Basic Sailplane Aerodynamics

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Introduction

According to the Concise Oxford Dictionary **aerodynamics** is *'the study of the interaction between the air and solid bodies moving through it'.*

Sailplanes are definitely solid objects: very solid indeed, when you consider that a typical standard class sailplane in flight weighs more than half a tonne. Open class two-seaters can weigh in at 800 kilogrammes. There are motor cars lighter than that!

When you really think about it, flight is an amazing phenomenon. Motorless flight is even higher on the amazing scale.

On a reasonably good soaring day these aircraft will typically fly distances exceeding 500 kilometres, averaging speeds of 100 kilometres per hour or more. World cross-country speed, distance and altitude sailplane records stand at 249 kph, 3009 kilometres and 14,938 metres respectively. And the record book is constantly being re-written.

So how is it then that these elegant but nonetheless inert and powerless creations can 'interact with the air' to effortlessly explore and exploit the sky world?

Read on to find out; or, if you know already, to refresh your understanding of sailplane aerodynamics.

PART 1 THE FLIGHT ENVIRONMENT

1 The Nature of Air

First we need to consider a sticky subject – air.

Air viscosity – where would we be without it? Firmly on the ground, that's where.

One of life's great good fortunes is that the air that we breathe is a viscous fluid. The simple reality is that without viscosity there would be no air resistance, no lift, no drag – in fact no heavier than air flight at all. Even the birds and insects would be grounded.

Aerodynamics begins with the happy fact that a body moving through the atmosphere experiences a force caused by air resistance. The three major factors in air resistance are ***viscosity, pressure and density***.

Like all known fluids, air is viscous which means that it offers resistance to shearing stress. **V*iscosity*** causes air to cling to objects passing through it. Think of a spoon moving through a honey pot. This is a good, even if exaggerated, illustration of the tendency for a viscous fluid to stick to a moving body.

Air has weight, and hence, ***density*.** At sea level, the weight of the air above (***pressure***), is 15 pounds per square inch (1013.25 hectoPascals). This decreases with height to 10 pounds per square inch at 10,000 feet and seven pounds per square inch at 20,000 feet. Being a gas, air is compressible. Consequently its density decreases with height because of the associated fall in pressure. At any given speed, the denser the air through which an object is passing the greater will be the air resistance.

Air ***viscosity, density*** and ***pressure*** are key factors in sailplane aerodynamics. In combination with the enormous power of the atmosphere generated by meteorological phenomena they create a perfect environment for soaring flight.

2 The Laws of Motion

As well as air resistance, an object moving through the atmosphere, like everything else on planet Earth, is subject to Newton's ***Laws of Motion,*** namely:

Law 1 A body stays at rest, or continues to move at a steady speed in a straight line, unless acted upon by an external force.

Law 2 The acceleration of a body is directly proportional to the force applied.

Law 3 To every action there is an equal and opposite reaction.

The main point is that if all the forces acting on a body – including an aircraft – are balanced, the result is ***equilibrium***: that is, “steady” motion “in a straight line”, or “rest”.

If all the forces are NOT balanced, the net unbalanced force produces ***acceleration***. (The effect of the laws of motion on sailplanes in flight are looked at later in this series)

PART 2 THE BASICS OF HEAVIER THAN AIR FLIGHT

3 The Four Forces

In straight and level flight four forces act upon an aircraft: ***lift, gravity, thrust*** and ***drag*****.** Lift counters gravity and drag counters thrust. While all four are in balance straight and steady flight is sustained.

Figure 1: The four forces acting on an aircraft in level flight

Powered aircraft obtain thrust from an engine. Once a sailplane has been launched – towed, winched or even catapulted aloft – it needs to obtain **THRUST** without the help of an engine. It does this simply by converting the potential energy it has accumulated by arriving at its starting altitude into kinetic energy as it glides downward, trading height for distance. In effect, thrust is the forward component of gravity resolved along the direction of movement. That's why when you fly faster you also descend faster.

In soaring flight sailplanes have access to the limitless power available in the atmosphere generated by solar energy. The combination of rising air, a glider capable of sinking more slowly than the air is rising and a pilot sufficiently skilled to exploit the two satisfies the thrust requirements of gliding and, indeed, soaring flight. C.E. (Wally) Wallington's "Meteorology for Glider Pilots", l977 is an excellent reference for detailed information about the way sailplanes draw upon the engine room of the atmosphere.

