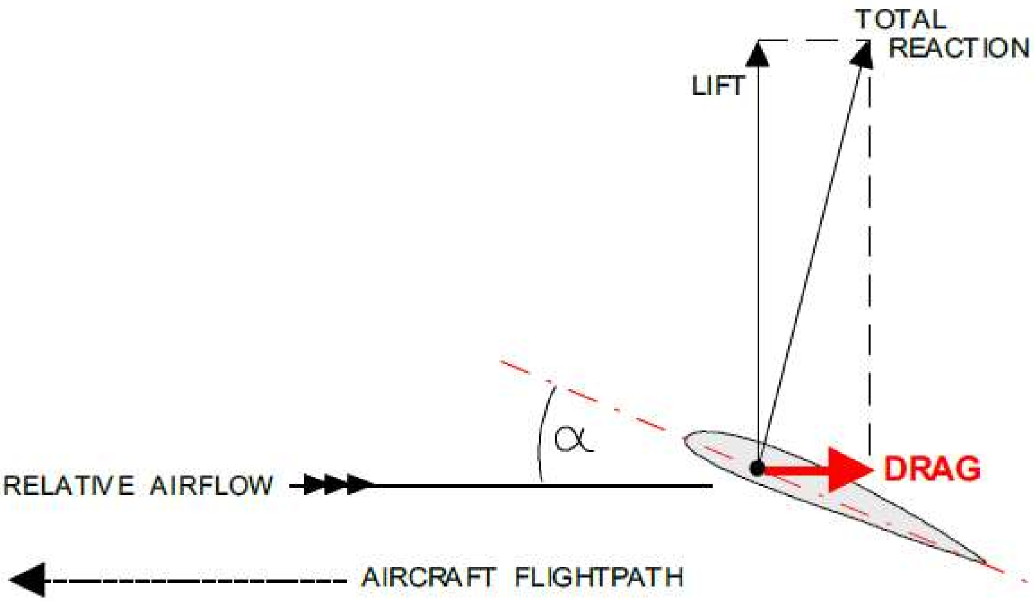
IV. DRAG

1) Definitions & Type

DRAG: Force opposing to a motion due to the air resistance. Drag acts parallel to and in the same direction as the relative airflow (in the opposite direction to the flight path). Please remember that when considering airflow velocity it does not make any difference to the airflow pattern whether the aircraft is moving through the air or the air is flowing past the aircraft: it is the relative velocity which is the important factor.

