Second Level Technologies
Benchmark TCH 2-20a

Power for Flight Pt 5

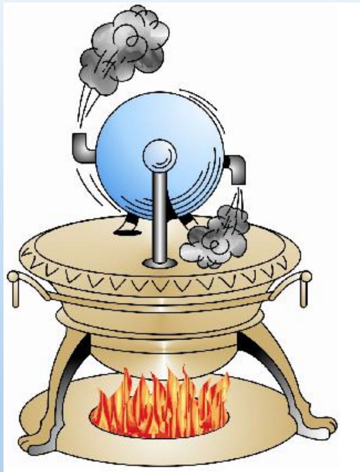
Exploring the ways that power can be produced give direct thrust.

WE COULD USE THE EXHAUST GAS FROM A GAS TURBINE ENGINE TO PRODUCE DIRECT THRUST

The traditional piston engine was now running at its limit of development but an entirely new type of engine was being developed that would take over and dominate the design of aero-engines from the middle of the 20th century onwards. This was the Gas Turbine engine.

Hero’s Steam Turbine Engine
He called it the(Aeolipile)

Hero of Alexandria
1st Century AD
Greek Mathematician & Engineer



Hero’s Reaction Steam
Turbine the Aeolipile

In1822 a French mining engineer, Claude Burdin, invented the word “turbine” from the Latin word “turbo” meaning a vortex. He suggested that the word described how the machine developed its power by rotating under the influence of a moving fluid i.e. water, air, steam or gas.

Turbines were not new, Hero of Alexandria, a Greek inventor demonstrated a steam turbine in the 1st century AD and water turbines had been around for centuries. The traditional water mill, used for grinding corn, was powered by a simple water wheel but even in Roman times there was a version of the water wheel that was actually a turbine. During the industrial revolution in this country when water power was still used to drive machinery in the large cotton mills it was found that a well designed turbine could be much more efficient, and very much smaller, than a water wheel.

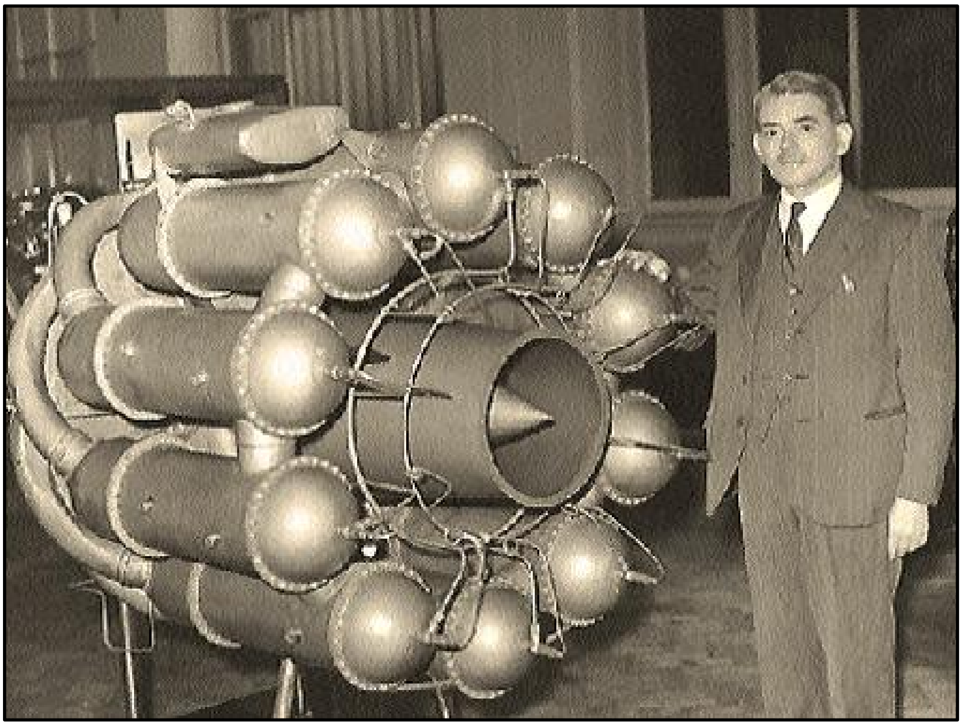
In the 19th century the design of water turbines was more fully understood and some of these new types of turbines are still running, almost one hundred years later, in our hydro-electric generating power stations.

