Kinetic theory and lift to drag ratio -
glide angle and model design

In designing our model gliders we seek to keep them in the air as long as possible from a given height. We also want full-size gliders and some models to go as far as possible. I hope you have read my articles on kinetic theory explanations of lift and drag. Turning those words over in my head I wondered if kinetic theory could also be used to think about flying performance. As you know by now, as a physicist I am fond of thought experiments.

We seek to increase lift or to reduce drag or both, or in other words the ratio between the two – 'lift to drag ratio' (L/D ratio). This is a measure of the aerodynamic efficiency of the aircraft.

The resulting equation couldn't be simpler:
L/D ratio = lift / drag
Being a ratio (fraction) with the same unit top and bottom it has no unit of measurement.

Note that drag includes not only the drag from the wings but also 'parasitic drag' from the rest of the aircraft. It is called parasitic because it is from parts of the aircraft that do not contribute to lift. It is also called 'form drag' and 'profile drag'. It's one reason why we use folding props on our gliders and fair in the servo arms and push rods.

To get the greatest distance or time from a certain height we want to maximise another ratio called 'glide ratio' but also known as 'glide angle'. Using FrSky telemetry I have measured it on a real model in still air. I programmed the transmitter (Tx) to speak the height given by the vario every ten seconds, which gave me the sink rate. It also spoke the air speed from an speed indicator indicator (ASI). This was better than trying to read the data off my Tx screen and I was able to integrate many readings in my head to get more typical average values. There is nothing worse than glancing at the screen only to realise that you can't see your model when you look back.

Picture 1 shows the FrSky ASI installed in the canopy of an ageing Hobby King Bixler.


Picture 1

Photo: Peter Scott

The values for the Bixler were 1 m/s fall and 6 m/s air speed, giving a glide ratio of 6:1. Full size gliders and, I imagine, high performance models have ratios between 30 and 60, though 40 is most likely for a high perfomance machine.

And now for the delightfully simple jump to the effect of L/D ratio on glide performance. Guess what?
Glide ratio = L/D ratio

The = really means an approximation, but close. I couldn't find the standard symbol for 'approximately equal to', only this one ≈ which was listed as meaning 'nearly equal to'. That is not the same thing at all, as sometimes an approximation will be exactly correct, and it could be above or below the value, not 'nearly' which implies 'under'. The correct symbol has a straight line on the bottom, not a curly one.

As the Bixler weighs about 1000 g this tells me that its total drag is 1000/6 or 167 g. Interestingly in a single-model climb and glide competition someone who changed to a folding prop usually won until we banned changes to the specification.

What does this mean for the best shape for an aircraft?

So, physicist's hat on. Thought experiment - 'I am an air particle'. An aircraft is moving towards me and looks certain to thump into me. Which bit of it I hit is a matter of chance. If I hit the front of a leading edge or the nose I will be knocked back through 180° and my whole impulse will produce drag. This is shown in Figure 1 as path A. If I hit a more sloping surface some impulse will be drag and some will be lift depending on the angle of the surface. This is shown in paths B and C.

The shape of the object is oval because it is more like an aircraft.

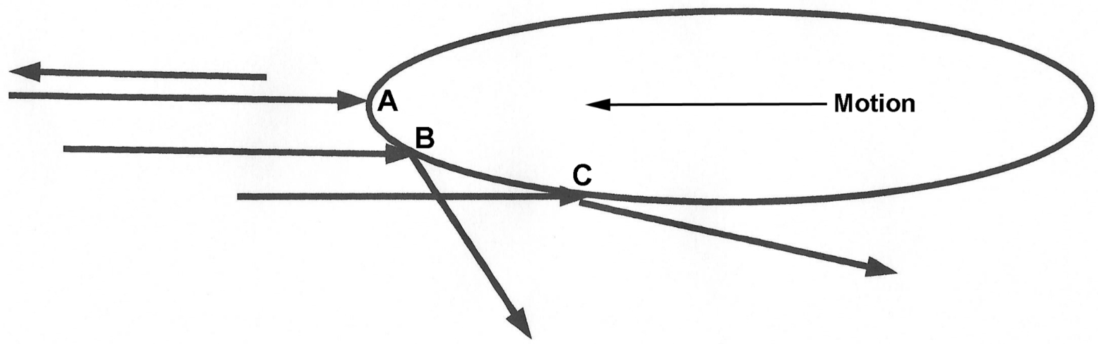

Figure 1

Let us examine one of these paths – C.

If you were awake during your Physics lessons you might recall the difference between scalars and vectors. A vector is a quantity that has both size and direction. The relevant example here is force. To work out the effect of a force you need to know both how big it is and in what direction it is pushing. Scalars have size but not direction. Examples are temperature and energy. So when analysing the effect of a force we must model both size and direction.

