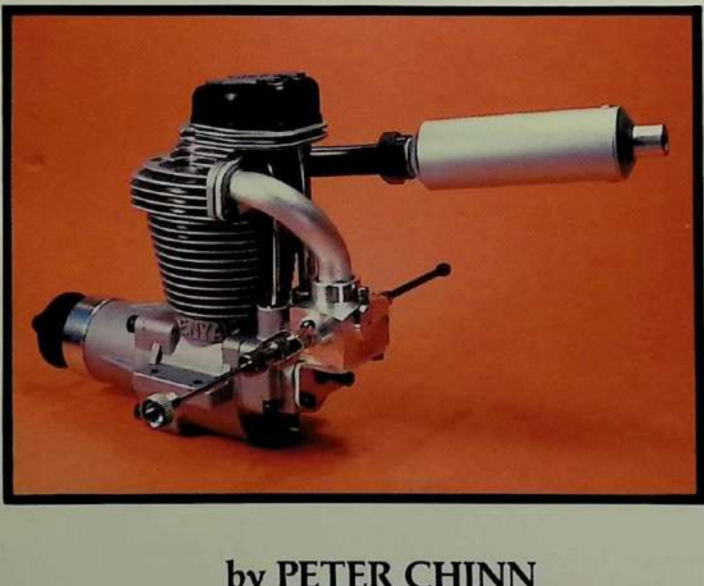
From the Publishers of Model Airplane News

Model Four-Stroke Engines

The History, Design, Development, and Operation of Model Four-Stroke Engines



by PETER CHINN

An Air Age Publication

THE AUTHOR

No one is better qualified to write and illustrate a book on model engines than Peter Chinn. For more than thirty years he has enjoyed an international reputation as the most widely read technical writer in this field. His articles have been published all over the world and translated into a dozen different languages. His ability to make technical matter comprehensible through easy-to-read texts, supported by meticulously prepared illustrations, is universally acknowledged. His reports on contemporary engines, highly regarded by readers and manufacturers alike, have been a feature of *Model Airplane News* magazine since the early nineteen-sixties.

The author's introduction to model building began just before WW-II when, as a schoolboy, he built—as did many others at that time—flying-scale kit models by Comet and Cleveland. An equally early fascination with internal combustion engines stemmed from his father's previous connections with the automotive industry (Renault, Talbot, and General Motors) but youthful hopes of combining these two interests in the shape of real "gas models" had to wait until after the war. His first engine, custom-built during army service in 1946, was tested out while aboard a motor-launch off the island of Giudecca in Venice. While in Italy, he also bought three early Italian diesels and these were followed by many famous American spark ignition and glowplug engines of the period: Arden, Atwood, K&B, McCoy, Dooling, etc. In 1949, to satisfy his curiosity about engine performance, he built his first test rig and began horsepower testing contemporary two-cycle motors. Subsequently his findings were published in one of the hobby magazines: as a result, he was asked by several manufacturers to carry out prototype testing and by the magazines's editor to contribute a regular series of reports.

Since those days, countless numbers of engines of all types have passed through Peter Chinn's hands and about six hundred have been the subjects of published test reports. He was the first to introduce readers to many new developments, including Wankel engines in the nineteen-sixties and the first production four-strokes in the 'seventies. His continuing interest in miniature engines is illustrated by a personal collection of over a thousand examples, both veteran and modern, charting half-a-century of progress, from Bill Brown's famous Brown-Junior lightweight two-stroke to the sophisticated multi-cylinder four-strokes of today.

ACKNOWLEDGEMENT

This book would not have been possible without the interest and cooperation, over many years, of numerous members of the model engine industry. The products of some of them are dealt with in these pages but thanks are also due to the many other manufacturers who are not engaged in four-stroke engine production, but whose two-stroke motors have been the source of a great deal of background experience in small i.c. engines generally.

Special thanks are due to those companies and individuals who have provided illustrations of prototype and non-production designs and the author would also like to put on record his indebtedness to Ian Munday, professional photographer, who was responsible for skillfully and painstakingly processing most of the photographs that appear in this volume.

P.G.F.C. 1986

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Model Four-Stroke Engines

by *Peter G.F. Chinn*

A Complete Guide to the History, Design, Development and Operation of Model Four-Stroke-Cycle Engines, including an Appendix with Specifications, Performance Data and Installation Drawings

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INTRODUCTION

It has been suggested that the four-stroke-cycle engine is the most exciting thing that has happened in the world of radio-controlled models since fully proportional control systems appeared in the nineteen-sixties.

It is certainly true to say that, so far as commercial developments are concerned, the emergence of the model four-stroke motor is a milestone that also ranks in importance with the first quantity-produced model two-cycle gasoline engines in the nineteen-thirties, the first compression-ignition and glowplug engines in the Forties and the first multi-channel radio-control systems in the Fifties.

Curiously, although four-cycle engines soon gained acceptance in Japan, where quantity production started in 1976, and in Great Britain and Western Europe, where four-strokes were also being manufactured, they made relatively little impact in the United States during the first few years. Since that time, however, with the range of four-cycle engines greatly expanded to include larger and more powerful types, the interest in four-strokes has intensified and nowhere more so than in the U.S.

Much progress has been made. One can now buy engines ranging in size from 3.5cc (0.20 cu in.) piston displacement to over 50cc (3.0 cu in.) and weighing between nine ounces and more than six pounds. In the case of the medium and larger sizes, engines are available with two or more cylinders, presenting much more realism in appearance and operation than the conventional single-cylinder two-stroke motor.

"Four-Cycle" or "Four-Stroke"

What is a four-cycle engine and which is correct, "four-cycle" or "four-stroke"? These terms relate to the working principle of the engine. In a two-stroke motor, the piston completes two strokes, one up and one down, for each cycle of operations. In a four-stroke, the piston completes four strokes per cycle. From this, it is clear that, to be precise, one should refer to *two-stroke cycle* and *four-stroke-cycle*. If these lengthy terms are to be shortened, it can be argued that "two-stroke" and "four-stroke" are more correct than "two-cycle" and "four-cycle" although the latter terms have been in common usage in the U.S. since the earliest days of internal combustion engines. "Two-stroke" and "four-stroke" are more familiar in the U.K. and elsewhere, although many British engineers have habitually referred to "two-cycle" and "four-cycle" in written works. Conversely, the use of "stroke" has become much more readily accepted in North America since the influx of foreign two-stroke motor cycles a few years back.

All of which boils down to the conclusion that, while "two-stroke" and "four-stroke" may be considered more correct, the alternatives are accepted usage and both terms, therefore, will be used in this book.

The technical differences between two-stroke-cycle and four-stroke-cycle engines are dealt with in Chapter 2.

Four-Stroke v. Two-Stroke

There remains the question: why have four-strokes suddenly become popular? The vast majority of model engines manufactured during the past half-century have been of the two-stroke type, so what are the advantages of four-stroke-cycle operation?

As we shall see in the next chapter, four-stroke motors are not completely new to the model scene. Amateur-built four-strokes were in existence long before two-strokes came onto the market in the early Thirties and commercially-produced four-strokes were offered from time to time over a period of more than thirty years before the first examples of the present generation of such motors were introduced.

The two-cycle model aircraft engine, as it first appeared from various American manufacturers during the nineteen-thirties, was simple, light in weight and, most important, relatively inexpensive. No model four-stroke could have competed with the two-stroke on such terms at that time. During the years since World War-II, two-stroke motors have been developed to cover the requirements of a wide variety of different applications, ranging from lightweight free-flight models to 200 mph control-line speed machines; from basic trainers to sophisticated, high-powered, aerobatic and scale radio-controlled aircraft.

In fact, the vast expansion of the hobby of model flying, world-wide, could not have taken place without the two-stroke motor, but it has been the immense growth, since the late

Sixties, of radio control, both in popularity and in sophistication, that has actually been mainly responsible for the emergence of the four-stroke motor.

Noise

The reason why, in the Seventies, manufacturers began to take another look at four-stroke motors was, very simply, the sheer noisiness of the two-stroke engine. For many years, complaints, by the general public, had been growing, concerning the noise created by model aircraft and had often resulted in modelers being banned from popular flying sites. The introduction of mufflers, first in Europe and Japan and later in the United States, did little to alleviate the problem because, at the same time, engines were becoming more powerful and faster-running to cope with the demands of more advanced models and pilots' greater skills. R/C flyers were also becoming more and more numerous and the advent of crystal-controlled R/C equipment enabled several modelers to operate their planes simultaneously, in the same area, adding further to the noise problem.

The four-cycle engine is inherently much quieter than the two-stroke for a number of reasons. Firstly, because the four-cycle motor has a power stroke only every second revolution, firing intervals are halved for a given crankshaft speed. This means that the exhaust frequency is also halved, compared with the intrusive high-pitched whine of the two-stroke. Secondly, the exhaust gases of a four-stroke are released more gradually over a much longer period, thereby lowering overall noise level. As a result, a four-cycle engine, even *without* an exhaust muffler, is usually less offensive than an equivalent displacement two-stroke fitted *with* a muffler. Finally, when a four-stroke is equipped with a muffler, the muffler does not need to be so large, yet will cause less power loss and provide more effective noise attenuation.

Realism

The lower pitched exhaust note produced by a four-stroke is not only less irritating; it is more "realistic" in that it is closer to the sound of a full-sized propeller-driven aircraft. Most model enthusiasts also experience a certain satisfaction in operating an engine that has such full-size aero-engine features as camshafts, pushrods, valves and rocker-arms, even though these may not be actually visible. Moreover, when, in addition to these characteristics, the engine has two or more cylinders instead of the customary one, the resemblance to a full-size engine is further enhanced: we are now close to possessing a true reduced scale working replica of an aircraft engine, not just a power unit for a model plane.

Cost

What about the four-stroke's disadvantages? Obviously, it has some. There are a lot more parts in a four-cycle engine (an exception can be claimed for the simplest type of rotary-valve four-stroke) and, consequently, a four-stroke is usually more expensive than a two-stroke of similar size. Since it has more components and also because it is more susceptible to internal corrosion if neglected, the four-stroke will call for a little more care and attention from its owner. However, just because it has more parts, does not mean that there is more to go wrong: most four-strokes are very reliable and, as they generally run cooler, working parts often last longer than the equivalent components in two-stroke motors.

Power

So far as power is concerned, a high performance two-stroke, of the same displacement, will still develop a higher output than the most powerful four-stroke available at the present time. Nor is it true (as is sometimes said) that the four-stroke is a "high-torque" engine. The four-stroke will achieve a higher cylinder pressure, due to the fact that its cylinder is more completely filled with combustible gas during the induction stroke, but its actual mean torque is halved, compared with the engine's brake mean effective pressure, because there is only one power stroke for every *two* revolutions of the crankshaft.

The presumption that more torque is developed by a four-stroke engine undoubtedly stems from the fact that larger props are usually recommended for four-strokes than for equivalent displacement two-strokes. This is simply a case of matching prop size to the performance characteristics of the engine. A reasonably powerful four-stroke may reach its peak horsepower at, say, 12,000 rpm, whereas a two-stroke may need to turn at 16,000 rpm, or faster, to reach its peak and, to approach such a speed, the two-stroke will need a significantly smaller diameter propeller.

Actually, this is not the whole story because aerodynamics also enter into the equation. Except for small racing models (and, more especially, ducted-fan models, wherein the engine—invariably a high-speed two-stroke—turns a small diameter fan within the fuselage at 20,000+ rpm to simulate a jet engine), it is better to have a relatively large prop than a small one turning faster. This applies especially to certain scale models where a relatively high wing-loading and, possibly, a bulky and drag-producing shape, means that maximum available thrust is more important at take-off and medium flying speeds, than at very high speeds. This explains why a four-stroke will fly some models just as satisfactorily as a two-stroke that may be rated at 30 to 50 percent greater peak bhp.

At this point, it should be noted that, performance-wise, the two-stroke may still have the last word, inasmuch as it is now possible to purchase a reduction-geared two-stroke that combines the advantages of high specific power output with the ability to turn a very large prop. Geared two-strokes, however, remain noisy and have not attracted a great deal of interest to date.

Future Development

The first five or six years of quantity production of model four-cycle engines was a period that saw the establishment of the four-stroke as a quiet and fascinating alternative to the two-stroke, mainly suitable for sport type models. In 1982, however, things began to change. A "second generation" of model four-strokes has appeared on the market since that time; engines in which more attention has been given to power output. Specific horsepower figures have increased by as much as fifty percent and are still rising.

These increased levels of performance have mostly been achieved by improving the engines' breathing via increased valve lift, enlarged valves and ports and improved combustion chamber shapes. Not surprisingly, these changes have also brought about higher noise levels and it is essential to use mufflers with the more powerful modern four-strokes.

Concern has been expressed that, if this course of development continues, there is some risk of four-strokes becoming as noisy as two-strokes, thereby destroying the very foundations on which the success of the four-stroke was originally built. Fortunately, as we have already pointed out, the four-stroke will always enjoy the advantage of a lower-pitched exhaust note and, so far as actual sound levels (i.e. decibel readings) are concerned, these can be kept under control with the development of the effective muffler systems to which the four-stroke cycle engine so readily lends itself.

CHAPTER 1

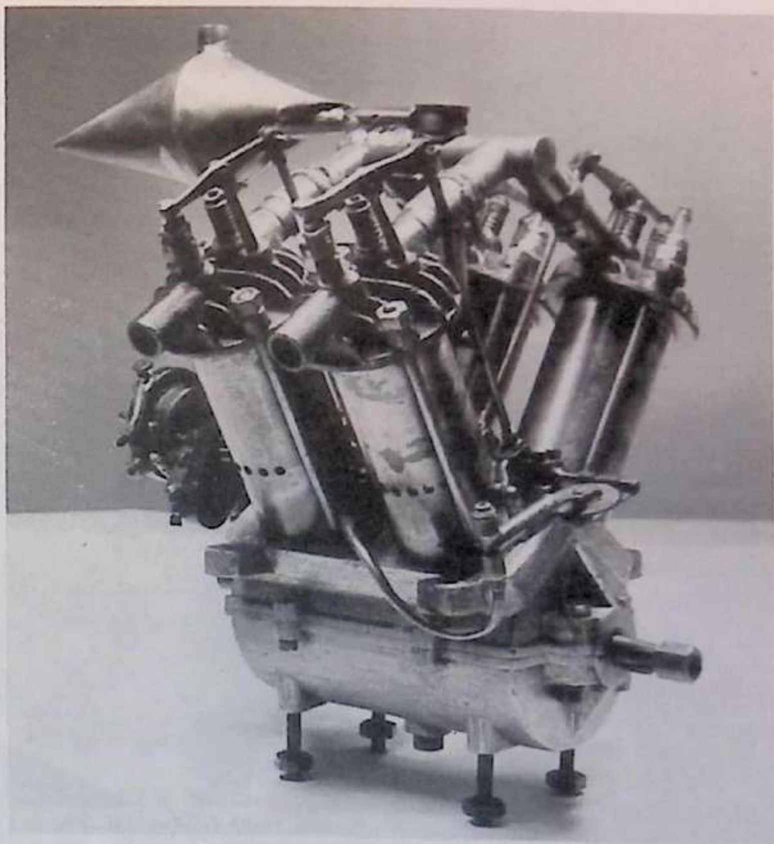
History and Development

IN THE BEGINNING

In 1907 an English automobile engineer, David Stanger, designed and built a four-cylinder vee-type four-cycle engine that was one of the first internal combustion engines to be used in a model aircraft. A couple of years later, at about the same time as a young man named Arden* was making pioneering flights in America with a single-cylinder motor, Stanger was flying his V-4 in an eight-foot span biplane. Stanger's model weighed 21 pounds and, according to contemporary reports, flew successfully for short durations.

The "short durations" were undoubtedly just that — to be counted in seconds rather than minutes — but their brevity was more likely due to inadequate inherent stability in the aircraft and to a need to contain flights within a reasonable straight-line distance, than to lack of engine performance. Remember, all heavier-than-air machines, model and full-size, were still in their infancy at that time. Later, Stanger installed the same engine, driving a 30-inch diameter propeller at 1,600 rpm, in a 10-foot span monoplane weighing 20 pounds.

In 1914, David Stanger established the first officially timed record for a gas engined model aircraft with a flight of 51 seconds. Made in the presence of Royal Aero Club observers, this flight actually stood as a British record for the next eighteen years until broken by the late Lieut. Colonel (then Captain) C.E. Bowden in 1932. The engine used by Stanger for his record model was a vee-twin, similar in design to the V-4, but its smaller displacement and lower weight had enabled him to build a lighter model. This was a canard biplane with a span of 7 feet and weighing just under 11 pounds. The engine turned a 22 inch diameter prop of 18 inches pitch at approximately 2,000 rpm.

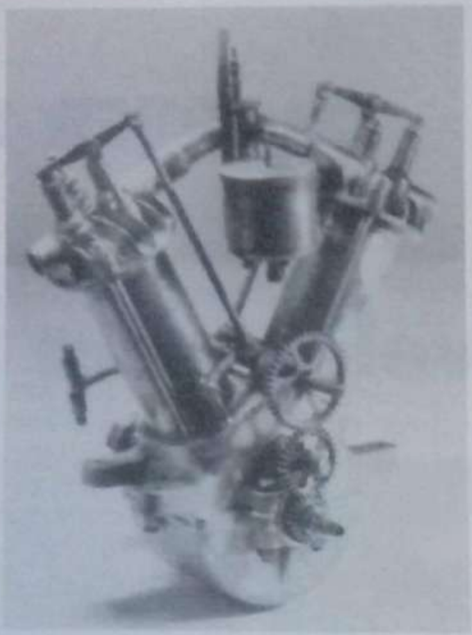


Stanger Vee-Four—1907

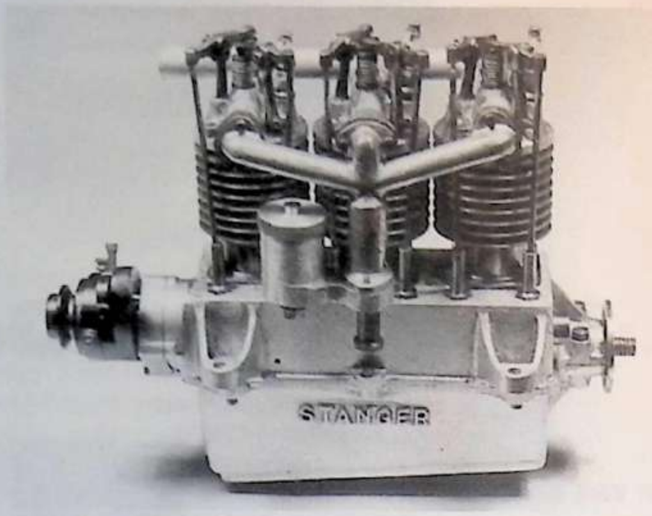
Interestingly, although the simple crankcase-charged two-cycle type engine was to be the norm for model aircraft for the next sixty years, both those early Stanger engines were of the four-cycle type and, remarkably enough, they are still in existence. Some years ago they were placed in the author's hands by Edgar T. Westbury, noted model engine designer, for safe keeping until such time as a place might be found for them in a museum or official collection. In due course, they were handed over to David Stanger's son, Alfred Stanger, from whom they were acquired, on behalf of Britain's Society of Model Aeronautical Engineers, by Lieut. Commander Alwyn Greenhalgh, the SMAE's official historian. Incidentally, there is another historical connection here: in 1936, a very youthful Alwyn Greenhalgh was a member of the successful Wakefield Cup team that visited the United States in that year. The Wakefield Cup event, inaugurated in 1928, was the world's first international model plane contest.

As the photograph shows, the 1907 four-cylinder Stanger was a narrow-vee engine with overhead poppet valves. The exhaust valves were operated through pushrods and rockers, in the usual way, from a camshaft just above the crankcase between the cylin-

**Thomas (Ray) Arden, famous, forty years later, as the designer of the Arden engines and as the originator of the model glowplug.*



Stanger Vee-Twin—1914 Record Holder



Stanger Inline 3-Cylinder

ders but, typical of certain full-size engines of the pre World War One period, automatic inlet valves were used. That is to say, the inlet valves were opened by atmospheric pressure as the piston descended on its suction stroke. The built-up two-throw two-bearing crankshaft was made in two halves, connected at the center by a flying web. It ran in bronze bushes at each end of a sandcast aluminum crankcase which was split along the engine's horizontal center-line.

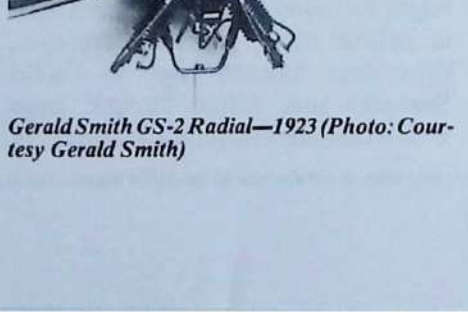
The Stanger V-4 was a big engine. It had bore and stroke measurements of 1.25 in. x 1.50 in., giving a displacement of 7.36 cubic inches or 120cc. Each of its cast-iron pistons (no full-sized engine used aluminum pistons in those days) had two compression rings and ran in a plain steel cylinder barrel. Only the cylinder-heads (also made of cast-iron) had cooling fins. One has to remember that early i.c. engines were quite lightly stressed and Stanger evidently considered that the slipstream from the prop would provide adequate cooling. The engine had a coil ignition system with a distributor at the rear, driven by the camshaft, to conduct the HT current to each spark plug. The camshaft was driven from the crankshaft through a train of three spur gears. Complete with a small brass gas tank mounted above its float-valve carburetor, but less ignition coil and battery, the V-4 checked out at 5 lb. 6 oz.

The V-Twin was basically "half" the V-4, with a displacement of 3.68 cu in (60cc) and weighed only 2 lb. 10 oz less ignition equipment. Its single-throw

Gerald Smith GS-1—1921 (Photo: Courtesy Gerald Smith)

crankshaft was made in one piece, supported in bearings front and rear, the connecting-rods having detachable bearing caps.

David Stanger built a number of other smaller displacement engines in later years. They included several



Gerald Smith GS-2 Radial—1923 (Photo: Courtesy Gerald Smith)

single-cylinder two-cycle engines, a three-cylinder two-stroke and the neat inline pushrod-OHV three-cylinder four-stroke illustrated.

THE GERALD SMITH ENGINES

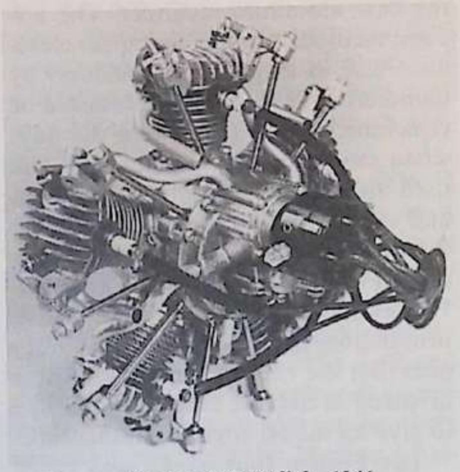
No history of internal combustion engines would be complete without reference to the achievements of Gerald Smith, an extraordinarily talented British engineer, who designed his first model four-stroke in 1920 and completed his latest one, no less than 65 years later, in 1985. His first engine, the Type GS-1, was a single-cylinder pushrod-OHV unit of 1.0 in. x 1.375 in. bore and stroke. In 1922-23, he built a large five-cylinder radial aircraft en-

Gerald Smith 18-Cylinder Radial—1930 (Photo: Courtesy Gerald Smith)

gine (GS-2) which used automatic inlet valves in the piston heads and pushrod operated overhead exhaust valves. It had a bore and stroke of 1.25 in. x 1.50 in., giving a total displacement of 9.2 cubic inches or 150cc. Both these engines won awards at the London

Model Engineer Exhibition, the GS-1 in 1922 and the GS-2 in 1924.

At the 1930 Model Engineer Exhibition, Gerald Smith took the top honors with an engine for which he will always be famous among the model engineering fraternity; the Type GS-3 twin-row 18-cylinder radial. At that time, Gerald Smith, a professional engineer, was with the Armstrong-Siddeley company which, like Pratt & Whitney in America, made 14-cylinder twin-row radial aircraft engines, but neither company had then produced an 18-cylinder engine. The GS-3 was actually designed in 1924, was nearly six years in the making and is still in

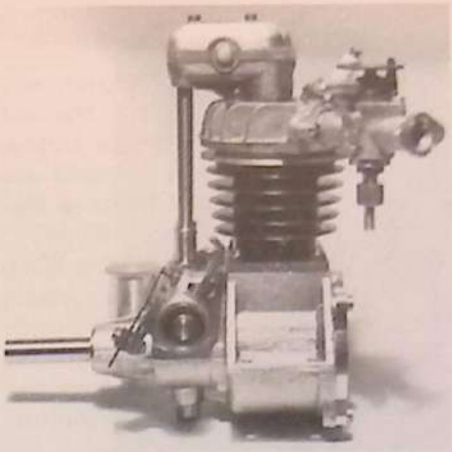


Burgess-Morton M5 Radial—1946

existence — having survived a German air raid in 1941 which damaged Gerald's workshop and destroyed the five-cylinder engine.

