CPL Theory
Aerodynamics (CADA)

CADA 1 – Basic Aerodynamics

CAE Oxford
Aviation Academy

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2. Related Documents

Related Documents	Document Identification

Amendments made to this document since the previous version are listed below. All amendments to this document have been made in accordance with CAE OAAM's document management procedure.

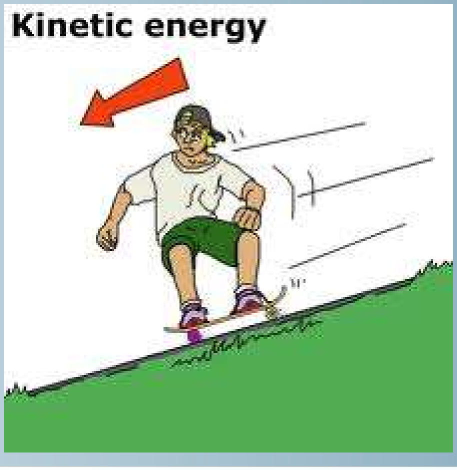
Slide	Changes

BASIC PHYSICS REVISION

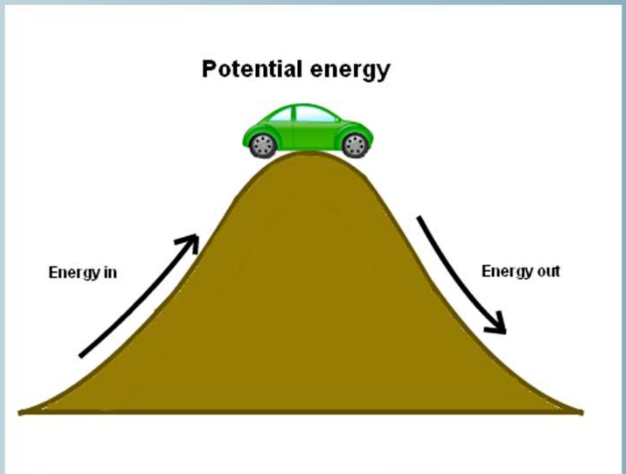
Kinetic & Potential Energy

"Energy cannot be created or destroyed - it can only be changed from one form to another."

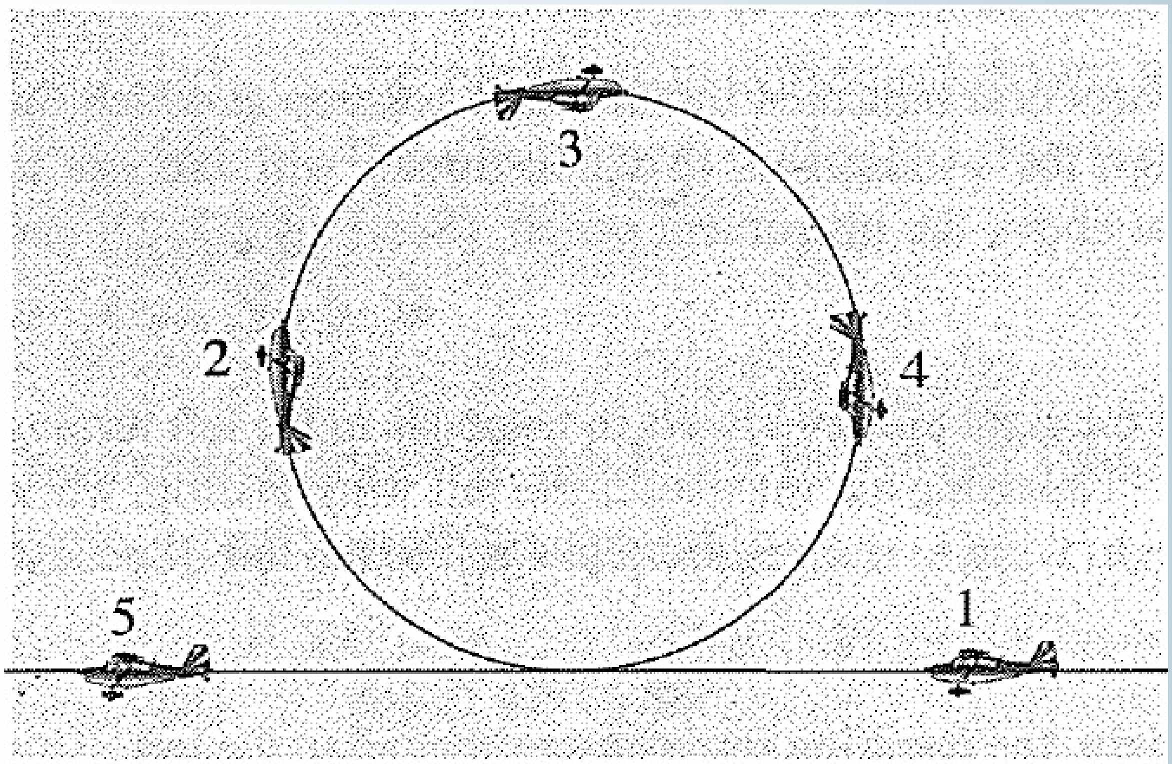
Two forms of energy evident in aviation are:



- Kinetic energy - energy an object possesses due to its speed
- Potential energy - energy an object possesses due to its height. This is more precisely known as gravitational potential energy



Kinetic & Potential Energy



1. At the commencement of the manoeuvre, the aircraft is flying fast but low. Most of its energy is due to its speed.

2. Its speed is being converted to height - kinetic energy is being converted to potential energy.

3. The aircraft has gained its maximum height but its speed is now at its slowest.

4./5. It loses height but gains speed - potential energy is being converted to kinetic energy. It exits the loop at much the same speed as it entered.

PRESSURE

Air Pressure

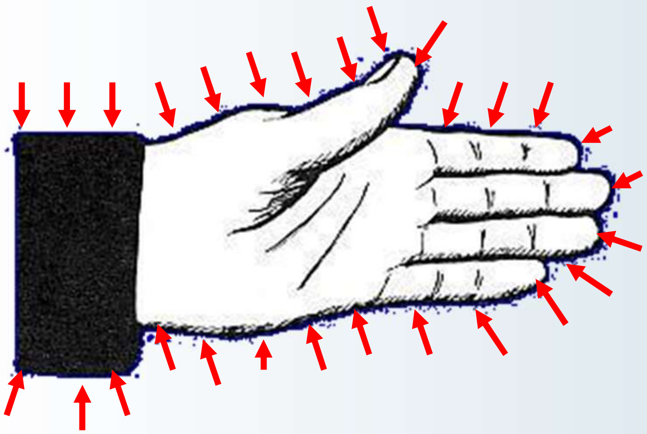
- Air Pressure – the force exerted by tiny particles known as air molecules. For our purposes, there are two types of air pressure:

1. Static Pressure (P_S)

2. Dynamic Pressure (P_D)

Static Pressure (P_S)

- The pressure acting on us as we sit here – caused by gravity pulling air molecules down towards the centre of the Earth



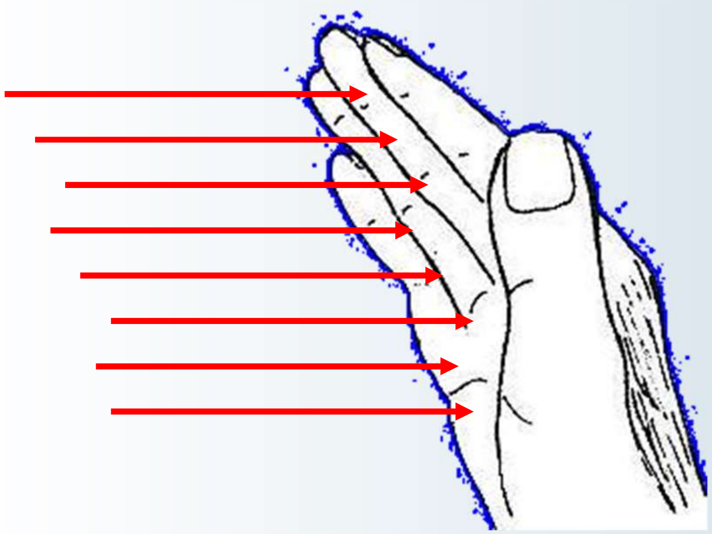
$$P = \frac{F}{A}$$

- Decreases as altitude increases due to the air being less dense at higher altitudes

"Air will move from an area of high pressure to an area of low pressure"

Dynamic Pressure (P_D)

