Understanding Sailplanes
by Martin Simons April 1995

Stalling

A wing generates lifting force by moving through the air at some speed. For efficient flight, lift must be generated without causing flow separation. When the flow over a wing separates, the wing is said to be stalled. The lifting power of a stalled wing is very poor while its drag is very great. Flight with a fully stalled wing is practically impossible.

The critical factor is the angle of attack. If the chord line of the wing is set at too great an angle to the flow, stalling results. This can be convincingly demonstrated with a very simple experiment (figure 1).

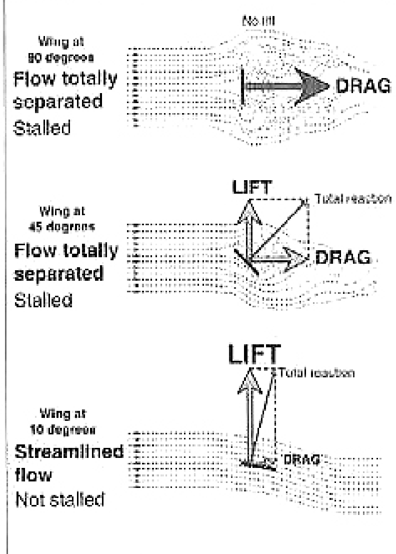

Figure 1. Experiments with a simple wing in the airflow from a fan

If a piece of card, representing a wing-like surface, is held in a horizontal air-stream, such as the breeze from a powerful fan, by chunking its angle this way and that it will be possible to feel the various forces that arise. If the surface is held in a vertical or nearly vertical plane, the only force arising will be drag, pushing the wing in the direction of the flow. At this angle of attack, about 90 degrees, the flow behind the card is totally separated.

If the angle of attack is reduced to about 45 degrees, massive flow separation still occurs. The drag force will still be very large. Some upward lift will be felt but the wing is stalled.

If the angle of attack is reduced in gradual stages from this, a point will be reached where the flow becomes streamlined.The lift force will increase and the drag will become much less. The wing is unstalled. Changing the angle this way and that slightly, establishes that the wing has a definite stalling angle, which represents the upper limit of usefulness in flight

The wing will stall at its stalling angle whatever the airspeed may be. A stall in flight can happen at any time, fast or slow, it the elevator is used too coarsely, forcing the wing to a high angle of attack. For instance, in a steep racing turn with the wings banked near the vertical, the lift force required from the wing is multiplied several times. The wing lift has to support not only the weight, but the inertia or centrifugal force generated in the turn. A turn with a bank angle of 80 degrees increases the load by nearly 6 times. (It is possible to break a wing under the strain of a steep turn, even at low airspeeds.) It is very easy to stall the wing in such a situation Another example is when a glider is being launched by towline. The wing litt has to support not only the weight but the pull on the line, which may be several limes greater than the weight of the model. If the pilot uses too much up elevator, even if the airspeed is high, a stall may result.

In aerobatics the wing may be deliberately stalled, to perform stalled turns, spins or flick rolls. In a vertical climb or dive, and in some other manoeuvres, the wing may be held at its aerodynamic zero or pass through it for a brief moment. In normal flight, the extremes are avoided.

Aerodynamic zero

A little more experimentation with card and fan will bring the wing to a very small angle at which it produces no lift at all. There will be some slight drag. If the card is perfectly flat, this zero lift angle will be when it is perfectly in line with the airflow. If, however, the card in the experiment is given a slight camber or gentle curvature, to reach aerodynamic zero it must be held at a slight negative or leading edge down angle (Figure 2).

