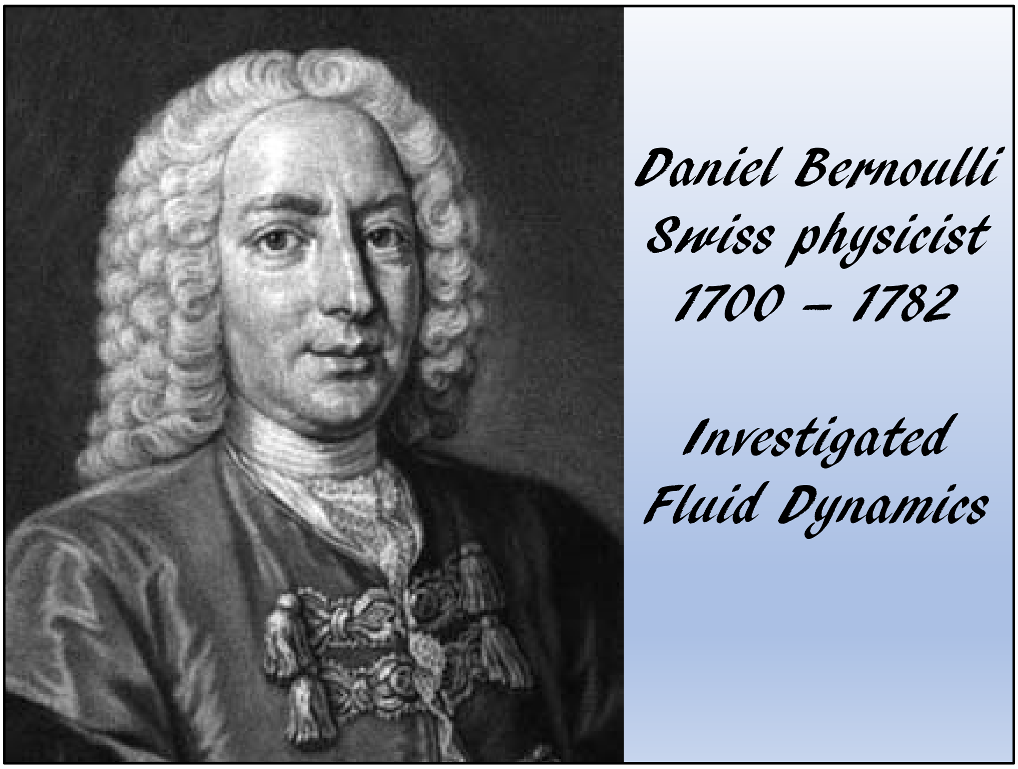
Second Level Technologies
Benchmark SCN 2-20a

