Fedden's Forgotten Flat Six

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Sir Roy Fedden was the leading proponent of the sleeve valve, brought to a high level of reliability in the Bristol Hercules engines that powered many WWII aircraft. In 1945 he founded a company under his own name. Designed for the civil market, Roy Fedden Ltd's Flat Six was rated at 160hp/185hp – streets ahead of the DH Gipsy Major. Unfortunately the company was forced to close before the Six had progressed beyond the prototype stage. While it was a significant advance on contemporary British engines, it had several disadvantages in a market that rapidly came to be dominated by American products. However, the Six remains one of the most elegant and intriguing light aircraft engines ever built.

KEYWORDS: Fedden, Flat Six, sleeve-valve, aero-engine

An Obscure Museum Exhibit

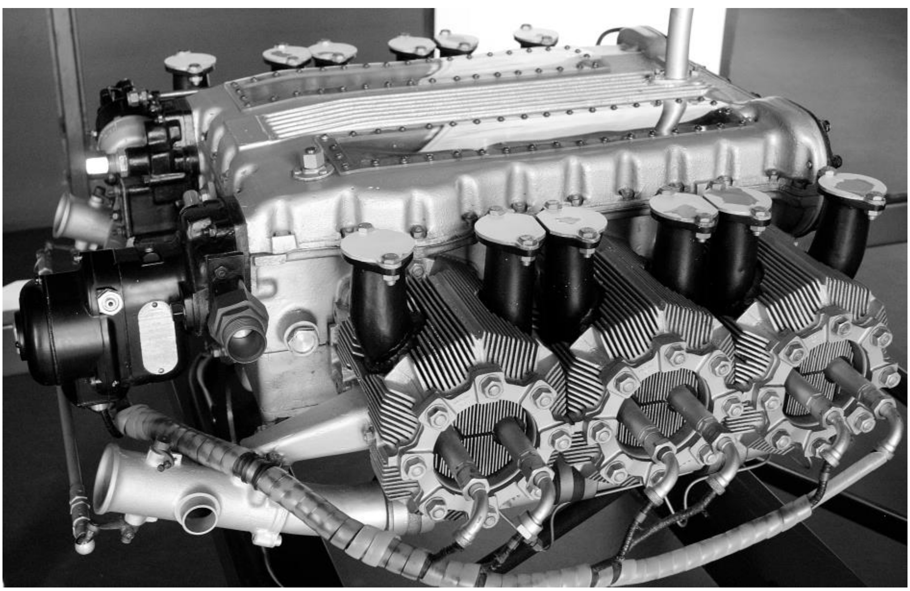

Figure 1. Feddon's Flat Six.

Sat at the far end of the Science Museum's Aeronautical Gallery, unnoticed by most visitors to that great South Kensington institution, is a remarkably compact and modern-looking aero engine (Figure 1). An air-cooled, fuel injected flat-six - it could be the sort of motor you might expect to find under the cowlings of any number of 2011 light aircraft – except this is not an American Continental or Lycoming; it is a Fedden and it was designed and built in England as long ago as 1946.

The maker’s name should strike a chord. One of the great aero engine designers, Sir Roy Fedden made efficiency his byword. Over the course of twenty-five years of relentless innovation and development, he and his team had by the mid 1940s almost doubled the specific output of Bristol’s famous piston aero engines, reducing the engine weight per horsepower from around 2lb/hp to very nearly 1lb/hp.[1] Partly, this had been through the use of supercharging – but Roy Fedden’s big idea, the thing he devoted most of his career to perfecting, was the sleeve valve.

Most of the competing aero engines of the time used poppet valves to admit mixture to the cylinder and allow exhaust gases out – the kind of penny-on-a-stick valves used in automotive engines to this day. Poppet valves are fine things; they are easy to manufacture, easy to service and reliable in operation. However, they tend to get in the way of other essentials in the cylinder head, like the spark plugs – aero engines must, of course, have two of these – and they block the passage of heat away from the combustion chamber. These factors become critical when you are trying to wring the utmost power from an engine. If the flame has too far to travel – say from spark plugs mounted at the sides of the cylinder – part of the charge may detonate, causing piston damage or failure. Being heated by the exhaust gases and having only a narrow seat and limited stem area to dissipate that heat, the exhaust valves themselves constitute hotspots, adding to the tendency for detonation.