- Kinetic energy due to **motion**



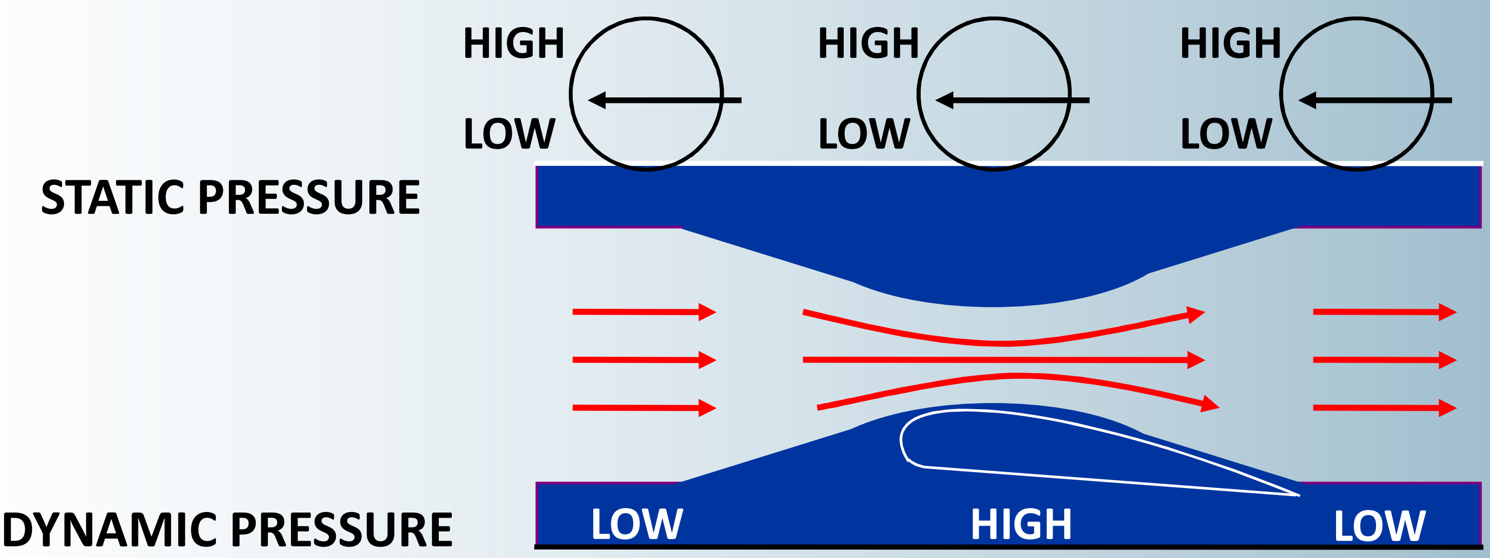
$$E_K = \frac{1}{2} m v^2$$

$$P_D = \frac{1}{2} \rho v^2$$

BERNOULLI'S THEOREM

Bernoulli's Theorem

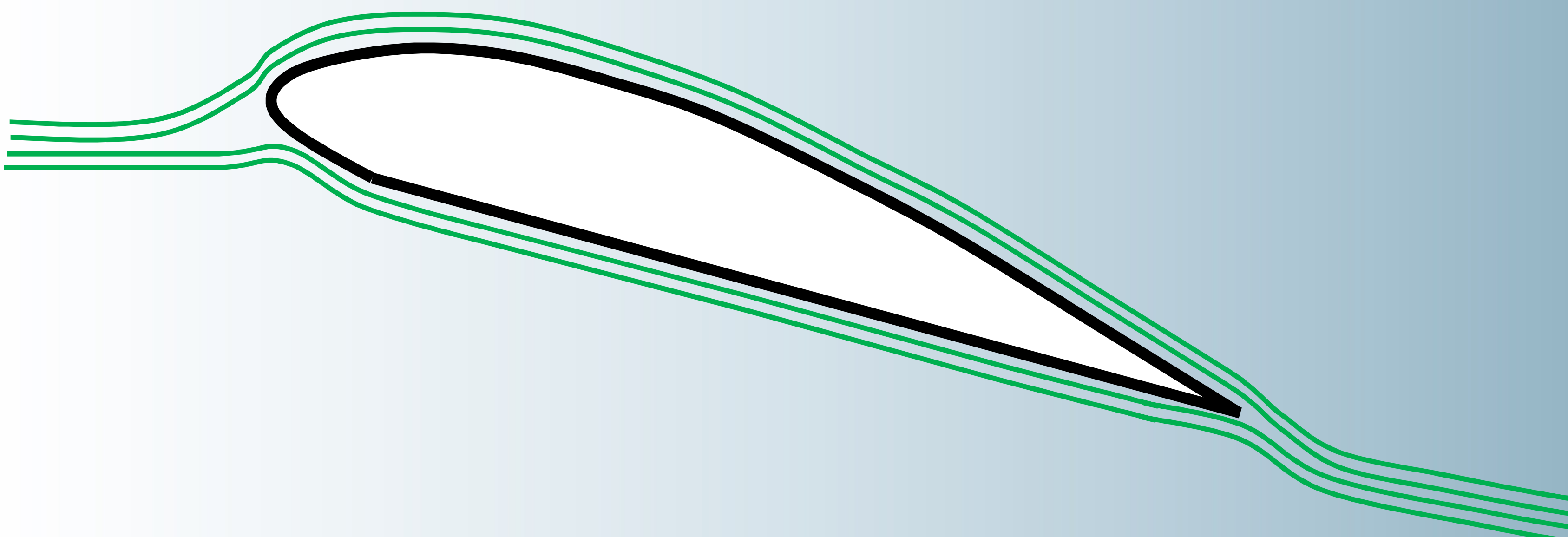
$$P_{TOTAL} = P_D + P_S$$



COANDĂ EFFECT

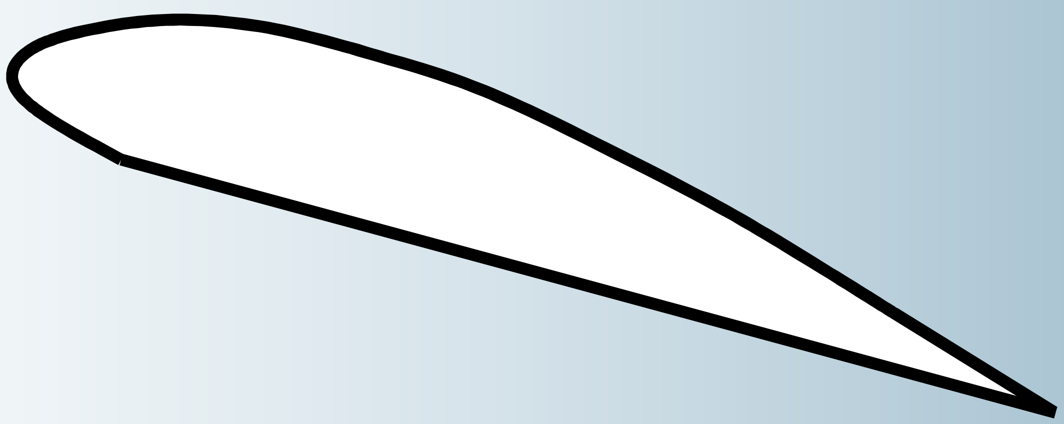
Coandă Effect

- The tendency of the airflow to follow a surface with gentle curvature rather than continue its original path until the stalling angle is reached – known as ***entrainment***
- Results in the air being deflected downward after it leaves the trailing edge
- Creates an equal and opposite reaction on the wing



HOW IT ALL WORKS

CADA 1 – Basic Aerodynamics

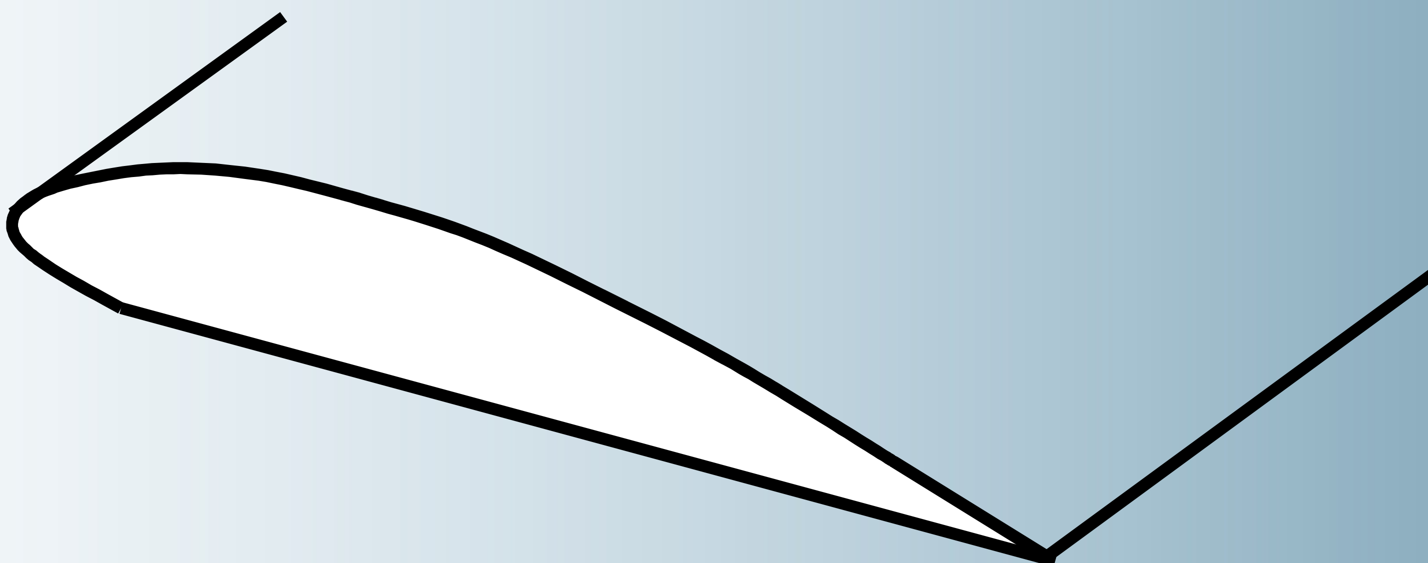


Aerofoil

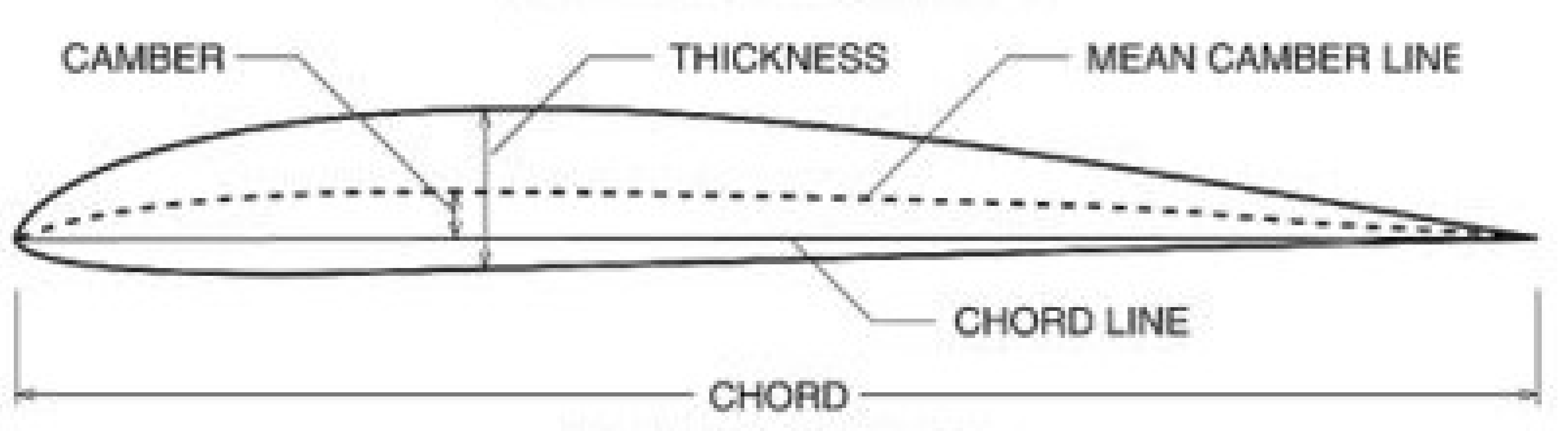
- Any surface which is designed to provide an aerodynamic force when interacting with a moving stream of air

- This could be a wing, rudder, elevator, etc.