Some idea of the complexity of the 18-cylinder radial may be gathered from the fact that it has four valves per cylinder, dual ignition (36 spark plugs) and a mixer fan in the induction system. The double-throw crankshaft runs in ball bearings and the cam drum is geared to rotate at one-tenth crankshaft speed, there being 5 cams on each track. The engine has a bore and stroke of 1.375 in. x 1.50 in., which works out at a total displacement of just over 40 cu in. or 657cc. It is approximately 15 inches in diameter measured across the exhaust pipes.

These early four-stroke engines were, of course, strictly "one-offs," not intended for use in models but, during the Thirties and Forties, Gerald Smith designed a number of high quality two-stroke engines, later models of which were also manufactured in small quan-



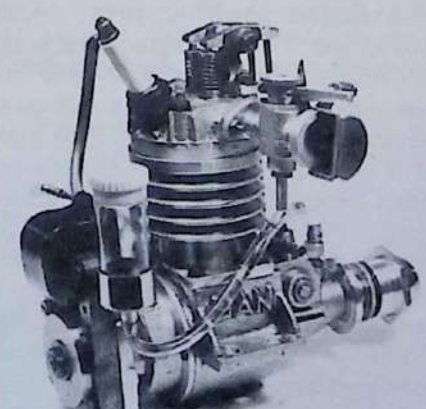
Jensen C.I. Special—1948

tities (a little over 300 in all) for model aircraft, boats and cars. In 1979 he was persuaded to design the Skylark engine, a high quality .60 cu in. magneto ignition two-stroke motor, of which a limited edition (14, plus 3 marine versions) was produced for discriminating "old-timer" enthusiasts. In 1983, his interest in four-strokes was reawakened and he designed and constructed, purely for his own satisfaction, another radial, this time a three-cylinder engine called the Osprey.

This engine, the twelfth Gerald Smith design, displays all the old G.S. professionalism and was extensively demonstrated at various events during 1985. It has a total displacement of 2.126 cu in. (34.85cc) and uses magneto ignition. Some further details of this engine will be found in later chapters.

THE RISE OF THE TWO-STROKE

During the Twenties and Thirties, many four-cycle engines were built on both sides of the Atlantic by amateur model engineers, some to their own



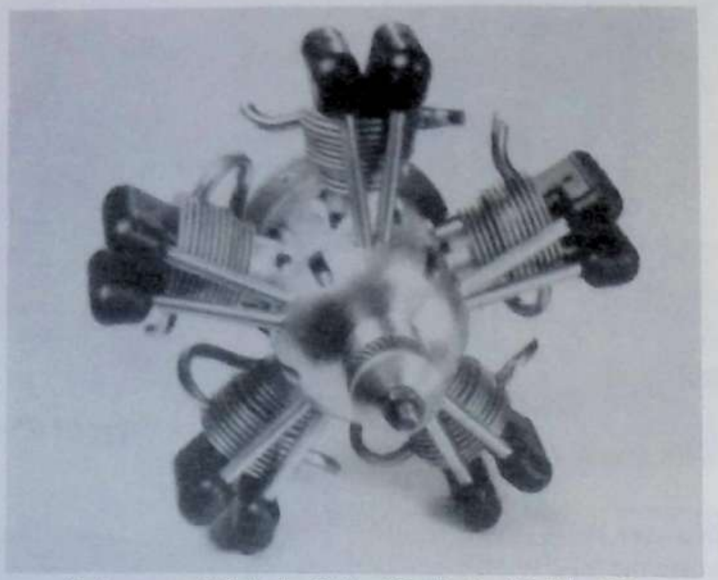
Gannet Aero 15cc—1968

O.S. Experimental 60—1974 (Photo: Courtesy O.S. Mfg.Co.)

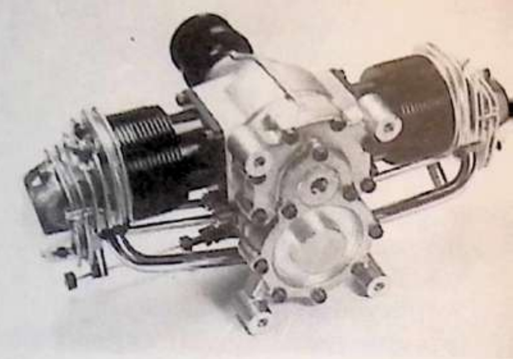
O.S. FS-60 Prototype—1975 (Photo: Courtesy of O.S. Mfg.Co.)

O.S. FS-60 First Production Model—1976

O.S. FS-60 Final Production Model—1983



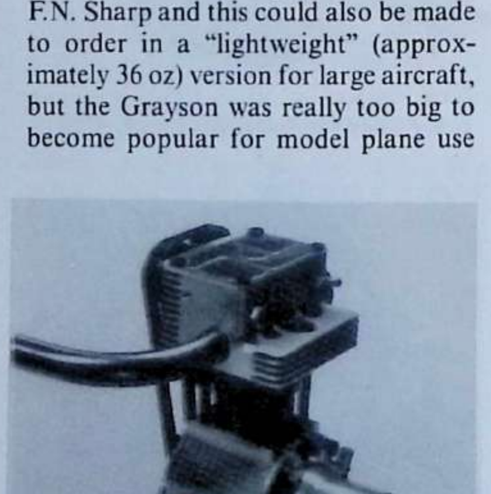
Technopower 5-Cylinder Original Production Model—1976



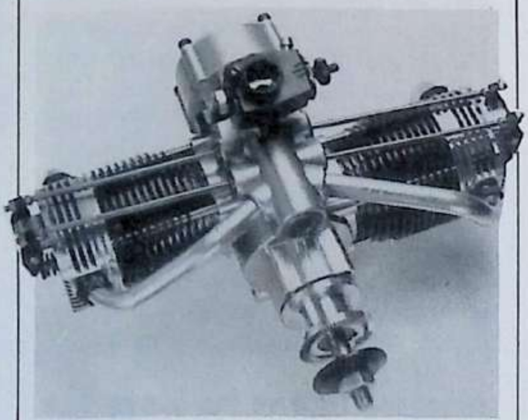
O.S. FT-120 Flat-Twin Prototype—1978

designs and others to the drawings of established model engine designers, such as Elmer Wall in the U.S., and Edgar Westbury in the U.K. but, for the most part, these engines were intended for model boats.

Through the middle and late Thirties, after pioneer work in the U.S.A. by Bill Brown, Mel Anderson and Bill Atwood, a steadily increasing variety of light and compact two-stroke motors for model planes appeared on the market, but the over-the-counter purchase of a lightweight four-cycle model aircraft engine was something that would remain very much in the future. In the early Thirties in England, an old-established engineering firm in London, E. Gray & Son Ltd., was offering the 25cc (1.53 cu in.) Grayson OHV speed boat engine designed by F.N. Sharp and this could also be made to order in a "lightweight" (approximately 36 oz) version for large aircraft, but the Grayson was really too big to become popular for model plane use at that time. These engines also later became available with bore and stroke measurements increased from 1¼ in. to $1^{5}/_{16}$ in., enlarging displacement to 1.78 cu in. or just over 29cc.



Schillings PL 10cc—1977



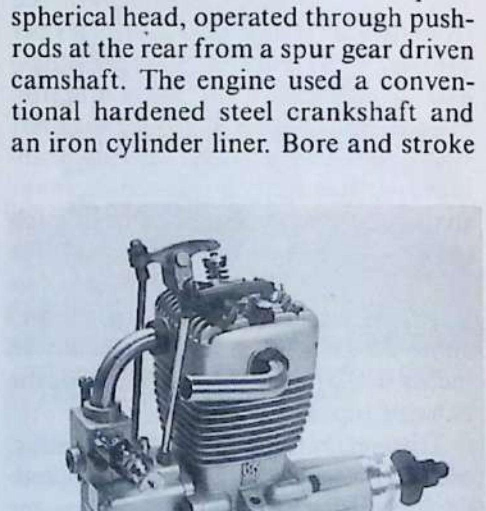
DAMO FS-218 Flat Twin—1977

FEENEY AND LEJA

The first serious attempt to break into the model aircraft engine market with relatively small four-stroke motors was by the "Feeney Engine Company" of Chicago. The Feeney four-cycle motors were announced in a full-page advertisement in the April 1940 issue of *Model Airplane News*. Feeney engines were offered in three displacements, nominally 1.18 cu in., 0.914 cu in. and 0.604 cu in., known, respectively, as the Models A, B and C. They used vertical overhead valves operated through pushrods from a rear-mounted skew-gear driven cross camshaft.

Although, from illustrations, the Feeney motors looked quite interesting, their construction was somewhat crude. Both crankshaft and camshaft, which ran directly in the aluminum crankcase material, were made of brass and the ringed piston ran directly in the cast aluminum cylinder. The advised method of taking up tappet clearance was to lengthen the pushrod by hammering to "extrude" it. It has to be remembered that these were the days when model aircraft engines were still used almost exclusively for free-flight and engine runs were kept very short. It would take quite a long time to wear out an engine by flying it in a model. However, the Feeney did not remain in production for very long. The story goes that the Feeney company became involved in defense contracts and had to give up model engine manufacture.

The Feeney four-stroke was based on a design by Casimir Leja and, in 1947, Leja announced a much improved engine of just under 1.0 cubic inch displacement to be known as the "Leja 4-Cycle" which was to be produced by a new company called Leja Engines Inc. It had inclined valves in a part-spherical head, operated through pushrods at the rear from a spur gear driven camshaft. The engine used a conventional hardened steel crankshaft and an iron cylinder liner. Bore and stroke



Kalt FC-1—1977

were 1.125 x 1.0 inch, giving a displacement of 0.994 cu in. or 16.3cc. Apparently, the Leja was tooled up for production but was never actually manufactured in quantity. Like many engines of the late Forties, it was probably a victim of the change of direction that occurred in the model engine market following the announcement of the Arden glowplug. Attention switched to the smaller and cheaper engines that the glowplug made possible and these became immensely popular over the next few years.

MORTON AND JENSEN

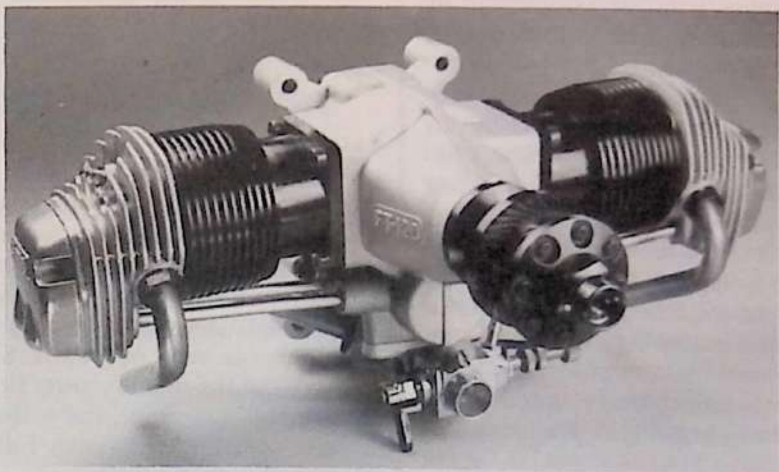
It is clear that, at the time, the market was not ready for a four-cycle engine. Two famous four-strokes that were produced in the late Forties but still failed commercially, were the American Morton M-5 and the British Jensen "C.I. Special."

The M-5 started life during WW-II as a workshop project—that is, as a set of working drawings and machining instructions. Later, castings were also made available. It was a most ambitious piece of work; a five-cylinder radial engine based on the LeBlond 5D 85-horsepower light aircraft engine and was designed by Morton Brothers who had produced the Morton Challenger single-cylinder two-stroke motor before the war. In 1944, Morton also issued drawings for a four-cylinder in-line L-head (side valve) engine of 0.736 cu in. (12.06cc) displacement.

In 1945, the M-5 was put on the market as a finished, ready-to-run unit. For the first year or so it was built in the Morton factory in Omaha, Nebraska, but, in 1946, the manufacturing rights and tooling were purchased by the Handicraft Division of the Burgess Battery Company, located at Lake Zurich, Illinois, who renamed the engine Burgess M-5. It has been reported that sets of parts for about a thousand motors were produced in all, but it is not known how many of these were sold as assembled engines.

The M-5 had a bore and stroke of 0.625 x 0.600 inch giving a total displacement of 0.920 cu in. or just over 15cc. It was assembled around a diecast aluminum alloy crankcase which was webbed inside to contain the two ball bearings supporting an overhung crankshaft. Unlike most radial engines, in which the pushrods are at the front, the M-5, following the LeBlond prototype, had its valve mechanism—timing gears, cams and pushrods—at the rear. The engine had inclined valves and the cylinder heads were integral with the cylinder barrels which were fitted with shrunk-in steel liners. The pistons were of aluminum but were not equipped with rings.

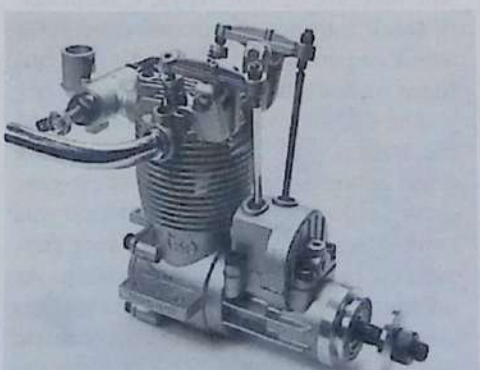
The M-5 weighed approximately 22 oz bare or 30 oz with ignition gear and radial mount. It was nominally rated at 0.5 bhp at 3,500 rpm—a figure, incidentally, which, experience indicates, was somewhat on the optimistic side. By 1948-1950, one could buy, for a quarter of the price of the M-5, an American single-cylinder glowplug two-stroke that would deliver more than twice as much power as the M-5 for half its weight. Against this kind of competition, coming at a time when control-line flying was putting a premium on engine power, it is not surprising that the M-5, for all its sophistication and scale appearance, failed to find a sufficiently large market to justify continued production.



O.S. FT-120 Gemini Flat-Twin—1979

Today, the M-5 is a highly prized collector's item and the same goes for the Jensen C.I. Special.

The C.I. Special first appeared in the late nineteen-forties. It was manufactured in the Channel Islands (hence "C.I. Special") by J&G Jensen Ltd. of St. Helier, on the island of Jersey and was very well engineered. It was, of course, a spark-ignition motor and could be obtained with an ignition coil and condenser or with a miniature magneto. It operated on straight gasoline (or methanol), lubrication being



Saito FA-30 Mk.I—1979

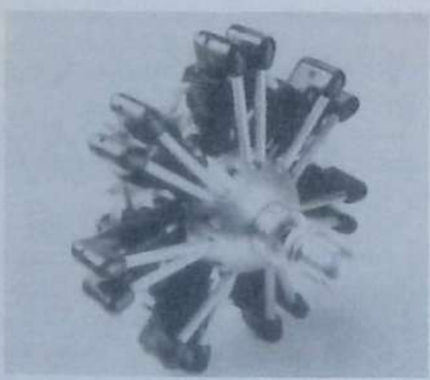
Enya 35-4C—1980

Robinson RVE—1980

by crankcase depression. An oil reservoir was mounted on the crankcase nose and a small cross-hole in the crankshaft drew oil into the crankcase to lubricate all parts, except the valve rockers.

The Jensen crankshaft was made from nickel-steel, hardened on the crankpin and supported in a single ball bearing plus a bronze outer bush. The engine had a transverse camshaft at the front, driven by crossed helical gears of steel and gunmetal. The vertical stainless steel valves operated in bronze guides and the hardened steel rockers were enclosed, as were the pushrods. The finned cylinder barrel, machined from a close grained cast-iron and lapped to a mirror finish, was fitted with a ringed cast aluminum piston and the conrod was a dural forging with a bronze bushed lower end.

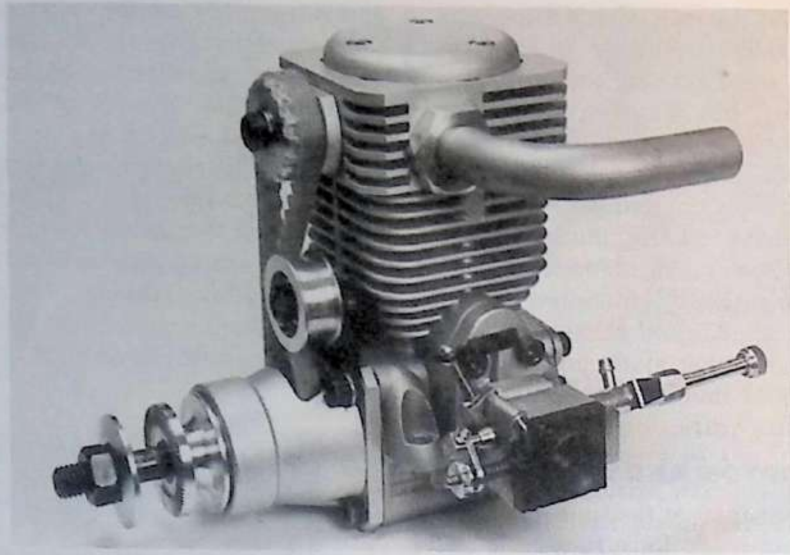
The C.I. Special was unique among commercial model engines at the time in having a barrel throttle carburetor with automatic mixture control — something that did not appear on production model two-stroke glowplug engines



Technopower-II 7-Cylinder Radial—1981

until about fifteen years later. The complete engine, less ignition equipment, weighed approximately 20 ounces. Its bore and stroke were $^{15}/_{16}$ in. x $^{7}/_{8}$ in., giving a displacement of 0.604 cu in. or 9.90cc. Claimed power output, running on gasoline with the standard 6.5:1 compression ratio, was 0.52 bhp at 10,000 rpm. This could be increased by raising the compression ratio and running on an alcohol fuel.

Like the Morton/Burgess M-5, the C.I. Special was available as a complete ready-to-run engine, or as a set of castings and materials for the home machinist. Alternatively, the Jensen company would supply the engine as a set of



Webra T-4—1980

ready-machined, ready-to-assemble parts. It could also be purchased with or without coil and condenser, or with a magneto. Despite this highly flexible approach to meeting the purchaser's requirements, sales of the C.I. Special fell short of the manufacturer's expectations and the engine was withdrawn from production in the early Fifties.

FOUR-STROKES IN THE DOLDRUMS

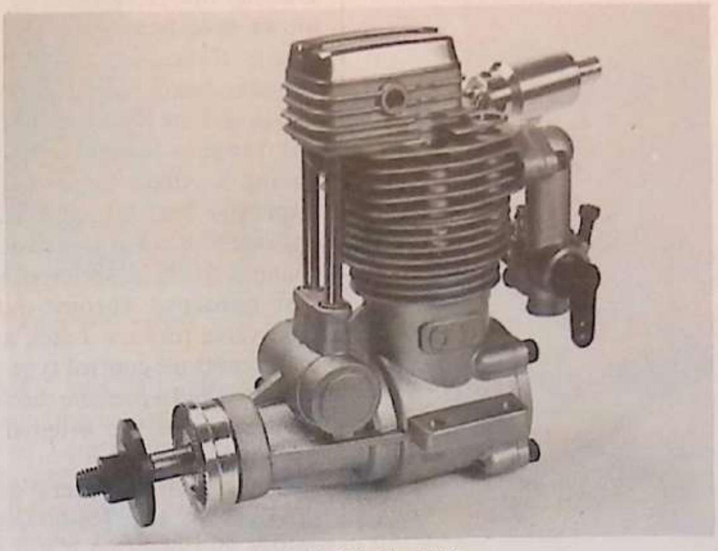
The Morton M-5 and the Jensen C.I. Special were, clearly, two very different approaches to the idea of persuading modelers to regard the four-stroke engine as a viable alternative to the popular two-stroke motor. The M-5 relied on novelty and realism, whereas the Jensen was expected to compete head-on with the .60 class two-strokes. The fact that neither stategy succeeded was enough to discourage well-established model engine manufacturers from repeating such experiments and some twenty-five years were to elapse before a successful challenge was mounted.

Saito FA-40 Mk.I—1981

That successful challenge came in 1976 in the shape of the Japanese O.S. FS-60. In the intervening years, however, a few four-cycle engines were marketed that escaped the attention of most model plane builders. This was usually because they were primarily intended for other uses (specifically model boats) or because they were hand-made in very small numbers by individuals and did not reach true "production" status or were not advertised. Also, it has to be remembered that, for many years, the largest model aircraft engines permitted, in the interest of safety, by both official rules and common consent, were 10cc (.61 cu in.) displacement.

In England, George A. Nurthen introduced his Gannet 15cc (0.91 cu in.) single-cylinder OHV water-cooled marine engine in 1956 and several hundred of these were subsequently produced by Gannet Engineering Ltd., over a period of about fifteen years, including some that were sold in the United States by Gannet's U.S. agents, Norco Marinecraft of Van Nuys, California. A small number of aircooled versions was also produced for aircraft use, but these were built to special order only.

The Gannet was similar in layout to the Jensen C.I. Special in that it had a cross camshaft at the front, skew-gear driven from the crankshaft which was supported in a single ball-bearing supplemented by a bronze outer bush. As on the Jensen, valve tappet clearances were adjusted by means of eccentric bushes in the valve rockers. Unlike the C.I. Special, however, the rockers,



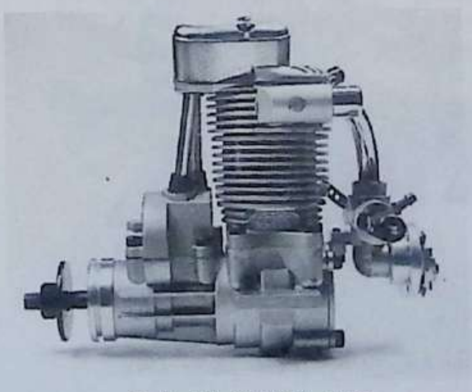
O.S. FS-40—1981

springs and pushrods were exposed. The engine was supplied with a magneto as optional equipment and in this form, weighed some 2¾ pounds. The engine's weight, and the fact that it preferred large diameter props, meant that it had limited appeal and was only suitable for a very large lightweight airframe.

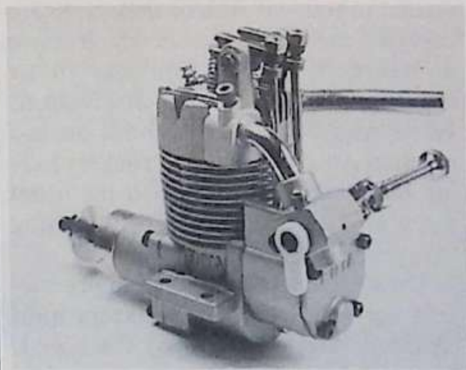
Another 15cc marine four-stroke which made a brief appearance in the U.K. (and about which, perhaps, the least said the better) was the Eljo. This, announced in 1967, sought to compete with the Gannet but was very heavy, bulky and crudely made. It was apparently designed originally for light industrial use — driving small generators, water pumps, etc. Fortunately, no attempt was made to offer it in an aircraft version.

ENTER THE GLOW-IGNITION FOUR-STROKE

All the earlier generation of four-stroke-cycle engines discussed so far were of the spark-ignition type, whereas, for two-stroke model aircraft engines, the glowplug had superseded spark-ignition twenty years earlier. It was fairly widely supposed that glowplug ignition would not be satisfactory in a four-stroke engine, i.e. that the plug would cool off too much during the four-cycle engine's exhaust and induction strokes. This was not so, a fact that was demonstrated most ably by Erich Handt in Germany who, in the early Seventies, constructed a variety of small four-cycle model aircraft engines, including .60 cu in. and 1.5 cu in. vee-twins and a .60 cu in. five-cyclinder radial, as well as various single cylinder motors. All were of the pushrod OHV type with spur-gear driven camshafts at the front and some of them were subsequently made in small batches and sold under the name EHMO (Erich Handt MOtor).



