The Curtiss OX-5

by Sandy Skinner

The Curtiss OX-5 was the most important and successful American engine of the First World War.

Before Liberty enthusiasts suffer a seizure, let's check the facts. The only significant Liberty powered aircraft to see WW1 active service was the DH4. In 1918 at the Armistice less than 200 DH4s, flyable or not, were at the front. In contrast more than 8,000 OX-5 powered Curtiss Jennies were built, training wartime pilots and supporting postwar barnstormers.

The big mistake is to judge the OX-5 and Liberty by the same standards. The Liberty was a high technology engine, drawing on the knowledge of the US automobile industry and Mercedes racing practice. The OX-5 was a low cost prewar design and not everybody loved it.

"A failure looking for somewhere to happen" —James Gilbert, author *The World's Worst Aircraft.*

"Probably the least reliable aviation engine in widespread use"—Herschel Smith, author *History of Aircraft Piston Engines.*

"Always unreliable—suffered from appalling quality control"—Bill Gunston, aviation guru and author *World Encyclopaedia of Aero Engines.*

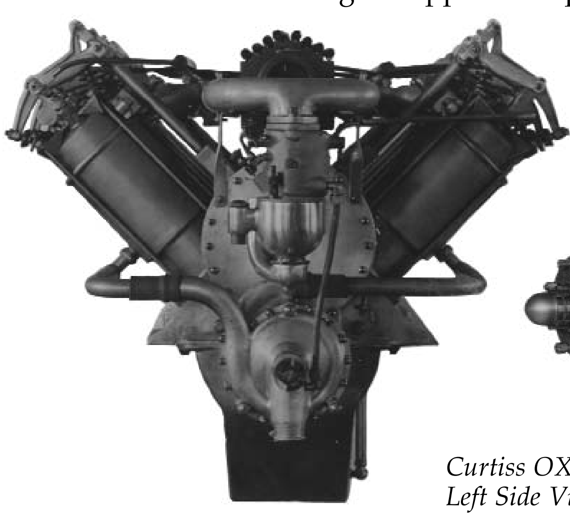
"A lovely engine—dead reliable, beautifully made and bloody quick"—Mark Walker, UK OX-5 expert and successful aero engined racing car builder and driver.

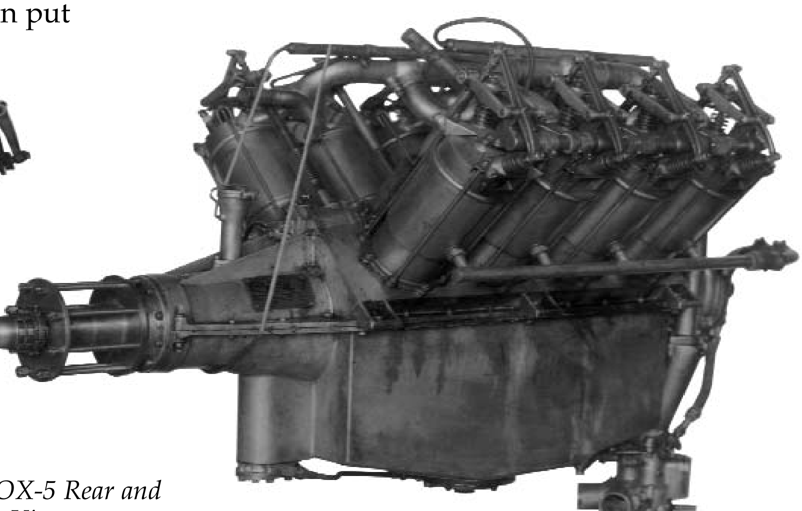
The OX Family

Glenn Curtiss started manufacture with motor cycle engines, developing a range of effective V-twins. A successful dirigible application put Curtiss in the aviation business. According to Curtiss expert and member of a distinguished aviation dynasty Larry Rinek the realisation that Curtiss could sell an aero V-twin for the same price as a complete motor cycle spurred his enthusiasm. A 40 hp air-cooled V-8 was put in a bike in 1906 as a testbed for aero applications, and was timed over a one mile course in January 1907 at 136.36 mph, boosting the Curtiss reputation for engineering skill and sheer bravery. By 1908 water cooling was taking over from air, and in 1909 Curtiss, flying his own biplane, won the first aviation Gordon Bennett trophy for heavier than air craft. He used a water cooled V-8 with mechanically operated overhead valves, clearly the forerunner of the 1912 Model O.

Curtiss development was evolutionary. Like most manufacturers of the time he had started with an F-head, with an atmospheric (vacuum) inlet valve above a mechanically operated side exhaust valve. By 1909 he had progressed to the then-popular inclined overhead valves with one rocker and one push-pull rod per cylinder. Illustrations show a similar and particularly neat push-pull implementation by Austrian-Daimler and a single pushrod, dual rocker installation from Salmson.

Unfortunately such single actions limit valve timing by making significant overlap impossible. By 1912 Curtiss experiments had led to separation of the actions operating the inlet and exhaust valves on the Model O, whose general architecture clearly foreshadowed the OX design.

