Second Level Technologies
Benchmark TCH 2-20a

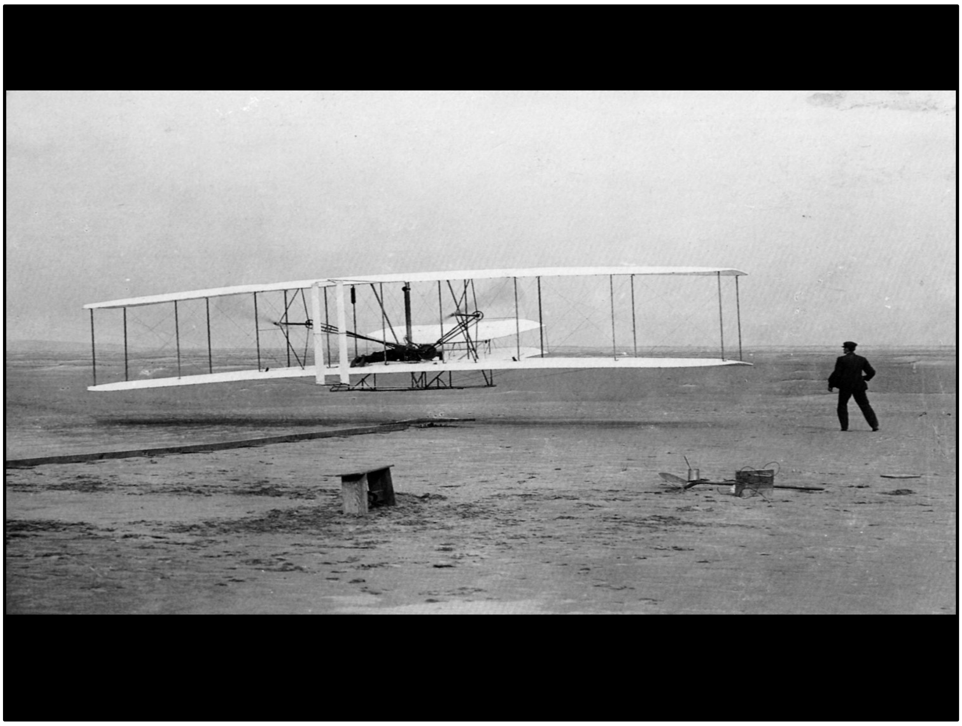
Power for Flight Pt 3

Exploring how thrust can be produced by a propeller or impeller.

*Exploring how
Propellers and Impellers
work and how they can convert
horsepower into thrust.*

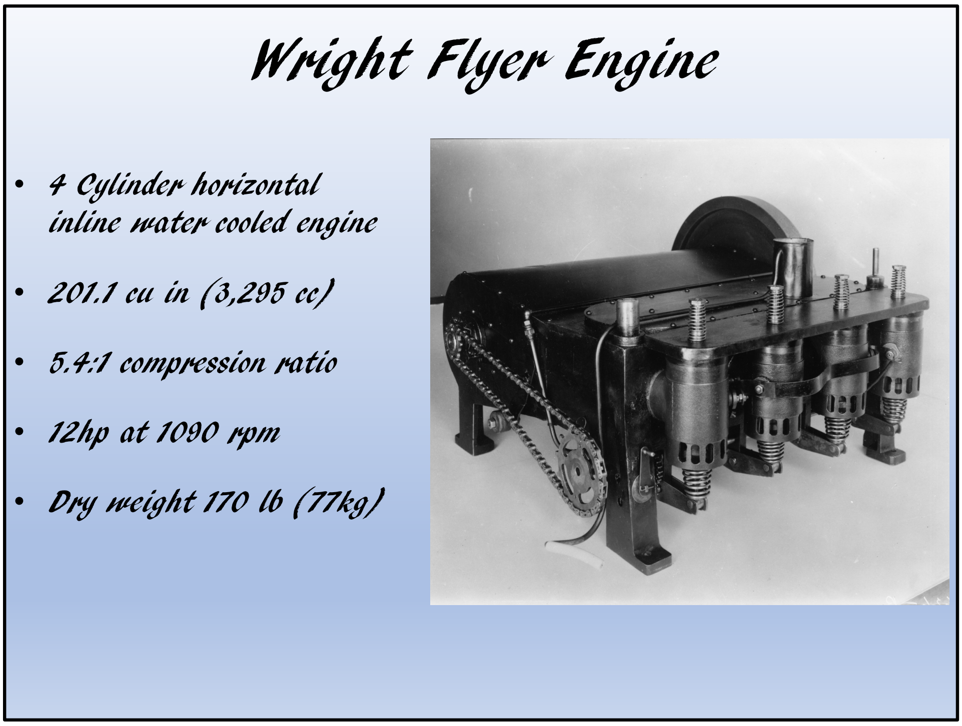
Producing Thrust using a...

