# **Early Aero Engines**

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The performance of any aircraft is always heavily dependent upon the capabilities of its power plant. In the pioneer years the stumbling block to sustainable flight was the power-to-weight ratio of the available engines. This lecture will look at the earliest attempts to attain powered flight, including the race between Professor Langley and the Wrights, which was won by the latter despite the brilliant engine created by Charles Manly for the Langley Aerodrome.

The development of the rotary engine was critical to flight during World War One, a period which saw the emergence of the two families of engines, the liquid-cooled inline and the air-cooled radial, which would persist until the invention of the jet engine. A number of specific types are examined, both successes and failures, and attempts made to explain why they fitted into these two categories. Some of the personalities crucial to this story, such as Ernst Henry, W.O. Bentley, Henry Royce and Louis Coatalen will also be mentioned.

KEYWORDS: USA and European pioneers, rotary and contra-rotating engines, Bentley, disasters, post-war.

## **Pioneering in America**

The key to successful flight is, more often than not, a good and reliable engine. Even the best airframe designs can come to nought if powered by an indifferent engine. In the early days of flight this was even more marked. Almost in contradiction of that statement, we begin by comparing two pioneering efforts, in one of which an indifferent airframe ruined the brilliant potential of its power plant.

In America at the end of the nineteenth century there were two parties trying to fly successfully, one with the resources of a major institution behind it and one with only its own hard work and determination. At the Smithsonian Institution in Washington DC, Samuel Pierpoint Langley, an eminent professor, had enjoyed some success with powered models, and then gone on to develop a full sized man-carrying version. He was assisted by a brilliant young engineer, Charles Manly (Figure 1). Langley's airframe was a dead end, but the engine which Manly built was way ahead of its time. The Smithsonian had originally ordered two rotary engines from a man named Stephen Balzer, but he proved unable to meet the power-to-weight ratio specified. Manly set to work to produce an engine to his



Figure 1. Charles Manly and Professor Langley.

own design. The end product, by 1903 standards, was remarkable. It was a non-rotating or "static" radial engine, which developed 52hp for an installed weight of around 4 lbs/hp (Figure 2). The engine incorporated some design features which were still in use decades later.

Two well-publicised failures of Langley's "Aerodrome" put paid to the project, and few people now recognise the names of Langley and Manly. But everyone recognises the names of Orville and Wilbur Wright. It is quite remarkable that two bicycle mechanics could, in five years of spare-time work, and with their own funds, develop from novices to the world's first competent aeronautical engineers, having a good knowledge of structures, aerodynamics and the question of aircraft stability and control. There was perhaps little special about their airframe, except that it incorporated the best features of all those which had preceded it, plus the recognition that an aircraft had to be controlled by the pilot. But, by dint of serious research and experimentation, the Wrights succeeded in arriving at an effective combination. Satisfied with the airframe design from their gliding work, they then set about finding a usable, in other words, light and powerful, engine. Like Langlev and Manly they concluded that they would have to build their own. Some historians believe that they adapted the Pope-Toledo automobile engine, others suggest that it was designed and built by the brothers and their workshop foreman, Charles Taylor. Whatever the true route may be, the



Smithsonian Institution Figure 2.Manly's 1903 engine for the Langley Aerodrome project

Wrights managed to fly into history with a fairly crude four-cylinder inline engine, giving only 12hp, and that only for a limited period (Figure 3).



Figure 3. The Wright Engine of 1903.

# Early Days in Europe

The development of aero engines for the next twenty years or so can be divided very roughly into the two different channels begun by Manly and the Wrights. One channel produces engines with radial layouts, and the other follows the inline layout, fairly directly developed from automobile engines. What is particularly interesting is that the main scene of action shifts from America, where there was surprisingly little interest in the Wrights' achievements, to Europe, and, in particular, to France. The French were shocked that their self-deluded lead in aviation had been usurped by the Wrights, and it took some years to catch up in all aspects. By 1910 though, a number of French engineers had produced respectable aero engines and supplied them to a wide variety of airframe designers, both competent and lunatic. The epochal year of European Aviation was 1909. By then there were many capable builders and pilots, and in that year Bleriot flew the Channel and the first major aviation meetings were held.