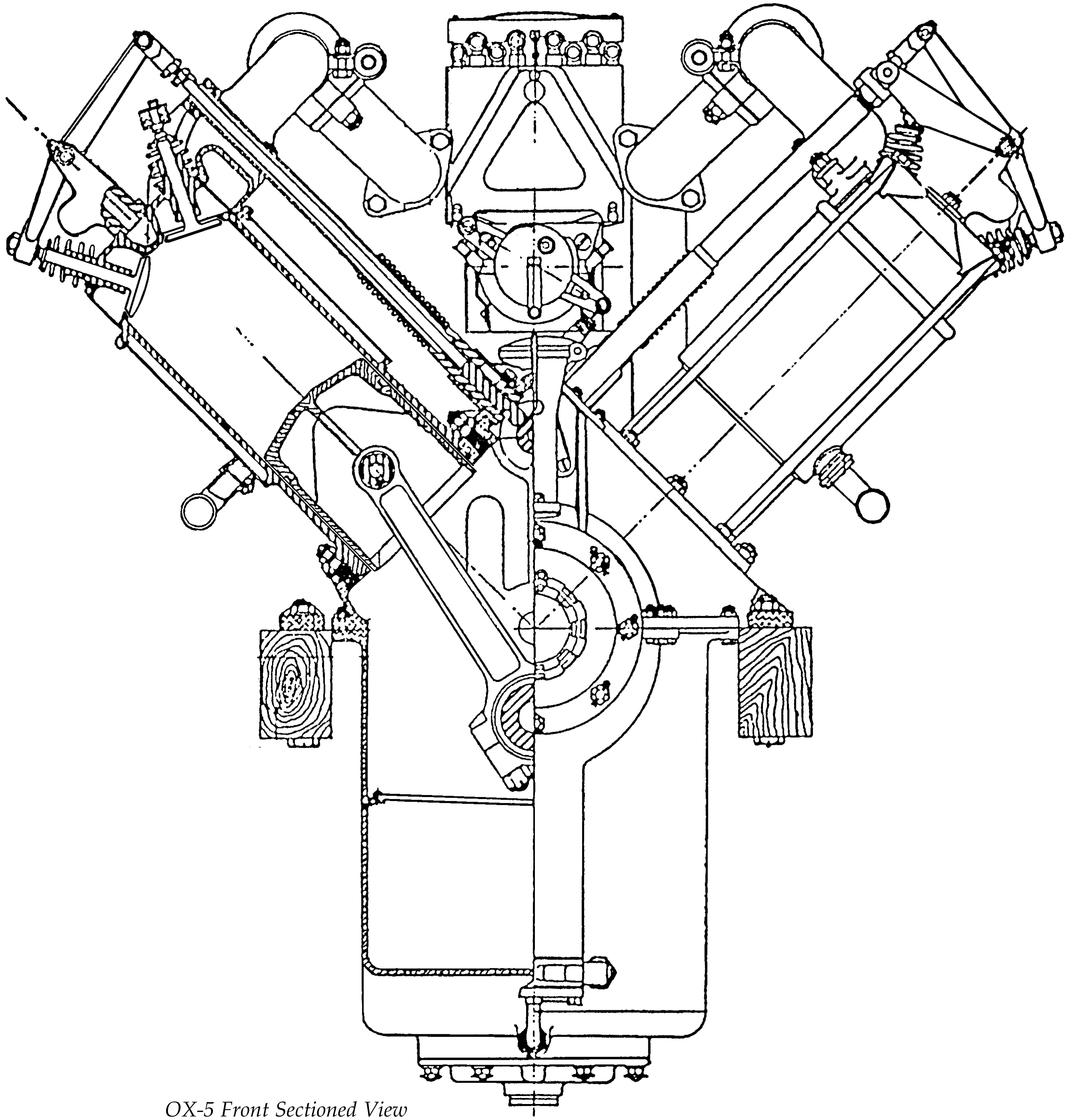




Curtiss OX-5 Rear and Left Side Views

The OX series with its characteristic push-pull valvegear arrived in 1913 and went through more or less identical 4 in bore and 5 in stroke variants up to the Dash 6. Only a handful of OX-5 engines was built before 1917, when production by Curtiss, subcontractors and licensees, particularly Willys, boomed on US entry into the war. Figures are far from certain and there appears to be some double counting in units built for Canada and the UK. An official source provided by Larry Rinek gives 8,458 units delivered to the US Government up to the Armistice out of orders for 9,450. Adding in overseas orders probably gives a grand total of about 12,000.

Types built in much smaller numbers included the dual magneto, twin plug 4.25 in bore, 100 hp OXX from 1914. This was followed by the 5 in bore, 7 in stroke V2 series with conventional valvegear, which looked very like a modern V-8 and delivered up to 250 hp. An advanced V, with four valve alloy heads, seems to have been planned but not necessarily built.



OX-5 Front Sectioned View

So Why the OX-5?

By 1914 Curtiss was the largest US aero engine builder, despite relying on batch production for fairly limited output. By the time the United States declared war on Germany in April 1917 the OX series was well established, and the OXX and V2 were in principle at least available.

The US was hard pressed for aero engines. The Bolling mission to France was a good idea but the Bugatti/Duesenberg/King 16 was a disaster and the Hispano V-8 tricky to build. The Liberty was a brilliant concept, implemented amazingly quickly but not fast enough to make any real impression on the war. The OXX and V2 were better engines, but there was more production experience behind the OX-5. A minor point against the dual ignition OXX is that it would have doubled overnight magneto requirements for what became the most popular US engine.

The OX-5 was there, production tooling existed, people understood it, it didn't need any trick manufacturing technology and it worked. The decision was a no-brainer—American mass production skills were called in and the engines rolled off the lines.

The OX-5 in the Metal

The OX-5 combined a few oddities with some attractive subtleties which aren't visible at first sight. To put the engine in the context of its time it is compared here with another very successful V-8, the single overhead cam per bank, light alloy monobloc 150 hp direct drive Hispano-Suiza T34. The speed of engine development at the start of WW1 means that the Hispano is in every way a more sophisticated engine; when making comparisons we must also make allowances.

	OX-5	**Hispano**
Effective design date*	1913	1915
Weight (kg/lb)	177/390	190/418
Bore (mm/in)	102/4.0	120/4.72
Stroke (mm/in)	127/5.0	130/5.12
Capacity (litres/cu in)	8.3/506	11.76/717
Rated hp	92	150
Rated rpm	1,400	1,450
Compression ratio	4.5:1	4.8:1
Consumption, fuel**	0.60	0.58
Consumption, oil**	0.03	0.036

*Date when definitive engine design became available
**(lb/hp/hr)

The direct drive crankcase is compact. Two rows of co-axial cam followers give an idea of the amount of stagger needed to take side by side rods. In front of the crankcase, the camshaft shows the eight exhaust cams, each flanked by a matched pair of inlet cams.

The basic architecture is a 90° V-8 with an alloy crankcase carrying staggered cast iron barrels with integral OHV heads. The crankcase is divided into four sections by massive and well proportioned main bearing webs and has an integral compartment for the propeller shaft extension. Minor changes suit it to tractor or pusher installation and left or right hand rotation.

A single plane five bearing crank is not counterbalanced and has a long front shaft extension keyed to take the propeller hub. Crankwebs are slim by later standards and bigends are inevitably long to accommodate side by side rods. A ball thrust bearing just behind the drive key is secured by a thread on the shaft and securing nut and takes loads in either pusher or tractor installations. The timing gear is keyed to the other end of the shaft, which terminates in a stub driving the water pump. Like Rolls-Royce, Curtiss analysed a test piece from every crank forging before machining.

Perhaps surprisingly, the shaft is soft. A 1925 aftermarket handbook from OX-5 specialists Nicholas-Beazley recommends that it should always be well supported since if it is "laid down resting on the gear and thrust bearing only, it will almost always bend a few thousandths out of true." Also, before lifting a crank bits of rubber tube should be fitted on the main bearing studs since "— the threads are much harder than the shaft, and the least touch will cause a nick in the journal."

Pistons are light alloy with two compression rings only. Nickel steel H-section connecting rods are fully machined and balanced. Identical rods side by side offer simple machining and easy inspection. Short rods help to keep the engine width down to a creditable 29.75 in despite inclined valves and inevitably sticking out exhaust rockers. For comparison, the compact Hispano is 33.5 in wide, up more than 12%.

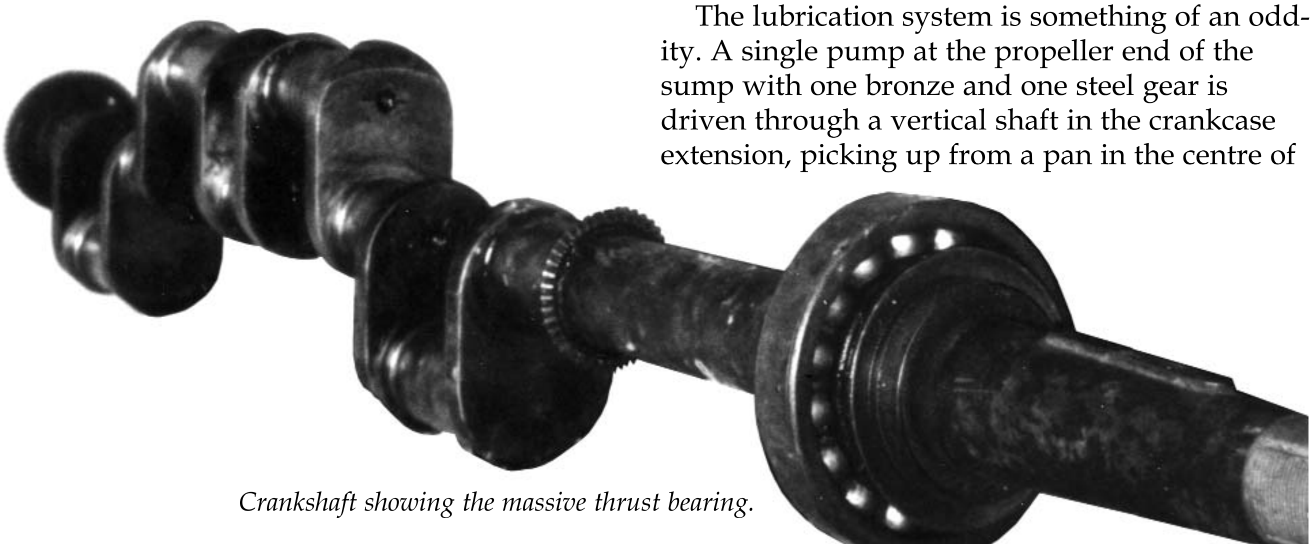
White metal shells are used in both main and bigend bearings with up to three thousands (0.003 in, 0.075 mm) clearance on the diameter. It's an indication of high Curtiss manufacturing standards that a sales document stresses that all bearings are reamed rather than scraped. "This method permits replacement without any fitting, as both the inside and outside diameters of the bearings are held so close in manufacture that new ones will drop more accurately in place than would be possible to fit them by hand." The US was always ahead of Europe in building the skills into the machine rather than trying to put things right afterwards.