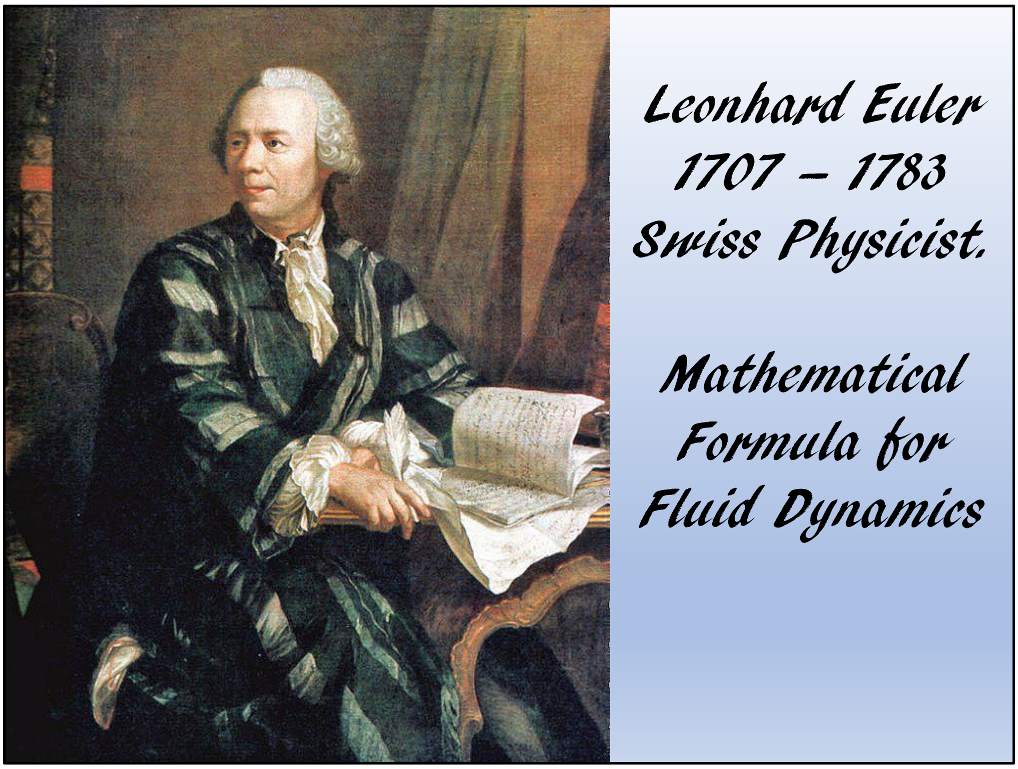
Physics of Flight Pt 3

Exploring the science
of dynamic flight.

Let's see how scientists discovered the laws of aerodynamics that showed how flight might be possible.



It all started with this man, Daniel Bernoulli. He was experimenting with water flowing in pipes and, among other interesting things, he found out that when water was flowing through pipes the pressure of the water dropped. Furthermore, the faster the water flowed the more the pressure dropped. Very curious.



This man, Leonhard Euler, living at about the same time as Bernoulli, was a mathematician and he believed that everything on earth could be defined by a mathematical formula. He was aware of Bernoulli's experiments and set out to find a formula to describe how the speed and pressure of the water would be linked mathematically.

Giovanni Battista Venturi

Italian Physicist
1746 - 1822

To understand what happens when we cause a fluid to move we have to go back to the theories and laws set out by Bernoulli and Euler and to look at one of the first practical applications of their work.

Giovanni Venturi was trying to solve the problem of how to find out how much water was flowing in a pipe without opening up the pipe to see. He knew of the Bernoulli experiments and the curious effect of reducing the pressure by speeding up a flow of water. Venturi surmised that if he could make a device to speed up the flow of water in a pipe he could somehow measure the reduction in pressure and, from that, deduce the flow rate.