The sleeve-valve engine does away with inlet and exhaust ports running through the cylinder head, allowing the spark plugs to be positioned centrally and eliminating the hotspots. Instead, the intake and exhaust ports break directly through the cylinder wall, where they are revealed alternately by cut-outs in an oscillating sleeve sat between piston and cylinder wall – a kind of moving cylinder liner that does the same work as those ‘pennies on sticks’ with a fraction of the component count (Figure 2).

If all this sounds too simple to be true, then in some ways it is. Early Daimler cars had used sleeve-valve engines noted for their near-silent operation – no crude poppet valves to be hammered open by the brutal action of a camshaft – but they left a characteristic trail of blue smoke. Oil control remained a perennial problem with even the single-sleeve design adopted by Fedden, and there was a mare’s nest of development problems, not least in ensuring the necessary working clearances were obtained and maintained with varying engine temperature.

Nevertheless, Roy Fedden and his team became masters of the sleeve valve and brought the idea to a high level of reliability in the Hercules engines that

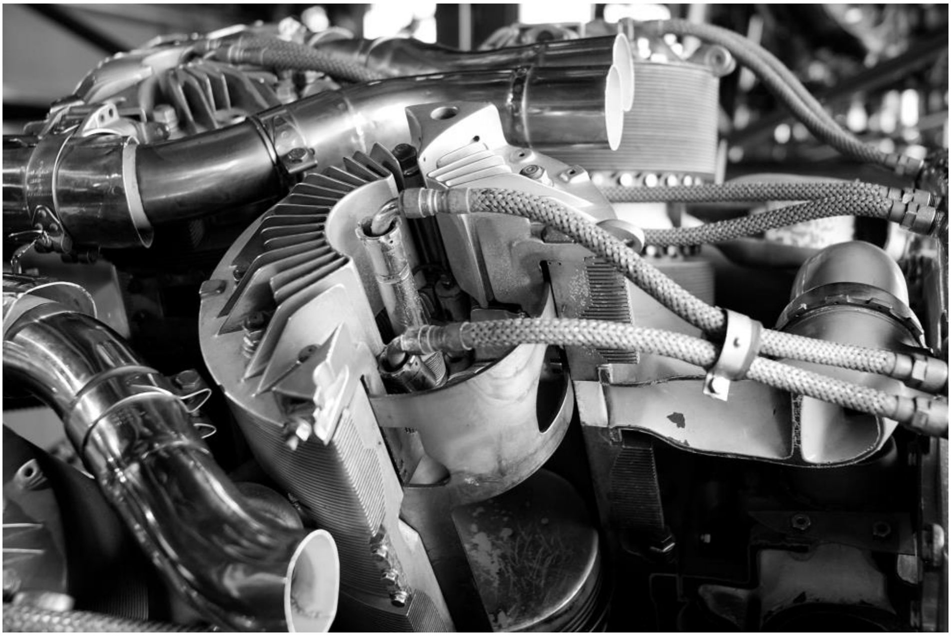
Figure 2. Centaurus Sleeve Valve Engine.

powered so many WWII bombers, using it to great effect in Bristol's ultimate radial, the mighty Centaurus.

Sadly, for all his fantastic technical achievements, Fedden's relationship with Bristol's board of directors grew progressively more strained to the point that in September 1942 it finally broke down, and he left the company.[2] Thus, after a spell as key technical advisor to the government, he came in 1945 to be heading his own company, Roy Fedden Ltd, and considering engines for the post-war civil market.

