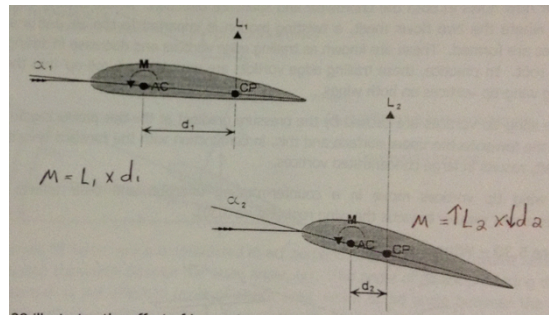
- Lift and drag forces depend on the pressure distribution about the wing cross section.

SYMETRICAL AEROFOIL

- At 0° AoA **no lift** is produced.
- The C_P **remains stationary** with an increase in AoA

THE AERODYNAMIC CENTRE

- A **fixed point** on the chord line at approx. **25% chord**.
- At normal AoA's, around this point **the pitching moment remains constant**.
- Lift creates a **pitch down** moment about the aerodynamic centre.
- When used as the point where the aerodynamic force is applied, AC helps to eliminate problem of CoP varying.

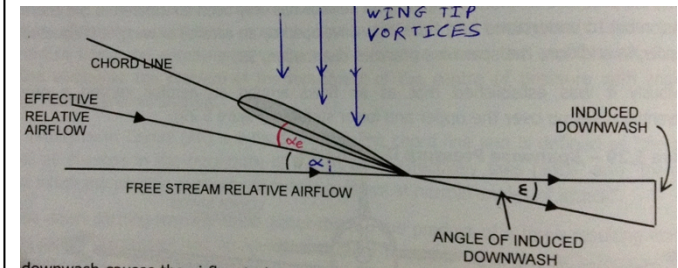


3D AIRFLOW

- Refers to **wingtips** and the **spanwise flow**.
- Lower surface = Spanwise flow root – tip
- Upper surface = Spanwise flow tip - root
- Due to pressure differential, **wingtip vortices** are created (counter-rotating).
- Trailing edge vortices** also created when lower surface air suddenly meets upper surface air.
- Both types decrease in strength from tip to root.

INDUCED DOWNWASH

- The net effect of the vortices is to **deflect the relative airflow**.
 - Deflects downwards at trailing edge
 - Deflects upwards at leading edge
- The resulting airflow at the leading edge is called the **effective relative airflow**.
- $\alpha = AoA$
- $\alpha_i = \text{Induced AoA}$
- $\alpha_e = \text{Effective AoA}$
- $\alpha_e = \alpha - \alpha_i$



INDUCED DRAG

- As lift remains perpendicular to relative airflow, it is **tilted aft and reduced in magnitude** as the AoA has decreased due to the effective relative airflow.
- The additional drag component created is known as **induced drag**.

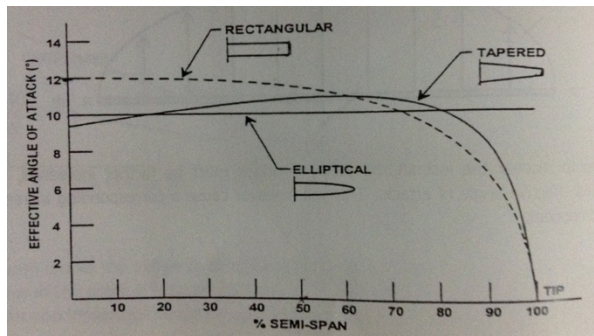
POF 5 – LIFT

DECREASING EFFECTIVE AoA

- Decreases lift
- Increases drag (due induced drag)
- Increases downwash
- As lift is increased, vortices are greater and the above effects are amplified.

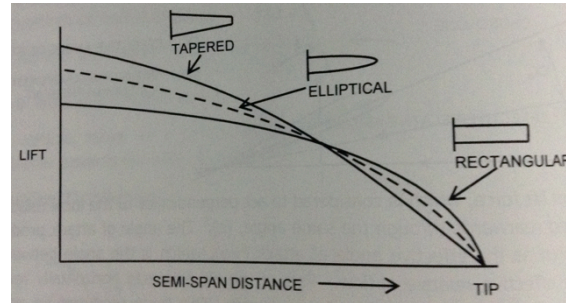
WING SHAPE AND EFFECTIVE AoA

- Rectangular wing produces much large vortex than a tapered section.
 - Wider tip chord allows more air to flow to upper surface.
 - Provides greatest lift at the root however.
- Elliptical has a constant effective AoA
 - Virtually no tip chord reduced vortices
 - Too expensive however



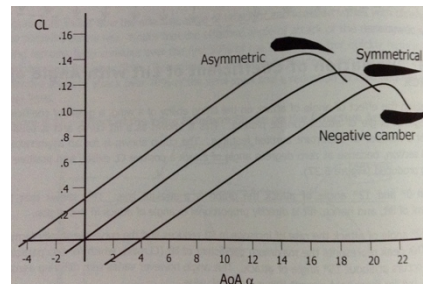
WING SHAPE AND TOTAL LIFT

- All wing types have a lift decrease from root to tip however.
 - Any reduction in wing tip vortices is offset by reduced area.



LIFT FORMULA

- $L = \frac{1}{2} \rho v^2 \times S \times C_L$
- Aerofoil shape and angle of attack amongst other factors are all combined to give to C_L
- As shape is fixed most changes to C_L in flight will be due to angle of attack.
- $C_{L_{max}}$ is reached at the **critical angle of attack**.



COMPONENTS OF LIFT FORMULA

- Variations in altitude affect the **density**.
- Variations in TAS affect **velocity**.
- S is mainly considered fixed.
- C_L mainly converts AoA into a usable figure for the lift equation. Includes most 'other factors.'

AIRSPEED EFFECT ON LIFT AND TAS

- ASI reading a constant airspeed during a climb means that dynamic pressure is constant.
- Lift is therefore constant (assuming no change in AoA).
- However, density must be reducing with altitude so velocity (TAS) will have to increase to keep P_D constant.
- Double IAS = Lift x4**

POF 5 – LIFT (FACTORS AFFECT C_L)

COMPRESSIBILITY

- **Air Compressible = Lift Reduced**
- Considering $A_1 \times \rho_1 \times V_1$ it can be seen that in the throat, density increases so there will be **less of an increase in velocity** to keep the constant.
- Static pressure therefore does not drop as much.

CAMBER

- **More Camber = More Lift**
- A negative camber provides downforce which is used on the elevator.

ASPECT RATIO

- **Higher AR = More Lift**
- A higher AR reduces the wing tip vortices and therefore increases lift.

SWEEPBACK

- **Higher Sweepback = Less Lift**
- Sweepback causes part of the airflow to flow parallel to the leading edge which does not produce lift.
- Performs better at high speed however (compensated at slow speed by HLDs)

LEADING EDGE RADIUS

- **Bigger Nose Radius = More Lift**
- Small nose radius can cause the flow to start to separate at the leading edge instead of the trailing edge.

REYNOLDS NUMBER

- **Large Reynolds Number = More Lift**

WHEN C_L = 0

- Symmetrical Wing = No Pitching Moment
- Positively Cambered = Pitch Down Moment
- Negatively Cambered = Pitch Up Moment

% OF C_{LMAX}

- **In straight and level flight at 1.3 V_S, the lift coefficient expressed as a percentage of C_{LMAX} is...**

$$\frac{1}{2} \rho 1.3V_S^2 S C_L = \frac{1}{2} \rho V_S^2 S C_{LMAX}$$

$$1.3V_S^2 C_L = V_S^2 C_{LMAX}$$

$$C_L = \frac{1}{1.3^2} C_{LMAX}$$

$$= 59 \%$$

POF 6 – DRAG

TOTAL DRAG

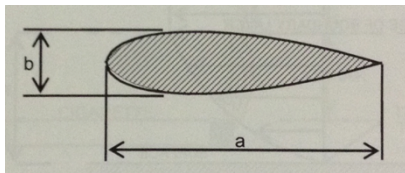
- **Parasite Drag** ($\propto IAS^2$)
 - *Form Drag (Fineness Ratio)*
 - *Skin Friction Drag (Boundary Layer)*
 - *Interference Drag (Connections)*
- **Induced Drag** ($\propto 1 / IAS^2$)

Form and skin friction can also be grouped into 'profile drag'

- Parasite Drag A.K.A **Zero Lift Drag**
- Induced Drag A.K.A **Lift Related Drag**

FORM DRAG

- A.K.A Pressure Drag
- Due to **turbulent airflow**
- For the same thickness, a longer object will produce less turbulent airflow.
- A higher **fineness ratio** (length to max thickness) will produce less form drag.

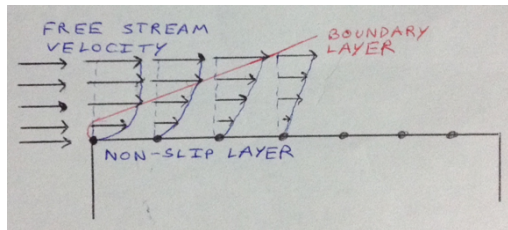


$$\text{Fineness Ratio} = \frac{a}{b}$$

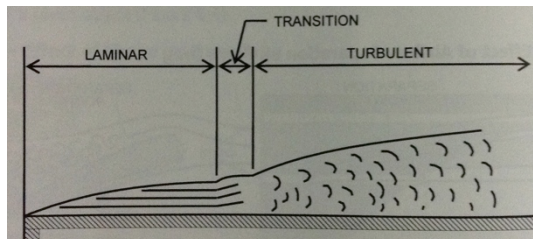
- An increase in AoA will reduce the fineness ratio (b increases and a decreases) and create more form drag.

SKIN FRICTION DRAG

- **Non-Slip Layer** - At the surface of a wing, air particles adhere to it and have zero velocity.
- As upper layers of air flow over this surface, they are slowed due to the viscosity of air.
- The reaction to retardation of the airflow is known as **skin friction** and it will try to drag the surface along with the flow.
- **Boundary Layer** - The layer of air between the surface and free stream velocity in which local retardation takes place.
- Boundary layer increases in thickness as you move rearwards over an aircraft wing.



- A **turbulent boundary layer** will create more skin friction drag than laminar layer.
- The change from laminar and turbulent is the **transition point**.



INTERFERENCE DRAG

- Total drag on an aircraft considered as a whole may be greater than the sum of the drags of the individual components.
- Airflow is disturbed where components are **joined together**.
- Mainly occurs between wing and fuselage.

INDUCED DRAG

- Result of **wing tip vortices**

$$D_i = \frac{1}{2} \rho v^2 S C_{Di}$$

$$C_{Di} = \frac{C_L^2}{\pi AR}$$

- As speed increases, C_L is reduced (due lower AoA) and hence C_{Di} decreases. Therefore, **induced drag decreases with an increase in velocity**. Specifically:

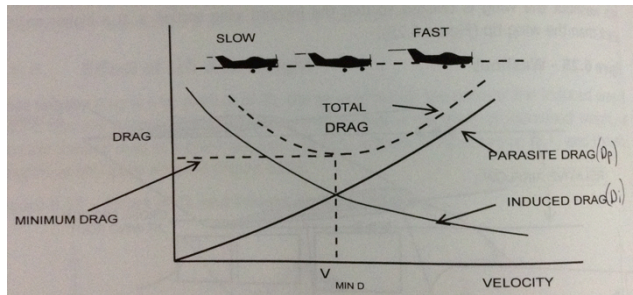
$$C_{Di} \propto \frac{1}{V^4}$$

- Induced drag can be **reduced** by:
 - Tapering
 - Wing Tip Modifications
 - Washout (Lower AoA at wing tip)
- Induced drag is greatest during takeoff where there is low airspeed requiring a high AoA.

POF 6 – DRAG

TOTAL DRAG

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



- At V_{MD} : $D_p = D_i$

DRAG AND ALTITUDE

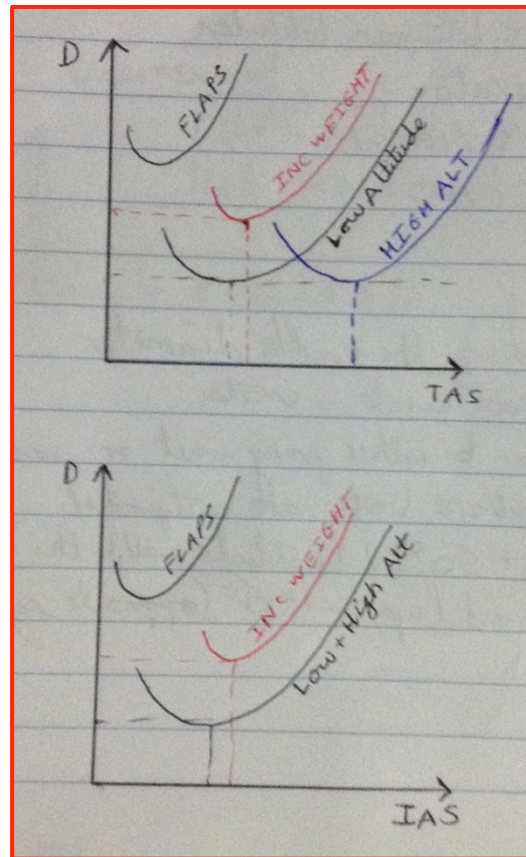
- At a higher altitude, you can fly faster for the same total drag.
- Pressure decreases so velocity increases.
- Shifts total drag curve to the **right**.
- Only affects D vs TAS as IAS is dynamic pressure so stays constant.

DRAG AND WEIGHT

- An increase in weight increases drag and speed.
- For the same AoA, V^2 must increase to maintain level flight.

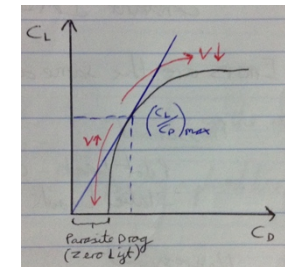
DRAG AND HLDs

- Used of HLDs increases drag and reduces speed.
- With an increased AoA, V^2 must decrease to maintain level flight.
- Flaps allow a lower AoA => Induced drag decreases but parasite increases.