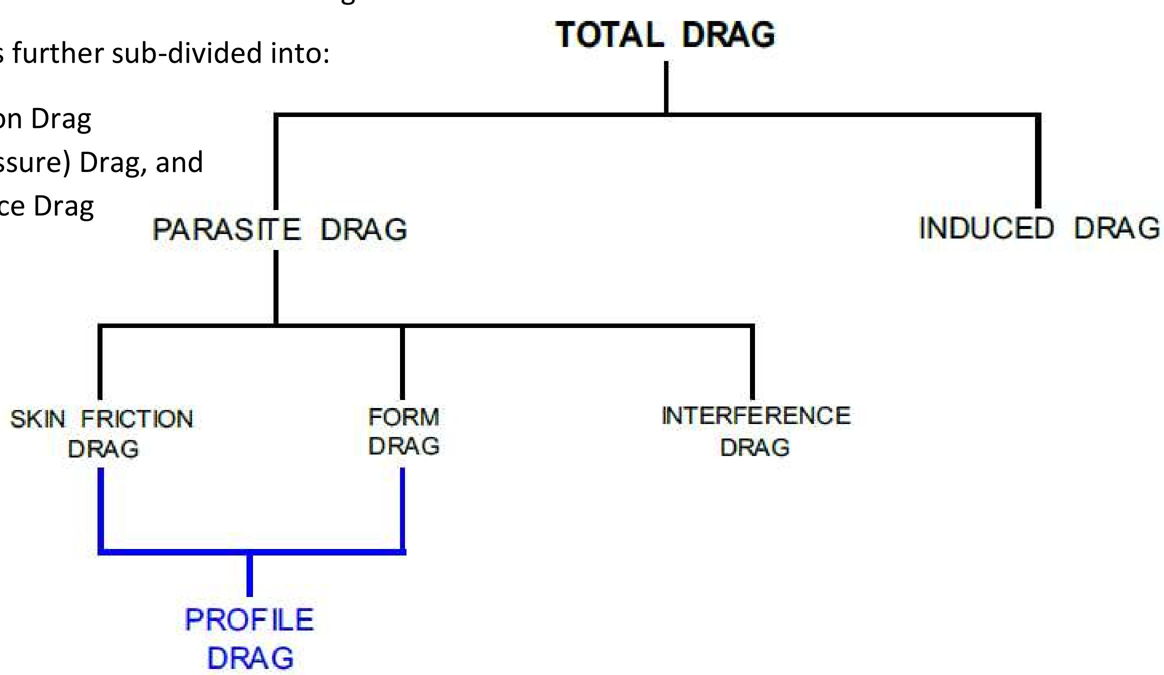


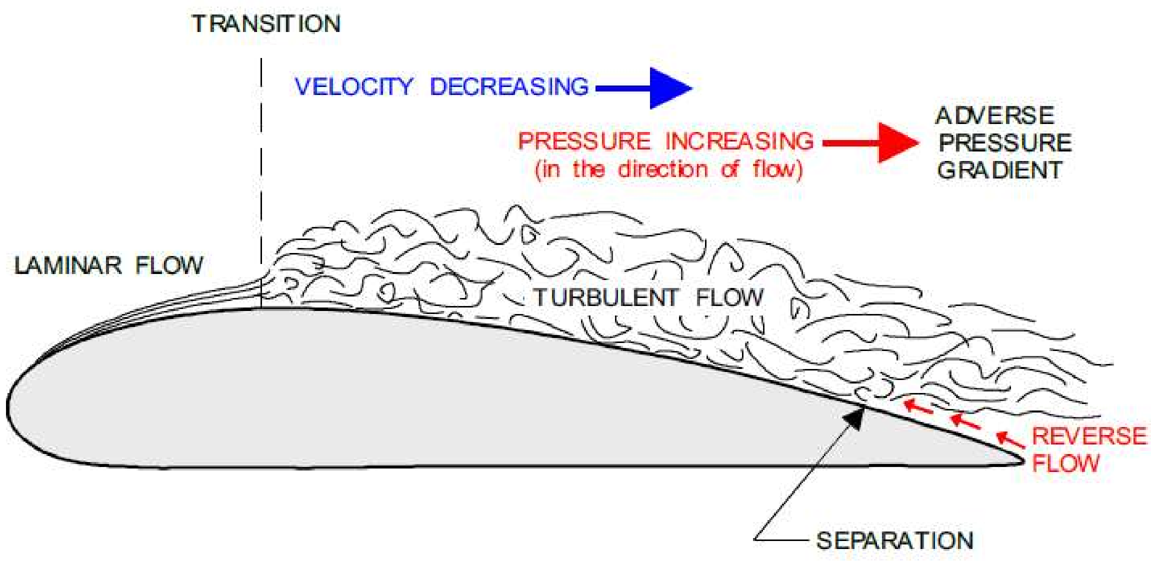
Every part of an aeroplane exposed to the airflow produces different types of resistance to forward motion which contribute to the Total Drag. Total Drag is sub-divided into two main types:

- PARASITE DRAG - independent of lift generation, and
- INDUCED DRAG - the result of lift generation.

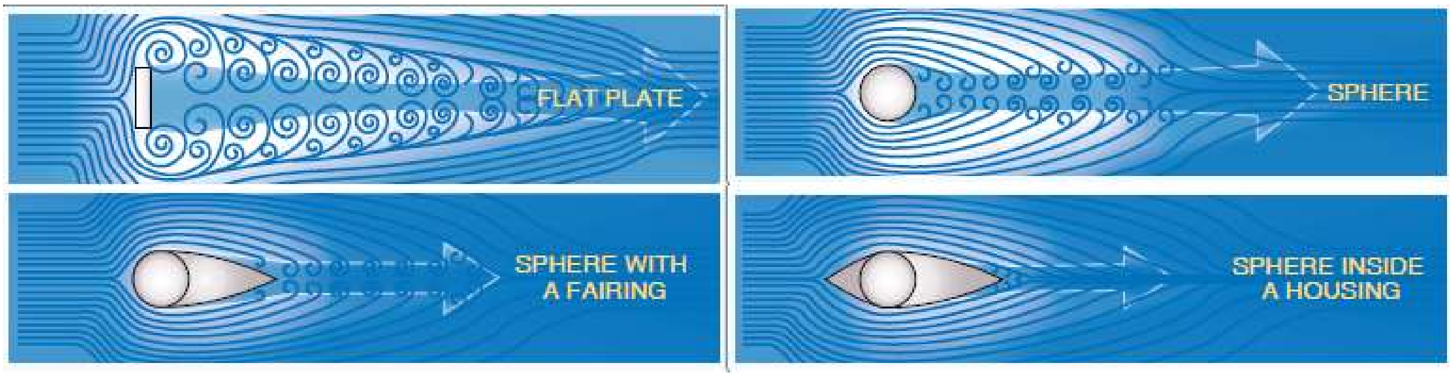
Parasite drag is further sub-divided into:

- Skin Friction Drag
- Form (Pressure) Drag, and
- Interference Drag

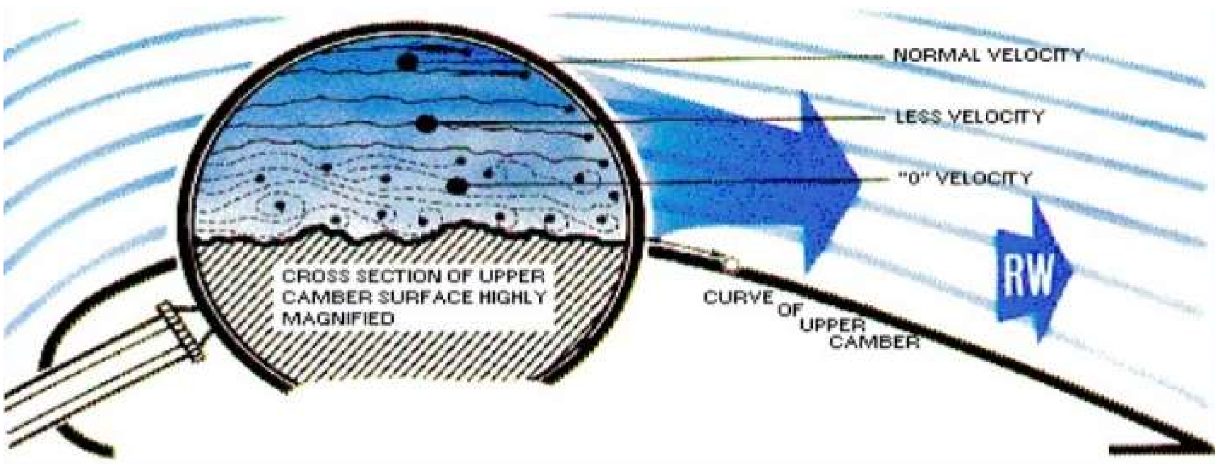




Form/pressure Drag: Drag due to the shape of the object, the thicker is the leading edge and the greater will be the differential pressure, making a higher adverse pressure gradient resulting in a higher drag



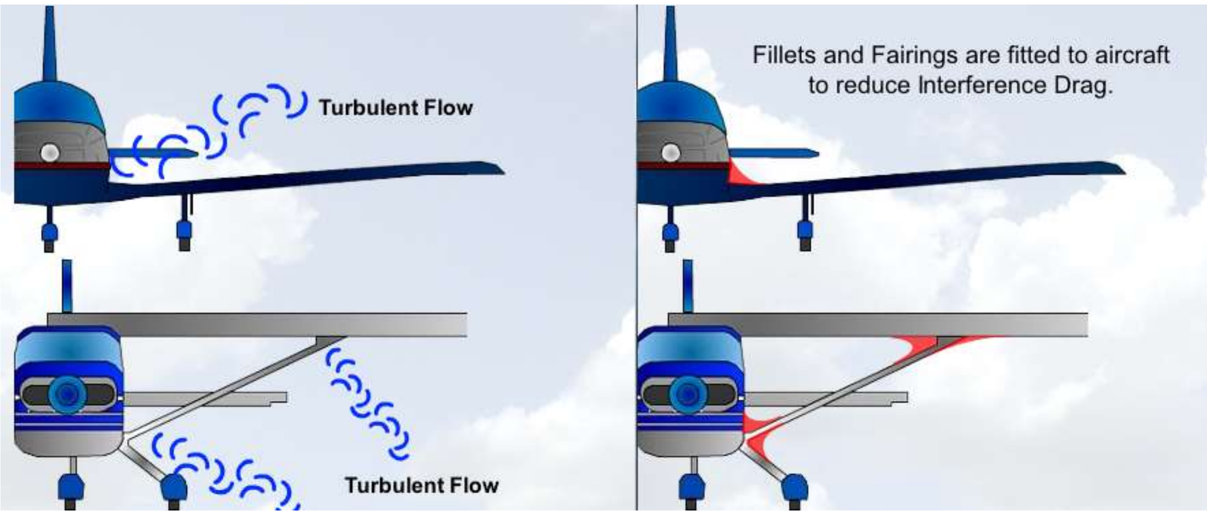
Skin Friction Drag: Drag due to surface roughness, the rougher is the surface, the more the airflow is slew down and loses its kinetic energy earlier.