America Led the Field

While British aero engine manufactures had excelled in developing high-output piston engines for the military, they were not so well placed to supply the post-war civil market. Fedden wrote in his report on a proposed 850 hp engine for air transport

> Military engines are designed with an eye to the last ounce of performance and frequently performance is attained at the cost of intricate machinery or fitting operations. It is considered that an essential requirement of a civil engine is that it should be sold as cheaply as is compatible with high quality and this means the simplest possible design from the production point of view.[3]

The 850 hp engine was intended to fill a gap in the market but at the bottom end, the existing British engines hardy represented cutting-edge technology. The de Havilland and Cirrus engines of 1945 were merely updated versions of the air-cooled inline fours of the 1920s and 30s – and these owed their origins to a Renault V8 of WWI vintage. By contrast, the Americans had new flat-fours and sixes on offer; compact, lightweight units better suited to light aircraft.

The pattern for these engines – a pattern that has endured until this day – was established by US manufacturer Continental (now Teledyne Continental Motors and just sold to the Chinese). A year older than the aeroplane, Continental was founded in 1902 by engineer Ross W. Judson. Judson and business partner Arthur W. Tobin incorporated the Autocar Equipment Company in 1904, advertising their automobile and marine engines as 'Continental Motors'.[4] The idea was to play up the sophistication of a product that, with Judson drawing his inspiration from contemporary European design, was superior to the run of American engines. In 1905 the Autocar name was dropped and the Continental Motor Manufacturing Company – later shortened to Continental Motors Company – came into being.

There is an early link, albeit a tenuous one, with Roy Fedden: in 1926, Continental purchased from British company Wallace Ltd world patent rights for the single-sleeve-valve that would later become a feature of Bristol and Napier aero-engines. Continental was beginning to take an interest in aviation. Ross Judson – who would these days no doubt be called a gadget freak – had in 1923 bought a flying boat for his personal use. By 1926, the company had a Fokker tri-motor to transport executives between the company's far-flung manufacturing facilities. The upshot of all this was the announcement early in 1927 that the Continental was working on its first aircraft engine, a nine-cylinder sleeve-valve radial engine called the R-790.

The R-790 never made it beyond the prototype stage. Instead, under the guidance of ex-Army Air Service engineer Robert Insley, the first Continental aero-engine to go into production was the Model A-70, a conventional, poppet-valve seven-cylinder radial that received its Approved Type Certificate just as the US stock market crashed in 1929.

Continental faced the 1930s knowing it had to diversify and develop its business beyond the automotive industry. In the 165hp A-70, it had a relatively expensive engine that was really only suited to the kind of big, four-seat aircraft that fewer and fewer people could then afford. In time, an enlarged version of the A-70, the R-670, would be fitted to military trainers like the Boeing PT-17. Stearman and Continental's future would be assured by the US Army's adoption of its air-cooled radials for tanks. However, the immediate need, as Continental well knew, was for something 'cheap and cheerful' to power the emerging generation of basic, two-seat aeroplanes typified by the Taylor (later, Piper) Cub.

The company broke new ground in 1930 by producing the A-40. This was the first 'flat-four', a configuration that got the cylinders out the way of the pilot's view and offered minimal aerodynamic drag. In this sense the engine was more than ‘cheerful’ – it was an inspired concept. Unfortunately, the detail design was dismal and, in opting for an inefficient side-valve layout and casting the cylinders in pairs, Continental overdid the cheap bit.

By using ‘steelbestos’ gaskets that blocked heat transfer to the cylinder heads, Continental had inadvertently produced a unit that was prone to cooking itself. Freshly recruited engineering test pilot Paul Wilcox partly solved the problem by designing finned aluminium exhaust muffs to take some heat away from the hot-running valve gear, but the definitive fix came from a customer who had – unbelievably – fitted an A-40 to an experimental helicopter. When he encountered cooling problems, this character devised his own head gaskets, based on a copper-aluminium-copper sandwich. Wilcox had the factory make up Chinese copies and “from that day on we had little head gasket trouble”.

The head gasket fix came after designer C.G. Taylor and business partner William T. Piper had acquired a pre-production A-40 for trials on the prototype E-2 Cub. Test pilot Bud Havens, Taylor and Piper “had twenty-six forced landings between us in the first thirty days,” recalled Taylor. Continental worked hard to get the A-40 working reliably: the Type certificate for the engine was issued on 15 May 1931 and certification for the A-40 powered E2 Cub followed a month later (can you imagine such a speedy sequence of events in 2011?)