In considering the aerodynamics of sailplanes it is reasonable to ignore the engine factor. Because **WEIGHT** of the aircraft is not an aerodynamic force, we will ignore it for the present (increasing sailplane weight and wing loading with water ballast is dealt with later in this series). The primary considerations therefore are dealt with in terms of the aerodynamic forces of **LIFT** and **DRAG**.

Lift and Drag are so fundamental to sailplanes that their performance is generally expressed in terms of the "polar curve" – the ratio of lift to drag (L/D) of the particular aircraft when flown at different speeds.

PART 3 LIFT

4 The Wing

You could be forgiven for thinking that after more than 100 years of heavier than air flight and the heights of refinement attained in modern military, commercial and sport aviation, there would very little left to be learned about how wings actually work to produce lift.

Well, if that's what you think, you would be wrong!

Conventional Wisdom

The fundamental challenge for the pioneers of heavier than air flight was how to overcome the weight of the object to be flown. The answer lay in using air resistance to generate a lifting force. It was well known that moving a flat plate inclined at a small angle through the air produces lift. You can see this for yourself by flicking a playing card and watching its flight path.

Plainly, this demonstrable reality needed scientific explanation. The end result is that generations of aviators over the past hundred years have been taught that the underlying physics of flight come from the fact that wings are designed to produce suction on their top surface and pressure underneath.
A fundamental assumption in this traditional teaching is that two air molecules, separated at the leading edge to travel above and below the wing respectively, will meet up again at the trailing edge. This is the so-called ‘equal transit time’ theory. The theory assumes that the greater curve of the wing’s upper surface causes the ‘upper’ air molecules to travel faster because they have further to go than the ‘lower’ molecules. This increase in air velocity over the top surface creates a lower pressure above the wing – in effect, a lifting force.

The basis for this belief in how wings work is Daniel Bernoulli’s theorem which, simply stated is: “as air velocity increases, pressure decreases and vice versa”.

Figure 2 reflects this longstanding view. It shows the pressure distribution around a wing**.**

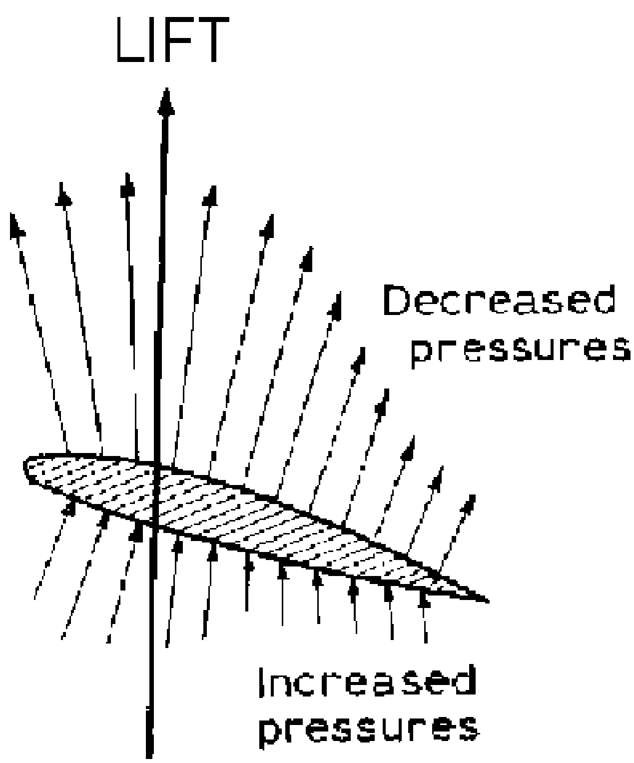


Figure 2: Distribution of pressure around an aerofoil at a low angle of attack
Source: AC Kermode "Mechanics Of Flight"

Contemporary Thinking

In the late l990s a new school of thought emerged. This came about because modern science has demonstrated that the suction generated by a typical wing is only a tiny fraction (between 2% and 5%) of the lift the wing actually produces.

Current thinking among aerodynamicists is that wings work because of the downward force they exert on the air. In terms of Newton's Third Law of Motion, the equal and opposite reaction to the downward force is a lifting force.

The new view is that the majority of lift results from the wing pushing air forwards and downwards. The consequent build-up of pressure below and ahead of the wing results in the wing being pushed upwards. In effect, the wing acts as a pump changing the momentum of the air by pushing it downwards and generating lift in the process. At the trailing edge of the wing, the downward diverted air forms a downwash.