Profile Drag: Sum of the Form/Pressure and Skin Friction Drag

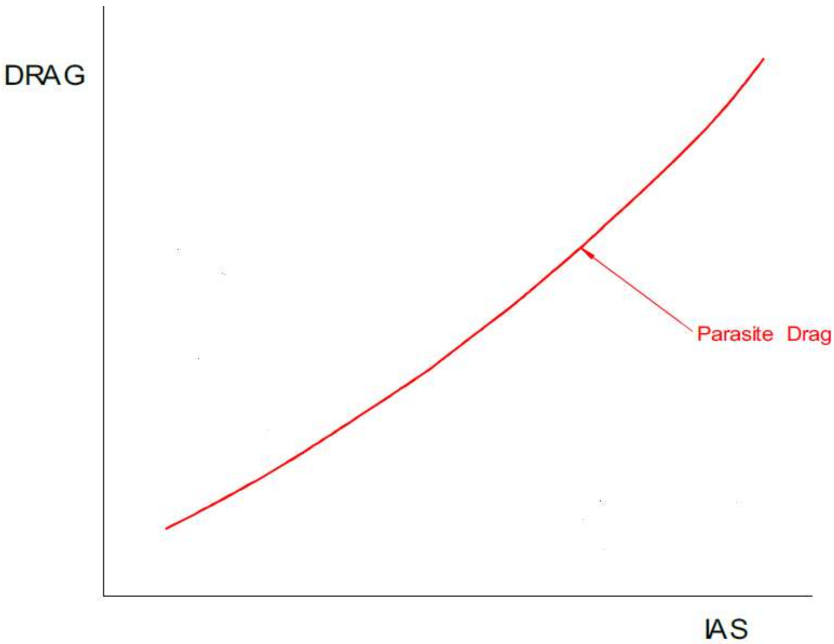
Interference Drag: Drag due to the acute angles at the junctions of the wing root to the fuselage. Acute angles cause more restriction to the airflow and so a higher drag.

The interference Drag can be reduced by fairing the angles, this means the shapes become more streamlined into the airflow.



Parasite Drag (D_P): Sum of the Profile Drag and the Interference Drag

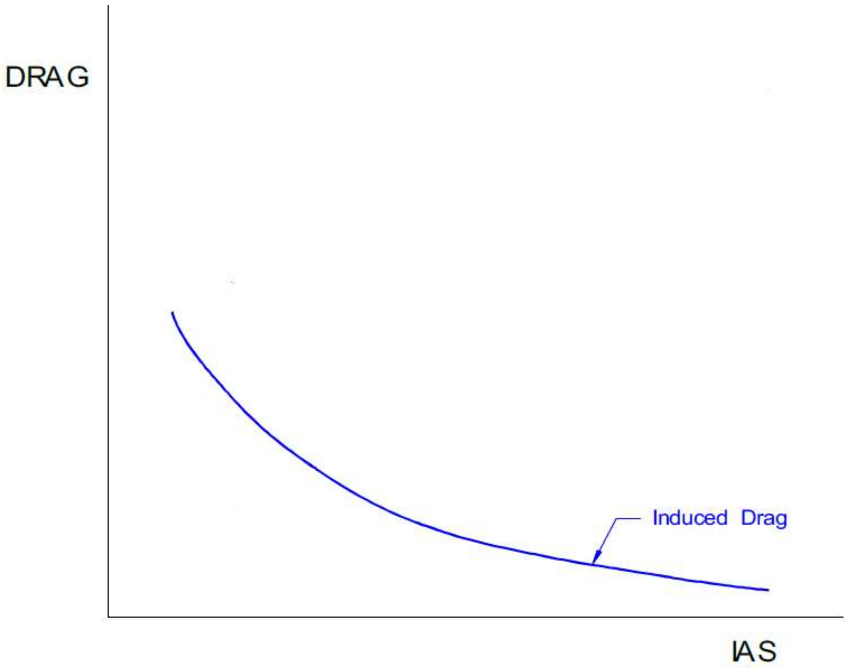
The Parasite Drag doesn't exist when the aircraft isn't moving, it starts to appear when a forward air speed exists, and the higher the speed the lower is the static pressure, so the adverse pressure gradient force will be higher and so the Parasite Drag increases. Thus the Parasite Drag increases with increasing airspeed.



<u>Induced Drag (D_i)</u>: Drag create due to differential at high AoA (see LIFT)

IT has been seen when the AoA increases, C_L increases and so the differential pressure at the lower and upper surface of the aerofoil increases, this makes the spanwise flow much greater and so the wingtip vortices will also be greater, which cause the upwashes and downwashes higher and so the generated LIFT will become more backward, leading to an increase in the induced Drag.

