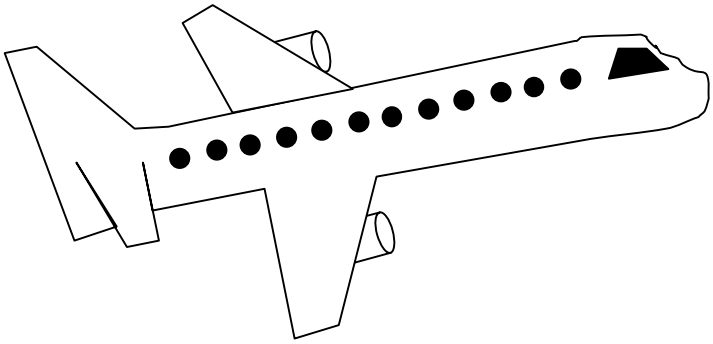
An Introduction to Flight

Materials prepared by Daniel Duke – 9th Sept 2013.
This document may be copied and edited freely with attribution.

This course has been designed to introduce students to the basic concepts of aerodynamics, lift and drag, with a focus on achieving understanding through simple analogies and hands on demonstration. The intended result is not a complete understanding of the exact physics but a 'working' understanding that will demystify heavier than air flight.

1. WHY DOES AN AEROPLANE STAY UP IN THE AIR?

An aeroplane is much heavier than air. Yet, somehow it manages to stay in the sky. Here is a drawing of an aeroplane. Which part of the plane do you think makes it stay up in the air?



A lot of people think that the engines on the aeroplane must keep it in the air. Some people think you have to have a pilot at the controls to keep a plane in the air. Maybe the plane has to be very carefully designed and engineered by experts to stay in the air?

None of these are the whole story. A simple paper aeroplane can float across the room, with no engines, no pilot, and a piece of paper does not require a team of smart engineers.

The reason a plane can stay up in the air is its wings. An aeroplane's wings disrupt the movement of air, and in doing so they cause the plane to be pushed upwards. About 100 years ago, the Wright Brothers from the United States figured this out, and when their simple canvas and wood plane flew on its own when rolled down a sand dune into a strong wind, history was made.

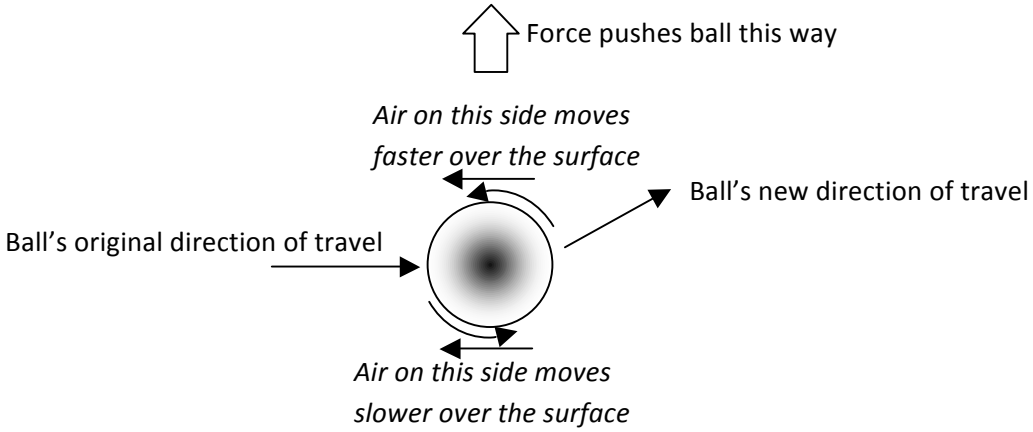
2. LIFT

An aeroplane's weight is always trying to pull it down to the ground, just like your weight pulls you down when you jump. The reason an aeroplane won't fall is that its wings are producing a force which can resist the pull of the plane's weight. It's not like a parachute, which just makes something fall more slowly, it actively pushes upward. We call it "LIFT" because it's what lifts the plane into the air.

There are several different possible explanations for why wings produce lift, but the full story is that there are several things going on. You might have heard someone tell you that it's because the air pressure is different on the top and the bottom of the wing. Sometimes this is the case :- if the air goes

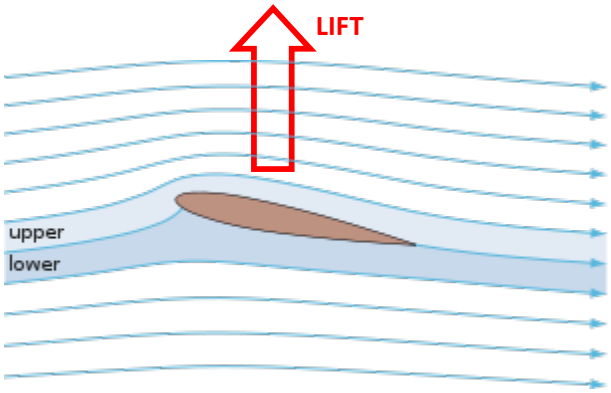
faster over the top of the wing than the bottom, its pressure drops, and the higher underside pressure will push up on the wing. But… it's not the main reason wings work. The main reason that wings produce lift is because the air is being rotated. But how?

You may have seen some of the great footballers like Beckham and Pele kick the ball and make it bend in the air, right into the goal. The reason that they can make a ball bend is that they are making it spin very fast while it's flying through the air. The ball is twisting the air flow around it as it spins, and this causes the air flow to be a little slower on one side and a little faster on the other side. The imbalance in the speed of the air over the surface of each side of the ball makes the ball move toward one side, and it bends. The same is often done in tennis.