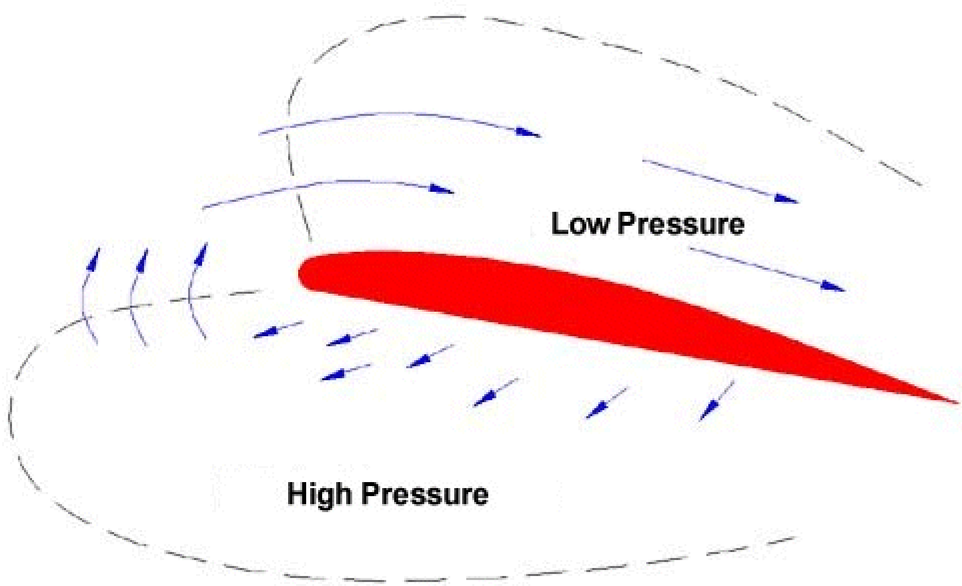


Figure 3: Pressure around an aerofoil depicting air deflection forward and downward (Source: Long. R)

The 'pump" theory holds that as the airflow bends up and over the wing it pulls on the air above it, accelerating that air downwards over the trailing edge. The airflow reflects an upwash at the leading edge and a downwash at the trailing edge.

Figure: 4.1: Illustration of Upwash and Downwash around an aerofoil (Source: Anderson and Eberhardt)

No less an authority than NASA debunks Bernoulli - based lift theory (incidentally, Bernoulli himself was not interested in flight: his field was fluid dynamics). NASA website: www.lerc.nasa.gov/WWW/K-12/airplane/wrong1.html goes so far as to label the view that lift results from air molecules separated at a wing's leading edge racing over top and wing surfaces to meet up again at the trailing edge (so called "equal transit time theory"), as "**Incorrect Theory"**.