- Propeller or an...
- Impeller

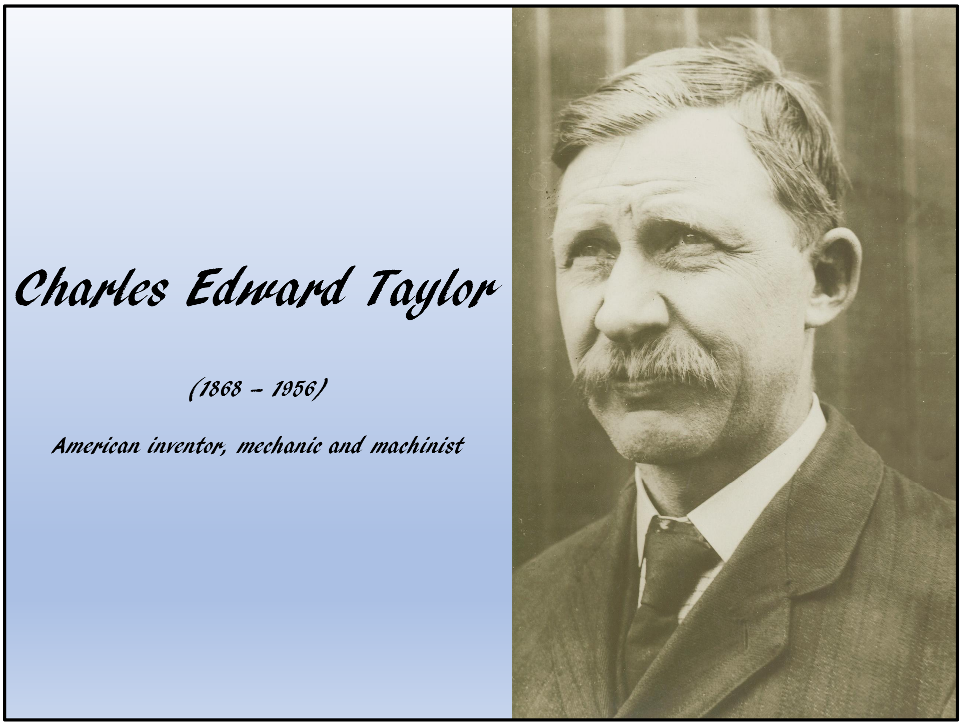


In December 1903 the Wright Brothers made the first powered flight in their aeroplane, the Wright Flyer at Kitty Hawk, North Carolina in America.

The Wright Brothers were very methodical engineers. They ran a bicycle shop in the days when the shop owners had to make the bicycles so they were also very familiar with working with light-weight structures and mechanisms. When they decided to build a powered aircraft they looked around to see what engines were available. There were no engines of the right power that were anywhere near the weight that was needed.



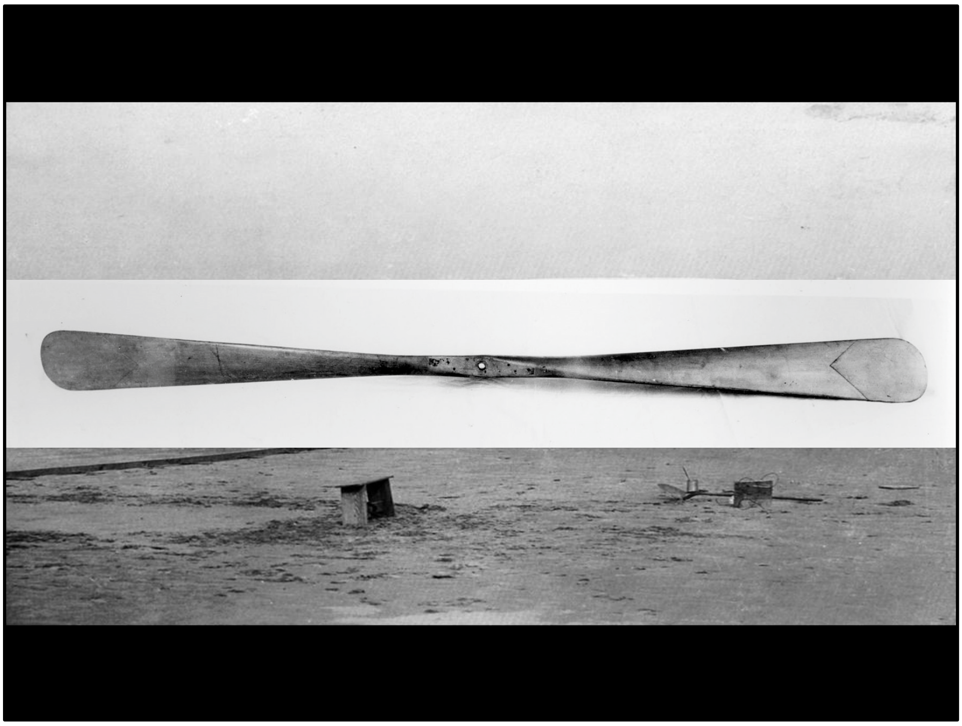
The Wright's Brothers' mechanic, Charlie Taylor, took on the challenge of building an engine from scratch and amazingly he managed to make all the parts in the bicycle workshop and the finished engine produced 10 horsepower and only weighed170lb [77kg]. It was this tremendous piece of work that made powered flight possible and the engine was later improved to develop 12 horsepower.



It is a pity that most everybody knows about the Wright Brothers but very few know that it was Charlie Taylor's engine that made the first flight possible.

The next problem was how to convert the power of the engine into useful thrust to push the aircraft through the air. The brothers had already calculated that they would need at least 90 lb [41kg force] of thrust to be able to achieve level flight. They decided to use propellers and again the Wrights looked at what had been done before by other pioneers and they were not impressed by any of the designs. So they started from first principles and decided that the blades of a propeller worked like small wings travelling very quickly through the air.

The brothers already knew that long thin wings were the most efficient so they designed a propeller that had long thin blades. They made and tested a wooden two-bladed propeller and found that if they used two propellers they could convert the 10 horsepower of the engine into the total thrust that would be needed. Their propellers turned out to be quite efficient and, considering that they were the first to be used on an aircraft, compare well with modern propellers designed with the aid of latest technology and materials.

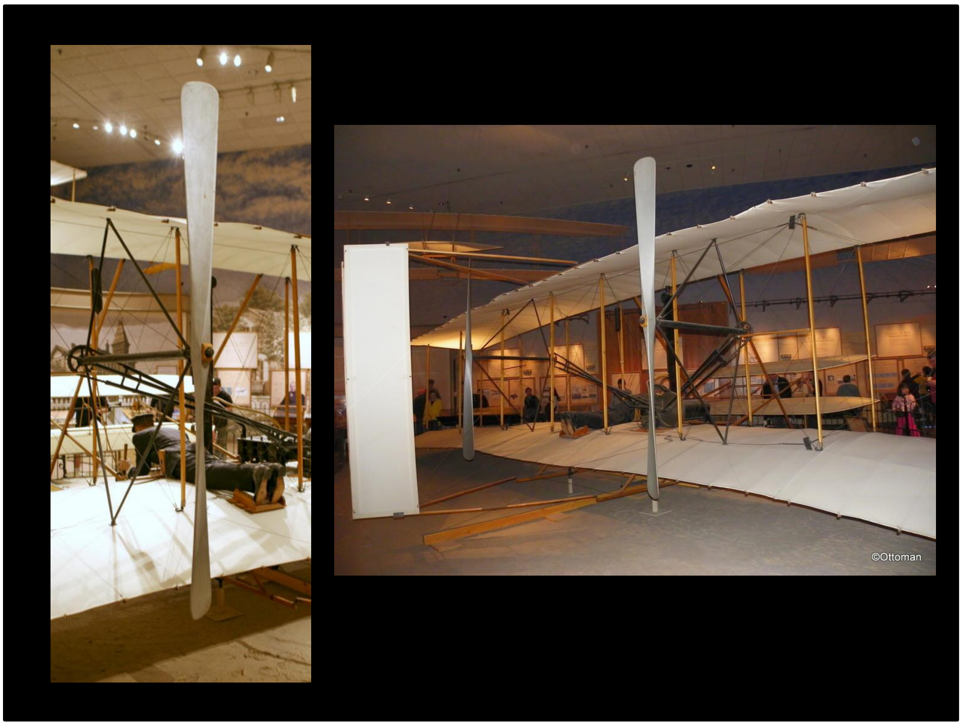


This is a propeller from the original Wright Flyer. Each propeller was 2.6 m [8½ feet] long.

