Second Level Technologies
Benchmark TCH 2-20a

Power for Flight Pt 4

Exploring the various ways of
producing power that can
be used to turn a
propeller to produce thrust.

Exploring how various types of power sources can be used to turn propellers to convert horsepower into thrust.

WE COULD USE THE
POWER OF THE
PILOT TO TURN A
PROPELLR

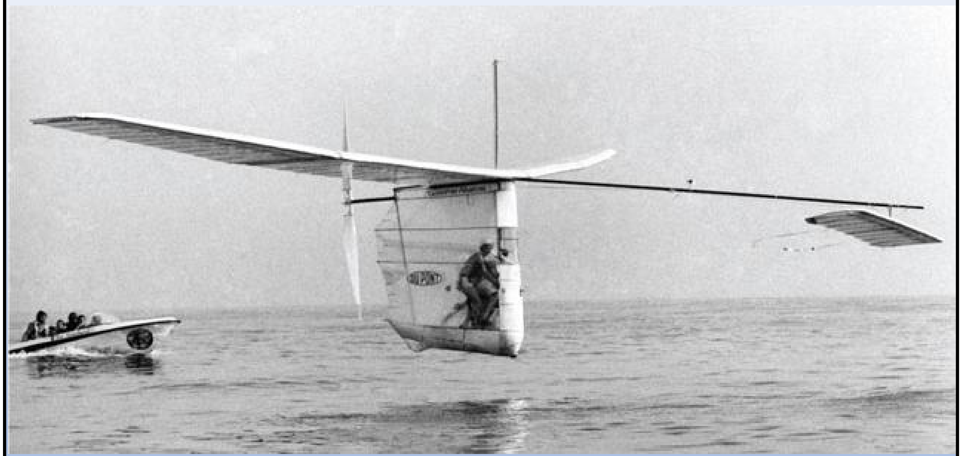
The Gossamer Condor.

Although some experimenters back in the 1920's attempted to fly aircraft using man-power they were discounted as not being true man-powered aircraft since they used external assistance systems to get off the ground and then used man-power to prolong the glide back to a landing.

In 1959, Henry Kremer a wealthy British businessman, decided to stimulate interest in manpowered flight by offering a prize of £50,000 for the first aircraft that could fly round two markers placed ½ mile apart in a figure-of-eight course.

The first aircraft to take-off using only the power of the pilot was in 1961. The aircraft was designed by the University of Southampton. It could only fly in a straight line, on a calm day and very close to the ground.

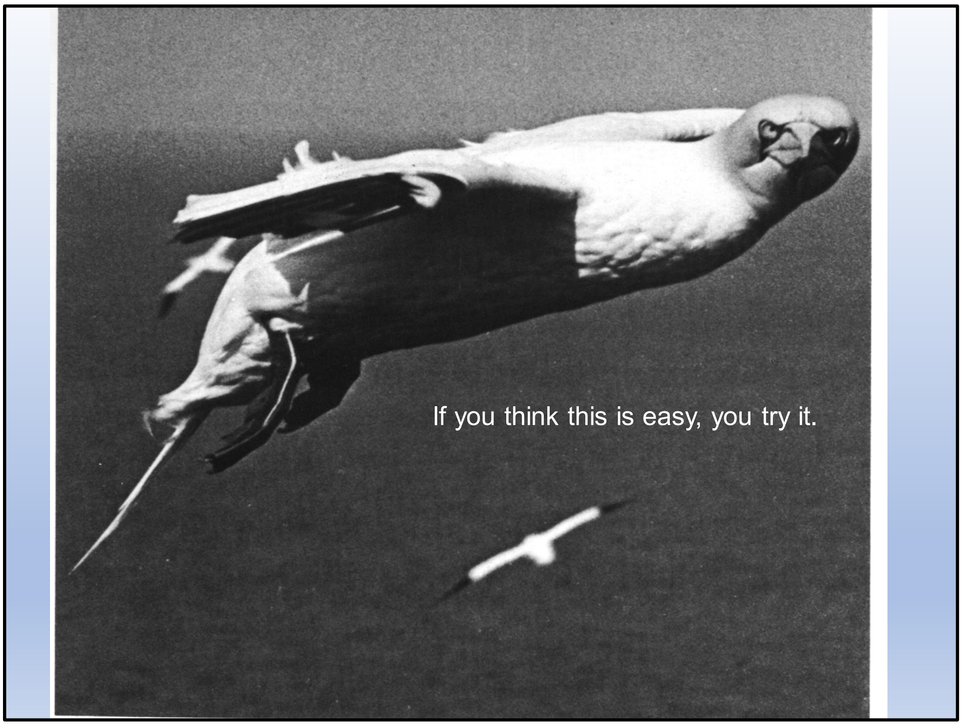
It was an American designer Dr Paul MacCready who rose to the challenge and it was his aircraft, Gossamer Condor, that was pedalled round the figure-of-eight course by Bryan Allen who was at the limit of his power. The aircraft weighed 70 lb[31.75kg] and flew at about 10 mph.



The Gossamer Albatross crossing the English Channel.

Henry Kremer now decided to increase the challenge and offered a large cash prize for the first man-powered aircraft to fly across the English Channel. In June 1979, the very light Gossamer Albatross covered the 22 miles in 2 hrs 49 mins, an average ground speed of just under 8mph. As you can see the aircraft was very large and was forced to fly very close to the water most of the way.

The designer was again Dr Paul MacCready and he won the £100,000 prize. Bryan Allen was the pilot again and he had to pedal very hard for nearly 3 hours, a remarkable feat of endurance.



So we can see that it is not so simple to produce the power for flight by pedalling. Humans are not very powerful. Top sprint cyclists may be able to produce over 2 horsepower for a few seconds but, for longer flights, the power output can drop to about 0.25 horsepower.

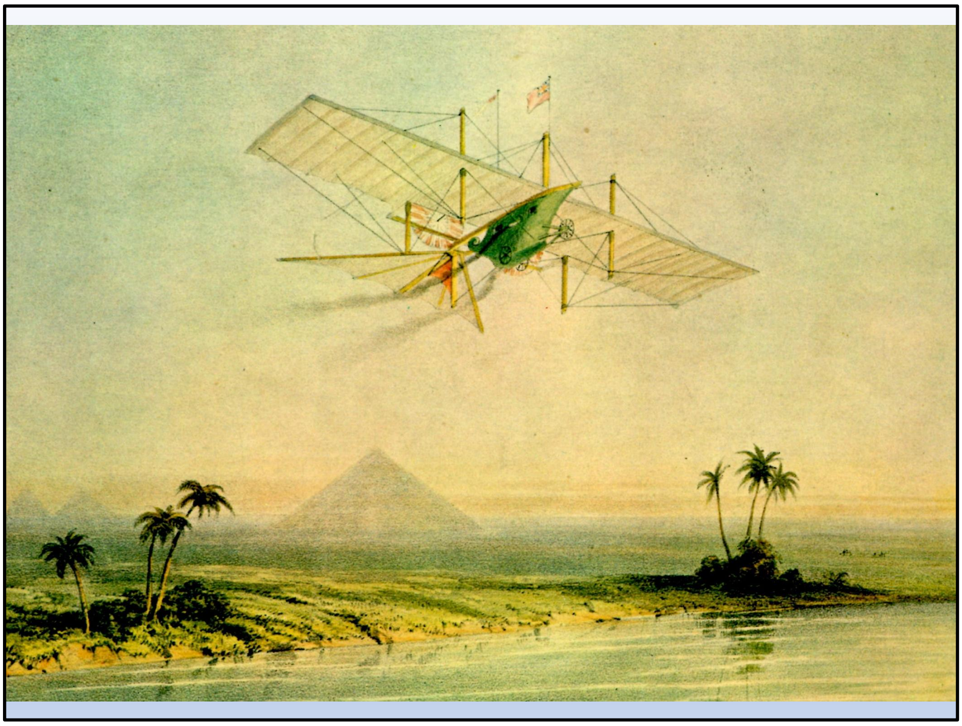
It needs a very large, very light and expensive aircraft to be able to support the weight of the airframe and the pilot at speeds of around 10mph. It can only be flown on days where there is no wind and is very vulnerable to damage.