LIFT TO DRAG RATIO

- "The needed lift for the minimum drag"
- $L / D = C_L / C_D$ (when $V = V_{MD}$)
- The most efficient AoA is about **3 / 4 degrees**.
- There is **only one speed** that will give this AoA which is V_{MD}
- If AoA is increased from $(C_L / C_D)_{MAX}$ a reduction in speed is required to maintain lift.



- An normal angles of attack, C_L is greater than C_D

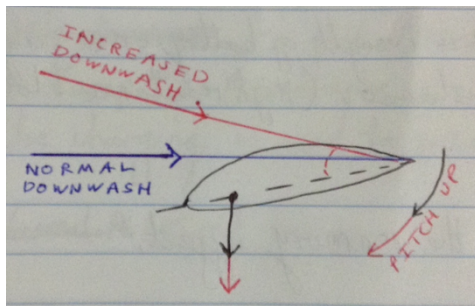
POF 8 – GROUND EFFECT

KEY FACTS

- Surface restricts the formation of **wing tip vortices**.
- **80% of induced drag** is lost during ground effect.
- Takes effect within a wingspan's length.
- Becomes **noticeable within $\frac{1}{2}$ wingspan**

INDUCED DRAG AND DOWNWASH

- When wing tip vortices occur, **downwash increases**.
- This causes the negative AoA to increase on the **tailplane**.
- This creates a **pitch up** moment.
- **Think: As downwash increases, someone sits on the tail.**



EFFECTS ON TAKEOFF

- Exit ground effect
- Wing tip vortices increase
- Effective AoA reduced
 - Lift decreases
 - Induced drag increases
 - Increased downwash = **Pitch up** tendency

* Aircraft should carry extra speed on takeoff in order to counter the decrease in lift when exiting ground effect.

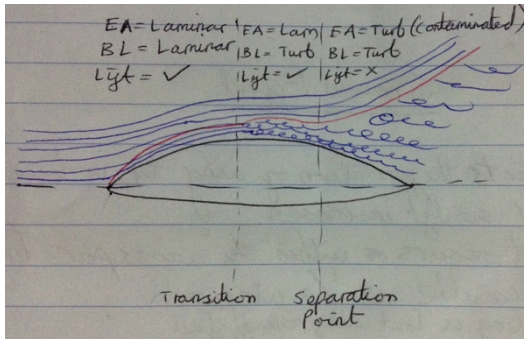
EFFECTS ON LANDING

- Enter ground effect
- Wing tip vortices decrease
- Effective AoA increased
 - Lift increased
 - Induced drag decreased
 - Reduced downwash = **Pitch down** tendency

POF - STALL

TRANSITION & SEPARATION POINT

- Move forward with increase in AoA and velocity.
- EA = External Airflow
- BL = Boundary Layer Airflow



STALL SPEED

- The minimum speed at which you're able to fly.
- $W = L = \frac{1}{2} \rho v_s^2 S C_{L_{Max}}$
- Increase weight = Increased stall speed

POF 9 - FIXED PITCH PROPELLOR

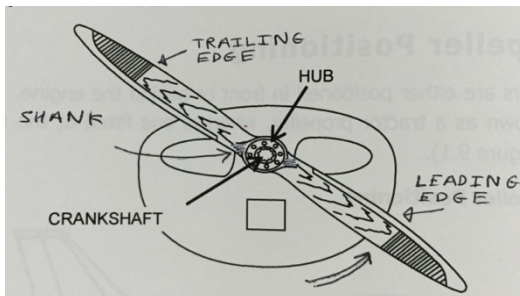
PURPOSE

- Convert power output from engine into thrust.

DIRECTION OF ROTATION

- As seen from cockpit.
- Anti-clockwise = Left handed prop
- Clockwise = Right handed prop

PROPELLOR ELEMENTS

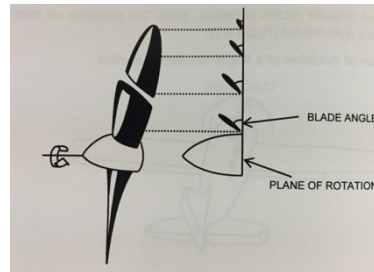


TERMS

- **Plane of Rotation** - 90° to crankshaft
- **Blade Angle** - Angle between chord line and plane of rotation.
- **Angle of Attack** - Angle between chord line and relative airflow.

PROPELLOR BLADE TWIST

- **Twisted along their length.**
- **Decreasing chord and depth of section** from root (hub) to tip.
- A **constant angle of attack** is maintained along the blade.

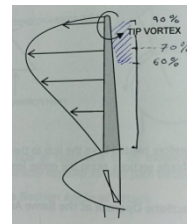


FINE VS COARSE PITCH

- Small blade angle = Fine pitch
- Large blade angle = Coarse pitch

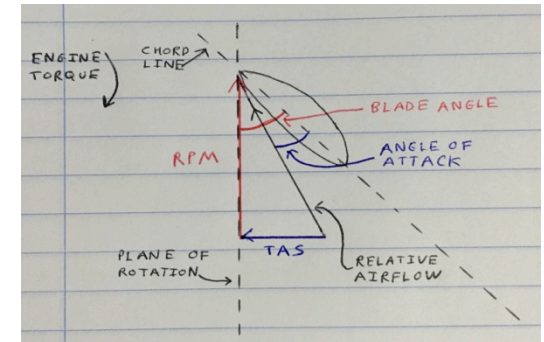
THRUST DISTRIBUTION

- Same AoA but greater TAS on tip leads to **thrust increase from root to tip.**
- **Tip vortices** however reduce thrust near to tip.
- **Reference pitch** is where max thrust occurs. This is at **70% of tip radius.**
- The **most effective area** of the prop blade for producing thrust is **60% - 90%**



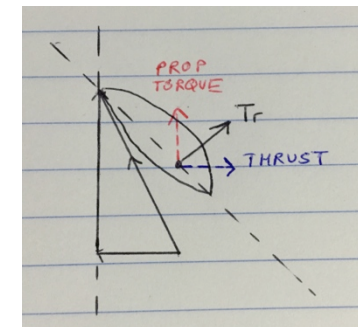
VELOCITY DIAGRAM

- Assumes a RH prop is about to descend.
- Since TAS is going backwards, we know **airflows** are being represented.



TOTAL REACTION

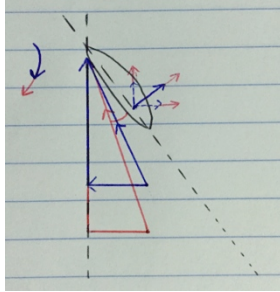
- **Prop Torque** - Act parallel to the plane of rotation. Opposes engine torque.
- **Thrust** - Parallel to direction of flight.



POF 9 – FIXED PITCH PROPELLOR

OPENING THROTTLE

- Engine Torque > Prop Torque = RPM Inc
- TAS remains constant
- AoA Increases

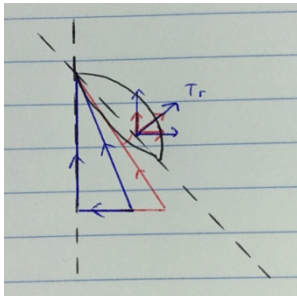


CLOSE THROTTLE

- Engine Torque < Prop Torque = RPM Decr.
- TAS remains constant
- AoA Decreases

TAS INCREASE

- Engine Torque = Prop Torque = RPM Const.
- AoA Decreases
- Since prop torque now less than engine torque, RPM will start to increase.



TAS DECREASE

- Engine Torque = Prop Torque = RPM Const.
- AoA Increase

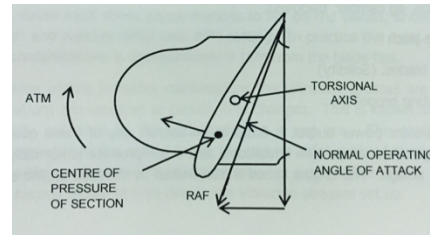
5 FORCES ON A PROP

1. CENTRIFUGAL TURNING MOMENT

- Tendency for blades to turn towards **fine pitch**.
- Due to centrifugal force.

2. AERODYNAMIC TURNING MOMENT

- Tendency for blades to turn towards **coarse pitch**.
- Due to centre of pressure acting ahead of the torsional axis.



3. CENTRIFUGAL FORCES

- **High stress** on propeller as blades are **pulled out of the hub**.

4. THRUST BENDING FORCES

- Will try to **bend blades forward** at the tips.
- Due to thrust loading.

5. TORQUE BENDING FORCES

- Prop blades **bent in direction opposite to their rotation**.

PROP EFFICIENCY

$$\text{Prop Efficiency} = \frac{\text{Thrust} \times \text{TAS}}{\text{Prop Torque} \times \text{RPM}}$$

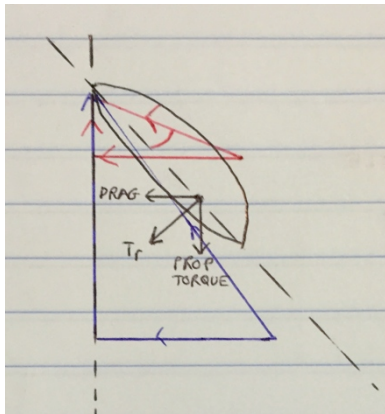
$$\text{Prop Efficiency} = \frac{\text{Thrust Horsepower}}{\text{Brake Horsepower}}$$

- Most efficient AoA = 3 – 4 degrees
- Brake horsepower aka shaft horsepower

POF 9 – FIXED PITCH PROPELLOR

WINDMILLING PROP

- Engine Lost
- Engine Torque < Prop Torque = RPM Decr.
- TAS Constant
- AoA decreases and becomes negative
- P torque now acts in plane of rotation and assists rotation.
- Drag opposes motion and has a decelerating effect.



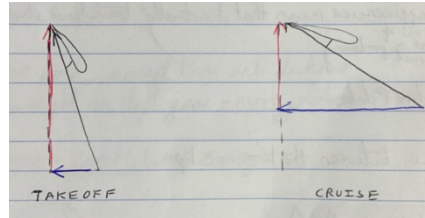
- A similar effect can result from significant increase in TAS with RPM constant.

FEATHERING PROP

- In order to **reduce drag** from a windmilling prop, the prop is set to **max coarse** setting.
- A windmilling prop has the highest drag.
- A feathered prop has the lowest drag.

FIXED PITCH & OPTIMAL AOA

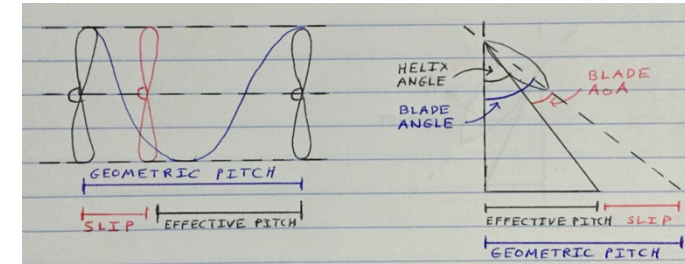
- During **takeoff**, a **fine pitch** is required to maintain the optimal AoA.
- During **cruise**, a **coarse pitch** is required to maintain the optimal AoA.



- With a FPP, it is only possible to operate at optimal AoA in one stage of flight.
- **Coarse setting is normally used on a FPP.**
 - Prevents windmilling prop when transition from takeoff to cruise.
 - RPM reduced and TAS increased.

EFFECTIVE PITCH

- **Geometric Pitch** is the distance a prop should **theoretically** travel using RPM and TAS calculation.
- **Effective Pitch** is the distance **actually** travelled by the prop due to propeller inefficiencies.
- **Slip = Geometric Pitch – Effective Pitch**
- **Helix Angle = Blade Angle – Blade AoA**
 - A.K.A Angle of Advance
- Slip $\propto$ Blade AoA
- Effective Pitch $\propto$ Helix Angle



POWER ABSORPTION

- **Ability of a propeller to absorb an engines power output.**
- Depends on the following factors:
 - Blade Size
 - Blade Section (Inc. camber = Better)
 - Blade Angle-pitch
 - Number of Blades (More = Better)
 - Contra-rotating props (overall torque reduced to more power can be transferred into RPM)

PROPELLER FATIGUE

- **Vibrations** in the blade can lead to the creation of **standing wave patterns**.
- Can cause **metal fatigue**.

PROPELLER ICING

- More likely to build up on **hub** due to lower rotational velocity.

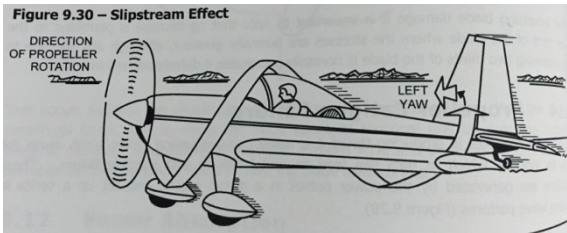
POF 9 - FIXED PITCH PROPELLOR

PROPELLOR EFFECTS

- Propellor Slipstream
 - Torque Reaction
 - Gyroscopic Effect
 - Asymmetric Blade Effect
- All 4 effects are present on all props during flight.
 - On takeoff, tailwheel aircraft experience all 4 but tricycle aircraft only the first 2.

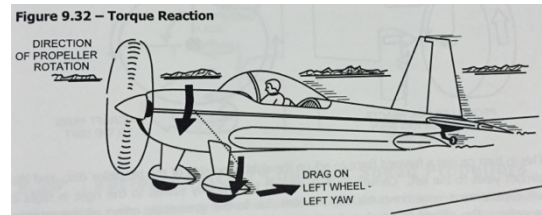
PROPELLOR SLIPSTREAM

- A clockwise prop will experience a left yaw.



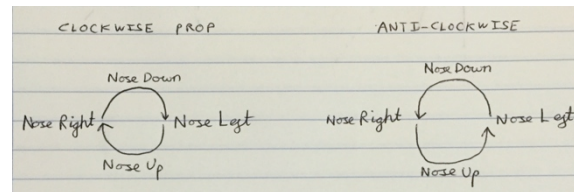
TORQUE REACTION

- With a clockwise prop, the airframe will be twisted anti-clockwise.
- More weight on the left gear leads to more drag on the left side and a left yaw is induced.