Figure 4. The 25hp Anzani "fan" radial engine.

The close rivals for the first flight across the Channel were Bleriot, in his own airframe powered by an Anzani engine (Figure 4), and Hubert Latham, in an Antoinette monoplane, powered by an Antoinette engine. The engine comparison is interesting.

The Anzani was a three-cylinder "half-radial", air cooled, producing about 25hp for short periods. The limited power it produced meant that it could only drive an aeroplane slowly, so that the slipstream cooling effect was inadequate to prevent the engine overheating, which caused the power to fall off.

## The Piston Engine Revolution

The designer of the Antoinettes, Leon Levavasseur, had built speedboats before he turned to aircraft, and the engines he designed for his boats had to be water-cooled. Because cylinder temperature could be better controlled, watercooled engines could produce more power from a given capacity, but the water jackets and plumbing meant that the engine was much heavier than an air-cooled unit. The aircraft therefore had to be bigger and heavier, which immediately meant more drag, so the overall performance was not much better than with a lightweight but underpowered air-cooled engine. This was the kind of dilemma which faced the pioneers of this age.



Figure 5. The 50hp Gnome rotary.

## **The Rotary Engine**

The lightweight airframes also demanded an engine that was free from vibration, because the supporting structure would not provide any damping, and the aeroplane could be literally shaken to pieces by a poor engine. In car engines a flywheel is used to damp out vibration, but flywheels are heavy and could not be tolerated in these early aircraft. At the Rheims aviation meeting in May 1909, Henri Farman replaced the engine of his machine with a brand new Gnome rotary, and walked off with most of the prizes. The rotary engine, which lasted for little more than a decade, had arrived in the form of the 50hp Gnome (Figure 5). Designed by the

Seguin brothers, the Gnome was not original but, like the earlier work of the Wrights, had been the result of logical development.

It is generally accepted that the idea of rotary engines for aeroplanes can be attributed to the Australian pioneer Lawrence Hargrave, who sketched a scheme for a rotary compressed air engine in the 1880s. Around 1906 there were Adams-Farwell and Balzer rotary-engined cars on the market. The Adams-Farwell was later offered for aircraft use, and further developed under the name Gyro. But the real success began with the Gnome series. The rotary provided its own flywheel, and so ran smoothly. Its air cooling was dependent upon its rotational speed of 1100 rpm, and so it stayed cool even in slow aircraft. There were drawbacks but the Gnome was the first really efficient and reliable engine available to the aircraft builders of the day. It was later followed by an even better design, the Le Rhone (Figure 6); an indifferent but much utilised one, the Clerget; several German copies; a remarkable contra-rotating German engine; and by the ultimate rotaries, the Bentley designs.

#### How the Rotary Works - a Simple Explanation

Any form of four-stroke engine with its cylinders arranged radially must have an odd number of cylinders, otherwise the four-stroke cycle cannot be repeated with each cylinder firing once in every two revolutions. There have been many radial engines, both fixed and rotary, which have had even numbers of cylinders, but those have been arranged in even-numbered multiple rows of odd-number discs.

The major difference between the rotary and the static radial engines is that the components which are normally expected to be stationary, such as crankcase and cylinders, are the ones which rotate. In a rotary engine the crankshaft is stationary and usually serves as one of the key points for fixing the engine to the airframe. The crankcase and cylinders rotate on bearings around the crankshaft, dragging the conrods and pistons around with them. Because the centre of rotation of the crankcase is the main axis of the crankshaft, and the centre of rotation of the conrods is the offset main bearing journal of the crankshaft, the motion of the conrods and pistons relative to the cylinder heads provides the necessary induction and compression actions to generate the four-stroke cycle.