Birds found out a long while ago that powered flight requires a lot of energy and they had to develop skeletons and muscles to be able to produce the power. Also they had to develop very fast and light-weight digestive systems to be able to quickly convert their food into power.

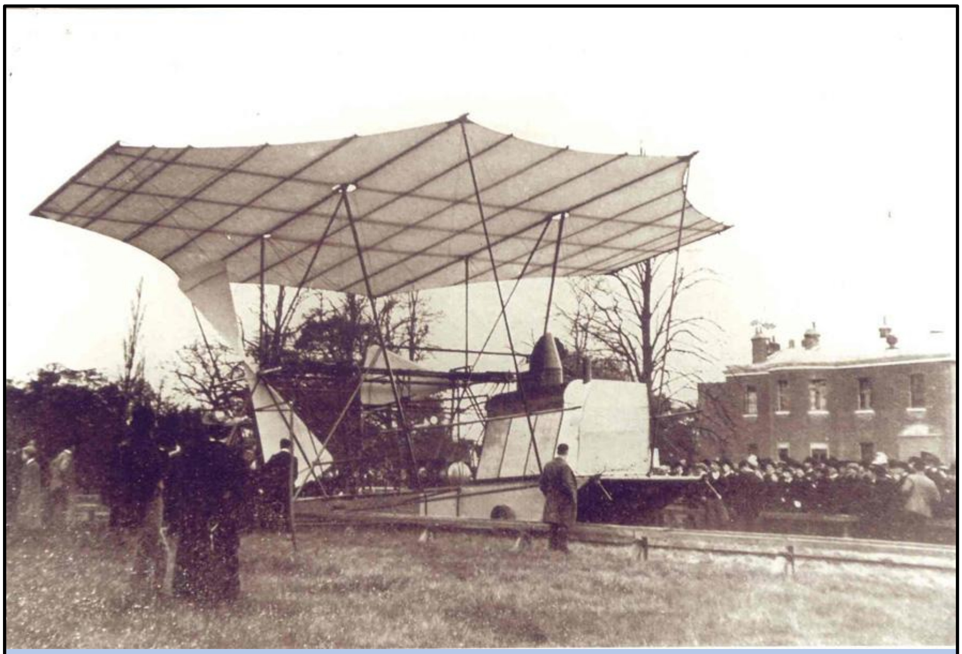
So, sadly, we have to accept that men will never fly around under their own power and it is never going to be the way to get around the world.

A different power source will be required.

WE COULD USE A STEAM ENGINE TO TURN A PROPELLER



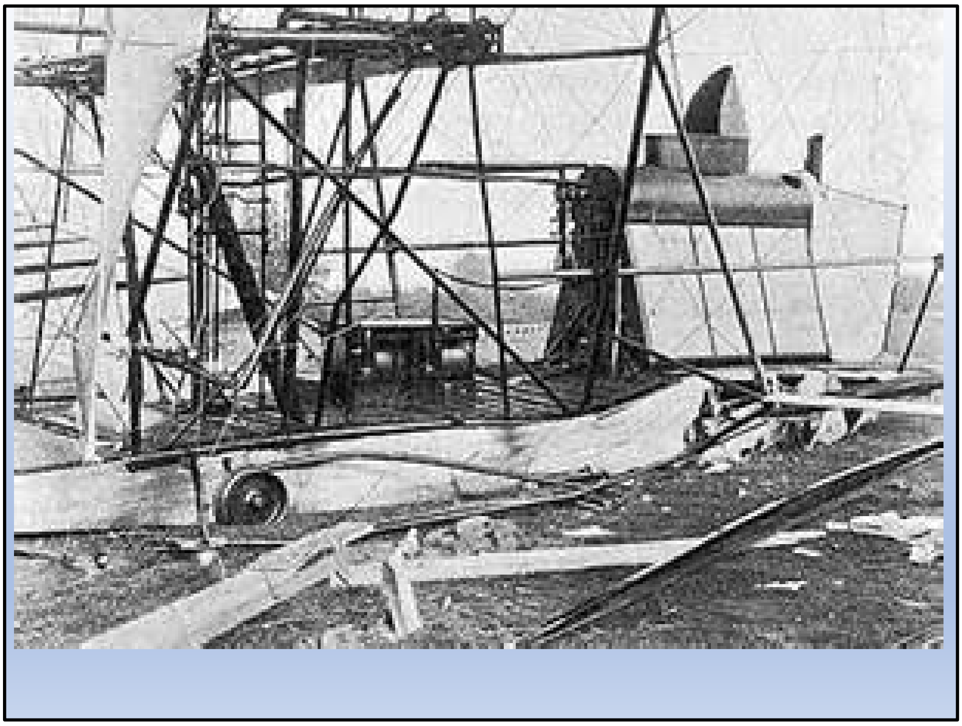
When the early pioneers first started to think about powered aircraft in the 19th century the only engines that were available were steam engines. The steam engines of the day were of course very heavy and needed large coal-fired boilers to produce the steam. However that did not deter the people who thought that one day it would be possible to fly around powered by steam. However, towards the end of the century in 1897 there were experiments in driving motor cars using steam engines and very light boilers were designed that could produce steam within a few minutes. These cars were for a time very successful and one of them set a speed record of 127 mph [204kph] in 1906. This picture is of Henson's steam-powered aerial carriage cruising down the river Nile in 1843. Needless to say, it never happened.



The development of light weight steam boilers and light steam engines encouraged some aviation pioneers to design and build aircraft using this power.

This strange looking aircraft was actually a test rig built by Hiram Maxim in 1889 to see if there would be enough power to lift an aircraft off the ground. It had a lightweight boiler and two steam engines of 360 horsepower and each turned a 17ft diameter propeller.

The test rig ran along a rail track and, since it was not intended to take-off, it was restrained by a second track above its wheels.



Unfortunately the test was too successful and the test rig accelerated to a speed where the lift on the wings was sufficient to break the restraining track and the aircraft left the rails, crashed, and was very badly damaged.

So steam powered aircraft were abandoned at this stage in the face of the increasing availability of more powerful and much lighter internal combustion engines.

So as a power system, steam was not to be the way forward.

WE COULD USE AN ELECTRIC MOTOR TO TURN A PROPELLER

Electric motors have been around since the first quarter of the 19th century but it was not until the end of the century that motors were commonly used in transport systems i.e. trams and trains. However the electric motors that powered these vehicles had to be connected to a power source through a system of electrified cables or rails.