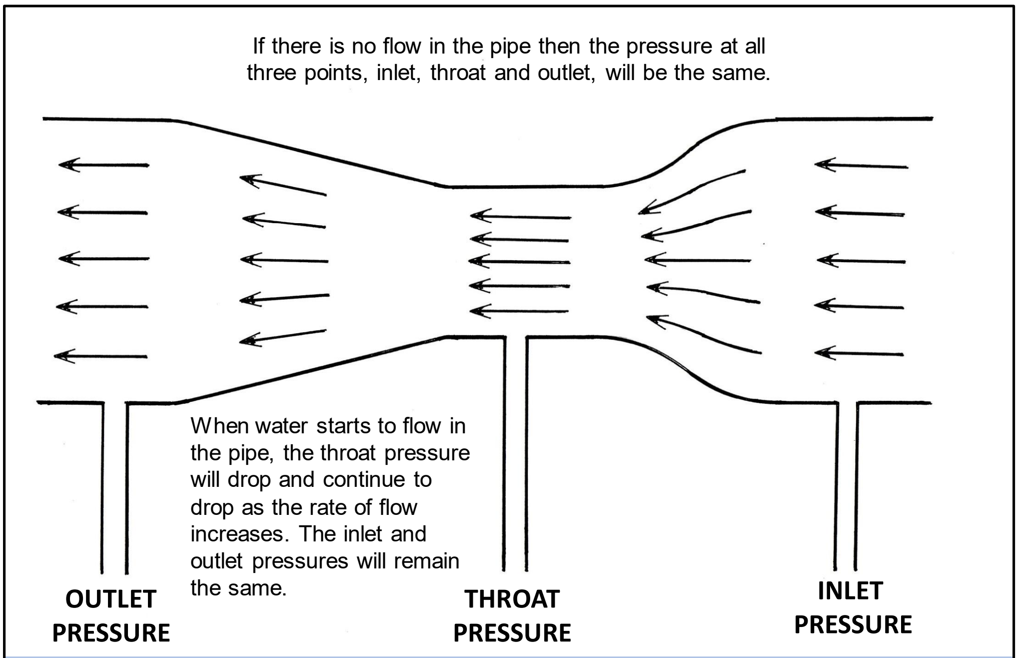
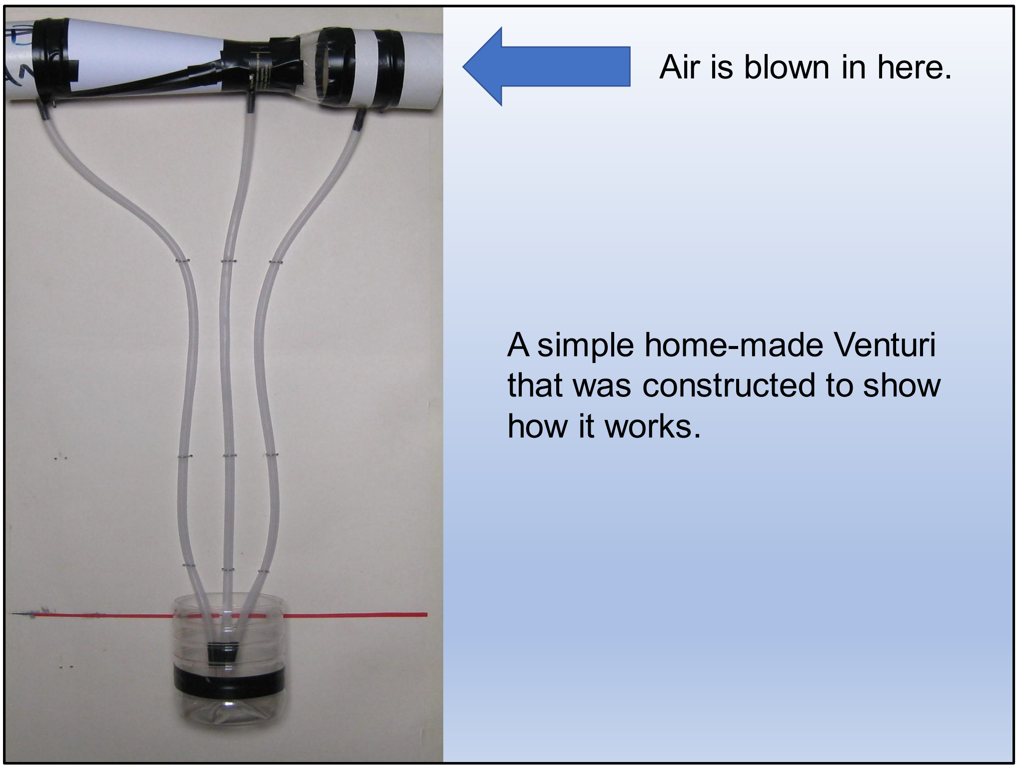


Diagram of a Venturi

Venturi eventually designed a device that achieved the result he was looking for and it bears his name to this day.

The basic idea was simple enough, it was just a section of the pipe that was smaller than the rest of the pipe, but the shape of the entry and exit from this small section was a bit more tricky to design. This diagram shows a typical section through a "Venturi".