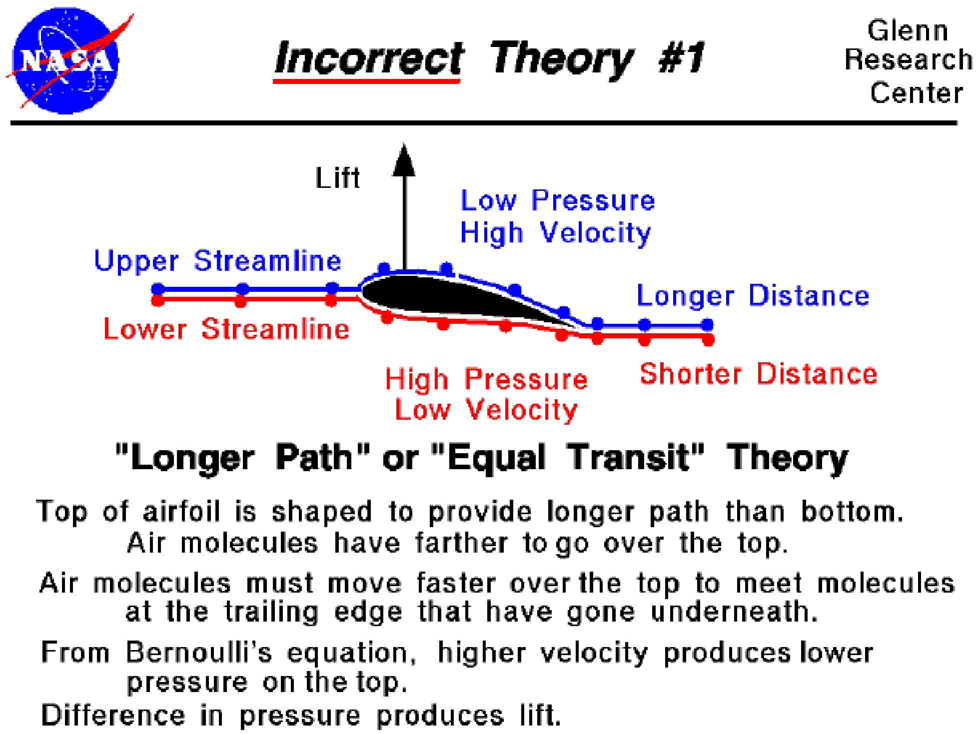


Figure 5:“Incorrect Theory” according to NASA

The “Equal Transit Time” theory can be shown as invalid by wind tunnel simulation. Figure 6 shows that smoke in a simulated wind tunnel travels over the top of a wing considerably faster than air going underneath. Air passing under the wing is, in fact, slowed down in relation to the “free stream“ airflow velocity.

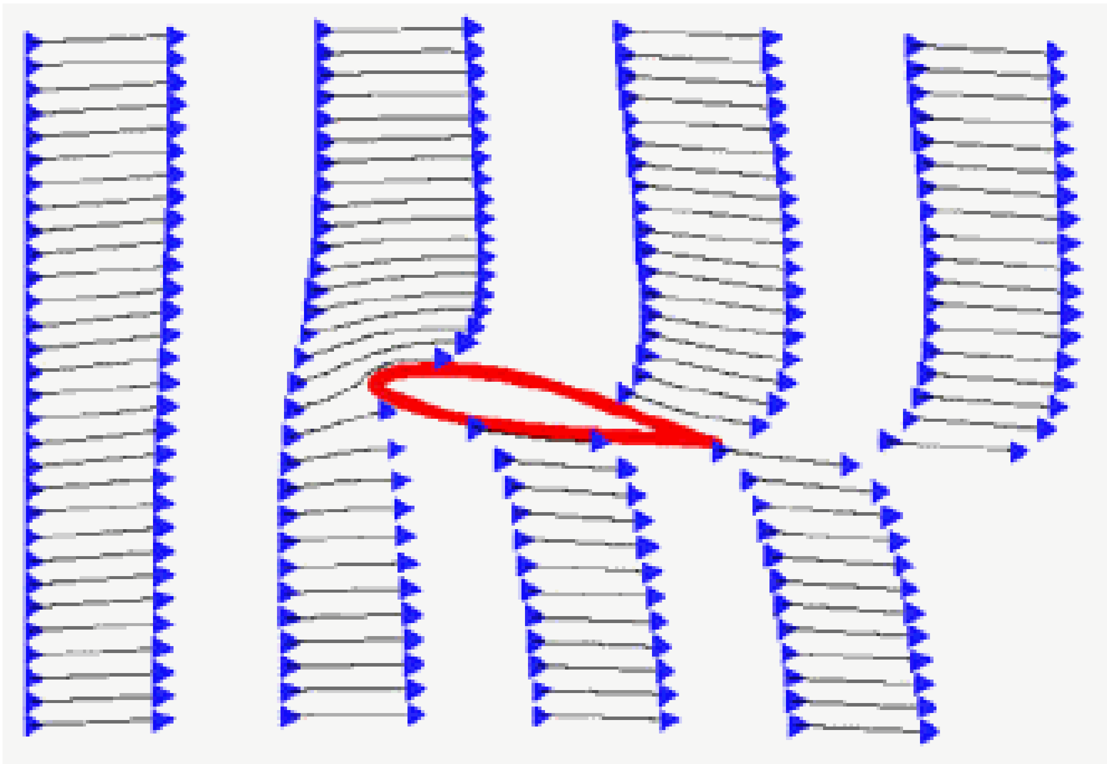


Figure 6 Simulated wing tunnel airflow showing difference in “free air stream velocity” above and below a wing at a positive angle of attack (Source: Anderson and Eberhardt)

The Coanda Effect

This “new” way of thinking about lift is not really all that new.

Back in 1930, the Romanian aerodynamicist, Henri Coanda, conducted experiments on air viscosity. He demonstrated that a moving fluid, including air, which comes in contact with a curved surface will follow that surface. The “Coanda Effect” is that *a stream of air (or other fluid) emerging from a nozzle tends to follow a nearly curved or flat surface, so long as the curvature of the surface, or the angle that the surface makes with the stream is not too sharp* (ie less than the stalling angle).

