Chapter 11.

Supercharging and Turbocharging.

We all probably understand supercharging at a basic level - take air at atmospheric pressure and pump it into an engine in greater quantities than the engine would normally inhale on its own and quite obviously the power output of the engine will be increased, assuming that fuel is added in proportion.

That sounds simple enough but the efficiency of the supercharger and the system around it is a vital factor in how a supercharged engine system will perform. The problem is that any act of compression will increase the temperature of the air discharged by the supercharger which means its pressure will rise and more work will be consumed in the process. In a nutshell a less efficient supercharger will heat the charge more than an efficient one.

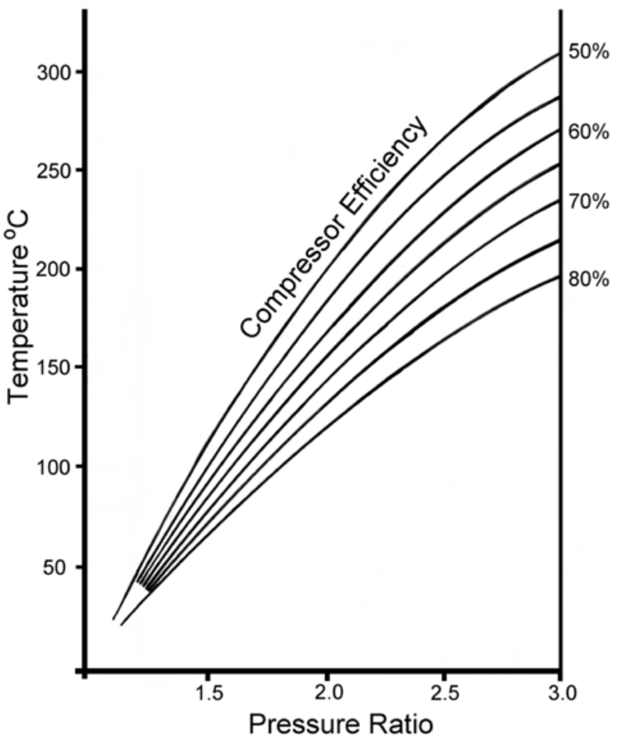

Fig. 11.1 Temperature rise according to compression pressure ratio and adiabatic efficiency of the compressor.

The efficiency of the supercharger, and here we are talking about adiabatic, or compressive efficiency (Fig. 11.1), determines 2 key factors - firstly, the power the process will consume and secondly, the temperature of the air it will deliver to the engine. In essence, adiabatic losses within the supercharger appear as raised delivery air temperature, thus causing a higher boost pressure without increasing charge density, and also predisposing the engine to the evils of detonation.

Every enthusiast who ever tinkered with an engine knows that cool air is better for power simply because of its greater density. The same is true of supercharging so the trick is to keep the compression heating effect to the absolute minimum. The best way to achieve this is to compress the air to the pressure required as efficiently as possible. The delivered air will still be quite hot so unless the level of boost is going to be less than about 6 lbs (0.4 bar) charge-cooling (inter-cooling) will usually be necessary to bring the temperature down further for best effect, but an efficient compressor is the ideal starting point. Generally it is undesirable to let the delivery air temperature exceed about 110^{o} C. There is also another advantage from keeping the charge temperature down – the exhaust temperature will be reduced by a similar amount for the same level of performance so durability should be improved.

The Full Potential of Supercharging.

Supercharging had been used with some success in motor racing from quite early days under lax rules concerning fuel composition so alcohol could be used as an evaporative charge coolant at a time when intercoolers had not been thought of. Supercharging then had far less appeal if the fuel had to be gasoline which was the case from 1958 in GP (F1) racing.

By the 1970s regulations for F1 racing had for some years included an option permitting supercharged engines to be used of half the capacity of those naturally aspirated. It illustrates how low the reputation of supercharging had become after the unfortunate debacle of the BRM V16 that nobody seriously pursued that route for over 20 years until Renault produced their first turbocharged V6 in 1977. This soon showed itself to be the equal of the Cosworth DFV V8 in terms of power but lag, drivability and reliability issues hampered it for some time. By about 1980 the potential was becoming clear and virtually all the engine manufacturers involved in F1 began work on turbocharged engines.

Prior to this time Keith Duckworth (Cosworth founder) had begun to call for either a ban on turbocharging or a limited fuel flow ruling but many people assumed he was motivated by a wish to keep the DFV competitive. In fact Duckworth was looking further ahead and realised that forced induction had the potential to increase power in a way that made engine size virtually irrelevant.

All things being equal power output is directly linked to air mass flow so any means of getting more air through an engine will increase power output. Increasing r.p.m. is one method; increasing induction pressure is another. Raising the operating speed is ultimately limited by mechanical integrity but if the induction pressure can be artificially raised then power will rise more or less in proportion. The size of the engine is no longer a limiting factor and this is what Duckworth anticipated. Within a few years F1 engine power outputs were to rise dramatically from the 500 or so b.h.p. of the DFV to well over 1000 b.h.p. from engines of half the size.