As a production unit, the A-40 demonstrated one further, rather worrying, idiosyncrasy: the crankshaft tended to break after 100 hours or so. Astonishingly, Continental had located the thrust bearing at the rear of the engine, putting the entire crankshaft under tension from propeller thrust. You might have thought the company’s reaction to this new problem would have been to fix it. Instead, taking aim squarely at the messenger – main customer Taylor Aircraft – Continental decided in 1933 to cease manufacture of its smallest aircraft engine.

Happily, the decision was soon reversed and, with redesigned thrust bearings, separately cast cylinders (to improve cooling) and dual magnetos, the A-40 was developed to the point that it had a 500 hour time between overhauls. Between 1931 and 1938 some 3,000 were sold, 70% going to Taylor Aircraft Company/Piper Aircraft Corporation to be fitted to Cubs. The latter became the archetypal light aircraft and Continental’s flat-four was established as the archetypal light aircraft engine. However, with power restricted by its outdated side-valve heads the A-40 remained, in the words of senior Continental engineer Carl Bachle, “a terrible engine”. Indeed, it was Bachle – later the engineer responsible for some of the best engines Continental ever made – who told his management that they “could never make the A-40 work right… forget it”.

Turning again to the Army Air Service, Continental recruited engine designer Harold A. Morehouse and it was he who laid out the A-40’s successor, the 50hp A-50, which went in to production in 1938. Resembling the A-40 only in its basic configuration, the A-50 had overhead valves and cross-flow porting. In order to eliminate the head gasket, which had been so troublesome in the A-40, the individual alloy heads were screwed on to the iron cylinders in a semi-permanent joint. Thanks to this redesign, individual cylinders could be 'pulled' without disturbing their neighbours. The crankcase was split vertically, the main, and camshaft bearings being mounted on internal webs. This not only made the whole assembly very stiff, but allowed it to be stripped down with ease. The A-50 established good design features that would remain essentially unchanged in Continental's engine line (Figure 3), all the way from the A-65 that powered the 1940s version of the Piper Cub familiar to Roy Fedden (Figure 4), to the O-200 to be found in the Cessna SkyCatcher Light Sport Aircraft in 2011.

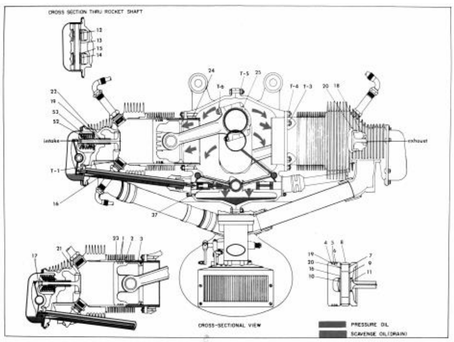

Figure 3. A-65 cross-section.

Figure 4. A-65 Engine.

By 1945, several other US manufacturers were building flat-fours and sixes very similar to the Continental. One of the most efficient of these, the six-cylinder Lycoming O-435 – 'O' for opposed, '435' for 435 cubic inches (7.1 litres) – was rated at 190hp and weighed 350lb. By comparison, the British de Havilland Gipsy Major I (four cylinders, 6.1 litres) was almost as heavy, yet produced just 130 hp. The DH Gipsy-Six just topped the O-435 in terms of power output, only did so at the cost of a swept volume of 9.2 litres and a weight of 468lb.[5]

The Americans were rather good at making small-capacity civil engines, as Roy Fedden, a frequent visitor to the USA, well knew. As he put it himself

> This country has a great deal of leeway to make up to produce machines to compete with those of American origin.

Who better to make up that deficit than Roy Fedden Ltd?

So, as the company continued to work on projects ranging from a utility car (powered by a three-cylinder sleeve-valve engine) to a large gas turbine aero engine, the Cotswold, Fedden set in motion the design of flat-six of more modest output – the engine that you can see today in the Science Museum.