The Turbinia

Steam driven turbines were not really developed until the 19th century and were proposed to be used to power ships. The British inventor, The Honourable Sir Charles Algernon Parsons, had a small steam launch built to demonstrate what his steam turbines could do. The launch, called the Turbinia, was powered by three turbines and carried out trials in 1894. The launch was very quick, it could do 34.5 knots [40 mph or 64kph]. This photo shows the Turbinia travelling at speed powered by her three steam turbines. The plume of black smoke from her funnel shows that she was probably running flat out at nearly 35 knots. This photo was taken at the mouth of the river Tyne near where she was built.

Parsons decided to show off his design by organising a publicity stunt. All the best warships in the British Navy were lined up as usual for the annual Royal Spithead review. Suddenly the Turbinia arrived unannounced and steamed up and down between the ships at high speed. The Navy were not amused at this boat stealing their limelight but the King was interested and of course it was not long before the Navy were fitting steam turbines to their warships.

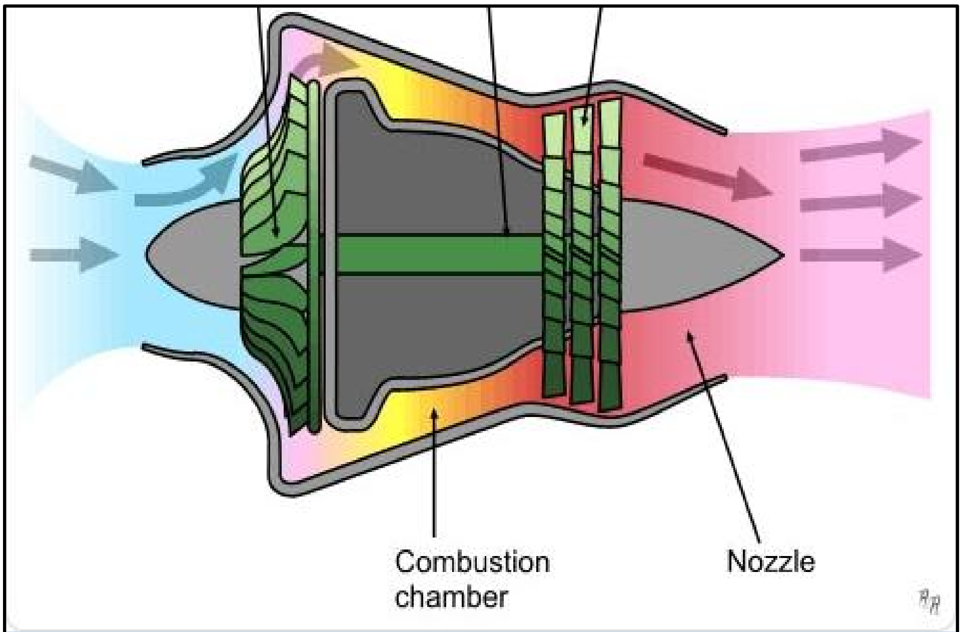
The first passenger ship to be fitted with a steam turbine was a Clyde-built excursion steamer, the King Edward, and it sailed up and down the Clyde estuary for fifty years.



It was not until the early 20th century that a young RAF officer, Frank Whittle, came up with the idea of driving a turbine with hot gas that was produced by burning fuel inside the engine. This was the big breakthrough in engine technology. The photo shows Frank Whittle standing beside his first working engine. It was quite bulky, the ten big shiny cylinders wrapped around the engine exhaust are the combustion chambers where the fuel was burned.