It was not until the middle of the 20th century that small motors became powerful enough to be run from batteries that were carried by the vehicle, such as the old milk floats that were used to deliver milk to people’s front doors without waking them up with a noisy engine.

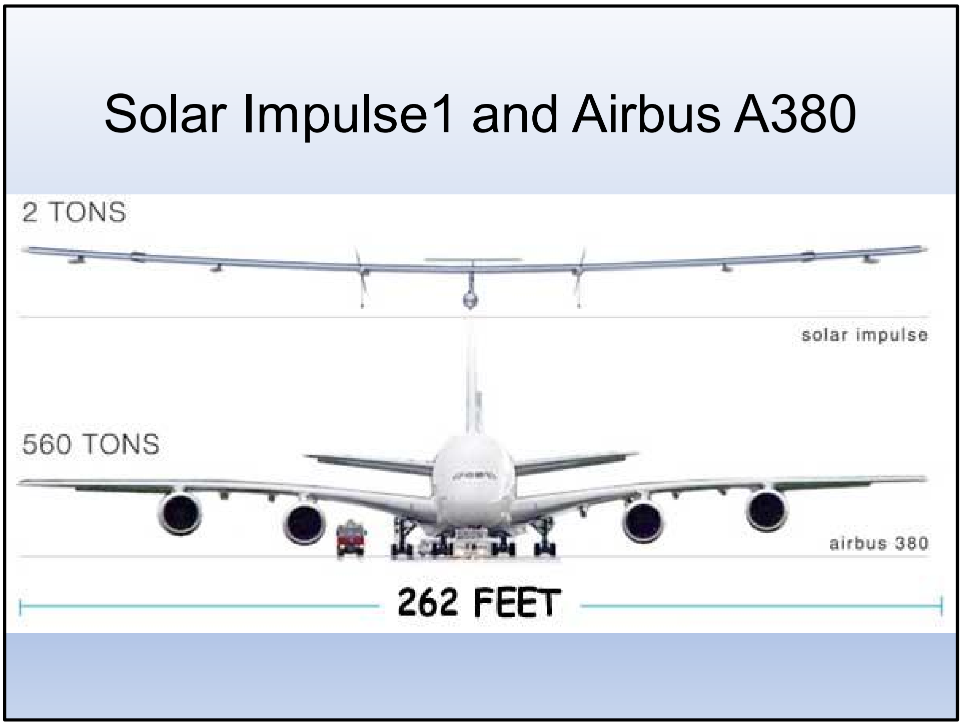
It was not until about twenty years ago, when there was a sudden development in more powerful batteries and motors, that it became feasible to consider using these in aircraft. However it was the life of the battery that would control the length of time that the aircraft would be able to stay in the air. The current development shows that it might be feasible to stay in the air for up to an hour. Not enough to take you on holiday to Florida. This photo is of the Airbus E Fan aircraft. A light sport or training aircraft able to stay airborne for about an hour. The electric motors that power the two fans are run from a battery pack. This was the first electrically powered aircraft to fly across the English Channel.

The Solar Impulse1

The endurance of battery powered electric aircraft was obviously going to be limited by the storage capacity of the battery. So it was proposed that the aircraft could generate its own electrical power while in flight. The development of more efficient photo-voltaic cells, otherwise know as solar panels, was now at a stage where enough power could be generated to drive motors to turn the propellers. The problem was that it needed a very large area of solar panels to generate the power. However, since the amount of power available would be limited, the aircraft would have to be very efficient and it would have to have a long thin wing. So the only feasible aircraft would be a very light aircraft with a very large wing.

The Solar Impulse1 first flew in December 2009. In July 2010 it flew for 26 hours including 9 hours of night flying.

This was the test aircraft for the final version, Solar Impulse 2, that was intended to fly around the world in 2015.



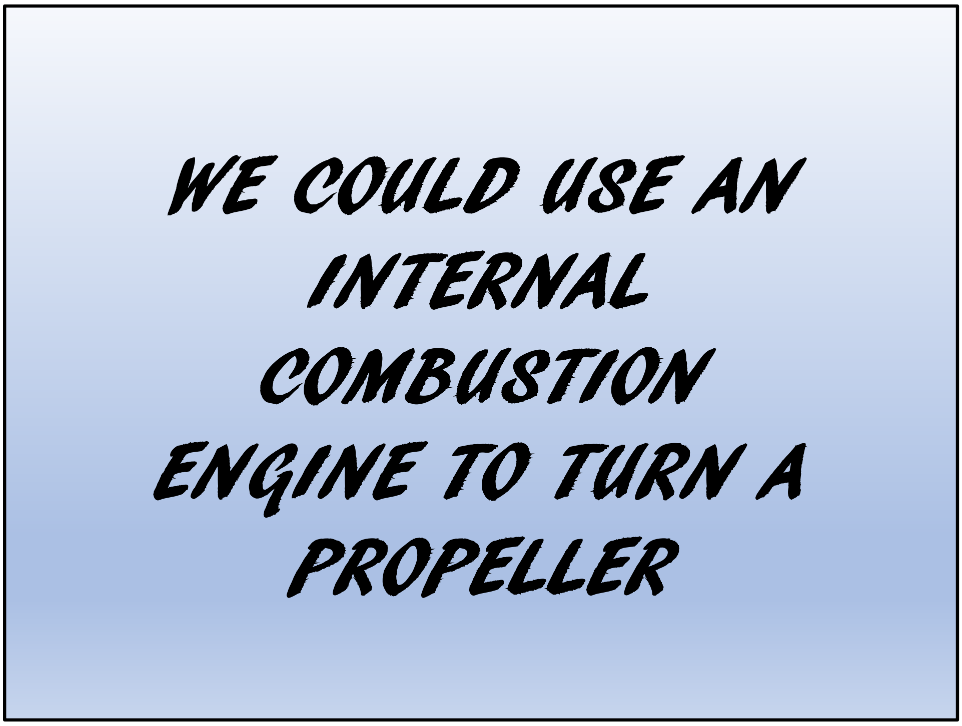
This diagram gives an idea of just how big and light a solar powered aircraft has to be to be able to fly on the electrical power generated by solar panels. After the Solar Impulse 1 test aircraft showed that it was possible to fly on the power generated by solar panels, a long distance flight was planned.

The Solar Impulse 2 started a long distance flight at Dubai on the 9th of March 2015 and returned on the 23rd of July 2016 having circumnavigated the world.