Saito FA-45 Mk.I—1981



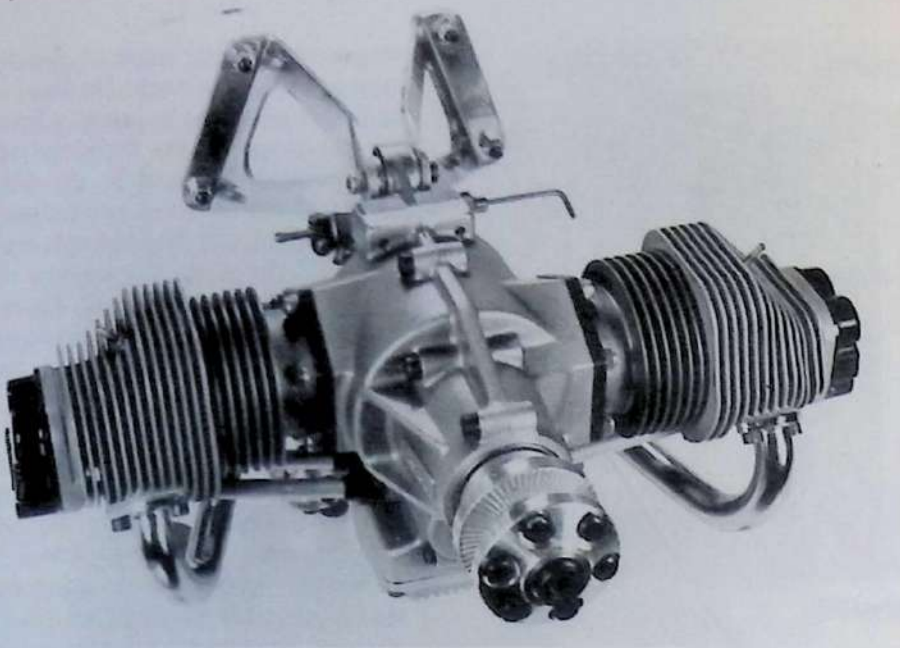
Enya 40-4C—1981

In England, during the same period, Glenn Hargrave, after experimenting with an unusual flat-twin two-stroke engine, had begun work on the scale-type five and seven cylinder four-cycle radial engines that eventually became the prototypes of the Technopower-II engines manufactured in the United States. An early Hargrave radial was displayed at the Nuremberg Hobby trade fair in 1974. The engines were first put into production in 1976 in the Irish Republic by Glenn Hargrave and John D. Stokes, a company being formed for this purpose under the name of Technopower Services Ltd., with premises close to Shannon Airport. These products were distributed, through a wholesaler, under the name of Powermax PM-5 and PM-7, but various difficulties arose which eventually led to the break-up of this connection. The engines might never have been heard of again but for the intervention of an American enthusiast, Wally Warner, who bought the designs from Glenn Hargrave, formed a U.S. company, Technopower-II Inc., and re-started production.

The original Anglo-Irish engines were not without teething troubles and not all of these had been eliminated by the time that Technopower-II's American versions were in production. A weakness of the design was its use of molded glass-reinforced nylon rocker boxes. These, because they supported the rocker shafts and could distort if the engine became overheated, tended to upset valve clearances and lead to misfiring. Later, they were replaced by aluminum rocker boxes which completely eliminated this problem. Soon afterwards, Wally Warner moved into the production of a full-size flat-twin light aircraft engine and Technopower-II Inc. was acquired by a new owner. By this time, the original five-cylinder engine had become the "Big Bore 5" model with linerless chromed-bore cylinder barrels, enlarged displacement and more power and two new models in the shape of a three-cylinder radial and a big 9-cylinder engine, had been added to the production list.

THE REVOLUTION BEGINS

Just before the first Irish-made Technopower radials came on the market in 1976, the four-stroke that finally achieved the widespread acceptance that had eluded all previous model four-strokes, namely the O.S. FS-60, was released in its native Japan.



Kavan FK-50 Mk.I Flat-Twin—1982

Design work on the FS-60 had begun in 1974 and the O.S. company's objectives were to develop an engine that would (a) set new standards of quietness of operation for model internal-combustion reciprocating engines and (b) run on glowplug ignition and on ordinary commercial ("two-stroke") glow fuel, so that the new owner would be able to make the transition from two-stroke to four-stroke as easily as possible.

The FS-60 was an immediate success in Japan and was also well received when it came to the U.S.A. and Europe a few months later, despite the fact that test reports (and, for that matter, the maker's own figures) revealed that its gross power output was less than 40 percent of that of its high-performance two-stroke brother, the O.S. Max-60FSR. Understandably, it was dismissed by hotshot pattern flyers as of no interest whatsoever, but sport flyers (at whom the engine had, in any case, been aimed) soon learned to appreciate its qualities for quiet, relaxing, Sunday afternoon flying with a slower type of model. It was pointed out by older R/C flyers that, not so many years previously, World R/C Championship events had been won using two-cycle engines having no more power than the FS-60.

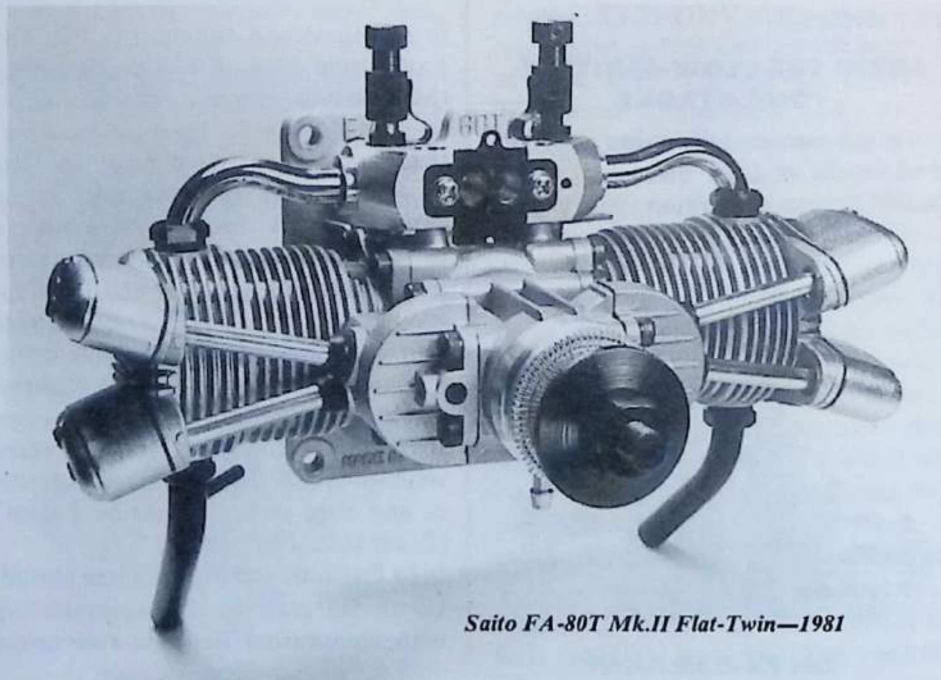
Outwardly, the FS-60 looked not unlike one of its two-stroke brethren, except for the addition of a rear housing for the camshaft, two exposed valve rocker arms on top of the cylinder head and two thin steel pushrods behind the cylinder. The engine contained five ball bearings: two for the crankshaft, two to support the camshaft and one installed in the rear wall of the crankcase carrying the timing pinion which drove an internally toothed spur gear on the front end of the camshaft. The inclined valves were operated by bronze-bushed machined aluminum alloy rockers having hardened steel pads and the usual screw and locknut adjusters for setting valve tappet clearances.

The O.S. FS-60 remained in production for more than seven years until replaced, early in 1984, by the FS-61. During the first year or two some minor modifications were made. The first of these were a slightly modified cylinder head with thicker stemmed valves and the replacement of the original tangent-flank cams with ones having a round flank profile, which improved both top-end and bottom-end performance. Another early change was the adoption of investment-cast hardened chrome-molybdenum steel valve rockers. Later, a new automatic mixture control type carburetor was fitted and a pressure diecast cylinder-head replaced the original machined bar stock heads.

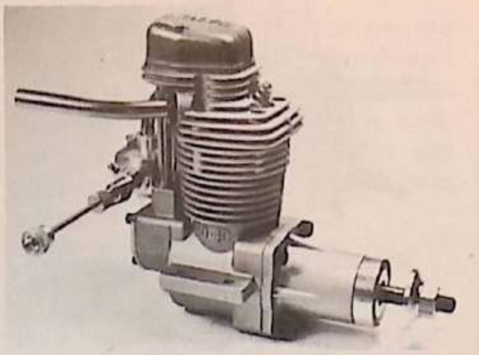
Other manufacturers watched the progress of the FS-60 and, in due course, decided that it was time to get into the four-stroke market themselves.

Among the first to do so was the Kalt Sangyo Company Ltd., well-known for its Kalt helicopters. At 7.42cc (0.453 cu in.) displacement, the Kalt FC-1 engine, introduced towards the end of 1977, was smaller than the O.S., but was an attractive little motor and ran extremely well. It had a rear spur-gear driven camshaft operating inclined valves in a part-spherical combustion chamber. Regrettably, production of the FC-1 was discontinued after only a year or two when Kalt withdrew from the engine market. This was not because of any shortcomings in the engine itself which, in fact, had been well received.

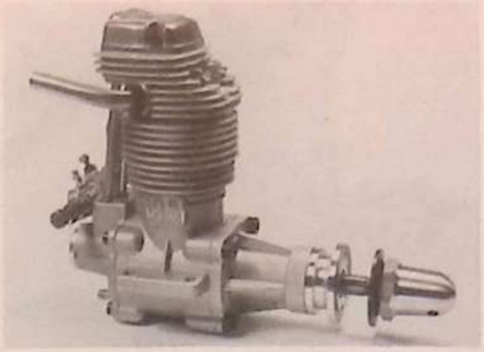
Also in 1977, four-strokes from two new European manufacturers appear-



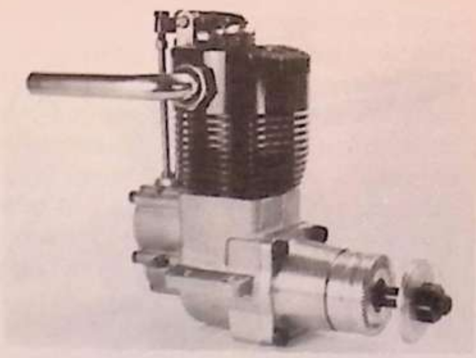
Saito FA-80T Mk.II Flat-Twin—1981



Enya 60-4C—1982



O.S. FS-80—1982



Magnum 91-S—1982

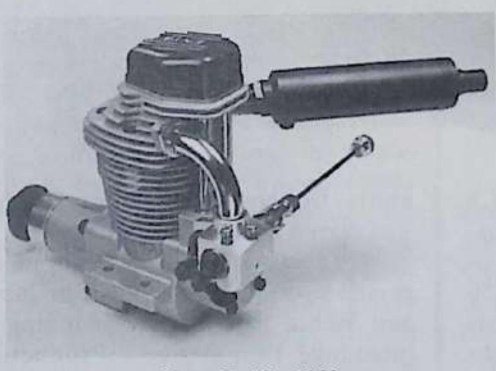
ed, "DAMO" and "PL." In Sweden, MCC (Marketing Consulting Corporation AB) of Uppsala announced the DAMO FS-218, a compact lightweight horizontally-opposed pushrod-OHV twin. The name DAMO was derived from those of the proprietors (Sten Dal and Lars Molin) of the machine shop in Stockholm where the engines were made.

With a bore and stroke of 24 x 20 mm, the FS-218 had a total displacement of nearly 18.1cc or just over 1.10 cu in., yet weighed a mere 23.5 oz; much lighter than any twin of similar displacement made before or since. The engine was well-finished and of very neat appearance, but designer Sten Dal's anxiety to keep the engine's weight at a minimum, in order to offer a good power/weight ratio, was, one suspects, partially responsible for the mechanical failures that beset these engines after their release to the modeling public. Another contributory cause may well have been the manufacturer's insistence that the engine needed *no oil* for normal operation. This recommendation was later modified to allow 0.5 percent lubricant and, for closely cowled installations or when more than 10 percent of nitromethane was included in the fuel, a maximum of 5 percent lubricant was approved.

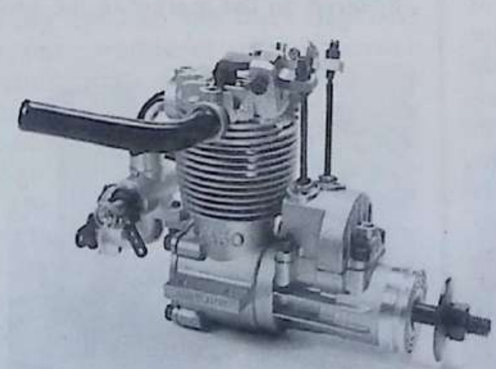
Tests (using 5 percent castor-oil) carried out in 1978 on a DAMO FS-218 for the purpose of a report in *Model Airplane News*, indicated after a two-hour break-in period, a quite good power output, but were brought to a halt when a connecting-rod broke.

The FS-218 was the only DAMO model marketed, but the German "PL" appeared in both single cylinder and twin cylinder models, the latter being more than twice as heavy as the Swedish engine.

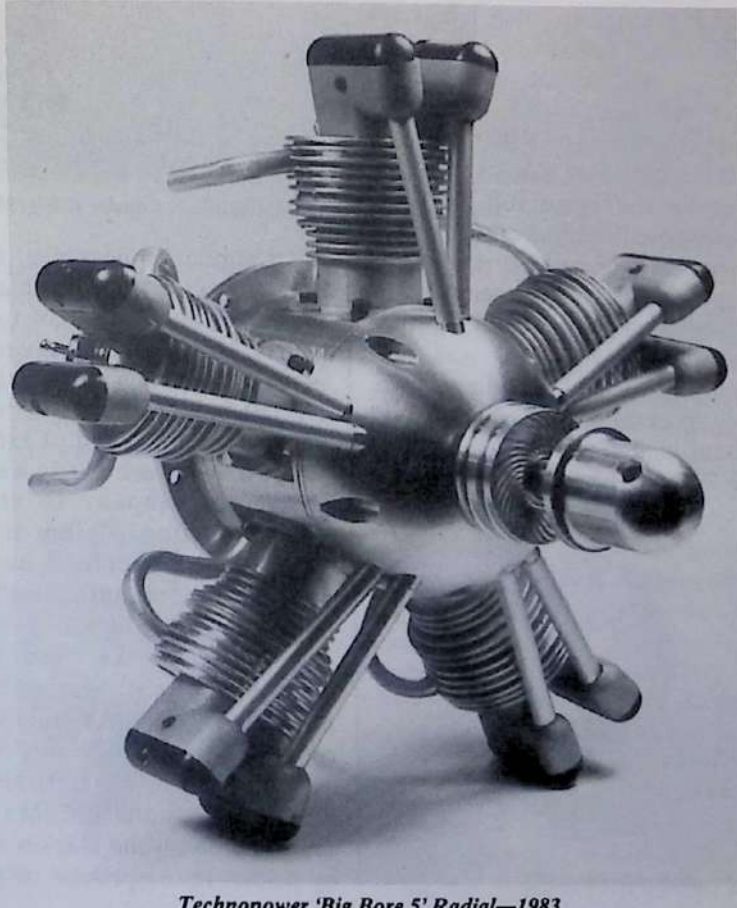
The PL engines were made in small numbers by Herr Schillings, trading under the name of Schillings and Company, of Aalen in the southern part of the German Federal Republic. These engines were machined from bar stock, no castings being used in their construction and each had a bore and stroke of 24 x 22 mm, giving the single cylinder unit a displacement of 9.95cc (.607 cu in.) and the twin a total volume of 19.9cc or 1.21 cu in. Instead of hav-



Enya 90-4C—1982

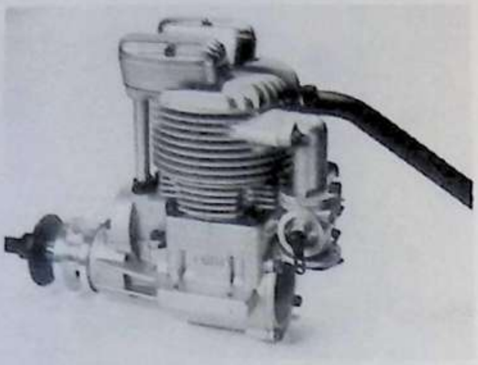


Saito FA-30 Mk.II—1982

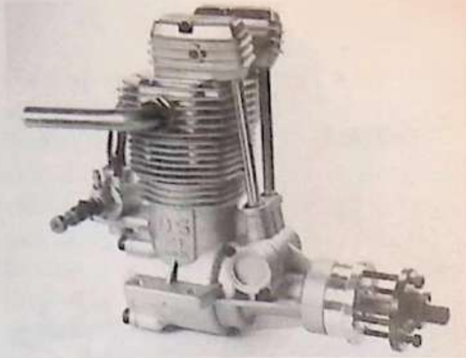


Technopower 'Big Bore 5' Radial—1983

Hirtenberger HP VT-21—1983



Saito FA-120—1983



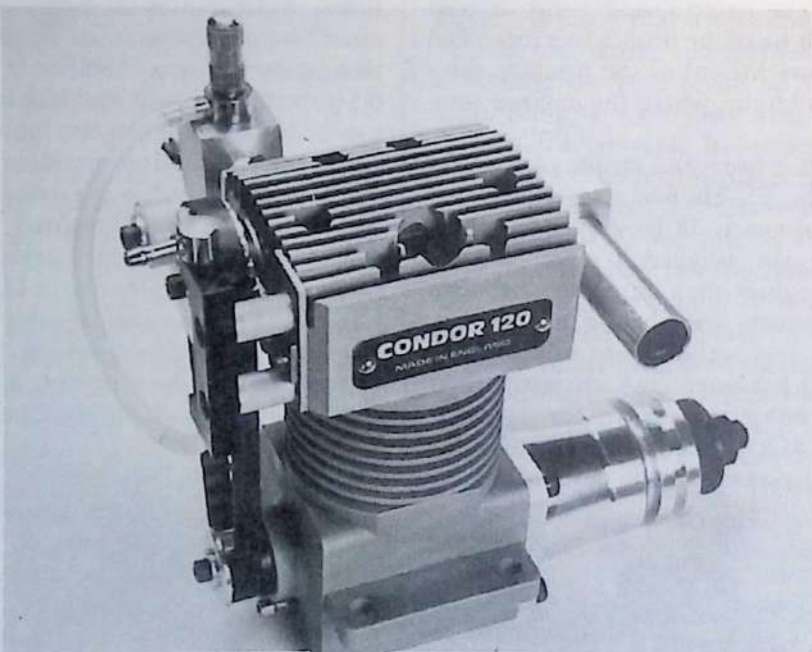
O.S. FS-120—1983

ing pushrods to operate their valves through rockers, they had toothed-belt driven twin overhead camshafts. The camshafts ran in needle-bearings and operated the valves through flat steel fingers that were adjustable for tappet clearance. The camshafts were driven by large external pulleys and a toothed belt from a small pulley at the back of the crankcase, thereby eliminating the need for separate timing gears.

The PL Twin was a 90-degree vee type engine and was essentially two single-cylinder units on a common crankcase. A flat-twin model was also offered. These were large and quite heavy engines. The .60 cu in. single cylinder model weighed just short of 31 oz and the Vee-Twin was over three pounds.

A rather more practical twin was the attractive scale-like O.S. FT-120 "Gemini" which, following a full two-year development period, came on the market in 1979 and was the subject of a test report in the April 1980 issue of *Model Airplane News*. Closely following the layout of a typical full-size horizontally-opposed light aircraft engine, it had a massive, one-piece, three ball-bearing crankshaft, a spur-gear driven two ball-bearing camshaft and fully enclosed valve gear. Weight was 34.1 oz, increasing to 36.7 oz when fitted with the optional special cast aluminum mount included.

The FT-120 has now been replaced by an improved Mk.II model. This has the same 19.90cc (1.215 cu in.) displacement as the original model but is slightly more compact and has substantially increased performance.

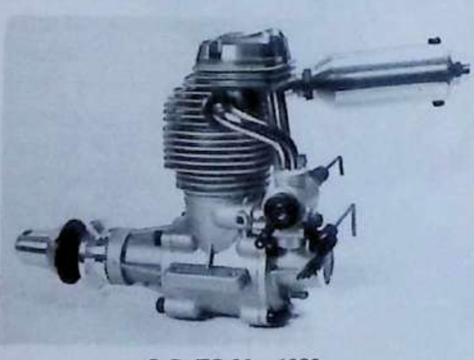


Condor 120—1983

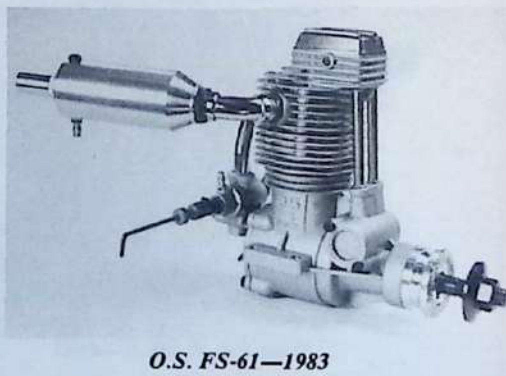
Of similar appearance, but with a bigger cylinder bore, enlarging displacement by 33 percent to 26.5cc or nearly 1.62 cu in. and giving a full 50 percent more power than the original FT-120, is the Gemini-160 first put into production at the end of 1984.

Saito Seisakusho Ltd., was the third Japanese company to embark on the production of four-stroke-cycle engines. Previously, it had specialized in the manufacture of steam engines and in modern Schnuerle-scavenged two-stroke model aircraft engines with spark (rather than glow-plug) ignition. Saito's first four-stroke, released early in 1979, was the FA-30. At the time, this was both the smallest (0.3035 cu in.) and the cheapest four-cycle engine on the market and thereby helped in the process of popularising four-strokes. The Saito was simpler in design than the O.S. FS-60 and Kalt FC-1 in that its camshaft, instead of being driven via a separate rear shaft, was mounted at the front, immediately above the crankshaft from which it was driven by a pair of spur gears.

1979 also saw two more major model engine manufacturers, Enya in Japan and Webra in Germany, planning to introduce four-strokes. Production versions of both engines eventually appeared on the market in the spring



O.S. FS-90—1983



O.S. FS-61—1983

of 1980. The Japanese engine was the Enya 35-4C, with conventional poppet valves operated via pushrods at the rear, but with two side-by-side camshafts, rather than one. For its size (just under .36 cu in.), the 35-4C was quite a lively performer.

ENTER THE ROTARY VALVE

The Webra T4, on the other hand, was a uniquely different design featuring a rotary valve in the cylinder head, in place of the usual poppet valves, and with the fuel/air charge routed, via a reed valve, through the crankcase, instead of directly to the inlet valve. Its rotary valve, inspired by that of the full-size Aspin rotary valve engine, was of the vertical axis conical type and was driven, from the crankshaft journal, by a toothed belt and pulleys, plus a pair of bevel gears. The idea of taking the fuel/air mixture through the crankcase was to utilize crankcase compression, occurring twice during each cycle, to provide a degree of "supercharging." In fact, this theory does not work out too well in practice and, in later versions of the T4, crankcase charging was abandoned.

At the time of its introduction in 1980, the Webra T4, with a nominal displacement of 14.314cc or 0.8735 cu in., was the largest single cylinder four-cycle model aircraft engine on offer. Tested for *Model Airplane News*, it recorded a power output of 1.10 brake horsepower at 11,200 rpm.

By 1980, it was obvious that four-stroke motors were here to stay. However, to make inroads into the popularity of two-strokes, it was also clear that manufacturers would have to produce more engines of a size and price that would appeal to all those everyday R/C model flyers who rarely looked beyond sport type two-strokes of around .40 cu in. displacement. The outcome of this reasoning was that, during 1980-81, the three Japanese volume producers of four-stroke motors, Enya, O.S. and Saito, each introduced a .40 size four-stroke motor developing upwards of 0.45 bhp and weighing between 12 and 13 ounces.

The first on the market, late in 1980, was the Saito FA-40. This was similar to the FA-30 in design but differed in construction and used a separate linerless chromed-bore cylinder casting. Despite a 32 percent increase in displacement to 6.581cc (0.4016 cu in.) the FA-40 was less than one ounce heavier

Webra T4-40—1983

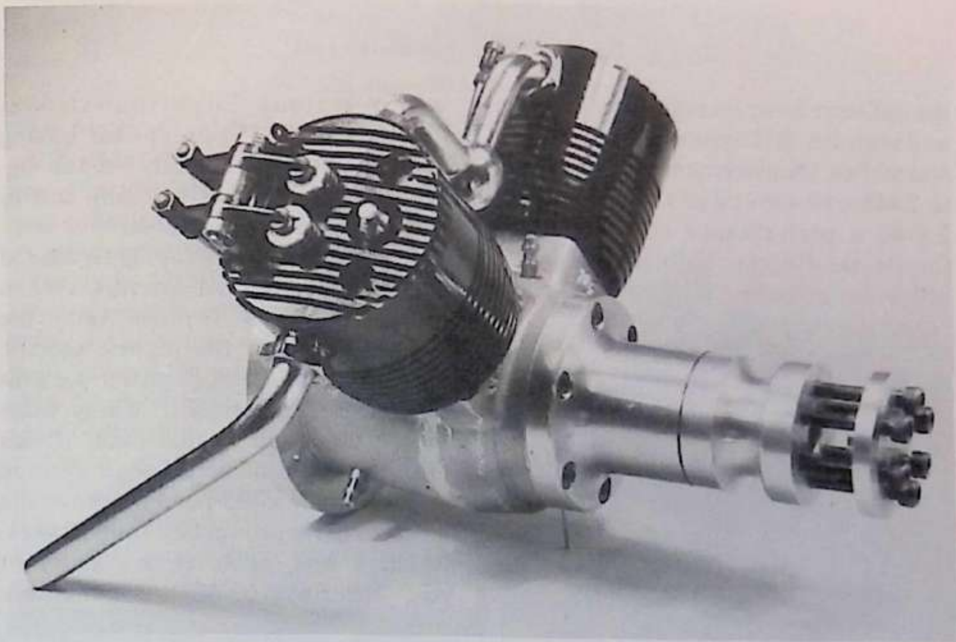
than the FA-30 at 12.5 oz.