Less than 20 years after turbocharging was finally banned in F1, naturally aspirated V10 engines of the same 3 litre size as the DFV were reaching close to 1000 b.h.p. by running up to 20,000 r.p.m., prompting yet more rule changes to mandate 8 cylinders, 2.4 litres and a maximum of 18,000 r.p.m. Ironically it was Cosworth who had first broken the 20,000 r.p.m. barrier in F1.

With modern technology a 20,000 r.p.m. turbocharged 1.5 litre F1 engine would quite possibly be capable of exceeding 2000 b.h.p. using 102 RON gasoline. Such is the potential!

The ultimate high power piston engines are to be found in drag racing where 8.2 litre (500 cu in) V8s loosely based on the iconic Chrysler Hemi production engine and burning nitromethane fuel in vast quantities, forced in by a huge positively driven supercharger, produce an estimated 8000 b.h.p. – but only for a few seconds at a time.

At close to 1000 b.h.p. per litre the mid 1980s F1 turbo engines must set the standard for the highest specific power so far observed from piston engines because they did not rely on huge quantities of a special high energy fuel containing much of the oxygen needed for the combustion process.

The Rolls-Royce Contribution.

If any proof is needed of how important supercharger efficiency is we only need to look back to the dark days of World War 2 and consider the tremendous development effort applied to the legendary Rolls-Royce Merlin aircraft engine, a 27 litre V12. Starting out with 790 b.h.p. in 1933, redesigned cylinder heads and many detail improvements lifted it to 1030 b.h.p. by 1939, yet by 1945 the in-service output had more than doubled to 2385 b.h.p. with experimental engines giving 2620 b.h.p. at 36lbs of boost. Whilst the availability of high octane fuel was an essential factor the major power gains were almost entirely due to improvements in the supercharger and induction system.

Yet probably the most influential supercharged engine of all time must be the Merlin's illustrious ancestor – the Rolls-Royce 'R' (Fig. 11.2). This amazing power unit was created in record time to power the Supermarine S6 and S6B racing seaplanes that won the Schneider Trophy permanently for England in 1931 and then set the world speed record in the air at 407 m.p.h. The ‘R’ was also used to capture world speed records on land and on water. It was quite simply the most advanced internal combustion engine in the world by a considerable margin.

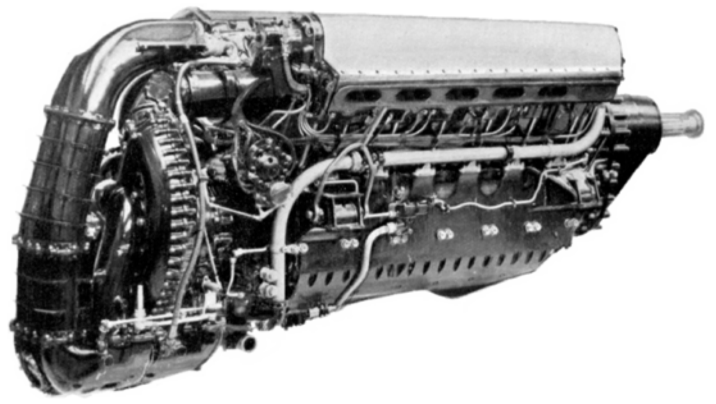

Fig. 11.2 Rolls-Royce ‘R’ supercharged 36.7 litre V12.

In 1934 the Italian Macchi-Castoldi MC72 took the air speed record to 440 m.p.h. (which still stands for a piston engine powered seaplane) but it took a pair of 25 litre Fiat V12s mounted in tandem in front of a huge supercharger to do it - and the personal support of Mussolini (Fig. 11.3). The MC72 had been intended as an opponent for the S6B in 1931 but was not ready in time. Two pilots were killed trying to tame it.

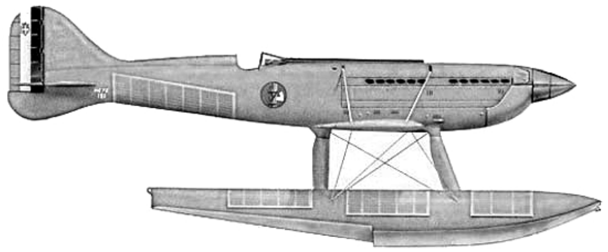

Fig. 11.3 Macchi-Castoldi MC72 holder of world seaplane speed record of 440 m.p.h.

There had been plenty of supercharged engines before those days but none that had been particularly impressive. The main application had been as a means of maintaining the power of aircraft engines in thin air at high altitude (Fig. 11.4) where the low air temperatures offset the heating effect of inefficient superchargers.

The Rolls-Royce ‘R’ was the first engine to show the full potential of supercharging at low level although it needed special fuel dosed with methanol and TEL (lead) to overcome the still relatively modest efficiency of the huge supercharger. This was a double sided centrifugal device (Fig. 11.5) spinning at 22,000 r.p.m. to provide just over 20 p.s.i. of boost with adiabatic efficiency of around 50% or so.