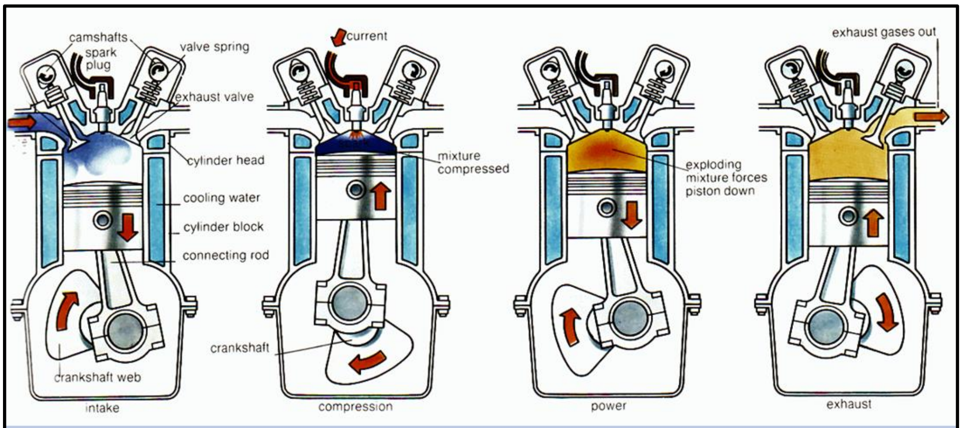
The “Round the World” flight was an interesting exercise in finding out what was possible in the field of electric flight but the cost of the aircraft and lack of payload and speed meant that it would be a long time before this technology would provide a world wide transport system. The Solar Impulse 2 aircraft had four electric motors of 17.4 horsepower.

The total flight time to get round the world was 558 ½ flight hours with the aircraft cruising at 56mph [90kph] by day and 37mph [60kph] by night. It carried two pilots who shared the work during the very long flights over the oceans.

So, another simpler and more powerful source of power would be needed to make powered flight practical.



These type of engines are called “internal combustion” because the fuel is burned inside the engine unlike a steam engine where the fuel is burned in a boiler outside the engine. The ones that we are going to look at now are usually called “piston” engines because the energy from the burning fuel is converted to “work” or horsepower by pushing pistons down cylinders.



SUCK SQUEEZE BANG BLOW

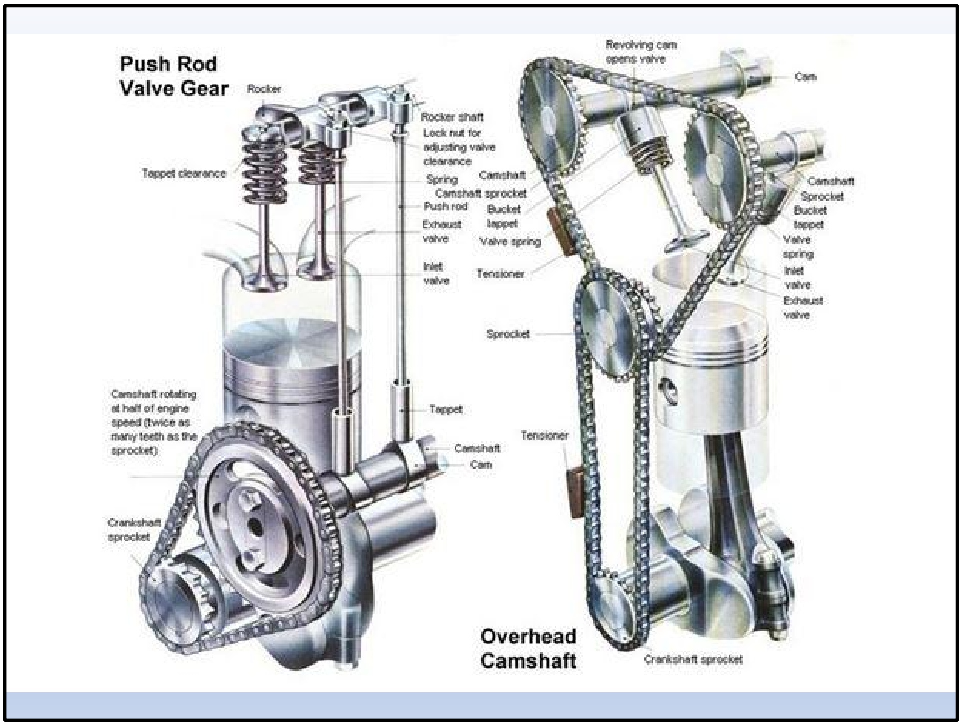
Stroke 1 sucks in the petrol/air mixture.
Stroke 2 squeezes the mixture into the top of the cylinder where it is ignited by the spark plug and explodes.
Stroke 3 the explosion drives the piston back down the cylinder.
Stroke 4 pushes the burnt mixture back out of the cylinder.

There are two main types of reciprocating internal combustion engines. The two-stroke engine where the fuel is burnt every time the piston comes up to the top of the cylinder and there is the more common four-stroke engine where the fuel is burnt every second time that the piston comes up to the top of the cylinder. This diagram is for a four-stroke engine.

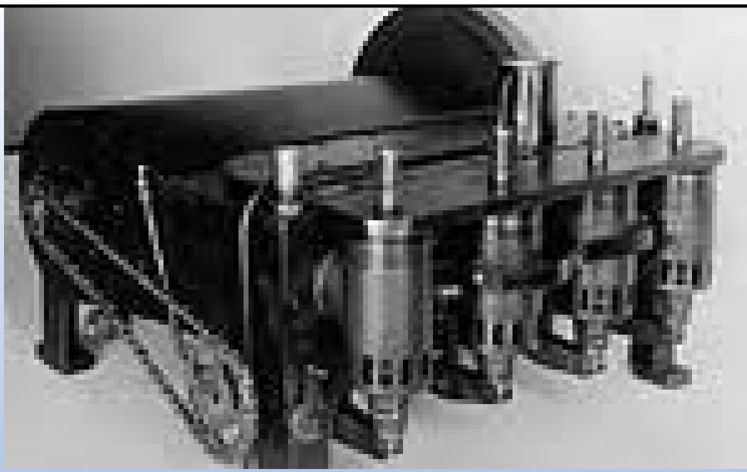
There are also two main types of fuel used in these engines, petrol and diesel oil. Petrol is highly refined oil and is very volatile, that is, it burns easily. Diesel oil is less highly refined and is less volatile, that is, it does not burn easily.

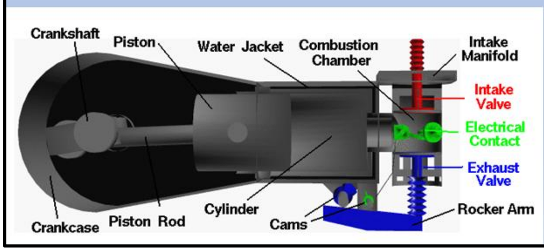
By far the most common types of aero-engine are the four-stroke types that burn aviation grade petrol.

The development of aero-engines over the years produced a great variety of types such as air-cooled and water-cooled with the cylinders arranged in-line or radially. Each type of engine had its advantages and disadvantages.



It is important to make sure that the valves allowing the fuel/air mixture into the cylinder and the exhaust gas out of the cylinder are opened and closed at the right time. This diagram shows two different ways of driving the inlet and exhaust valves. The overhead camshaft is the most popular nowadays.

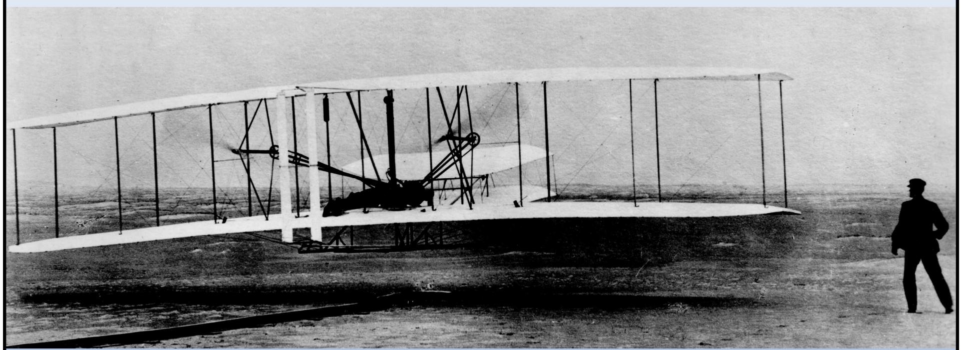




This is the engine that Charlie Taylor made. The diagram shows how the valves worked.

