4 Lift/Drag

4.1 Lift/Drag Ratio

4.1.1 Review of C_L / α and C_D / α Curves

An aircraft designer does not only have to make sure that enough lift is produced by the wings but also at a reasonable amount of thrust, i.e. without simultaneously producing too much drag. Up until now we have been dealing with lift and drag separately. In order to determine the performance and efficiency of an airfoil at a particular angle of attack (and airspeed), lift and drag must be considered together.

You remember that the lift curve shows a steady increase in the coefficient of lift with an increase in the angle of attack, up to the stall angle of attack. Beyond the stall angle of attack, the coefficient of lift decreases rapidly due to the stall of the airfoil. The coefficient of drag versus angle of attack curve shows that C_D increases steadily all the way as the angle of attack increases. *Fig. PF 4.1.*

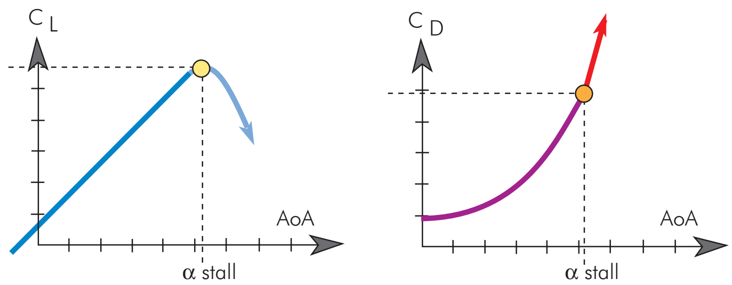

Fig. PF 4.1 Lift and drag versus AoA

We can see that C_D has its minimum value at small angles of attack. As the stall angle is approached, the drag increases at a progressively higher rate due to separated flow.

> C_D has its minimum value at small angles of attack. With an increase in the AoA, drag increases at a progressively higher rate.

In order to evaluate the wing efficiency we must consider more than just the lift produced. In fact, a wing has its greatest lifting ability just prior to the stalling angle of attack. Unfortunately, near the stalling angle, the wing also generates considerable drag.

A wing has its greatest lifting ability ($C_L$max) at the stall AoA but also very high induced drag.

The minimum drag occurs at a fairly low angle of attack, in this case slightly above zero degrees AoA. Unfortunately, the lifting ability is very low at low angles of attack as shown in *fig. PF 4.1.*

At each angle of attack, the lift/drag ratio is the ratio between lift and drag or between the coefficient of lift and the coefficient of drag. It expresses the aircraft efficiency.

4.1.2 Polar and Lift/Drag Ratio Curves

We can draw a curve that shows the variation of the C_D as a function of the C_L. In other words, for a given aircraft it shows how much drag is produced for a given lift at every angle of attack. This curve is called the **polar curve.** *Fig. PF 4.2.*

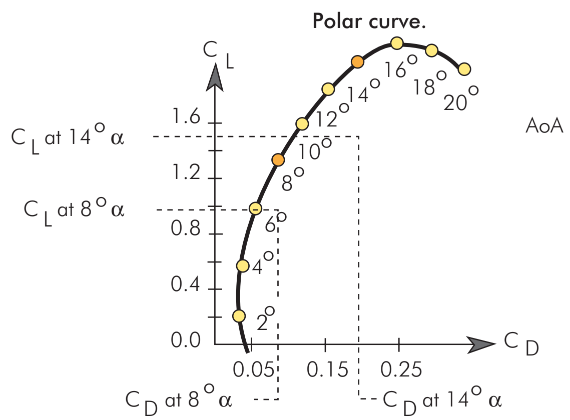

Fig. PF 4.2 Lift and drag coefficients at different angles of attack, Polar curve

The polar curve shows the variation in C_D as a function of C_L.

Each point of the polar curve is obtained for a given angle of attack and shows the corresponding values of the coefficients of lift and drag.