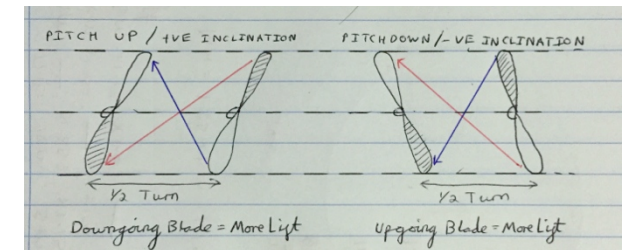
GYROSCOPIC EFFECT

- Once the tailwheel leaves the ground, a forward force is applied to top of the prop.
- Precession cause a nose left movement on a clockwise prop.



ASYMETRIC BLADE EFFECT (P-FACTOR)

- Affects taildragger on initial takeoff roll when the axis of rotation is inclined.
 - The **downgoing blade produces more thrust**.
 - Has a faster velocity due to further distance to travel.
 - A left yawing tendency is induced with a clockwise prop.
 - Effect increases with both an increase in AoA and RPM.
-
- In flight, pitch up = left yaw (RH Prop)
 - In flight, pitch down = right yaw (RH Prop)



POF 9 - VARIABLE PITCH PROP / CONSTANT SPEED PROP

CONTROLS

- Throttle = MAP
- Prop Lever = Blade Angle

PURPOSE

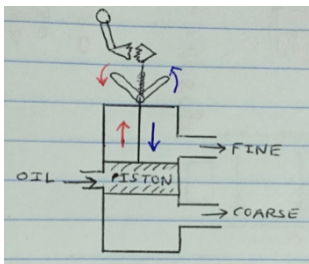
- The FPP only has an optimal AoA at one stage of flight.
- A CSP allows the optimal AoA to be maintained throughout all stages of flight.

GOVERNOR / CONSTANT SPEED UNIT

- Detects changes in RPM
- Corrects propeller torque (using pitch) to get to the desired RPM.
- In doing the above, the prop is kept operating at the most efficient AoA.
- Prop torque reverts to original amount (kept constant) once CSU has acted.

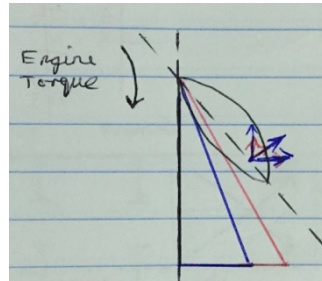
GOVERNOR OPERATION

- RPM Increase = Coarser Pitch (Red)
- RPM Decrease = Finer Pitch (Blue)



EXAMPLE - TAS INCREASE

- TAS Increases
- AoA Decreases
- Prop Torque Decreases
- Engine Torque > Prop Torque = RPM Inc
- Governor gives coarse pitch
- AoA Increases
- Prop Torque Increases
- RPM Constant



FEATHER OPERATION

- A windmilling prop can now be avoided.
- Blade angle is changed to achieve minimum drag.
- Feather position is normally in a fully back detent on prop lever.

PROP REVERSE

- A negative angle of attack can be set.
- Reverse position is normally in a fully forward detent on prop lever (towards fine pitch).

AOA & GOVERNOR

- To determine result of governor, look to see what happens to AoA. It will change blade angle as required to regain optimal AoA.
- **Increased AoA = Finer Pitch**
- **Decreased AoA = Coarse Pitch**

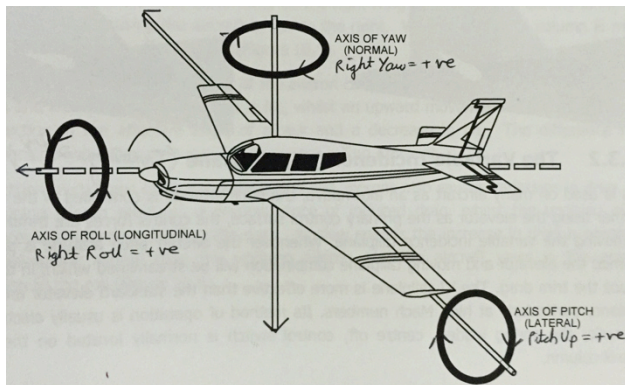
POF 10 – PRIMARY FLYING CONTROLS

OVERVIEW

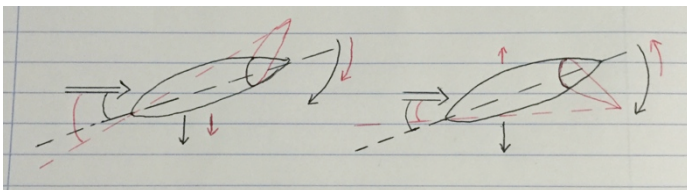
- **Primary** = Directly control attitude
- **Secondary** = Affect lift, drag and stick forces
- Force applied to the CoG = **translation**
- Force applied outside of CoG = **moment**

AIRCRAFT AXES

- **Positive direction** determined by pointing thumb in direction of axes. The fingers curl in the positive direction.



- If asked about what influences lateral control it is aileron movement about the longitudinal axis.



ELEVATORS

- **Primary Effect:** Pitch
- **Secondary Effect:** None
- The **tailplane** consists of a **stabiliser** and **elevator**.
- Tailplane provides a **default downforce** to counter the pitch down moment resulting from lift at the wings.
- CC Rearwards = **Elevators Up** = **Increased negative AoA** = Increased downforce causing a pitch up (around CoG).
- CC Forwards = **Elevators Down** = **Reduced negative AoA** = Decreased downforce causing a pitch down (around CoG).

STABILATOR

- An **all-moving tailplane**
- Same pitch angle can be achieved using **less deflection**.
- Less form drag produced
- Ideally suited to military (high-speed)
- Hydraulic power required to move it is very large however.

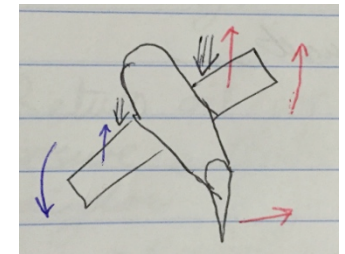
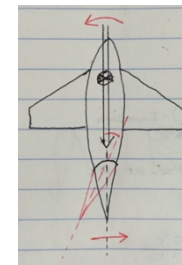


VARIABLE INCIDENCE TAILPLANE

- Most common in commercial aircraft.
- Compromise between tailplane and stabilator.
- **Trimming the stabilator** streamlines elevator changes, reducing trim drag.
- Jam at high IAS requires higher landing speed.
- Less sensitive to flutter.

RUDDER

- **Primary Effect:** Yaw
- **Secondary Effect:** Roll (To same side)
- Deflection left = Right force = Left Yaw
- Deflection right = Left force = Right Yaw
- With a left yaw, the relative airflow over the right wing increases.
 - More lift on right wing causes a roll to the left.
- Provides the directional control.



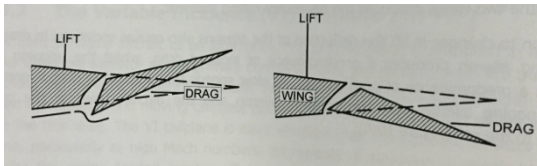
AILERONS

- **Primary Effect:** Roll
- **Secondary Effect:** Adverse Yaw
- Roll generated by increasing lift on one wing and decreasing it on the other.
- **Outboard ailerons** used for slow flight. Max moment is generated.
- **Inboard ailerons** used for high speed flight. Less moment required at faster speeds.
- Roll rate increases with altitude due to less aerodynamic damping.

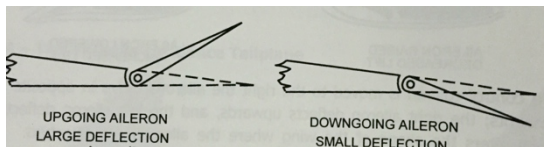
POF 10 – PRIMARY FLYING CONTROLS

ADVERSE AILERON YAW

- Increase in lift on **upgoing wing** gives greater wing tip vortices. This leads to **more induced drag**.
- The **downgoing wing** experiences **less induced drag**.
- There are a few different methods of reducing the effects to adverse aileron yaw.
- **Frise Ailerons**
 - Leading edge of the aileron on the downgoing wing is exposed beneath the wing.
 - Extra form drag is created to balance that induced on the upgoing wing.

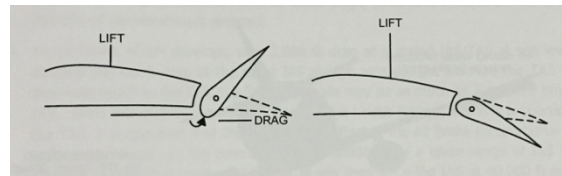


- **Differential Ailerons**
 - Upgoing wing is deflected less to less induced drag is created.
 - Downgoing wing is deflected more to increase form drag.
 - By doing so, the drag on both sides is equalised.



• **Frize / Differential Ailerons**

- Combination
- Upgoing wing deflected less
- Downgoing wing exposed
- Less form drag generated on downgoing wing --> more efficiency.



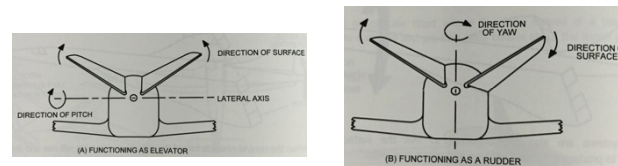
• **Rudder Coupled Ailerons**

- Rudder deflected automatically to provide a coordinated turn.

COMBINED SURFACES

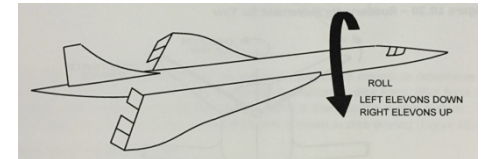
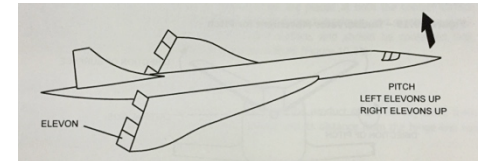
RUDDERVATORS

- Combined **rudder and tailplane**.
- **Symmetrical Deflection = Elevator**
- **Asymmetrical Deflection = Rudder**



ELEVONS

- Combined **elevator and ailerons**
- **Symmetrical Deflection = Elevator**
- **Asymmetrical Deflection = Aileron**



CANARDS

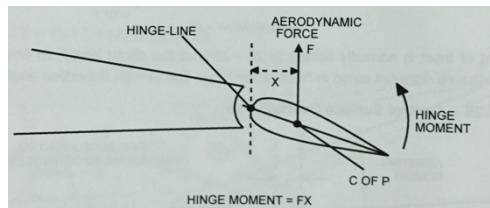
- Normally, the pitch down moment due to lift is countered by a downforce on tailplane.
 - This force essentially acts as weight and increases drag.
- Canards are positioned forward of the CoG and balance the pitch down with a lift force.
 - This is much more efficient

POF 10 – PRIMARY FLYING CONTROLS

AERODYNAMIC BALANCE

AERODYNAMIC BALANCE

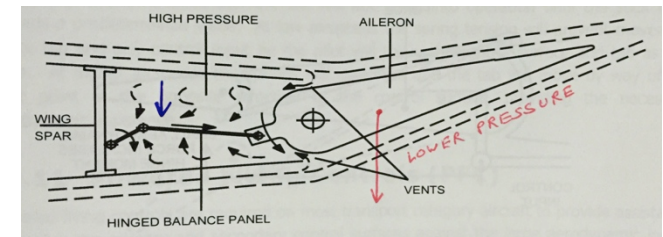
- A **hinge moment** is produced when a control surface is deflected.
- This acts to oppose the pilots input.
- If the hinge moment becomes too great, we need to reduce it in order to allow for easier deflection and lighter stick forces.
- Aerodynamic balance is about **managing stick forces for reversible controls**.
 - Irreversible controls are those in FBW aircraft where stick force do not matter.



- **Options for aerodynamically balancing:**
 - Inset Hinge
 - Horn Balance
 - Internal Balance
 - Balance Tab
 - Anti-Balance Tab
 - Servo Tab
 - Spring Servo Tab

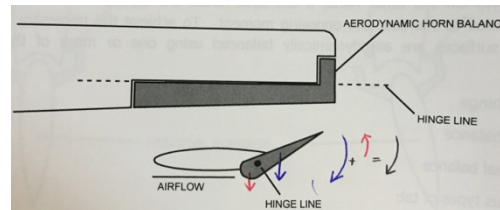
INSET HINGE

- Hinge line brought nearer to CoP.
- Hinge moment reduced => **Overall decrease in stick forces.**
- Must not move hinge line behind CoP or **reverse controls** will occur.



HORN BALANCE

- Horn deflected into the airflow **assists the intended deflection.**
- Hinge moment reduced => **Overall decrease in stick forces.**

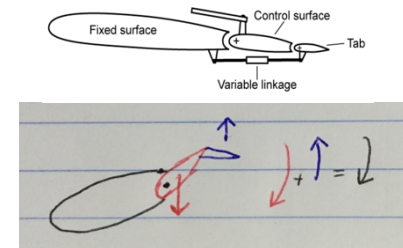


INTERNAL BALANCE

- **Hinge balance panel** divides the control surface into **two vented components**.
- Consider a elevator deflected up.
 - Lower pressure on bottom goes into lower compartment.
 - As pressure acts high to low, the hinge assists with the intended deflection.
- Hinge moment reduced => **Overall decrease in stick forces.**

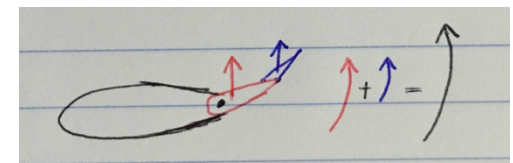
BALANCE TAB

- Acts in the **opposite direction** of control surface deflection.
- **Reduces stick forces**
- **Decreases control surface effectiveness** (less area used to generate lift)



ANTI - BALANCE TAB

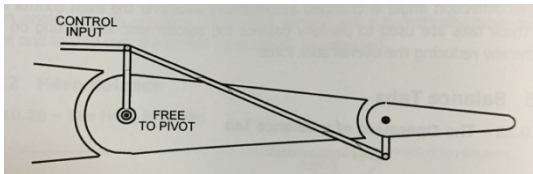
- Acts in the **same direction** of control surface deflection.
- **Increases stick forces**
- **Increases control surface effectiveness**
- Used when needed to prevent over control



POF 10 – PRIMARY FLYING CONTROLS

SERVO TAB (PILOT CONTROLLED)

- The servo tab is deflected initially which leads to deflection of the main control surface.
- Easier to deflect a small surface so **overall stick forces are reduced.**
- Overall control surface **effectiveness is reduced.**
 - At slow airspeeds, airflow passing over servo is insufficient to produce required hinge movement.
- Servo tab acts in **opposite direction** in control surface.
- If the elevator becomes jammed, reduced **inverted controls** are possible.



