HOW A WING WORKS

There are many explanations about how Lift, the force that holds an aircraft in the air, is generated. Often these are inadequate. Furthermore, a misleading treatment of this subject from the early stages of flying training can lead a pilot into misconceptions about the way in which his aircraft flies -even a misunderstanding as to the very function of the "stick", his primary aircraft control. Pilots continue to have heated discussions as to whose theory of lift is correct, but it becomes more serious when flying instructors and professional pilots mistake the basic theory. As this is a question that I am repeatedly asked, my answer is as follows.

The "Bernoulli" and the "Newton" Theories of Wing Lift

Traditionally, flying schools and academies have taught the "Bernoulli" principle that lift is generated by a pressure difference across the wing. More recently, an increasing number of dissidents have been proponents of "Newton's" principle that Lift is produced from the reaction caused by deflecting a flowing mass of air from the wing.

The truth is that neither the Bernoulli nor the Newton theories are in fact theories of lift at all. Newton presented his three laws of motion in 1686, long before aeroplanes with lifting wings were conceived. Daniel Bernoulli, far from being in competition with Newton, continued Newton's work on the flow of water to such an extent that in 1738 he published his work "Hydrodynamica" in which he dealt with issues of fluid dynamics using the conservation of energy.

Pressure and Velocity

Consider a wing moving through a sea of calm air molecules. As it does so, the molecules are separated – some go above and some go below the wing. Each molecule is free to move as it needs to. It is not affected (theoretically) by contact with the wing or with its neighbouring molecules. As it moves, it is given a small velocity, which it then passes on to its neighbour, who then bounces the next neighbour and so on, resulting in an overall movement and re-distribution of the molecules. (Those molecules adjacent to the wing itself also impact the wing, giving it an overall force as well!)

Bernoulli was able to accurately define this redistribution associated with such a flow of a fluid. When a fluid moves, its pressure must also change in order to maintain a steady energy state. A steady energy state is the master condition because energy cannot be created nor destroyed in a closed system, which is a law of nature, or we would have perpetual motion. More practically, air under pressure contains energy, as one knows from pressing the valve on your car tyre. When the valve is released, the pent-up pressure energy causes the air to escapes rapidly and in doing so, is converted to speed energy. This is felt on one's hand and can be quite forceful. This process is reversible; to put the air back into the tyre involves lots of work on a foot pump, where energy is imparted to the air by storing it (and energy) under high pressure in the tyre. So the pressure and speed of a gas or fluid are related. This is what Bernoulli was about, but he presented his case far more eloquently.

As the air molecules move over the wing, we have an increase in velocity and a reduction in pressure. Adding up all of these pressure differences should give us a Resultant reaction on the wing, which we conveniently break down into Lift and Drag. This is what can be found by students in wind tunnel experiments at universities.

One might therefore think that "Bernoulli's" Principle is sufficient explanation.

There is, however, another part to the story.

Momentum and Reaction

As pressure and velocity are related, we ought also to consider the combined effects of the velocity imparted to our molecules. If we sum all of these velocities around our wing, we discover an overall deflection to the airflow. The wing has served to deflect the "sheet" of air downwards and slightly forwards (yes, forwards), producing an overall upwards and rearwards aerodynamic force (which we call the Resultant Reaction). This is described by Newton's Third Law: for every Action (airflow turned downwards), there is an equal and opposite Reaction (wing forced upwards).

One is now totally confused and inclined to wonder if anyone has actually measured the lift contribution from each hypothesis?

Well, for the die-hard followers of each, let us stop right here, as there is more to the story.

Yet another Theory!

Daniel Bernoulli had a colleague, Leonard Euler. Euler stated that in the flow of a fluid, not only must *energy* be conserved, but so also must *mass and momentum*. We have effectively covered the conservation of momentum by discussing the reaction of the wing to the deflection of the airflow. Let us consider the conservation of mass. This is more difficult for the simple reason that the molecules are free to move in 3-dimensions and there is more to consider than just a pressure change as the flow moves from left to right across the page. The latter is complicated by virtue that a change in the velocity of a gas in one direction results in a change in the velocity of the gas in a direction perpendicular to the original change. Again, Euler tackled this issue quite eloquently by describing the total fluid flow in terms of three doublets of differential simultaneous equations. The whole truth of the understanding of the wing is in these 6 simple equations, but it takes a somewhat agile and mathematical mind to integrate and solve them – more than the average pilot has in his flight bag!

Visualising the Working Wing

Let us try and picture the overall effect of airflow on a wing. It is all very well drawing a picture of an aerofoil on a whiteboard with envelopes showing peaks of high and low pressures, but this does not really explain the workings of a wing in a practical sense. A wing does two things. Firstly, it deflects the "airflow" downwards and forwards, creating an upwards and rearwards reaction. The Resultant (from which we define Lift), has an accomplice that is often forgotten but is absolutely crucial for a pilot to understand the way in which his aeroplane flies. In fact, the entire stability of the aeroplane is dependent upon this factor - which is to pitch the nose downwards. It is in the manipulation of this pitching moment that pilots are given direct control of the angle of attack of their wing.

As this pitching moment goes hand in hand with the production of Lift, any explanation of the way in which a wing works should make this effect clearly visible. If the wing is seen as producing lift by pushing the airflow downwards off its trailing edge, with a consequent upwards push from behind, then the lifting force and the nose-down pitching force can be visualised. (Also consider that when the airflow is drawn up and over the leading edge, that the latter is drawn down and under the airflow – a nose down pitching motion). So the Newton model makes a better explanation to visualise than the Bernoulli model from the point of view of Stability and Control.

Old Fallacies

Many flying instructors attempt to explain the "Bernoulli" theory incorrectly by insisting that the pressure reduction on the top half of the wing is because the air molecules have further to travel over the more highly curved top surface and must therefore speed up in order to meet up at the trailing edge of the wing, with adjacent molecules from which they were separated at the leading edge. This assumes that the air is "thinned out" on the top surface as it speeds up. In practice, this is not the case and is not borne out by Bernoulli's Theorem – which makes no such claim. In fact the molecules over the top surface actually surpass those over the bottom surface. This goes some way into describing the bunching up and lateral spreading of molecules underneath the wing, the overall deflection downwards as well as a vortex effect around the wing profile.

Many "Newton" advocates are also under a misapprehension that it is the bouncing / deflecting effect of the bottom surface that imparts lift-producing energy to the wing. We must also remember that the greater momentum is over the top surface. It is the curved acceleration of the airflow with associated pressure drop over the top of the wing that causes the downwash - a major contributor to Lift. So whilst the airflow may be visualised as being forced downwards on the bottom side, the upper flow must also be seen as being "sucked" downwards by the deflected airstream underneath and also pushed downwards by the high pressure free-stream layers above the wing "pushing" against an adverse airflow direction away from the wing behind the peak of the aerofoil.

For Pilots

To go back to the original argument, neither the "Bernoulli" nor the "Newton" principles offer the whole explanation, but they are each correct in themselves and will give correct results in the laboratory. The whole truth is found in the Euler equations in which the airflow must satisfy the three conditions of conservation of energy, conservation of momentum and conservation of mass. To truly understand the whole theory of lift, one must have a good understanding of the Euler equations and principles.

For a pilot, the "Newton" model is perhaps the more useful to visualise than the "Bernoulli" approach, but these conservation of momentum and conservation of energy ideas are just 2 ways of looking at a 3-sided issue.

(…and we have not even considered circular flow and the conservation of vorticity!)

Darren Audet
Advanced Flying (London) Ltd