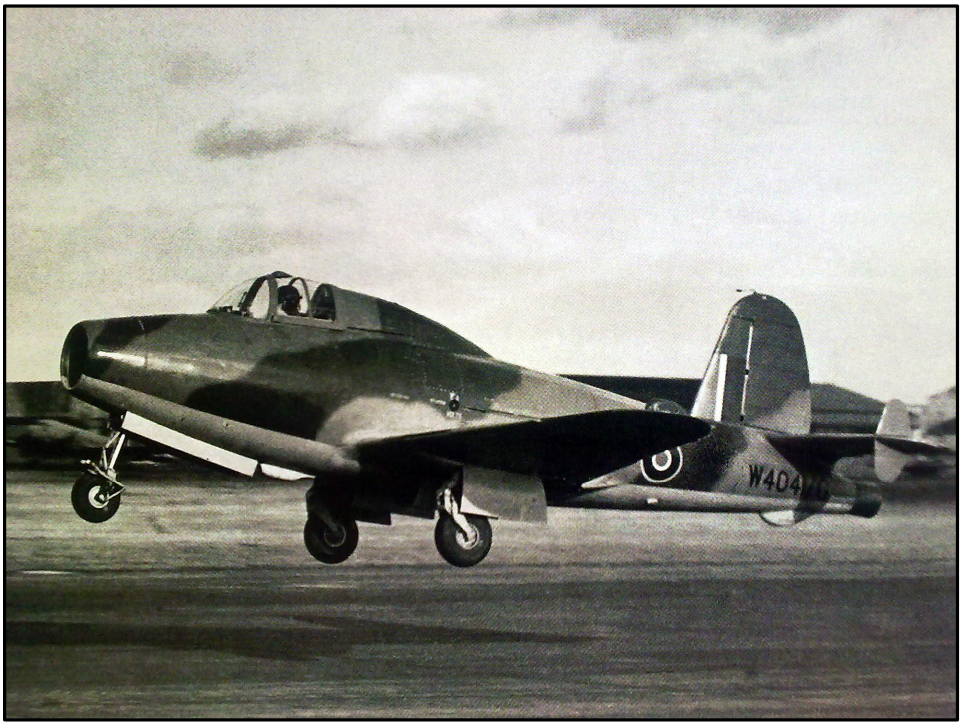
To be able to burn the fuel quickly and efficiently, the engine needed to be supplied with a lot of air so the turbine was used to drive a compressor at the front of the engine to force air into the fuel combustion chambers. All modern gas turbine engines still work that way.

Not all of the energy in the hot gas was used to turn the turbine and most of it came out of the back of the engine in a high speed stream of exhaust gas. As the engine threw this gas out behind it the effect was to push the engine forwards and so useful thrust was developed to push the engine and aircraft forward. This engine type was named the “turbojet” but was known colloquially as a “Jet” engine.