It was made from layers of wood (known as 'laminations') and shaped with simple hand tools. The brothers had calculated that two propellers would be needed to produce the thrust that was needed but they made the clever decision to have the two propellers rotating in opposite directions to cancel any torque forces which would have made their 'Flyer' deviate from travelling in a straight line. This undesirable effect is known as torque reaction.

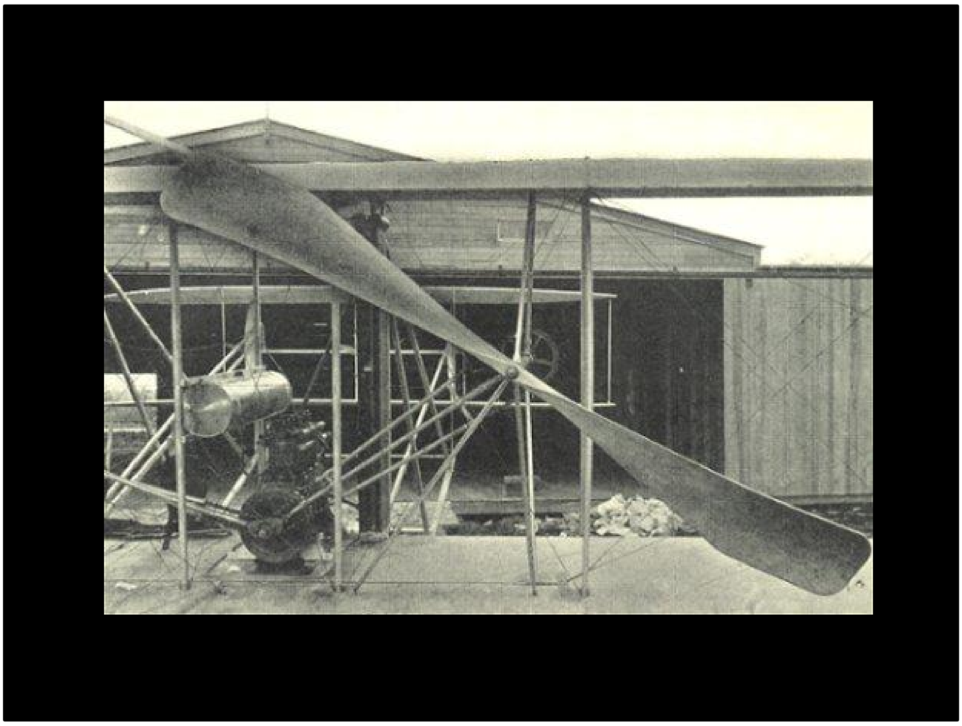
The propellers were driven by the engine via a gearbox and bicycle chains *(click)…*

*…*so it was a simple matter to cross one of the chains to make one of the propellers turn in the opposite direction as you can see.

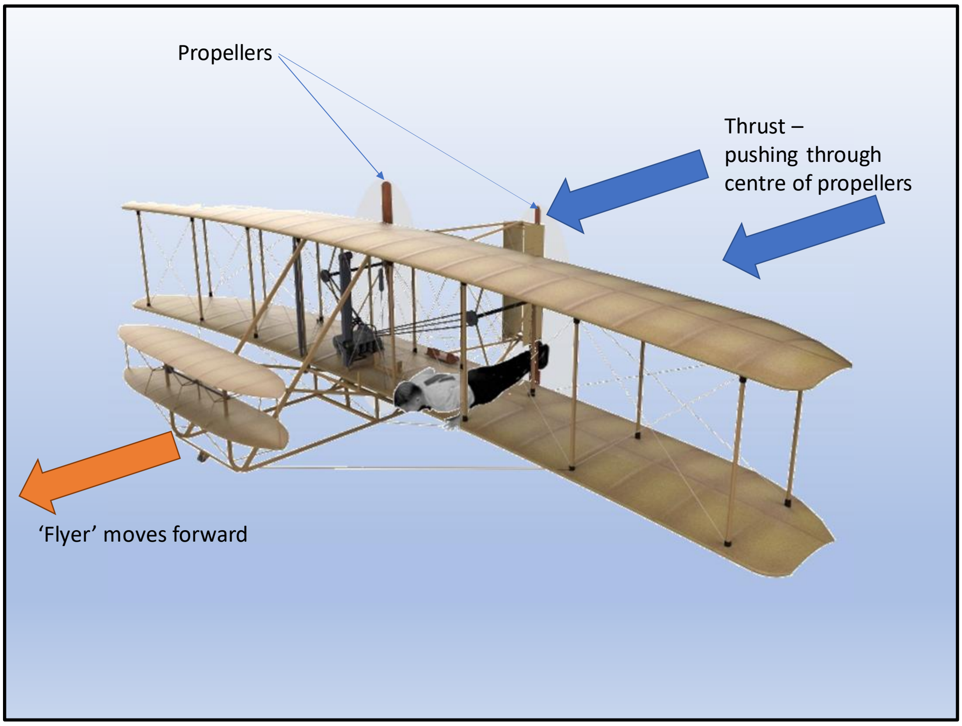


These pictures show the propellers on the original Wright ‘Flyer’ which is displayed in the National Air and Space Museum in Washing ton DC.

You can see how the left propeller runs anti-clockwise direction when viewed from this direction, pushing the air backwards and the ‘Flyer’ forwards, while the right propeller runs clockwise.