Ahead of its Time

While air-cooling and the opposed layout are very 'American', the Fedden Flat Six is distinguished by its very clean external appearance and unusual axial cylinder cooling fins. Of course, this is a sleeve-valve engine: instead of the usual camshaft and, in this case, twelve each of tappets, pushrods, rockers and poppet valves, there are a pair of shafts carrying worm gears that drive six cranks, three on each side of the engine (Figure 5). These cranks each drive a sleeve, pierced towards its upper extremity by five circumferentially arranged cut-outs that control inlet and exhaust flow via three intake, and two exhaust ports in the cylinder walls.

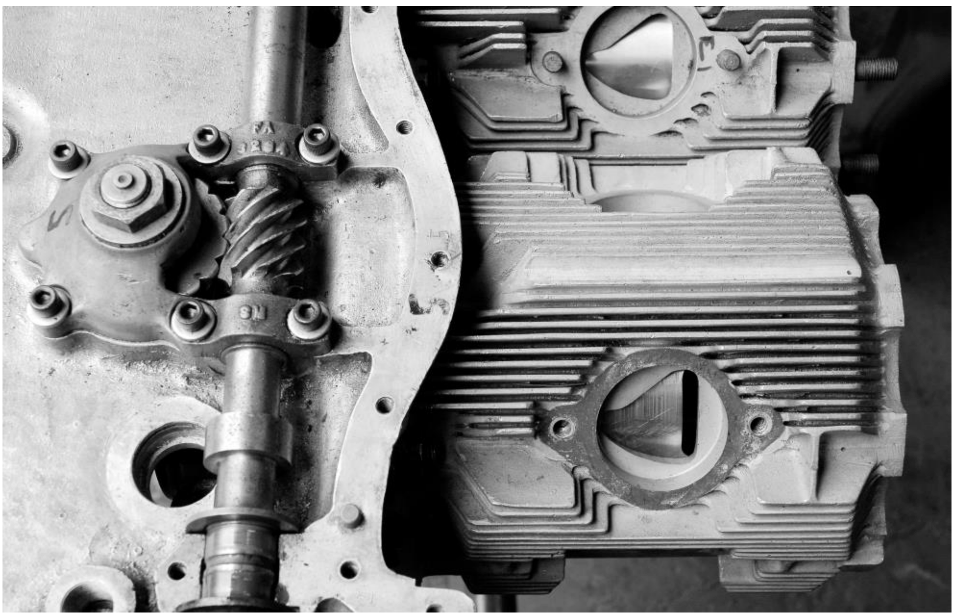

Figure 5. Sleeve Drive.

Otherwise devoid of fittings or ports, the cylinder heads – or 'junkheads', as they are known in sleeve-valve parlance – carry dual, centrally mounted spark plugs, ignition for one set being provided by a magneto and for the other by an automotive-type coil and distributor system (Figure 6). This duplex ignition system, which provides good spark energy at low engine speed thanks to the coil and reliable ignition at higher speed thanks to the magneto, had been seen in the USA, on Jacobs engines. However, one significant departure from contemporary light aircraft engine practice – and something rather ahead of its time – was Fedden's use of fuel injection, a neat little mechanical distributor-pump being mounted at the propeller-drive end of the crankcase (Figure 7).

Figure 6. Front view.

Figure 7. Propeller drive end.

What is not immediately apparent is that the engine displayed in South Kensington is designed for a pusher application, where one unit would have been buried in each wing of a twin-engine aircraft. Buried engines were very much in fashion in the mid-1940s and the sole surviving company brochure illustration the author has been able to examine shows the Flat Six mounted with the accessory end forward, intake slots in the leading edge supplying air to a plenum from which cold intake air (no carburettors to ice up, remember) and cooling air appear to be supplied (Figure 8). Metal baffles, sealed at their edges with flexible strip, direct air from the underside of the engine, to flow axially along the cylinders towards the crankcase. Carefully formed ducts direct part of the flow from the plenum down into the deeply recessed junk heads, providing a discrete cooling for these critical components in much the same way it was done with the big Bristol sleeve-valve radials.