This simple model of a Venturi was made from pieces of plastic drinks bottles, cardboard, adhesive tape and plastic tubes.
Water is added to the tank at the bottom and air is blown through the Venturi by an electric hair dryer.
When air is blown through the Venturi the water level in the three tubes is affected by the pressure in each section of the Venturi.
The inlet and outlet pressures will be the same but the low pressure in the throat of the Venturi will lift the water level in the central pipe showing that air is indeed flowing.
This simple home-made Venturi was constructed to show that the principle actually works.

When our early ancestors saw birds, bats and butterflies moving around in the sky he had no idea how they could do that. Of course they did not even know that there was such a thing as air.

Birds, some mammals, some insects and even some fish had found the secret of flight and it was all to do with having some kind of wing that could produce an upward force which was at least equivalent to the weight of the animal.

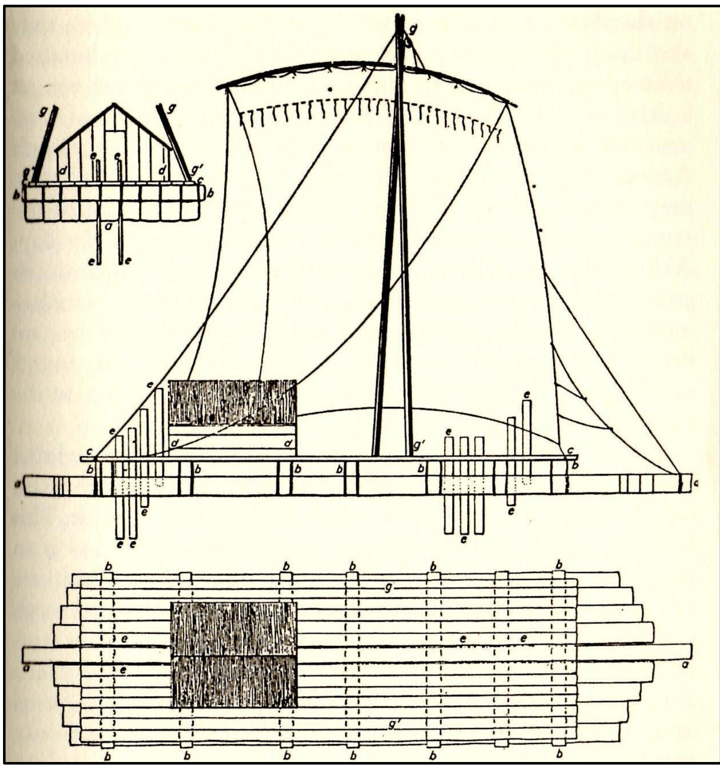
Wings were obviously the means of flight but when experiments with wings covered with feathers did not work humans had to think again. So there was more to it than just a shape like a bird's wing. How on earth did humans think that they could fly like birds? Of course we never can because we are built for walking and running and not for flying. The best we can do is surround ourselves with a flying machine and try to control it.

The best brains of the physicists and engineers tried to solve the puzzle but it was not until quite recently at the end of the 19^{th} century that the explanation was found.

However, before we find out about that, there is another part of the story to be told.

Polynesian sailing catamaran

Early explorers of the southern hemisphere discovered that the islanders of the South Pacific had been building boats for many centuries that used a very different kind of design from the square rigged ships of the Northern European races.
However, although this information was relayed back home, it seemed to have been largely ignored by the ship builders of Europe.
The Pacific islanders needed fast boats to be able to cover the large distances between islands. The boats did not have much space in them to carry food and water for lengthy trips so speed was important. The typical boats had very long thin “V” shaped double hulls, we call them catamarans, and fore-and-aft sails. Although the islanders did not know it at the time, they had invented a wing that developed aerodynamic lift. This type of sail allowed the boat to travel into the wind but specifically was very good at powering the boat along quickly when sailing at right angles to the prevailing wind.