The Enya 40-4C was introduced in the fall of 1981 and was a bored version of the 35-4C model. Outwardly, it looked exactly the same as the 35-4C. Internally, it used a ringed piston in a steel liner, rather than a ringless piston and a chromed bore aluminum liner. Cylinder bore was increased by 1.35 mm, enlarging the engine to 6.64cc or 0.4052 cu in.

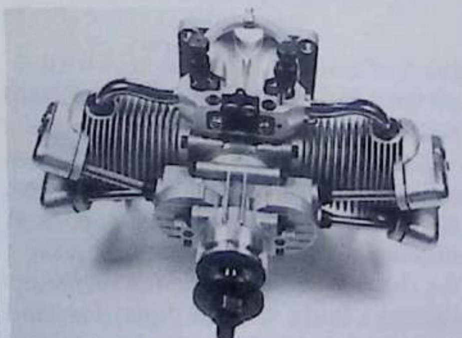
The O.S. FS-40, announced a month or two earlier, was a completely new design. It had a single complex pressure casting embodying the crankcase, cylinder casing and front bearing plus the housing for the front skew-gear driven camshaft and, for the first time in a small mass-produced engine, it also had fully enclosed valve gear. Its camshaft was supported in two ball journal bearings, like the larger O.S. four-strokes but, despite these refinements, it weighed a modest 12 oz. It quickly became the best seller in the O.S. four-stroke range, introducing tens of thousands of modelers to the delights of four-strokes.

During 1981, Saito also announced two more four-strokes. The first was the twin-cylinder FA-80T (0.8032 cu in.). This flat-twin had FA-40 size cylinders, but with new cylinder heads having each rocker assembly enclosed in a neat steamlined rocker box. An attractive looking engine, it had the highly controversial arrangement (for a flat-twin) of a single-throw overhung crankshaft—i.e. both connecting-rods coupled to the same crankpin so that both pistons move simultaneously in the same direction. (This means that reciprocating masses do not balance each other and firing intervals are unequal.) In fact, the FA-80T worked extremely well, especially when, in its later Series II version, it was equipped with a twin choke carburetor having individual mixture control to each cylinder.

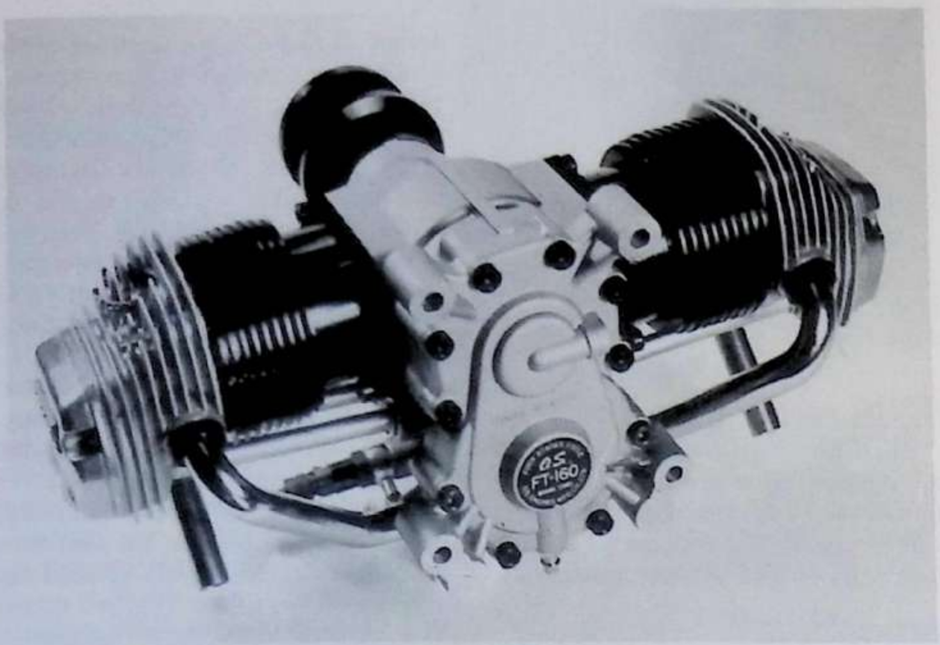
The other new Saito was the FA-45. This was based on the FA-40 but with



Magnum 182V Vee-Twin—1984



Saito FA-90T Mk.II Flat-Twin—1984



O.S. Gemini-160 Flat-Twin—1984

the cylinder bore increased by 1.4 mm and with FA-80T type enclosed rocker assemblies. Displacement was increased to 7.488cc (0.4569 cu in.). This gave the FA-45 a performance edge over the four-stroke 40s, especially on the bigger props, for a modest weight increase of

Enya 46-4C—1984

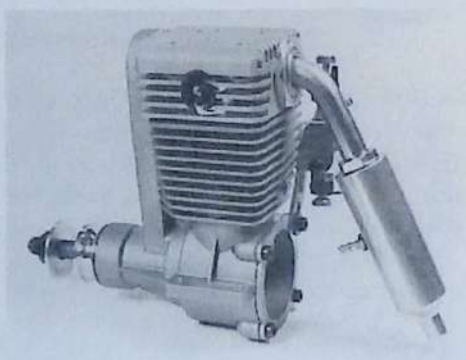
between one and two ounces. A few months after the introduction of the FA-45, a Series II version of the FA-40, fitted with FA-45 type enclosed valve gear, replaced the original FA-40.

The logical next step for Saito was to produce a 15cc version of the FA-80T twin, by substituting FA-45 cylinders and this course was followed in the spring of 1982 with the introduction of the FA90T.

THE SECOND GENERATION

1982 can be said to have marked a turning point in the development of the model four-cycle motor. In that year, the Enya brothers released their 60-4C model. Its general design and construction followed the pattern set with previous Enya four-strokes (35-4C and 40-4C) except for having fully enclosed valve gear, but the significant point is that it finally laid to rest any ideas that four-strokes were only powerful enough for lightly loaded fly-for-fun types of aircraft. When tested for *Model Airplane News*, the Enya 60-4C had the highest specific output (i.e. brake horsepower per unit of piston displacement) of any four-stroke tested up to that time. It was about 20 percent better than average and as much as 35 percent above the levels of early production four-strokes.

There was, however, a penalty to pay. The Enya 60-4C was noticeably



Webra T4-80—1985

noisier and it was clear that, whereas most of its less lively rivals could be operated in an open exhaust condition without attracting too much attention, the 60-4C really needed a muffler. A muffler was, therefore, made by Enya for the engine. In its original form, this caused a fairly marked power loss and also had a tendency to loosen and detach itself from the engine's exhaust pipe when hot but, later, an improved muffler was issued which was less restrictive and had a more secure method of attachment.

An analysis of the test model Enya 60-4C, at the time, revealed that its extra power was largely attributable to the design of its cylinder head assembly; most particularly to its lengthened rocker arms which increased valve lift for improved breathing. This is not surprising. It is to the cylinder head, ports and valve gear that engineers traditionally look first for improvements in full-size four-cycle engine performance and, after the Enya 60-4C, this was to influence the future design of commercial model four-strokes also.

FAI RULE CHANGES

Although, by the early nineteen-eighties, four-stroke-cycle engines were becoming more widely used, there remained one area where they were virtually excluded. This was in the official FAI World Championship classes, notably Class F4C (radio-controlled scale) and Class F3A (radio-controlled aerobatics). Here, because of the four-stroke's lower specific power output, it was placed at a considerable disadvantage, compared with high-performance-two-strokes, under the existing rule limiting total piston displacement for all types of engines to 10cc.

In December 1981, decisions were taken by the C.I.A.M. (the world governing body for model aeronautics under the auspices of the *Federation Aeronautique Internationale*) at the delegates' annual meeting in Paris, to amend the rules to allow the use of four-cycle engines of up to 15cc (0.915 cu in.) displacement in Class F4C and up to 20cc (1.220 cu in.) for Class F3A. In both cases, the 10cc (0.610 cu in.) limit remained in force for two-stroke motors and the revised rules were to come into use with effect from Janu-

Enya 80-4C—1985

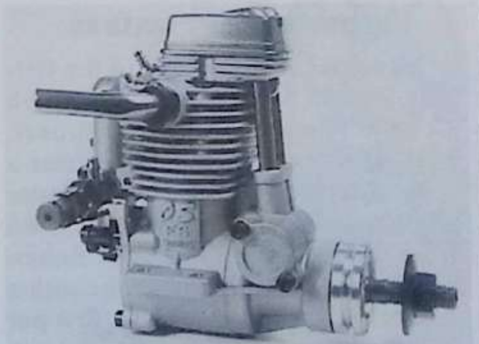
Enya R120-4C—1985

ary 1983. A further modification to the scale rules was agreed at the following C.I.A.M. annual meeting, whereby, for four-stroke motors, maximum displacement was raised to 20cc for a single-engined aircraft and to a total of 40cc for models having two or more engines. At the same time, while the 10cc two-stroke rule remained in force for single engined models, the permitted total displacement for other two-stroke powered models was raised to a 15cc combined displacement for twin-engined models and to 20cc where three or more two-strokes were used.

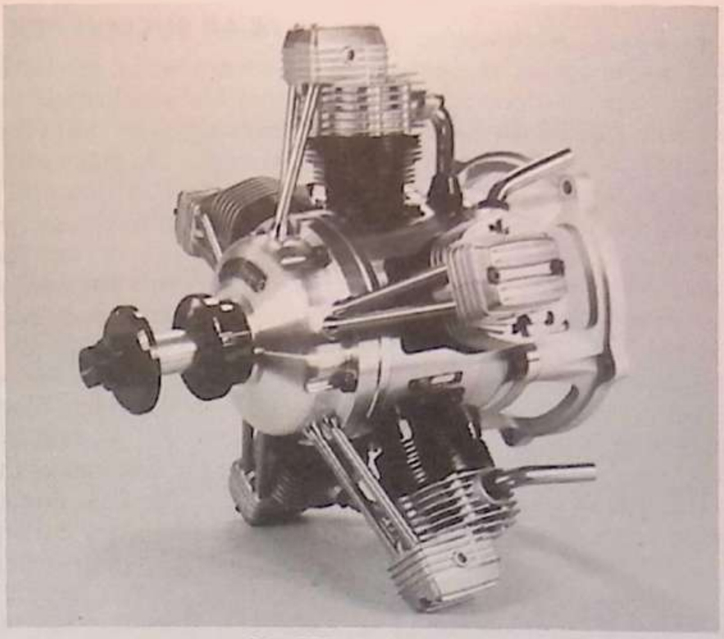
All this was quite good news for the manufacturers of four-strokes, the only reservation being that those who had begun work on 15cc four-strokes for scale use were, a year later, having to decide whether to continue, or to enlarge their new designs to 20cc, or to add a completely new 20cc unit.

The Enya factory, which was ready to introduce its new 15cc model well in advance of the 1983 season, had gone ahead and done so in October 1982. The engine, the 90-4C, lived up to expectations, producing, on test, close to 1.3 bhp with its muffler fitted.

Before this, however, two new 15cc engines had also appeared in England.



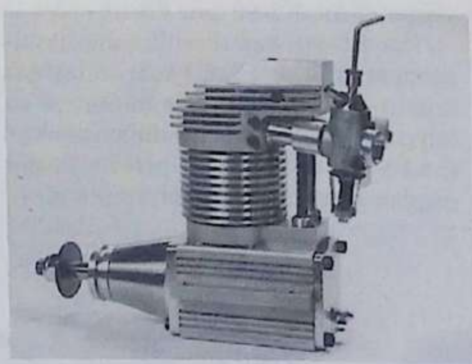
O.S. FS-20—1985



O.S. FRS-300 Sirius Radial—1986

The Magnum 91-S was actually in small scale production in 1981 and was a conventional design with a single rear spur-gear driven camshaft and exposed pushrods and rockers. Subsequently tested in its Mk.II version, it proved to be most useful when pulling the relatively large props often required for scale models. It was also made available later with an electronic spark-ignition system.

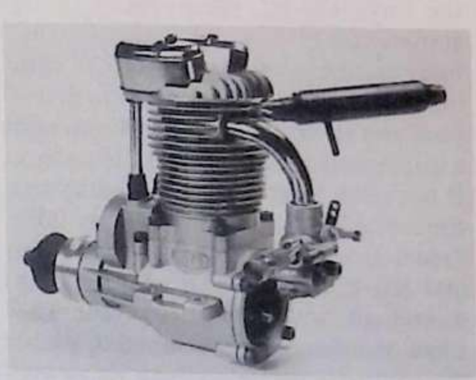
The other British 15cc engine was the Condor 91, the first (1982) production model four-stroke engine to use a horizontal cylindrical rotary valve. The



Laser 75—1985

valve was driven by a toothed belt and pulleys at the rear, the pulley on the rotary-valve having twice as many teeth, thereby eliminating the need for separate timing gears. The engine also had the novel feature of a mechanical fuel pump driven by the rotary-valve pulley.

The Condor was a heftily proportioned engine and this enabled its bore and stroke measurements to be safely



Saito FA-65—1985

increased from 28 x 24 mm to 30.12 x 28.0 mm to enlarge its displacement to 19.95cc (1.217 cu in.) without increasing its weight or outside dimensions. The Condor 120 was one of the first (early 1983) 20cc class four-strokes on the market and its relatively simple construction meant that it could be offered at a somewhat lower price than its three poppet valve Japanese competitors.

The first two of these latter, the O.S. FS-120 and the Saito FA-120, also appeared early in 1983. The O.S. had originally been laid out in 1982 as a 15cc unit but was not marketed as such. Instead, it was stretched to 20cc when the revised FAI ruling legalized 20cc engines for F4C Scale as well as for F3A Aerobatics. It employed a front cross camshaft layout, as used for the FS-40, but with inclined valves and separate rocker boxes. A powerful engine, its 15cc origins meant that it was also relatively light and compact and this gave it an uncommonly good power/weight ratio.

The sturdy Saito FA-120 followed the usual Saito layout of a spur-gear driven front camshaft and inclined valves. This was combined with the lowest stroke/bore ratio of any of the 20cc four-strokes at 0.775 : 1 to give a large diameter cylinder-head that would accommodate extra large valves. The most interesting structural feature of this engine was that, unlike all contemporary model aircraft engines (as distinct from some pre-war designs and current converted chainsaw two-strokes) the FA-120 did not have a detachable cylinder-head. Instead, the head was cast in one piece with the cylinder barrel. Subsequently, Saito introduced this feature into their other engines.

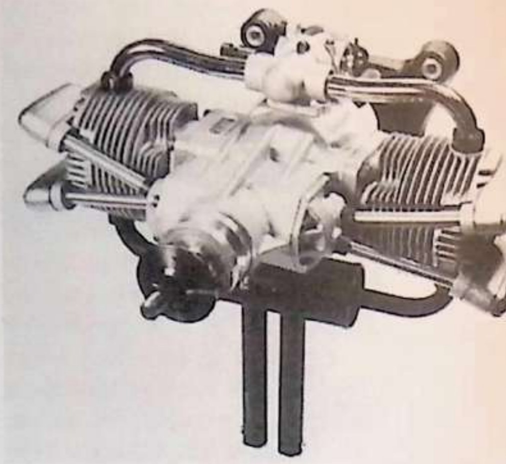
The last of the Japanese 20cc trio, the Enya 120-4C, released in the late summer of 1983, was based on 90-4C body castings and other parts, but with internal dimensions increased to give a bore and stroke of 31.0 x 26.4 mm and a displacement of 19.93cc (1.216 cu in.). It has since been overshadowed by the Enya R.120-4C, an entirely new 20cc model, larger and heavier than the original 120-4C and capable of producing more than two brake horsepower. The Enya company has continued to place the emphasis on power with its newer engines. The 46-4C, for example, introduced before the R.120-4C, proved to be substantially more powerful than any other four-stroke of similar displacement and weight, when released in 1984.

FS-60 SUCCESSORS

After seven years of production, the engine that had sparked off the four-stroke revolution, the O.S. FS-60, was finally withdrawn to make way for the new and much more powerful FS-61. Earlier, the O.S. management had been reluctant to abandon its conviction that the four-stroke's role was solely to provide modelers with quiet operation, believing that the pursuit of higher power would only result in the development of four-strokes that would prove almost as noisy as two-strokes. However, such are the demands of the market place, that the O.S. factory was forced to respond to the challenge set by Enya and develop four-strokes having substantially higher specific power outputs. This decision was reinforced by the revised FAI regulations, which positively encouraged the use of four-stroke engines in the international R/C contest classes. Inevitably, four-stroke manufacturers would now be competing with each other for the attention of modelers in these popular categories, categories in which a competitive power output is always of major importance.

The first new O.S. engine to be produced to meet these requirements was the 20cc FS-120 already mentioned. The FS-60 remained in production, backed up by two enlarged displacement versions of it, the FS-75 and FS-80, before a realignment, at the end of 1983, brought replacements in the shape of the FS-90 and FS-61.

The FS-90 was the ultimate development of the FS-60 rear camshaft layout and, in fact, was packaged to have the same mounting dimensions as the FS-60, despite a 50 percent larger displacement and a power output more than twice that of the FS-60. A new and more efficient combustion chamber shape, larger valves, revised cam profiles, cam followers and valve rockers to increase valve lift, bigger ports and passages and many other refinements, raised the FS-90's power output (1.32 bhp at 11,500 rpm) and, particularly, its power/weight ratio, to highly competitive levels.



Saito FA-270T Flat-Twin—1984

The FS-61, on the other hand, was completely different from the FS-60 and followed the FS-40 and FS-120 in having a front camshaft, skew-gear driven from the crankshaft. Bore and stroke were the same as for the FS-60, but power output on test was raised from 0.62 bhp at 10,500 to nearly 0.90 bhp at 11,500 rpm.

O.S. designers have remained true to their belief that every effort should be made to ensure that four-strokes maintain a significant advantage over two-strokes in quietness of operation. To cope with the higher noise levels resulting from these newer engines' increased performance, they have developed more efficient mufflers which significantly reduce noise levels while causing negligible power loss. The test figures just quoted for the FS-90 and FS-61 were both achieved with these silencers fitted.

O.S. Super-Gemini Flat-Twin—1985

MORE ROTARY VALVES

Mention has been made of the German Webra T4 .87 cu in. and the British Condor .91 and 1.2 cu in. four-strokes, both with rotary valves, the former a vertical axis conical valve and the latter a horizontal axis cylindrical type. Also from the U.K. was the unique Robinson RVE .60 cu in. four-stroke with a vertical axis rotary disc valve, first put into small scale production in 1980. This was a quite complex design in which the rotary valve was shaft driven from bevel gearing in the rear of the crankcase and spur gears in the head.

A similar drive system was adopted by the old-established Austrian manufacturer of cartridges and percussion-caps, the *Hirtenberger Patronenfabrik*, for its first model four-stroke engine, the HP VT-21 engine introduced early in 1983. In this case, the rotary valve was of a vertical axis cylindrical pattern. The VT-21 was unusual for several other reasons: it had the crankcase and front housing split horizontally in line with the crankshaft axis; it had the upper half of the case cast in unit with the cylinder casing and head and it was the smallest four-stroke on the market. HP subsequently introduced a .49 cu in. model and has since announced .25 and .61 versions.

The simplest rotary valve four-cycle design to date—in fact, the simplest four-cycle design of any type—is the Webra horizontal axis rotary valve layout. Introduced in production form at the end of 1983 in the Webra T4-40, this consists of a chromed brass horizontal cylindrical valve located, fore and aft, in the cylinder-head and driven directly, at half-speed, by a toothed pulley and belt from the crankshaft journal. The same system was subsequently adopted (1985) for the bigger T4-60 and T4-80 models.

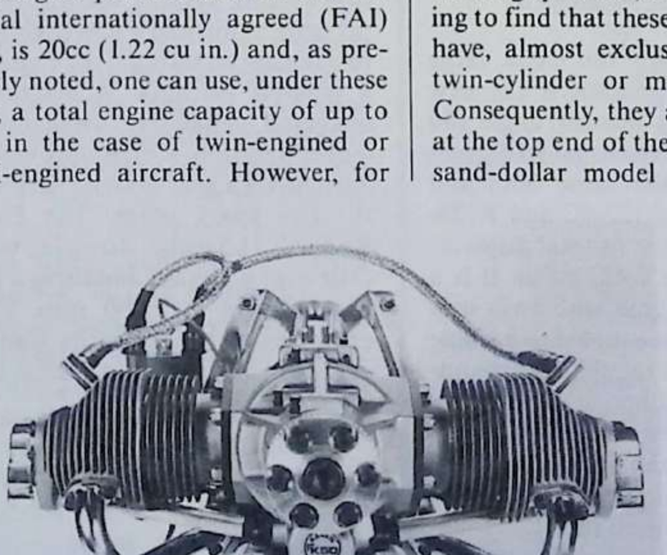
THE BIG ONES...

The largest displacement four-stroke-cycle engine permitted under current official internationally agreed (FAI) rules, is 20cc (1.22 cu in.) and, as previously noted, one can use, under these rules, a total engine capacity of up to 40cc in the case of twin-engined or multi-engined aircraft. However, for those who wish to build even larger models, or to use more than 20cc in a single-engined model, several four-stroke motors are now available to meet these requirements.

Technopower 9-Cylinder Radial—1982

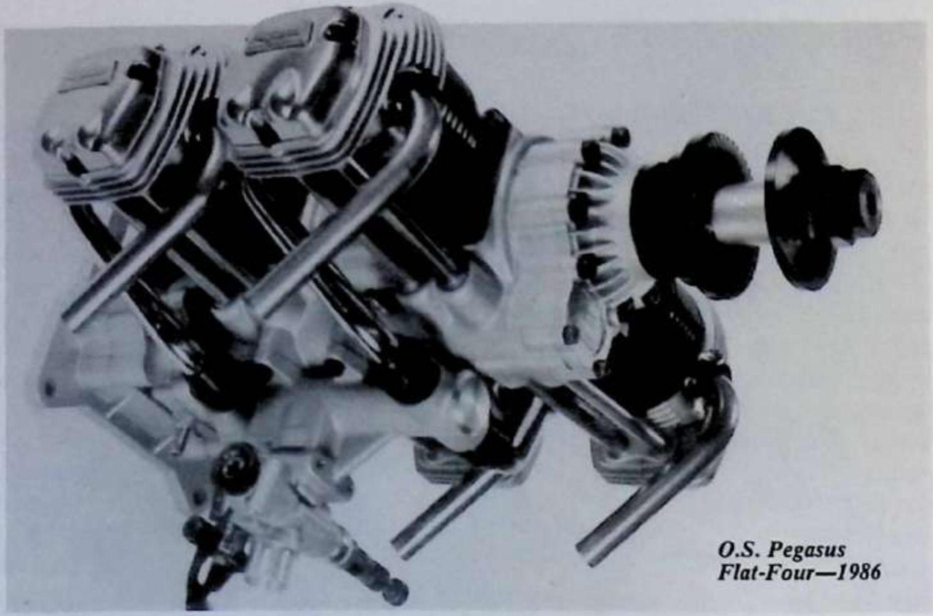
Really big single-cylinder four-cycle engines tend to have somewhat lumpy running qualities, so it is not surprising to find that these over-20cc engines have, almost exclusively, been of the twin-cylinder or multi-cylinder type. Consequently, they are not cheap and, at the top end of the market, the thousand-dollar model aircraft engine is now very much a reality.

Taking 20cc as our starting point, we should, strictly speaking, include, in this category, the Technopower 7-cylinder and 5-cylinder "Big Bore" radials previously mentioned, but these lightweight scale-type engines, designed long before "Quarter-Scale" or "Giant-Scale" models came on the scene, were intended for the smaller models (e.g. one-sixth scale) normally powered by .60 cu in. two-stroke motors. More in keeping with large scale model requirements was Technopower's highly impressive looking (3.6 cu in.) 9-cylinder radial. This engine, built to special order, was first announced towards the end of 1981. It had a diameter of 8¾ in. and weighed 4 lb. 13 oz. However, even at a sixteen-hundred dollar selling price, the manufacturer found it uneconomic to continue production, although, at the time these words are being written, work is in hand to re-introduce the engine in improved form.



Kavan FK-50 Mk.II Flat-Twin—1986

The 26.5cc (1.62 cu in.) O.S. "Gemini-160" horizontally-opposed twin, has already been mentioned. O.S. also has a third model in the Gemini series, the FT-240, or "Super-Gemini" intro-



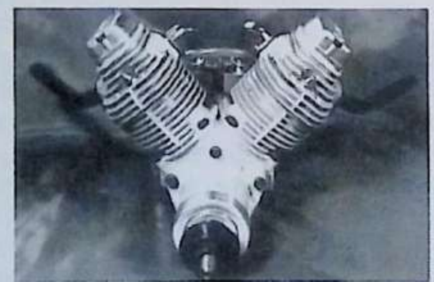
O.S. Pegasus Flat-Four—1986

duced in 1985, which has a displacement of nearly 40cc.