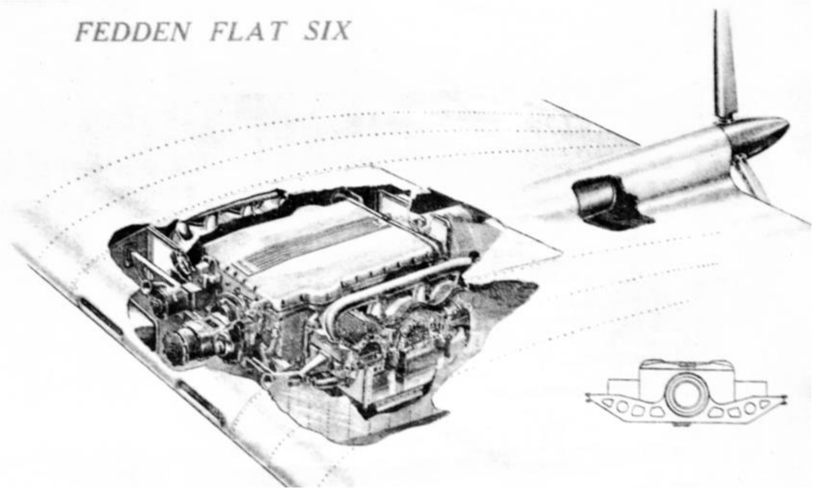

Figure 8. Installation artwork.

The illustration does not show any kind of fan assistance for the cooling air, which makes one wonder if heat might have built up during ground running. Of course, any kind of exit duct to the low pressure region on top the wing or at the trailing edge close to the pusher propeller would have done the job when the aircraft was in flight – but it is hard to imagine a buried engine getting anything like the cooling flow a conventional tractor layout, with intakes positioned close behind the propeller, would see when idling.

The Fedden Flat Six was rated at 160hp (direct drive) or 185hp (geared). Its displacement was 325 cu in (5.3 litres) and it weighed 310lb (without propeller reduction gearing). These figures put it streets ahead of the Gipsy Major I and suggest it might have offered fair competition to the contemporary 7.1 litre Lycoming O-435.

Sadly, this was not to be, as the cancellation in May 1947 of government funding for the company's biggest project, the Cotswold gas turbine, together with the loss of its manufacturing facility, led to the demise of Roy Fedden Ltd before the Flat Six had progressed beyond the prototype stage. While Roy Fedden continued to act as an engineering consultant and became closely involved with the College of Aeronautics at Cranfield (an institution he had long advocated, subsequently Cranfield Institute of Technology and now Cranfield University), no other manufacturer ever took up his sleeve-valve light aircraft engine.

A World-Beating Design?

Even if Fedden had found a partner to put the Flat Six into production, you have to wonder if it would have become a world-beater. There is more to a successful engine than a good power-to-weight ratio – reliability and ease of maintenance are important factors. Certainly, the sleeve-valve engine had reached maturity by the mid- to late 1940s and the post-war Hercules bettered any American radial with a time between overhauls (TBO) of 3,000 hours. However, the big Bristol radials had a reputation of being tricky to work on, even if units could be readily removed and exchanged as complete 'power eggs' – an idea promoted by Fedden after he had inspected captured German engines during the war (Figure 9).

The one man who has more hands-on experience of the Fedden Flat Six than anyone else alive today, Rolls-Royce Heritage Trust volunteer Stewart Morrow, says that the engine does not strike him as being easy to maintain.[6] Not least of the problems is that there is little space between the closely set cylinders of an opposed engine for access to the sleeve valve's characteristic three-port inlet tracts (Figure 10):

> In order to seat the flanges of the inlet manifold, the cylinder assemblies are drawn together by studs with opposed left, and right-hand threads – double-ended bolts, if you like. This means you cannot readily pull a cylinder for

Figure 9. Bristol Centaurus.