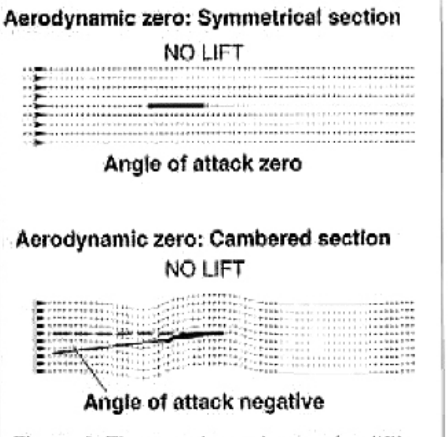

Figure 2. The aerodynamic zero (no lift) angle of attack for symmetrical and cambered wings

The angle at which no lift appears, is the aerodynamic zero for the wing. The aerodynamic zero angle otf attack varies according to the details of the camber. If the section is a flat plate or a perfectly symmetrical form that might he used for an aeroplane fin, the aerodynamic zero will be found when the wing is geometrically at zero angle of attack. For almost all other types of section, aerodynamic zero is found when the wing is at a negative angle. For lift to be generated, the angle of attack must be more than the aerodynamic zero

The normal limits

Two important angles have now been mentioned. At some small angle of attack, usually negative geometrically, a wing will generate no lift. This is the aerodynamic zero. At the stalling angle, the flow separates, drag increases greatly and lift is reduced, often quite suddenly between these two angles, the wing us capable of operating effectively, giving lift without excessive drag. These angles represent the upper and lower limits for normal flying and aircraft are designed, as a rule, to stay within these or to exceed them only occasionally. The pilot controls the angle of attack to prevent the wing reaching either its aerodynamic zero or its stalling angle, except perhaps momentarily in acrobatics.

It is worth mentioning that if the angle of attack is reduced beyond the aerodynamic zero, the wing will produce lift in the opposite sense. This enables flight to continue upside down. The aircraft may be turned onto its back, and the elevators used to bring the wing to a sufficient (negative) angle of attack to support the weight. Again, if this angle of attack is too great, a stall will result The wing therefore has one aerodynamic zero but two stalling angles, positive and negative (Figure 3).

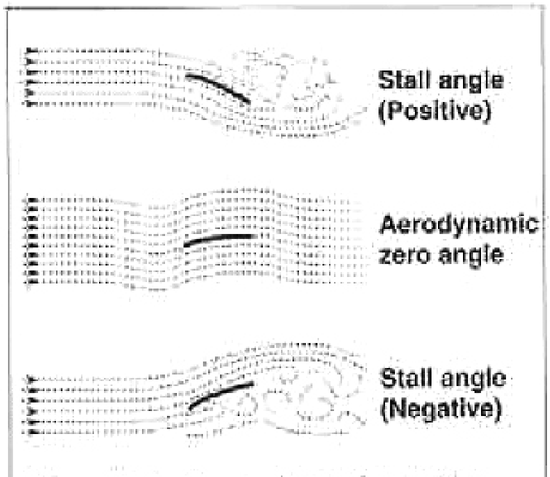

Figure 3. Positive and negative stalling angles

How lift is generated

Air cannot pile up in one place like blown sand or snow. As the wing moves forwards it cannot push up a heap of air in front like a bulldozer. The air is fluid, it flows around, over and under, and beyond the wing. As much air must pass the trailing edge in each moment of time, as passes the leading edge. At angles of attack above aerodynamic zero, the flow above the wing has somewhat longer distance to travel before it can rejoin the general stream. In order to keep its place without lagging behind and so causing the impossible heaping up, the streamlined flow above the wing must move faster than that underneath (Figure 4).

