From The Aeronautics File

By Max Feil

Not long after learning to fly radio controlled airplanes, I became interested in the science behind the magic of flight. What I discovered was that many aspects of aeronautics and aerodynamics are not really hard to understand, and can be explained using few (if any) mathematical equations. I also discovered that there is a lot of needlessly confusing and incorrect information out there, even among the scientific community and in many so-called “authoritative” texts. I am a great believer that even a complicated phenomenon can be explained in a simplified manner **without** introducing blatant errors. All that is required is a little perseverance and a desire to get things right, qualities which too few authors seem to have.

This is the first of what I hope will be a series of articles that will cover interesting topics from the science of aeronautics. Hopefully they will add to the pleasure of flying your favourite aircraft, and perhaps some will even make you a better pilot.

Topic number one: Explanation of Lift

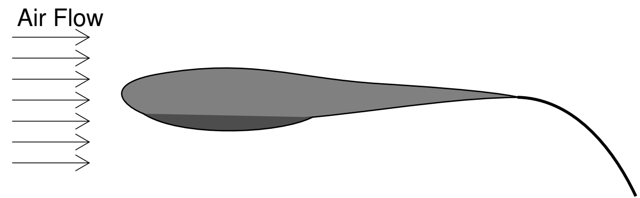
The explanation of lift is one of the most fundamental topics in aeronautics, but it is probably also the one riddled with the most misinformation. Whether you're a child in grade 7 science class, a private pilot studying for your written exam, or an aeronautical engineer, chances are you will encounter attempts to explain lift that are either incorrect or at best inadequate. Even scientists who understand the mathematics of flight have a hard time agreeing on a simple, intuitive explanation.

Probably the biggest culprit is the following myth:

“A wing produces lift because the top surface of the wing is longer. The air flowing over the top of the wing has to travel faster to meet up with the air flowing over the bottom of the wing. Lift is then created by Bernoulli's Principle which states that faster flowing air exerts less pressure.”

If this is how lift was explained to you, you're not alone. I would have used this explanation myself just a few short months ago. This popular myth can be found in many reference books, including Encyclopedia Britannica and the Time-Life Science series. Unfortunately it has not even a remote basis in fact.

While it is true that air flows more quickly over the top of a lift-producing wing than the bottom, it is definitely not true that the ratio of the top vs. bottom surface distances has anything to do with this. In fact, the air flowing over the top of the wing flows much faster than distance ratio would dictate, especially at higher angles of attack. The two air flows definitely do not have to meet up with each other at the trailing edge. Wind tunnel tests prove this, and show that the air flowing over the top arrives at the trailing edge much sooner than the air flowing over the bottom of the wing. In addition, it is quite easy to draw an airfoil whose lower surface is clearly longer than its upper surface, but which provides a significant amount of lift (see below). This is basically a symmetrical airfoil with a lump on the lower surface, and a thin flap-like trailing edge. What we really have is an undercambered airfoil at a positive angle of attack which makes it face the airstream as shown. To prove that the lower surface is longer than the upper surface, just use a string to measure the curved length. In spite of this, the speed of air flowing over the top surface will be greater than the speed over the bottom surface.



Then why does air flow faster over the top of a wing than the bottom? This question is not easy to answer since it is probably not the best question to ask. Probably the best answer is “because the pressure is lower there”, but this will not satisfy somebody who is trying to use Bernoulli's Principle to arrive at the lower pressure. The fervent need that many people seem to have to explain the faster air flow over the top of a wing leads us to an explanation often used in private pilot manuals:

“The top of a wing acts like one half of a venturi tube in that it constricts the airflow, thereby speeding it up.”

This explanation is not a good one at all. About the only thing a venturi tube has in common with a wing is that Bernoulli's principle holds in both cases. In that sense the venturi tube explanation applies only in a very general way to a wing producing lift. In both cases we can consider air speeding up due to an effective “constriction”, however in the case of a wing this “constriction” is more than just the increase in height of the top surface of the wing. Angle of attack and the curved shape of the airfoil both play a significant role and aren't represented in the venturi tube analogy. In addition, the venturi analogy does not explain the contribution of the lower surface of the wing, and, in general, does not lead to an adequate picture of the pressure profile on the surfaces of an airfoil. We can do much better.

Before I try to give an explanation of lift, I want to talk a little bit more about Bernoulli's principle. Many people think that Bernoulli's principle “explains” lift, but it is really just a relationship that holds when fluids (like air) flow in a certain way. Bernoulli's Principle is usually stated as “faster flowing air exerts less pressure”, however it is just as valid to say that “lower pressure air flows faster”. It is also not often mentioned that the air must all start out at the same speed and pressure for Bernoulli's principle to hold. (As an aside, a more precise statement of Bernoulli's principle is “the total pressure of a fluid (static pressure plus dynamic pressure) is constant along a stream line”.) As an example, take the misleading experiment most often used to “demonstrate” Bernoulli's principle. Hold a piece of piece of paper so that it curves over your finger, then blow across the top. The paper will rise. However most people do not realize that the paper would NOT rise if it was flat, even though you are blowing air across the top of it at a furious rate. Bernoulli's principle does not apply directly in this case. This is because the air on the two sides of the paper did not start out from the same source. The air on the bottom is ambient air from the room, but the air on the top came from your mouth where you actually increased its speed without decreasing its pressure by forcing it out of your mouth. As a result the air on both sides of the flat paper actually has the same pressure, even though the air on the top is moving faster. The reason that a curved piece of paper does rise is that the air from your mouth speeds up **even more** as it follows the curve of the paper, which in turn lowers the pressure according to Bernoulli. You can relax, though, since Bernoulli's principle does apply quite well to the wing of your airplane - it won't fall out of the sky now that I've told you this!