When the aircraft travels at a faster airspeed, it requires a lower AoA to maintain the same required LIFT, meaning that at faster speed, the D_i decreases.



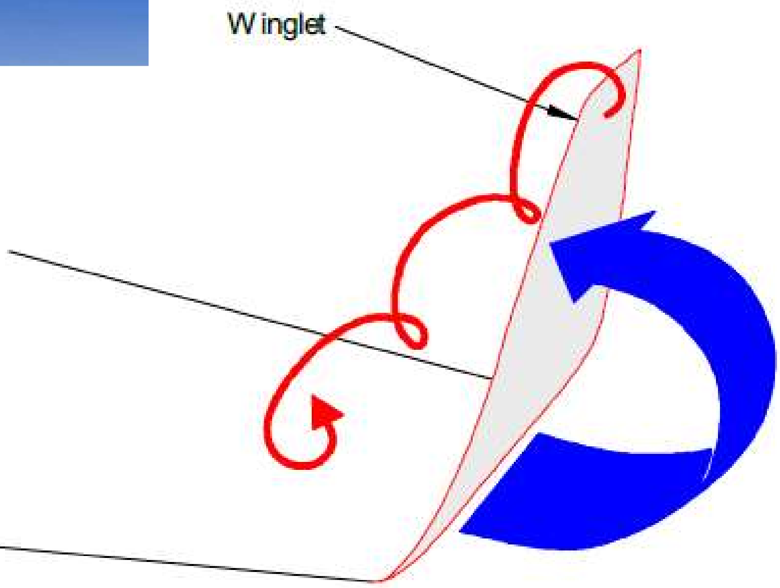
Different technics exist to minimise the induced Drag, this is done by adding devices to create a barrier to the wing tip vortices, such as:

- Winglets
- Wing tip tanks
- Wing end plates

WINGLET

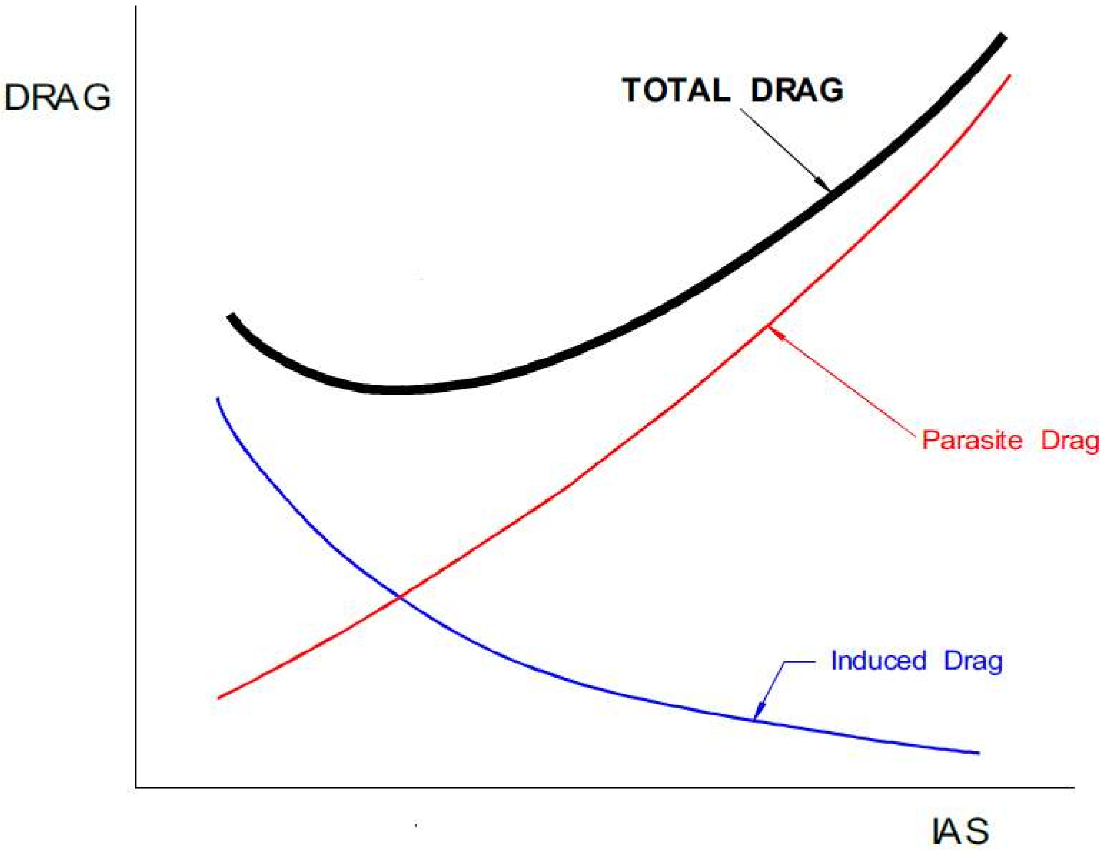
WING TIP TANKS

WING END PLATE



Total Drag (D_{TOT}): Sum of the Parasite Drag and the Induced Drag

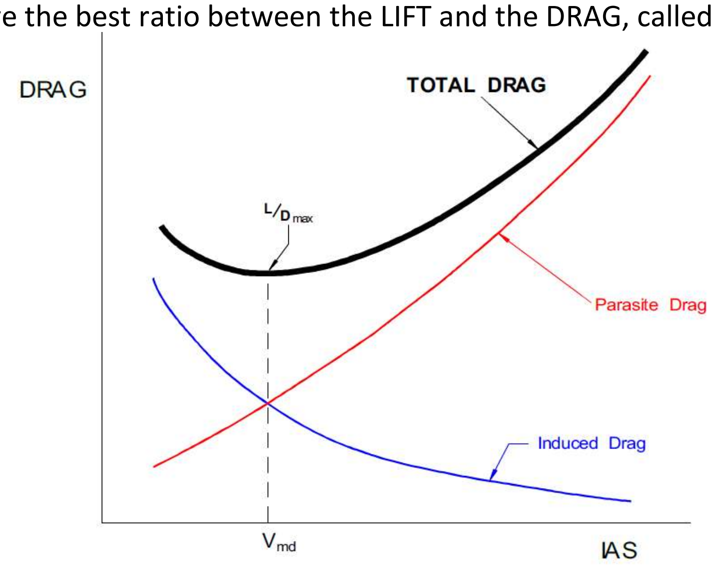
At a low airspeed, the D_{TOT} is mainly high due to the D_i, it decreases with increasing airspeed, however then it starts to increase again mainly due to the D_P which is becoming significant a high airspeed.



2) DRAG Analysis & DRAG Equation

The DRAG curve

It has been seen that the DRAG will initially decrease, then it will increase with increasing the airspeed. So at given airspeed, the DRAG will reach its minimum value before it starts to increase again. The speed at which the aircraft reaches the minimum DRAG is called **V_{MD}, the Minimum Drag Speed**. When flying the Minimum Drag Speed, the aircraft has the least DRAG and so will achieve the best ratio between the LIFT and the DRAG, called the **Best L/D**.