When the Wright Brothers looked at what kind of engine would be available to power their aircraft they automatically thought of using an internal combustion engine. This type of engine had been around in various forms for about forty years and Daimler's petrol engine which first ran in 1883 had been by this time developed to improve its power and reliability. However the Brothers could not find a current version of engine that was light enough or powerful enough to use in their aircraft.

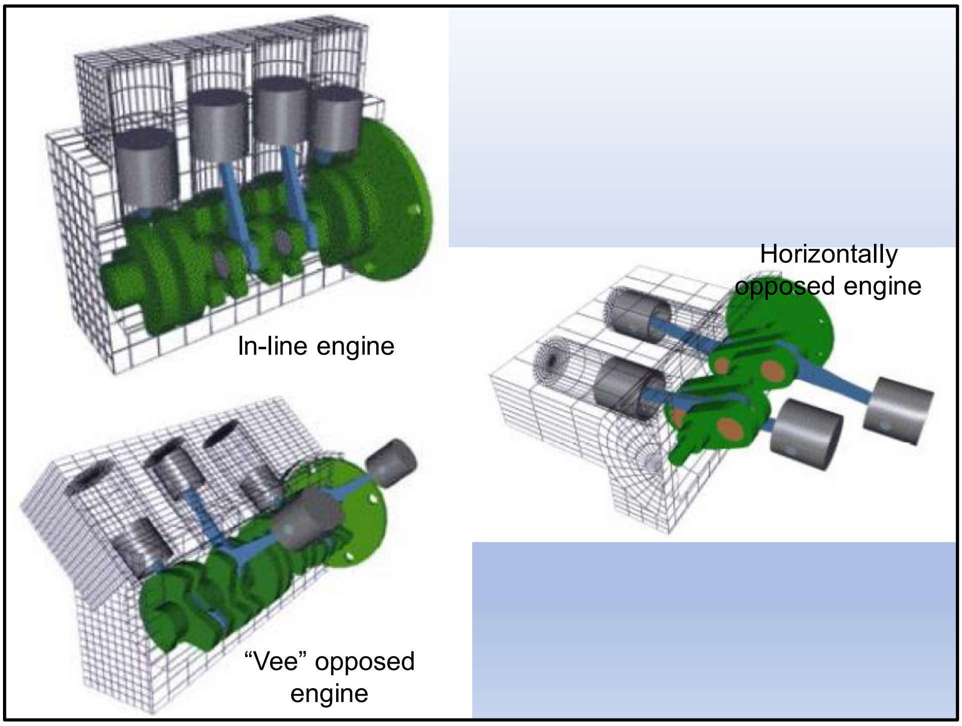
The Wright Brothers' resourceful engineer, Charlie Taylor, took on the challenge of manufacturing an engine from scratch and, with the minimum of machine tools, created a light 4 cylinder engine that produced 10 and then eventually 12 horsepower.



This famous photograph shows an aircraft taking-off under its own power for the very first time in the world.

The engine was fitted to the aircraft and it drove the two propellers that you can see behind the wings. The engine lay on top of the bottom wing and the pilot lay down beside it. It must have been very noisy. At first the Wright Brothers thought that the best way to control the aircraft was to lie down with their heads facing forward but they soon changed their minds and sat up just like modern pilots.

This is a famous photograph for it shows an aircraft taking-off under its own power for the very first time in the world.

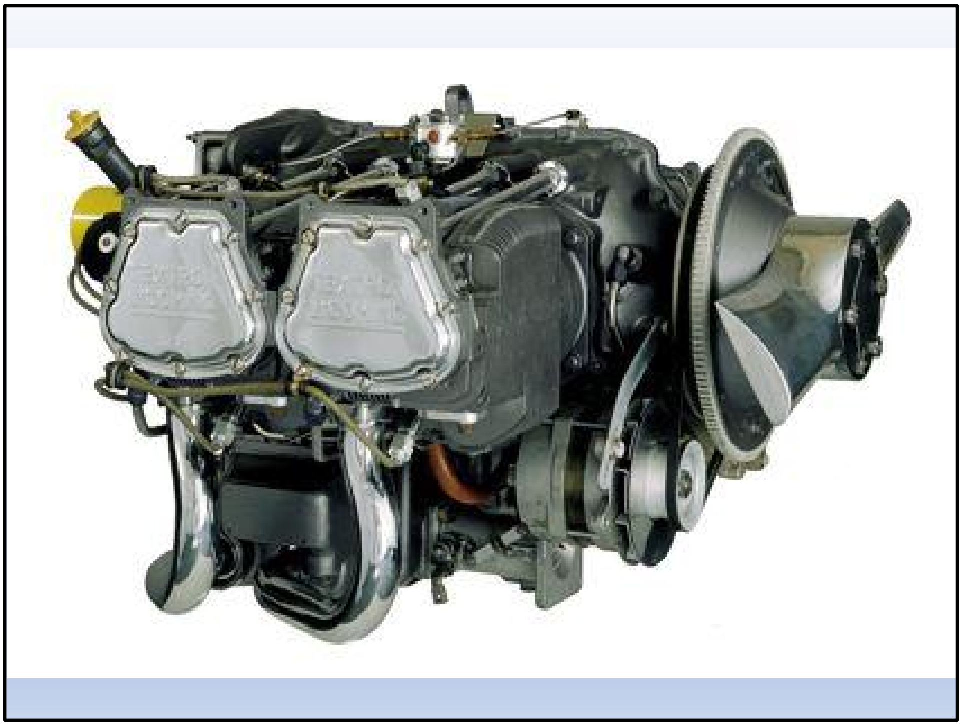


To make more powerful engines, it was usual to add more cylinders. The cylinders could be mounted one behind the other but, to prevent the engine from becoming too long, the cylinders could be mounted opposite each other either horizontally or in a "Vee" shape.

Engines have to be cooled to prevent the lubricating oil from burning.