- Shown below is a cross-sectional view of an aerofoil

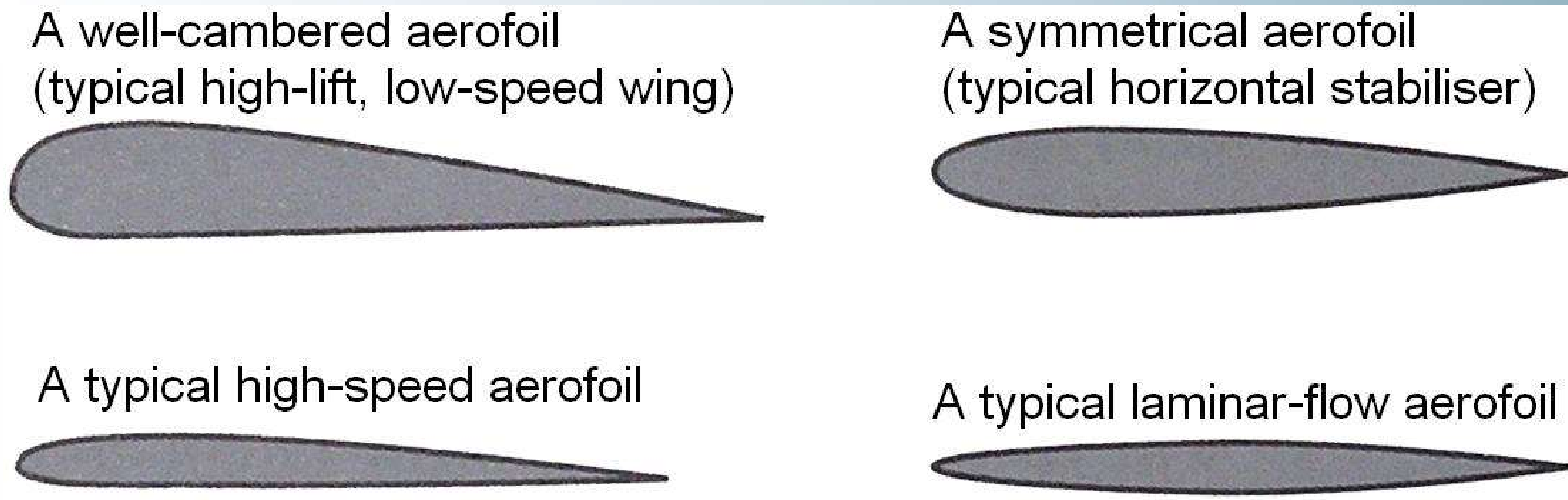


Aerofoil



- **Chordline:** The straight line joining the Leading Edge to the Trailing Edge
- **Mean Camber Line:** The line drawn halfway between the upper and lower surfaces
- **Thickness:** The distance between the upper and lower surfaces
- **Camber:** The curvature of an aerofoil
- The shape of the aerofoil is based on the intended application

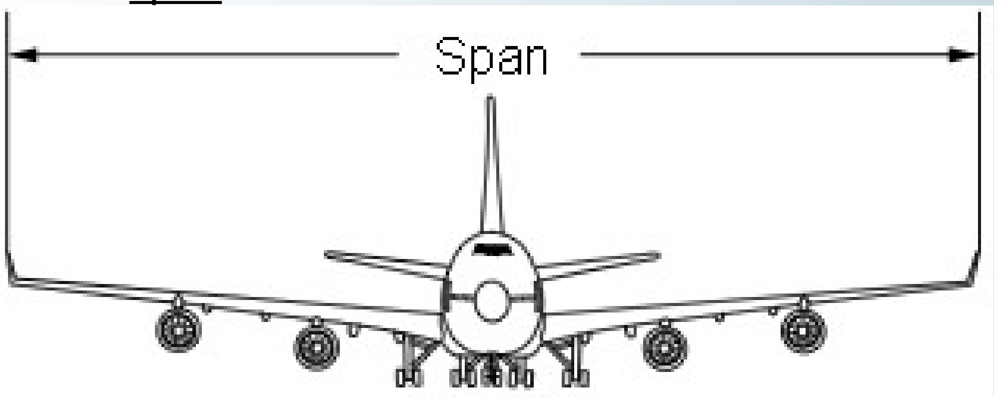
Aerofoil



- The point of maximum camber is where there is the greatest distance between the chordline and the mean camber line (usually about 30% of the chord back from the leading edge)
- The Cessna 172 has a typical low-speed, high-lift wing and the maximum camber is about 25% of the chord back from the leading edge
- A Boeing 737 has a laminar-flow aerofoil designed for high speed cruise. It has less camber and the maximum camber is at about 50% chord

Aerofoil

- Another consideration when designing wings is the relationship between chord and span



$$\text{Aspect Ratio} = \frac{\text{Span}}{\text{Chord}}$$

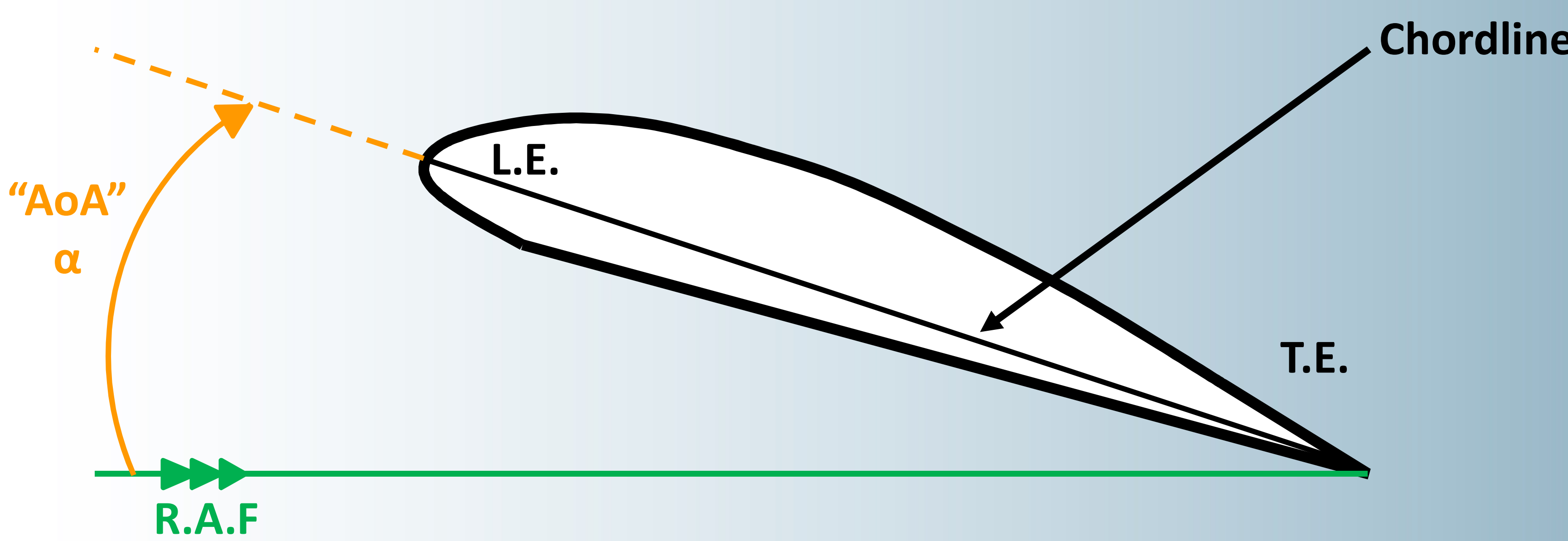
- A wing of high aspect ratio can reduce **induced drag**

High aspect ratio – long narrow wings

Low aspect ratio – short fat wings

CADA 1 – Basic Aerodynamics

- **Relative Airflow (R.A.F):** Opposite to the direction of the path of the aircraft
- **Angle of Attack (AoA):** The angle between the chordline and relative airflow