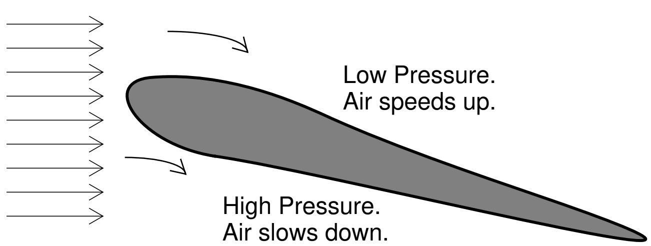
I will now try to explain lift in my own words as best I can. For more detailed information, I can send you a package of detailed technical articles that use even longer words than I'm using here.

First of all, we will assume that the air flows cleanly over the airfoil. This is actually not an easy assumption to make, and aerodynamicists spend most of their time explaining why and how the flow follows the curves of the airfoil. Once we assume flow, however, the rest is comparatively simple. There are two pretty good ways to explain lift, but they really amount to the same thing:

i) Show a movie of an airfoil producing lift in a wind tunnel. From this we can see that the air flows considerably faster over the top of the wing than the bottom, especially when the angle of attack of the airfoil is increased. Since the conditions for Bernoulli's Principle apply, we can deduce that the pressure over the top of the wing is lower than pressure over the bottom of the wing. This pressure difference then explains lift.

   Note that we avoided any discussion of why the air goes faster over the top of the wing. It is not necessary, and can get us into trouble.

ii) Another good explanation of lift is to note that air flows along the ***curved*** surfaces of the airfoil. It curves along the top of the airfoil, and it curves along the bottom of the airfoil. This curving redirects the air downward, especially at high angles of attack.



   Now note that air always flows from areas of higher pressure to areas of lower pressure. This means that flowing air always curves toward areas of lower pressure and away from areas of higher pressure. It follows that the pressure *has* to be less than ambient on the top of the wing (where the air curves toward the wing), and greater than ambient at the bottom of the wing (where the air curves away from the wing).

   To be totally correct, in some cases the pressure will not actually be higher than ambient along the bottom of an airfoil. For example, a symmetrical airfoil at a low angle of attack will not actually be directing air down using its lower surface, so it will have a lower pressure than ambient on the lower surface. It will still be lifting, however, since the pressure on the upper surface will be even lower. (At a zero angle of attack, a symmetrical airfoil will have lower than ambient but equal pressures on both sides.)

   Now that we have lower pressure above the wing than below, lift is explained. We don't need to go any further, but if we want to talk about the speed of the air flow, because the conditions for Bernoulli's Principle hold we can further deduce that the air flows faster over the top surface of the wing than the bottom. In fact, the more strongly “curved away” from the airflow the airfoil surface is, the less the pressure is, so the greater the speed of the flow. This breaks down when the curve gets too great, the air flow separates from the surface, and the wing stalls.

Note that explanations of lift based on Bernoulli (speed vs. pressure) and those based on Newton (action-reaction) are really the same. The Bernoulli equation is just a different form of the momentum equation (F=mA). Therefore it is not correct to say that “not all of lift is explained by Bernoulli's principle”, which was the premise of an erroneous article entitled “Lift, Butterflies, and Myths about Bernoulli” by David Sheahan in the December 1991 issue of Radio Control Modeler (RCM). Newton's laws and Bernoulli's principle are physical laws that coexist quite nicely, each describing aspects of what is happening as air flows past a wing. (The RCM article made three other serious errors, namely: 1. It gave a totally incorrect description of Bernoulli’s principle, 2. It said that speed change of the air on the top vs. the bottom of the wing is proportional to the length travelled and that this has been verified by testing, which is not true at all, and 3. It said that “Bernoulli lift” (his term) points straight up from the surface of the wing and therefore contributes less to lift at higher angles of attack. This last statement is already buried under several layers of errors and simply isn’t correct.)

Finally, it is worth mentioning that the way the top of a wing produces lift is the same as the way the bottom of a wing produces lift. Many other explanations separate the two into “Bernoulli/venturi” lift for the top and “air deflection” lift for the bottom, whereas in reality the air simply curves along either surface in a very similar manner. Bernoulli's principal applies fully in both cases. The air going over the top will speed up as it enters the lower pressure region, and the air going under the wing will slow down as it enters the higher pressure region.

There, that's it for now. In my next article I plan to talk about what goes into determining the correct center of gravity for an airplane, which may help you figure out where to place the CG on that radical new and odd-looking design you’re working on!