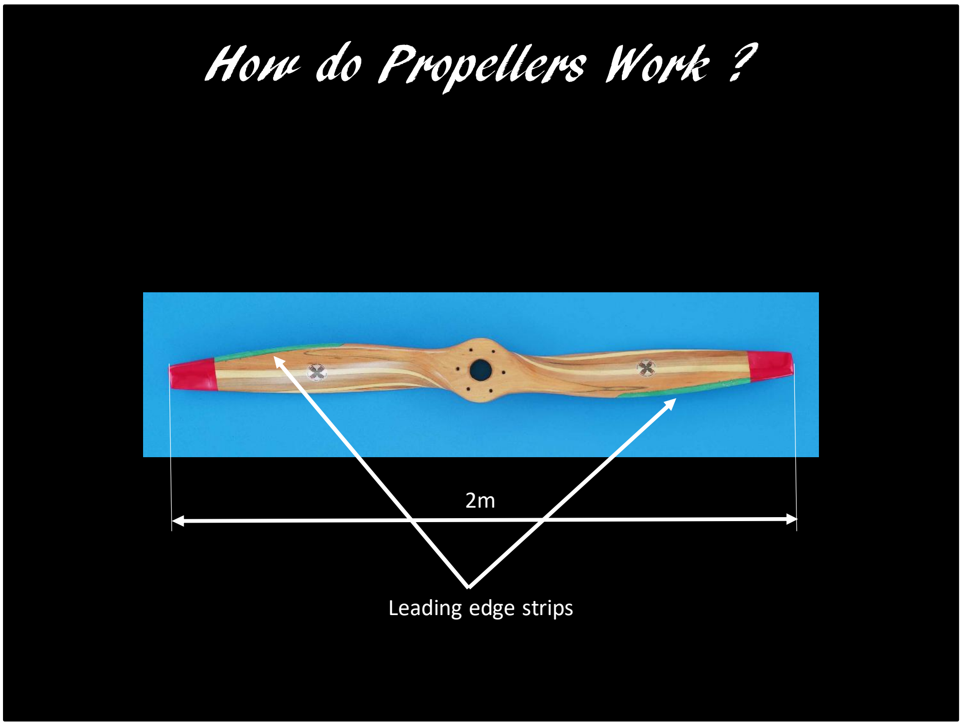
Later, the brothers modified the shape of the propeller blades to prevent the blades twisting under power. Charlie Taylor's engine and fuel tank can be seen sitting on top of the lower wing. The tall black shape between the engine and the propeller hub is the radiator which cooled the water that surrounded the hot cylinders of the engine – just like in a car.



This shows how the Wright Flyer was pushed through the air by the thrust from the two propellers *(click)*, which generate thrust which acts by pushing through the hubs of the propellers *(click)*, which causes the 'Flyer' to move forward.

The aircraft flew at about 30 mph. *(Click)*

So, how do propellers work?

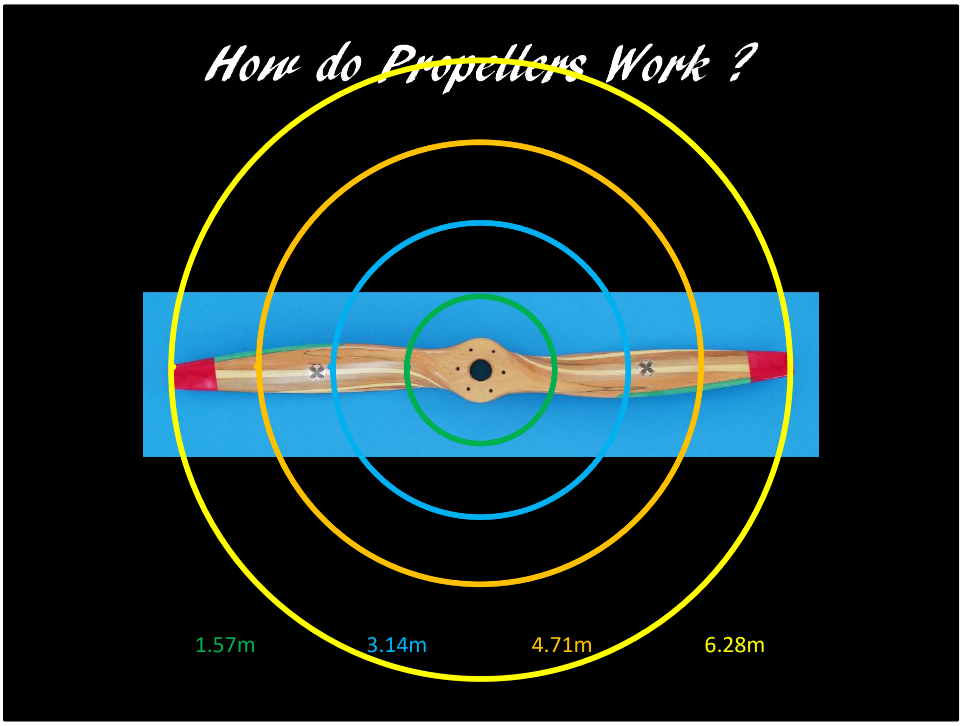


This is a small modern wooden propeller for a light aircraft with a 70 horsepower engine. This propeller is designed to spin clockwise *(Click)* - if it were fitted to an aeroplane, we would be looking at it from in front of the nose, not a good place to stand, when the engine is running!

Note the protective strips along the leading edge of the propeller *(Click)* – this is the part which hits the air, insects, stones and anything else that gets in the way and needs to be carefully looked after.

The grain of the wood grain shows the twist and inclination of the blades. As the propeller rotates, this shaping of the blades causes large amounts of air to be thrown behind the blades. Throwing the air backwards produces a reaction that pushes the propeller forwards. This is an example of Newton's 3rd Law, for every action, there is a reaction.