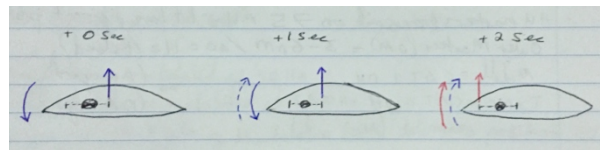
SPRING SERVO TAB (PILOT CONTROLLED)

- **Effectiveness increased at low speeds compared with the others.**
- At low speeds, servo and control surface act as one piece
 - Spring tension prevents tab movement
- At high speeds, servo is allowed to move and provides the necessary aerodynamic assistance.

FLUTTER AND MASS BALANCING

FLUTTER

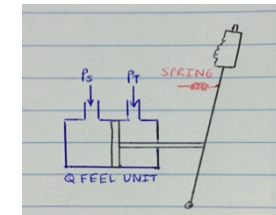
- Small variations in AoA cause the CoP to constantly move either side of the wings centre of gravity.
- **Aeroelastic resistance** will oppose the moment created by T_r acting through CoP
 1. Pitch down moment created
 2. Aeroelastic resistance acts with a slight lag but then prevents moment as required.
 3. When CoP switches side, the aeroelastic resistance still lags and there is now a resultant pitch up moment.
- As the CoP keeps switching sides, the **aeroelastic resistance amplifies the moment and flutter results.**
- Prevented by installing a **mass balance** to ensure CoP always stays the same side of control surfaces CoG.
- **Not required on hydraulically powered flight controls as the computers can prevent flutter.**



POWERED FLYING CONTROLS

POWERED FLYING CONTROLS

- **AKA “Irreversible Controls”**
 - No feedback from control surfaces to the stick so stick forces cannot become directly reversed.
- **Component 1 – Control Input System**
 - EG/ Stick or yoke
- **Component 2 – Power Control Unit**
 - EG/ Hydraulic Actuator
- **Component 3 – Artificial Feel System**
 - Spring type is good for low speed
 - Q Feel Unit is good for high speed



- Spring hydraulic Q feel unit is good for both.
- Here, the difference in pressure is used to control pressure in a **hydraulic actuator** which in turn creates artificial stick forces.

POF 11 - SECONDARY FLYING CONTROLS

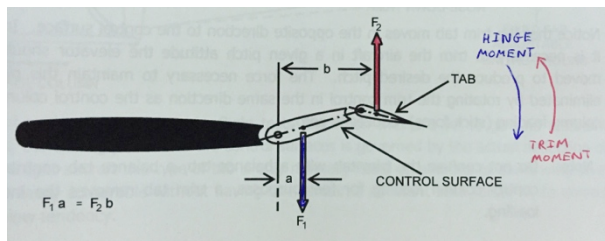
TRIMMING CONTROL SURFACES

TRIMMING PRINCIPLE

- Reduce stick forces to **zero**
- Unlike aerodynamic balance which is managing stick forces.

TRIM TAB

- Used on **reversible controls** including **power assisted controls**.
- Completely **controlled by the pilot** (unlike balance tabs)
- **Deflected in opposite sense** to the control surface.
 - Trim Wheel Back = Pitch Up Trim = Trib Tab Down
- Trim tab creates a hinge moment which exactly **balances the hinge moment** produced by a control surface.
- Due to the larger arm, a smaller force from the trim tab is required.
- Deflecting the trim tab to full nose up will decrease the nose up pitch authority.
- Trim tab only moves when trim wheel is moved.
- Trim tabs are not required on hydraulically powered flight controls.



FIXED TRIM TAB

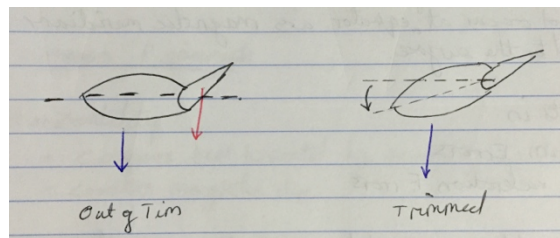
- Used to correct for slipstream on rudder or low wing tendency for example.
- Cannot be changed in flight.

STICK STABILITY

- Following trimming, stick stability remains unchanged.

STABILISER TRIM

- **Variable Incidence Tailplane / All Moving Tailplane**
- Used on **irreversible flight controls**
- Two main effects:
 - Reduced trim drag
 - Relieve loads on power control unit
- Deflecting the moving tailplane down increases the down force allowing the elevator to produce less force.
- **To pitch for trim up, move the tailplane down** (think align surfaces)
- **Trim runaway** more likely.
- **When trimmed:**
 - Power Assisted = Depends
 - Fully Powered = Zero Deflection



POF 11 – SECONDARY FLYING CONTROLS

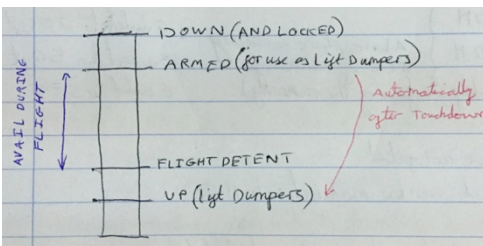
SPOLIERS

PURPOSE

- Reduce C_L
- Increase C_D

OPERATION MODES

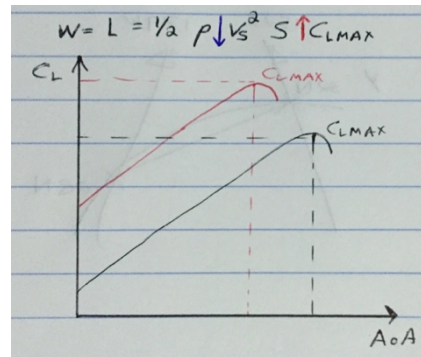
- **Speedbrakes**
 - Operated symmetrically during flight
 - Increase ROD and descent gradient
- **Roll Spoilers**
 - Used asymmetrically during flight
 - Operated automatically by a spoiler mix unit
 - Decrease C_L and increase C_D on the downgoing wing
- **Ground Spoilers / Lift Dumpers**
 - Symmetrically with max deployment
 - Deployed automatically by air / ground logic system (WoW + Idle throttle)
- Due to increase in parasite drag, V_{MD} will decrease when spoilers are deployed.



C_{LMAX} AUGMENTATION DEVICES

TRAILING EDGE FLAPS

- Increase effective angle of attack
- Increase camber
- Camber + Effective AoA Effect:
 - C_L increases
 - C_{LMAX} increases $\Rightarrow V_S$ Decreases
- Additional Effective AoA Effect:
 - Critical angle of attack decreases since it is now harder for air to flow smoothly over the surface.



EFFECT ON C_D & C_L

- Trailing edge flaps allow you to fly slower for the same lift.
 - This applies to all C_{LMAX} augmentation devices.
- At the same IAS and maintaining level flight, C_L remains constant.
 - Although C_L increases initially, to maintain level flight the AoA must be reduced.
 - With IAS constant, dynamic pressure is constant so C_L must remain constant in the lift equation.
- C_D increases
 - C_{Dp} (parasite) increases
 - C_{Di} (induced) decreases due to lower AoA

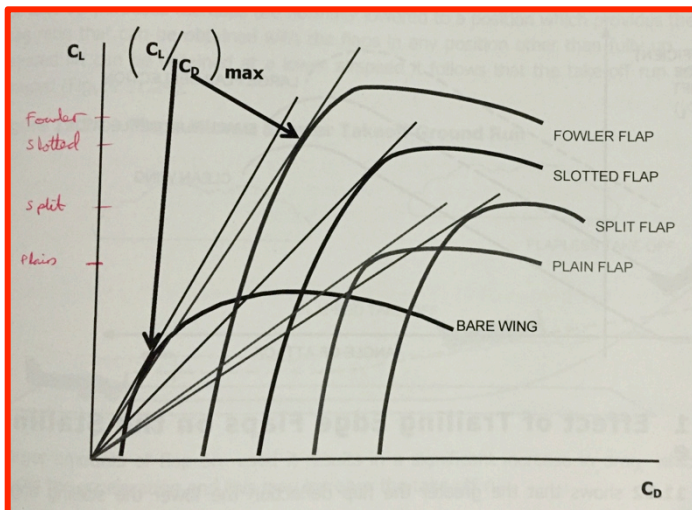
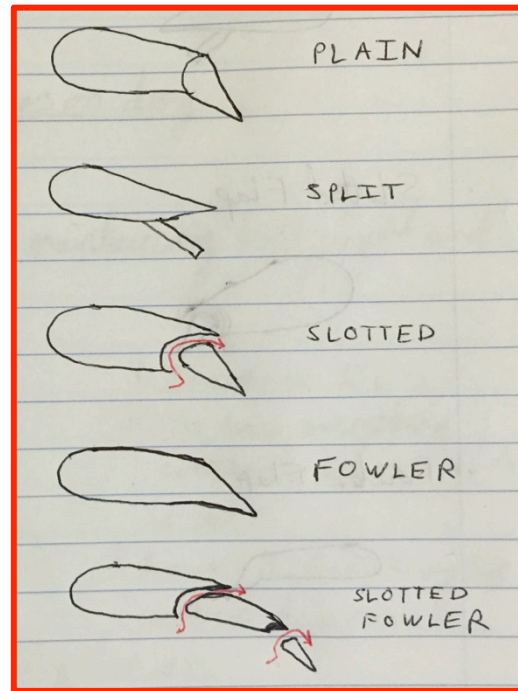
EFFECT ON ATTITUDE

- As flaps are deployed, the max camber moves aft.
- CoP moves back
- Pitch down moment increases

POF 11 - SECONDARY FLYING CONTROLS

FLAP TYPES

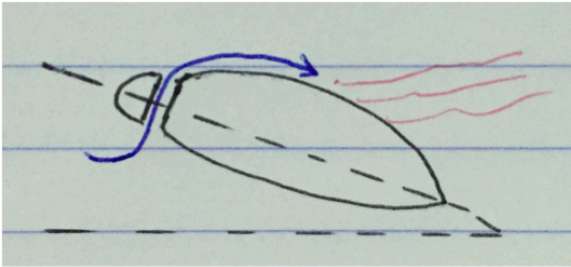
- **Plain Flap**
 - Datum Flap
 - Changes camber and AoA
- **Split Flap**
 - Higher Critical AoA
 - Higher Drag
 - Produces better lift at high AoA due to reduced boundary separation.
- **Slotted Flap**
 - Re-energises the boundary layer
- **Fowler Flap**
 - Increases surface
- **Slotted Fowler Flap**
 - Increases surface + re-energises the boundary layer



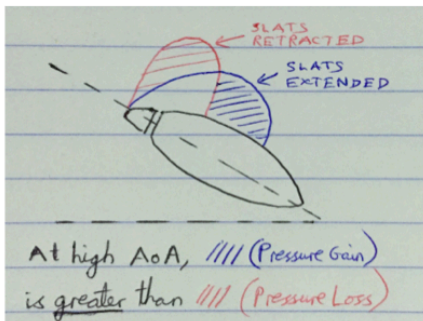
POF – TRANSPORT CATEGORY HIGH LIFT DEVICES

LEADING EDGE SLATS

- **Slot re-energises the boundary layer** and pushes the separation point aft.
- **Increases Critical AoA**
 - Smoother airflow possible



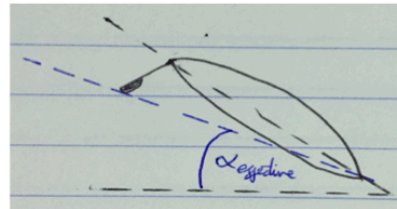
- At high AoA's a **stronger pressure distribution** results from deploying slats.
 - At low AoA's, there is no gain in the pressure differential.
- **Increases C_L & C_{LMAX}**



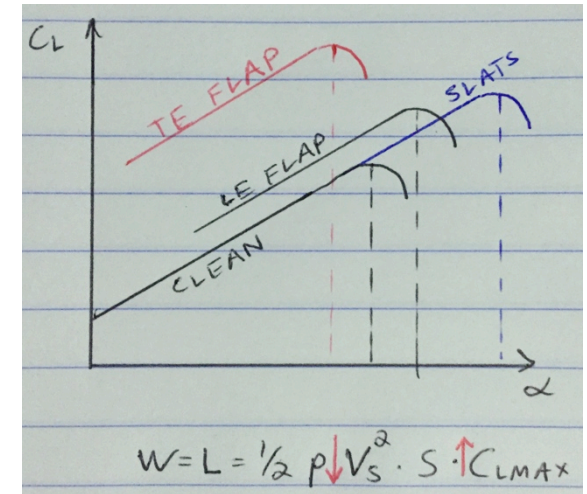
- Note that slats do not **change camber / surface**

LEADING EDGE FLAPS

- **Effective AoA Decreases**
- **Critical AoA Increases**
- **Increases Camber**
- **C_L & C_{LMAX} Increase**
 - Decreases stalling speed
- Can be either **drooped** or **kreuger design**.



SUMMARY OF C_{LMAX} DEVICES



RETRACTION / EXTENSION ORDER

- **Slats** always **extend first & retract last**
- Provides the greatest **safety margin** from the critical angle of attack.

FLAP PROTECTION

- **Asymmetry Protection**
 - Prevents one wing stalling leading to a spin.
- **Flap Load Relief**
 - At high speed, force of air will cause flap retraction.