Accessory drives were neatly grouped. A straight cut pinion engaging with the camshaft gear drove an eight cylinder magneto in the centre of the V. Standard equipment was a US-built Berling D-81-X2. A dog drive from the cam gear drove a tachometer and air pump, with the crank driven water pump immediately below. Hand starting was an optional extra.

Engine mounts are six well braced lugs and 3/8 in holding down bolts. The manual tells you to put a thin strip of copper under each lug, then check with a feeler gauge to make sure they pull down evenly on their bearers. If they don't, a charming period note tells you to take out the copper and sandpaper the bearer.

Design Details

The lubrication system is something of an oddity. A single pump at the propeller end of the sump with one bronze and one steel gear is driven through a vertical shaft in the crankcase extension, picking up from a pan in the centre of



Crankshaft showing the massive thrust bearing.

the sump. It delivers at a rated 40 – 60 psi (2.8 - 4.2 kg/cm^2) to the propeller end of the hollow camshaft and so to all five camshaft bearings. Drillings lead to the main bearing housings, with oil finally making its way through drilled crankwebs and hollow pins to the bigends.

An optimistic drawing in the official 1918 handbook shows spray making its way directly to the cylinder walls, circulating neatly within the piston crown and entering through holes in the gudgeon pin bosses to travel in both directions at once, oiling either/or the piston bosses and little end. It then lands in the sump, where a nice little float indicator tells the mechanic if not the pilot what's going on, before starting all over again.

The system works provided the engine as a whole is in reasonable condition, but it's not a very good idea. Oil pressure at the bottom end is determined to a considerable degree by wear in the camshaft bushes.

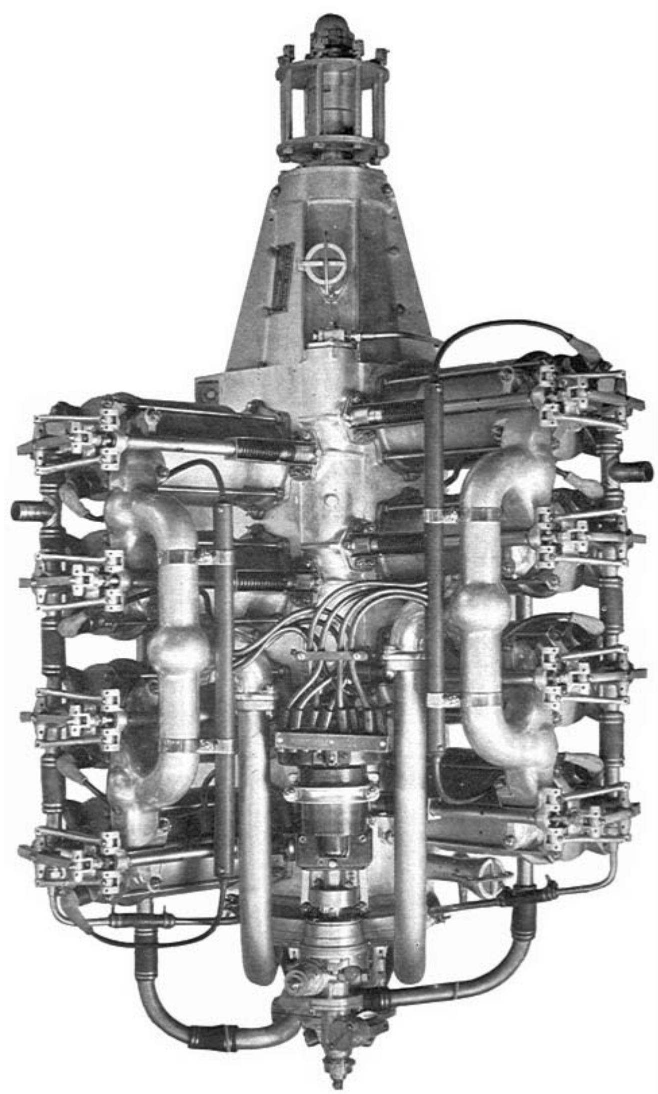
In August 1929 the magazine *Aviation* published a three part feature about Parks Air College, an Illinois flying school operating 30 OX-5 powered aircraft. A standard procedure on overhaul was to fit replacement split aluminium bushes to Brinell 115, presumably in search of longer bearing life. This seems high, since in 1937 Devereaux of High Duty Alloys called for special materials and precision fitting when using bearings of comparable hardness. He specified "specially hardened polished shafts, clean oil and exact clearances and specially fine machining" for shafts running in 120 Brinell aluminium alloy bearings—not a low cost approach.

Clearly, there was a problem for long term OX-5 users which could have been avoided with a more conventional lubrication system delivering full pressure direct to the crank with reduced pressure to the cam and accessory bearings. The original military users would scarcely have been affected.

Cylinder barrels are conventional for the period. A good grade of cast iron is used for the integral barrel and head, with a pair of bands on the barrel to take a corrosion resistant brazed on Monel (67% Ni, 28% Cu alloy) water jacket, replaced in the later engines with much cheaper steel. This is Benz practice, rather than the costly Mercedes welded steel design adopted on, among others, the Liberty and is said to have been liable to failure through vibration. It would be interesting to know whether Curtiss used furnace brazing, which should have stood up, or hand work which probably wouldn't.

Each barrel is held down by a base flange with eight nickel steel studs, four short and four long extended upwards to a four armed steel spider bearing on the top of the head. This arrangement, reminiscent of an early Renault, doesn't make a lot of sense in the fixed head Curtiss particularly since the pressed steel spider is flimsy. On a number of surviving engines the long studs have been cropped, sometimes crudely, leaving eight short studs to retain each barrel.

Water inlets are brazed in position low on each water jacket. An alarming service manual drawing appears to show an engine being slung on these rather than on the more solid cast lower bands on the barrels. At the top, water outlets form part of each rocker standard and are con-



Top View showing inlet manifold, cooling plumbing and water pump above carburettor.

nected by rubber tubes to one another and finally to the radiator top tank.

The elegant camshaft driven double outlet water pump has a separate bypass to a water heated inlet manifold carrying a twin choke updraught carburettor. The manual warns against airlocks while filling the system; a pressure filler of the type familiar to owners of mid-engined, front radiator cars might be a good idea. Notoriously, the packed gland of the pump is directly above the carburettor, into which it drips. Pump glands were a common nuisance right up to the R-R Merlin. At least the Curtiss layout was an improvement on the original U-16 Bugatti whose incontinence was hidden by allowing leakage to pass directly into the sump.

Integrally cast valve guides offered savings in manufacturing cost; the downside is that badly worn guides meant a scrapped barrel. This isn't wholly unreasonable, since the engines weren't built to last forever. Standard guides wear fairly quickly; Leslie C Miller, President of the south California Miller Airplane Products, (not Harry A Miller of twincam fame) supplied the postwar aftermarket with a screw-in valve guide conversion and replacement seats. A photograph shows a barrel mounted on an angle fixture for milling out the original guide and threading the casting to take a replacement.

The Zenith Carburettor

The Curtiss manual is short and to the point. "If adjustment is found necessary it should be attempted only by one thoroughly competent and strictly according to the instruction pamphlet issued by the manufacturer of the carburettor." Helpfully, "A lost or damaged pamphlet will be replaced on request." Obviously, one would have thought, "It will be well to give the name and model of the carburettor when making enquiry."