The direction of the impulse force from the bouncing particle will be roughly at right angles (normal) to the surface at the point of collision. Being a vector, the force can be split into two parts, called 'components', at right angles to each other, using a diagram and a method called 'resolution'.The shallower the angle a of the impact is, the smaller the drag component and the higher the lift component will be. It will produce a smaller overall impact force on the surface but the drag component will be much less than the lift one. This is shown in Figure 2.

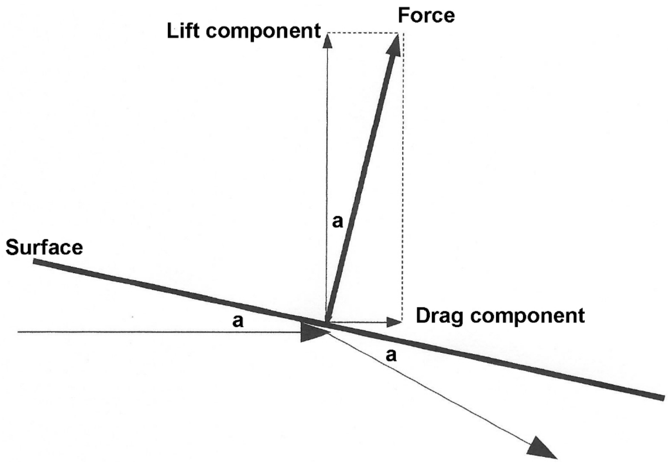

Figure 2

So what determines the ratio of lift to drag is the ratio of the sums of all of the vertical components to the sums of all of the horizontal components of the impulse forces of all of the particles that hit the aircraft's surfaces at all kinds of different angles. (I usually avoid long sentences like that.)

What about flaps?

What happens when we lower flaps? Angle a shown in Figure 2 increases. This means that the impulse force is much larger. It also means that it is more evenly divided between lift and drag. As you see from Figure 3, drag goes up much more than lift. This has the desired effects of both reducing airspeed and increasing lift. A greater angle such as in air brakes or 'barn door flaps' will produce much more drag than lift but we usually only use those on, or just above, the ground.

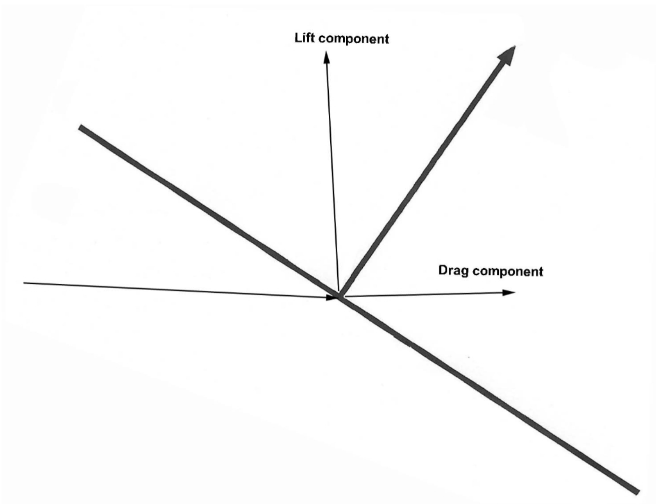

Figure 3

Figure 3 also shows the effect of any projections into the airflow including surface roughness. More of that later.

What does this tell us about design and construction?

First let's consider parasitic drag, which is the drag from everything but the wings. The angle at which the particles hit the surfaces should be as low as possible. Gently sloping shapes with sharp points and edges are better than more angular ones. Projections should be kept to a minimum and where they can't be avoided a fairing should be added. Any sudden change of a surface such as canopy edges will also act as a projection.

Similarly, as mentioned above surface roughness will have the same effect as many small projections. Remember that the particles are minute compared with any roughness. For them it's mountainous. A nitrogen gas molecule (80% of the air) is effectively (collision diameter) about 360 pm (picometres). For polished surfaces the roughness peak to trough will be around 2 um (micrometres). One micrometre equals a million picometres. So the number of molecules piled up to equal that much roughness is 2 000 000 / 360 or about 5500. 5500 average people standing on each other's shoulders will be 8250 m high, which is roughly the height of Mount Everest. So a particle compared with the roughness is like a person compared with Everest. By the way that's another calculation that I had to do several times before I believed it. It reminds me of Dr. Seuss' story of Yertle the Turtle. It also sounds like the usual queue to get up the mountain.

Of course surface roughness does rather mess with the idea of the force on the surface being at right angles. But we are dealing with the averages of countless collisions, and the roughness will not be in sharp peaks like a mountain range, so the variations due to roughness will average out.

For wings the situation is much more complicated. Aerofoils are developed by studying them in wind tunnels though software does a good job too. Angles of attack and airspeeds are varied and the lift and drag forces are measured. Control surfaces including ailerons, flaps, slots and airbrakes are moved and the effect measured. Smoke streamers or tufts are photographed to show how the air is flowing.