POF 13 – FORCES IN STEADY STRAIGHT & LEVEL FLIGHT

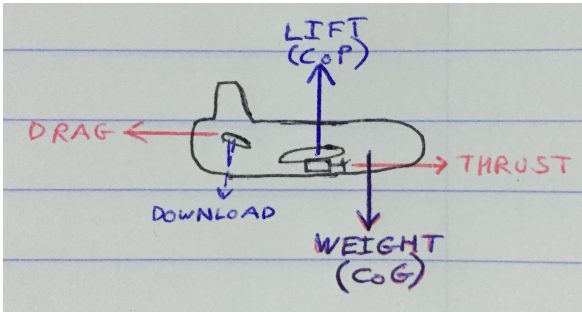
“STEADY STRAIGHT & LEVEL”

- **Steady** – Non Accelerated
- **Straight** – Flying in a straight line
- **Level** – Wings level

FORCE DIAGRAM

$$L = W (+ DL)$$

$$T = D$$



TRIM DRAG

- The download from the tailplane acts as extra weight.
- Extra weight means more lift required and hence more induced drag.
- This extra induced drag is known as **trim drag**.
- **Increases as CoG moves forward**
- **Canards** allow for zero trim drag.

LOAD FACTOR

- Load Factor = Lift / Weight
- In S & L flight, the **load factor is 1**

SPECIFIC RANGE (JET)

$$SR (Jet) = \frac{TAS}{Drag} \times \frac{1}{SFC}$$

$$SR = \frac{NM}{Kg (fuel)}$$

Division by time

$$SR = \frac{TAS}{FF (Fuel Flow)} \quad (1)$$

Given $SFC = \frac{FF}{THRUST} \quad (2)$

(2) → (1)

$$SR = \frac{TAS}{SFC \times THRUST} = \frac{TAS}{THRUST} \times \frac{1}{SFC}$$

In S & L, $THRUST = DRAG$

$$SR = \frac{TAS}{DRAG} \times \frac{1}{SFC}$$

AERODYNAMIC EFFICIENCY ENGINE EFFICIENCY

SPECIFIC RANGE (JET)

$$SR (Prop) = \frac{TAS}{Power Required} \times \frac{1}{SFC}$$

$$SR = \frac{NM}{Kg (fuel)}$$

Division by time

$$SR = \frac{TAS}{FF (Fuel Flow)} \quad (1)$$

Given $SFC = \frac{FF}{P_A} \quad (2)$ where $P_A = \text{Power Avail}$
 $P_R = \text{Power Req}$

(2) → (1)

$$SR = \frac{TAS}{P_A \times SFC} = \frac{TAS}{P_A} \times \frac{1}{SFC}$$

In S & L, $P_A = P_R$

$$SR = \frac{TAS}{P_R} \times \frac{1}{SFC}$$

AERODYNAMIC EFFICIENCY ENGINE EFFICIENCY

POF 13 – FORCES IN STEADY STRAIGHT & LEVEL FLIGHT

BEST ENDURANCE

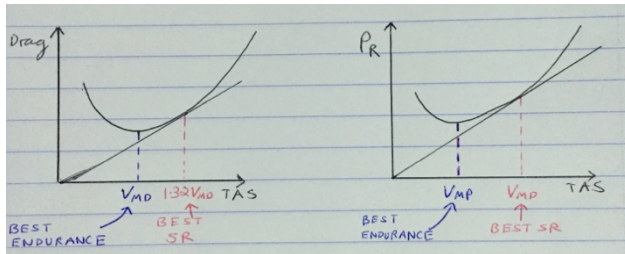
- The best endurance of an aircraft is found when the fuel consumption is least.
- For a **Jet aircraft**, this is at V_{MD}
- For a **piston aircraft**, this is at V_{MP}

BEST SPECIFIC RANGE

- The best specific range of an aircraft is a function of the aerodynamic efficiency.
- For a **jet aircraft**, this is achieved with the **best TAS/DRAG** ratio.
- For a **piston aircraft**, this is achieved with the best **TAS/Power Req** ratio.
- These speeds can be found via the tangent through the origin.

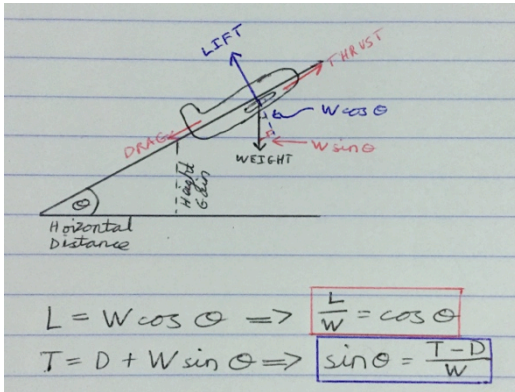
CURVES

- Note that the **Best SR speed is always greater than the best endurance speed.**



POF 14 - CLIMBING

FORCES IN A CLIMB



LOAD FACTOR

- It can be seen that the **load factor in a climb is less than 1.**
- Therefore, **lift is less than weight.**

CLIMB GRADIENT

$$\text{Climb Gradient \%} = \frac{\text{Height Gain}}{\text{Horizontal Distance}} \times 100$$

$$\text{Climb Gradient \%} = \tan \theta \times 100$$

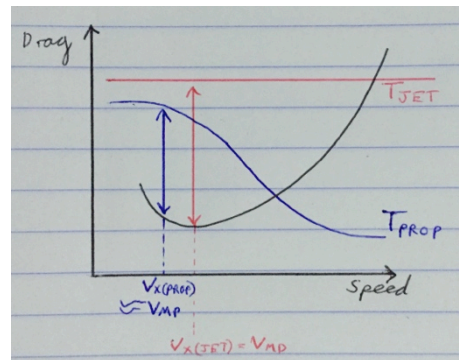
$$\text{At small angles: } \tan \theta = \sin \theta$$

$$\text{Climb Gradient \%} = \sin \theta \times 100$$

$$\text{Climb Gradient \%} = \frac{T - D}{W} \times 100$$

MAX CLIMB GRADIENT (V_X)

- It can be seen that the max climb gradient is obtained when $T - D$ is at it's largest value.
- Max climb gradient is therefore dependent on **excess thrust.**
- Jet** = V_{MD}
- Prop** $\sim V_{MP}$
- Jet curve is constant due ram recovery.
- Prop curve constant initially as blade angle increases then decreases when it can no longer compensate and AoA reduces.

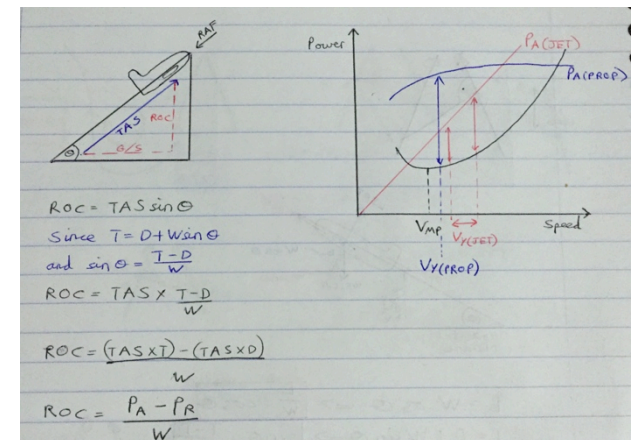


MAX RATE OF CLIMB (V_Y)

- TAS in a climb can be broken down into ROC and Groundspeed.
- Resolving the ROC component, it can be seen that:

$$\text{ROC} = \frac{P_A - P_R}{W}$$

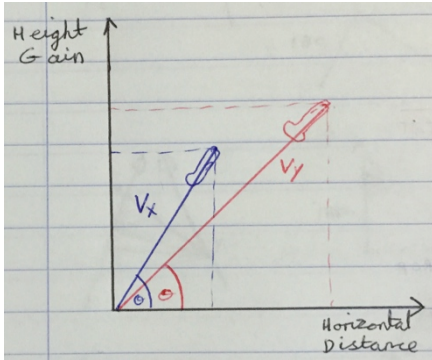
- Depends on **excess power.**
- Note that **V_Y is always greater than V_X**



POF 14 - CLIMBING

$$\frac{V_x}{V_y}$$

- A snapshot taken 5 minutes after departure shows that V_x is **preferable when obstacle clearance is required**.



CEILINGS

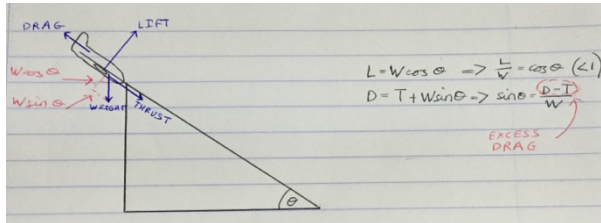
- **Absolute Ceiling** – When ROC = 0
- **Service Ceiling** – Altitude at which you have a given ROC.
 - Basically a safety margin from absolute
 - Normally 100 fpm in prop
 - Normally 500 fpm in jet

FACTORS AFFECTING CLIMB PERFORMANCE

- **“Climb Performance” refers to climb gradient and ROC.**
 - Performance is independent of the climb angle. A320 and C152 can have the same climb angle but very different performance!
- **Altitude**
 - Increase in altitude reduces the ROC and Gradient.
 - Thrust reduces and drag stays constant.
- **Weight**
 - Increase decreases ROC and Gradient
- **Wind**
 - Headwind increases climb gradient
 - Tailwind decreases climb gradient
 - No effect of rate of climb

POF 14 - DESCENDING

FORCES IN A DESCENT



MAX RATE OF DESCENT

- TAS in a climb can be broken down into ROD and Groundspeed.
- Resolving the ROD component, it can be seen that:

$$ROD = \frac{P_R - P_A}{W}$$

- Depends on **excess power**.

LOAD FACTOR

- It can be seen that the **load factor in a descent is less than 1**.
- Therefore, **lift is less than weight**.

DESCENT GRADIENT

- It can be seen the descent gradient depends on **excess drag (D - T)**

$$\text{Descent Gradient \%} = \frac{D - T}{W} \times 100$$

- This occurs at the highest possible speed with flaps, spoilers etc extended if possible (since it gives max parasite drag)

GLIDE RATIO

- Best glide ratio occurs when **L/D is max**.
- This occurs at V_{MD} which gives the optimal angle of attack.

$$\text{Glide Ratio} = \frac{L}{D} = \frac{\text{Range}}{\text{Initial Height}}$$

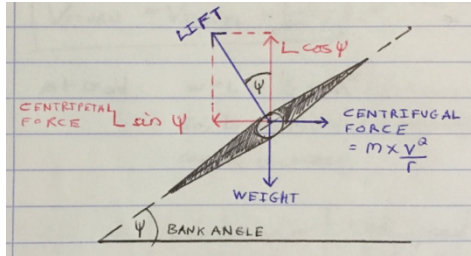
BEST RANGE SPEED VS ENDURANCE SPEED

- Like the climb, the **endurance speed is always less than the speed for best range**.

	Glide Ratio Changes	Incr. Weight	Wind		AoA		Speed		Flaps
			Head	Tail	↑	↓	$> V_{MD}$	$< V_{MD}$	
Range (Distance Travelled)		-----	↓	↑	↓		↓		↓
Endurance (Time In Air)		↓	-----						

POF 16 - TURNING

FORCES IN A TURN



LOAD FACTOR

- In order to turn, lift is deflected from the vertical so there is a **horizontal component (centripetal force) that results in a turn.**
- In doing so however, a vertical component of the lift that was balancing the weight has been removed.
- In order **to maintain altitude, an increase in lift is therefore required.**
- Since lift is greater than weight, the **load factor in a turn is greater than 1.**
- This can be seen from balancing the vertical component of the forces to give:

$$L \cos \psi = W$$

$$\frac{L}{W} = \frac{1}{\cos \psi}$$

STALL SPEED IN A TURN

- If flying at the critical angle of attack and we enter a turn, lift must be increased to maintain constant altitude.
- If C_{LMAX} cannot be increased any further, the only way of achieving the required additional lift is by increasing the stall speed V_s

$$W = \uparrow L = \frac{1}{2} \rho \uparrow v_s^2 \cdot S \cdot C_{LMAX}$$

- The stall speed in a turn can be calculated from:

$$V_{STURN} = V_{SLEVEL} \times \sqrt{\frac{1}{\cos \psi}}$$

TURN RADIUS

- Once the horizontal component of lift has been displaced into the turn, an equal and opposite force is required to prevent further acceleration and allow a constant radius turn.
- Therefore, to achieve a constant radius turn, **centripetal force must be equal to the centrifugal force.**

$$r = \frac{TAS^2}{g \times \tan \psi}$$

- $g = 10 \text{ m/s}^2$
- To convert kts $\rightarrow$ m/s, divide by 2

EFFECT OF MASS ON TURN RADIUS

- Increasing mass will have **no effect** on the turn radius as it is independent of mass.
- When considering the **minimum turn radius** however, the **radius will increase with an increase in mass.**
- This occurs since the minimum radius is achieved when TAS is smallest $\Rightarrow$ at V_s
- Since, V_s increases with an increase in mass however, the minimum turn radius will increase.

$$r_{min} = \frac{v_s^2}{g \times \tan \psi}$$

OVERBANKING AND UNDERBANKING

- In a **turn at constant altitude, there is a tendency to overbank** since the outside wing travels at a faster speed, thus producing more lift.
- In a **climbing turn, there is tendency to overbank.**
- In a **descending turn, there is tendency to underbank.**

POF 17 - STALLING

CRITICAL ANGLE OF ATTACK

- **At the critical angle of attack:**
 - Lift = Weight
 - C_L is maximum
- **After the critical angle of attack:**
 - C_L reduces and drag increases.
 - Lift can no longer pay for weight and the aircraft is stalled.

STALL SPEED DEFINITION

- **The minimum CAS at which the aircraft is controllable.**

WEIGHT AND STALL SPEED

- **As weight is increased**, more lift is required. If at C_{LMAX} it cannot be increased any further so **V_s must increase.**
 - $W = L = \frac{1}{2} \rho \uparrow v_s^2 s C_{LMAX}$

$$V_{S2} = V_{S1} \times \sqrt{\frac{W_1}{W_2}}$$

CG POSITION & STALL SPEED

- **As the CoG moves forward, V_s increases.**
- Has the same effect as increasing weight since more downforce is required

HLDs & STALL SPEED

- **Increases $C_{LMAX} \Rightarrow V_s$ decreases** to maintain the same amount of lift.