An obviously superior alternative to converted chainsaw two-strokes of equivalent power, the Super-Gemini is similar in basic design to the other Gemini models, but is much larger, with a bore and stroke of 30.4 x 27.5 mm, giving an actual displacement of 39.92cc or 2.436 cu in. It has an overall width of nearly 9½ inches (compared with 7¾ in. for the Gemini-160) and a weight of 4 lb. 7 oz including a pair of sturdy steel firewall mounts.

Slightly larger than the Super-Gemini and six ounces heavier, is the Saito FA-270T. This is another flat twin but, in contrast to the O.S. twins, has its cams and pushrods at the front like the Saito FA-80T and FA-90T. Unlike these smaller Saito models, however, the FA-270T has a conventional two-throw crankshaft so that reciprocating masses are balanced and firing intervals equally spaced. The FA-270T has a bore and stroke of 32.0 x 28.0 mm, giving a displacement of 45.04cc or 2.748 cu in.

With the same piston stroke as the Saito FA-270T, but a 2.0 mm larger cylinder bore, the German Kavan FK-50 flat-twin has a displacement of 50.84cc or 3.10 cu in. and weighs 5½ lb., or 6½ lb. in its Mk.II spark-ignition version. Like the O.S. Gemini twins, the Kavan twin follows the typical horizontal-opposed light aircraft engine layout in which a single spur-gear driven camshaft is located below the crankshaft with encased pushrods below the cylinders operating enclosed valve rockers. The FK-50 is, in fact, styled along the lines of the Continental horizontally-opposed light aircraft engines and carries the "Continental" logo on its rocker covers. The engine is unusual, among production four-strokes, in that it uses a plunger type pump to circulate oil from a sump below the crankcase. To ensure adequate upper cylinder lubrication, the FK-50 also requires a small percentage of oil to be added to the fuel in the normal manner. The Mk.II performs impressively and, on test, produced an output of nearly four horsepower.



Enya VT-240 Vee-Twin—1986 (Photo: Courtesy Enya Metal Products Co.)

Enya's entry into the extra large four-cycle engine market is the new VT-240. This is a narrow angle (80 degree rather than the usual 90 degree) vee-twin having the same bore and stroke as the Enya 120-4C and R120-4C, which means that its total displacement is 39.85cc or 2.432 cu in. It is a fairly compact engine with twin carburetors at the rear coupled to a single throttle arm and is rated by the manufacturer at 2.5-3.2 bhp.

Two multi-cylinder engines of distinctive design were announced in 1984 by the German Schillings company which formerly manufactured the "PL" four-strokes mentioned earlier. The smaller of the two is an inline four-cylinder unit with twin overhead camshafts driven by toothed belts at the rear. It has bore and stroke dimensions of 24 x 21 mm, giving a total displacement of 38.00cc or 2.32 cu in. The larger motor is an eight-cylinder vee type, having two camshafts per bank, again toothed-belt driven. It has the same bore and stroke as the inline four, which means that the Schillings V8 has a total displacement of 76cc or 4.64 cu in. These are not "production" engines in the normal sense: they are made in small numbers only and, it is understood, to special order.

A fitting entry into the tenth year of its involvement in the volume production of four-stroke-cycle model internal combustion engines, O.S., the world's oldest and largest model engine manufacturing company, announced two impressive multi-cylinder power units, the FF-240 and the FR5-300. The FF-240, now named "Pegasus," is a horizontally-opposed four-cylinder motor of 39.81cc (2.429 cu in.) displacement. Not surprisingly, it has many of the features of the twin-cylinder FT-120 Gemini, including its 24 x 22 mm bore and stroke, which enables it to use FT-120 piston and cylinder assemblies. The FR5-300 is a five-cylinder radial engine of 49.76cc (3.037 cu in.) total volume. It also has a 24 x 22 mm bore and stroke and uses FS-61 cylinder head assemblies.

Finally, this history of model four-stroke motors would not be complete without mention of another large radial, the splendid 5.7 cu in. (93.4cc) five cylinder engine designed and made by Forest Edwards of Grass Valley, CA 95945. This has a bore and stroke of 1.10 x 1.20 in. and is built just like a full size radial, including a dry sump lubrication system incorporating a pressure pump and a scavenging pump to circulate oil through the engine from a separate oil tank. A magnetically-triggered capacitive discharge electronic ignition system provides HT current via a gear driven distributor to the five spark plugs. The Edwards Radial is 11.5 inches diameter, weighs a little over 8 pounds and turns a 24 x 14 Zinger prop at 5,500 rpm. Further examples of the Edwards Radial are currently being built to special order.

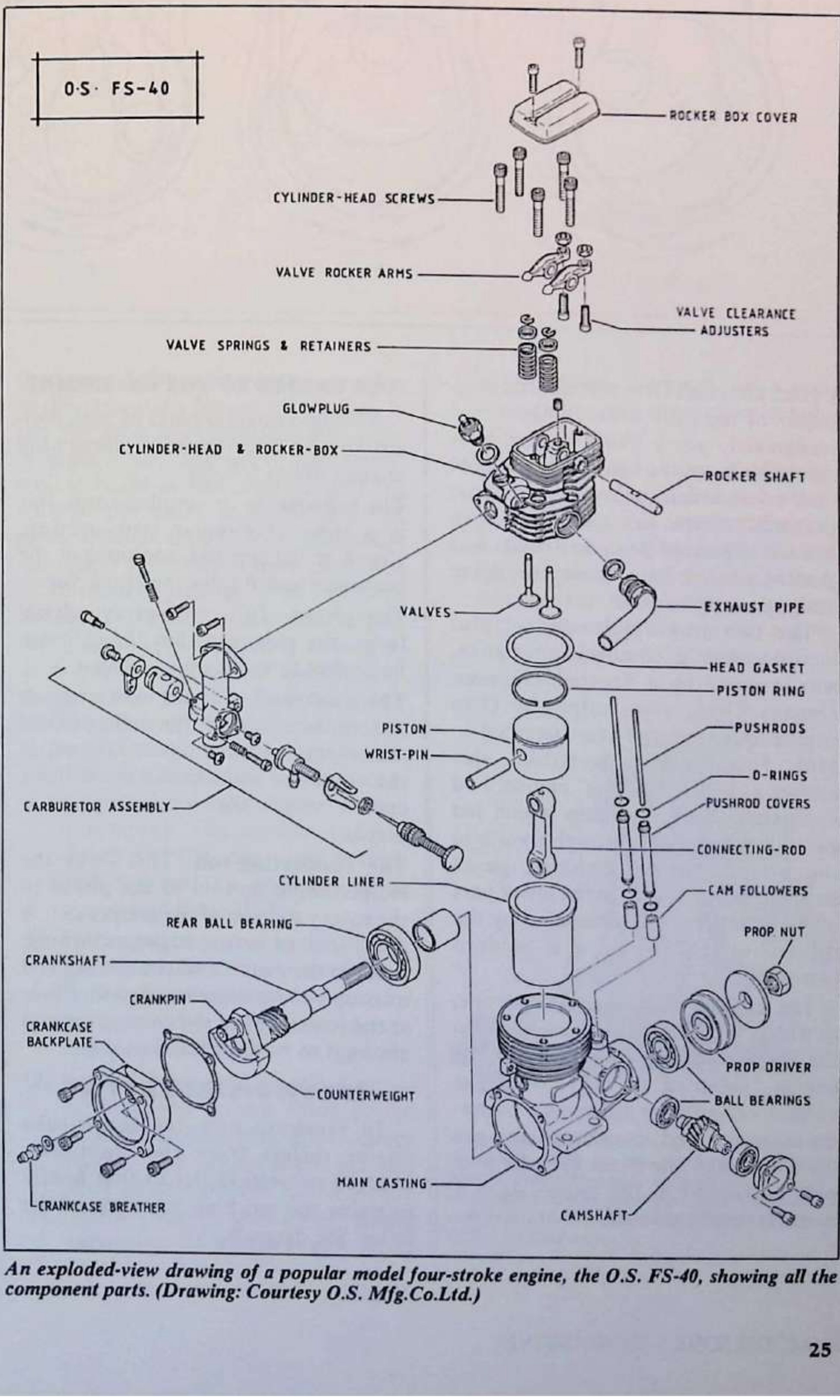
CHAPTER 2

The Four-Stroke-Cycle Principle

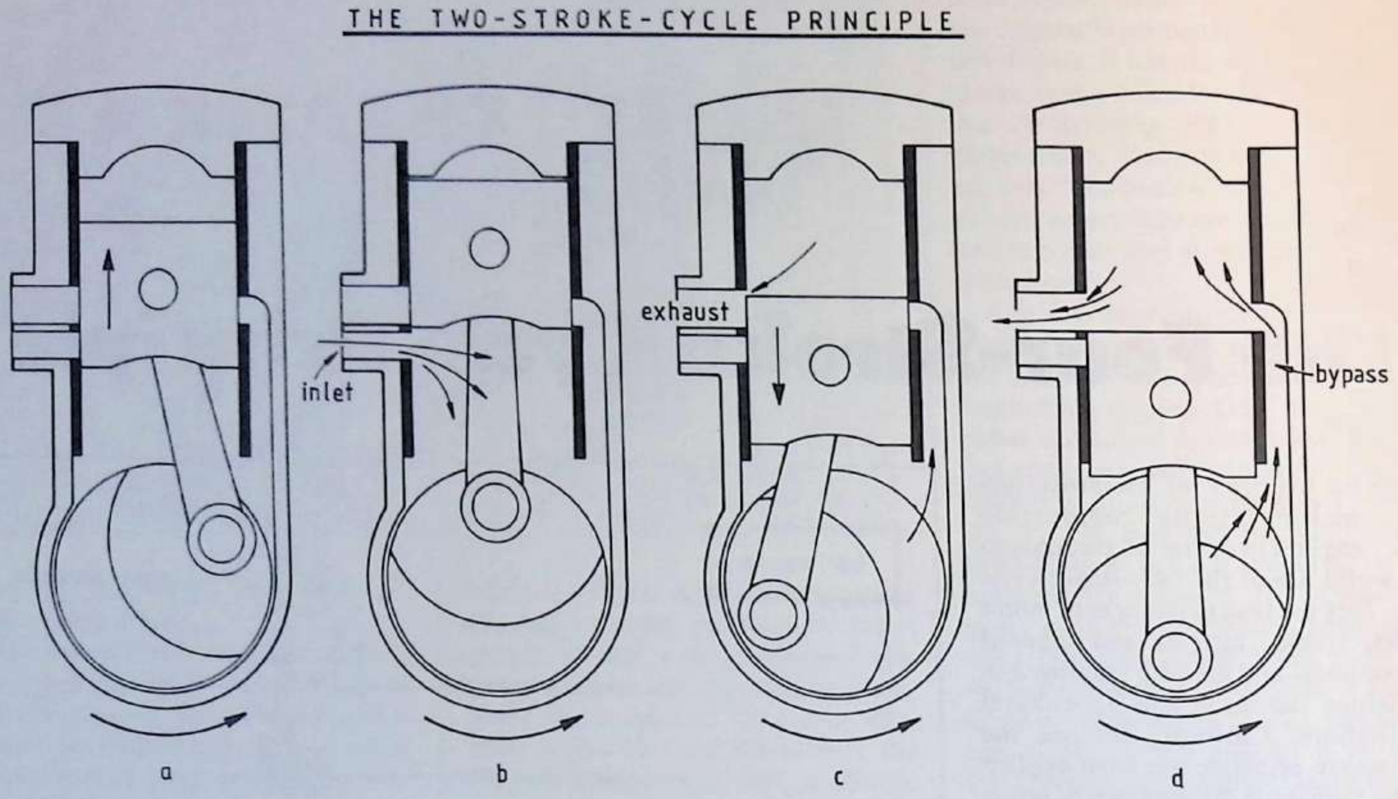
The majority of reciprocating-piston internal-combustion engines in operation throughout the world are of the four-stroke-cycle type. They are used to power cars, motor cycles, trucks, aircraft and inboard power-boats and are also employed in numerous industrial and agricultural applications. Curiously enough, the two-stroke principle has been applied to two even more diverse types of prime movers: on the one hand to the smallest fractional-horsepower model engines and, on the other, to huge slow-running turbocharged marine diesels developing 40,000 horsepower—although it is fair to remark that these are far removed from conventional crankcase-charged two-strokes. Most of us are familiar with the latter in one form or another, i.e. as model aircraft engines, as outboard motors, or as the power source for some types of motor-cycles and forestry or garden machinery.

All these engines, two-stroke and four-stroke, are descended from the early gas engines of the nineteenth century that originated in France, Germany and Great Britain. The first commercially successful example of these was the Lenoir gas engine introduced in France in 1860 by Etienne Lenoir and subsequently manufactured in some hundreds for driving water-pumps, factory machinery, etc. The Lenoir engine, however, had a double-acting cylinder with slide valves, like a steam engine, and did not compress the gas before ignition; consequently it was not very efficient.

In 1878, a German manufacturer of gas engines, Dr. N.A. Otto, put into production a new engine incorporating a compression stroke and working on the four-stroke-cycle principle as we know it today. Hence the reason why the four-stroke has often been referred to, in the past, as the "Otto



An exploded-view drawing of a popular model four-stroke engine, the O.S. FS-40, showing all the component parts. (Drawing: Courtesy O.S. Mfg.Co.Ltd.)



Cycle," although Otto was not the originator of the four-stroke. Others had recognized, many years earlier, that compression of the charge was important to the realization of the true potential of the gas engine and, in France, Alphonse Beau de Rochas was granted a patent for a four-cycle engine design as early as 1862.

The two-stroke cycle engine, also incorporating a compression stroke, was invented by a Scottish engineer, Dugald Clerk, soon after the Otto engine appeared and was patented in 1881. This original two-stroke, also known as a "Clerk-Cycle" engine, had a separate charging pump which fed gas into the cylinder through a valve in the cylinder-head. Exhaust gases escaped through ports in the lower part of the cylinder when uncovered by the descending piston, as in a modern two-stroke.

The crankcase-charged two-stroke, as widely used nowadays, is credited to the English engineer Joseph Day. His engine, patented in 1889, used the volume beneath the piston as a pumping chamber and transferred the gas from the crankcase to the cylinder by a port uncovered by the piston, as in a modern small two-stroke.

THE BASICS OF THE I.C. ENGINE

The fundamental parts of both two-stroke and four-stroke reciprocating engines are as follows:

The cylinder. In its simplest form, this is a tube of circular cross-section, closed at the top end and open at the bottom where it joins the *crankcase*.

The piston. This, also of cylindrical form, fits closely within the cylinder, but is free to move up and down.

The crankshaft. Carried in bearings in the crankcase, this is the main shaft of the engine, with the power take-off at the outer end and a crank at the inner end to which the connecting-rod is fitted.

The connecting-rod. This links the reciprocating motion of the piston to the rotary motion of the crankshaft. A *piston-pin*, or *wrist-pin*, passes through holes in the piston and connecting-rod to couple them together. Another hole at the lower end of the connecting-rod allows it to fit onto the *crankpin*.

THE TWO-STROKE CYCLE

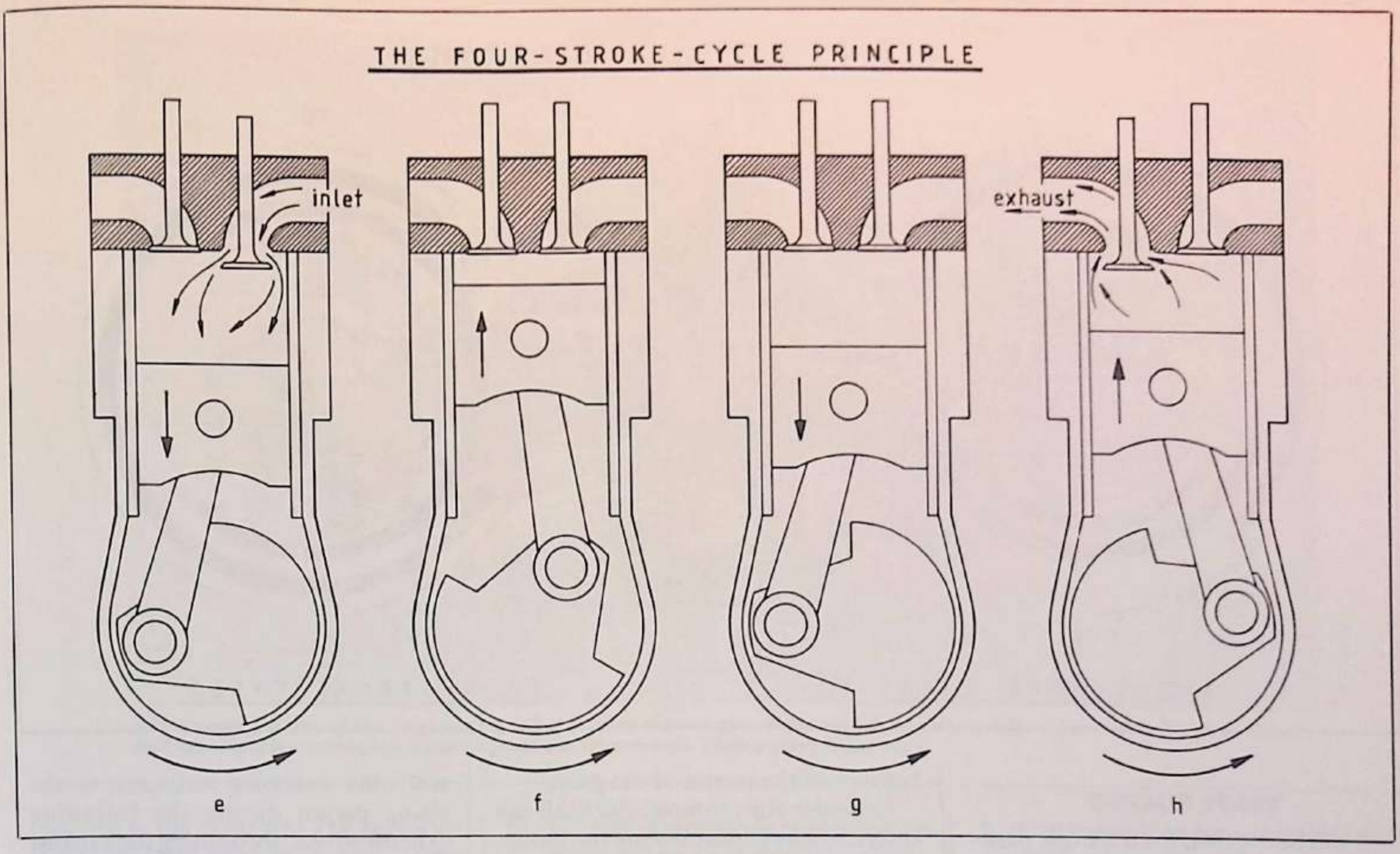
To illustrate how the four-stroke engine differs from the crankcase-charged two-stroke, let us first briefly examine the working principle of the latter. See diagram.

This shows a cross section of a simple side-port crossflow-scavenged two-stroke engine. The engine has no valves. Instead, the fuel/air mixture enters through ports in the cylinder wall which are opened and closed as the piston passes over them. The piston is shown at four different positions in the cycle of operations as follows:

(a) Piston rising. Exhaust and bypass ports closed. Fuel/air mixture being compressed in cylinder, thereby raising its temperature and aiding fuel vaporisation. Inlet port just about to open and admit fresh fuel/air mixture to crankcase wherein pressure has been lowered by rising piston.

(b) Piston at top of its stroke. Mixture confined in small space between piston and cylinder head (combustion chamber) ignited and about to drive piston down for power stroke. Fresh mixture being admitted to crankcase.

(c) Piston approaching bottom of stroke. Power phase nearing completion as exhaust port opens to release exhaust gases. Inlet port closed. Fresh gas compressed in crankcase. Bypass port to cylinder about to open.



(d) Piston at bottom of its stroke. Bypass port open, allowing transfer of fresh gas, previously compressed in crankcase, to enter cylinder, helping to drive out (scavenge) remaining spent gases through exhaust port.

In the three-port or side-port type engine shown, fresh mixture enters the engine through a piston-controlled port in the lower part of the cylinder. This is the method of induction still used by many of the simpler types of two-cycle engine, such as chainsaw engines, but most modern model two-strokes, like the majority of high-performance two-stroke motor-cycle engines, used a form of rotary-valve, enabling the induction period to be lengthened and its opening and closing points to be more appropriately timed. An alternative, mostly used in outboard motors, is the automatic reed-valve, placed between the carburetor and a port in the crankcase wall. Another solution is a light poppet valve, similarly located and actuated by a cam on the crankshaft main journal.

THE FOUR-STROKE CYCLE

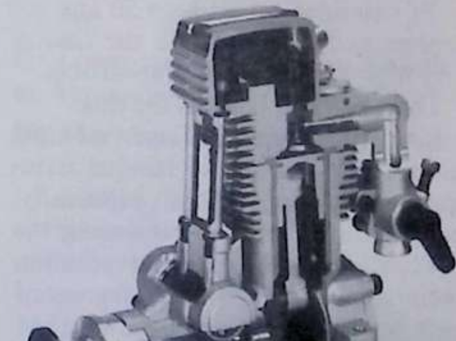
Apart from the fact that the two-stroke engine completes its cycle in two, instead of four, strokes of the piston, the essential difference between a motor of this type and a four-stroke engine, is that the latter has valves (usually in the cylinder head) instead of piston-controlled ports in the cylinder wall, to control the entry and discharge of gases. In some early four-cycle engines, automatic inlet valves were used, but in all modern engines, both inlet and exhaust valves are mechanically operated, opening and closing in a predetermined sequence, as indicated in the diagram.

(e) First downward stroke of the piston. Known, variously, as the induction stroke, admission stroke, inlet stroke, intake stroke or suction stroke. The exhaust valve is closed and the inlet valve is open allowing fuel/air mixture to be drawn into the cylinder.

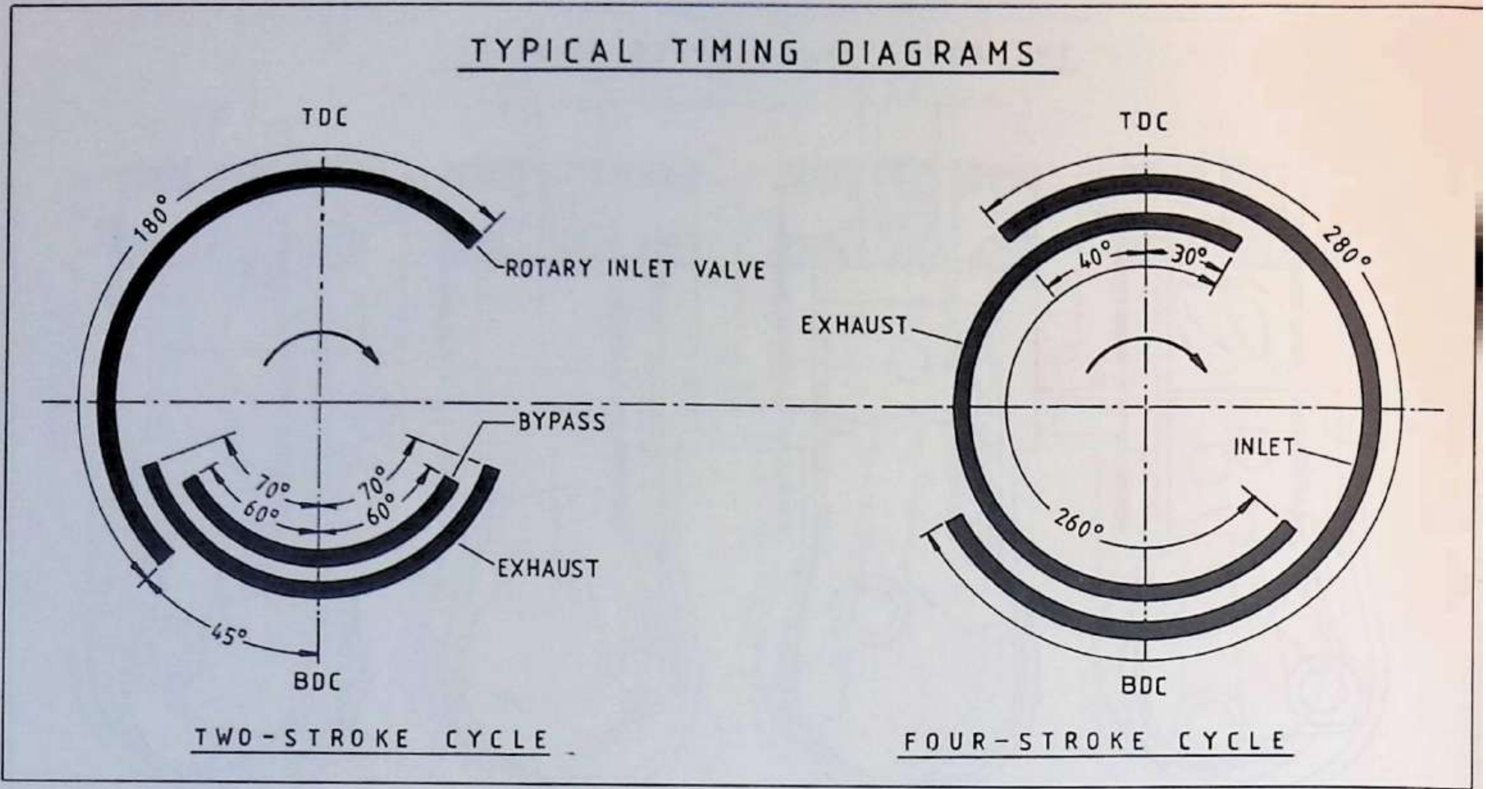
(f) First upward stroke of the piston. Known as the compression stroke. Both valves are closed and fuel/air charge is being compressed into combustion chamber, prior to ignition.