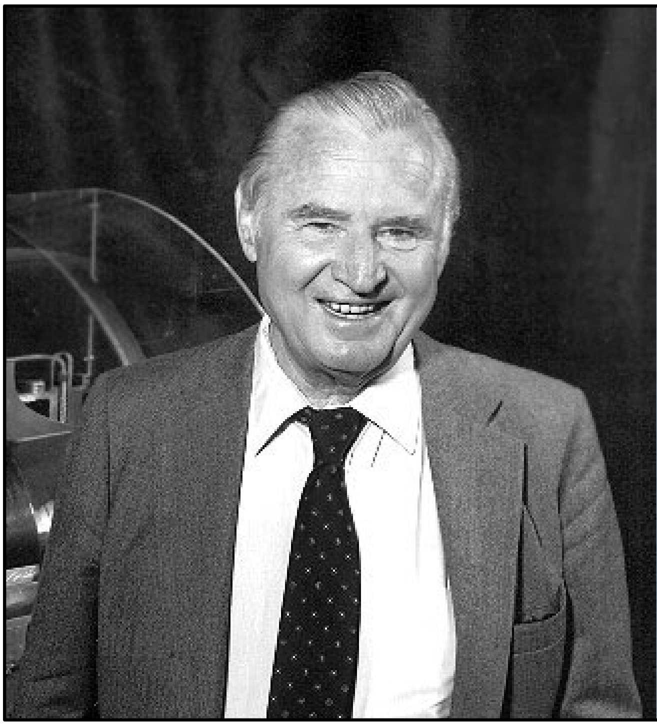


The Centrifugal turbojet

Whittle's engine was the type called a centrifugal turbojet and this is how it worked. The centrifugal compressor dragged the air into the front of the engine by throwing it outwards into the combustion chambers. The fuel was injected into the combustion chambers where it burned causing the air to greatly expand so that it rushed out of the back of the engine turning the turbine as it went. The turbine was connected to the compressor by a shaft so that the whole system was self-sustaining. This system worked well although the engine was a rather bulky.



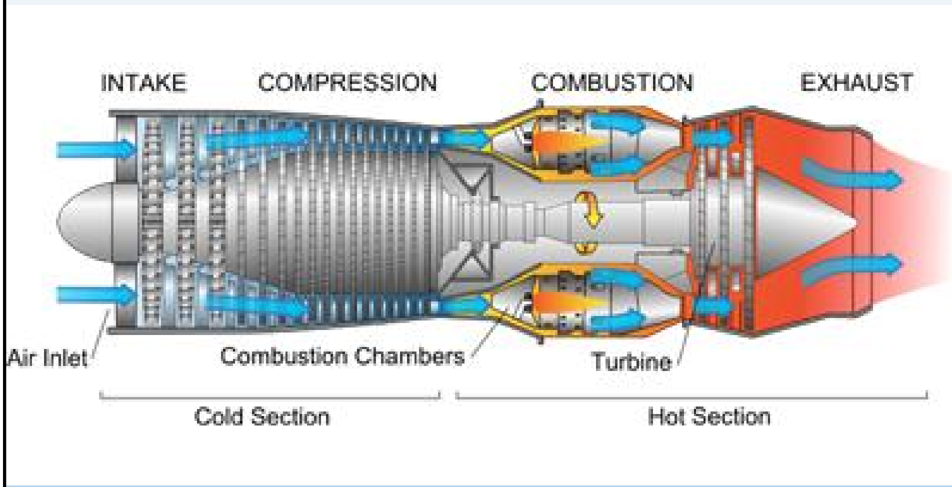
In 1938, the very first British aircraft to fly powered by a turbojet engine, was the experimental Gloster e28/39. It eventually achieved a speed of 505mph at 30,000ft.



The German aero engine designer,

Hans von Ohain

Unbeknown to Frank Whittle and the British High Command, this German engineer named Hans von Ohain, was also developing a turbojet engine. Of course, during the war, this was a big secret. The German Luftwaffe could see that there was a potential to develop a high speed fighter aircraft using this type of engine. The engine development was going very slowly with many problems to be overcome so the design task was given to the Junkers aircraft company and they produced the final design and the production engines. The result was a compact engine of a slightly different type to Frank Whittle's.



The Axial-flow Turbojet Engine.

The type of engine invented by Hans von Ohain was called an Axial turbojet. The multi-stage axial compressor drags the air into the front of the engine and accelerates it back into the combustion chambers. The fuel is injected into the combustion chambers where it is burned causing the air to greatly expand so that it rushes out of the back of the engine turning the turbines as it goes. The turbines are connected to the compressor section by a shaft so that the whole system is self-sustaining. In this type of engine the air keeps going in a straight line through the engine and it is this feature that allows the engine to be much slimmer than the Centrifugal compressor type.

The Germans found that this type of engine was difficult to design but eventually nearly all turbojet engines in the world were made this way.