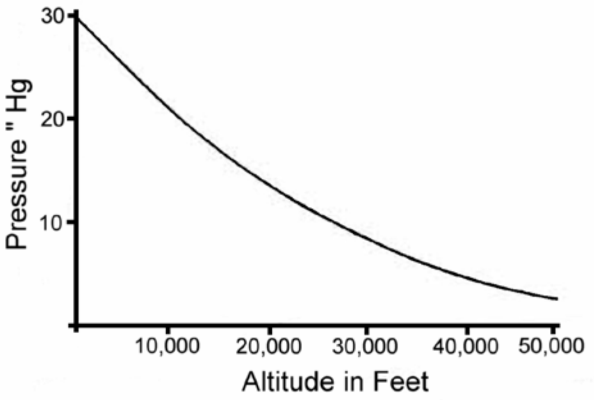

Fig. 11.4 Atmospheric pressure change with altitude.

The ‘R’ was also an early application of Sam Heron’s innovative sodium cooled exhaust valves. These were hollow and half filled with sodium which melted and sloshed up and down to conduct heat away from the valve head. They are still widely used in high performance engines today.

The sheer effort that went into creating the ‘R’ was astonishing for the time. Just testing one was a mammoth operation requiring two other aircraft engines (Kestrels – a 21 litre front line V12 military engine of the period) as support, one to produce the simulated air velocity at the intake duct and another to sweep fumes from the short exhaust stub pipes out of the test cell and keep ambient temperatures within bounds. Supplementary electric fans were also strategically placed around the engine. A staff of eight technicians was needed to conduct the test procedure which must have created a din well beyond what would be accepted today. The forbearance of those living anywhere near RR’s

Nightingale Road factory in Derby was sorely tried at times, as of course it was to be in later wartime but by then there was a more pressing justification.

An ‘R’ engine was only passed off as fit for use when it proved capable of running at continuous full power for one hour. In the final development full power was 2,783 b.h.p. at 3400 r.p.m. with almost 1.5 bar of boost pressure, but this was never used because of fears that the airframe could not handle the huge torque reaction. Even at a slightly lower rating used for the world speed record it had been found that torque reaction was causing one float of the S6B to dig into the water during take-off runs! The MC72 overcame this problem by having contra-rotating propellers, one driven by each of the tandem engines. Contra-rotating propellers via gears were often used to tame the torque reaction effects of several later high powered engines like the Rolls-Royce Griffon and a small number of late Merlins.

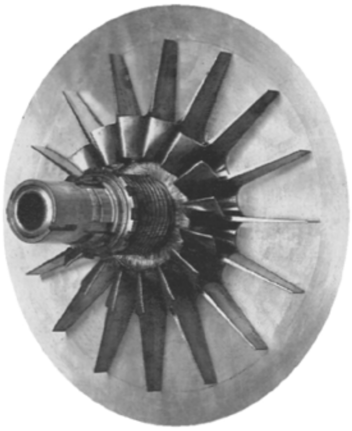

Fig. 11.5 Typical early centrifugal supercharger impeller for an aircraft engine.

It is easy to look back at that period when national egos and reputations were associated so strongly with something so apparently useless as seaplane racing, yet in truth it drove technology forward by a remarkable extent. These aircraft were capable of well over 400 m.p.h., and at low altitude, not higher up in thinner air where most aircraft reach their maximum, so there can be little doubt that if they had been equipped with variable pitch propellers and not been encumbered by a pair of massive floats they would have been flying at well beyond 450 m.p.h. It was to be nearly 15 years before front line fighters were reaching such speeds, driven by the needs of war. It is quite possible that if Reginald Mitchell’s team at Supermarine had not created the S6B seaplane they would not have had the capability to produce the legendary Spitfire just a few years later. Certainly Rolls-Royce’s Merlin engine owed a lot to the ‘R’ so perhaps seaplane racing played a more important role in the course of modern history than is generally thought.

Whilst the Merlin is undoubtedly the most important descendent from the ‘R’ the more direct line is through the later Griffon with the same 36.7 litres which powered a number of aircraft towards the end of WW2, almost matching the outstanding power output of the original ‘R’ as a matter of routine. Contra-rotating propellers were by then available to deal with effects of torque reaction. Amazingly the Griffon survived in front line military use until 1991 powering the Shackleton airborne early warning aircraft (itself descended from the Merlin powered Lancaster bomber).

Aircraft superchargers were virtually all of the centrifugal type and Rolls-Royce installations started out with an efficiency of around 37% in the 1920s rising to nearly 80% by the end of the WW2. Multiple gear ratio drives, multiple impellers in series (stages) and charge coolers all featured in the onward march of the Merlin in particular, aided by fuels with anti-knock ratings far beyond the original octane scale.

The final 10-15% which made the real difference came about largely through the efforts of mathematician Stanley Hooker (later Sir Stanley) who later became a key figure in the British jet engine business (he was even called out of retirement to knock the RB211 into shape after it had bankrupted Rolls-Royce in 1971). Hooker’s work was possibly the first stage of engine design progressing from an art based on experience and judgment, into a science.

17 pages follow.