(g) Second downward stroke. Known as the power stroke, firing stroke or expansion stroke. Both valves closed. The compressed gas has been ignited by the ignition plug (spark plug or glowplug). Rapid expansion of burning gas drives piston down. Exhaust valve will open before piston reaches the bottom of its stroke.

(h) Second upward stroke. Known as the exhaust stroke. Exhaust valve open. Burnt gases expelled through exhaust valve. Inlet valve remains closed until just before piston reaches top of its stroke. Exhaust valve closes just after piston begins its next downward stroke.



A cutaway model of the O.S. FS-40. Visible in this photograph are the overhead valve gear, piston, connecting-rod, cylinder-liner, crankshaft, ball-bearings, skew-gear drive to camshaft, cam followers and pushrods. (Photo: Courtesy O.S. Mfg.Co.Ltd.)



VALVE TIMING

It will be realised, from the last paragraph, that, for a short time, both valves are open at the same time. This is known as valve overlap. It might be thought that the valves should always open and close when the piston is at the top or bottom of its stroke. In other words, that the inlet valve would open for exactly 180 degrees of crankshaft rotation while the piston is descending on the induction stroke and that the exhaust valve would open for exactly 180 degrees while the piston is rising on the exhaust stroke. This is not so. It is common, with modern engines, for inlet and exhaust periods to be extended by between 50 and 100 degrees and even more in the case of very high performance four-strokes.

There are two reasons for this.

Firstly, valves do not open or close instantaneously. The orthodox cam-operated poppet-valve, especially, scarcely moves off its seat during the first ten degrees of crankshaft rotation when opening and, after 20 degrees of shaft rotation, may not have reached more than 5 percent of its total lift.

Secondly, even if the valves could be fully opened and fully closed instantaneously, the top and bottom dead center positions would not be the best points at which they should begin operating if the cylinder is to be most effectively scavenged of exhaust gases and recharged with fresh gas. This is because of the inertia of the gases.

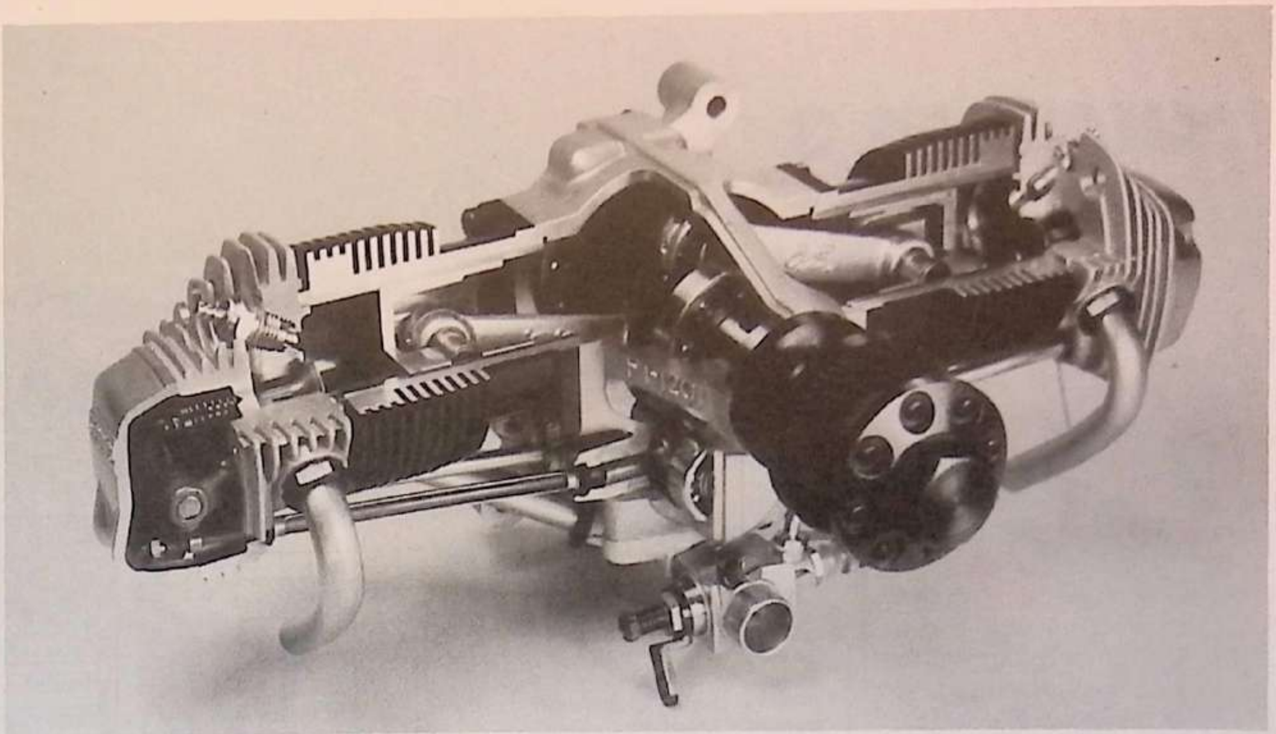
Consider, for example, the fresh gas entering the cylinder during the induction stroke. The downward movement of the piston reduces the pressure in the cylinder and atmospheric pressure causes the fuel/air mixture from the carburetor to enter the cylinder. The inertia of this fresh gas causes it to lag behind the piston initially and it is still accelerating, trying to catch up, when the piston begins to slow down towards the bottom of its stroke. As a result, the momentum of the gas will cause it to continue to enter the cylinder after the bottom-dead-center (BDC) position of the crank is passed and the piston has begun to move upward again — *provided that closure of the inlet valve is suitably delayed.* This, of course, is a most desirable state of affairs since it means that a greater weight of combustible mixture is admitted to the cylinder and this will increase power.

Whereas the closure of the inlet valve is delayed past the BDC position, the opening of the exhaust valve is brought forward. That is to say, the exhaust valve begins to open well before the piston has completed its power stroke.

At first sight, this might appear to be counter-productive since it means that the burning gases are being released before they are fully expanded and their energy fully utilized. The problem here is that if gas pressure is not sufficiently reduced before the piston reaches the bottom of its stroke, it will offer excessive resistance to the rising piston during the following exhaust stroke. By opening the exhaust valve early, movement of gases through the exhaust port is initiated before the piston begins its upward stroke. Gas movement is accelerated through the exhaust system as the piston rises and its momentum creates a negative pressure in the cylinder as the piston slows towards the TDC position. By timing the inlet valve to open before the piston reaches the top of its stroke, this negative pressure will begin drawing the fresh mixture into the cylinder before the piston actually begins its induction stroke.

The opening and closing points of the valves can, therefore, have a marked effect on the engine's *volumetric efficiency* (i.e. the scavenging of spent gases from the cylinder and their replacement by the maximum weight of fresh gas) and high volumetric efficiency is essential to the realisation of high power output. However, the ideal valve timing varies considerably, according to the type of engine under consideration: i.e. whether maximum power output is the designer's number one objective, or whether the ability to function efficiently at lower speeds and at reduced throttle openings is of greater significance.

The actual timing of the opening and closing of the valves is controlled by the shape of the cams that operate them and the movement of these cams



This cutaway model of the original O.S. FT-120 gives a good idea of the layout of a conventional four-cycle flat twin. Small ball-bearing below crankshaft supports front end of camshaft. Timing gears are at rear.

relative to the crankpin. The performance characteristics of a four-stroke engine can be altered quite dramatically by modification of the cams, hence the reason why a special camshaft is one of the first things that a hot-rodder thinks about when uprating a stock automobile engine.

The various types of valve gear will be dealt with in later chapters. Meanwhile, having examined the respective working principles of both four-stroke and two-stroke engines, it is appropriate to conclude this chapter by briefly summarising the advantages and disadvantages of the four-stroke-cycle engine, *vis-a-vis* the crankcase-charged two-stroke, for model use.

Taking the disadvantages first, these are:

1) Greater cost due to more complex construction.
2) Generally, a four-stroke has a lower peak power output than a high-performance two-stroke of the same displacement.
3) Not suitable for ducted fan or high-performance racing type aircraft.
4) Despite developing higher b.m.e.p. (cylinder pressures) four-strokes produce lower mean torque than high performance two-strokes of similar displacement, due to having only half as many power strokes at the same rpm.
5) Glowplug ignition four-strokes are more prone to detonation if run with an over-lean needle setting at full throttle on an excessively heavy load.
6) Higher b.m.e.p. and more widely spaced maximum torque intervals (720 degrees instead of 360 degrees) mean that single-cylinder four-strokes have noticeably less smooth running qualities in the very large sizes, making it desirable to adopt a considerably more expensive twin-cylinder or multi-cylinder layout with four-strokes of over 20cc (1.2 cu in.) displacement.

Four-stroke enthusiasts, however, will consider these disadvantages outweighed by the four-cycle engine's advantages, namely:

1) Lower pitched, much less objectionable exhaust note, due to halving of firing intervals for given rpm.
2) Reduced level of noise emission due to exhaust gases being discharged more gradually over longer period through exhaust valve in cylinder head, instead of being abruptly released at high pressure by piston uncovering large port in cylinder wall.
3) Can be made to operate quietly with relatively small muffler and without undue loss of power.
4) Higher volumetric efficiency due to more complete charging of cylinder than is possible with naturally aspirated crankcase-charged two-stroke.
5) Delivers its maximum power at shaft speeds more compatible with the majority of propeller-driven radio-controlled model aircraft.
6) Greater flexibility due to reduced charge dilution at small throttle openings.
7) Cooler running due to halving of number of firing strokes for given rpm.
8) Lower specific fuel consumption.
9) Generally cleaner running.
10) More "realistic" running characteristics and, with twin-cylinder and multi-cylinder engines, more scale-like appearance.

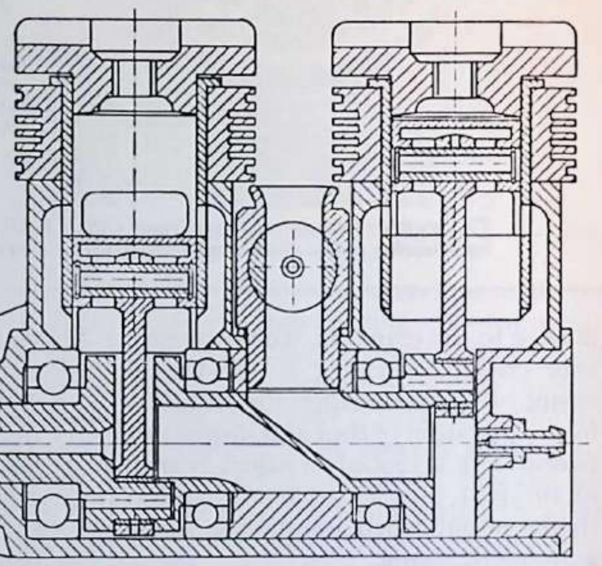
CHAPTER 3

Types Of Four-Stroke Engines

In the interests of simplicity and a moderate selling price, the vast majority of model engines have always been of the single-cylinder type. However, whereas twin and multi-cylinder engines are quite rare in the two-stroke-cycle classes, they are becoming much more widely available among the four-strokes. In fact, about thirty percent of the various types of four-stroke engines manufactured since 1976 have had more than one cylinder.

There are good reasons for dividing an engine's total swept volume between two or more cylinders. They include better balance, reduced torque fluctuations (and, in consequence, much smoother running), a quieter exhaust, greater realism in appearance and operation and, in some cases, easier or more complete containment within a scale cowling.

Of course, these advantages are not the exclusive province of the four-stroke. They also apply, in greater or lesser measure, to two-strokes. Therefore, a brief examination of the various configurations, as they apply to both two-strokes and four-strokes, is called for.



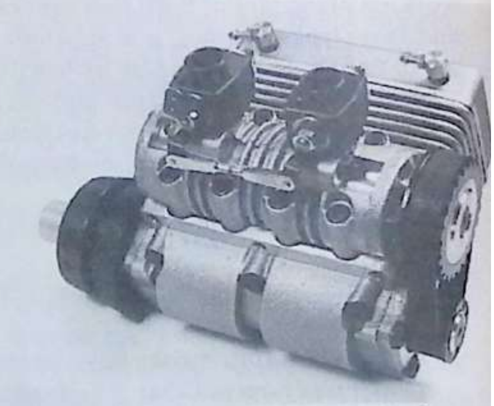
A good example of an alternate-firing inline twin-cylinder two-stroke, the Italian B&C 61. Note how a centrally-located shaft rotary-valve system is used to feed separate crankcase chambers alternately. (Drawing: Courtesy G. Bertella.)

INLINE TWINS—TWO-STROKE

The inline twin has its cylinders placed one behind the other. In a two-stroke engine, this invariably means that the cylinders fire alternately, at equally spaced intervals. The two cranks, always located at 180 degrees to each other, are separated by a center bearing that is placed in a wall dividing the crankcase into separate front and rear gas-tight chambers. This separation is necessary in order that each cylinder can be fed from its own primary compression chamber. In effect, the alternate-firing inline two-stroke twin is two complete single-cylinder engines coupled together in tandem.

Such an engine can be very smooth running. As one piston descends, the other is rising, so that excellent balance of the reciprocating parts is achieved at the expense of a slight rocking couple along the crankshaft axis. Furthermore, torque fluctuations are markedly reduced, since firing strokes now occur every half revolution of the crankshaft, instead of every complete revolution, again contributing to reduced vibration.

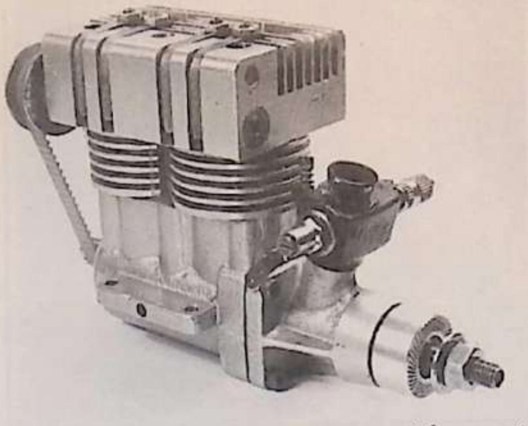
The disadvantages of the inline twin are its extra length (usually increasing overall weight compared with a single-cylinder two-stroke of similar displacement) and the tendency for the rear cylinder (in an air-cooled engine) to run hot. It also has a higher pitched exhaust note, although noise levels can be lowered by exhausting both cylinders into a common expansion chamber muffler to reduce pressure fluctuations.



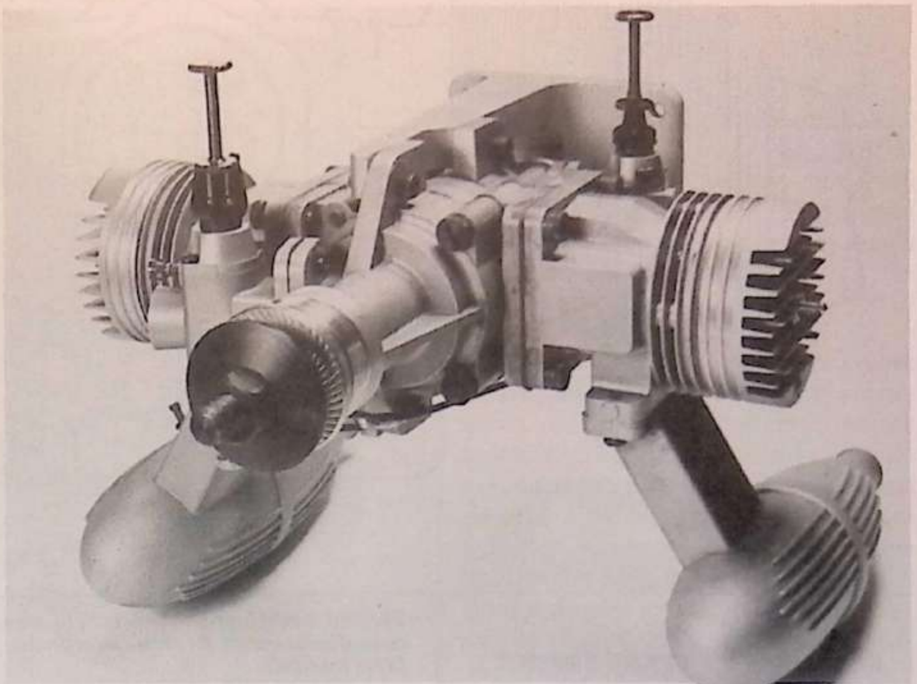
Another Italian two-stroke inline twin, this time high-performance marine unit with separa toothed-belt driven twin rotary-valves. Now collectors' item, the 1.2 cu in. OPS B-20 w designed by Gualtiero Picco in 1971.

INLINE TWINS—FOUR-STROKE

An inline four-stroke twin with its crankpins at 180 degrees, as in an inline two-stroke twin, achieves similarly good mechanical balance. However, since each cylinder fires only once every two revolutions of the crankshaft,



Inline four-stroke twins are uncommon at the present time. This prototype Green-CAP .61 cu in. engine is of the parallel-twin type in which the pistons travel up and down together while firing alternately at equal intervals to give smoother torque delivery.



Two-stroke flat-twins, like this 1.2 cu in. American Fox Twin, have excellent balance. Use of twin rotary-valves and twin carburetors is an attempt to overcome the two-stroke flat-twin's uneven cylinder charging tendencies.

torque impulses, while reduced in magnitude compared with a single cylinder engine, will not be equally spaced. They will, in fact, occur at intervals that alternate between 180 degrees and 540 degrees of crank rotation.

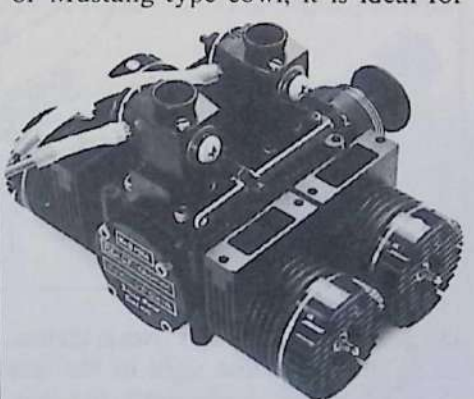
FOUR-STROKE PARALLEL TWIN

There is an alternative inline twin four-stroke set-up. This is to have the crankpins in line, instead of opposed at 180 degrees to each other, so that the pistons travel up and down together, but with the operating cycles phased 360 degrees apart to give regularly spaced torque impulses. With this arrangement, the reciprocating masses remain unbalanced, as in a single cylinder engine and a rocking couple still remains as a result of the alternate fore and aft firing strokes, but, compared with a single cylinder engine of equal displacement, the parallel twin has the advantages of smoother torque delivery and an attenuated exhaust noise level. Motor cycle buffs may recall that the Triumph Speed-Twin engine was of the parallel twin type.

Generally speaking, the inline twin four-stroke does not have a great deal to recommend it for model aircraft use, although it does have the merit of a low frontal area. A notably compact engine of this type was the 10cc (0.61 cu in.) overhead camshaft prototype engine built in England by D.F. Green and illustrated here.

HORIZONTALLY OPPOSED TWINS

The horizontally-opposed or "flat" twin has long been the most favored type of twin cylinder engine for model aircraft. While, for scale models, it is not the right shape to fit into a Spitfire or Mustang type cowl, it is ideal for



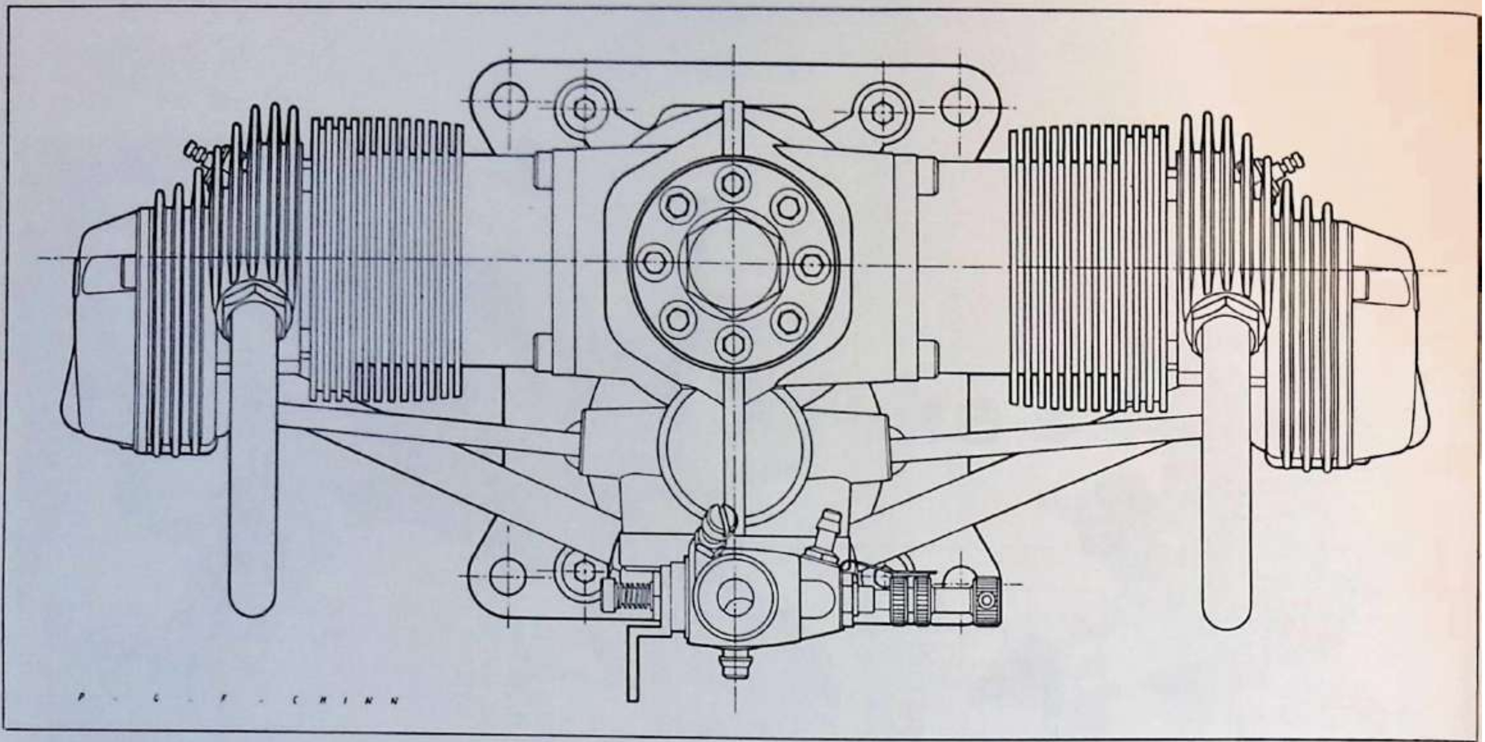
Multi-cylinder model two-stroke engines are rare. A most notable example was this very compact and smooth-running 1.2 cu in. flat-four designed by Louis Ross in 1971 and manufactured by the Northfield Precision Instrument Corporation of Island Park, NY.

the typical flat-four and flat-six type installation (e.g. Continental, Lycoming, etc.) of various powers used by lightplanes and by modern private and light executive aircraft. It can also be accommodated in a radial cowl a little more easily than a single-cylinder four-stroke of similar displacement.