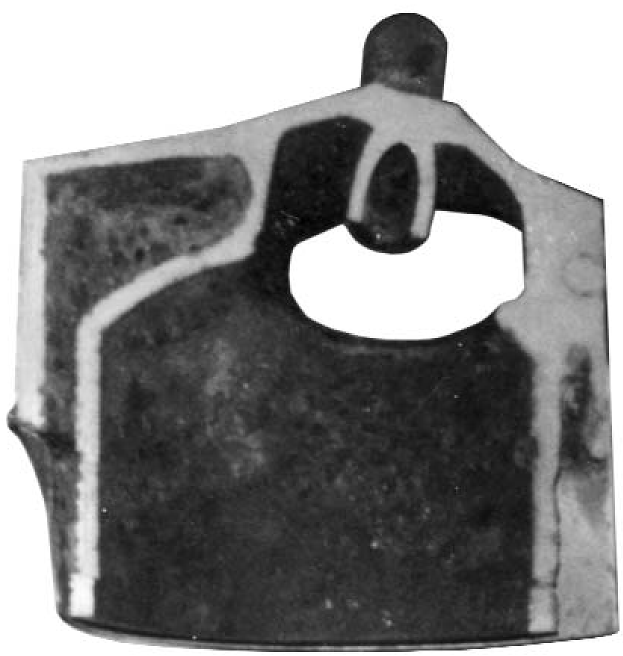
Luckily A. L. Dyke, best known for his automobile encyclopaedia, produced *Dyke's Aero Engine Instructor* which gives a reasonably complete OX-5 specification and valve and ignition timing instructions. It also includes full details of the standard 1.5in. Zenith O6DS twin barrel carburettor.

Dyke makes it clear that the venturi and main, compensating and idling jets should be set and left alone. Slightly different settings are specified by Dyke and by Curtiss in the official parts list:

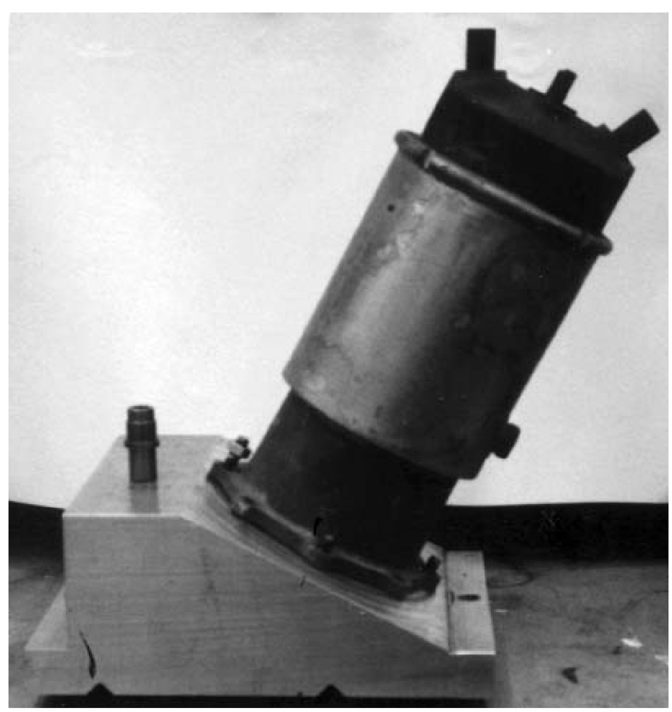
	Venturi	Main Jet	Compensating Jet	Idling Jet
Dyke	22	120	100	70
Curtiss	22	120	100-110	78

Float chamber fuel level:

below top of main jet 1/32 in.
below top of bowl 1 9/64 in.



Sectioned barrels show careful core positioning and thin wall iron casting. The US is consistently better at iron casting than the Brits.



A cylinder barrel on an angle fixing ready for machining out the integral valve guides.

The only adjustment is the idling setting, controlled by a pair of screws on the side of the barrels. Screwing IN richens the idling mixture. Extra fuel drawn from the compensator jet well richens the mixture under sudden acceleration.

The main difference between the OX-5 instrument and conventional automotive Zeniths is a hand controlled altitude (mixture) control valve. This consists of air inlets just above the choke tube on each barrel containing a small throttle valve operated by a single control. Opening the valves as the aircraft gains height reduces suction on the main jet and weakens the mixture.

The *Aviation* article on maintenance at Parks Air College mentions modifications. The needle valve is checked particularly carefully and replaced if there are any signs of wear. Pessimistically, the float is always replaced. Float weight pivot pins are soldered for security.

A 3/32 in hole is drilled above each throttle valve to richen the idle mixture and prevent cutting out when the throttle is fully closed. Altitude valves are plugged with corks and lockwired for a delightfully pragmatic reason: "— a plane equipped with an OX-5 engine seldom gains sufficient altitude to make use of it."

OX-5 Problems

The fact that the OX series ran quickly to Dash Five might suggest steady development. In fact the basic design was retained and the same relatively minor service problems continued.

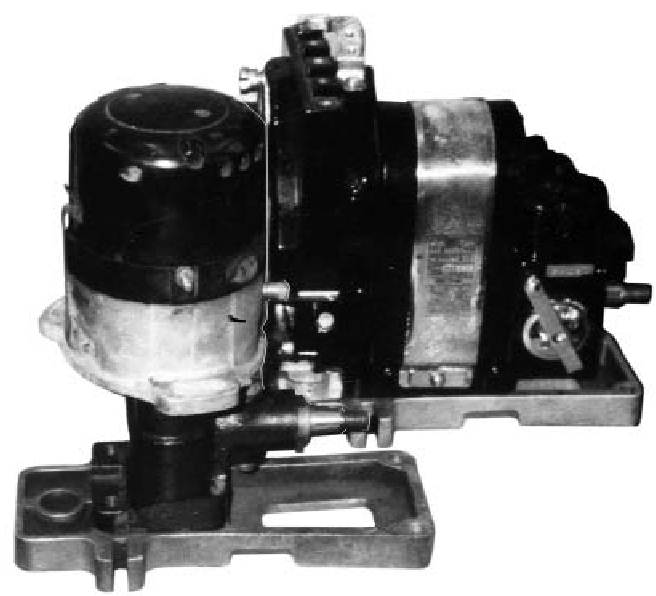
The most generally recorded problem is water pump leakage into the carburettor, mounted directly below the pump. To be fair, nobody cracked the water pump gland problem until the development of reliable carbon face seals. Even in 1949 intercooler pump gland leakage on civil Merlins was grounding BOAC Argonauts (DC-4) and causing grief to Hives and his engineers, who "solved" the problem by defining an acceptable rate of leakage and topping up the system. Modern OX-5 owners could well bolt on a deflector and take the R-R policy line. Car users will, of course, have relocated the carb.

Single ignition really wasn't a good idea, particularly if it was a Dixie, guaranteed to fail early and at quite the wrong moment. It appears that development of the twin magneto OXX was spurred by the US Navy, which wasn't keen on one instrument of doubtful reliability. As we have noted, Parks Air College didn't think much of OX-5 auxiliaries. A standard mod was to dump the Berling contact breaker and remachine the taper to take a Bosch ZU assembly. An alternative developed by current owners is neat right angle gears driving V-8 distributors, saving a great deal of cost and weight.

Contemporary reports say the OX-5 vibrated. Today's UK car users say it doesn't. It would be interesting to hear from a current Curtiss JN-4 pilot with a soundly rebuilt engine and well balanced propeller.

The fact is that any single plane (flat) V-8 crank has by definition a horizontal transverse couple which may not matter too much at the relatively low speeds involved. The option of a 90° crank wasn't available for the excellent reason that nobody seems to have thought of it. To digress, the V-8 was well established by the time the Curtiss O series was designed. Five years earlier Darracq had built what is probably the world's first 200 hp engine and the lovely Antoinette was ready to fly. It was 1926 before Cadillac took the smoother 90° route and 1932 before Ford commercialised it. In any case the flat crank is much cheaper, lighter and simpler to make than the right angle arrangement, and what's good enough for Birkigt's Hispano and Keith Duckworth's DFV is good enough for me.

Valve trains were problematical, as shown by the popularity of the Miller retrofits. The issue of valve train design and manufacture is discussed later.



Front: A neat modern angle drive and distributor. Behind it, the much heavier and less reliable magneto.