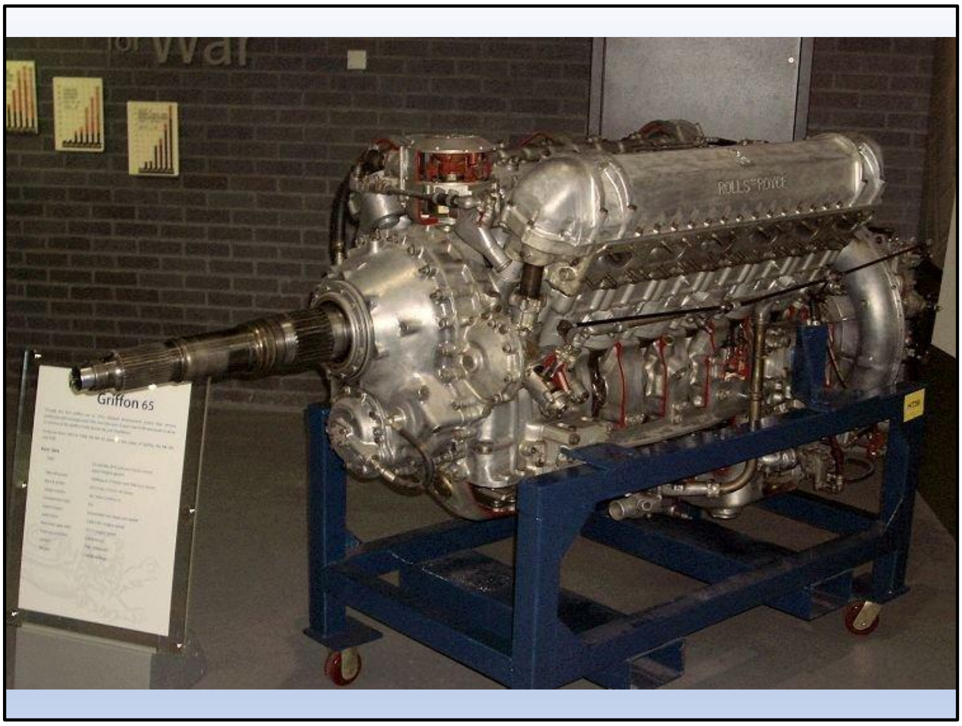
The cylinders can be provided with thin cooling fins and the airflow can be directed to flow around and through the fins thus cooling the cylinders. This is a light solution since it does not add any weight to the engine but it can be difficult to get the air to a rear cylinder and, if the weather is hot, the cooling can be less.

Or, like most car engines, the cylinders can be surrounded with water mixed with a de-icing fluid to prevent freezing in cold weather. Most car engines have this type of cooling system. This is a heavier system due to the weight of the fluid, and a radiator is required to cool the fluid before it is sent back to the engine. Also, if the system springs a leak, the engine overheats and stops.



This is the Lycoming IO-360-A1B6 engine and it is an example of a small 200 horsepower four cylinder air cooled engine. You can see the thin cooling fins on the cylinders and the problem, as with all these types of engine, is that it is difficult to direct the cooling air to the fins of the rear cylinders that are hiding behind the front ones.

This aircraft, the Scottish Aviation Bulldog, was built at Prestwick and was used as a military pilot training aircraft. The aircraft was powered by the 200 horsepower Lycoming engine. The cowling, that is fitted fairly tightly around the engine, was fitted with baffles that directed the cooling air to the fins on all the four cylinders.



This is the 2,000 horsepower Rolls Royce Griffon engine. It has two rows of six cylinders arranged in a Vee shape. It would have been very difficult to get cooling air to travel back along the length of the engine so the cylinders are liquid cooled. We could look at two very different aircraft that used this engine.

This aircraft, the Supermarine Spitfire Mark XIX, was powered by the Rolls Royce Griffon engine and as you can see it needed five blades on the large propeller to absorb the power from the big engine. This aircraft could fly at 450 mph

This aircraft, the Avro Shackleton, was powered by four Griffon engines and, in this case, each engine was fitted with two propellers to absorb the power. These aircraft could fly out over the sea looking for submarines and stay airborne for 15 hours or more.

In an attempt to find more power, the Italian engine manufacturer, Fiat, simply bolted two engines together. This very long engine produced over 3,000 HP and was fitted to a racing seaplane.

The lower photo shows the aircraft, the Macchi-Castoldi MC72, and, to this day, it holds the world speed record for a propeller-driven seaplane. The top speed was 440.68 mph and was set in 1934. You can see all twelve of the right hand exhaust stubs showing that the engine was almost half the length of the aircraft.

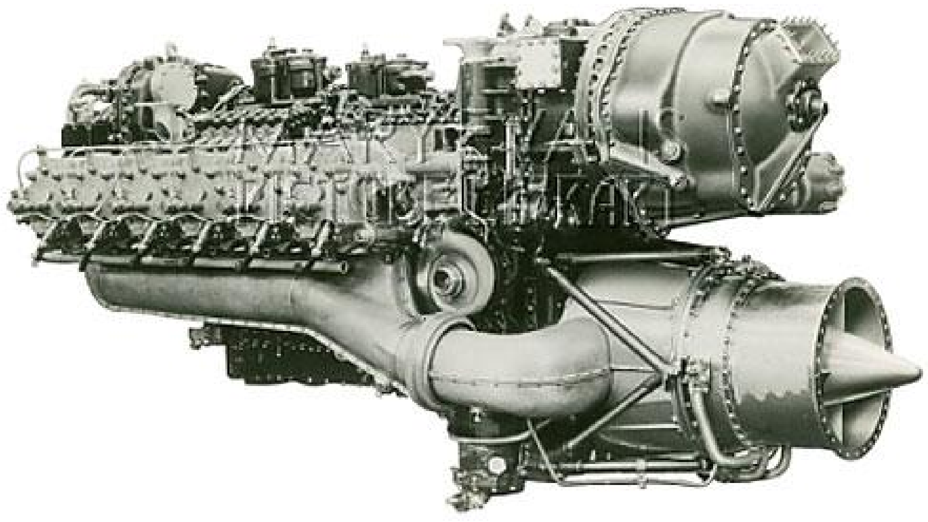
We need more power!

There was still a need for an engine with more power that would allow heavier aircraft to fly at much greater altitudes. Engines need the oxygen in the air to be able to burn the fuel to produce the power but, just like humans, they run out of energy as the altitude increases. When mountaineers try to get above about 20,000 feet [6,000 metres] they usually have to start breathing additional oxygen that they take with them in pressurized cylinders. Carrying oxygen in cylinders would not work for the amount of oxygen that a large engine would need so another method had to be used.

High altitude engines were designed and fitted with either superchargers or turbochargers to force more air into the engine air intake to make the engine think it is running at a much lower altitude.

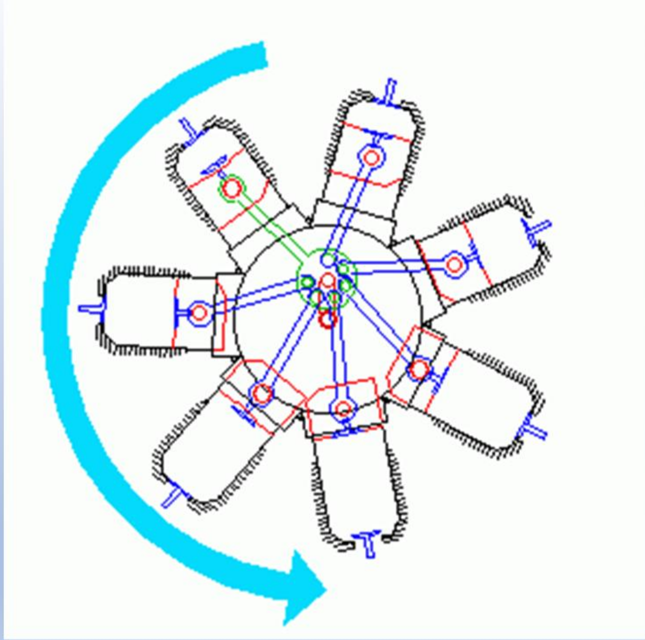
Superchargers are directly driven by the engine and therefore use some of the engine power however, they more than compensate for that by allowing the engine to produce more power.