The long end of the crankshaft which is bolted to the airframe is hollow and the carburettor is mounted at the airframe end, opposite from the propeller. Petrol vapour is thus sucked into the crankcase and then admitted to the space above the piston crown by a variety of means, depending upon the particular design of rotary engine. There was also some variety in the details of the valve gear but every type utilised some form of drum-cam driven from the front of the crankcase. Ignition was provided from magnetos mounted on a stationary plate on the crankshaft's long end and driven by a ring gear fixed to the rotating crankcase. The same gear usually drove the oil pump, delivering castor oil to the main bearing journal at least, with the rest of the engine having to rely on splash in many cases.



Figure 6. An 80hp Le Rhone installed in a Sopwith Pup.

# The Different Types of Rotary Engine

What were the major differences between the various types of rotary? The first Gnomes established the basic layout, with the carburettor fixed on the end of the hollow crankshaft, so that petrol vapour was drawn into the crankcase and generally swashed about with the lubricating oil. Castor oil was the best oil available for lubrication, having the additional advantage that it did not mix with petrol. The inlet valve was in the piston crown, which opened by suction on the inlet stroke, admitting mixture into the cylinder. The exhaust valve was in the cylinder head, operated by a central cam ring. When the exhaust valve opened thegases swept burnt and unburnt castor oil into the atmosphere, which is why rotaries always leave a trail of blue smoke behind them. There was no throttle as such, and engine speed was controlled by shorting out the sparking plugs with the "blip switch" on the control column. The thin inlet valve spring had an unfortunate habit of breaking, and this usually led to a fire in the crankcase. The Gnome Monosoupape or "single valve", was developed with a porting arrangement rather like a two-stroke, whereby a very rich uninflammable mixture was maintained in the crankcase and admitted to the cylinders via the inlet port. Weakening air was admitted via the single valve in the cylinder head, to provide a normal mixture for ignition. Both types of Gnome were built in different power outputs, from 1909 until 1918.

The Le Rhone had two valves in the cylinder head, operated by a single push-pull tappet rod, again operated by central cams. Its cylinders differed from the Gnome, in that a cast iron liner, with better lubrication and heat conducting properties than steel, was shrunk into the steel cylinder. The mixture was transferred from the crankcase to the cylinders via copper induction pipes. The

## The Piston Engine Revolution

main bearings used a shoe-in-groove arrangement, with conrods of three different lengths riding in three concentric grooves in a bronze-lined dinner plate of a central bearing, derived from Manly's design. It had a proper throttle and was the favourite engine of many WW1 pilots. The Clerget (Figure 7) was much like a Gnome, with steel cylinders with one master and a set of slave connecting rods, but it had two valves operated by individual pushrods. French-built engines were of reasonable quality, but the Clergets licence-built by the British pump making company, Gwynne's, soon developed a reputation for unreliability. This is where a man called Bentley enters the story (Figure 8). His effect upon the British aero engines of WW1 is grossly under-rated.



Figure 7. A 130hp Clerget being installed, showing the mounting plate in the airframe.

## W.O. Bentley's Contribution to the Rotary Story

Bentley had trained as a practical engineer before the war and, going into the car business with a brother, had discovered the merit of aluminium pistons through a French contact, and had used them successfully in motor trials. He had kept this as a commercial secret, but realised its military potential after war broke out. He



Figure 8. W.O. Bentley in the 1930s.

offered his services to the RNAS and was commissioned as an engines specialist. Eventually he was sent to Gwynne's to improve the quality of their product.

Although Bentley was successful in improving the Clerget, and indeed uprating it from 110 to 130 hp, he was soon aware of serious limitations with the basic design. Ignoring some of the politics, he convinced his RNAS superiors of the validity of his own ideas, and set about designing his own rotary. He combined the best features of existing engines, the two valves and gear of the Clerget, the cast iron liner of the Le Rhone, but added his knowledge of the benefits of aluminium which he used for not only the pistons but also the main cylinder muffs. The engine was in production by mid-1917 in its 150hp version, and this was so successful that the 230hp Bentley was put into production early the following year (Figure 9). The larger Bentley was undoubtedly the zenith of the rotary engine.