The finish on the wing surface is important of course. Highly polished sheeted or glass coated surfaces are best, though are usually heavier. Next best are built up ones with shiny covering such as plastic film. Spars, edges of sheeting and leading and trailing edges that produce projections not parallel with the airflow should be shaped or buried to minimise the projections. I remember cutting endless ribs with holes for buried spars when I flew free flight A/2 F1a gliders. No laser cutting then!

The joins between control and flying surfaces are ideally filled in with film or tape though there are practical limits to that. I wonder if anyone has tried flexible trailing edges rather than hinged ones. Early aircraft, like the Sopwith Tabloid shown in Picture 2, sometimes had wings that twisted to cause roll rather than using hinged ailerons. Now that would be an interesting project for a model glider.

Picture 2

Model Sopwith Tabloid
from Norfolk UK

Photo: Peter Scott

Servo arms and control linkages should be enclosed in fairings if possible. There was an RCSD article ingeniously showing how to use the clip-on tops of spray bottles to make fairings. You trim them, hopefully leaving tabs to help to hold them on when glued. There are examples in picture 3 :

Picture 3

Photo: Peter Scott

Can computers help with kinetic theory modelling?

Of course we now have super-computers capable of modelling the random motion of each of thousands of millions particles as they move around an aerofoil - in other words we could build a mathematical kinetic theory model. However there are times when a visible analogue computer, which is what a wind tunnel is, is cheaper and better than mindless digital bludgeoning. Designers can experiment with small changes to the profile of the aerofoil and experience the effects rather than looking at numbers and graphs.

For an example in a different field, the London School of Economics has an analogue computer model of the economy called MONIAC. It has water in pipes with tanks and valves to model such things as money supply and inflation.
https://en.wikipedia.org/wiki/MONIAC

Low drag flying

The first thing is to minimise the aircraft's drag by good design, construction and finishing. Then we need to pay attention to the trim of the model and our behaviour.

First - trim. For minimum drag, control surfaces should be exactly neutral. Trimming should be done by adjustments to the centre of gravity.

Secondly - behaviour. Once trimmed into a 'hands-off' stable state, control surface movement should be at the absolute minimum. Every control movement increases drag by adding projections into the airflow. The exception to the 'minimum rule' will of course be to maintain circling when lift is found. Then because of the rising air we can afford the reduction in glide ratio, though we have all experienced dropping out of a thermal due to clumsily done circling.

Of course you knew all of that. But the science behind it helps understanding.

What about L/D for powered aircraft?

The Gimli glider

This is one of the classic heroic stories of aviation dating from 1983. The skill of the pilot Captain Pearson, who also flew gliders, in gliding a Boeing 767 for 17 minutes over 65 km (40 miles) from 12 500 m (41 000 ft) altitude, was unsurpassed. The reason I include it here is that the glide ratio was calculated at 12:1 by the air traffic controllers. That enabled them to select a disused military airfield at Gimli as being at a suitable distance for a landing. No doubt they took the prevailing wind into account too. The coolness and skills of the ATCs was as outstanding as the pilot's. The glide ratio is surprising considering the parasitic drag from the engines. No folding props there.

Actually the airfield wasn't entirely disused as people were at a car event there. They were somewhat taken aback by the sight of a huge, silent aircraft heading straight towards them. It came in at speed as the usual flaps were out of action. Fortunately the 767's nosewheel hadn't locked by gravity so it collapsed and the aircraft's nose scraped along the ground. It stopped before the end of the runway.

In 2014 the 767 C-GAUN was scrapped, but you can buy 'lucky' key rings made from its skin. Many have asked what is so lucky about running out of fuel at 12 500 m.

If you have never read about it the full story can be found on:
https://en.wikipedia.org/wiki/Gimli_Glider

Kinetic theory, Brownian motion and you

In 1827 a botanist called Robert Brown was looking through his microscope at pollen grains suspended in water. He noticed that the grains were jiggling about in a random pattern with no apparent cause. It became known as 'Brownian Motion'. The mystery remained until 1905 when Einstein suggested that it was the invisible moving water particles that were bashing the pollen hither and thither. He reasoned that the particles must be moving very fast as they were too small to see so must have much lower mass than the pollen.

If you have a microscope with enough magnification to see pollen, you can repeat Brown's experiment. Ideally dip the lens into a water drop on a slide into which you have mixed a little pollen, and use lighting from the side. It might also enchant your kids and grand-kids when you explain that's what keeps you in the air when you fly. There is more information and some excellent simulations of the motion on wikipedia at https://en.wikipedia.org/wiki/Brownian_motion.

Your comments

As a scientist I expect and welcome criticism and comments about my ideas in the three kinetic theory articles. Please feel free to contact me at peter@peterscott.website. I accept that you might destroy my ideas but that is the way that science works. However what usually happens is that the ideas are improved.

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