For each angle of attack we can calculate the lift/drag ratio by dividing C_L by C_D (or lift by drag). In this way we can draw a curve representing the variation of the L/D ratio **as a function of the angle of attack.** *Fig. PF 4.3.*

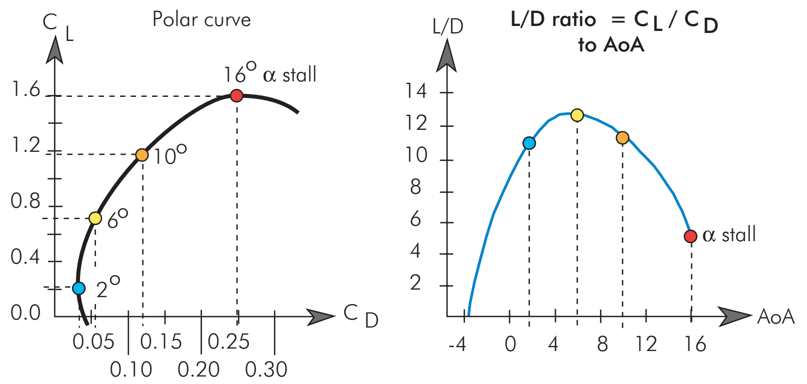

Fig. PF 4.3 Polar curve and L/D to AoA curve

4.1.3 Best Lift/Drag Ratio

For a light aircraft with a normally cambered wing we can see that, when the angle of attack is increased, the L/D ratio rapidly increases from zero to the maximum value. Then, as the angle of attack is increased further, the L/D ratio decreases until the stalling angle is reached and keeps decreasing even beyond that angle. The reason for this behaviour is that when the angle of attack is increased until the lift/drag ratio reaches its maximum value, both C_L and C_D increase but C_L increases more than C_D.

When the angle of attack is increased beyond the maximum lift/drag ratio, C_D increases more than C_L.

A straight line inclined at a given angle, γ, from the axis origin on C_L - C_D plane, represents the LIFT/DRAG RATIO.

The smaller the angle between C_L axis and the straight line, the greater the lift/drag ratio. If we draw another straight line from origin of coordinates through point C and D we find the ratio between C_L and the C_D to be equal to 10. *Fig. PF 4.4.*

We can say that each straight line drawn from the axis origin represents a given lift/drag ratio. This lift/drag ratio is proportional to the straight line inclination which is measured by the angle γ.

The smaller the angle γ, the greater the lift/drag ratio.

We have said that each point on the polar curve represents a given angle of attack. Thus, to create a certain lift at a low AoA, the speed needs to be high **causing very high**

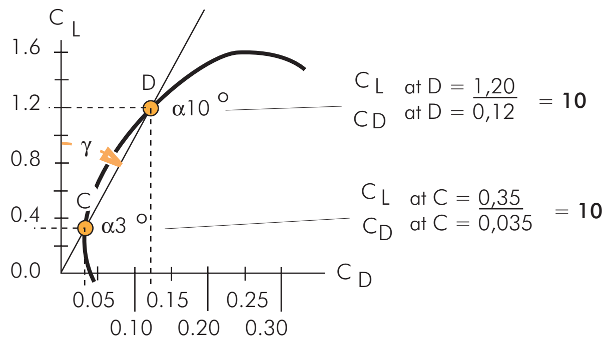

Fig. PF 4.4 AoA that gives C_L / C_D equal to 10

zero lift drag D_0, and at a high AoA the speed is low causing very high induced drag D_i. The same is true for an AoA of 3º and 10º respectively. *Fig. PF 4.4*.

The same lift over drag relations exists at low speed as well as high speed.

In order to find the **AoA for the best C_L/C_D** on the polar curve, we must draw the **tangent** to the curve starting from the axis origin. We can see that the best lift/drag ratio in this example is at 5º AoA which is equal to a lift/drag ratio of 13. *Fig. PF 4.5.*

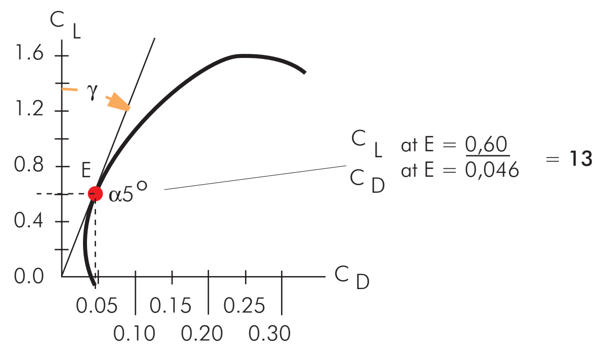

Fig. PF 4.5 AoA that gives the highest C_L / C_D equal to 13

The line which is the tangent to the polar curve represents the best lift/drag ratio.