What does this have to do with aeroplanes? The LIFT force that keeps a plane aloft is very similar to the force that causes a football to bend. When the air is made to turn direction around some object like a football, it pushes sideways on the object.

Aeroplane wings are designed so that they disrupt the airflow differently on the top to the bottom. Here is a picture of a typical aeroplane's wing, if we cut a slice through it and look side-on:



You can see that the air bends up over the top of the wing, but it also bends underneath too. So the air is rotating or curving a little bit.

For the football, the air is moving straight across the ball and the ball spins to produce a force. For the aeroplane wing, the wing is moving straight, and the air is spinning slightly. Just like the spinning football bends through the air sideways, the air rotating around the wing makes the wing bend upwards, and it pushes the plane up into the air!

Important fact to remember: An aeroplane wing produces a "lift force" because its shape makes the air rotate around it, not just because the air pressure changes.

The strength of the Lift depends on the speed of the incoming air stream. As a general rule, the lifting force increases four times for every doubling of the aeroplane's speed (we call this a "square law"). The strength of the lift also depends on the angle of the wing as compared to the incoming airstream. It turns out that if you tilt an aeroplane's wing at about 4 degrees, you get the most lift. If you tilt it any more, then the air will no longer stick to the wing's top surface, and the lifting force disappears quickly (this is called "stall"). This is why it is so tricky to find that 'perfect' angle to throw a paper plane.

3. DRAG

When you throw a paper plane, it slows down until it drops out of the air. Why does this happen?

When an aeroplane moves forward through the air, it encounters resistance. The air pushes back on the plane. This will cause the plane to slow down. We call this resisting force DRAG because it tries to drag the plane backward in the air.

Large aeroplanes use *engines* to overcome the drag. A big jet engine pushes a fast stream of air out the back of the plane, and propels it forward, resisting the drag so that it can keep flying forwards.

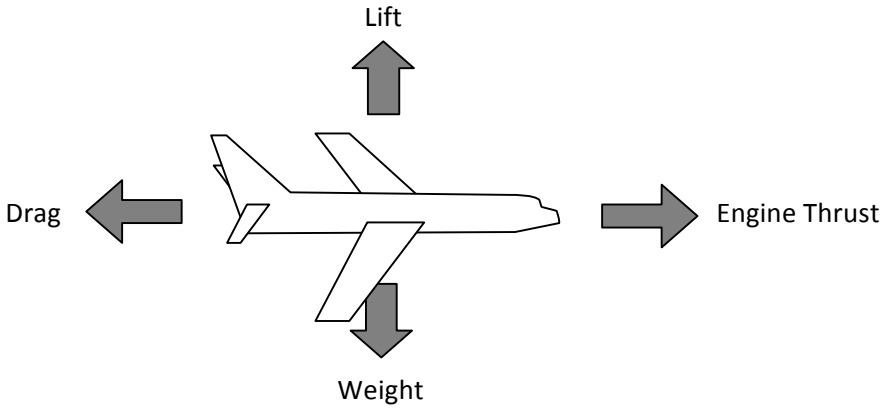
4. GLIDERS

What happens if there is no engine? The plane will not fall out of the sky! It glides gently. Without an engine, drag will cause the aeroplane to slow down. As it slows down, the wings make less lift, since the lift depends on the square of the forward speed. The result is that the plane descends in height as its weight overcomes the drag. A skilled pilot (or paper plane designer!) can tilt the glider at such an angle that it will produce more lift as it slows, so that it will descend at a smooth rate. A Boeing 747 , at its usual height, can travel over 100km without any engine power at all, simply gliding!

Advanced question: Would it be possible to completely remove all the drag by making the plane very slim and smooth? Unfortunately, we cannot get rid of all the drag. This is because the wing, in the process of making Lift, has to impart some rotation onto the air, and in doing so, it encounters air resistance. So if we are to make Lift, we also must put up with some Drag. There are two main kinds of Drag: that caused by the shape of the plane's body, "Parasitic Drag," and drag caused by making Lift to keep the plane aloft, "Induced Drag." Aeroplanes that travel past the sound barrier also make other kinds of drag due to the presence of supersonic shock waves – this is why it is difficult to break the sound barrier, and a very advanced aeroplane like Concorde is needed to do so.

5. FORCE BALANCE ON AN AEROPLANE

If our aeroplane is flying level and steady, then we have four forces acting on the plane. The lift is keeping the plane up in the air, and the weight is trying to pull it down. The drag is pulling the plane backward, and the engine thrust will push the plane forward. If all are balanced, then the plane will fly forward at a steady speed and remain at a constant height above ground, and we are flying!



The pilot controls the forward speed with the engine thrust, since if the engine thrust is more than enough to overcome the drag, the plane will gain speed, and if it is insufficient, then drag will slow down the plane. The pilot makes the plane gain height by tilting the fins on the back of the plane. This causes the whole plane to rotate upward or downward. The plane can turn left and right by turning the rudder, just like on a boat, and flaps on the ends of the wings can also be used to make one of the wings produce less or more lift, causing the plane to roll to one side, and turn.

CLASS ACTIVITY: PAPER AEROPLANES

The best paper aeroplane is the one that can fly the furthest distance, since this means it produced the most lift and had the least drag.

Have the class all make a paper aeroplane and see whose flies the furthest! Try different wing sizes and shapes – figure out which shape gives a low drag and high lift (i.e. a long travel distance!) To be fair, the students should throw planes in a non-windy area and all from the same height.