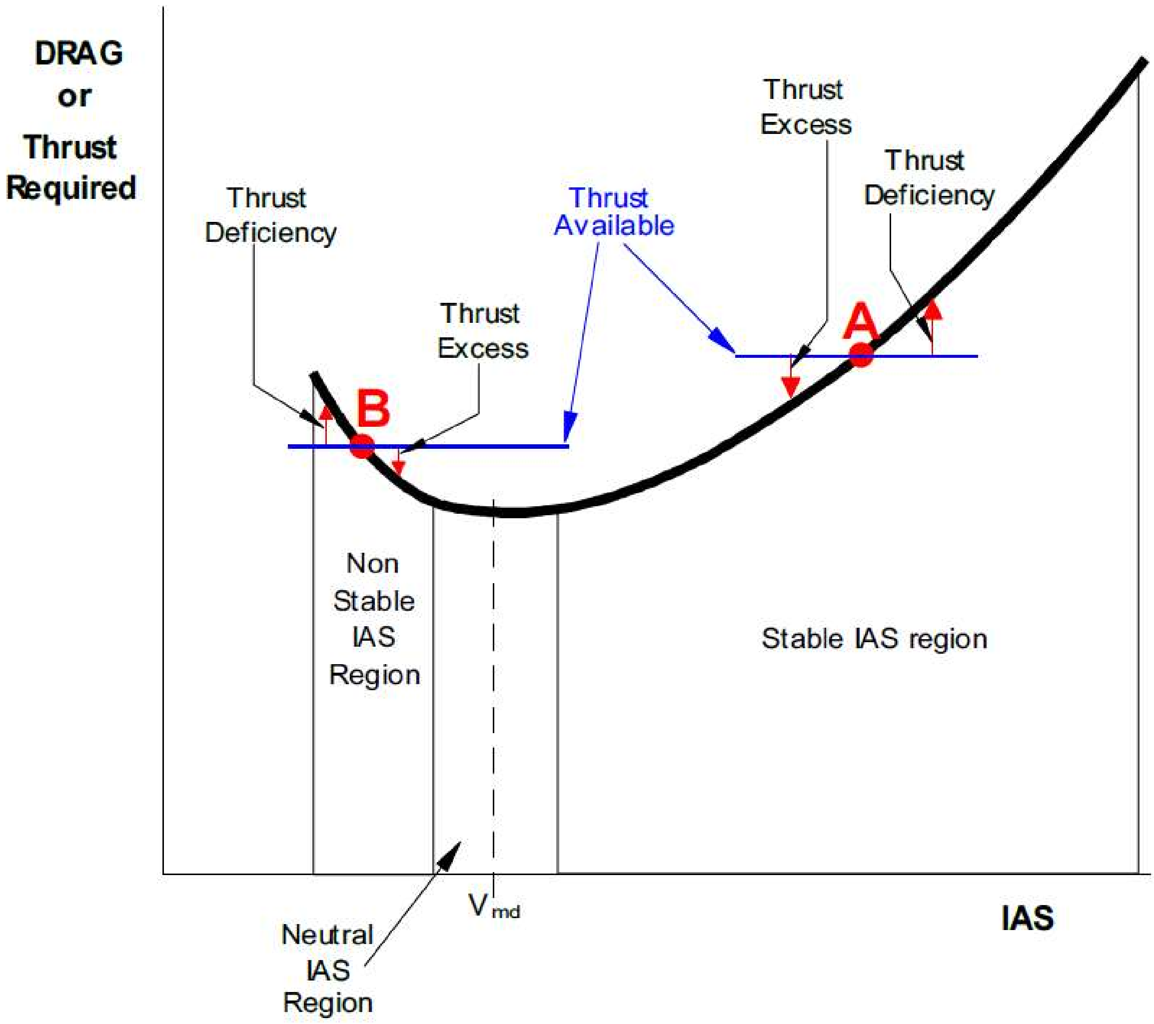


The DRAG is a force that exists when the aircraft has forward airspeed, this DRAG is a force acting against the aircraft flight path and so will make it to decelerate and so decrease its forward speed. So to maintain the forward speed, the aircraft's engine must produce the same amount of THRUST to keep the airspeed. If the DRAG is higher than the THRUST, the airspeed decreases, and when the DRAG is less than the THRUST, the airspeed increases. In real there's no need to think much, the pilot will watch its airspeed indicator and adjust the THRUST as much as needed to keep the required indicated airspeed (IAS).

If we look at the DRAG curve below, we can see that after V_{MD}, the THRUST required to maintain a higher airspeed increases, this can look obvious: A higher speed needs a higher THRUST.

However this doesn't look obvious when we look before V_{MD}, because a lower airspeed needs a higher THRUST. You must put in mind that the CORRECT interpretation of this graph is: A higher airspeed after V_{MD} required a higher THRUST to maintain the airspeed because the DRAG is higher, and a lower airspeed below V_{MD} requires also a higher THRUST because the DRAG increases.

We can say that the DRAG curves shows the THRUST REQUIRED for a given airspeed, and so call it the **THRUST REQUIRED CURVE.**



Stability Region

Something is said to be stable when, after disturbing or changing it, it tends to come back to its initial position or value.

If we look at the area after V_{MD}, we can see, if there's for some reason, a fluctuation in the airspeed, for example an increase in the airspeed, the DRAG will be higher and this, without increasing the THRUST, will make the aircraft to decelerate and so come back to its initial airspeed where the DRAG will be equal to the THRUST maintained. This area is called the Stable IAS Region.

Something is said to be unstable when, after disturbing or changing it, it tends to go further away from its initial position or value.

If we look at the area after V_{MD}, we can see, if there's for some reason, a fluctuation in the airspeed, for example an decrease in the airspeed, the DRAG will be higher and this, without increasing the THRUST, will make the aircraft to decelerate to a further lower airspeed. This area is called the Non Stable IAS Region.

Something is said to be neutral when, after disturbing or changing it, it will remain in the same position or keep the same value, without tending to come back or go away from its initial value or position.

If we look at the area near V_{MD}, we can see, if there's for some reason, a fluctuation in the airspeed, for example an decrease in the airspeed, the DRAG will be almost the same (flat curve) and this, without changing the THRUST, the aircraft will neither accelerate or decelerate to a another airspeed, the DRAG is still equal to the THRUST. This area is called the Neutral IAS Region.

*Remember, in the non-stable IAS region, also known as **the backside of the Drag Curve**, a slower/faster speed requires more/less THRUST to be maintained.*

Thrust Deficiency

The engines have a certain amount of THRUST that can be provided, this called the THRUST AVAILABLE. On the Graph we can see two different THRUST AVAILABLE (the examples are not concrete, the THRUST AVAILABLE depends on the engine). For a given airspeed, there's a given amount of DRAG.