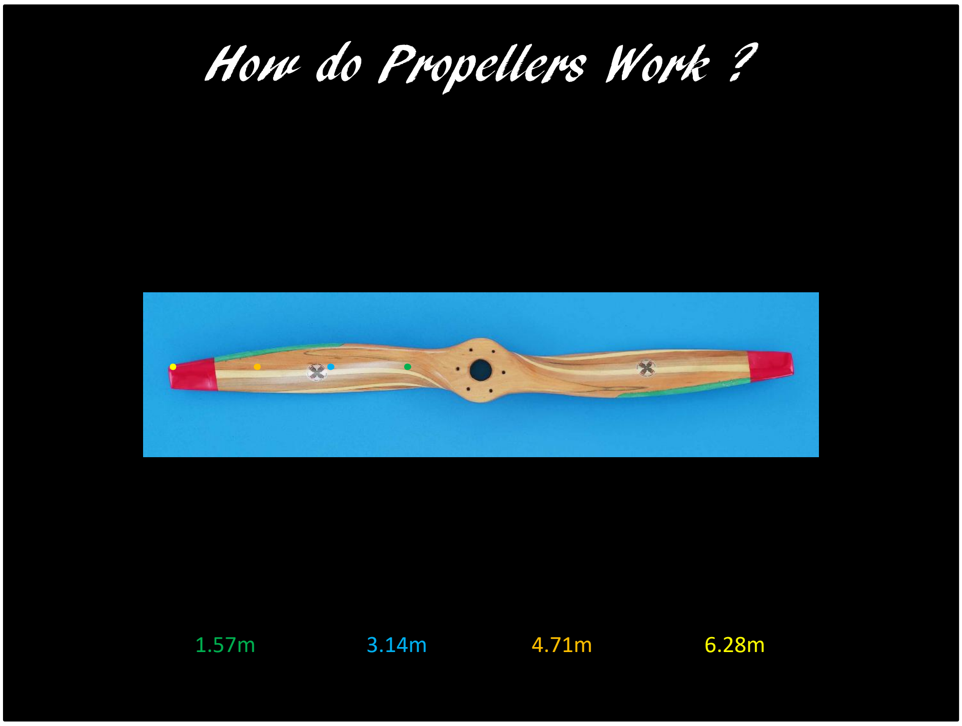
Propeller blades are just rotating wings with a horizontal axis of rotation so the aerodynamic force produced is directed forwards to provide Thrust. We know that a wing generates Lift by producing a pressure difference between the upper and lower surfaces. Similarly a propeller generates Thrust by producing a pressure difference between the forward and aft surfaces of the blades. However, propeller blades work much harder than wings and there are many problems to solve.



Let's put some test markings onto one of the propeller blades – the green marker is 0.25m from the centre, the blue marker 0.5m, the orange marker 0.75m and the yellow marker at the tip, 1.0m from the centre.

Now let's get the engine running *(click)* and note how the test marks travel in a circle around the centre of the propeller. The green mark *(click)* travels a distance of 1.57m for each rotation. The blue mark *(click)* travels 3.14m each time round. The orange mark *(click)* travels 4.71m, and the yellow mark *(click)* 6.28m.

We have our data now, so let's switch the engine off. *(Click)*



Looking at the data, it is clear that the green mark, closest to the centre has travelled the least far, whilst the yellow mark has travelled the furthest. As all the marks have been travelling for the same time, the further away from the centre the mark, the faster it must be travelling.

How far has the centre of the propeller travelled? (0m)

If the propeller was spinning at one revolution per second, how fast were the test marks travelling in metres per second?

(Green 1.57m/s, blue 3.14m/s, orange 4.71m/s, yellow 6.28m/s)

This is similar to a playpark merry-go-round. If you stand in the middle you will just slowly revolve but if you hang onto the rails at the outside you will whizz round with the wind in your hair.

As we have already decided that the propeller works just like a wing, this means more 'lift' is generated towards the tips than at the centre because they are travelling faster. However, as it is directed forward we call it 'thrust'.

Lets look at the speed associated with our propeller turning at a realistic speed.

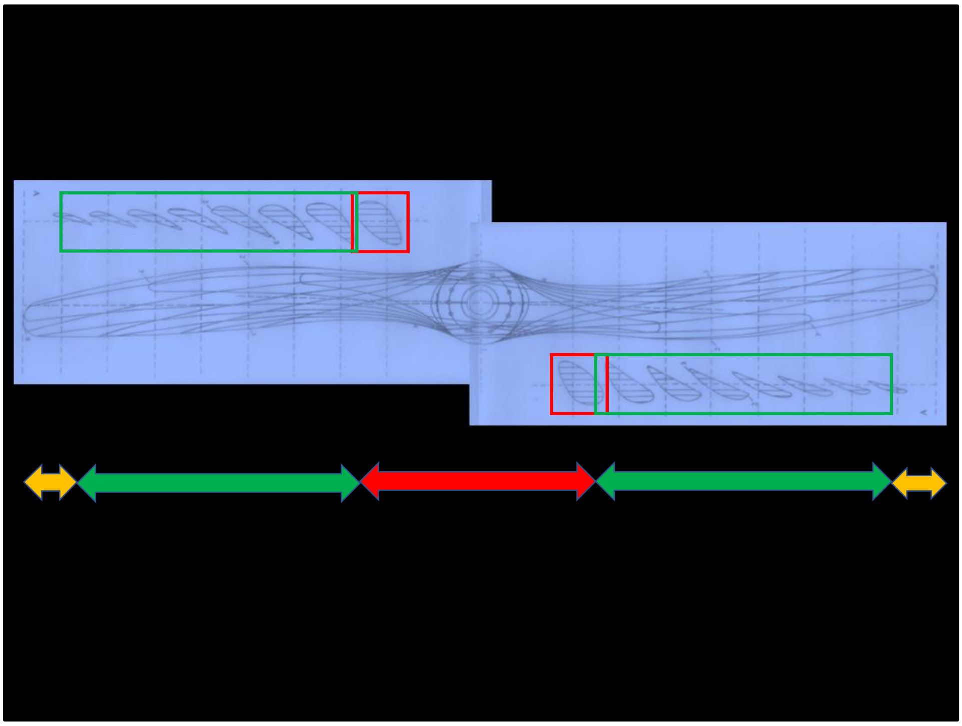
Speeds of a Typical Real Propeller

Test Marker	Propeller Diameter (m)	Rotation Rate (RPM)	Rotation Rate (RPS)	Speed (m/s)	Speed (km/h)	Speed (MPH)
Green	2.0	2400	40	62.8	226.1	140.5
Blue	2.0	2400	40	125.6	452.2	281.0
Orange	2.0	2400	40	188.4	678.2	421.4
Yellow	2.0	2400	40	251.2	904.3	561.9

The left hand column identifies our test marks from the previous slide, and we have already identified the propeller diameter as 2m.