Finally, there is the whole question of quality control. Sir Roy Fedden's remarks on a batch of 250 engines overhauled (or remade) by Brazil Straker, originally in the 1966 centenary journal of the Royal Aeronautical Society, have been widely quoted:

" — some with broken drills still in the oil holes of the crankshafts –"

" — others with an unbelievable amount of rubbish in the crankcases — including a dollar bill –"

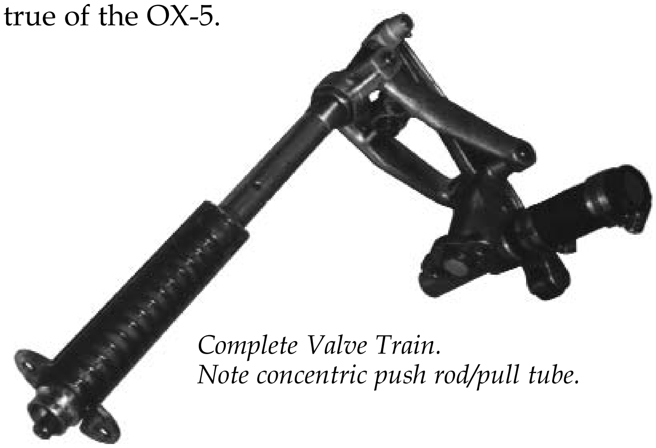
He may have had a point. Early in 2004 the writer warned one UK enthusiast to look out for bad workmanship and build quality on his newly acquired OX-5. He rang,

"You were right. Either crap workmanship or sabotage."

"Oh Dear" (or words to that effect) "What's wrong?"

"There's a main bearing cap and stud floating around in the crankcase. But it doesn't matter, it's a spare. All the caps and so on are where they're meant to be."

Modern commentators have suggested sabotage, the traditional cry when the real trouble is rotten training or manufacturing practices. In the case of the Liberty it seems that there may have been some truth in the accusation; the German tradition of workmanship had resulted in a good number of sympathisers on engineering shop floors who were hardly likely to do their best on engines destined for the allies. The same may be true of the OX-5.



Complete Valve Train.
Note concentric push rod/pull tube.

Valves removed for checking. Several show deckled outer edges, a sure sign of inclined valves floating and touching.

In reality the OX-5's early reputation for unreliability may have stemmed from its success. Aero engine manufacture was widely subcontracted, with some suppliers having no idea of the quality control requirements of aero engines. Getting the Liberty and Hispano into production was equally fraught; some licensees simply gave up, unable to meet the standards required. Managing dispersed production was only really solved during WW2, with a highly developed system of manufacturing quality control in the "shadow factories" building Rolls-Royce and Bristol engines.

To compensate for all this, the OX-5 had very real virtues. It was cheap to buy and maintain. The separate cylinder design made it easy to deal with piston or valve trouble. A favourite barnstormer trick was to unbolt a cylinder and put it on a fencepost to hold the valves up while work went on. Like the Model T, it was ubiquitous; you could always find bits and someone who knew how to fit them.

Was it Overweight?

Various later references knock the weight of the OX-5.

"Excessive –" (Gilbert)

"Heavy, short-lived –" (Herschel Smith)

These thoughts were presumably in comparison with other WW1 engines. But were they fair? To check, we should look at a weight table for the OX-5 and its contemporaries.

Type	Design Date	HP	Capacity litres	Weight lb	lb/l	lb/hp
Curtiss OX5	1913	92	8.30	390	47.0	4.33
Renault 80hp	1910	80	8.80	462	52.5	5.78
Peugeot L112	1916	200	11.31	802	70.9	4.01
Hispano 8A	1915	150	11.76	418	35.5	2.78
Liberty L12	1917	400	27.06	845	31.2	2.11

WW1 spurred development from the relatively crude air cooled Renault V-8 to the state of the art Liberty "consensus engine", included for the sake of comparison. The odd engine out is the Peugeot, a high speed (2,000rpm) V-8 using the twin OHC technology developed with outstanding success by the company in its prewar racing cars. Cast iron construction throughout, two massive twin-cam heads and generally complex design made it impossibly heavy. Despite its output the offer of a license was turned down flat by the US purchasing commission in favour of the Hispano.

The OX-5 comes out rather well. In absolute terms it is the lightest of the widely used engines. Weight per litre capacity isn't bad, although it can't really compete with the expensive sophistication of the Hisso. Where the OX-5 falls down is in the key horsepower to weight ratio; good by the standards of the prewar period but hopelessly outclassed by the next generation. In other words, we asked the wrong question and must conclude:

- The OX-5 certainly wasn't overweight by absolute standards
- Its power to weight ratio was better than average pre-WW1 but useless for combat aircraft by 1917
- The answer was more power

Could it Have Been Lighter?

In general the OX-5 was built light. The crankcase is nicely proportioned and the crank weighs a very reasonable 43 lb (19.5 kg). Journals are hollow but don't follow the extravagant Mercedes practice of progressively reducing the diameter of the centre bore towards the drive end. The saving can hardly have been worth the trouble. Light alloy pistons and almost straight sided H-section rods weigh roughly 4 lb (1.8 kg) per set with gudgeon pin. Weight could be reduced, but not enough to make any impression on the weight of the engine as a whole.

Barrels are perhaps lighter than one would expect at only 12 lb (5.45 kg) for a single 1,030 cc (63 cu in) unit, which compares well with 19.25 lb (8.75 kg) for a single 2,458 cc (150 cu in) welded steel Mercedes barrel, a vastly more costly and possibly less reliable structure. As will be seen on the section, the Curtiss casting is thin wall with accurately positioned cores; USA standard production iron casting technology has traditionally been very much better than the Brits were able to maintain.

Which brings us to a third conclusion: the OX-5 was as light as the state of the art allowed.

The Big Valvegear Question

The OX-5 combustion chamber shape is attractive. It is close to a hemisphere, with two valves per cylinder at an included angle of about 55° and commendably clean porting.

A great deal has been written about hemispherical combustion chambers, much of it rubbish. The great Sir Harry Ricardo summed it up, saying that the ideal chamber would be a true sphere but only if the point of ignition was at the centre. His practical solution was of course the hemisphere. Combustion benefits apart, this allows inclined valves whose size is not directly limited by the length of the combustion chamber. One downside, as can be seen from the photo of valves removed during overhaul, is that if the engine is over-revved the valves can touch and be damaged.

To digress yet again, piston projection in a high compression hemispherical head can produce a combustion space the shape of a warped piece of orange peel, which is not quite what Sir Harry had in mind.

Operating the necessarily inclined overhead valves in a hemispherical combustion chamber isn't simple. The best answer is twin OHC, but this tends to need large, heavy castings and expensive drives. The WW1 twincam V-8 Peugeot is less than 30% larger capacity than the OX-5 but almost exactly double the weight. Pushrods are possible; one of the neatest V-8 angled pushrod implementations was Chrysler's famed Hemi of the '50s but it was heavier than the competition. Most builders of inline engines ducked the issue by sticking to vertical valves, while pushrods were simple and practical as one-pot-at-a-time implementations on radials.

Earlier Curtiss developments led logically to the definitive OX-5 valvegear. The gear driven camshaft was in the expected position within the cylinder V. Coaxial cam followers ran in a bronze guide for each cylinder. Exhaust cams were conventional, with one either side of each a matched pair of inlet cams which can best be described as circles with a flat on them.

The central exhaust follower was solid and surrounded by a tubular inlet follower pegged to prevent rotation and slotted to form a pair of fingers which tracked the twin inlet cams, whose maximum radius was the same as the radius of the exhaust cam at its highest point. This prevented the exhaust and cam inlet follower from getting tangled up.

Both rockers were carried on a single standard at the centre of each head. The exhaust valve was operated through a perfectly ordinary pushrod and a long rocker spanning the head. A clevis at the rocker end avoided the possibility of a pushrod jumping out of its cup.

The inlet valve was actuated by a coaxial pull tube surrounding the exhaust pushrod and attached at the top by a pivoted crossbar to an H-shaped light alloy rocking arm which bore down on the inlet valve. An external compression spring attached to the crankcase by a pressed steel stirrup maintained downward pressure on the pullrod and inlet cam follower.

As the inlet cams rotated the follower arrived at the flat section and was depressed by the external spring, opening the valve. Further rotation lifted the follower and pullrod against spring pressure and allowed the valve to close.