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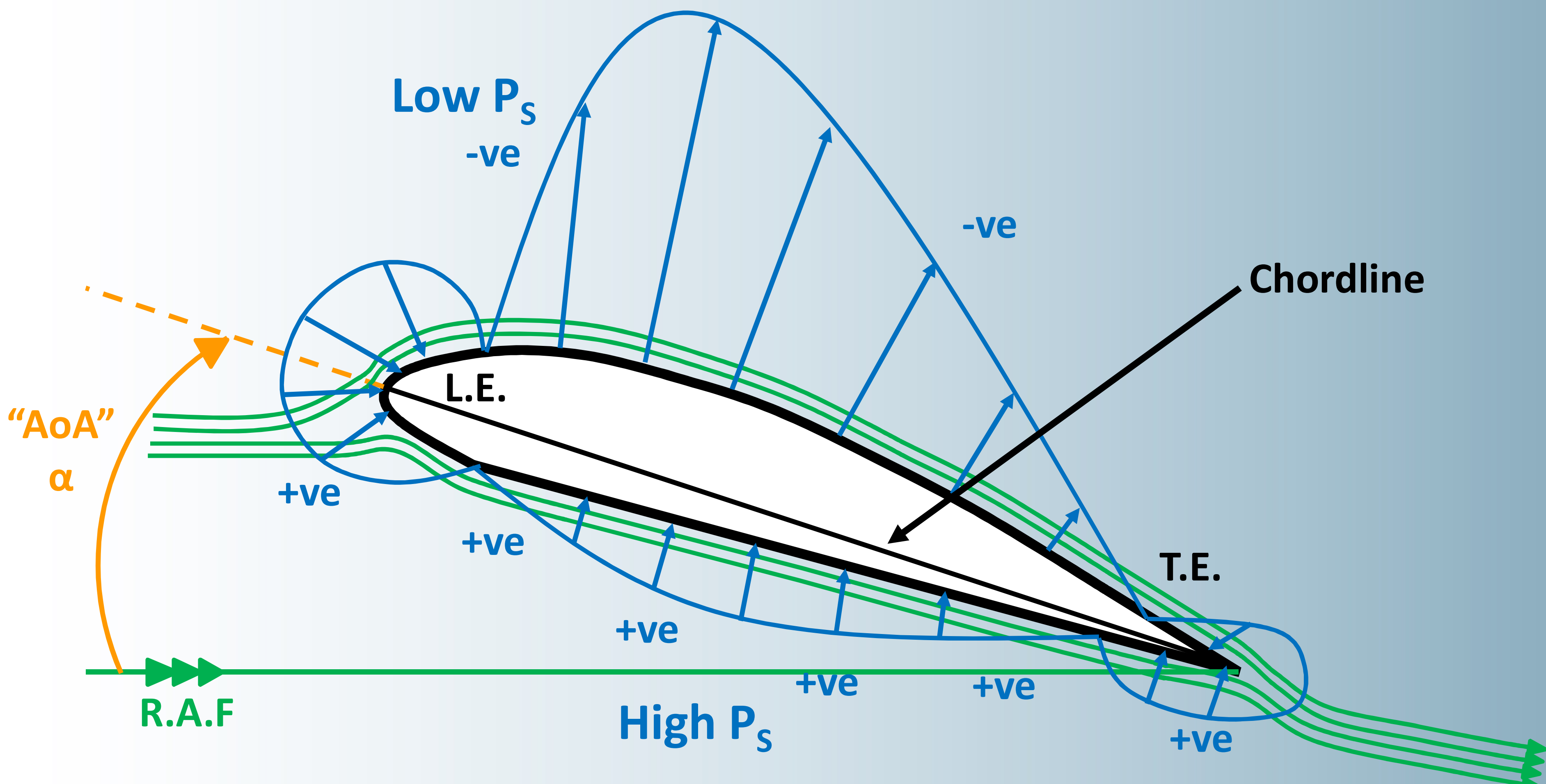
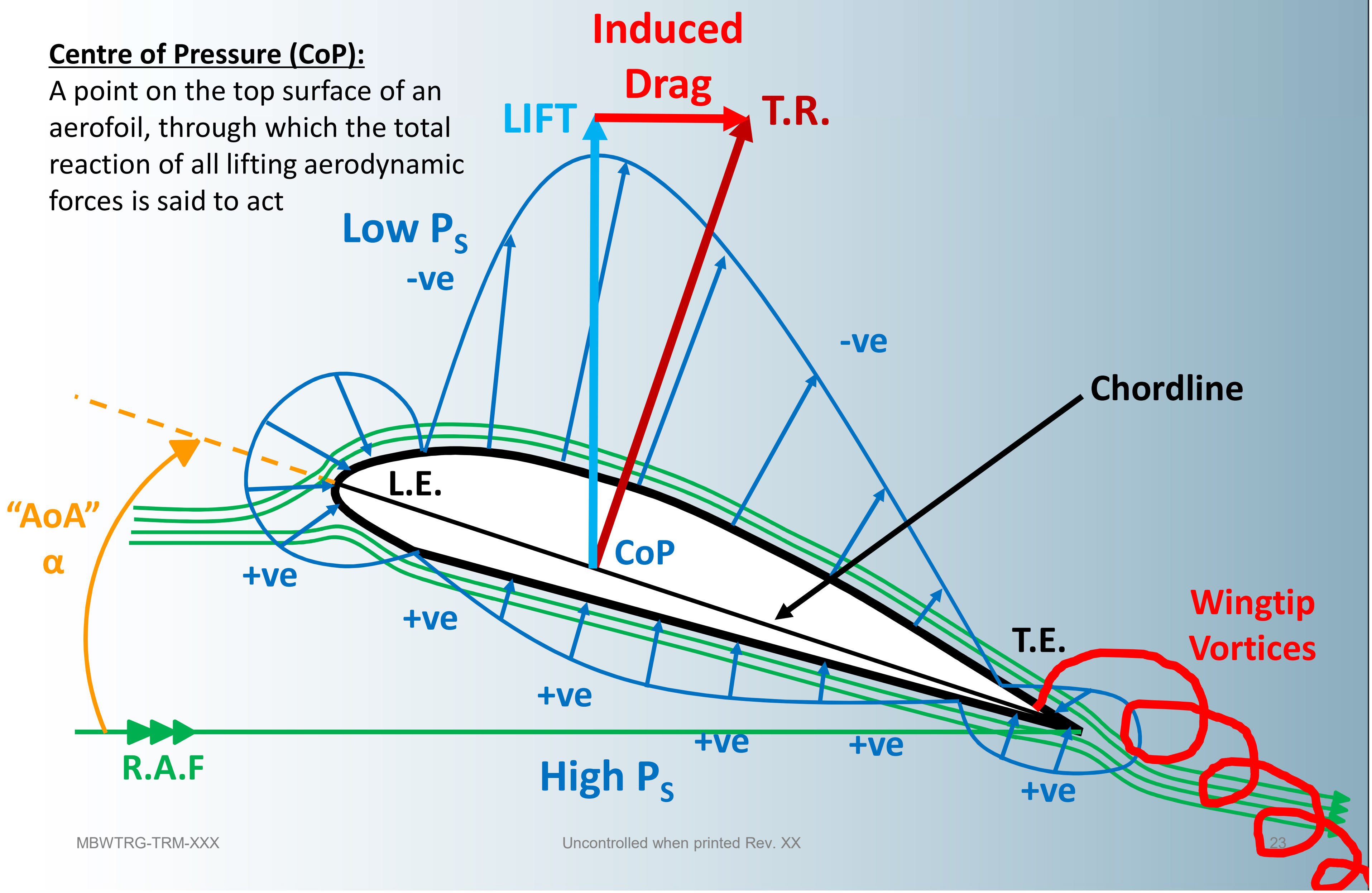


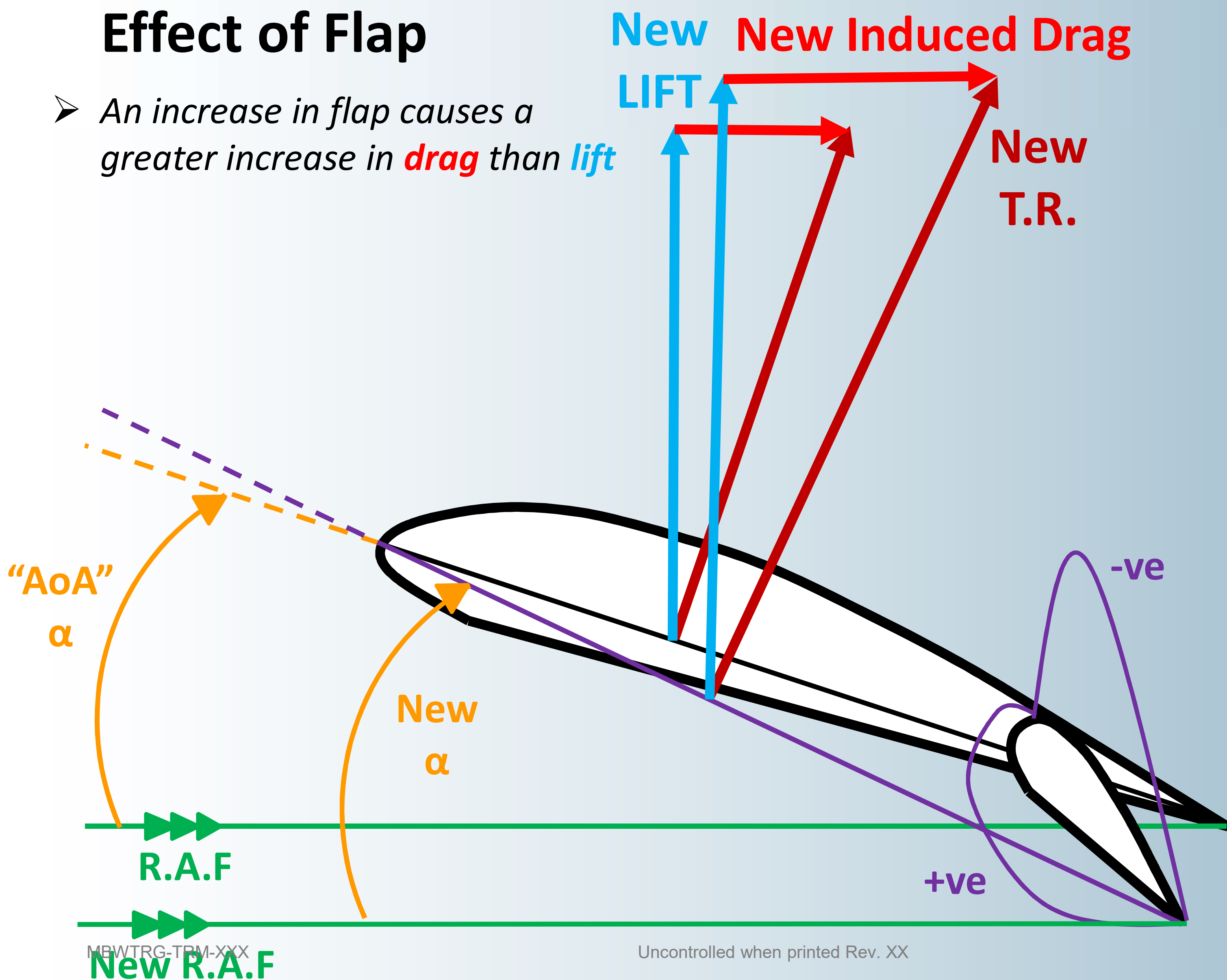
Centre of Pressure (CoP):
A point on the top surface of an aerofoil, through which the total reaction of all lifting aerodynamic forces is said to act



EFFECT OF FLAP

Effect of Flap

- *An increase in flap causes a greater increase in **drag** than **lift***



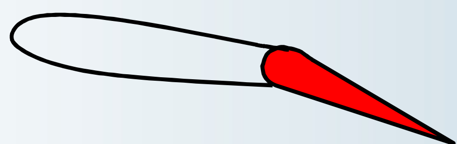
LIFT EQUATION

Lift Equation

$$L = \underbrace{C_L}_{\text{Angle of Attack, Wing Shape}} \underbrace{\tfrac{1}{2} \rho v^2}_{\text{Dynamic Pressure} = \text{IAS}} S$$

α°

(Angle of Attack)



Wing Shape

Dynamic Pressure = IAS

Maximum Planform Surface Area

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

How can we increase our C_L?