Figure 7.1: The Coanda Effect (Source: Naudin J L,1999)

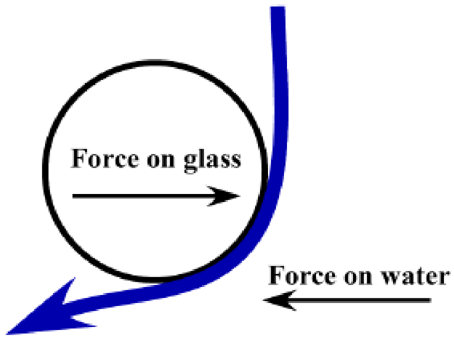
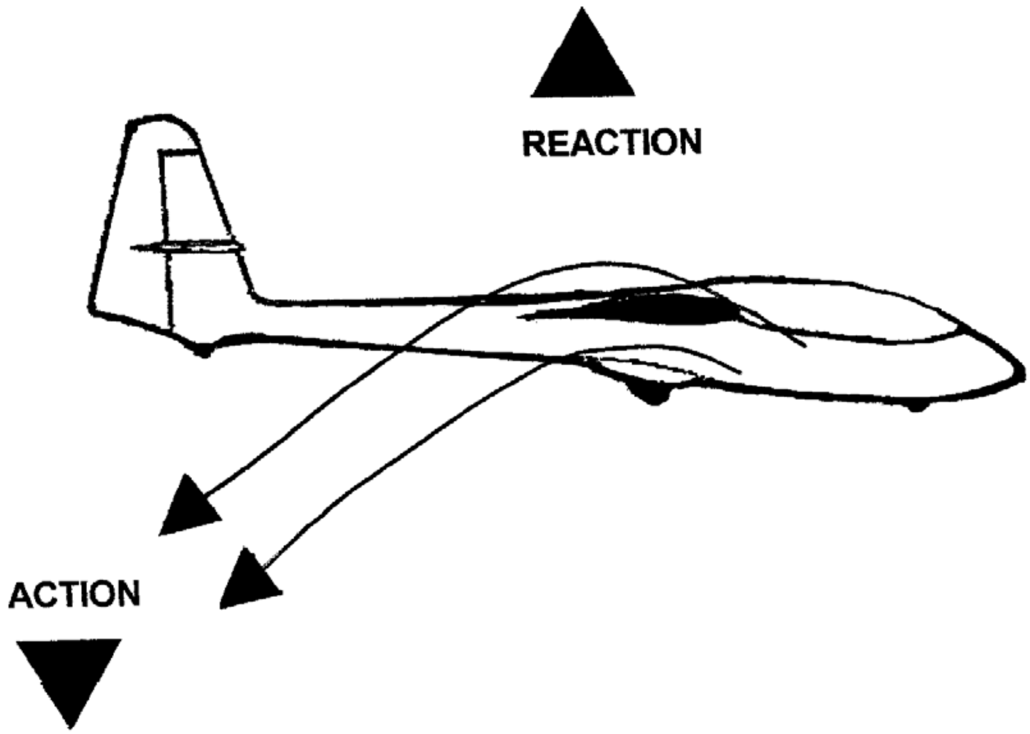


Figure 7.2 Coanda forces (Source: Anderson and Eberhardt)

Based on the “Coanda Effect” it can be seen that the downward curve on top of a wing ensures that the airflow over the wing will be deflected downwards.

Newton’s Third Law applies and the wing is pushed upwards by the effect of



equal an opposite reaction.

Figure 7: The wing deflects air downwards and is pushed upwards by equal and opposite reaction. (source: Davis, J. *Australian Flying*)

It is also fair to reason that the downward movement of air from the top of the wing creates a region of reduced pressure over the top surface.

In effect there is a combination of forces acting on the wing simultaneously to push and suck it upwards.

Still not convinced? Are you hooked on the traditional “wings suck so they fly” theory? Then think about this: Why do wings still sustain inverted flight….?

So, what **DOES** make a wing work?

Does it suck?

Does it pump?

Does it push?

Does it levitate by black magic? …. Just kidding!!

Take your pick: suck, pump or push. You'd be pretty safe in concluding that the answer lies in a combination of all three. And, no doubt, other elements are yet to be discovered in this deceptively simple science of lift.

Regardless of the various explanations, the central fact is that wings DO work. Furthermore they continue to evolve in efficiency and performance.

Other aspects of lift and wing functions of particular relevance to sailplanes, such as laminar flow, wingtip vortices and ground effect will be dealt with later in this series.

NEXT ARTICLE IN THIS SERIES: AEROFOILS, WINGS, DRAG

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