To summarise this rather odd process:

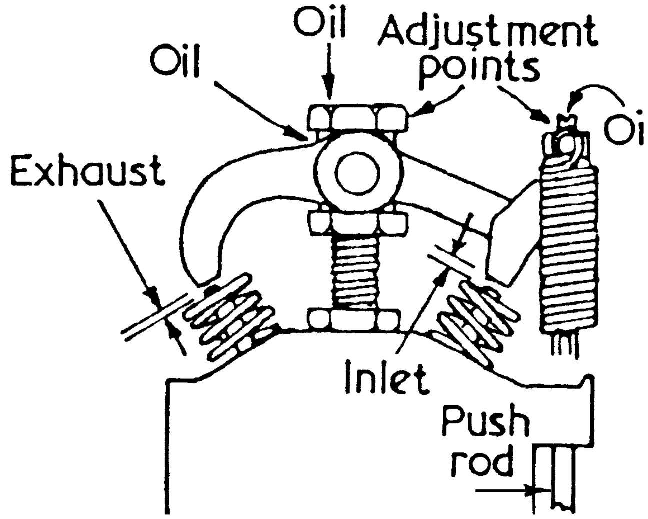
• The exhaust cam, pushrod and valve spring mechanism is completely conventional.

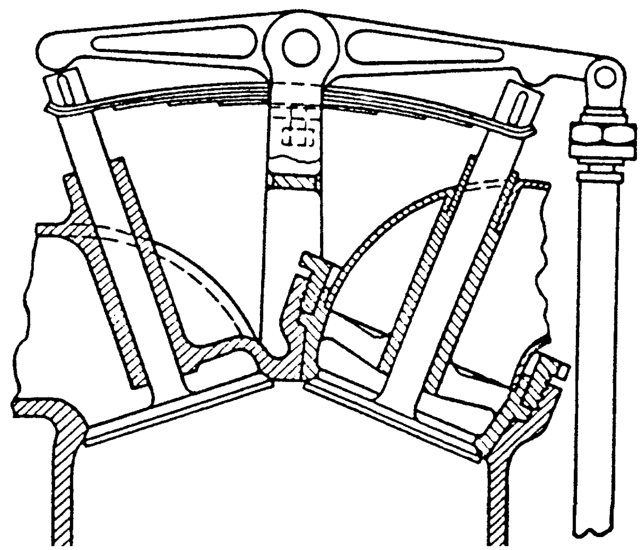
• The inlet valve spring is very light; its only function is to close and seal the valve

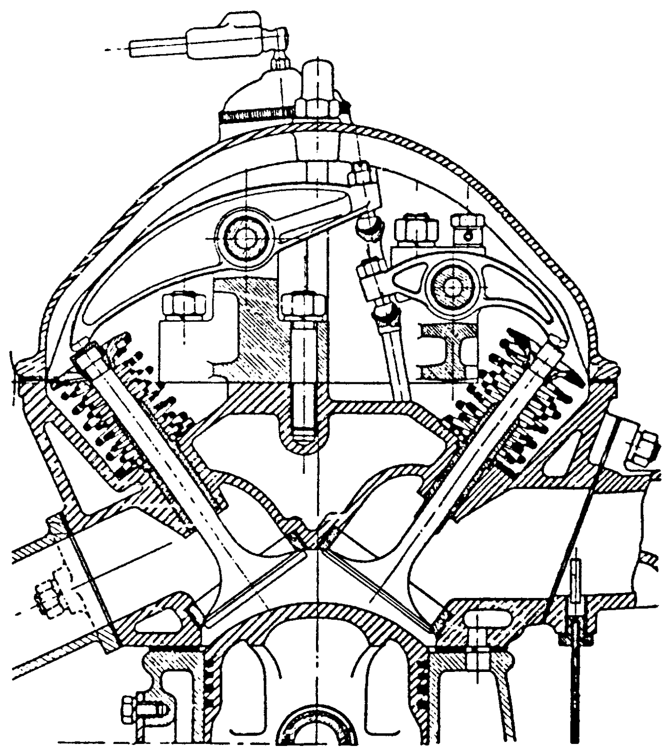
• The inlet cam allows the follower and coaxial pullrod to drop under external spring pressure, pulling down the H-shaped rocking arm and opening the inlet valve. Valve opening is powered by the spring, not the cam.

To add to the fun, the Curtiss parts list referred to the inlet pullrod as a pushrod. Just don't ask.

Both valve springs were slightly barrel-shaped, an arrangement which has no known benefit. Inlet springs were wound with a lighter gauge wire than exhausts. A look at the mechanism will show that the conventional inlet spring, needing to return the valve and maintain seating pressure,







Variations on a theme: Operating inclined valves from a single low mounted camshaft isn't as simple as it seems.

Right Top: Salmson 1921 single pushrod. A large rocker opens the exhaust valve. The pushrod drops on to the base circle of the same cam to let a pair of tension springs acting on a crossbar open the inlet. The design has some affinities with the OX-5 but avoids clevis joints and the added complexity of coaxial valve operating gear. The drawback of these single cam per cylinder systems is the problem of providing valve overlap, not an issue which greatly troubled the pioneers.

Right Centre: A single push-pull rod was used on Curtiss engines prior to the OX series. The design was not unusual at the time. This neat implementation is Austrian Daimler, 1915. A subtlety is the pivoted leaf spring, acting as a helper as a valve is opened and increasing the sealing load on the valve opposite.

Right Bottom: Talbot Lago 1936. A modern implementation with two inclined pushrods. A similar design is used on Chrysler's superb Hemi of the 1950s. A large exhaust rocker is required. Also note the domed piston compromising the hemispherical head shape. Modern systems with enclosed valvegear are highly efficient but need a wide, heavy head casting.

must be weaker than the pullrod spring. Tensions at standard test lengths recommended by Curtiss were:

Spring	**Tension at Test Length**
exhaust valve	35 lb (16 kg) at 1.625 in (41 mm)
inlet valve	16 lb (7.3 kg) at 1.625 in (41 mm)
inlet pulldown	40 lb (18 kg) at 2.750 in (70 mm)

Measured installed lengths on an engine in good condition correlate closely with these standard figures, which should be safe to use when engine building. A very experienced US based OX-5 builder advised a UK owner that accurate setting of spring lengths and loads is absolutely essential for efficient and reliable running.

The whole plot may sound complicated, but it's logical. Exhaust valve operation is obvious; the valve angle means that the rocker has to be longer than one would wish, but it works. The inlet causes mechanical complications because its stem points in the opposite direction. So, instead of pushing the valve, it's pulled; after all, why not?

One reason why not is that it is frankly inelegant. To quote Rinek, "The cluttered valvetrain appearance resembles a series of mousetraps." Aesthetics apart, there are mechanical snags:

1) Poor lubrication — The exposed mechanism has rather a lot of wearing pivots with poor oiling arrangements. Bearing pins for the rockers and clevises are hollow and the book tells us that "minute holes are drilled in alignment with the external holes. As oil is forced [by oilgun] into these external holes the hollow spaces inside the pins act as reservoirs, and will oil evenly all bearings of the rocker arm mechanism for several hours after being filled" - but what keeps it in?

2) Cam wear — The external spring applies continuous loading to the inlet cam/follower interface. Both wear rather faster than in a conventional design, and regrinding is a common repair.

3) Unpredictable valvetrain wear — The pullrod arc is set by the pivot at its top end and involves about 0.040 in (1 mm) sideways movement where the tube passes through the compression spring stirrup. In practice it rubs, introducing unpredictable friction and wear. There is no quick answer to this. The stirrup is purely a reaction point for the compression spring and does not act as a guide. Pullrod and spring are a fairly close fit in the stirrup and there is little scope for a larger clearance hole. Better use could have been made of whip in the flimsy steel stirrup if its mounting studs had been across rather than along the axis of the camshaft, an insight for which the writer is indebted to OX-5 owner Roger Sweet. A hinge mechanism at the top of the stirrup has been tried; a neater answer could be a low friction, perhaps PTFE, washer at the top of the stirrup.

The result is an inefficient valve train with limited life between major rebuilds.