## The Contra-Rotating Rotary Engine

The Germans almost eclipsed the Bentley with the Siemens-Halske contra-rotating rotary. Rotary engines could have a major effect upon the handling of the aircraft they powered. The Sopwith Camel is a prime example of the gyroscopic effect of 350 lbs of metal, rotating at 1200 rpm, upon the controllability of the aeroplane. Many Camel pupils were killed by spinning into the ground. The bigger the engine, the bigger the problem. The Germans sought to solve the problem by designing an engine where the propeller rotated in the opposite direction to the engine. Although the relative speed was around 1800 rpm, the engine was only turning at 900 rpm



Figure 9. The 230hp Bentley BR2 engine, without and with its front plate and pushrods.

and the gyroscopic effect was reduced. It was a complex engine, designed when Germany was struggling for supplies and when only poor lubricants were generallyavailable. The slower engine revolutions affected engine cooling and seizures were commonplace. The rotary was really a dead-end street and the end of WW1 saw the demise of its development, although post-war economics kept it flying for at least another decade.

# Early In-Line Engines

The path of improvement of the inline engine was much more rational. Although there will always be important exceptions, large inline engines are usually liquid-cooled, because of the problems of air cooling the rear cylinders of a large V-8 or V-12. An early air-cooled V-8 was the 70hp Renault, with big cast iron finned cylinders, and an early use of reduction gearing, where the propeller was fixed to the end of the camshaft and turned at half engine speed. A similar design was the Curtiss OX series, but this was as unreliable as the Renault, and confined to training aircraft in the main. The Renault was used by Royal Aircraft Factory at Farnborough pre-war, and became the subject of some development, by Farnborough, leading to the RAF1 and RAF4 engines which saw much WW1 service in aircraft such as the BE2 and RE8 series, but they were not good engines.

The early developments in liquid-cooled aero engines cannot be divorced from car engines - both types were often built by the same firms. In particular, the 1912 Grand Prix Peugeot was historic. Designed by a brilliant young Swiss engineer, Ernst Henry, even today its engine would be recognisable as a high

# The Piston Engine Revolution

performance engine - twin overhead camshafts, four valves per cylinder and hemispherical combustion chambers. In the racing world it allowed small capacity high-speed engines to compete with large capacity slow-speed ones and won both the 1912 and 1913 Grand Prix races. The same families began to be seen in aero-engines, the Germans, particularly Mercedes, favoured slow-speed, and the French high-speed engines, such as the Hispano-Suiza.

#### The Beginning of Rolls-Royce Aero Engines

Rolls-Royce had been reluctant to compromise their car business early in a war which was going to be "over by Christmas," but as things dragged on they grudgingly accepted a contract to build a few Renaults for the Admiralty.



Figure 10. Mercedes 160hp (left) and Rolls-Royce Eagle 375hp (right).

Bentley paid them an early visit to explain his aluminium pistons to them but soon saw that the company was not happy with the Renault design. Back in London, Bentley was tipped off by an old motoring friend that the Mercedes racer, which had won the 1914 Grand Prix, was hidden in the basement of the London dealers where it had been on show when war broke out. He found the car and suggested to his superiors that Rolls-Royce might be ready to embark on a design of their own, and that the excellent German engine could give them a head start. This first-class German water-cooled cylinder design was grafted onto a Rolls-Royce crankcase and fitted with Bentley-inspired aluminium pistons to produce the straight-six Hawk design. This was rapidly scaled up to the 200hp V-12 Falcon and then to the 300hp Eagle (Figure 10). In the event, the Eagle was produced in quantity first, going to war in the DH4, then the Falcon powered the Bristol Fighter, and finally the100hp Hawk provided reliable power for the valuable antisubmarine work of small naval airships. Rolls-Royce produced engines in the highspeed class and was the first company to produce a reliable reduction gear to keep propeller revolutions down.