When the DRAG is below the THRUST AVAILABLE, it means that the engine can compensate for that amount of DRAG, without the need to use all the THRUST AVAILABLE, the space between the DRAG and the THRUST AVAILABLE is the remaining THRUST in reserve that could be used for another purpose (example in CLIMB which will be covered later in the lesson), that reserve is called the **EXCESS OF THRUST AVAILABLE**.

When the DRAG is above the THRUST AVAILABLE, it means that the engine cannot compensate for that amount of DRAG, and so the airspeed cannot be maintained because there's not enough THRUST AVAILABLE, the space between the DRAG and the THRUST AVAILABLE is called the **THRUST DEFICIENCY**.

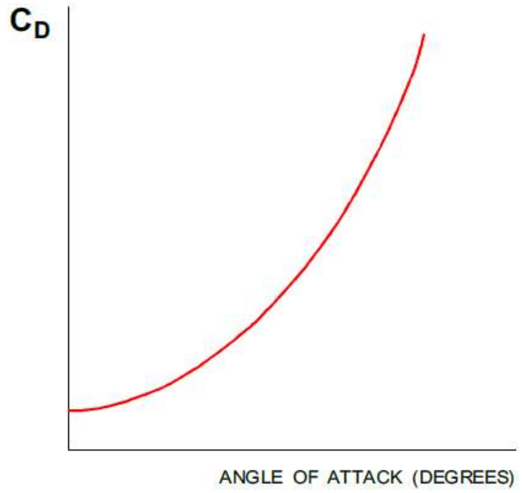
At the point A, the aircraft will achieve its maximum indicated airspeed, because there's no further THRUST to provide to maintain a higher airspeed where the DRAG is higher.

At the point B, the aircraft will achieve its minimum indicated airspeed, because at a lower airspeed the DRAG will increase and the engine won't be able to compensate for that DRAG. However in practice, before reaching that speed would have already reached its AoA_{CRIT} because a lower airspeed required a higher AoA.

The coefficient of Drag C_D

C_D: Coefficient of Drag, number defining the capability of an aerofoil to create Drag at a given AoA.

Disregarding the airspeed or for the same airspeed, at a low AoA, the D_i is less, in addition, the aerofoil will cause less restriction to the airflow, so even the Form (Pressure) Drag will be less. However at a higher AoA, the D_i will be higher and the Form (Pressure) Drag will also be higher. This means that an aerofoil has more Drag capability at a higher AoA. **The C_D increases with increasing AoA.**



The Drag Formula

$$D = \tfrac{1}{2}\rho V^2 .\ S.\ C_D$$

$\tfrac{1}{2}\rho V^2$: The Dynamic Pressure (often written **Q**), it is simply the kinetic energy of the air, the Q depends on the airspeed and on the density (ρ). When the density is higher, the amount of molecules will be higher and so the airflow will have a higher kinetic energy or Q, so the differential pressure will be higher and also the adverse pressure gradient (cause of the DRAG). As well, when the airspeed increase, the static pressure will be more reduced above the aerofoil and the differential pressure will be higher and also the adverse pressure gradient.

S: The wings area. On the drawing, the DRAG has been described only at the aerofoil, which is one section of the wing. Remember the wing is an infinite number of aerofoil (wingspan) and also the averse pressure gradient is generated from different points along the aerofoil (chord). The wing area is simply **S=wingspan x chord**. The wider is the wing area and the higher is the DRAG.

C_D: The Coefficient of Drag. The Coefficient of Drag depends on the AoA only (in an airflow <M0,4). The higher the AoA, the higher is the C_D and higher the DRAG.

Note that the formula is similar the LIFT formula except the C_L which is replaced by C_D. This is normal because the LIFT and the DRAG are both aerodynamic force. All aerodynamic force (F) are: ***$F = \frac{1}{2}\rho V^2 . S . C_F$***

<u>The effect of aircraft gross weight on Total Drag</u>

The effect of variation in aircraft gross weight on Total Drag can be seen on the curve below. As fuel is consumed in flight, the gross weight will decrease. As the aircraft weight decreases, less Lift is required, so a lower C_L will be maintain with a lower AoA, which will reduce the induced drag. Total Drag will be less and V_{MD} will occur at a lower IAS. (The Drag Curve moved down and left)

If an aircraft is operated at a higher gross weight, more Lift will be required. If more Lift is generated at a higher AoA, the induced drag will be higher. Total drag will be greater and V_{MD} will occur at a higher IAS. (The Drag Curve moved up and right)