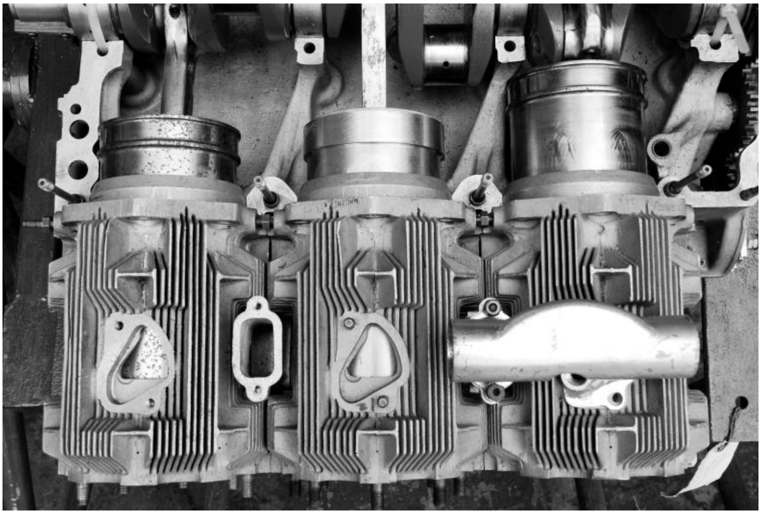

Figure 10. Cylinder bank.

inspection, as you are able to do with a Continental or Lycoming – you have to remove the bank of three, complete with the inlet manifold.

Light aircraft propellers are limited in diameter by sensible consideration of ground clearance etc. As the blade tips approach the speed of sound, aerodynamic efficiency falls and noise becomes a serious issue. For these reasons, propeller speed is generally limited to maximum of 2,800 rpm and typically 2,500 rpm or less at cruising speed. The Fedden Six's higher rating of 185hp was produced at 3,400 rpm, requiring reduction gearing for the propeller.

At least one source cites this power figure alongside the quoted weight for the lower-rated, direct-drive version of the engine.[7] In the absence of any information on the type of reduction gear envisaged by Fedden – it may well never have existed in any form beyond a design scheme – it is difficult to make any meaningful estimate of the weight penalty, although it would be in the order of 30lb or so.

Nor can one say for sure that the reduction gear would have proved satisfactory in service. One of Cessna's forgotten models, the 1958 C175 Skylark fell victim to high-frequency vibration generated by its Continental GO-300 ('G' for geared) engine, which led to reliability problems and a perceived lack of refinement. Indeed, the Americans found gearing to be so troublesome in the light aircraft application that for several decades they confined its use to a small number of high-power models. It is only in recent times that a geared engine has seen wide success in the light aircraft market, in the form of the small-capacity, high revving Rotax 912, an Austrian design that in its basic layout is still very similar to the Continental A-50/A-65/O-200.

Returning to the historical context, by 1953 US manufacturer and Continental rival Lycoming had certificated its four-cylinder O-320, which almost matched the 160 hp direct-drive power rating of the Fedden Flat Six, yet weighed over 60lb less. With its simple pushrod-operated valve gear and detachable cylinders with integral heads, the O-320 was designed very much along the lines of Continental's air-cooled fours, albeit with the camshaft mounted above the crankshaft in its vertically split alloy crankcase (Figure 11). The O-320 eventually came to power Cessna's 172 Skyhawk, which has been produced in greater numbers than any other light aircraft (over 43,000 built before recession hit the market in 2008, and still in production today).

We will never know quite how much power the Fedden Flat Six might have been coaxed into producing, given the financing and development it was denied so soon after it was born. While it was a significant advance on the British engines of the post-war era, we can only guess at its potential competitiveness in a market that rapidly came to be dominated by ultra reliable, and seemingly low technology, American products. However, one thing we do know; Roy Fedden conceived one of the most elegant and intriguing light aircraft engines ever built.