## Aluminium Blocks Emerge

A German design also provided the basis for another important British inline engine. Dr Porsche designed the pre-war Austro-Daimler six-cylinder inline which was built under licence by Beardmores, the Germanic tag being dropped soon after war started. Another young engineer, by the name of Frank Halford, uprated the original 120hp Beardmore to 160hp. The two engines were used in machines such as the FE2b and Martinsyde Elephant, both aircraft and engines being solid and reliable rather than spectacular. Halford went to France and was an official observer of the early trials of a revolutionary new engine called the Hispano-Suiza.



Figure 11. Hispano-Suiza V-8 on a test bed.

The Hispano-Suiza was a V-8 water-cooled engine which made extensive use of aluminium in its crankcase (Figure 11). Halford's attempts to create a new version of the Beardmore, replacing the steel sheet water jackets with aluminium castings began one of the several British aero engine disasters. His new engine, the Beardmore-Halford-Pullinger, originally planned for 300hp, was to power the new DH9 bomber, having been selected from other competing designs by an official committee. The committee also placed orders for the engine with the Siddeley-Deasy company. Siddeley himself thought the engine too expensive to produce, and modified it; it was later found that the engines from the two companies were not even interchangeable in the engine bearers. There were also severe technical problems of many kinds. The engine was derated to 230 hp, and the DH9 went to the Front, several months after the DH4 it was to replace, with less power and a poorer performance.

#### Hispano-Suiza and Sunbeam Arab

That same committee also had to decide on a V-8 for mass production in Britain. Their choice lay between the Hispano Suiza and the Sunbeam Arab. The Hispano was the original engine of its type. Designed by a brilliant Swedish engineer Marc Birkigt, it had been the first engine to pass a fifty hour test in France in late 1915, and by early 1917 was already at the front in early Spad fighters. The engine had its problems, but it was compact, light and powerful for its day. As noted above, it was also the first engine to make extensive use of aluminium for its cylinder blocks, and of dry liners, with a steel sleeve screwed into the aluminium blocks.

The Sunbeam Arab was the most notable example of plagiarism by Louis Coatalen, chief engineer of the Sunbeam Company. Several of his steady but unspectacular designs were in use in aircraft such as the Short seaplanes, but he was a competitive little man, and undoubtedly wanted to produce a front-line engine. The Arab was almost a straight pinch from the Hispano, but with added troubles. The Hispano was suffering from reduction gear problems, and vibration in certain circumstances. Coatalen included reduction gears, and also chose to use articulated conrods, which give slightly different strokes between the two cylinder banks, obviously with a greater risk of vibration. Thousands of Arabs were ordered, mainly for the Bristol Fighter, a two-seater reconnaissance aircraft and for the airframes competing for the 1918 aircraft programme. Very few Arabs had reached the Front by the Armistice.

Fortunately for Britain, the Admiralty had pressed the Air Board in 1916 to order 2000 Hispanos from the Mayen company in Paris. Mayen built a whole new factory, and their engines started to come through in early 1918 when there were some 400 SE5s alone, incomplete for lack of engines. Hispanos built by the French Brasier company had badly-hardened reduction gears, and so desperate was the engine supply situation that they were sent to the Front, with endorsements to "take care" in the engine logbooks. The Wolseley company was contracted to build the 150hp Hispano, but misunderstood the contract and developed their own highcompression version. By the time they got it right it was an excellent engine, but deliveries were inevitably late.

To add to the chaos there were never enough Rolls-Royces to go around because Henry Royce would not let any other company take out licences. Eventually he relented and allowed the Brazil Straker Company in Bristol to build his designs, but only because their Chief Engineer, Roy Fedden, had solved the problem of crankshaft breakages in the Hawk. Fedden went on to be the driving force behind the Bristol Engine Company, after Brazil Straker had survived a series of mergers and liquidations.