The British government was soon to discover that not only had the Germans fitted their axial turbojet engines into this aircraft but they had secretly flown an experimental aircraft, the Heinklel He178 in 1939. This photo is of the Messerschmit Me262 which first flew in 1942 and went into service in 1944. The RAF pilots who came across it for the first time during the war were very impressed by its speed.

The Royal Air Force also got their first turbojet powered fighter, the Gloster Meteor, into service in 1943 slightly ahead of the Germans. But both the British and German “jet” fighters arrived too late to really influence the outcome of the war. The photo shows a Meteor manoeuvring at high speed. The cloud over the wing shows the low pressure area that is producing the lift.

However the design of these aircraft, particularly the German Me262, was to influence the design of the next generation of “jet” fighters after the war.

Before we go any further with the “turbojet” story we have to look at the performance of these early engines. They were extremely unreliable and sometimes only lasted ten hours before they had to be completely rebuilt. However it was obvious that with better materials these engines would be able to produce enough thrust to power military fighter aircraft to high speeds up to, and in excess of, the speed of sound. This is in fact what happened about ten years later.

The de Havilland Comet

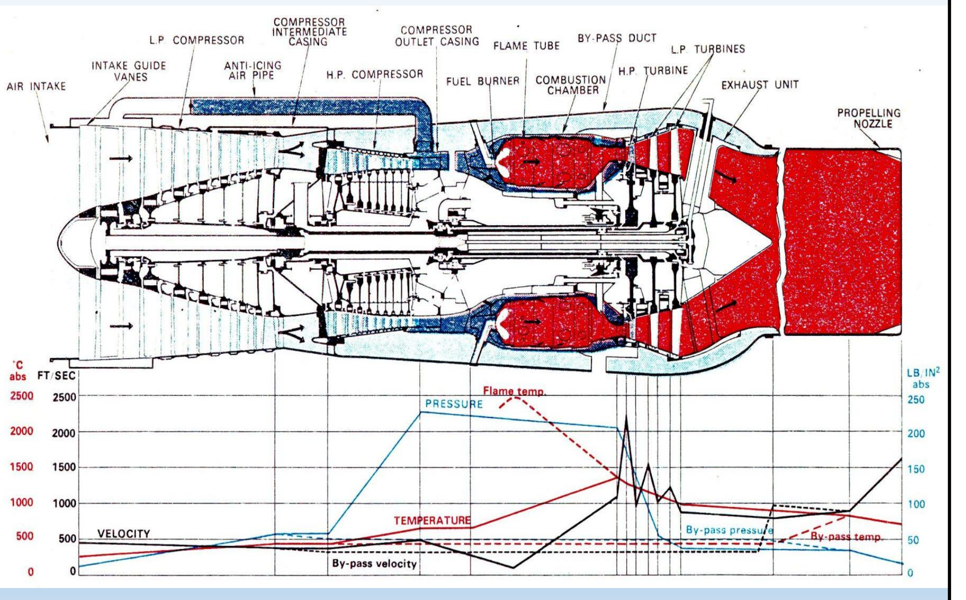
The large increase in thrust in turbojet engines came with the penalty of a very large fuel consumption. Nevertheless the designers of airliners could see that this new kind of power could allow passenger aircraft to fly at high speed at high altitude with much less noise and vibration than piston engine aircraft.

The de-Havilland company in Britain built the first turbojet powered airliner and it first flew in July 1949.

The Boeing 707

The American company, Boeing, came up with a different layout of aircraft influenced by the aerodynamic advances made by the Germans during the war. The Boeing 707 went into service shortly after the Comet and went on the become used by airlines all over the world.

Before long it was realised that the Turbojet engine was really too inefficient for use on sub-sonic aircraft and, as a result, the development of engines for civil airliners went off in another direction. More of that later.



This diagram shows what is happening inside a Turbojet engine. If you follow the black line [velocity] at the bottom of the diagram it shows the air entering the front of the engine at about 300 mph, due to the forward speed of the aircraft. The compressor then squeezes the air into the combustion chambers where it is heated by the burning fuel. The turbine discs uses some of the energy in the high speed air to drive the compressor. The shape of the exhaust nozzle speeds up the exhaust and it leaves the engine at about 1,100 mph. It is this exhaust speed that produces the thrust.