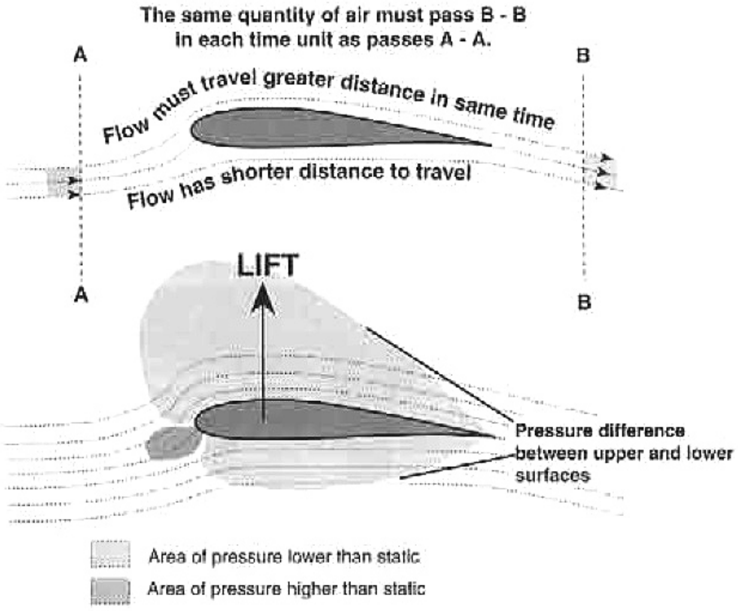

Figure 4. How lift is generated. The speed of the airflow over the upper surface of the wing is faster than that below. This creates a difference In pressure between the two sides, which creates lift.

Note. The flow under the wing usually increases in speed as well as that above so the pressure on both sides is less than the static pressure The lift is created by the difference between the surfaces. The high pressure area at the extreme leading edge is associated with the stagnation point where the air meets the wing and divides to pass above and below.

[Ed. Actually lift generation is a bit more complicated than that. See the forthcoming article on kinetic theory]

The difference in flow speed creates a difference in air pressure between the two surfaces, low pressure above and higher pressure below the wing. This pressure difference, normally spread over the entire wing area, is the source of the lifting force.

It may seem puzzling that an increase of flow speed above the wing creates a reduction of pressure. If we stand in a strong wind, the force on our bodies is larger than in a slower airflow. But the pressure on a wing is felt, or measured, on the surface at right angles to the ait motion at each place In strong winds, when roofs are blown off buildings, it is usually the reduced pressure over them that lifts them off the walls. The roof behaves like a crude wing.

The energy in the flow has two components, one due to its speed, often called kinetic energy, and the other the pressure it exerts at each point on the surface of the wing. This is an aspect of potential energy. The flow must accelerate over the longer route above the wing, so energy has to be found to speed it up. This can only come by exchanging some of the potential, or pressure energy, for kinetic or speed energy. The power to accelerate the flow is subtracted from the pressure, which therefore is reduced. The faster the flow passing over the skin of the wing, the smaller the pressure. This principle was originally discovered by Daniel Bernoulli, who worked on water flows and published his results in 1738. Bernoulli's theorem can be applied to air flow providing the speed of sound is not approached,

As the flow slows down again after the wing has gone through, its speed and hence pressure, returns to the normal or static value.

The underside of a wing is referred to as the high pressure side, but this is only relative to the upper surface. Often, the flow speed under a wing accelerates to some extent this causes a reduction of pressure, compared with the static pressure Useful aerodynamic litt will be produced by the wing as a whole so long as there is the required **pressure difference** between upper and lower sides.

Wing area and loading

An important relationship between wing area and mass to be lifted, is expressed as wing loading. A wing loading of 5 kg/sq m, for instance, means that each square metre of wing area is expected to carry 5 kg of mass. A source of misunderstanding is to forget that, in modem aerodynamics, mass is measured in kilogrammes and forces such as weight, lift and drag, in newtons To find the lift force in newtons required to support a model, the mass in kg must be multiplied by the gravitational factor 'g', which is 9.81 (Common domestic scales do not show newtons weight, they read kilogrammes mass, though no-one worries about this much.)

To find the wing loading of a model aeroplane, the total mass, including any fuel or ballast, must be divided by the wing area, to give the average mass supported by each square metre of wing. A jet airliner might fly with a wing loading o! 700 kg/sq m. a modern (full size) contest sailplane full of water ballast might exceed 50 kg/sq m. Model aeroplanes and gliders rarely reach 10 kg/sq m and are excluded from most competitions, and insurance policies, if this figure is exceeded.