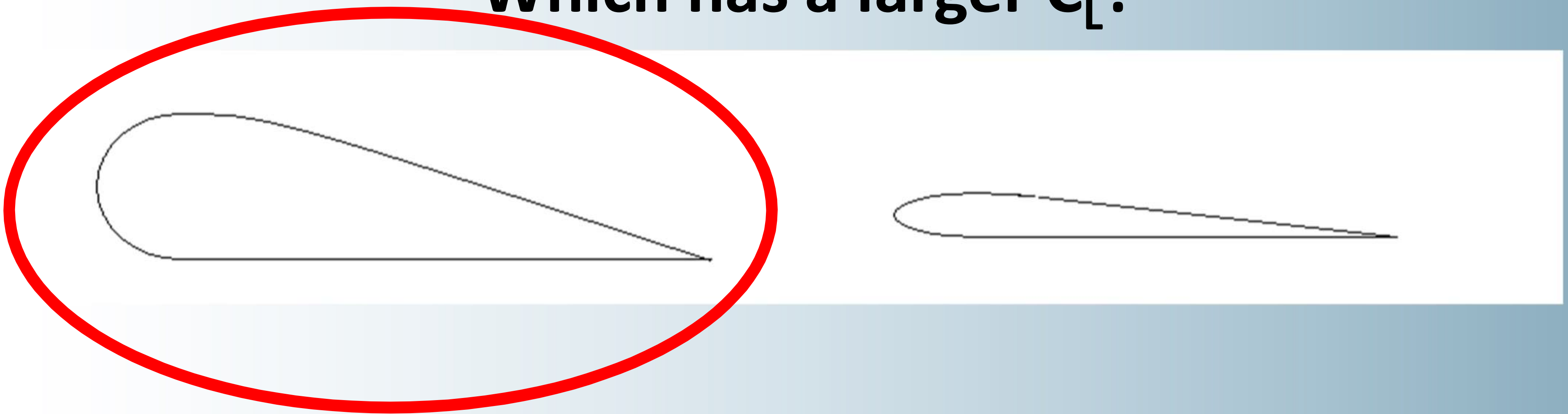
- Increase AoA
- Increase Camber
- Deploy Flap
- Increase *Thickness/Chord Ratio*

Thickness/Chord Ratio

The thickness/chord ratio, or t/c, describes an aerofoils relative thickness. It is a factor in determining an aerofoils inflight characteristics.

t/c ≈ 13% **t/c ≈ 20%**

Which has a larger C_L?



DRAG

Drag

Total Drag = Parasite Drag + Induced Drag

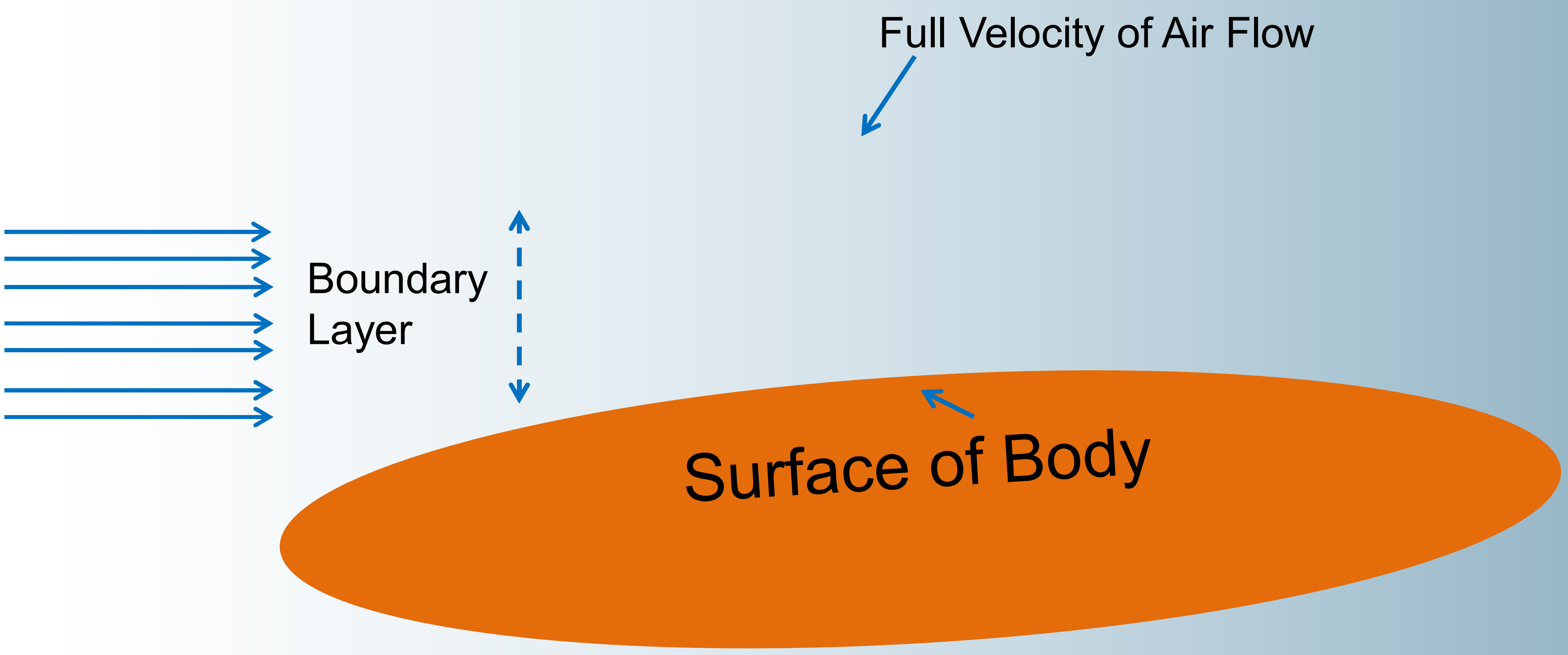
Parasite Drag: opposes the motion of the an object within a fluid (the atmosphere)

Parasite drag = <u>skin friction drag</u> + <u>interference drag</u> + <u>form drag</u>.

Parasite Drag

a) Skin Friction

Exists between an object (aircraft) and the air in which it's moving through.

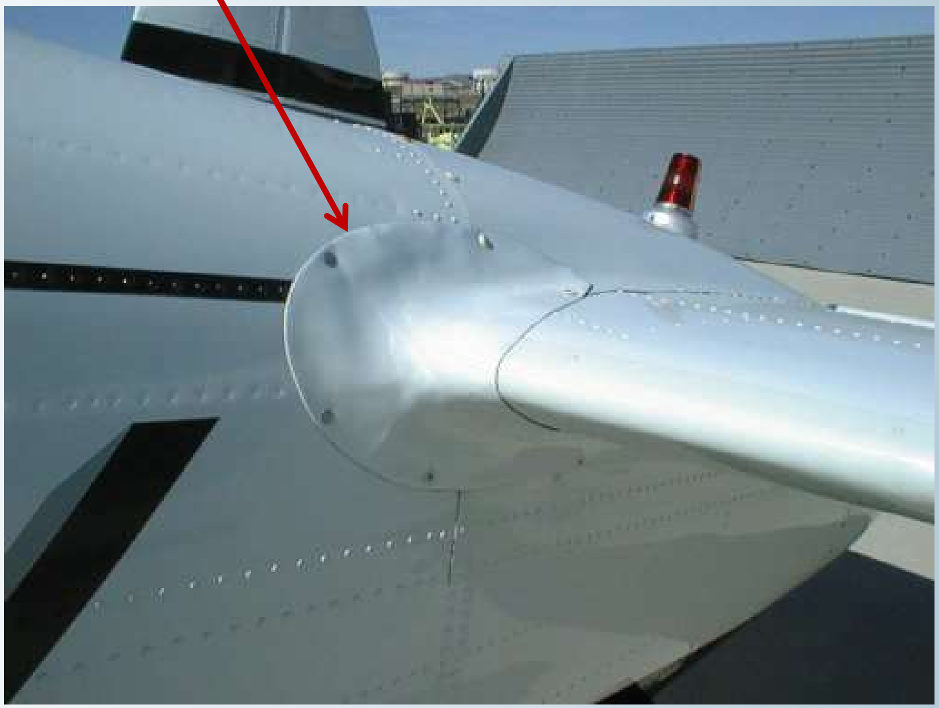


Parasite Drag

b) Interference Drag

Air mixing at junctions creates turbulence in the region of the joint

Occurs most frequently at the intersection of the fuselage with the wings , tailplane etc. reduced by use of fairings



Parasite Drag

c) Form Drag

Results from airflow separation.