In this example the best lift/drag ratio is 13, that is; the **lift is 13 x the drag.** The best lift/drag ratio for normal light aircraft is typically between 15 and 20 depending on several factors concerning the wings. In general, the optimum angle of attack is about 4°

In the case of gliders, the L/D can reach values of 30 to 60, thus the drag is so low that you should be able to pull it in the air with only one hand, despite its mass of 400 to 500 kg, including the pilot! *Fig. PF 4.6.*

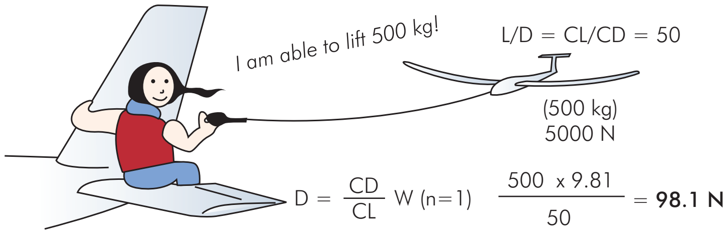

Fig. PF 4.6 L/D of glider

A normal light aeroplane creates a lift 15 to 20 times higher than the drag simultaneously produced. A glider with L/D of >30 can be pulled in the air by use of one hand only!

The angle of attack at which we obtain **the best lift/drag ratio** is called the **Most Efficient Angle of Attack.** For a normal light aircraft the value is approximately a 4-5º. *Fig. PF 4.7.*

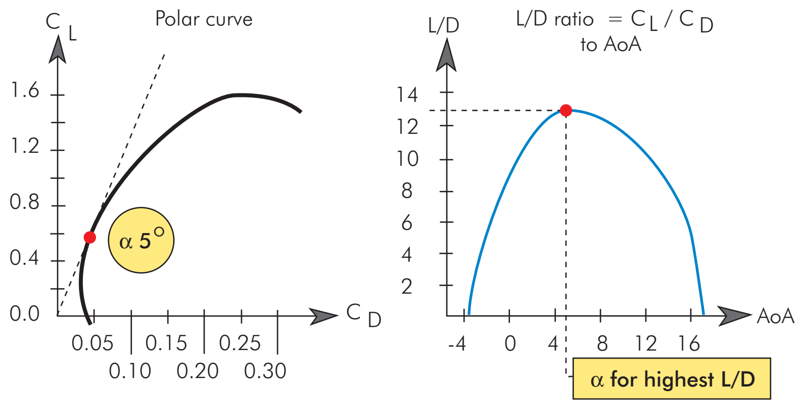

Fig. PF 4.7 Example of AoA that gives the highest L/D

The angle of attack at which we obtain the best lift/drag ratio is called the MOST EFFICIENT ANGLE OF ATTACK.

4.2 Factors Affecting the Lift/Drag Ratio

All items that affect the aeroplane's drag, affect C_D/C_L ratio as well. Increasing drag at a given C_L increases the C_D/C_L ratio, thus decreases C_L/C_D ratio. These items are:

- Wing section. The wing section with the lowest drag yields the best C_L/C_D ratio.
- Use of flaps. Deployment of high lift devices will in most cases increase the drag. Only when being near or at speeds for stall for a clean wing can the use of flaps reduce drag somewhat. But during all other flight conditions, high lift devices reduce the lift/drag ratio. *Fig. PF 4.8*.