The rotation rate of 2400 revolutions per minute (RPM) is a typical propeller rotation rate for a light aircraft. (RPM is the same quantity that is shown on your rev counter in the car, although in that case it measures engine speed.) To make that calculations easier, the revolutions per second has also been calculated simply by dividing RPM by 60. Note that 40 turns per second is quite fast!

It is when the speed of travel is worked out based on this rotation rate that there are some surprisingly high figures. The yellow mark at the propeller tip is travelling at over 550 miles per hour. This is why aircraft propellers are such dangerous things, and pilots and engineers who need to go near them and/or handle them, treat them with a great deal of respect.

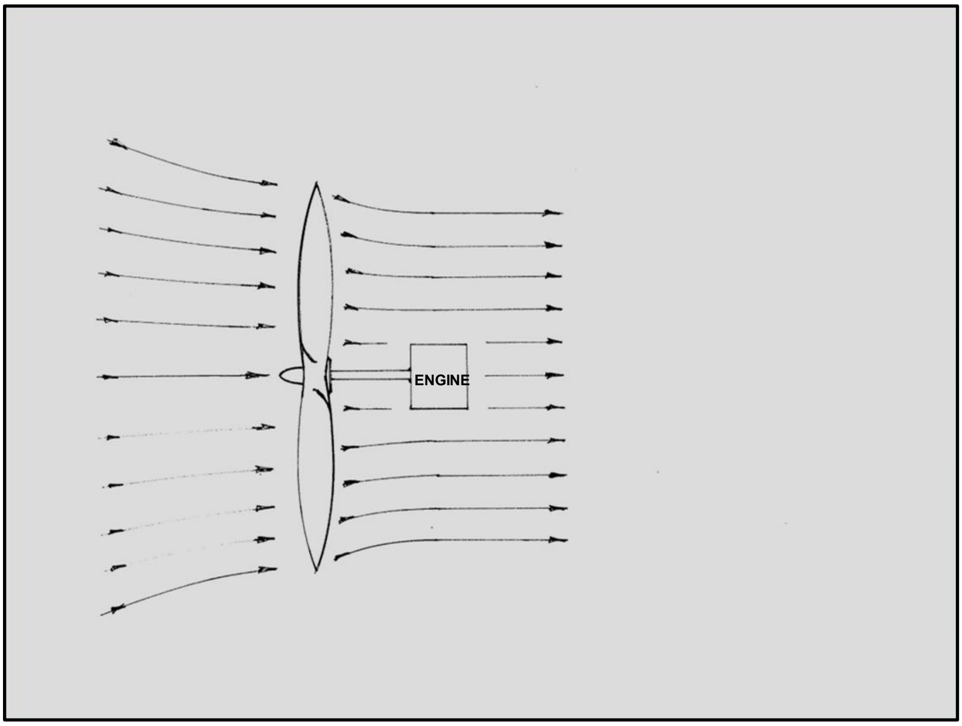


If we look at the sections through a typical propeller we can see that the shapes in the centre area, *(click)* in the red band, are not good for producing lift and we also now know that they are moving relatively slowly. The cross sections (*click)* in this area are not good aerofoils and the main purpose of this area is to provide strength.

The next sections, *(click)* in the green bands, do have a good aerofoil (or wing) cross-sectional shape. They are travelling more quickly and produce most of the thrust.

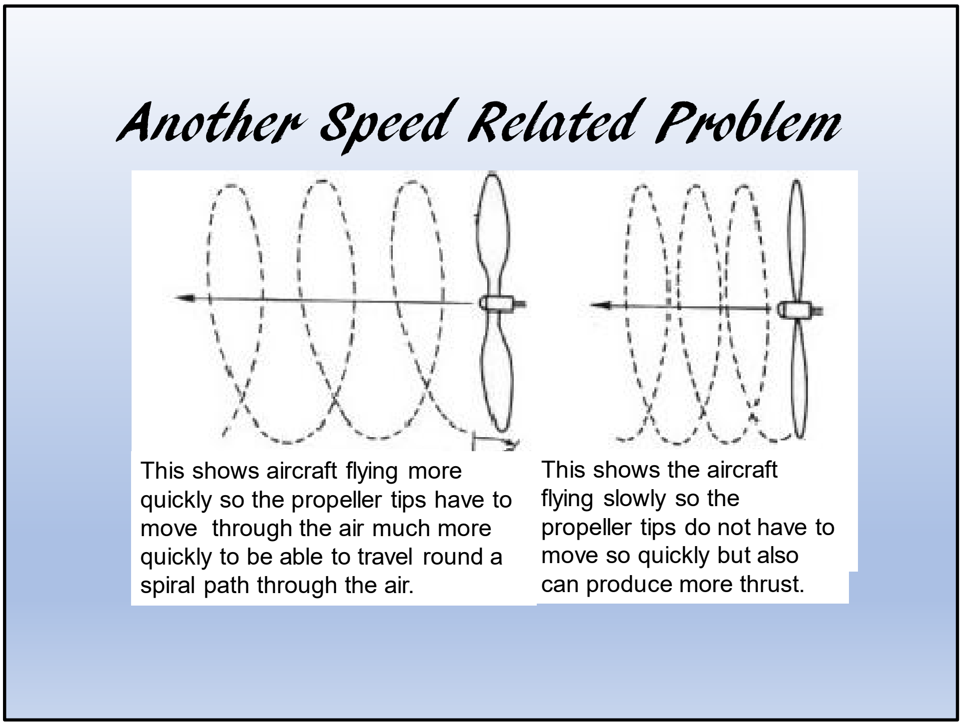
The last small sections, *(click)* in the yellow bands, have the same problem as wings in that the air tries to escape around the tip so these areas do not work so well.

So propellers are not as efficient as we would like them to be.



This diagram of a propeller shows how air is sucked in from ahead of the propeller and then accelerated by the blades to flow quickly aft behind the propeller.

The air that the propeller accelerates backwards is called the “slipstream” and, because it is travelling quickly, its pressure is low. The surrounding air, at a higher pressure, squeezes the slipstream so that it is actually smaller than the diameter of the propeller.



There is another problem with propellers.