Reduced by using streamlined parts (e.g. Spat)

Fineness Ratio

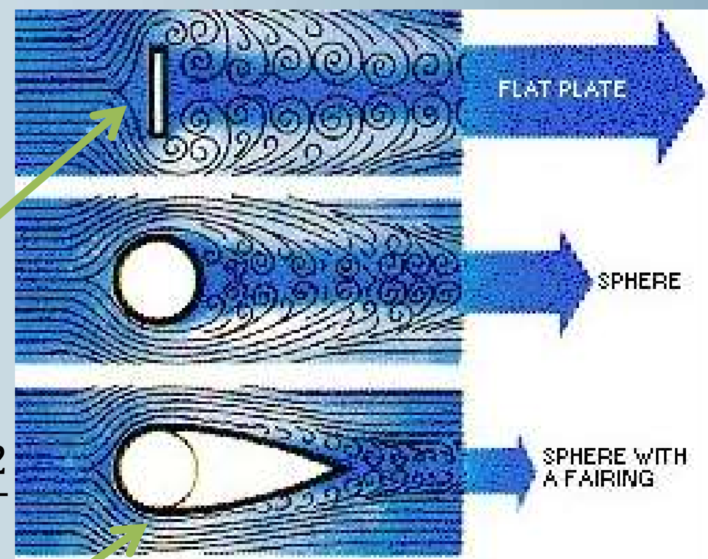
The length of a body by its maximum width

$$\frac{\textbf{LENGTH}}{\textbf{WIDTH}}$$

$e.g.\frac{1}{4}$

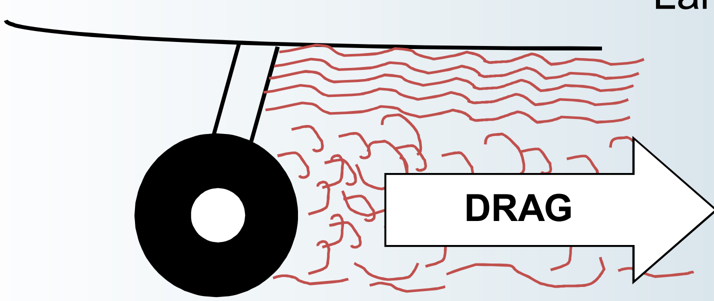
$e.g.\frac{4}{4}$

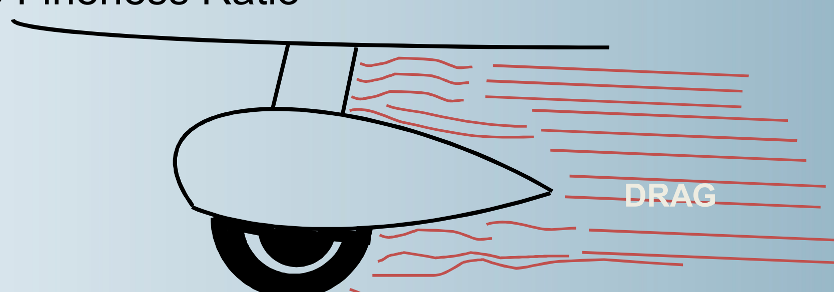
$e.g.\frac{12}{4}$



Small Fineness Ratio

Large Fineness Ratio





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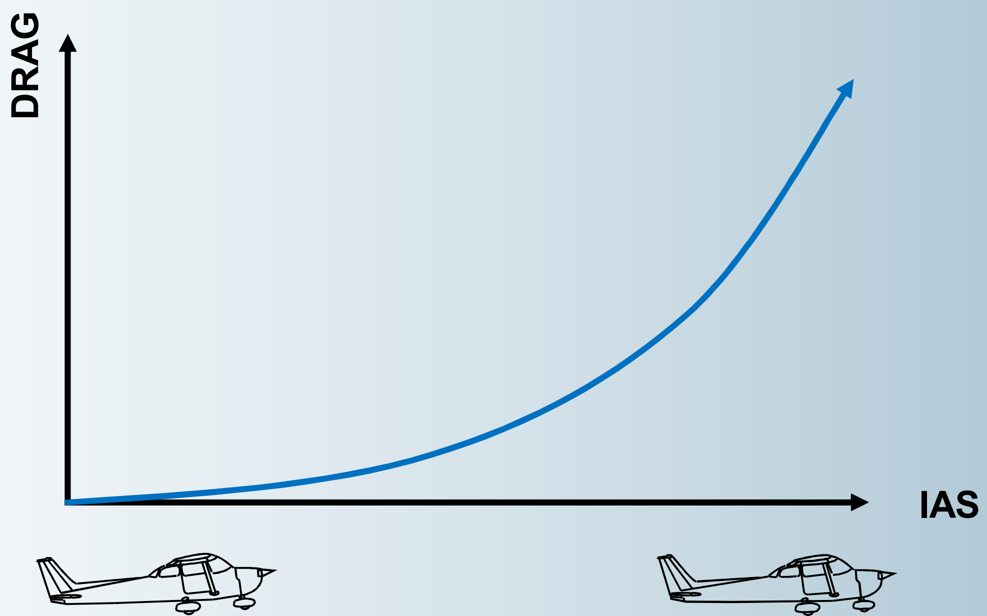
Parasite Drag

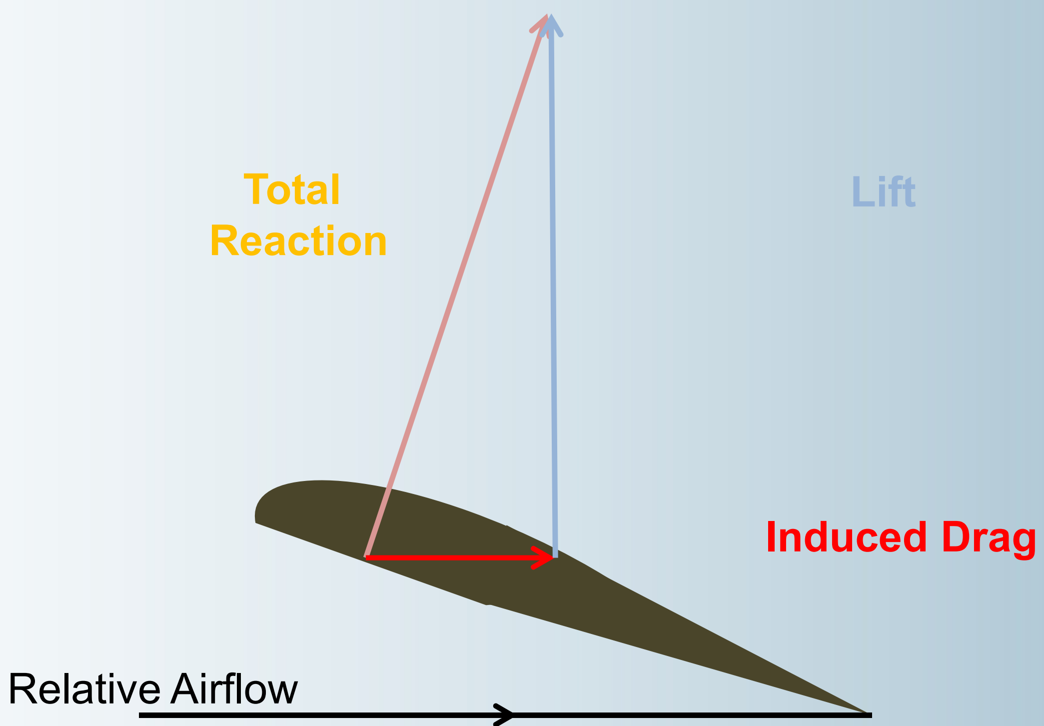
When airspeed ↑ Parasite drag ↑



Induced Drag

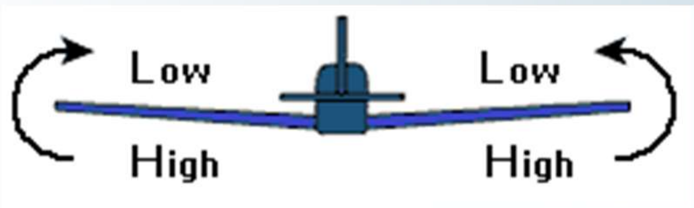
Is a by product of Lift.

Induced drag ↑ with ↑ AoA.



Induced Drag

- Is a by product of Lift.
- At wing tips air leaks to the upper surface creating swirling vortices.
- The slower the aircraft flies, the more air has time to spill over the wing tip
- The greater the pressure difference between the bottom and top surface, the greater the induced drag



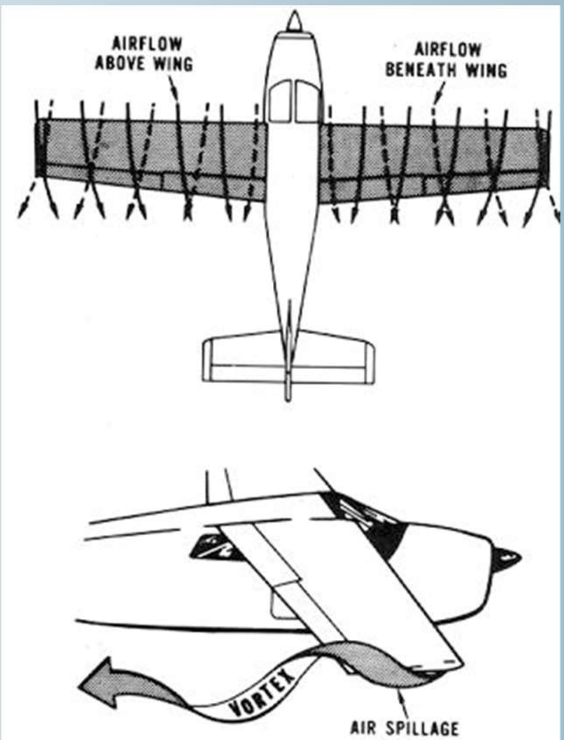


Figure 17-17 Wingtip Vortices

Induced Drag

What increases the pressure difference?