There was still a need for high thrust engines in the military market where fighters needed to fly much faster than airliners. If you want to fly at 1,000 mph then the exhaust coming out of the back of the engine has to be travelling much faster than the aircraft or there would be no thrust. When you see a modern fighter starting its take-off run at full power the exhaust gas could be travelling backwards at about 1,500 mph or more. If you look carefully you may see the supersonic shock waves in the exhaust. So, military Turbojets were developed to produce more thrust.

The Rolls Royce Avon turbojet engine

This is one of the most successful British Turbojet engines, the Rolls Royce Avon. It entered service in 1950 and was in production for 24 years. Over 11,000 were built. Over that time it was developed to increase its thrust from 7,300lb to 12,700 lb.

A inconvenient fact about turbojet engines.

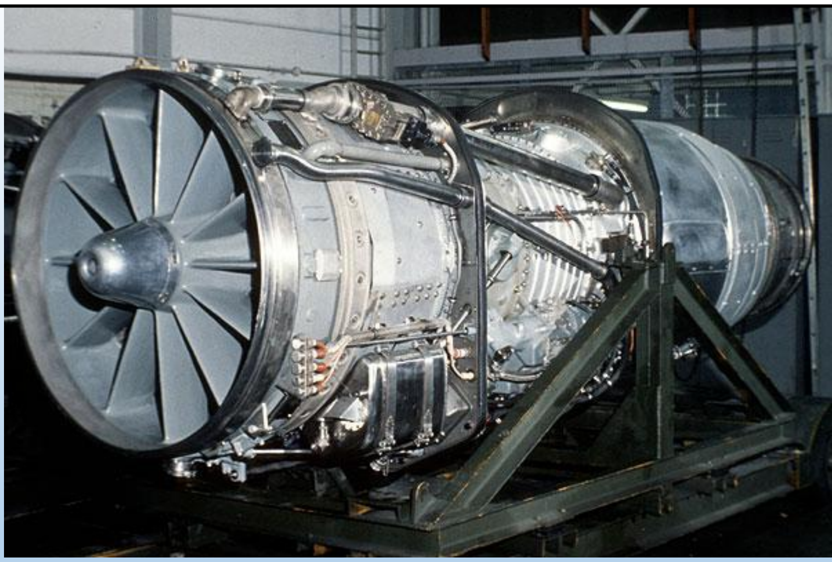
It probably seems like a strange fact that the compressor blades at the front of the turbojet engine can not accept air at more than half the speed of sound, Mach 0.5.

So we have what seems to be an odd fact that an engine that cannot run in an airflow any faster than Mach 0.5 is bolted to an aircraft that is capable of three or four times that speed.

So we are back to the same problem that the propeller driven aircraft had. If the tips of the compressor blades were allowed to reach a speed that was close to the speed of sound then their efficiency would drop and the whole compressor system would be unable to compress the air into the combustion chambers. This situation could result in the engine "surging" which is what happens when the pressure of the air behind the compressor suddenly becomes higher than the pressure ahead of the compressor. The result will be the equivalent of a very violent sneeze that can be very damaging to the aircraft and the engine. To avoid this problem the engine intake has to be carefully designed to slow the air down as it travels towards the engine. Not as easy as it seems sometimes.

The English Electric Lightning fighter aircraft.