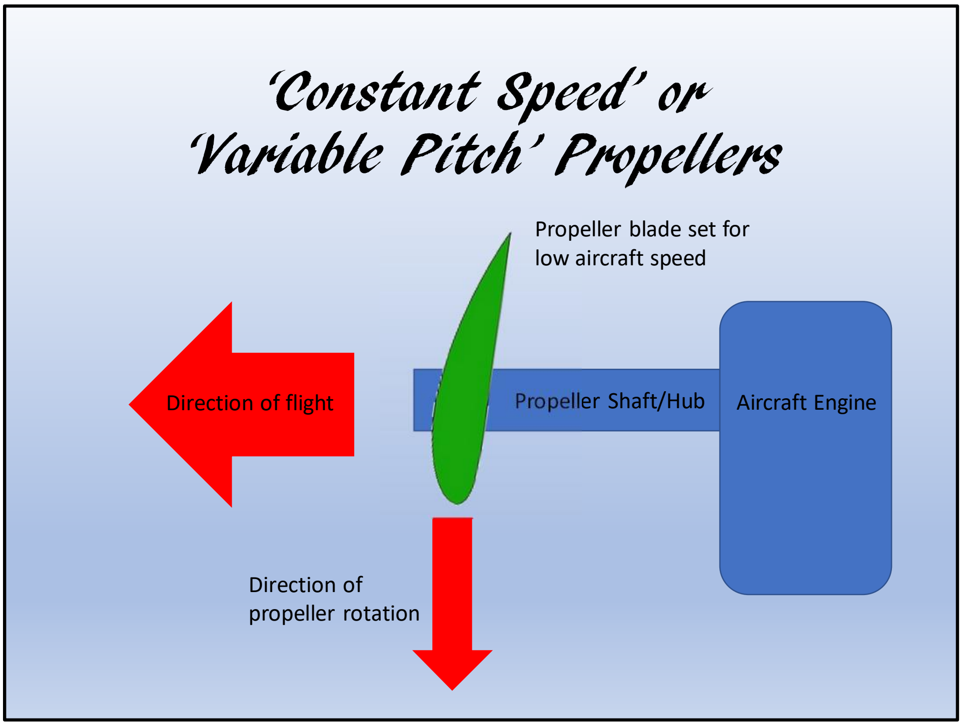
We know that the tips of the blades are travelling very fast even before the aircraft has started to move. When the aircraft flies through the air the propeller not only revolves but travels forward at the same speed of the aircraft so the propeller tips have to travel through the air much faster than the aircraft.

In the example that we have just seen, the propeller tips are travelling at 904kph [560MPH] before the aircraft even moves. If the aircraft now takes-off and cruises at high altitude at 320kph [200MPH] the propeller tips will now have to fly through the air at 880kph [760MPH].

Now this is a problem because the propeller tips are now travelling through the air at a speed exceeding the speed of sound which could be 1,060kph [660MPH] at the cruise altitude. This means the tips are not able to produce thrust efficiently.
It is this problem that prevents propeller driven aircraft from ever being able to reach the speed of sound.

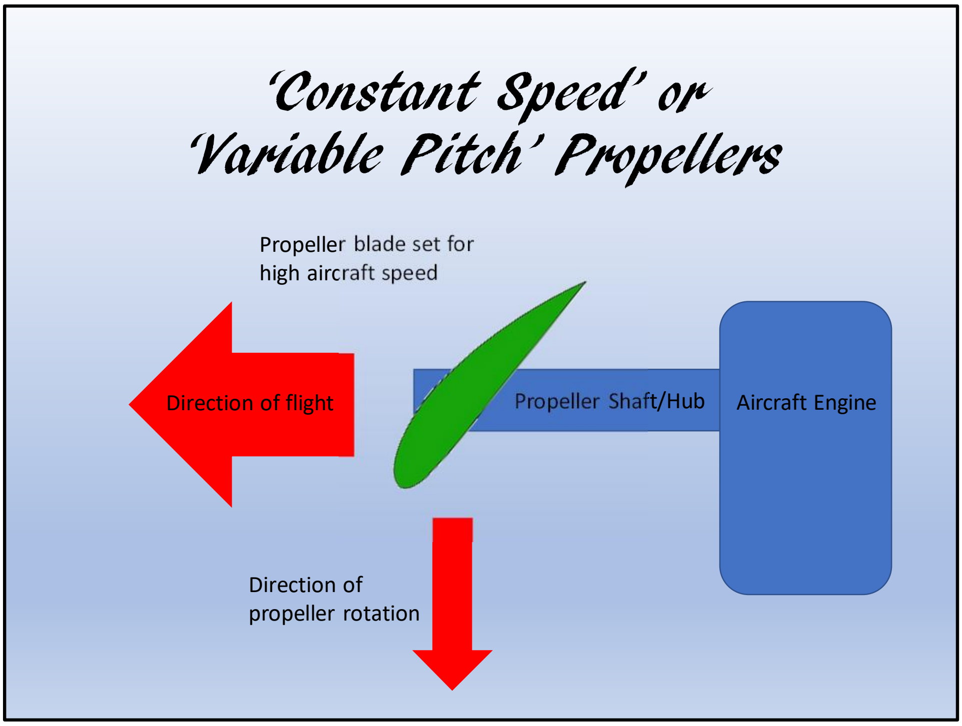
Some aircraft have propellers whose tips do routinely exceed the speed of sound like this North American Harvard trainer…. *(click)*

You will recognise the angry, rasping sound if you hear it, quite unlike any other aircraft.



One way of alleviating this problem is to change the shape of the propeller in flight. This is obviously not a trivial thing to do, but is similar to changing gear in your car. By doing this, the propeller can be made to work harder at a lower speed. This type of propeller is known as a 'constant speed' or 'variable pitch' propeller and the blades can be rotated about their axis in flight. This can be achieved automatically, or manually by the pilot – again just like changing gear in your car. *(Use Page Up and Page Down to see the different settings)*

At low speed, the blade is set to this fine pitch to reduce its drag as it works hard to get the aircraft moving during its take-off run and initial climb.



At higher speed, the blade cuts the air at a much coarser angle allowing greater quantities of air to be thrown backwards at a given speed.

Externally this, much more complex design, looks very similar to a fixed pitch propeller just like we considered earlier, although the usually have three or more blades *(click)* like this one..