In the FAI rule book for model aircraft, grammes and square decimetres are the units employed. A wing loading of 10 kg/sq is 10000 grammes per 100 sq dm, which cancels down to 100 g/sq dm. Only the addition of a zero is required, or moving a decimal point one place, to convert. In the old British Imperial measures, model wing loadings are expressed in ounces per square foot. 5 kg/sq m then becomes 16.4 oz/sq ft. Conversions are less easy with this system but a rough approximation can be made if the loading in ounces/sq ft is divided by 3.3 to give, nearly, kg/sq m.

The area of a wing is determined by viewing it in plan projection (Figure 5). If there is some dihedral or polyhedral, the projected view is slightly foreshortened Normally this makes very little difference, but if, for instance, there are vertical winglets at the tips, they are not counted. This can lead to anomalies since winglets behave to some extent as if they were extensions of the wing in span and area.

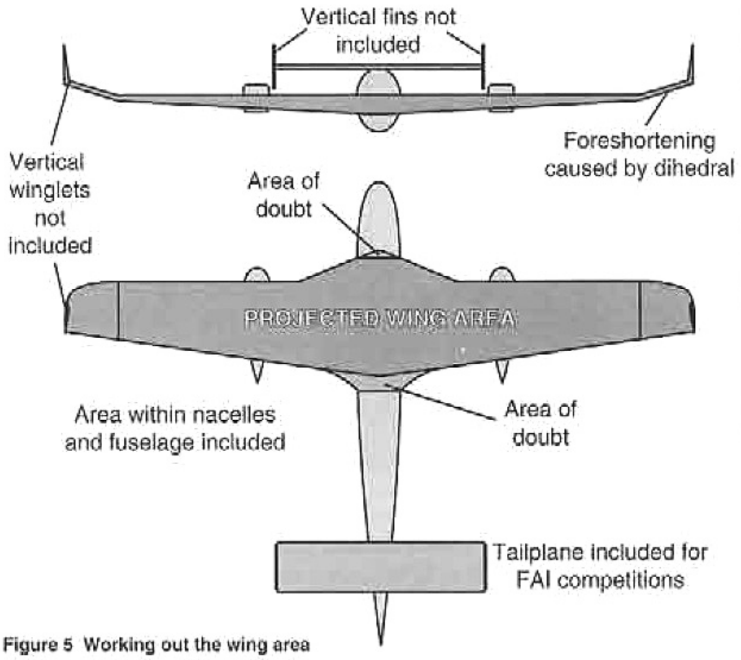

Figure 5 Working out the wing area

It is not always realised by model builders that the total area of a wing includes any portions of the fuselage, or engine nacelles, that lie within the general outline. For the sake of consistency (and, often, to comply with competition rules), adherence to this convention is essential. Some small difficulties arise. An arbitrary decision may have to be made about how the lines of the wing should be carried through a wide fuselage. In special cases, long strakes at leading and trailing edges, or very large fairings, may have to be included as part of the wing.

When a professional designer refers to the wing area, it is only the area of the mainplanes that is intended. It is assumed that the tailplane, for instance, contributes negligible lift. This is nearly always good enough for practical purposes. In nearly all cases the tailplane produces a down load which adds slightly to the total lift the wing has to provide. If the layout is unorthodox, as with a tandem wing aeroplane, this dues not apply and the total area is counted as part of the wing.

In this particular respect, the FAI does not follow the usual aerodynamic conventions. In model flying contests, the total area checked for compliance with the rules invariably includes all surfaces such as tail planes, forewings and anything else that can be considered to produce useful lift. The FAI rule was introduced many decades ago when some modellers thought of using enormous tailplanes to add to the total lifting area, without counting as part of the wing. This did not really yield much, if any. advantage but it was thought to do so at the time. The rule was made to prevent such apparent cheating.

Since the FAI area includes the tail or foreplanes, the wing loading proper is always somewhat more than the FAI loading.