- Aircraft Weight
  - W=L
    Heavy aircraft must create more lift, therefore a stronger pressure difference must exist

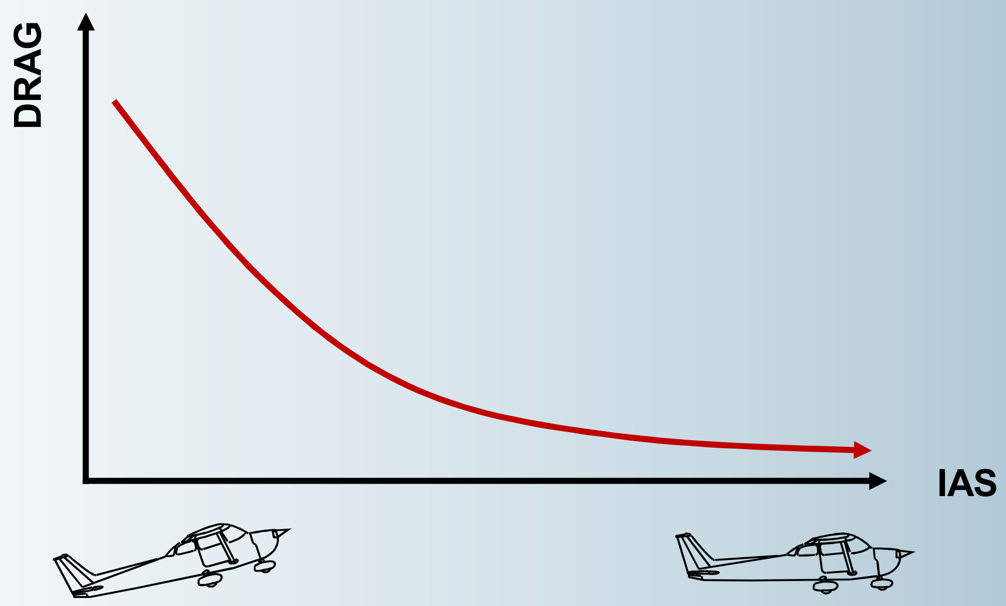
- Angle of Attack (AoA)

- Wing Plan Form (Aspect Ratio)
  - A high aspect ratio wing (long and skinny) has a smaller wing tip, therefore less area for the high pressure to spill over the tip

$$\textbf{Aspect Ratio} = \frac{\textbf{Span}}{\textbf{Chord}}$$

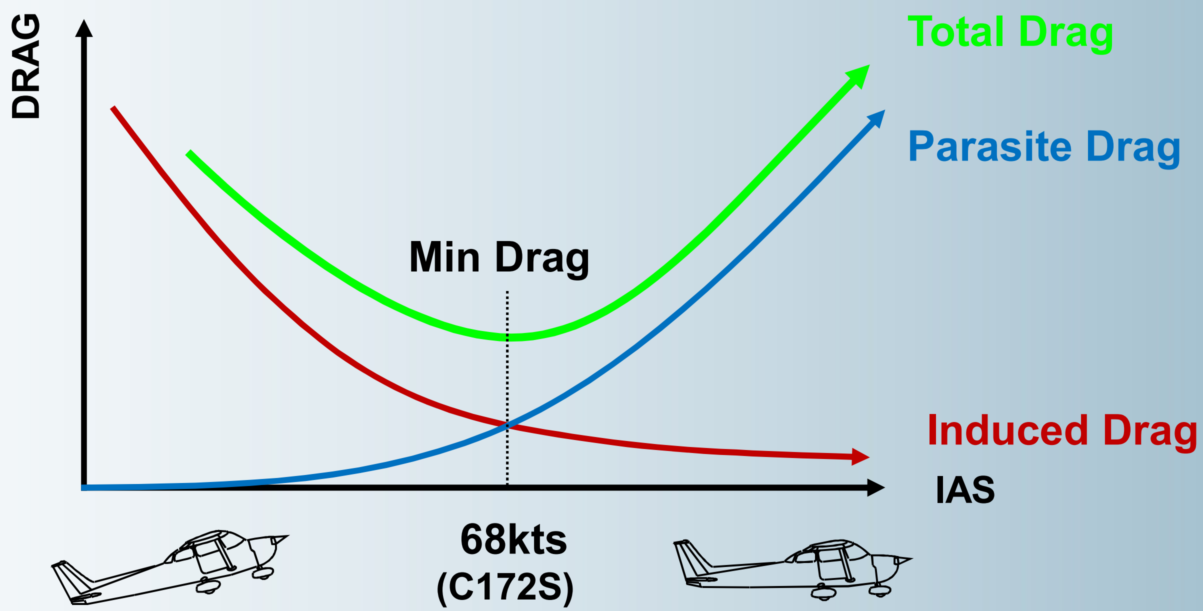
Induced Drag

When airspeed ↑ Induced drag ↓



Drag

TOTAL DRAG = Parasite drag + Induced drag



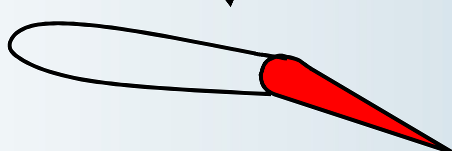
DRAG EQUATION

Lift Equation

$$D = C_D \underbrace{\tfrac{1}{2}\,\rho\, v^2}_{\text{Dynamic Pressure = IAS}} S$$

α°

(Angle of Attack)



Wing Shape

Surface Area

WAKE TURBULENCE

Wake Turbulence

A result of the air spilling around the wingtip from the region of higher pressure below the wing to the lower pressure above

The *greater the AoA* (and therefore the pressure differential), the greater the flow around the wingtips (and the *greater the wake turbulence*).

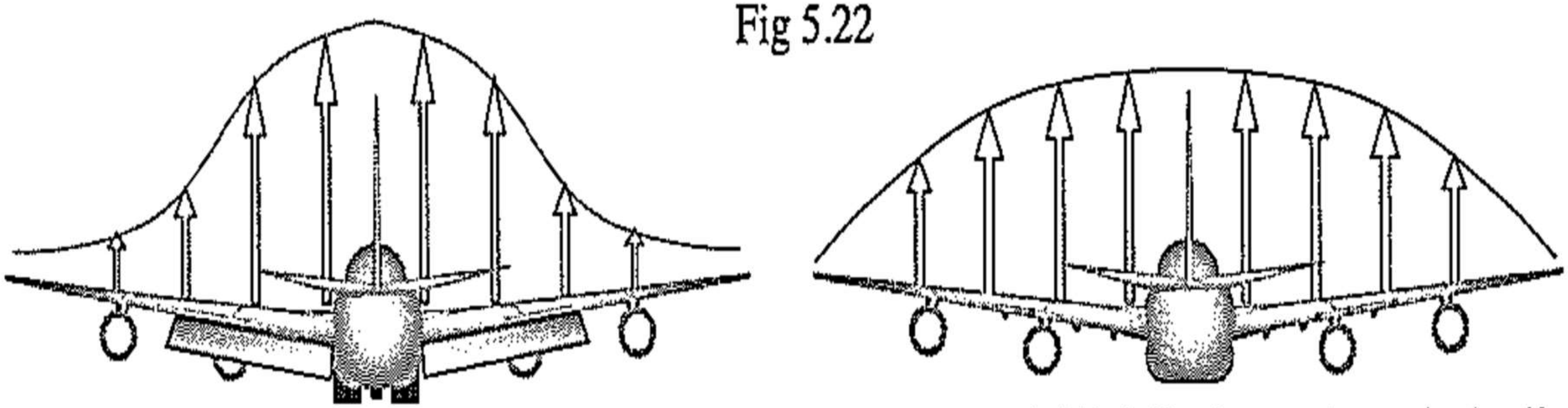
Wake Turbulence

Wake turbulence is affected by:

AoA	Increase AoA = Increase WT
IAS	Deacrease IAS = Increase WT
Aircraft Weight	Increase Weight = Increase WT
Aspect Ratio	Increase A.R = Decrease WT
Time	Increase Dissipating time = Decrease WT

Wingtip vortices are of greatest strength when the aircraft is heavy, slow with gear and flaps up

Wake Turbulence



With flap extended, most of the lift is gererated over the inboard section.

With flap retracted, the lift is distirbuted more evenly across the wing with more being made near the wing tips.

A Wing flying slowly with flaps up will always make more wake turbulence

Wake Turbulence is strongest just prior to take-off

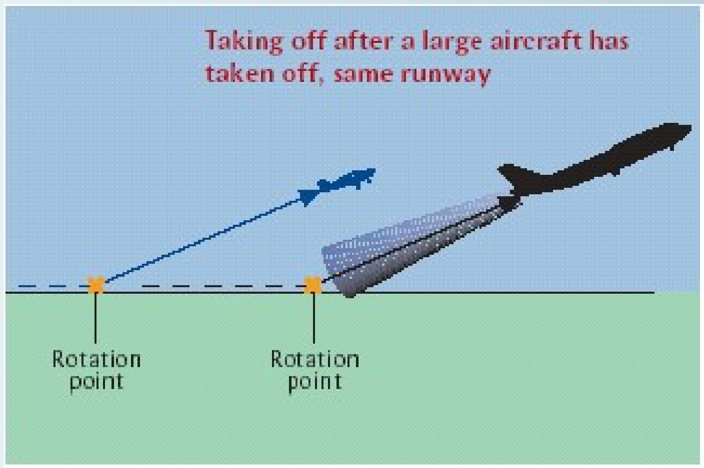
Avoiding Wake Turbulence

Shaded areas = high risk zones i.e.: AVOID

Avoiding Wake Turbulence

If possible fly *upwind and above* the flightpath of the aircraft producing wake turbulence, avoiding it altogether.

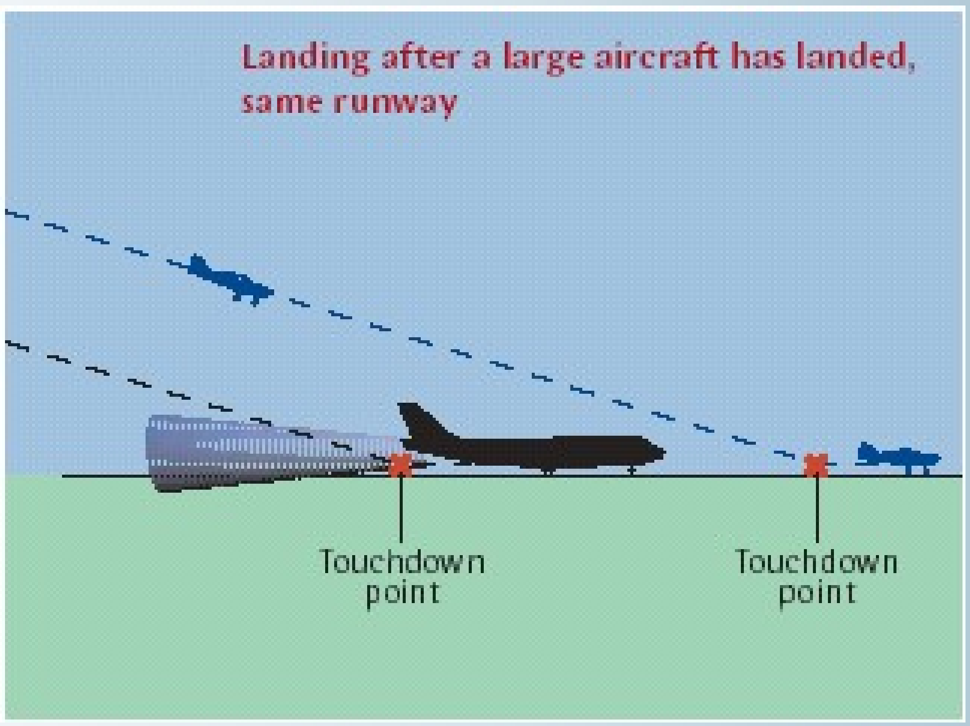
For *take-off* aim to lift off well *before* the *rotation point* of the preceding, departing aircraft and climb well above its flightpath.