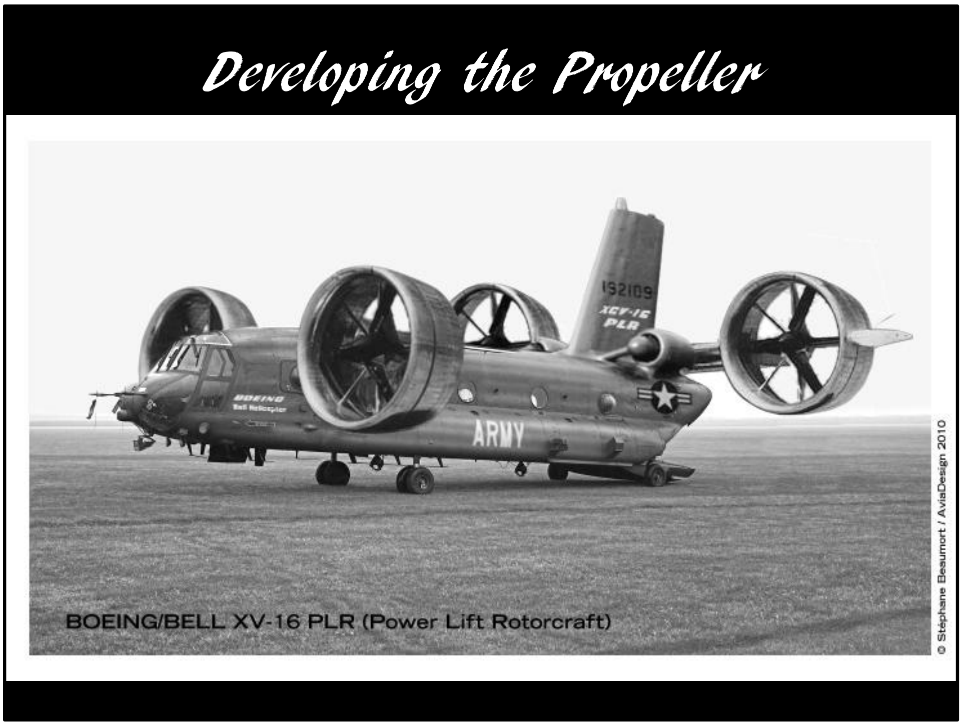
This photo shows a typical variable pitch propeller on a light aircraft.

One question often asked about propellers is 'how many blades should it have?'

This slide shows the development of the famous Supermarine Spitfire from its first flight in 1938 when its Rolls-Royce Merlin engine produced about 1000HP attached to a 2 blade propeller, through to the final post-war developments by which time its Rolls-Royce Griffon engine was producing over 2300HP, necessitating a 6 blade, contra-rotating propeller to absorb all that power. *(Click through the images to watch the development of this iconic aircraft and its propeller)*

This is the new the Airbus A400M military transport aircraft. Each engine develops 11,000 horsepower and it needs eight blades to be able to convert this power to thrust. The aircraft is known as the Atlas in Royal Air Force service.

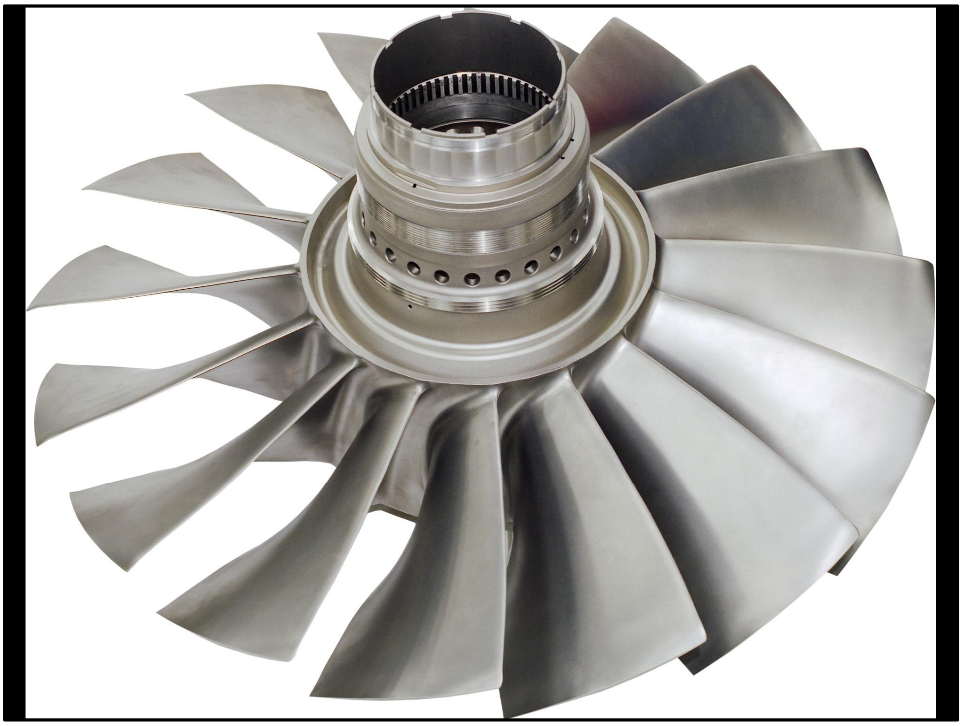
This big Russian military aircraft, the TU95 Bear, has four very powerful engines of 14,800 horsepower each. The designers managed to convert this power into thrust by having two contra-rotating propellers on each engine. This is the most powerful propeller driven aircraft ever.



Engineers started to think of ways to improve the design of the propeller so it was proposed to make two changes.

Firstly, add a smooth fairing, or spinner to the propeller hub to smooth the flow to the blades and secondly, put a close fitting cowling around the blades to stop the air from leaking round the tips.

The concept was tried out on a few experimental aeroplanes too *(click*), like this strange conversion of a Chinook helicopter.



Now the design was taken a stage further by changing the centre portion, or hub, into a disc with a smooth fairing on its nose and by adding more blades to reduce the diameter but still provide the thrust. So now the propeller changed to look like this and was now called an impeller.

This small observation aircraft was called the Edgley Optica and had its impeller mounted inside a duct behind the cockpit. It was found that this had the additional advantage of reducing the noise of the propeller and engine.

Impeller design was not taken much further but it did show how the traditional propeller could be made much more efficient if it was multi-bladed and fitted inside a cowling.

More of the story of impellers later ----