POWER & STALL SPEED

- **Increased Power = Decreased Stall Speed**
 - When at critical AoA with power on, a component of weight is being supported by thrust.
 - Since lift required to maintain level flight is now decreased, the stall speed can be decreased.
 - $\downarrow W = \downarrow L = \frac{1}{2} \rho \downarrow v_s^2 s C_{LMAX}$
- Increasing power also **increases the critical angle of attack.**
 - Boundary layer is re-energised

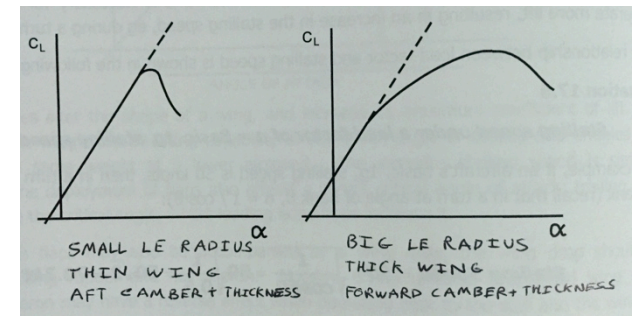
MANOEUVERS & STALL SPEED

- "Maneuver" = Load Factor (n) > 1 $\Rightarrow$ Turn
- If lift required increases at critical angle of attack, stall speed must increase.
 - $W = L = \frac{1}{2} \rho \uparrow v_s^2 s C_{LMAX}$

$$V_{S2} = V_{S1} \times \sqrt{\frac{n_1}{n_2}}$$

WING SECTION & STALLING CHARACTERISTICS

- A small leading edge radius = abrupt stall
- A big leading edge radius = smooth stall
- Aft positions of max camber and thickness will also lead to a more abrupt stall (i.e. Flaps)



CP POSITION

- CP normally moves forward with increasing angles of attack.
- **Up to and above the critical angle of attack, CP moves after to approx. 50% chord.**

POF 17 - STALLING

3D STALL

STALL REGOGNITION (BUFFET)

- If the wing planform results in the wing stalling from root – to – tip, buffet provides an indication of impending stall.
- The separation point moves forward and **turbulent airflow flows back over the elevators producing buffet.**

EFFECT OF PLANFORM

Rectangular Wing (Good Behaviour)

- Stalls root-to-tip
- CP moves aft
- Good controllability
- Good pre-stall warning (buffet)

Elliptical Wing (Poor Behaviour)

- Whole wing stalls at once
- CP moves aft
- Poor controllability
- Less pre-stall warning (buffet)

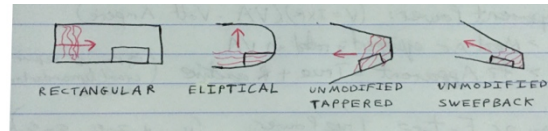
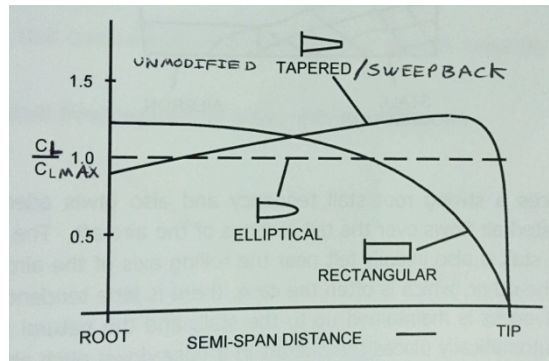
Unmodified Tappered (Worst Behaviour)

- Stalls tip - root
- CP moves aft
- Poor controllability
- No pre-stall warning (buffet)

Unmodified Sweepback

- Same as tapered but CP moves forward!
- This decreases the pitch down moment so a pitch up tendency at the stall results.
- This is very bad for stall recovery!

EFFECT OF PLANFORM



TIP STALL ALLEVIATION

TIP STALL ALLEVIATION

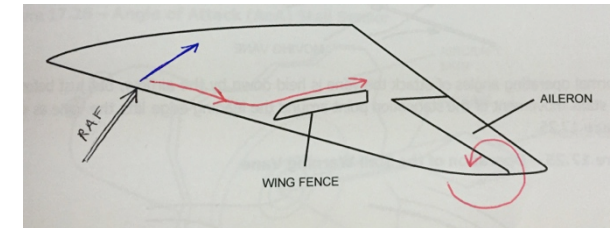
- For planforms where the tip stalls first, various methods can be used to alleviate this problem.

WASHOUT

- Wing is twisted so **the root has a higher angle of attack.**
- This results in the root reaching critical angle of attack before the tip.

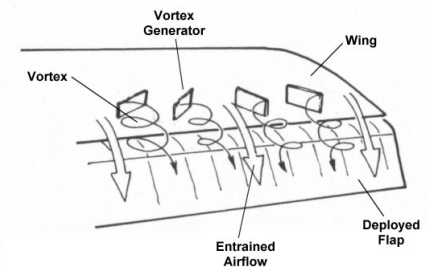
WING FENCES

- For sweptback wings, a portion of the relative airflow will flow along the top of the wing towards the tip.
- This opposes the natural tip-root flow on the upper surface which will reduce wing tip vortices and increase the effective angle of attack at the wing tip.
- Therefore, wing fences are installed to **prevent opposition to the tip – root airflow.**



VORTEX GENERATORS

- Vortex generators **re-energise the boundary layer close to the wing tips.**



POF 17 - STALLING

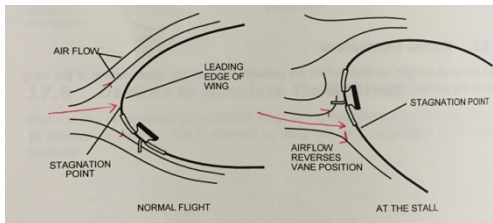
STALL WARNING

AERODYNAMIC WARNINGS

- **Buffet & stick shaking**
- Only noticeable on **reversible controls**

STALL WARNING DEVICES

- **Stall Warning Vane**
 - Based on the movement of the stagnation point causing the vane to be lifted when close to the critical angle of attack.

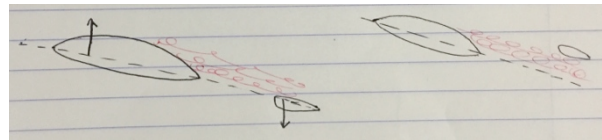


- **Stall Strip**
 - Causes a premature separation at the root, thus giving an earlier buffet.
- **Stall Angle of Attack Sensor**
 - Warns when near critical angle of attack
- **Stick Shaker**
 - Activates when the speed reaches $1.05 V_S$ or $V_S + 5$ kts
- **Stick Pusher**
 - Physically prevents exceeding a given angle of attack

TYPES OF STALL

SUPER STALL / DEEP STALL

- Occurs when a **pitch up moment occurs at the stall.**
- Impossible to recover from.
- A **high unmodified swept back** wing has a pitch up moment due to the CP moving forward.
- A **T-Tail aircraft** has a pitch up moment since airflow is disturbed over the bottom of the tailplane thus reducing the pitch down moment normally produced.



ACCELERATED STALL / G-STALL

- Occurs at **load factors > 1**
- This results in a **higher stall speed** and therefore an accelerated stall.

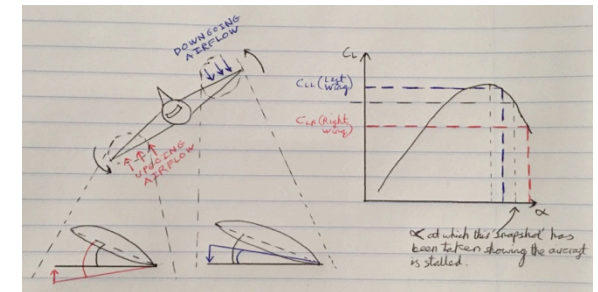
STALL RECOVERY TECHNIQUE

- Neutral Controls
- Increase Power
- Slowly Pitch-Up

TYPES OF SPIN

INCIPIENT SPIN (ASYMETRIC STALL)

- Occurs when there is **wing drop at the stall.**
- The effect of the wing drop will be for the angle of attack to increase further on the dropped wing due to upgoing airflow and decrease on the upgoing wing.
- As a result, the downgoing wing becomes more stalled and the upgoing wing less stalled.
- This **induces a rolling moment towards the downgoing wing.**

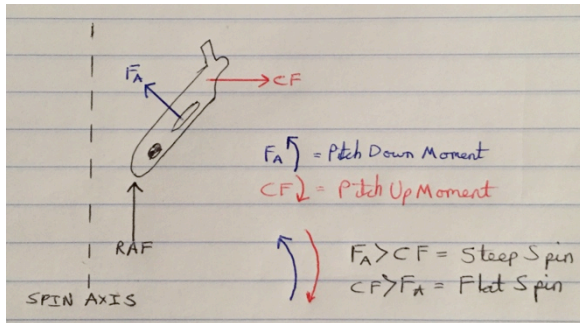


- **Recovery is achieved by:**
 - Neutral Controls
 - Rudder is direction of higher wing
- Ailerons cannot be used as they will intensify the rolling moment.
- Yaw is used to firstly stop the rotation.
- The secondary effect of yaw is roll that will act to level the wings.
- Failure to correct the incipient spin can lead to the fully developed spin.

POF 17 - STALLING

FULLY DEVELOPED SPIN

- If the incipient spin is left uncorrected, the aircraft will eventually settle in a rotation about a spin axis with **a steady rate of rotation and sink.**
- The balance between the aerodynamic force moment and the centrifugal force moment will determine whether the spin is steep or flat.
- If the aerodynamic force moment is greater than the centrifugal moment = Steep Spin
- If the centrifugal moment is greater than the aerodynamic force moment = Flat Spin



- **Effect of CG**
 - Forward CG = Steep Spin (Good)
 - Aft CG = Flat Spin (Bad)
- **Effect of Power**
 - Low Wing Engine = Flatter Spin
 - High Wing Engine = Steeper Spin
- **Recovery Technique**
 - Neutral Controls
 - Reduce Power Slightly (Low Wing Engine)
 - Rudder in direction of higher wing

POF 18 - STABILITY

WHAT IS STABILITY?

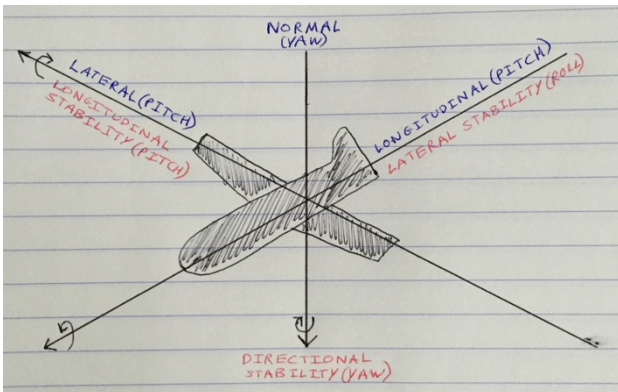
- The built-in tendency of an airplane to **return to its trimmed condition**.
- The 'trimmed condition' refers to:
 - Attitude
 - Stick Forces
 - Speed
- **Stability is the opposite of controllability**

DISTURBANCE

- A disturbance is **anything that tries to take the aircraft out of its trim condition**.
- Disturbance can be due to:
 - Change in airflow
 - Pilot Input

STABILITY AXIS

- Longitudinal stability can be observed by sitting on the lateral axis etc

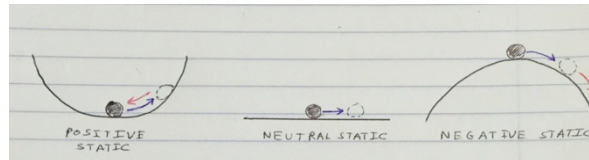


TYPES OF STABILITY

- **Static Stability** – The aircraft's first reaction
- **Dynamic Stability** – Reaction with time

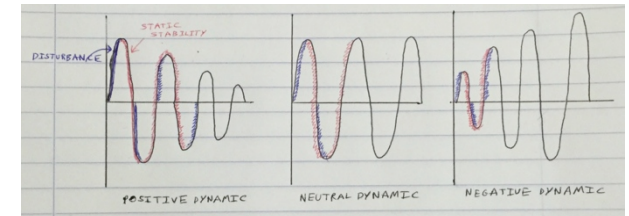
STATIC STABILITY

- **Positive Static Stability / Statically Stable**
 - First reaction tries to return object to its original position.
- **Neutral Static Stability**
 - There is no first reaction
- **Negative Static Stability / Statically Unstable**
 - First reaction causes further deviation



DYNAMIC STABILITY

- **Positive Dynamic Stability**
 - Static stability creates an overshoot which is sensed as another disturbance.
 - A further static stability reaction occurs
 - Over time, static stability causes the disturbance to reduce.
- **Neutral Dynamic Stability**
 - Disturbance remains the same over time
- **Negative Dynamic Stability**
 - Disturbance amplified over time
- **+ ve Static Stability allows for:**
 - Positive, Neutral or Negative Dynamic Stab
- **Neutral Static Stability allows for:**
 - Neutral Dynamic Stability
- **-ve Static Stability allows for:**
 - Negative Dynamic Stability

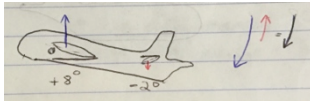
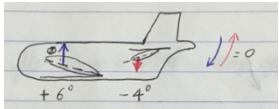


POF 18 - STABILITY

LONGITUDINAL STABILITY

LONGITUDINAL STABILITY

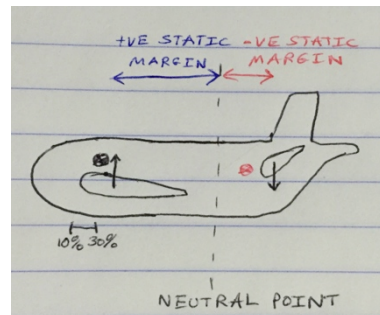
- About the **lateral axis**
- Responsible Structure: **Horizontal Stabiliser**
- In straight and level flight, pitch down moment from wings and pitch up moment from tailplane balance.
- When displaced into a positive attitude, the wing angle of attack increases and the tailplane angle of attack reduces.
- Wing pitch down moment increases and tailplane pitch up moment decreases.
- Net effect is a pitch down moment to restore aircraft to its trimmed condition.