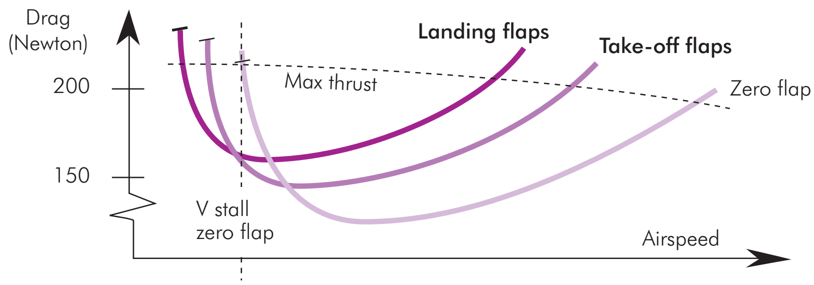

Fig. PF 4.8 Increased drag with flaps

- Gear down .Selecting the gear down decreases the C_L/C_D ratio.
- Aspect ratio. Because a high aspect ratio reduces the induced drag, the C_L/C_D ratio at a certain C_L is high when the aspect ratio is high.
- Aeroplane mass. At the same speed, the C_L/C_D ratio is higher when the mass is higher. However, at a higher speed, when the C_L value is equal to the C_L at the lower mass, the C_L/C_D ratios are also equal.
- Wing planform. The wing planform with the lowest induced drag yields the best C_L/C_D ratio.
- Aeroplane speed (AoA). The speed with the minimum drag yields the best C_L/C_D ratio.

4.3 Ground Effect

4.3.1 Airflow Within Ground Effect

When the aircraft is flying near the ground it changes behaviour because the presence of the ground modifies the airflow around the wing. We will now see what the so-called ground effect does to the aircraft.

Out of ground effect, the required lift is provided by means of an angle of attack that supplies the wing with a given coefficient of lift. Close to a lifting surface in free air we always have a certain upwash in front of the airfoil and a certain downwash behind it. Due to the wing tip vortices, the wing experiences a local mean airflow which is inclined downwards and the total aerodynamic force is inclined slightly further backwards. This increases the induced drag by a given amount. *Fig. PF 4.9.*

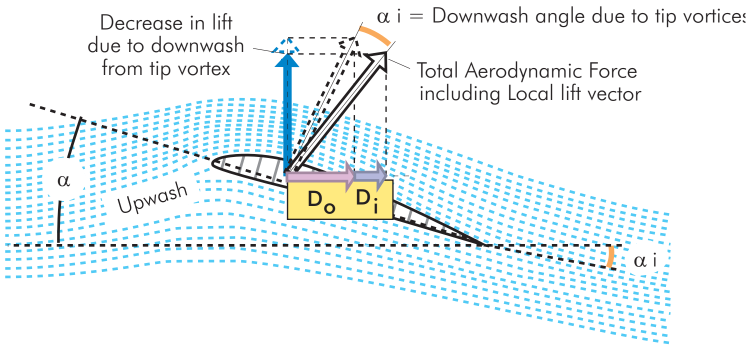

Fig. PF 4.9 Out of ground effect

When creating lift, the downwash of the tip vortices is the direct cause for the creation of induced drag.

4.3.2 Effect on Lift and Drag

As we have seen, without the presence of the ground the tip vortices modify the flow around an aeroplane wing. The local angle of attack of a certain wing section is reduced by an induced angle attack, causing a reduced lift force and inducing an extra contribution to the drag force, called induced drag.

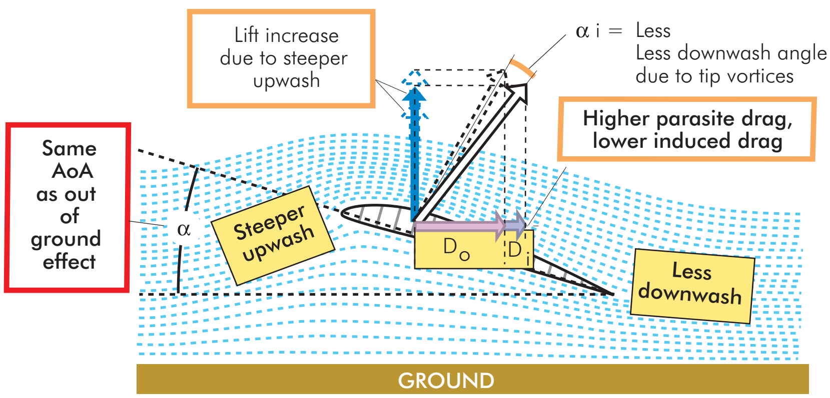

Fig. PF 4.10 At same AoA in ground effect