A drawing of a "balsa" showing the "guaras" sticking down into the water between the logs of the raft.

In the 16th century, when Spanish explorers managed to cross from the Atlantic to the Pacific at the Panama isthmus and built new ships to sail down the west coast of South America, they reported that they had encountered very strange sailing vessels well out to sea.

These vessels were very large rafts made of seven or nine tree trunks lashed together supporting an open work deck that was fitted with accommodation for two or three families, some animals and many tons of freight. The Spanish word for raft is "balsa", and we have called the trees that these rafts were made from "Balsa wood" ever since. Much to the surprise of the Spanish sailors they found that these apparently cumbersome "balsas" were able to sail just as fast and much closer into the wind than the Spanish ships.

It also turned out that the natives had invented a thin wooden blade device that they called a "guara". A number of these guaras were pushed down into the water between the logs of the raft and not only prevented the raft from being pushed sideways through the water by pressure on the sail from a side-wind, but also by careful adjustment, could also be used to steer the “balsa”.

Dutch sailing barge

Although the fore-and-aft sails of the South Pacific catamarans and the South American “guaras” had been reported at least two centuries before, it was not until the 18th century that European boat builders began to realise the benefits of combining these two devices.

The Dutch barge builders added the equivalent of the “guaras” by hanging lee-boards on the sides of the barges and changed the sails to the fore-and-aft type and found that the barges could be sailed accurately along the canals in most wind conditions.

Large racing yachts

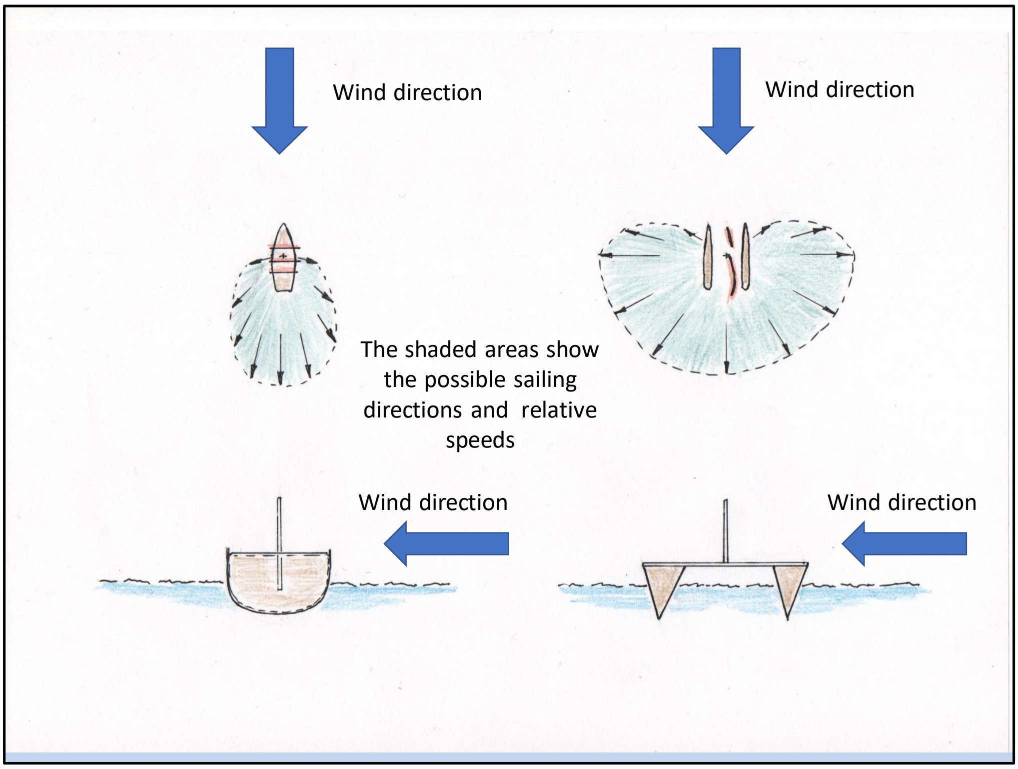
The Dutch merchants also needed a way of finding out the condition of cargos coming from abroad before their ships reached port so that the value of the shipment could be assessed and bought from under the noses of other merchants. So a fast boat rigged with fore-and-aft sails and having a fixed deep blade shaped keel was developed to be able to race out and intercept the incoming ships. These fast boats were known as “hunters”, “jachtschip” in Dutch, and they have been know as Yachts ever since.