- Longitudinal Dihedral**
 - Difference between the angles of incidence of the wing and tailplane.
 - This results in longitudinal stability.

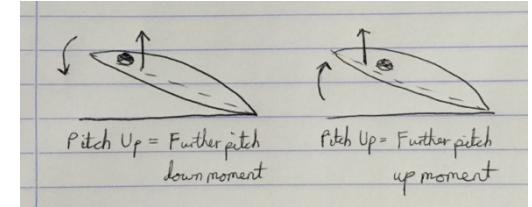
CG POSITION

- Since moment is the force x distance from CG, it can be seen a change in the CG position will affect the tailplane moment more since it is further from the CG.
- Forward CG = Increased Stability**
 - Arm increased => Tailplane moment increased
- Aft CG = Decreased Stability**
 - Arm decreased => Tailplane moment decreased
- Neutral Point**
 - The CG position resulting in neutral static stability
 - This the aerodynamic centre of the aircraft
 - Stability can also be referenced to the neutral point
- Static Margin**
 - Distance of CG from neutral point
- + ve Static Margin = Stable**
- ve Static Margin = Unstable**
- Typically the CG varies between 10% - 30% of the MAC and so is **always on the stable side**.



CP POSITION

- CP forward of CG = De-stabilising Effect**
- CP aft of CG = Stabilising Effect**



TAILPLANE DESIGN

- Any factor which leads to an increase in the horizontal stabiliser moment will increase stability.
- Stability therefore increases with:**
 - Increased negative camber
 - Increased thickness
 - Increased area
 - More negative incidence angle
 - Sweepback (Increases arm. Small tailplanes however may result in a bigger decrease in lift than gain in arm)

POWER

- High Wing Mounted = Stabilising Effect**
- Low Wing Mounted = Destabilising Effect**

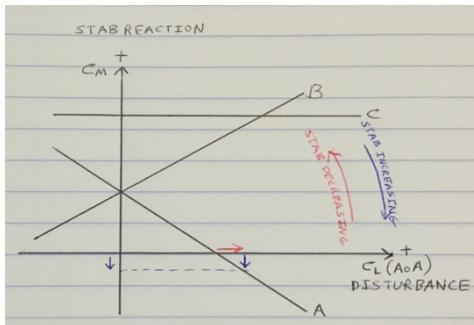
ALTITUDE

- Increased Altitude -> Decreased Aerodynamic Damping -> **Decreased Stability**

POF 18 - STABILITY

STABILITY GRAPH

- Considering the curve A for example:
 - When the AoA is increased, the stability reaction is a pitch down moment.
 - Therefore, positive stability exists.
- A = Stable
- B = Unstable
- C = Neutral
- Steeper negative gradient = more stable
- Steeper positive gradient = more unstable



ELEVATOR POSITION

- When the elevator is deflected, the **stability curve is shifted**.
- Assume moments originally balance at zero degrees of AoA.
- Upwards elevator deflection will cause downforce on tail to increase and lift from wing to increase as well.
- The tailplane AoA gradually reduces as the pitch attitude increases and thus the downforce from tail begins to gradually reduce.
- Eventually, the pitch down moment from tail equals the pitch up moment from wing and a new 'stable AoA' is achieved.
- If the new AoA is 5 degrees, the graph intercept now occurs at 5 degrees instead of zero.

LONGITUDINAL DYNAMIC STABILITY

- Long Period Oscillation (Phugoid / 1st Mode)**
 - Occurs over 20 – 100 seconds
 - Caused by horizontal disturbance in speed (headwind / tailwind gust)
 - Results in an airspeed change
 - No change in angle of attack
- Short Period Oscillation (2nd Mode)**
 - Occurs over 1 – 2 seconds
 - Caused by vertical disturbance in airflow (upgust / down gust)
 - AoA changes
 - No change in airspeed
 - Pitch damper required to prevent pilot induced oscillations

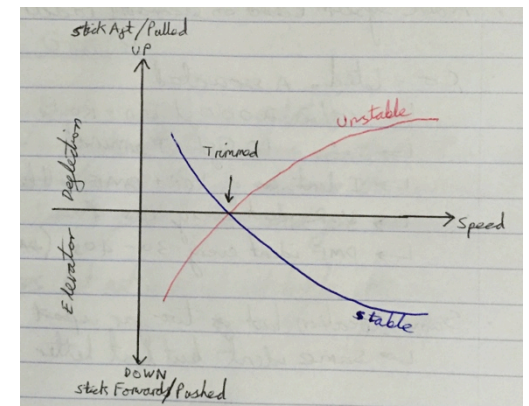
STICK FORCE STABILITY

TYPES OF STABILITY

- Stick Free Stability**
 - Hands-Off
 - Only applies to reversible controls
- Stick Fixed Stability**
 - Hands-On
 - Greater stick deflection required = greater stability

CONTROL FORCE STABILITY GRAPH

- At the trimmed condition, the stick is neutral and elevator deflection is zero.
- With an increase in speed, a pitch down is required to maintain level flight.
- With unstable stick stability, the opposite is true.



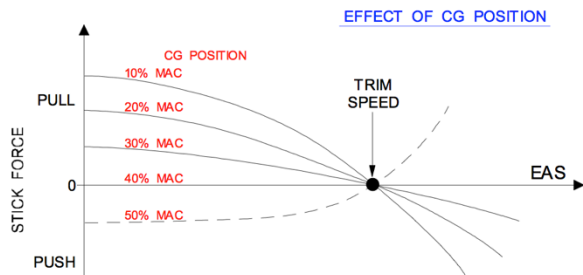
POF 18 - STABILITY

STICK FORCE GRADEINT

- When speed is increased above the trim speed, an increasing push force on controls is required (and vice-versa)
- This increase should be a **max of 1 lb per 6 kts**

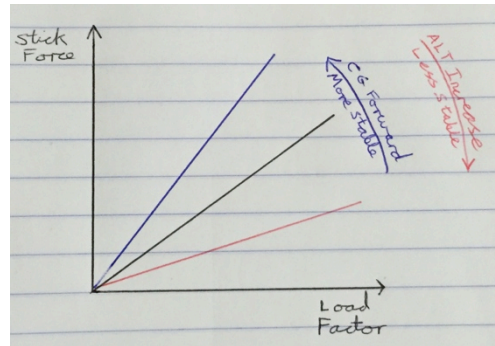
STICK FORCES AND CG

- As the CG is moved forward (decreasing MAC %) the stability increases so more stick forces are required.
- At the neutral point, the stick forces required are zero.
- Aft of the neutral point, stick force instability exists



MANOEUVRE (LOAD FACTOR) STABILITY

- With increasing load factor, stick forces increase => Always positive gradient on curve.
- Steeper gradient (more stable) occurs when CG is moved forward.
- Shallower gradient (less stable) occurs with increasing altitude as the aerodynamic damping reduces.



- Manoeuvre Point**
 - The CG position along the longitudinal axis that results in neutral stick force stability.
 - X-axis on the above graph
 - Always further aft than the neutral point

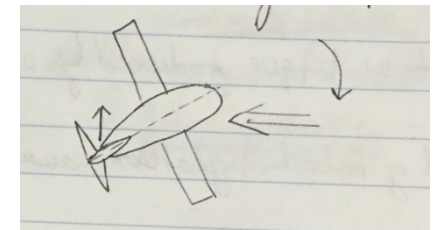
INCREASING MANOEUVRE STABILITY

- Spring**
 - Speed and load factor insensitive
- Bobweight**
 - Speed and load factor sensitive
 - With increasing load factors, weight of bobweight increases.

DIRECTIONAL STATIC STABILITY

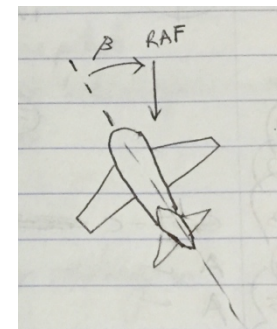
DIRECTIONAL STATIC STABILITY

- Axis:** Normal (Yaw)
- Main Structure Responsible: **Vertical Stabiliser**
- The vertical stabiliser will always to align the aircraft with the relative airflow.



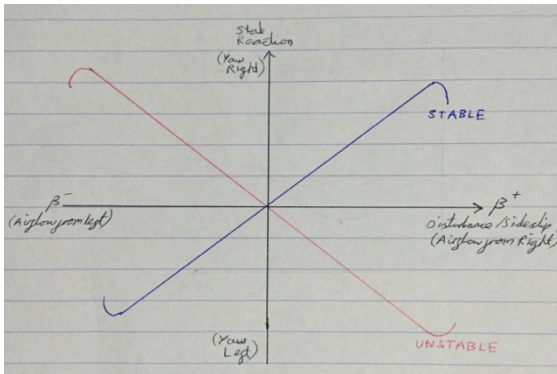
SIDESLIP

- Sideslip is used to describe the direction of the initial disturbance.
- If the relative airflow is from the right, the aircraft has positive sideslip.
- Therefore, if aircraft yaws left (negative yaw) it is described as having positive sideslip.



POF 18 - STABILITY

DIRECTIONAL STABILITY GRAPH



CG POSITION

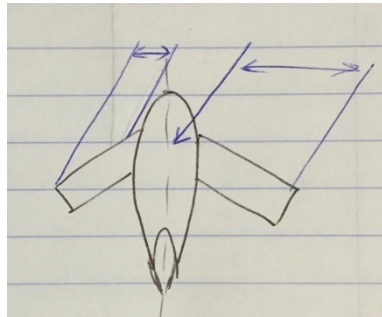
- Forward CG increases the lever arm and therefore has a stabilising effect.
- Aft CG has a destabilising effect.

TAILPLANE DESIGN

- Profile – Stability increases with:
 - Increasing camber
 - Increasing thickness
 - Increasing area
 - Increasing sweepback
- Elliptical Tailplane
 - More efficient => greater force
- Dorsal Fin
 - Increases directional and static lateral stability (greater surface area)
- Ventral Fin
 - Increases directional static stability
 - Decreases lateral static stability

WING SWEEPBACK

- With a positive sideslip, there is more airflow across the right wing,
- Increased drag on the right wing results in a tendency to yaw into wind.
- Therefore, **wing sweepback has a stabilising effect**



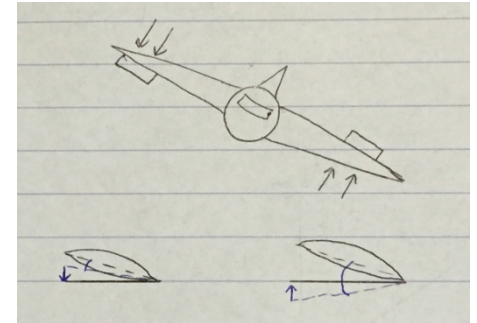
FUSELAGE & NACELLES

- Disturbs airflow over the tailplane reducing the moment from the tailplane.
- Therefore has a **destabilising effect**

LATERAL STATIC STABILITY

FUSELAGE & NACELLES

- **Axis:** Longitudinal (Roll)
- Main Structure Responsible: **Wings**
- Angle of attack increased on the downgoing wing due to airflow from below.
- Angle of attack decreased on the upgoing wing due to airflow from above.
- **Restoring moment** produced

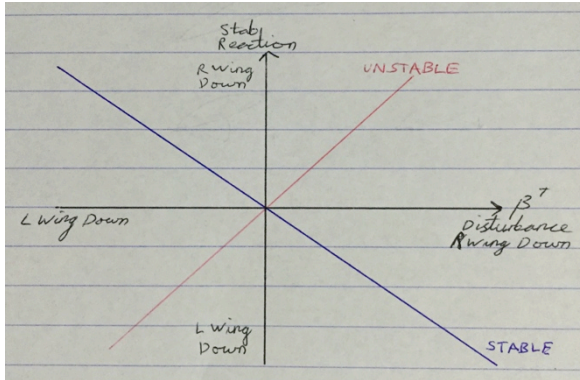


SIDESLIP

- Sideslip is used to represent the disturbance.
- A positive sideslip (RAF from the right) exists when the aircraft is turning to the right,

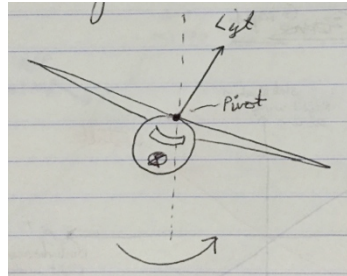
POF 18 - STABILITY

LATERAL STABILITY GRAPH



HIGH WING

- High wing has an **intense stabilising effect**
- Lift acts as a pivot and the CG is displaced to one side resulting in a **pendulous effect**

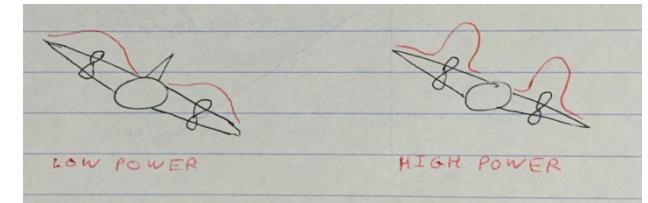


WING SWEEPBACK

- Sweepback has a **stabilising effect**
- Like with directional stability, there is more airflow across the wing in the direction of the turn.
- This time however, we consider more lift is produced on the downgoing wing as a result.