Turbochargers are driven by the exhaust gas from the engine and use the power that would otherwise be wasted.



The Napier Nomad aero engine.

The Napier Nomad was probably the last of the big in-line engines and it was very unusual and very complicated. It was a 12 cylinder two-stroke diesel and had both a supercharger and a very large turbocharger. It was very large and weighed 3,580 lb [1,620kg] however it was able to develop over 3,000 horsepower up to quite high altitude and, best of all, it was the most efficient of all the piston engines to date. However by the time that the prototype engines had been tested the design was already out of date and the aircraft industry was looking at an entirely new kind of engine. The very large in-line piston engines had reached a dead end.



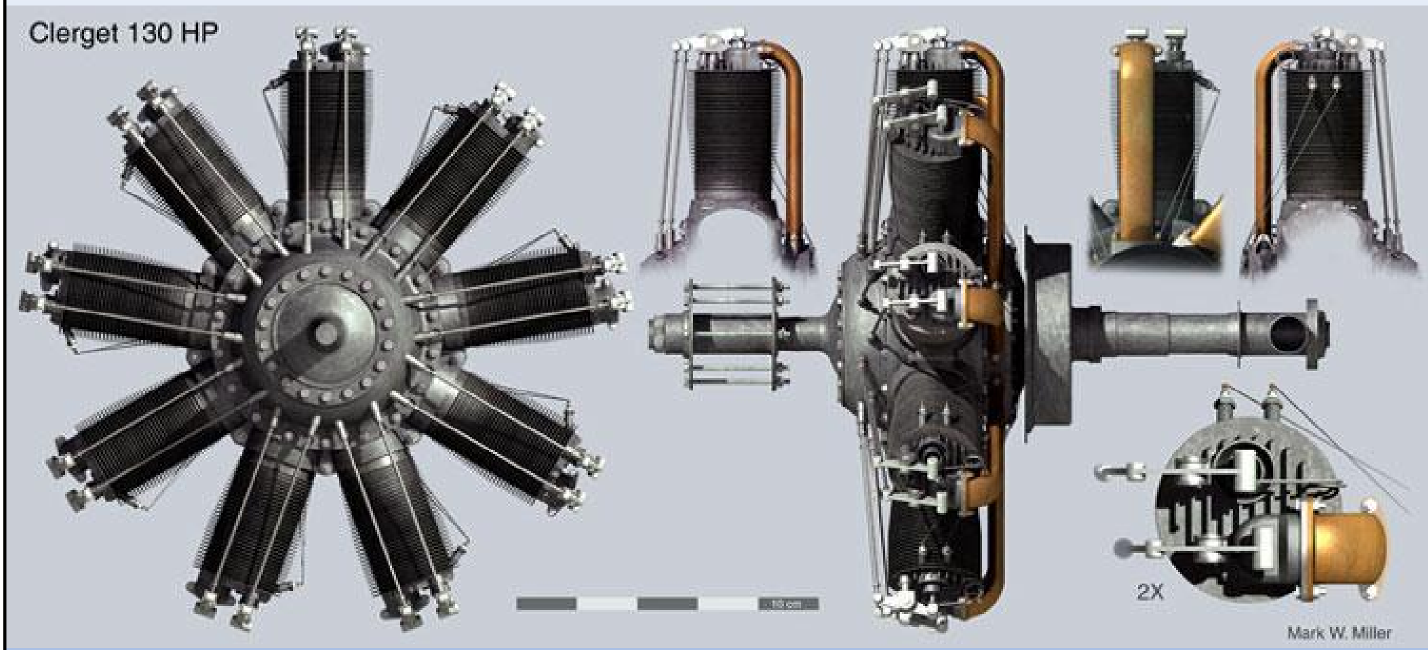
This is a diagram of a rotary type of radial engine.

Meantime, during all the years that in-line piston aero-engines were being designed, another type of piston engine was developing down another route.

There seemed to be such a big advantage in having an air-cooled engine that the problem was solved by placing all of the cylinders at the front of the engine so that they were all cooled equally. These engines had their cylinders arranged radially around the crankcase and became known as radial engines.

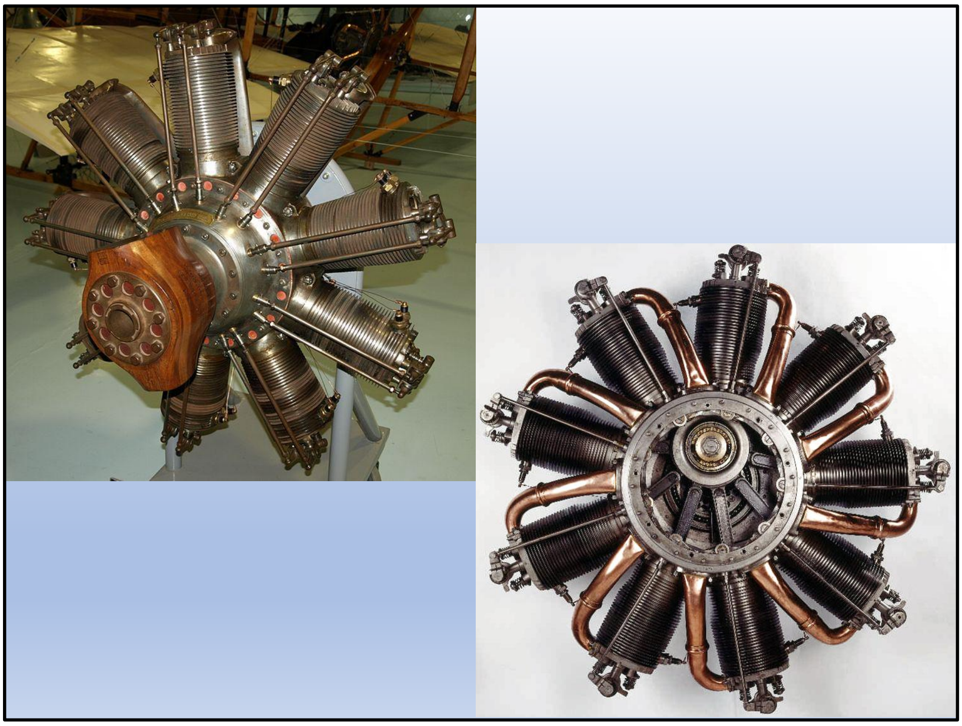
Some of the early versions of these engines, notably designed by French aero-engineers, were designed to have the whole crankcase and cylinders rotate on the crankshaft. These type of radial engines were known as rotary engines. The rotary engines were produced in large quantities during the First World War but they soon fell out of favour and were overtaken by the standard radial engines.

The disadvantage of the radial layout was that the engine was bigger and therefore had more drag.