Although the original inventors of the centre-board and fore-and-aft sail may not have understood how they worked we now know that both these devices develop the force that we would now call “lift”, one working in air and the other working in water. The sails of this modern racing catamaran are designed to be almost the same as an aircraft wing and are able to generate a large lift force to power the boat at high speed.

The boat also has very sophisticated keels which provide the side force to prevent the boat from being pushed sideways through the water.

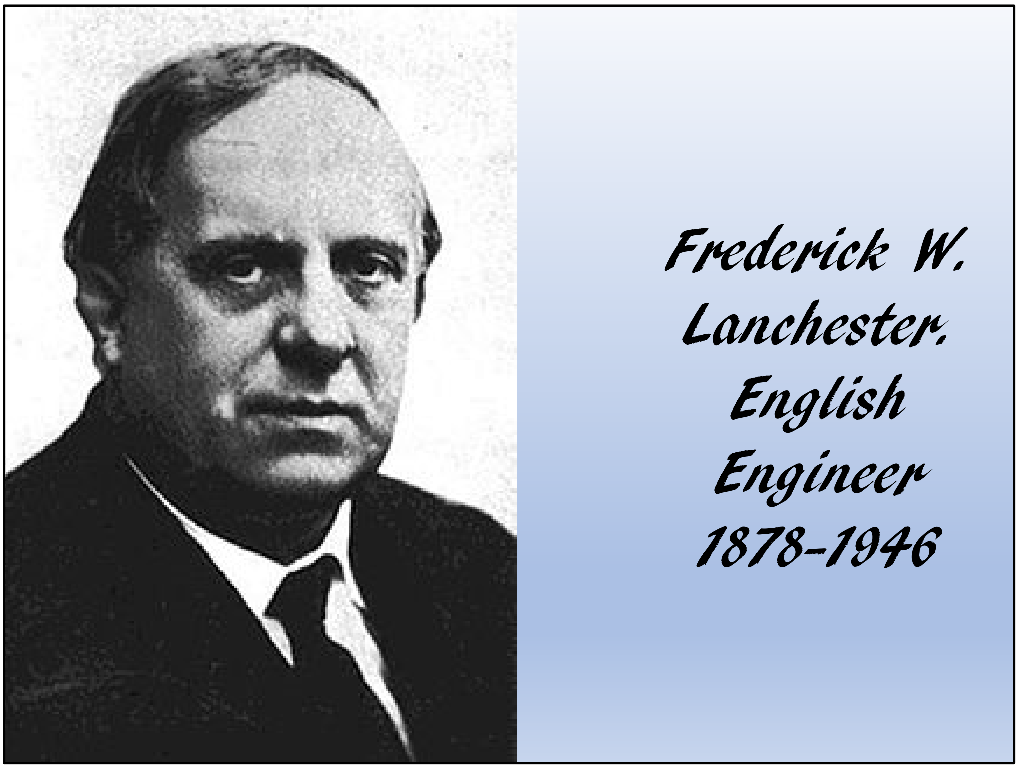
Our modern understanding of aerodynamics and hydrodynamics allows us to build very fast racing yachts that can reach very high speeds. The world record speed for a sailing boat is 75 mph in a 30 mph wind.

So now we have found out about devices that provide lift on boats we now have to find out how the principle was applied to aircraft wings.