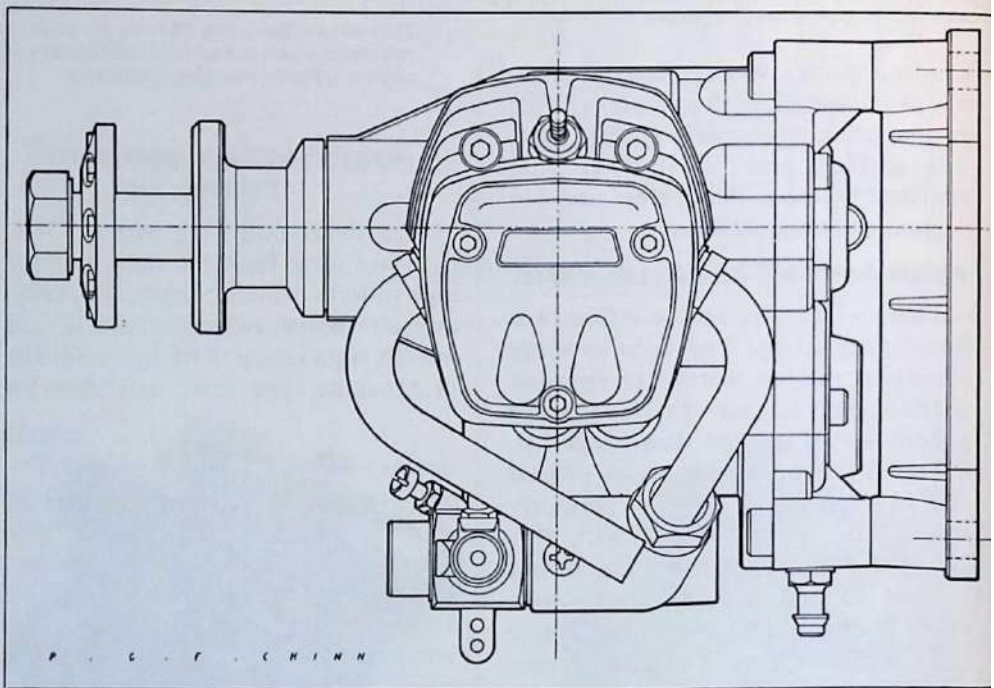
TWO-STROKE FLAT TWINS

In a horizontally-opposed two-stroke, the crankpins are, of course, placed at 180 degrees to each other and near perfect balance can be achieved by virtue of the fact that the reciprocating masses move inwardly and outwardly together, during which time they also maintain identical connecting-rod angles so that piston acceleration and deceleration are precisely matched, further contributing to smoothness. A slight rocking couple remains, but this is less than with an inline two-stroke twin, since the crankpins are separated only by a flying web (not by a center bearing and two webs) so that cylinder offset is much reduced. The cylinders are equally exposed to the cooling airstream and, since the engine uses a common crank chamber, it can be made shorter and lighter.

There are just two disadvantages with this layout, compared with an inline two-stroke twin. Firstly, as the cylinders fire simultaneously, torque impulses are at intervals of 360 degrees instead of 180 degrees. Secondly, with a single crank chamber supplying both cylinders, it is difficult to ensure that both cylinders are always equally charged. This can sometimes lead to one cylinder cutting out prematurely when the engine is throttled down.



The first model four-stroke twin to be manufactured in quantity, the original O.S. FT-120 Gemini of 1. cu in. displacement. It follows an orthodox flat-twin configuration with two-throw crankshaft and equ firing intervals.



FOUR-STROKE FLAT TWINS

Here, as in a flat-twin two-stroke, excellent primary balance, with only a small rocking couple, is achieved. The cylinders are timed to fire alternately, so that torque fluctuations occur regularly at 360 degree intervals. As the engine is not charged through its crankcase, distribution of mixture to the cylinders is usually more even than with a two-stroke but, if the designer so wishes, separate carburetors can be used with a four-stroke to ensure that each cylinder receives the optimum mixture strength in accordance with its precise requirements.

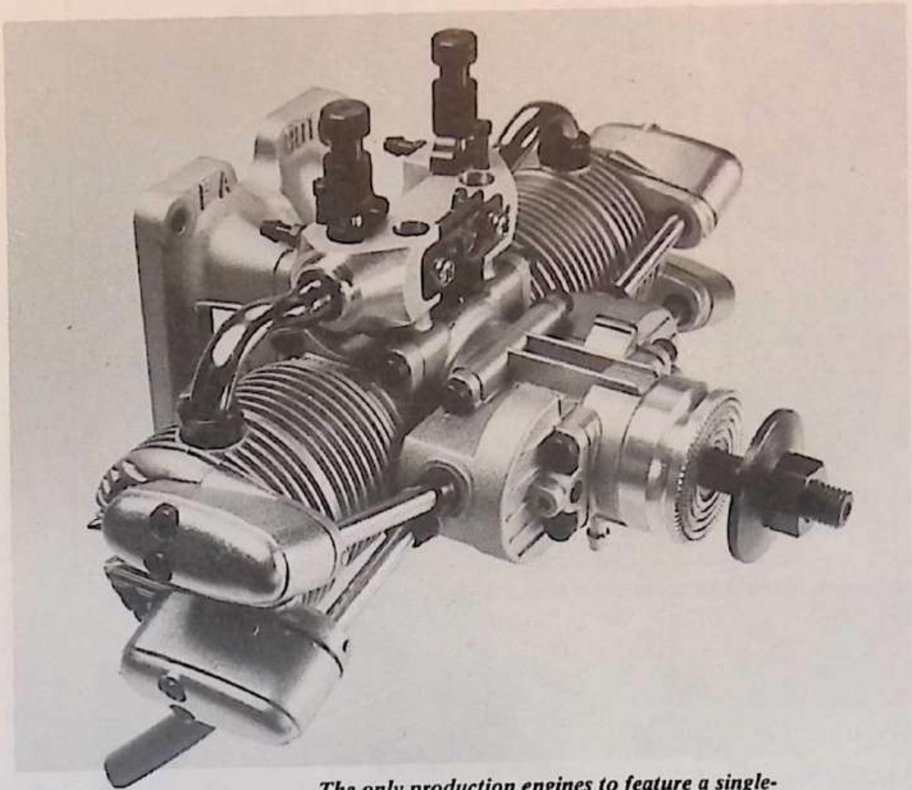
The types of flat-twins so far discussed use a two-throw crankshaft supported in main bearings front and rear, a layout that is common to all full-sized flat-twin and almost all model flat-twin four-strokes.

SINGLE-CRANK FLAT TWINS

There is, however, an alternative flat-twin arrangement for four-strokes. This is where both connecting-rods are coupled to the same crankpin. It means that both pistons are always travelling in the same direction, side-to-side, instead of in opposite directions, and the reciprocating masses no longer balance each other. Furthermore, the power strokes are not regularly spaced, but must occur, alternately, at intervals of 180 and 540 degrees of crank rotation.

This combination of two vibration producing features was sufficient to persuade the designers of full-sized flat-twin engines to abandon this particular design long ago. Nevertheless, one should not lose sight of the fact that, while the single-crank flat-twin lacks the refinement of the conventional two-throw flat-twin, it still has an advantage over the single-cylinder four-stroke engine. The latter combines poor engine balance with torque fluctuations that are more severe than for any other type of engine, plus large exhaust pressure variations that make silencing more difficult. The single-crank flat-twin's torque impulses, though irregular, are halved in intensity, as is each cylinder's release of exhaust gases.

This may not seem to be sufficient reason for giving any attention to the single-crank flat-twin, until one considers that it does offer a much simpler and therefore cheaper approach to twin-cylinder four-stroke design. The crankshaft needs only to be of a simple overhung crank type, like that of a single cylinder engine. There is no need for a rear main bearing, or for the lower ends of the connecting-rods to have detachable bearing caps. By using a fork and blade arrangement, the two connecting-rods can operate in the same plane, enabling the cylinders to have a common axis, thereby elimina-



The only production engines to feature a single-crank flat-twin layout are the Saito FA-80T (shown) and FA-90T.

ting the usual small rocking couple. Lastly, this type of engine can be made a little more compact and, therefore, lighter.

The Japanese Saito company adopted the single-crank flat-twin layout for its 13cc FA-80T and 15cc FA-90T models. These relatively small twins run very well and with quite acceptable levels of vibration. For the very much larger 45cc Saito FA-270T, however, the same manufacturer uses the more orthodox flat-twin arrangement based on a two-throw crankshaft.

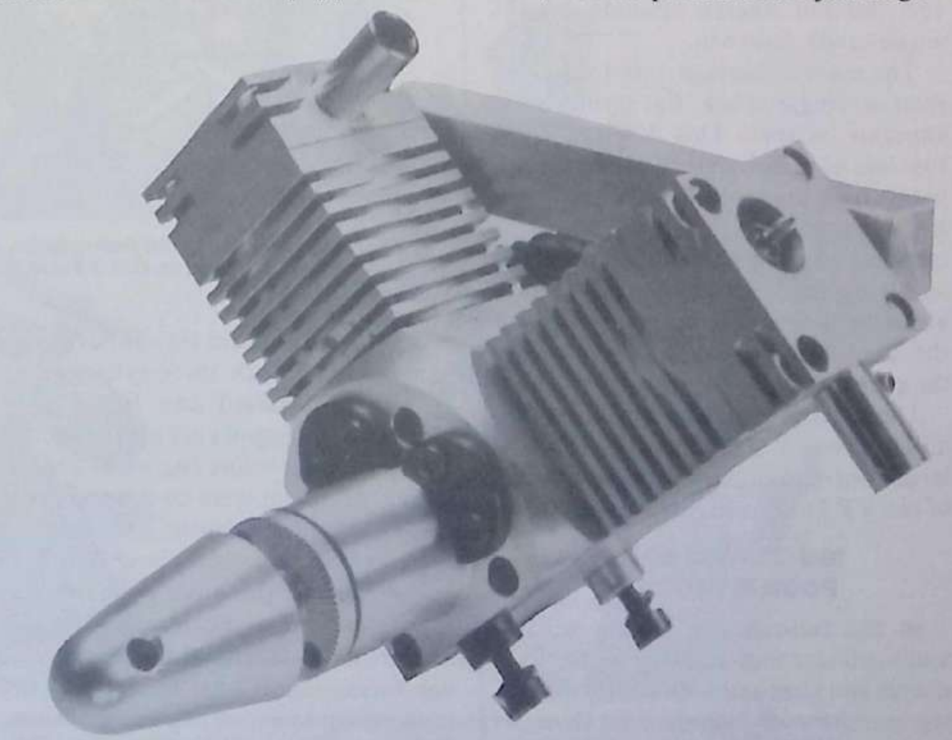
One quite different problem which arises with a single-crank flat-twin is that, because the pistons are always moving in the same direction, the effective volume of the crank chamber always remains the same. This is a disadvantage because the small quantity of blowby gases that inevitably escape from the combustion chamber, past the pistons and into the crankcase, tend to accumulate and condense. Here their acid content has a corrosive effect on the many adjacent steel parts of the engine. By contrast, the pumping action of the pistons of a conventional flat-twin is effective in scavenging most of these contaminants from the interior of the engine—although not all are removed and precautions need to be taken to inhibit corrosion with all four-strokes. (See Chapter 12)

To compensate for their lack of crankcase self-scavenging, the Saito FA-80T and FA-90T are equipped with a small rotary compressor built into the rear of the crankcase, which pressurises the crank chamber with fresh air. Contaminants, both gaseous and liquid, are ejected through a nipple below the crankcase nose.

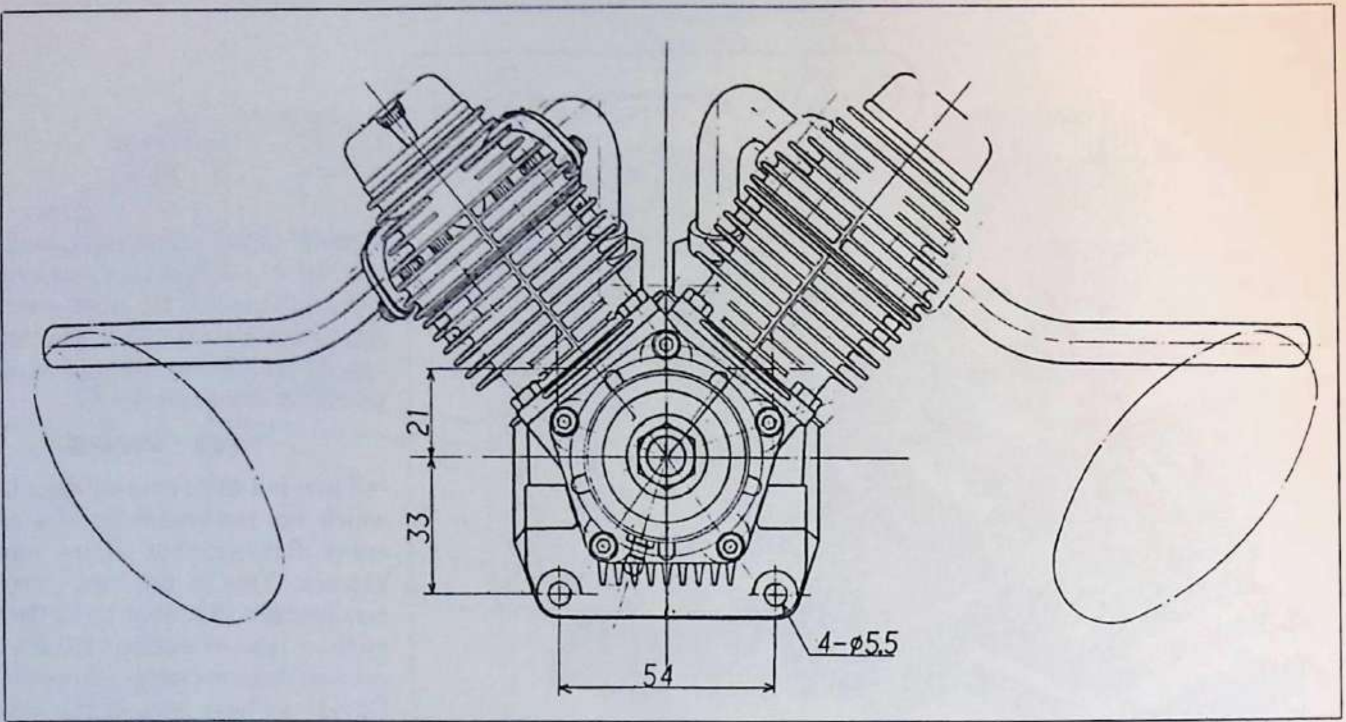
"VEE" TWINS

There is a third twin-cylinder layout which has the simplicity of a single-crank flat-twin but offers superior balance. This is the "vee" twin, an arrangement that used to be the most popular type of engine used for twin-cylinder motor-cycles. (Most Harley-Davidsons have been of this type.) It does not have an ideal shape for scale model aircraft in that it does not conveniently fit into either an inline or a flat type cowl, being more suited to a radial cowl, but it does have the advantage of being not too expensive to manufacture.

Vee-twin model four-strokes have appeared in the shape of the 20cc (1.2 cu in.) Schillings PL twin from Germany and the 30cc (1.8 cu in.) Magnum 182V and 20cc (1.2 cu in.) Laser Twin both from Great Britain. In Austria, the firm of *Dylla & Rosner Motoren* also made a vee-twin in the late nineteen-seventies. This, like the production Dylla single-



The Austrian Dylla .72 cu in. Vee-Twin rotary-valve four-stroke was highly unusual in having bevel-gear driven rotating cylinder liners.



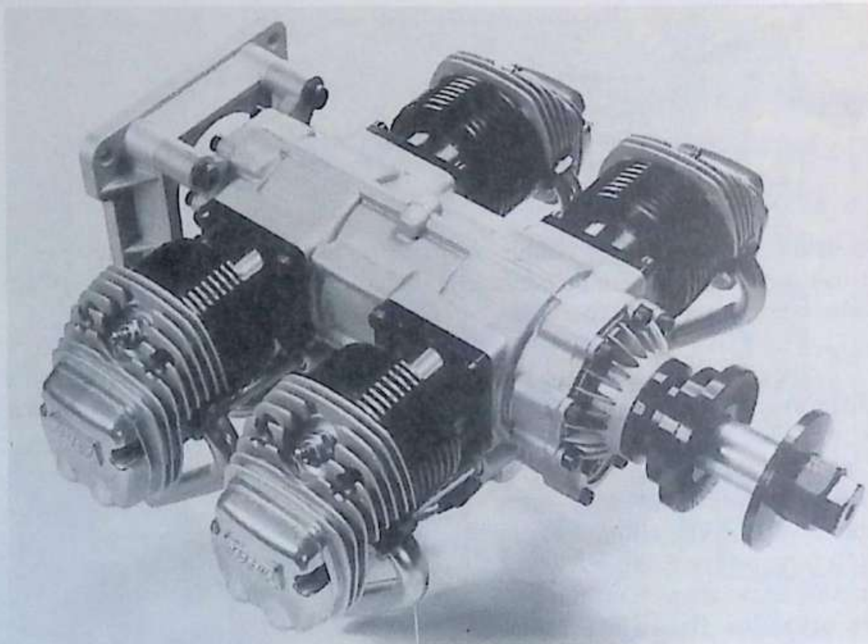
Factory sketch of the Enya VT-240, the first model vee-twin four-stroke to use other than a 90-degree angle between the cylinder axes. (Drawing: Courtesy Enya Metal Products Co.Ltd.)

cylinder engines, employed the highly unusual feature of a rotary-valve in which the entire cylinder liner revolved. The Dylla Twin, which had a displacement of 11.75cc or 0.72 cu in., does not seem to have progressed much beyond the prototype stage.

All the model vee-twins mentioned have their cylinder axes at 90 degrees and the resulting firing intervals are, alternately, 270 degrees and 450 degrees of crank angle; still unequal but producing smoother torque delivery than the 180-540 degree spacing of the single-crank flat-twin.

The main advantage of the vee-twin, over a single-crank flat-twin, is its superior balance. This is because the two sets of reciprocating masses, moving at right angles to each other, result in primary unbalanced forces that combine to produce a constant radial revolving force and this can be balanced by means of a counterweight on the crankweb diametrically opposite the crankpin.

The Enya company has also adopted a vee-twin layout for its entry into the large four-stroke market in the shape of the VT-240 model. (See Chapter 1)

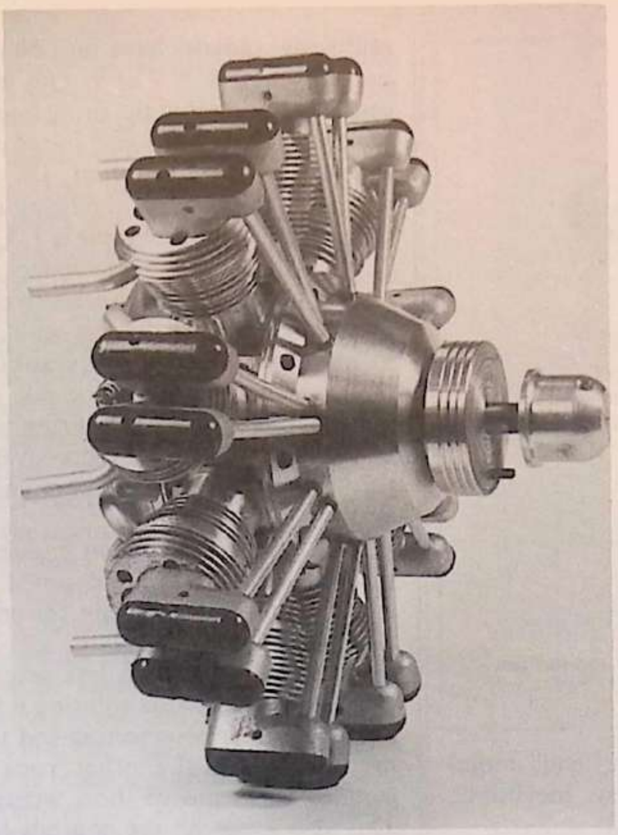


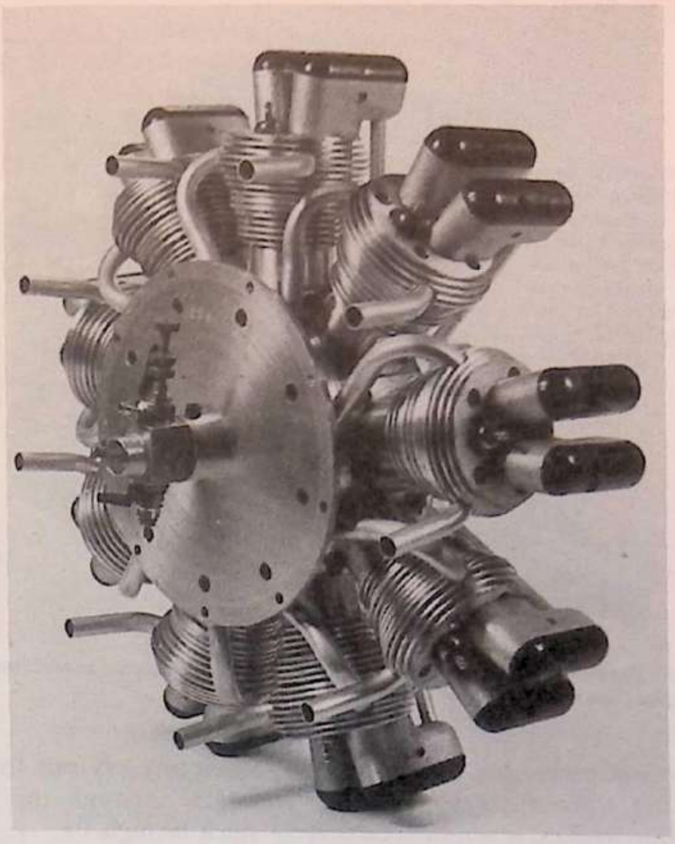
The first production model four-cylinder, horizontally-opposed four-stroke; the realistic-looking 2.4 cu in. O.S. FF-240 'Pegasus'.

MULTI-CYLINDER FOUR-STROKES

In the full-size i.c. engine world, multi-cylinder four-stroke motors of all shapes and sizes and with widely differing numbers of cylinders in various formations have been manufactured. Commonly used in automobile manufacture are four and six cylinder inline engines, but both three-cylinder (e.g. Suzuki, Daihatsu) and five-cylinder (Audi) inline engines are also produced. Eight-cylinder inline engines (Packard, Buick, Hudson) were commonplace in the U.S. in the Twenties and Thirties, but these straight-eights have now been superseded by the more compact vee-eight type whose shorter crankshaft is less prone to torsional vibration. The vee formation is also used for many modern six-cylinder engines and some fours. Vee-twelve engines are still made for a few high performance cars (e.g. Jaguar) but vee-sixteen cylinder engines, like those that graced Cadillac and Marmon classics, are a thing of the past. Horizontally opposed motors are less widely used in automotive engineering. They have mostly been confined to two and four-cylinder units used in a few European mass-produced small cars (e.g. Citroen, Volkswagen) or, at the other end of the scale, to high-performance six, eight and twelve cylinder engines for sports and racing cars (e.g. Porsche, Alfa-Romeo, Ferrari).

In the aircraft world, gas turbines

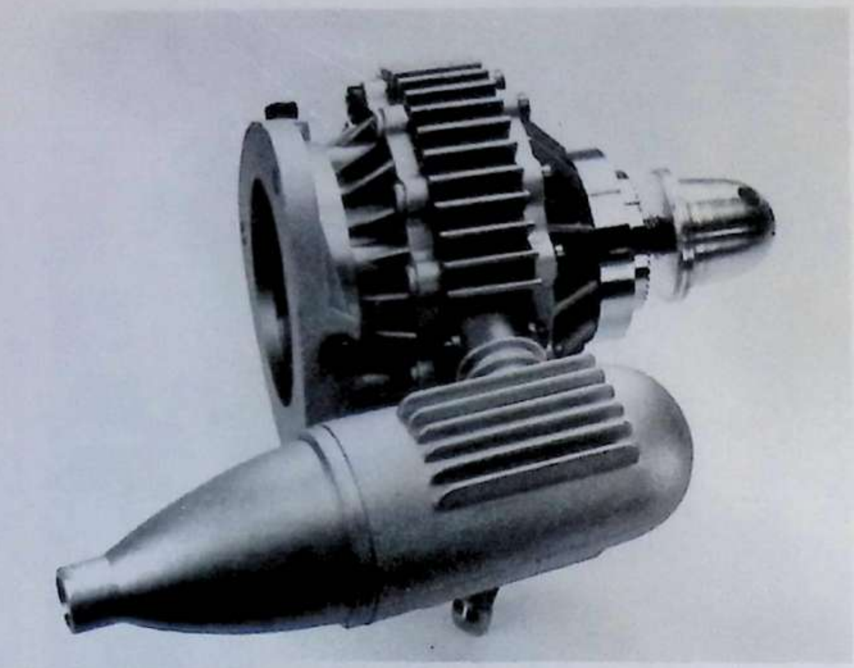




(turbojet, turbofan and turboprop) have largely replaced big reciprocating engines for military and commercial use. Powerful vee-twelves, like the Rolls-Royce Merlin, Allison V-1710 and Daimler-Benz DB-601, are no longer manufactured, nor are massive twin-row and multi-row radials (Wright, Pratt & Whitney, Bristol) of up to twenty-eight cylinders, but a few smaller radials remain. The four-cylinder and six-cylinder inline engines for light and medium sized aircraft that were used in the pre-jet age have also mostly given way to four and six cylinder horizontally-opposed motors—

The first 9-cylinder radial engine to be offered to the model builder: the American-made 3.6 cu in. Technopower 'Nine' Radial. It has a diameter of 8¾ inches and a relatively modest weight of 4.8 lb.