When *taking off* behind an aircraft which has just landed aim to rotate well *beyond its touchdown point* or *delay the take-off* (wait for vortices to dissipate), as per wake turbulence separation standards in the JEPPS ATC AU-810

Avoiding Wake Turbulence

For *landing* after a preceding landing aircraft aim to approach *above it's flightpath* and land a safe distance *beyond* its *touchdown point*.



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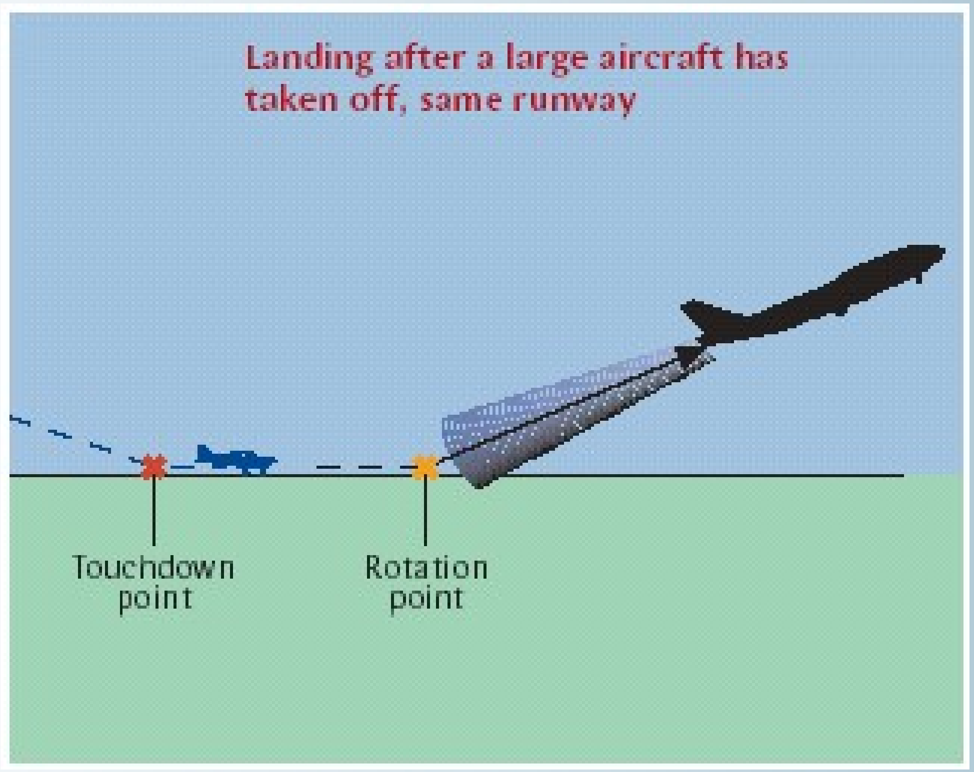
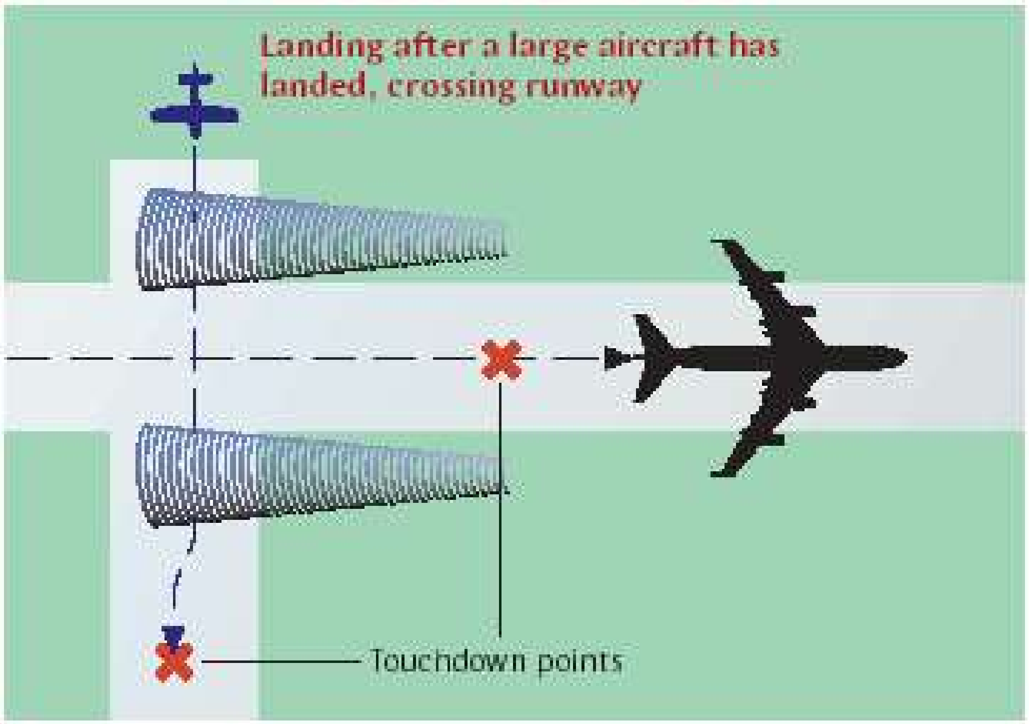
Avoiding Wake Turbulence

For *landing* after a large aircraft has departed aim to touchdown *well before* its *point of rotation*.



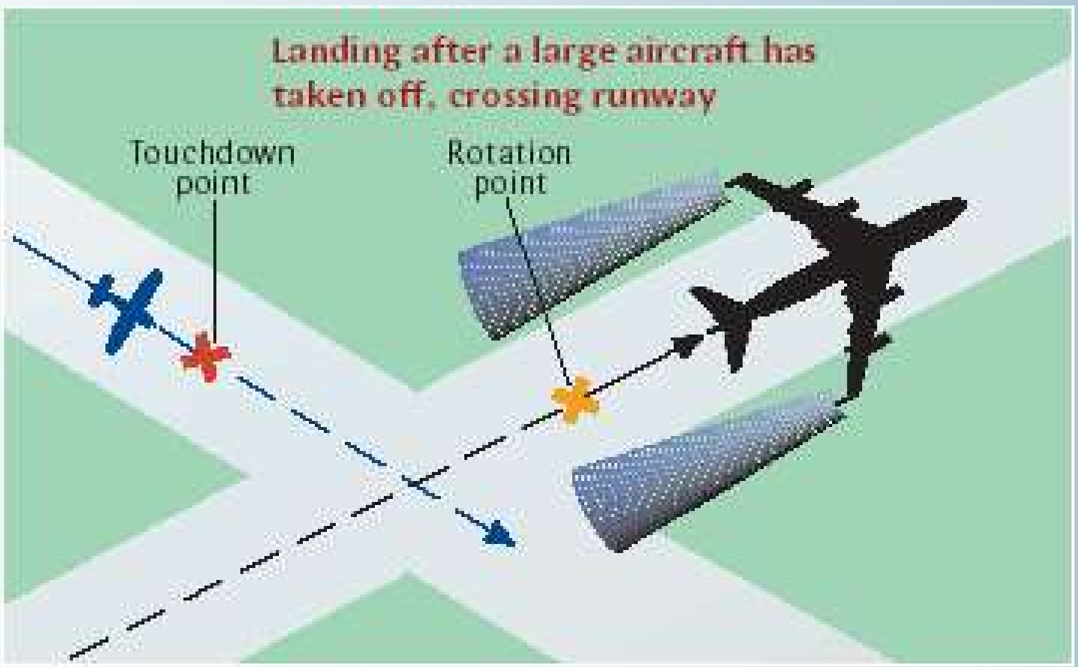
Avoiding Wake Turbulence

When landing on a *crossing runway* plan to cross *above* the larger, landing aircraft's *flightpath* and *touchdown* well *beyond* the runway it has landed on (see below).



Avoiding Wake Turbulence

When *landing* behind a *larger aircraft taking off* from a *crossing runway*, if the larger aircraft *rotates beyond* the *intersection, touch down before* the *intersection*. If *it rotates prior* to the intersection *discontinue* the approach unless the landing run can be completed before the intersection (see below).



Avoiding Wake Turbulence

Wake Turbulence vortices sink at a rate of approx. 400-500fpm behind the flight path

At 900ft the vortices stabilise and once stabilised, the cover an area of sky equal to 2 wingspans horizontally by 1 wingspan vertically

Therefore, when *avoiding* wake turbulence *en-route* aim to stay at least *200' above* and *1000' below* the aircraft's flightpath.

In the event a *heavy aircraft* conducts a *baulked approach* it should be assumed the *entire length of the runway* could pose a *hazard* and the departure or approach delayed or discontinued respectively.

Vortices can persist for up to 3 minutes on the ground and up to 5 minutes at altitude

Helicopter Wake Turbulence

Helicopters also produce wake turbulence (rotor downwash), the strength of which is usually far greater than a fixed-wing aircraft of similar weight. The strongest wake turbulence occurs when the helicopter is operating at lower speeds.

Rotor downwash can be hazardous up to a radius of ≈ 3 x rotor diameter

Wake turbulence associated with a Sikorsky S-76