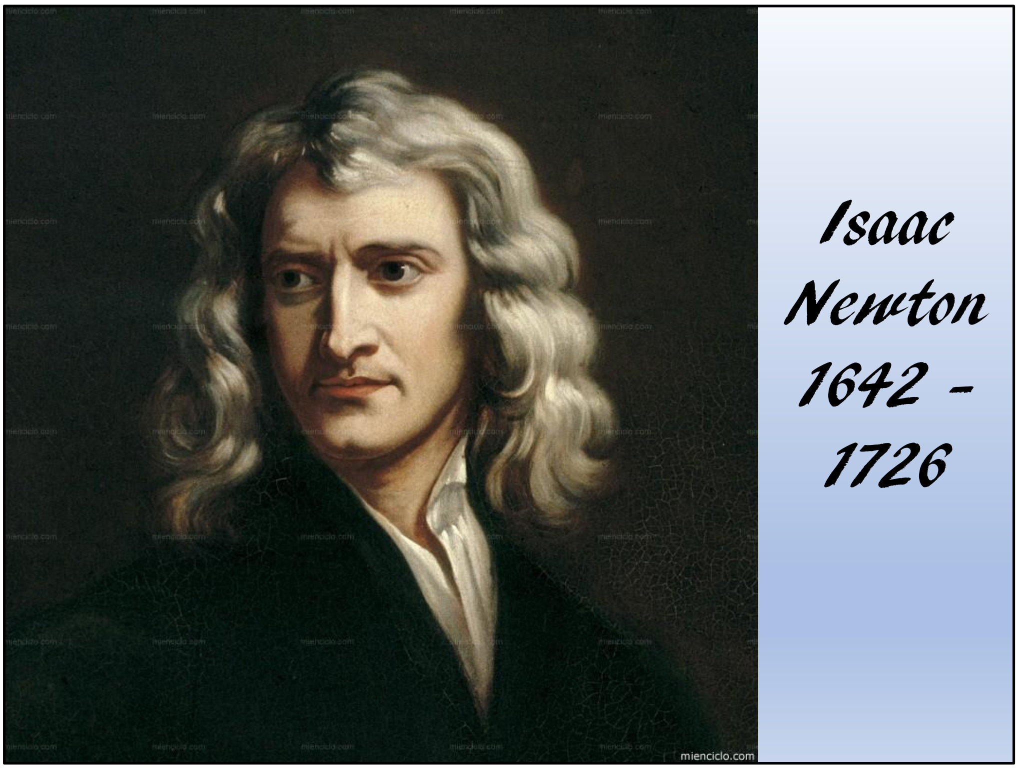


This diagram shows the advantage that fore and aft sails have over square sails. The square rigged ship on the left could really only sail down-wind and in quite a restricted direction. Also the large rounded hull was good for carrying a large cargo but it could be quite easily pushed sideways across the surface of the sea by a side wind. The twin-hulled catamarans with fore and aft rigged sails could sail in many more directions and could sail quickly at right angles to the wind and even sail towards the wind. The slim V shaped hulls were not much good for carrying cargo but the steep–sided hulls resisted being pushed sideways when sailing across the wind.