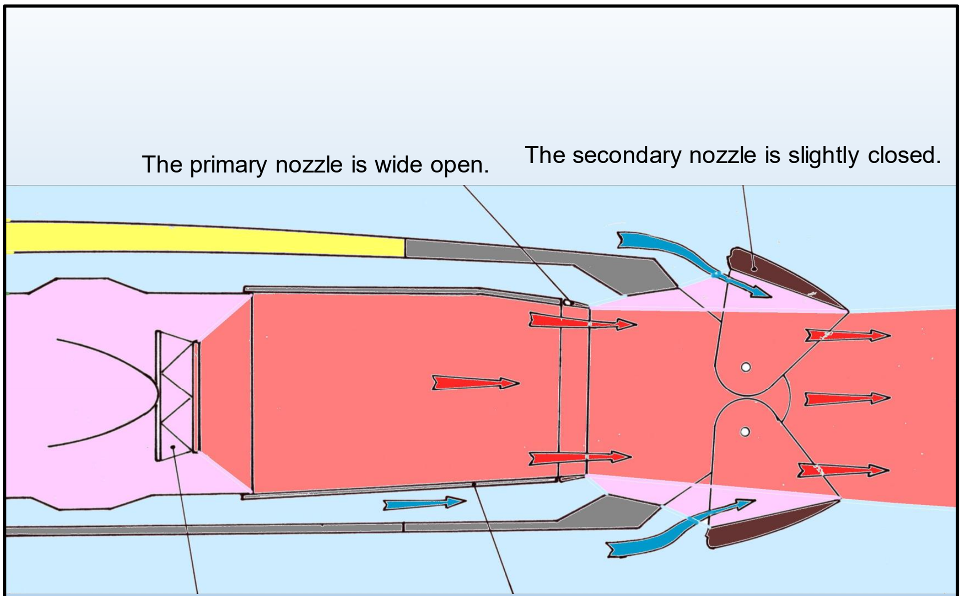
This Is the English Electric Lightning fighter aircraft. It was designed to take-off and climb very quickly to intercept enemy aircraft about to enter British airspace. It was powered by two Avon engines mounted one above the other. This aircraft could climb at 20,000 ft/min and reach 36,000 ft in 3 minutes. The highest it was ever known to fly was 87,000 ft [27 kilometres].



This is the mighty Olympus engine. The Bristol engines were all called after mythical Greek Gods but this one, being the most powerful, was called after the home of the Gods.

The next most significant British turbojet engine was the Bristol BE10 Olympus. The original design of this engine dated back to 1946 and was the first in the world to have a twin spool. This engine started out with a thrust of 10,000lb but over the years it was developed to produce 20,000lb of thrust. Four of these engines powered the Vulcan “V” bomber and because of its twin spool arrangement the engine was capable of rapid power changes unlike many other engines of this era. There were a number of other aircraft that were intended to be powered by versions of this engine but none of the aircraft ever went into production.

It was not until the 1960’s when the Concorde was being designed that a consortium of the French company SNECMA and Rolls Royce got together to further develop the engine. The final version, the Type 593, was able to produce a thrust of 32,000lb. The Concorde needed to have a turbojet engine because it cruised at about 1,300mph so the jet engine exhaust had to be faster than that to produce a thrust.



The problem with Concorde was that it would need a total thrust of 114,000lb to be able to climb away safely with an engine failed. So each of the remaining three engines would have to produce a thrust of 38,000 lb.

The problem was solved by using a system called "re-heat", sometimes called an "after-burner". This system was known about and tried on the very earliest of the turbojet engines and was commonly used on engines in military aircraft. By simply squirting extra fuel into the flame in the engine exhaust the exhaust gas could be expanded by the extra heat and therefore speeded up. In the case of the Olympus engine in Concorde, the thrust was increased from 32,000 lb to 38,000 lb which is what was needed.

The disadvantage of this system was that it used an awful lot of fuel but, the advantage was that it could be used for the few minutes during the take-off to increase the thrust without having to have a much bigger engine whose thrust would not be needed for the rest of the flight.

Of course other countries were developing their own turbo-jet engines. The USA produced a large range of engines and in Europe, the French, German and Swedish engine companies came up with some very interesting engines.

Eventually, towards the end of the 20th Century the cost of developing the engines became prohibitive and so a variety of consortiums were formed to spread the cost across two or more companies and nations. Engine design and development became an international industry.