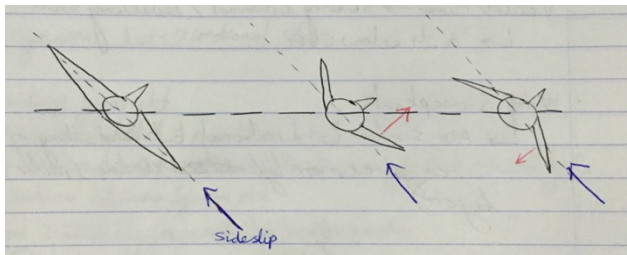
POWER (MULTI-ENGINE PROP)

- Power has a **de-stabilising effect**
- With high power settings, more airflow occurs over the wind behind the props.
- Since total lift is still the same, the distribution changes and there is less lift at the tips but more in the centre of the wing.
- Dihedral effect is reduced



ANHEDRAL / DIHEDRAL

- With dihedral, the wing itself has a positive angle of attack to the relative airflow.
- **Dihedral has a stabilising effect**
- With anhedral, the wing itself has a negative angle of attack to the relative airflow.
- **Dihedral has a destabilising effect**

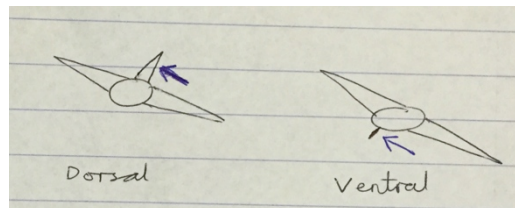


HIGH VERTICAL FIN

- High vertical fin has a **stabilising affect** due to the weathercock tendency

VENTRAL / DORSAL FIN

- **Dorsal Fin** is on the upper surface
 - Stabilising effect
 - Acts as a higher vertical fin
- **Ventral Fin** is on the lower surface
 - Destabilising effect
 - More surface area on bottom induces a further roll moment



HIGH LIFT DEVICES

- **De-stabilising effect**
- Again, lift is distributed more towards the root and the dihedral effect is reduced.

POF 18 - STABILITY

LATERAL & DIRECTIONAL DYNAMIC STABILITY

DIRECTIONAL VS LATERAL STABILITY

- Considering a sideslip from the right....
- Directional stability wants to yaw the aircraft right into the wind
- Lateral stability wants to roll the aircraft left to wings level
- The balance between directional and lateral stability determines the dynamic stability

SPIRAL INSTABILITY (APERIODIC)

- **Directional Stability > Lateral Stability**
- Mainly caused by a disturbance in roll

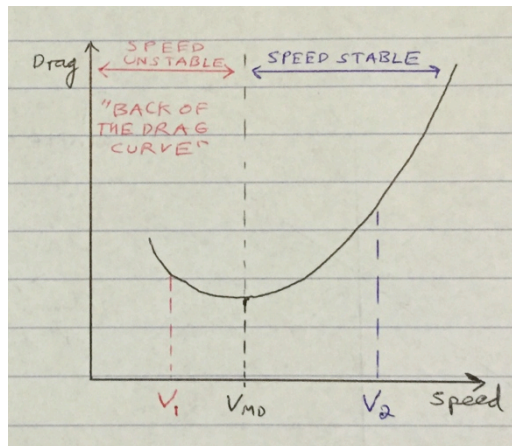
DUTCH ROLL (OSCILLATORY)

- **Lateral Stability > Directional Stability**
- Mainly caused by a disturbance in yaw
- Can result from asymmetric engine failure
- **Yaw damper** is mandatory if aircraft subject to dutch roll

SPEED STABILITY

SPEED STABILITY

- When speed less than V_{MD} (as in V_1), a decrease in speed increases the drag. Increased drag further slows the speed and an unstable condition exists.
- When speed greater than V_{MD} (as in V_2), a decrease in speed decreases drag and aircraft speed increases back to original. A stable condition exists.



POF 19 – ASYMMETRIC FLIGHT

CONSEQUENCES

- There are two main consequences to asymmetric flight:
 - Altitude Loss
 - Yawing Moment

ALTITUDE LOSS

CORRECTIVE ACTION

- Thrust set to MCT
- Angle of attack set (up to 5°) in order to achieve the driftdown speed
- Driftdown to the level off altitude

YAWING MOMENT

CORRECTIVE ACTION

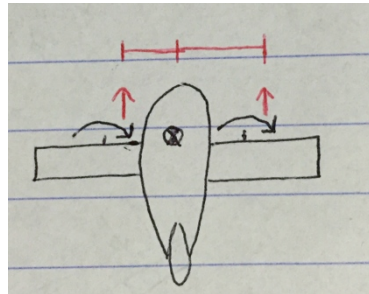
- Rudder used to correct yaw
- Can also apply bank up to 5° towards the side of the live engine

CG POSITION AND YAWING MOMENT

- Aft CG reduces the lever arm and the ability for the rudder to counter the yawing moment is reduced.

CRITICAL ENGINE (PROP)

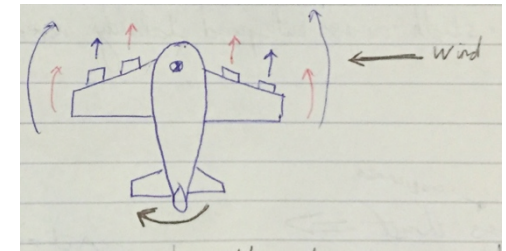
- The critical engine is the “**worst engine that could fail**”
- If both props are clockwise rotating, the **left prop will be the critical engine**.
 - Asymmetric blade effect means the thrust is produced on the side of the prop.
 - Loosing the left prop results in a greater yawing moment from the right prop as the arm from thrust to CG is greatest.



- If both props are counter-clockwise rotating, the right prop will be the critical engine.
- With counter rotating props there is no critical engine.

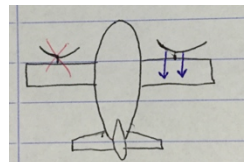
CRITICAL ENGINE (JET)

- The critical engine in a jet depends on the position of the wind.
- The critical engine is the **outboard engine on the side of the wind**.
- With a wind from the right, the aircraft will naturally have a yaw right tendency.
- Loosing the outboard right engine removes the biggest counteracting moment.



PROPELLOR SLIPSTREAM

- Wing on the side of the live engine will produce more lift.
- Roll towards the dead engine is induced adding to the yawing moment.



WEIGHT

- Increased weight = increased yawing moment

POF 19 – ASYMMETRIC FLIGHT

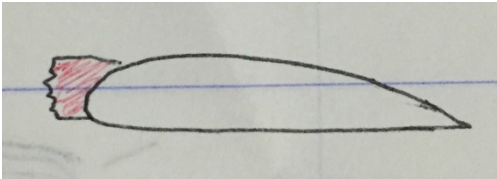
MIN CONTROL SPEEDS

- **V_{MCG} – Min Control Speed On Ground**
 - Max deviation from centerline: 30 ft
 - Must be possible without NWS
- **V_{MCA} – Min Control Speed In Air**
- **V_{MCL} – Min Control Speed During Landing**
 - Minimum roll rate of 20 degrees towards the live engine in not more than 5 secs
- **Increased Altitude (V_{MCG} & V_{MCA})**
 - Decrease with an increase in altitude
 - Since these speeds occurs with max thrust and thrust decreases with altitude, the minimum control speed will be lower.
- **Increased Altitude (V_{MCL})**
 - No change with altitude
 - This speeds occurs at flight idle which is not affected by altitude

POF 21 – ICE & FROST

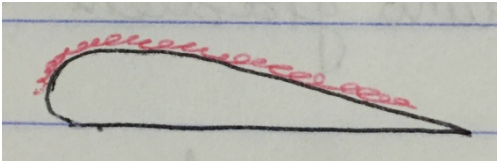
ICE

- Forms on the **leading edge** (due to presence of the stagnation point)
- **Aerofoil Shape – Changes**



FROST

- Forms over the **whole wing**
- Aerofoil Shape – No Change
- **Increases skin friction drag**
- Most common when aircraft is parked

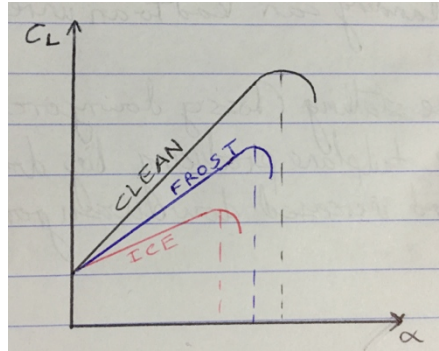


EFFECT OF ICE & FROST

- **Overall decrease in C_L**
- **C_{LMAX} decreases**
- **Critical AoA decreases**
- As a result of the above, **V_S increases**
- With frost, the additional weight further increases V_S

ICE VS FROST

- **Ice is more severe**



EFFECT ON HLDs

- Ice reduced the ability of HLDs to re-energise the boundary layer.
- C_{LMAX} augmentation reduced from 20 – 50% to 5 – 10%

EFFECT ON STALL WARNING DEVICES

- The stall warning system is calibrated to V_S without ice and frost present.
- Since ice and frost increase V_S , a **stall can occur before the SWS activates.**

EFFECT ON TAKEOFF

- Reduction in C_L requires a greater takeoff speed which **increases the takeoff run.**
- The higher takeoff speed increases drag, resulting in less excess thrust and a **reduced climb gradient.**

EFFECT ON LANDING

- Reduction in C_L and increased drag results in an **excessive sink rate.**
- Higher landing speed required **increases the landing distance required.**
- **Unrecoverable pitch down moment due to ice on tailplane stalling possible**
 - In the landing phase, the tailplane is at high angles of attack due to downwash from the HLDs.
 - Ice on the tailplane can cause it to stall
 - Loss of downforce causes pitch down moment

POF 21 – ADVERSE WEATHER

WINDSHEAR

DEFINITION

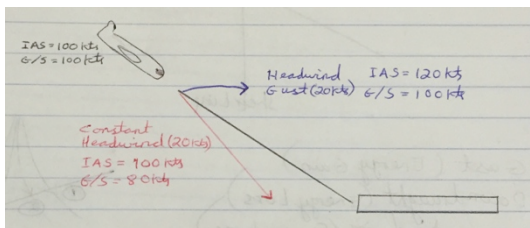
- **Any sudden change in wind velocity and / or direction with:**
 - Altitude (Vertical Windshear)
 - Horizontal Distance (Horizontal Windshear)

GUST

- **Vertical Gust**
 - AoA – Changes
 - Speed - Constant
- **Horizontal Gust**
 - AoA – Constant
 - Speed - Changes

HORIZONTAL GUST & LOAD FACTOR

- A **horizontal headwind gust** momentarily increases the IAS. Since the AoA is constant, lift increases and the **load factor exceeds 1**.
- On an ILS, a headwind will cause you to fall below the glidepath whilst a headwind gust will result in flying above the glidepath.



UPDRAUGHTS / DOWNDRAUGHTS

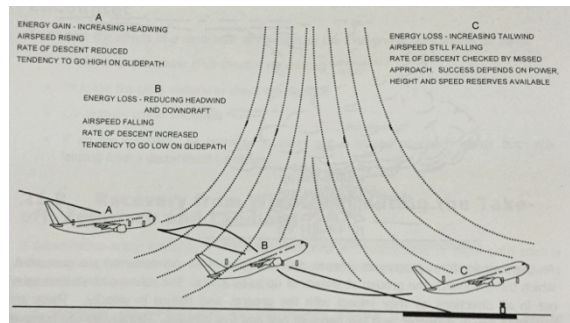
- AoA Changes
- **Speed always decreases**

WINDSHEAR INDICATIONS

- **IAS $\pm$ 15 kts**
- **V/S $\pm$ 500 fpm**

MICROBURST EFFECTS

1. Energy Gain (Gust)
2. Energy Loss (Downdraught)
3. Energy Loss (Loss of headwind)



POF – FLIGHT ENVELOPE

LOAD FACTORS

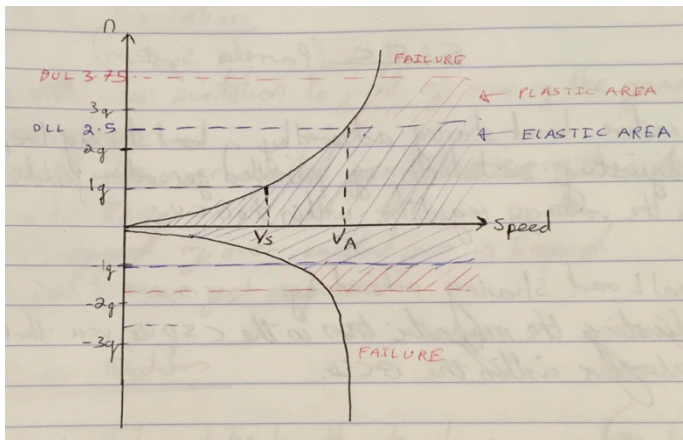
DUL VS DLL

- **Design Limit Load (DLL)**
 - Max load the structure can endure without permanent deformation.
- **Design Ultimate Load (DUL)**
 - Max load the structure can ensure without failure.
- **DUL = DLL x 1.5 (Safety Factor)**

DLL LIMITS

- **Transport Category:** + 2.5 → - 1
- **Transport (Flaps Ext):** +2 → -1
- **Normal Category:** +3.8 → -1.52
- **Utility Category:** + 4.4 → - 1.76
- **Aerobatic Category:** + 6 → - 3

FLIGHT ENVELOPE



DESIGN SPEEDS

VS - STALL SPEED

- First speed where lift equals weight (load factor equal to 1)

VA - DESIGN MANOEUVRE SPEED

- Max speed where full sudden deflection of elevators does not result in a load factor greater than DLL.
- The aircraft stalls before reaching DLL

$$V_{A(NEW)} = V_{A(OLD)} \times \sqrt{\frac{W_{NEW}}{W_{OLD}}}$$

VB - MAX GUST INTENSITY

- Must ensure a gust of ± 66 fps at 20,000 ft

VC - DESIGN CRUISE SPEED

- Must ensure a gust of ± 50 fps at 20,000 ft
- Must be at least 43 kts greater than VB
- Max of 0.8 VD

VD - DESIGN DIVE SPEED

- Must ensure a gust of ± 25 fps at 20,000 ft

GUST LOAD FACTOR (GLF)

GUST LOAD FACTOR

$$N_{(NEW)} = N_{(OLD)} \times \frac{C_{L(NEW)}}{C_{L(OLD)}}$$

$$\frac{V_{(NEW)}}{V_{(OLD)}} = \frac{\Delta N_{(NEW)}}{\Delta N_{(OLD)}}$$

$$V_{(NEW)} = V_{(OLD)} \times \sqrt{N}$$

FACTORS AFFECTING GLF

∞	$1 / \infty$
Speed	Sweepback
Aspect Ratio	Altitude
Wing Area	Weight
-	Wing Loading