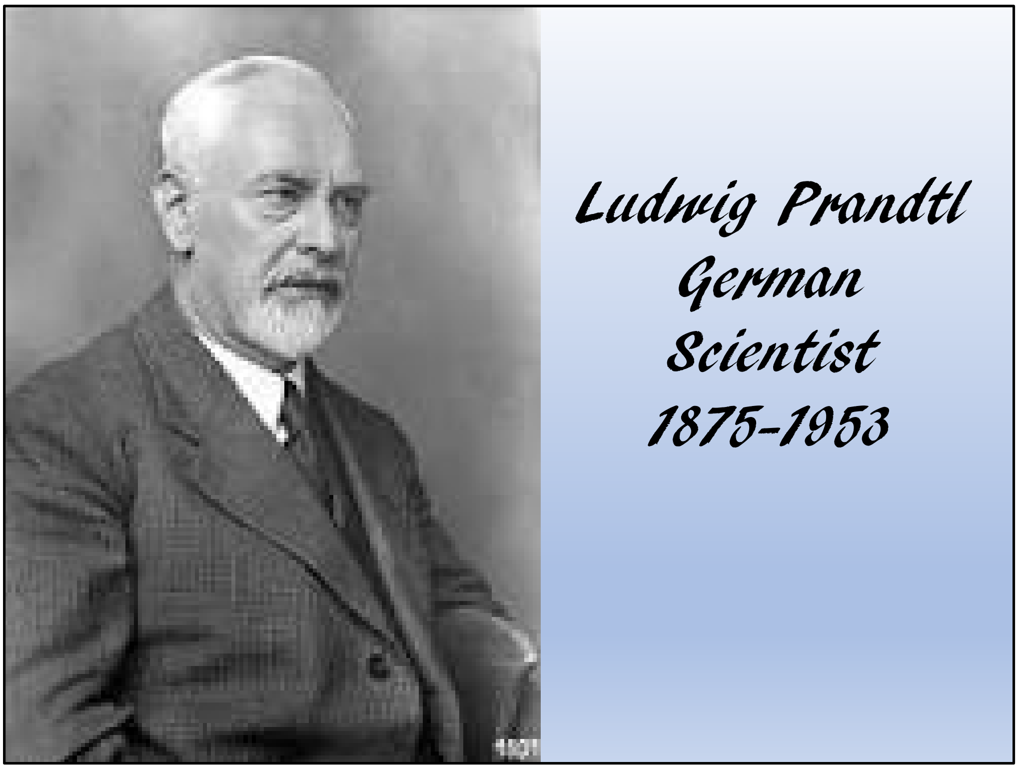
The old square rigged ship captains had a constant fear of being blown towards a coastline with no harbour or safe anchorage. They could not sail away from danger and the best they could do would be to drop anchor and hope that it would hold the ship until the wind changed direction. Thousands of ships and their crews were shipwrecked and lost in this way.



Frederick Lanchester studied the flight of birds but, since it was too difficult to visualise what happened when a bird flapped its wings, he concentrated on trying to figure out how seagulls managed to glide on air currents with their wings held stiffly out. Lanchester knew that air was heavy, it had mass, and so he assumed that somehow the wing was accelerating air downwards and generating a force that was equivalent to the weight of the bird. Isaac Newton's 2^{nd} law of motion said that:- Force = Mass x Acceleration so Lanchester proposed the theory that the wing was accelerating the air downwards with enough force to support the bird. He decided that the wing shape caused the air that it passed through to circulate, like a mini tornado, and that as long as the wing moved forward, this circulation was maintained and was constantly produced by the wing. Lanchester proposed this theory to his engineering peers but his idea was not accepted.



Newton’s second law
Force = Mass x Acceleration



However, in Germany, Ludwig Prandtl realised that Lanchester had hit on the right idea and set about trying to develop the theory of the creation of lift. Prandtl refined Lanchester's theory and went on to add his own insight as to how the circulation around the wing was formed and could be quantified. In so doing he set the rules for modern aerodynamics and the analysis of fluid mechanics.

Nowadays, with the aid of wind tunnels exploring the flow around aerofoils, and the use of powerful computers that can calculate the local flow and pressure in great detail, the science of aerodynamics has reached a very advanced state. The basic theory however remains the same.

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$$q = \frac{1}{2} \rho V^2$$

The original formula

The formula can be re-written to give two very useful formulae

$$DRAG = \frac{1}{2} \rho V^2 S C_d$$

$$LIFT = \frac{1}{2} \rho V^2 S C_L$$

Now that we have Leonhard Euler's Formula from the eighteenth century we can explore what we could find out using these formulae.

Lets have a look at aerodynamic drag first. Go to Physics of Flight Pt 4