Valvegear Performance

Contemporary accounts confirm that valvegear was the limiting factor for revs and hence power. Manifolding was fairly strangled but not ridiculously so, and the bottom end could certainly handle higher revs. There was no problem with material quality; inlets are in nickel steel and exhausts tungsten steel. Valve sizes and lifts are adequate but timing is typical of the era, as shown by the only slightly more enterprising 150 hp Hispano design. Separate inlet and exhaust cams mean that there is no impediment to valve overlap, but for some reason Curtiss failed to take advantage of this. For comparison, the table shows the OX-5, 150 hp Hispano and typical timing for a conservatively rated passenger car engine of the pre-engine management system era:

	OX-5*	**Hispano**	**"Modern"**
Inlet opens	15.5° ATDC	10° ATDC	18° BTDC
Inlet closes	40° ABDC	50° ABDC	64° ABDC
Exhaust opens	48° BBDC	45° BBDC	58° BBDC
Exhaust closes	3° ATDC	10° ATDC	22° ATDC
Overlap	-14.5°	0°	40°
Diameter **	48.5/1.91	50.0/1.97	
Inlet lift	8.74/0.344	10.0/0.394	
Exhaust	9.86/0.388	10.0/0.394	

* The Curtiss manual allows 3° tolerance on valve timing

** Both engines use same diameter inlet and exhaust valves. Units are mm/in.

Miller Improvements

Miller Airplane Products provided useful retrofits. The big improvement was a more positive lubrication arrangement which added significantly to valve train life. Advertisements offered a "Cincinnati Ball Crank Uniflow Oil Cup", but in practice the package included a slightly deeper section inlet rocker fitted with a hydraulic pattern greaser and drilled oil holes leading to bronze bushes at all wearing points. Regular application of a greasegun was obviously necessary, but the same went for the rocker arms on practically all the popular radials of the '20s.

This was claimed to exclude dirt from the bearings, improve valve train and exhaust valve life and give an extra 25-50 rpm. Practical experience certainly shows real improvements in valvegear life. Miller also claimed 15% better fuel consumption through lower friction, which sounds implausible.

Other improvements were less convincing. A new exhaust rocker made from nickel chrome steel and nickel plated had a hardened roller at the valve end. This probably didn't do much good, since the sliding action at the end of the long rocker was minimal.

Miller Improvements; the Big Question

A more contentious modification was "positive intake valve control". A pressed steel saddle located on the valve guide below the inlet spring was fixed to the rocking arm by a steel crossbar, similar to a boat's rope cleat, retained by a split-pinned (cotter-pinned) nut.

A search of contemporary literature has turned up a single, not particularly good, illustration in the Nicholas-Beazley catalogue but no fitting instructions. The point at issue is that system action depends on how far the inlet valve spring is compressed with the valve closed. Opinions range from an almost coilbound spring to something close to the original installed length.

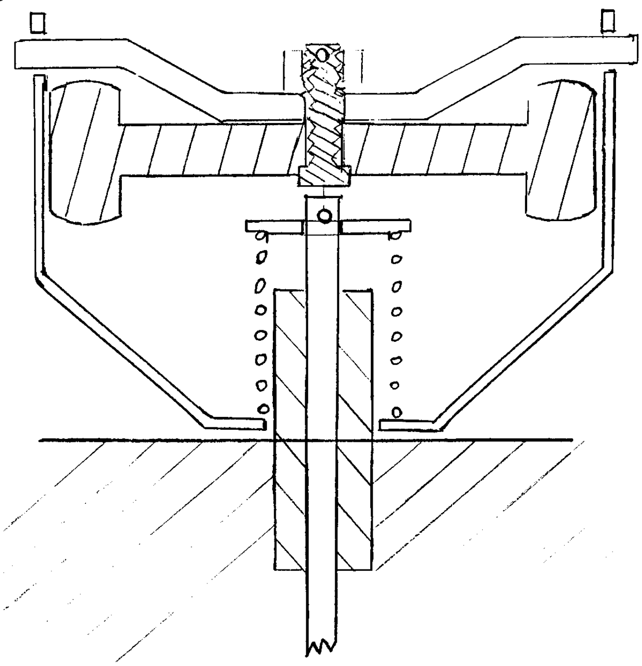
A near-coilbound spring results in a crude desmodromic action. Its only real function is to take up clearances, and in theory it could be replaced by a spacer. We should note that the Ducati Desmo and Mercedes-Benz M196 worked beautifully without any valve springs at all, but relied on impeccable manufacture and assembly.

The alternative is an installation with the valve spring more or less the same length as the standard arrangement and the saddle set just clear of the head casting, as shown in the drawing, with the valve closed. In one sense this continues to provide a quasi-desmodromic action by the positive closing action of the saddle. However, this acts through the valve spring and continues to be subject to valve float whether caused by over-revving or periodicities in the spring. Much the same effect could be achieved by a stronger valve spring.

Either way there are drawbacks. The system upsets the delicate balance between the pullrod spring opening the valve and the valve spring closing it. The inlet spring no longer reacts against a fixed point, leaving the cam to do all the work of closing the valve. The inlet valve and spring are no longer decoupled from the inertia of the heavy rocker and pullrod linkage; good high performance engine practice usually means keeping valve inertia as low as possible.

It would be unfair to comment without knowing more about Miller's underlying theory and installation recommendations but the author's provisional view is that there seems to have been

Inlet rockers, showing the Miller "Positive Action" valve yoke.



Best available data suggests that the Miller "Positive Action" system for OX-5 inlet valves was installed as shown, with the saddle just clear of the head face with the valve seated. It would be helpful if we could see a copy of Miller's original instructions.

a certain lack of clarity of thought. In practice the second option described above and shown in a drawing seems the most likely, if only because it has been used successfully for more than 20,000 miles on the road and racing in the very successful Curtiss Monarch. Reliability of this road equipped competition car was good enough for it to be driven far into France, win an Edwardian race, and come home under its own power.

OX-5 Service and Maintenance

The Curtiss Hand Book dated 1918 is authoritative. In 1928 an unidentified source published an update (Mechanics' Manual) "authorized by the Curtiss Aeroplane and Motor Corporation". A 1925 handbook from Nicholas-Beazley Airplane Co., Inc., a Curtiss sales and parts operation, includes details of Miller parts. Copies of all three are readily available and between them provide all the details for a service schedule:

Hours	Action	Source
0	Clean, install, oil up Check run 3-5 minutes Oil pressure 40 psi @ 500 rpm Oil pressure 60 psi @ 1,400 rpm	1
Before each flight	Oil all rocker arm bearings, inlet pullrod stirrups	2
5	Oil change (3.3 UK gal (15 l) Mobil A clean oil strainer	1
10	Oil change and oil strainer clean, then at 10 hr intervals	1
50	Inspection "To do this properly it must be completely dismantled."	1

Oddly enough no service intervals are specified for valve clearance or spark plug checks.

The Parks Air College repair shop was dedicated to OX-5s and operated its own service schedule. Abut 75 years later, maintenance boss Shedenham comes across as a man with high standards who knew what he was doing, delivering a regular 700 to 1,000 flying hours between full engine overhauls. Time between top overhauls was 200 to 375 hours, with only the most hopeless pilots getting the figure as low as 125 to 250 hours. The secret was a fixed schedule for continuous skilled attention. A mechanic made a daily check on valves, cooling system and points and carried out minor adjustments, handing the aircraft over to a service mechanic for any further repairs. A daily check report was made on each plane.

The regular inspection schedule differed from standard:

Daily	Minor attention as required
15 hrs	Oil change
30 hrs	Oil change, oil strainer clean
100 hrs	Mandatory Department of Commerce Inspection
500 hrs	Engine removed for inspection

A 25psi drop in oil pressure was regarded as a sign of trouble.

This was a highly professional schedule which relied on the daily check. It was probably a good deal more economical in cost and available flying hours than the standard Curtiss approach.