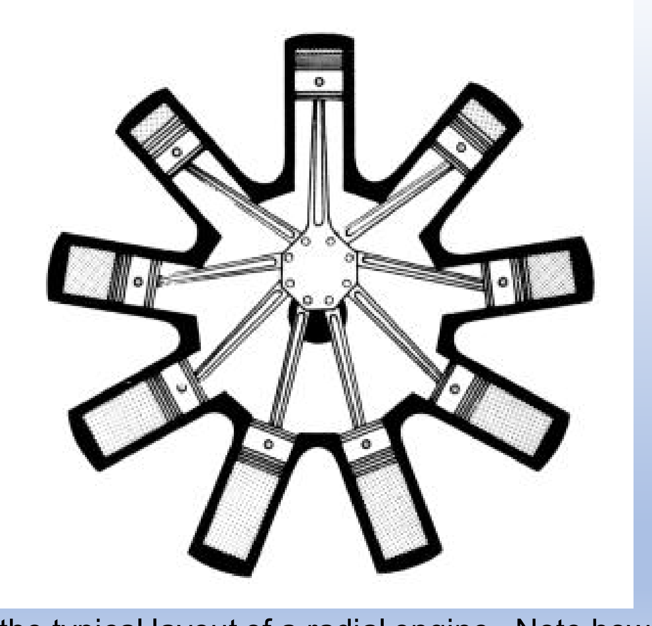
This is what a typical rotary engine looked like.

This French engine designed by Clerget developed 130 horsepower and weighed about 380 lb.



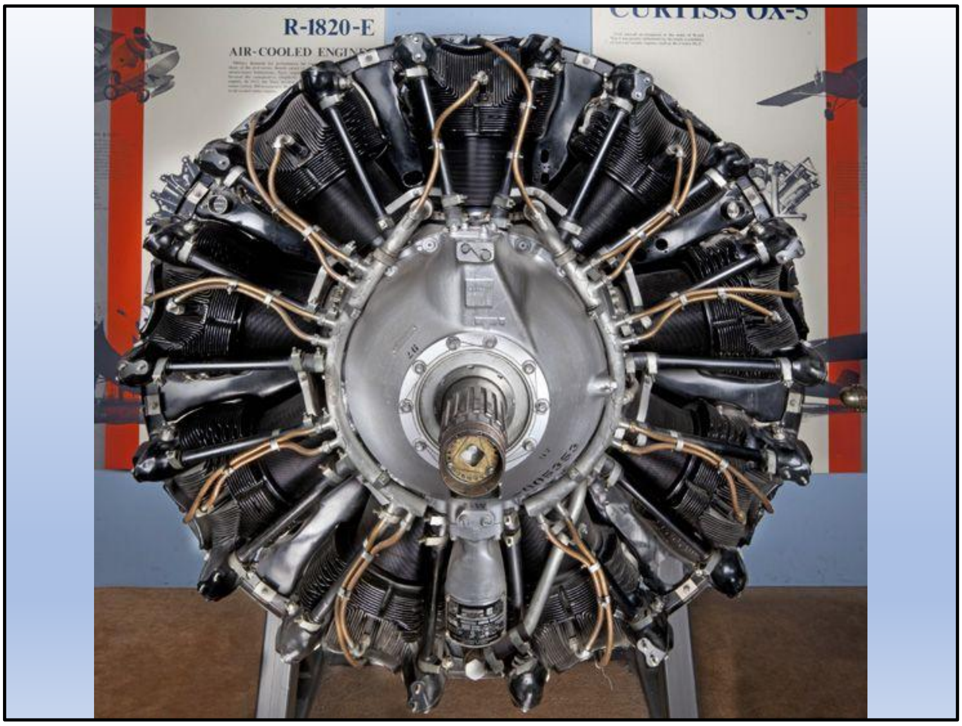
This is the French designed Clerget 9B 130 hp Rotary Engine. The cylinders spin round and round to keep them cool. They also threw their oil out when they were running so the pilots had difficulty keeping their goggles clean and came back from flights with their faces black with oil.

This is the British designed Sopwith Camel fitted with a rotary engine. This was one of the best fighting aircraft in the sky during the First World War in 1917.



This is the typical layout of a radial engine. Note how all the cylinders are equally exposed to the cooling air.

It soon became obvious to the engine designers that there would be a limit to the amount of power that a rotary engine could produce. Although these engines were light and reasonably reliable it would not be feasible to spin all the engine on the crankshaft when the engines became more powerful. So, the next stage of engine design produced a whole series of very successful radial engines where only the crankshaft and propeller rotated. The feature that allowed these engines to work was to have one master connecting rod with all the other rods connected to it rather than to the crankshaft.

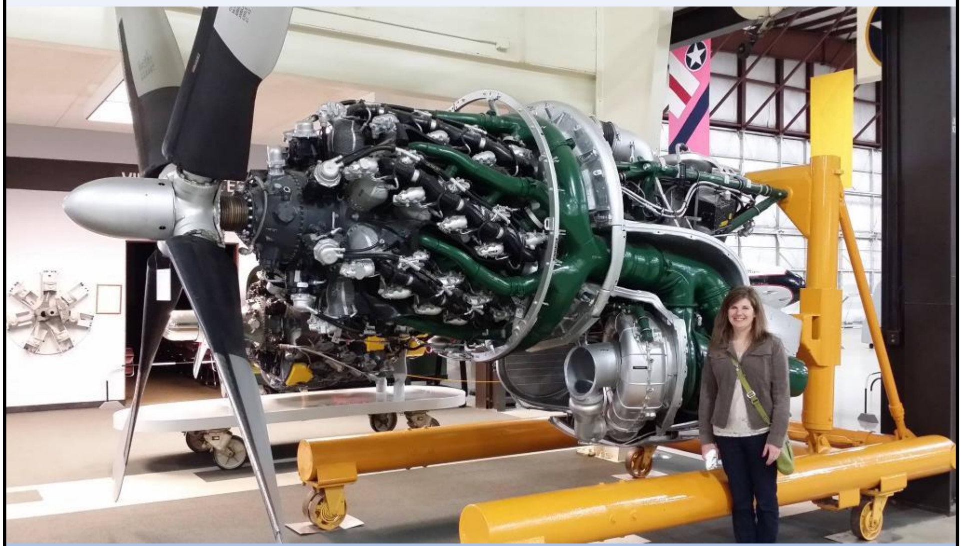


This is the American Wright Cyclone engine and it has nine cylinders in a ring right round the crankcase.

These aircraft are typical of the kinds of airliners that used radial engines up until the 1950s when they were replaced by heavier and faster aircraft which needed more power.

The Pratt and Whitney Twin Wasp Engine

The engine designers tried to find ways of producing more power but, like the in-line engines this usually was achieved by adding another row of cylinders. The problem with this was that, since the cylinders were air cooled, the second row of cylinders could not be hidden behind the front row so the number of cylinders in each row had to be reduced.
This is the Pratt and Whitney Twin Wasp engine and was typical of a radial engine with two rows of cylinders. There could only be seven cylinders in each row to allow the cooling air to get to the rear cylinders.



The Pratt and Whitney R 4360 engine of 3,800 horsepower.

However, still more power was needed for the increasing weight, speed and higher cruising altitude of aircraft. The designers now added two more rows of cylinders to their radial engines and the result was a more powerful engine but, because it was difficult to keep the rear cylinders cool, the engines were less reliable. It was quite common to see aircraft arriving from a long trans-Atlantic flight with one engine stopped and oil running out of its cowlings.

This is the Pratt and Whitney R 4360 engine with four rows of cylinders, 28 in total. It was so long and had so many cylinders that it was nicknamed the “corn cob” engine. It could produce more than 3,800 horsepower.

It became obvious that it was unlikely that piston engines could be developed to produce any more power so these large engines were the end of the line for piston engines