Fedden Six and Competitors (1939-53)

Type	date	power (hp)	weight (lb)	capacity (cu in/lit)
DH Gipsy Major I	1939	130	305	374/6.12
DH Gipsy-Six Ser.I	1939	200	468	561/9.19

Lycoming O-435	1945	190	350	434/7.10
Fedden Flat Six	1947	185*/160**	310**	325/5.35
Lycoming O-320	1953	150	244	320/5.25

*with propeller reduction gear
**direct-drive

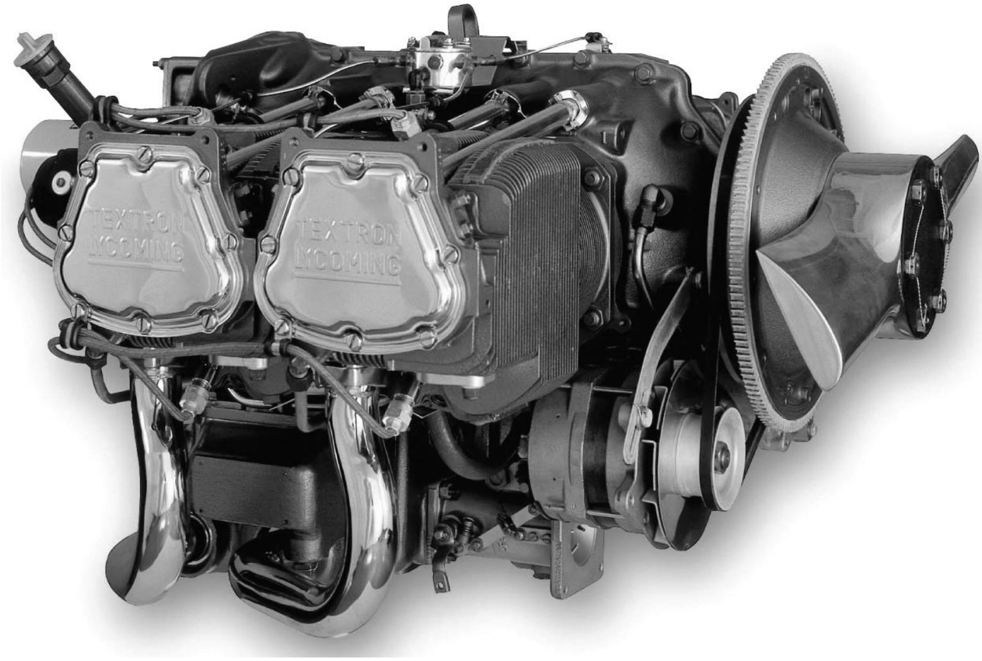

Figure 11. oi360.

Appendix A: Surviving Relics in Safe Hands

Eight years after Roy Fedden's death, Cranfield University presented to the Science Museum in 1981 all the remaining Flat Six material. The inventory comprised one complete Flat Six engine, crankcase castings (one set of which came from an engine that had run, but failed) and a number of damaged, unfinished and incomplete components – 'pieces that were considered scrap at the time,' as one of the museum's curators put it – as well as the manufacturing drawings and a single-cylinder test engine.

The Science Museum in turn passed most of the Roy Fedden Ltd material to the Bristol Branch of the Rolls-Royce Heritage Trust, retaining the one complete Flat Six engine and copies of the drawings. In recent years the RRHT, itself running out of storage space, has placed the drawings in the care of the Gloucestershire Archive.

There the story might have ended, were it not for the splendid efforts of RRHT volunteer Stewart Morrow. Over the course of the last ten or twelve years, Stewart has finish-machined the surviving cylinder castings and other components, working to Fedden engineering drawings, and combined these with the salvaged crankcase in building up a second Flat Six for display.

Unfortunately, as it has mild steel replica sleeves and non-original pistons, and is missing several key ancillaries, there is no prospect of RRHT's Flat Six ever being made a runner. However, with considerable ingenuity, Stewart has got the single-cylinder test engine to run (he believes it did not run, or at least did not run properly in period) and today he is happy to fire it up, demonstrating to visitors the one living part of Roy Fedden's light aircraft engine legacy.

Acknowledgements

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