Overhaul meant a 100% strip and action depending on condition. The first step was a check with thin oil under pressure with the engine inverted and the sump off. Leakage at various bearings determined the amount of work to be done. Full bottom end grind and remetal jobs were carried out and cam bearings checked particularly carefully, confirming that wear here can be a problem. As a general rule pistons and barrels were replaced, not bored, which sidesteps the issue of valve guide wear and is all very well when a good stock of cheap replacements is available. Magnetos and carburettors got particular attention since they were known to be significant factors in emergency landings, which were expensive.

Costs are interesting. The service manager estimated rebuilds as costing between $150 and $350, but claimed that outside work could make money at a standard charge of $250, presumably plus the cost of any damaged parts. We can compare this with the Nicholas-Beazley price list in 1925:

	OX-5	OXX-6
Brand new	$1000	$1250
Government overhauled	$600	
Overhauled	$750	
Used, serviceable	$write	$write

At first sight the propsed rebuild service looks a good deal; however, ex-Service engines could probably still be picked up for a pittance if one was prepared to go looking for them.

Uprating the OX-5

First to have a go at the engine was AHR (later Sir Roy) Fedden. His celebrated 1966 RAeS paper claims redesigned oil pumps, induction systems and crankcases (this last a surprise) as well as modified carburettion and ignition. The new manifolds are apparent on an example preserved at the American Air Museum, Duxford. There is more research to be done on this development.

An interesting 1920 byway, presumably addressed to the post-WW1 civil market, is the Tank air cooled engine built by Milwaukee Parts Corporation. According to Kim McCutcheon, AEHS President, this used only the Curtiss crank and rods. Photographs show a crankcase which differs significantly from the Curtiss model. Apparently a few still fly.

Of course there is still scope for development, but why? The engine works perfectly well and is an historic artifact. Who are we to mess about with it almost a century later?

One answer is that non-aero use as pioneered by Curtiss himself inevitably calls for longterm reliability between maintenance work.

It's probably worth sending oil direct to the main bearings with a secondary supply to the cam, and fitting an external full-flow filter which, together with frequent oil changes, has proved to be the most effective way of extending the life of classic high performance engines. The writer's almost identical modifications on a competition OHV development of the Model B Ford proved highly successful.

Obvious minor changes would help: modern oil seals, carburettor in the V, lighter, more reliable and fully controlled coil ignition, and better water pump sealing. Anyone worried about torsional vibration could reflect that viscous fluid dampers are untuned and should be able to deal with the various critical orders thrown at it by a flat crank V-8.

The most important exercise, of benefit to all owners, would be thorough computer analysis and simulation of the cam forms and valve train. It is only in the past ten years or so that a combination of cheap computing power, graphics programs, and above all modeling and simulation software has made it practical and economical for amateurs to simulate the action of a complex mechanical train under almost any conditions. One UK enthusiast has already built a basic test rig. This has to be the way forward, and there is every reason to think that an optimised system could greatly improve engine life as well as efficiency.

Envoi (Postscript)

Was the OX-5 a sound engine doing a good job, or an overweight dog? It's rather like the Model T or the VW Beetle—unesteemed at the time, built in vast numbers and the basis for some very sporting machines. The OX-5 soldiers on in Jennies and propels lightweight chassis, usually US-origin, up UK speed hillclimbs in times pre-WW1 Grand Prix cars can only dream of.

Rather than reopen old arguments, let's just say that it carries on giving a lot of pleasure to an awful lot of people. It's far too early for the old girl's epitaph, but it should be the same as Sir Christopher Wren's: Si monumentum requeris, circumspice.

So many people have contributed to this paper that it's impossible to mention them all. Particular thanks go to Larry Rinek, US guru and author of a valuable SAE paper; UK bibliophile Jamie Fairchild; Mark Walker and Duncan Pittaway, OX-5 racers and godfathers of the UK OX-5 renaissance; and Roger Sweet, who let me examine and photograph a stripped engine and made valuable comments.

This previously unpublished clearance table of unknown US origin was made available by Roger Sweet and checked against Curtiss figures with no significant variations. All dimensions are thousandths of an inch (0.025 mm) unless otherwise marked.

Valve guide inlet	0.002
Valve guide exhaust	0.004
Valve seat width	1/16 in
Tappet clearance inlet	0.010
Tappet clearance exhaust	0.010
Rocker bearing pin	0.0075
Piston at top land	0.017- 0.021
Piston at second land	0.011-0.015
Piston at skirt	0.008-0.012
Gudgeon pin in piston	Press fit cold (12 lb) (5.4kg) tension to move
Gudgeon pin in little end	Medium drive fit
Bigend	0.0015-0.003
Main bearing	0.0015-0.003
Camshaft in bearing	0.001
Camshaft bearing in case	0.001
Thrust bearing in case	0.002
Thrust bearing on crankshaft	0.000
Timing gear tooth clearance	0.010
Oil pump gears end play	0.0015
Water pump bearings	0.0015-0.0035

Zenith carburettor data — Twin choke Type 06DS	
Venturi diameter	22mm
Main jet	120
Compensator jet	100-110
Ignition	Berling magneto D-81-X2
Firing at full advance	28° BTDC (3/8 in piston travel)
Breaker points gap	0.018-0.020
Plug gap	0.025

Cylinder numbering
Propeller
7—8
5—6
3—4
1—2

The Curtiss Hand Book includes an instruction and fault finding section with the main headings: Important Don'ts; Skipping or Irregular Operation; Lost Power and Overheating; Noisy Operation. It's all good sound stuff which adds little to our knowledge of the engine.

Note on Sources

Original Curtiss Aeroplane and Motor Corporation material, in particular the 1917 Parts List and 1918 Handbook, form the factual basis for this paper. They and other material were supplied efficiently and economically by www.esscoaircraft.com.

Glenn H Curtiss: an early American innovator in aviation and motorcycle engines: Larry M. Rinek (SAE Technical Paper Series 940571, ISSN 0148-7191, SAE 1994) provided valuable historical information.

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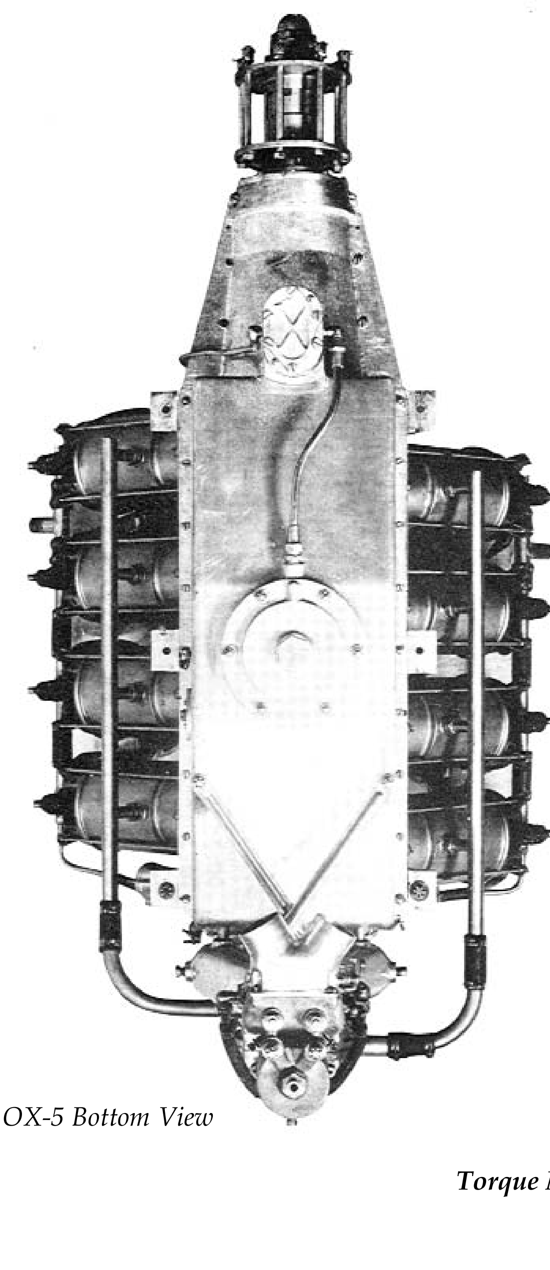

OX-5 Bottom View