By 1918 Allied air forces depended heavily upon the Hispano and still, remarkably, on some of the early rotary engines. Britain also had the excellent Rolls-Royce and Bentley engines, and the French industry had also produced some newer inline engines, particularly the Renault and Lorraine Dietrich, based on the Mercedes. Italy was now producing some reasonable power plants, as well, notably from Fiat and SPA. Germany had made little real progress, although engine outputs had gone up. Most of their engines were still large capacity, slow-revving units, or copies of Gnome and Le Rhone rotaries. When America entered the war, Germany instituted the Amerikaprogram, but the only new engine which emerged in time was the BMW III, a six-cylinder water-cooled inline, which was the preferred engine for the Fokker DVII. Although this had excellent high altitude characteristics, it was basically a Mercedes derivative. Benz had a Hispano derivative under development, but it saw little service before the Armistice.

#### Disasters of 1918 - The Liberty and the Dragonfly

There were still two near disasters to come on the Allied side. The USA had never come close to the European industry since about 1908. Their indigenous engines and airframes were totally unsuited to the European war. They bought some European-made equipment, and set about building licence versions of others. Engines such as the Hispano were not suited to American mass production methods, and only a handful was licence-built. Some big name industrialists got themselves appointed to the material side of the expanding US war machine, and set about designing their own engine, which would suit American methods of production, and also their own bank accounts. So resulted the Liberty. Schemed originally as a 250hp V-8, it had to be immediately upgraded to a 400+hp V-12 (Figure 12). Massive plans were laid for manufacture of both engines and for the airframes to take it, but the early engines were a disaster, and British plans to bolster Rolls-Royce-powered aircraft with Libertys came to nought before the Armistice. The Liberty was eventually put right, and did good post-war service, but some of its protagonists were very lucky to escape gaol sentences when their wartime wangles were publicised.

In April 1917 the Air Board realised that the static air-cooled radial could offer greater reliability than liquid-cooled engines which often suffered from plumbing problems. A specification was issued for a 300 hp air-cooled radial of comparatively light weight - a major challenge. At Brazil Straker Fedden took up the challenge and his work began the line of brilliant Bristol engines, but he was able to build only prototypes before the Armistice. On the other hand, Granville Bradshaw, of the ABC Engine Company, convinced the hierarchy that he had just what they wanted. His Wasp engine was about to begin trials in late 1917, and he claimed that he could enlarge the Wasp to meet the new requirements. His 350hp



Figure 12. The 400hp Liberty V-12.

Dragonfly, weighing little more than 600lbs would revolutionise air warfare. He claimed that he would overcome the traditional overheating problems of air-cooled engines by plating his cylinders with copper, for better heat transfer. Technical specialists such as Bentley declared that Bradshaw was talking hogwash, but the politicians gave him their blessing, and ordered massive production of an engine whose prototype was not yet built.

In the event the specialists were proved right. The Dragonfly overheated and, although inadequately understood at the time, it also suffered from synchronous torsional vibration, with the engine speed being close to the natural frequency of the crankshaft. Hence the engine regularly shook itself to pieces. New machines waiting for Dragonflies had to be re-engined with the 230hp Bentley rotary so that test flying could begin. If the war had dragged on into 1919 the commitment to Dragonfly-powered machines could have led to disaster for Britain's airmen.

## And Post-War

In the post-war world, might-have-beens seemed not to matter. Bradshaw was awarded £48,000 for his engine designs, although not one aircraft had gone to the front with one of his engines. Bentley was awarded a measly £8000 for all his work. His QC at the Awards Commission declined his fee in protest. However, whereas in 1914 aero engines had been hand-built in very small numbers, Britain now had an aero engine industry. The Rolls-Royce story is well known, as is the Bristol one. Napier had just completed its Lion and that engine would power a whole generation of postwar machines. And the ancient V-8 Renault would be split

in two by Frank Halford to power a little De Havilland aeroplane called a Moth. But that is a whole different story.

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## **Notes on Contributor**

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