Beautifully-made three-cylinder four-stroke by Gerald Smith, who has been building model engines for 65 years. Osprey 2.13 cu in. radial runs on gasoline mixture with spark-ignition via magneto of Gerald Smith's own design and construction. Turns 22x10 prop at 4,000 rpm. Idles at 500 rpm. (Photos: Courtesy Gerald Smith)



O.S. Type 49-PI Wankel engine, the world's only production model rotary combustion engine. See Chapter 10 for details.

notably Continental and Lycoming.

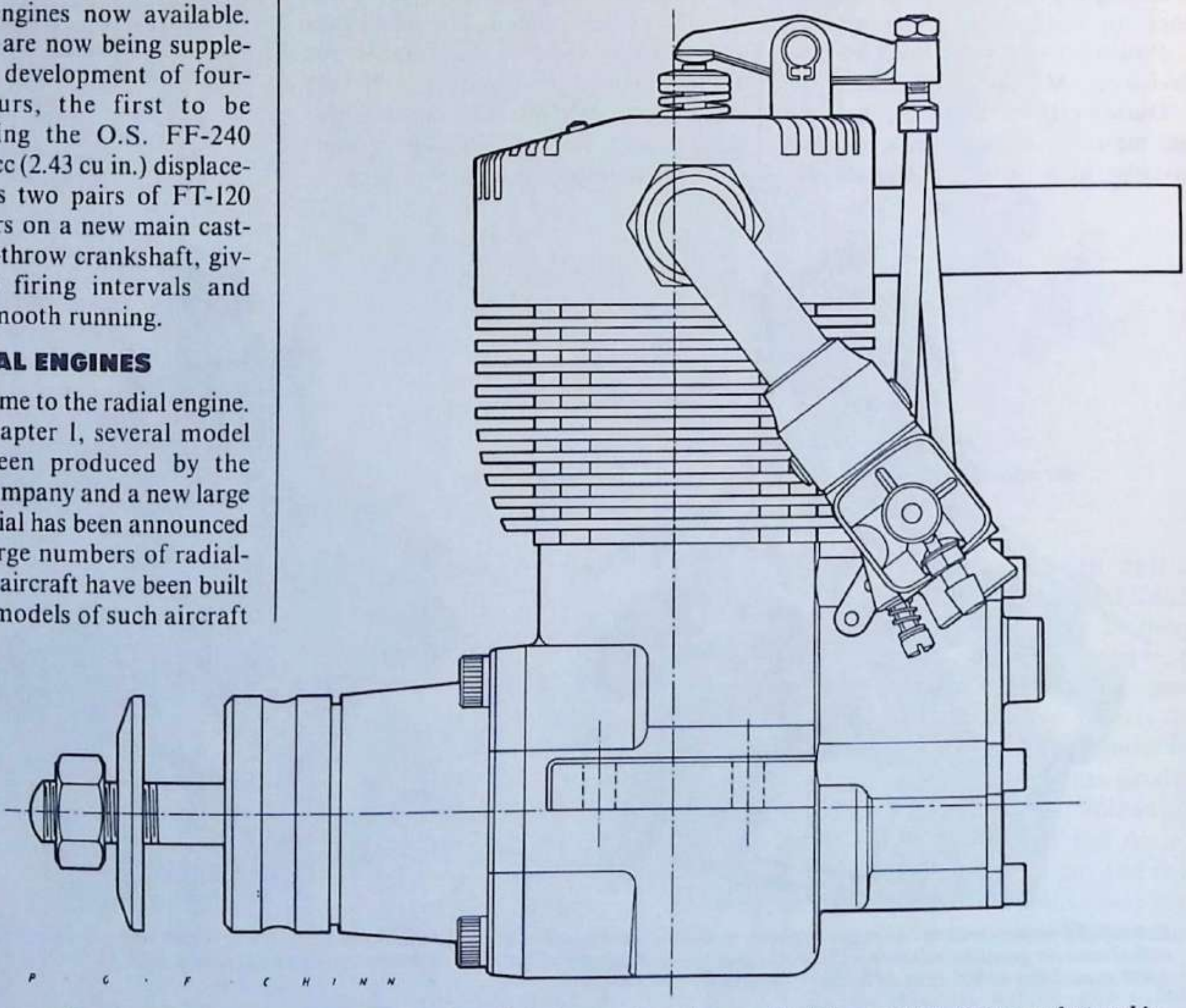
Relating these facts to available model four-strokes, it will be seen that scale models of the last mentioned types of aircraft are reasonably well catered for by the various horizontally-opposed twin cylinder engines now available. However, these are now being supplemented by the development of four-stroke flat-fours, the first to be announced being the O.S. FF-240 Pegasus of 39.8cc (2.43 cu in.) displacement. This uses two pairs of FT-120 Gemini cylinders on a new main casting with a four-throw crankshaft, giving 180-degree firing intervals and exceptionally smooth running.

RADIAL ENGINES

Finally, we come to the radial engine. As noted in Chapter 1, several model radials have been produced by the Technopower company and a new large five-cylinder radial has been announced by O.S. Very large numbers of radial-engined full-size aircraft have been built in the past and models of such aircraft obviously cry out for a "real" radial engine, though the cost, inevitably, must be high.

All single row radial four-stroke engines (and each row of twin row or multi row radials) have an odd number of cylinders: 5, 7 or 9. This is necessary to ensure that the firing intervals are equally spaced during the two revolutions of the crankshaft, i.e. for a seven-cylinder engine, the firing order through the complete cycle is 1, 3, 5, 7, 2, 4, 6. (Of course, the cylinders must not be timed to fire consecutively. If they were, all the cylinders would fire in one revolution of the crankshaft, after which there would be one complete "idling" revolution during which all the cylinders would successively go through admission and compression strokes only.)

In a (single row) radial engine, all the connecting-rods are coupled to a single crankpin. Obviously, the crankpin cannot accommodate, say, five connecting-rods (much less seven or nine), so the orthodox solution is for a special "master" connecting-rod to be used to which the other rods are coupled by means of short wristpins. This also keeps all the conrods (and, therefore, the cylinders) in the same plane. With suitable counterbalancing



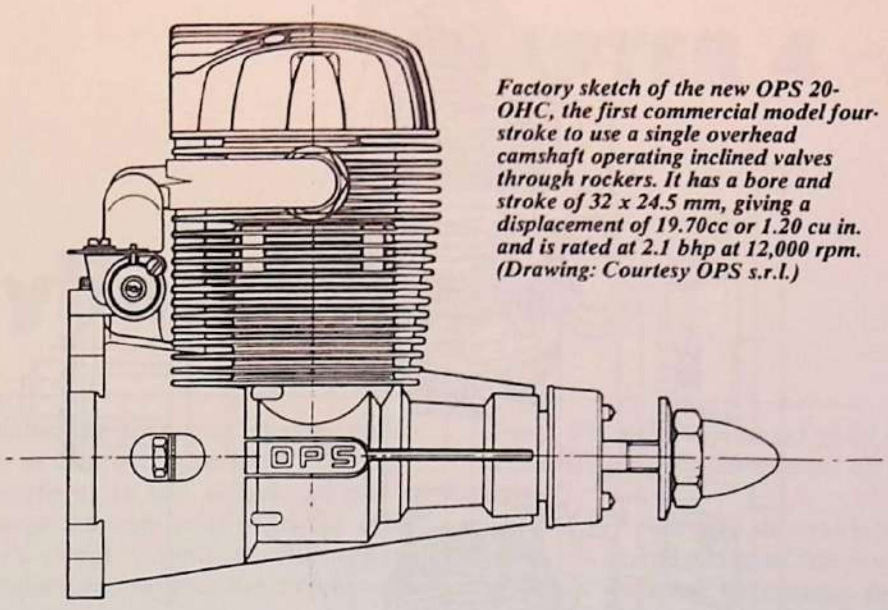
Among the first of the larger displacement (15cc) single-cylinder four-cycle engines was the Magnum 91-S, first manufactured in 1981. An example of essentially orthodox design, it had exposed overhead valve gear, a plain discoid combustion chamber and a spur gear driven rear camshaft with symmetrical timing allowing the engine to be run in either direction. This drawing is of the 1983 Mk.II model.

weights added to the crankshaft, the radial engine is a well balanced and smooth running unit.

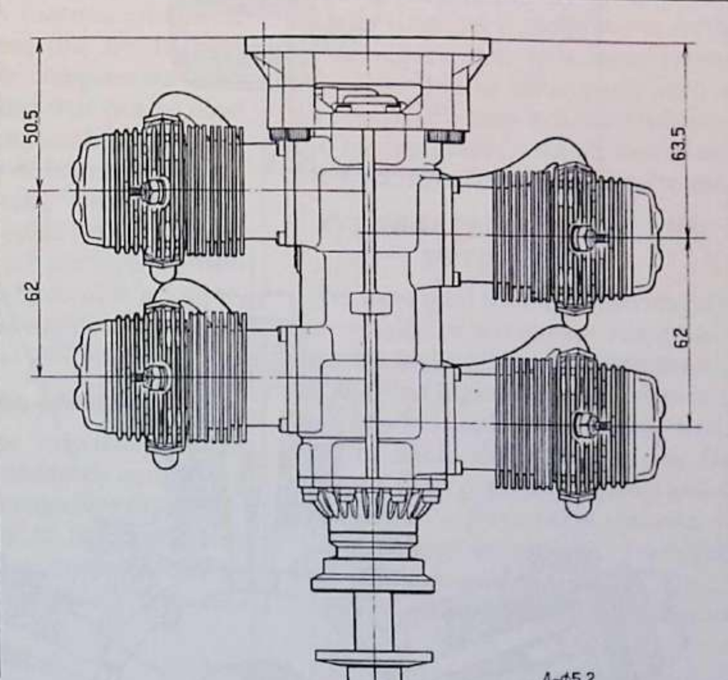
In full size radials, the normal method of supplying mixture to the individual inlet pipes is via a circular manifold, drawing fuel and air from a single carburetor or, in the case of the more powerful types, through an annular chamber into which air and injected fuel is forced from a supercharger. A simpler arrangement commonly used for model radials is to employ the crankcase as a delivery chamber, the carburetor being mounted in its center and the inlet pipes to the cylinders radiating from it.

A beneficial by-product of this system is that, drawing the fresh mixture through the crankcase in this way also helps to remove corrosive blowby gases. As in the case of the single-crank flat-twin, the radial's crank chamber volume remains constant and, without this scavenging action, blowby gases would remain, to condense and form harmful acids.

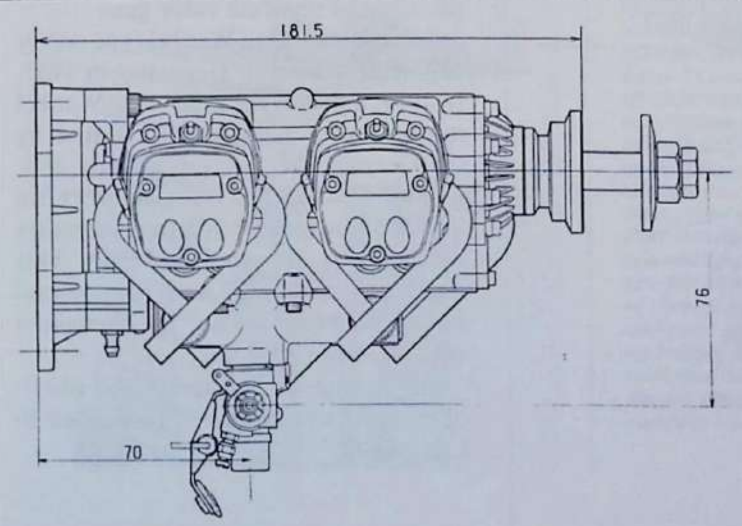
Incidentally, the earliest radial aircraft engines did not have their cylinders radiating at equal intervals all round the crankcase: instead, the cylinders were arranged in a fan-like formation so that their axes were inclined upwards from the crankshaft. This was because of designers' early fears about cylinders disposed below the crankcase becoming flooded with oil. Typical of such engines was the three-cylinder Anzani used in the historic Bleriot monoplane which made the first flight across the English Channel from France to England in 1909. This engine had a bore and stroke of 100 x 150 mm and was rated at 25 horsepower at

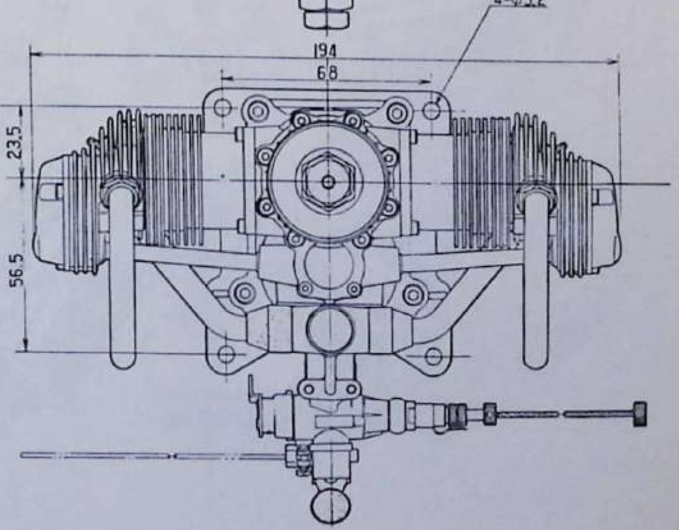


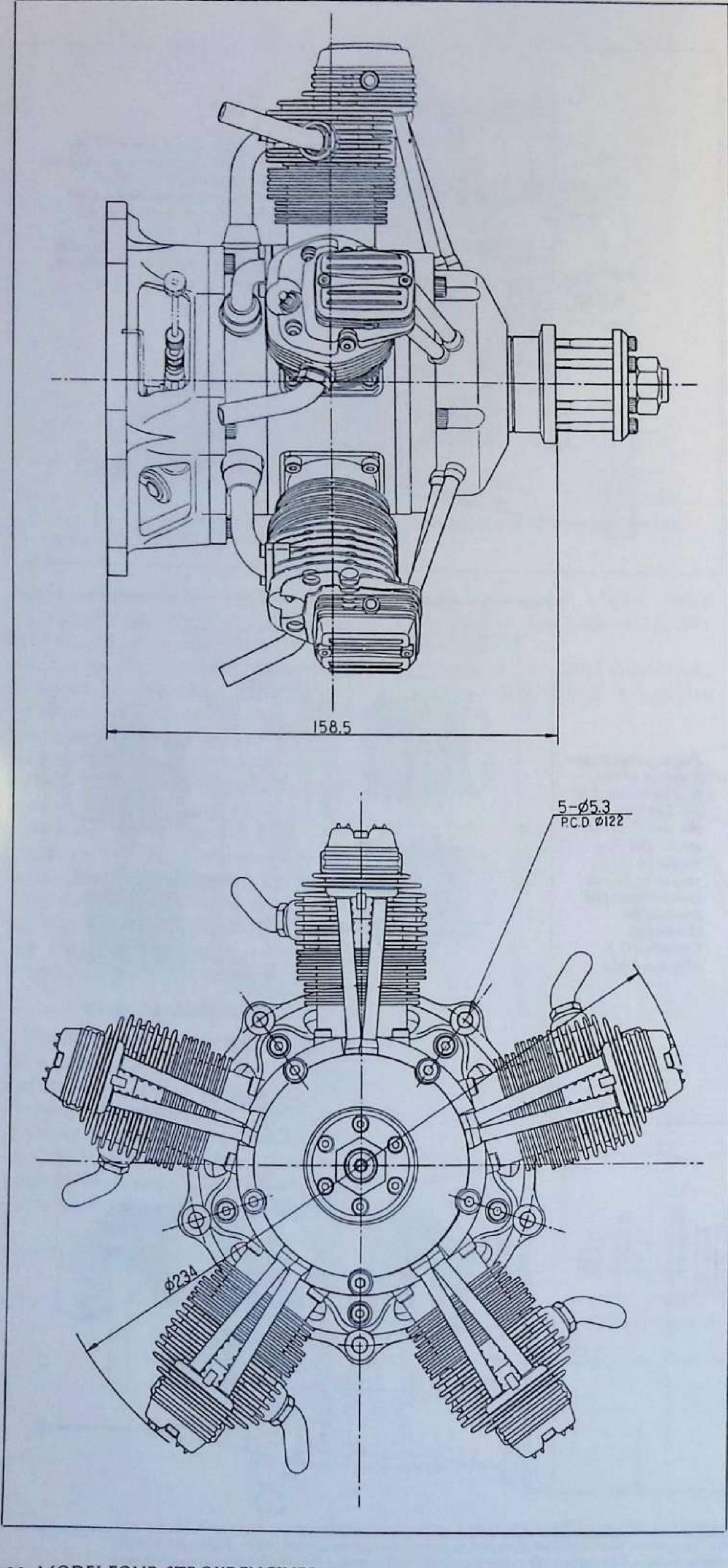
Factory sketch of the new OPS 20-OHC, the first commercial model four-stroke to use a single overhead camshaft operating inclined valves through rockers. It has a bore and stroke of 32 x 24.5 mm, giving a displacement of 19.70cc or 1.20 cu in. and is rated at 2.1 bhp at 12,000 rpm. (Drawing: Courtesy OPS s.r.l.)



Factory three-view drawing of the four-cylinder O.S. FF-240 'Pegasus', the first four-stroke flat-four model aircraft engine to be put into commercial production. (Drawing: Courtesy O.S. Mfg.Co.Ltd.)







Factory drawings of the O.S. FR5-300 five-cylinder radial engine. With a total displacement of just over 3.0 cu in., this is the largest engine yet built by the 50-year-old O.S. company. (Drawing: Courtesy O.S. Mfg.Co.Ltd.)

1,400 rpm, which, for a displacement of 3,534cc or nearly 216 cu in., is indicative of the modest performance levels of engines at that time.

ROTARY ENGINES

Another variant of the radial engine that was widely used during the first two decades of full-size flying, was the rotary engine. This was a radial motor in which the crankshaft remained stationary and the rest of the engine rotated around it, complete with propeller. The idea was that the engine was more effectively cooled and could be made lighter. No model engines of this type have been produced commercially, although some very fine reduced-scale working replicas have been made by model engineers from time to time.

Nowadays, a rotary engine generally means something quite different: namely a Wankel type rotary combustion engine. In the Wankel, the conventional piston and cylinder are replaced by a highly ingenious arrangement of a three-sided rotor, rotating eccentrically within an epitrochoidal shaped chamber, to produce induction, compression, expansion and exhaust phases like a four-stroke, but without the complication of separate valve gear.

The first working Wankel type rotary engine appeared in Germany in 1957. In 1967, a prototype miniature Wankel motor was publicly demonstrated by the German Graupner company and, two years later, the O.S.-Graupner 5cc Wankel motor was put into production by the O.S. company in Japan. This engine, the first and only commercial model Wankel to date, has remained in production ever since.

An account of the design and development of this engine is contained in Chapter 10.

CHAPTER 4

The Cylinder Head

Bizarre as it might sound, the heart of a modern four-stroke-cycle engine is really in its head. That is to say, the cylinder head, with its combustion chamber, ports and valves, must be regarded as the engine's most important component. No other part of the four-cycle internal combustion engine has contributed so much to its evolution and enabled it to reach such heights of efficiency and performance.

The power developed by any i.c. engine is primarily dependent on: (a) its *volumetric efficiency*, (b) its *thermal efficiency* and (c) its *mechanical efficiency*. The design of the four-stroke's cylinder head and valve gear affects the first two of these very considerably; the third, less so.

VOLUMETRIC EFFICIENCY

A normally aspirated (i.e. non-supercharged) i.c. engine never draws in as much air as is indicated by the actual swept volume of the cylinder. This is because of the restrictions on gas flow imposed by the engine's gas passages and ports and also because the fresh charge is preheated and expanded as it enters the hot engine, thereby reducing its density. Volumetric efficiency, therefore, is the actual weight of charge induced, relative to the cylinder's swept volume at atmospheric temperature and pressure, expressed as a percentage.

THERMAL EFFICIENCY

To achieve high thermal efficiency, the main requirements are (a) the highest practicable compression-ratio (i.e. the highest ratio that can be used without *detonation* occurring) and (b) the minimum loss of heat to the combustion chamber walls. The former can be influenced by (apart from choice of fuel) the design of the combustion chamber; the latter by its dimensions—i.e. the total surface area of the walls through which heat will be lost.

MECHANICAL EFFICIENCY

The mechanical efficiency of an engine can be expressed by comparing its actual *brake horsepower* (bhp) output, as developed at the crankshaft (and measured on a dynamometer or "brake") with the (higher) *indicated horsepower* (ihp) calculated from the mean effective pressure exerted on the piston.

The loss of power at the crankshaft is due to a combination of the *pumping losses* incurred in passing gases through the engine and the *frictional losses* in its moving parts. Frictional losses are caused mainly by the piston, with its rings, as it reciprocates in the cylinder bore and, to a lesser extent, by the friction of other parts such as the crankshaft, camshaft, cam followers and timing gears. A small loss is also attributable to the overhead valve gear.

COMPRESSION RATIO AND DETONATION

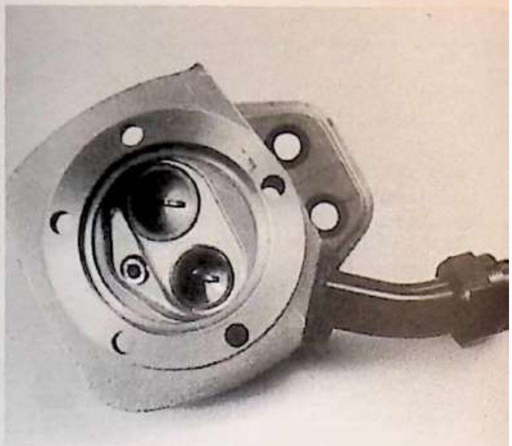
We have seen that high thermal efficiency calls for a compact combustion chamber and a high compression-ratio, but that the highest compression-ratio that can be used is governed by the need to avoid detonation of the fuel mixture. (The practical implications of detonation—popularly known as "knock," "ping" or "pinking"—are dealt with in Chapter 11.)

The onset of detonation, as com-

An example of good cylinder head design. Laser 75 combines efficient wedge-shaped combustion chamber with 30-degree valve inclination and straight ports for unimpeded gas flow. Plug location and generous squish area provide combination of short flame travel and good squish turbulence to minimize detonation despite relatively high compression ratio.

Left: Admirable examples of pressure die-casting seen in the original O.S. FT-120 Gemini cylinder heads and rocker-box components. Simple discoid combustion chamber design, but with fairly large valves and well located glowplug.

Right: The high-performance Enya R120-4C was the first commercial model four-stroke to follow full-size practice in having an inlet valve substantially larger than its exhaust valve.



pression-ratio is increased, can be delayed by various means. The value of fuels of high octane (or "anti-knock") rating became well-known in the Twenties and Thirties with the introduction of tetra-ethyl-lead fluid as a gasoline additive. Alcohol based fuels, such as methyl-alcohol (methanol) also permit the use of higher compression-ratios. Of recent years, the use of leaded gasoline for automotive purposes in particular, has become environmentally unacceptable and this has stimulated the development of other means of raising effective compression-ratios — i.e. modification of the combustion chamber — and this has been of all-round benefit irrespective of the type of fuel used.

To understand how detonation is caused, it is necessary to know a little of the process that takes place in the combustion chamber when the mixture is ignited by the spark plug or glowplug.

Combustion of the fuel/air mixture is very rapid but not instantaneous. There is a slight delay, called ignition lag, between the moment of ignition and the point at which the gas begins to burn. The burning of the gas, once started, should be progressive, beginning at the point of ignition and moving outwards as a flame front, leaving expanding gases behind it. Thus the remaining unburnt mixture (or "end gas") is more highly compressed and heated by the advancing flame front and this may cause spontaneous combustion, resulting in the sharp metallic knock or "ping" that indicates detonation.

PLUG LOCATION AND TURBULENCE

The modification of the combustion chamber to suppress detonation can be tackled in two ways.

Firstly, it helps to have the ignition plug located fairly centrally so that flame travel is short, giving less time for the unburnt gases to self-ignite. The plug should also be biassed towards the hottest part of the combustion chamber (i.e. near the exhaust valve) so that the "end gas" is burnt in the coolest part of the combustion chamber. (Here it needs to be said that although this theory has been proven in full-size i.c. engine practice, it seems less likely that ignition plug position is quite so critical with the small dimensions of model engine cylinders.)

Secondly, it is also helpful to accelerate the combustion process by imparting a swirling motion to the fuel/air mixture in the combustion chamber. This is called *turbulence* and can be induced in two ways.

Induction turbulence is promoted during the suction stroke if the inlet port is so designed that the mixture enters the cylinder at an angle and at high velocity. The degree to which such control of inlet gas velocity and direction can be exerted, may be limited in a high performance engine by the need for large ports and unimpeded gas flow.

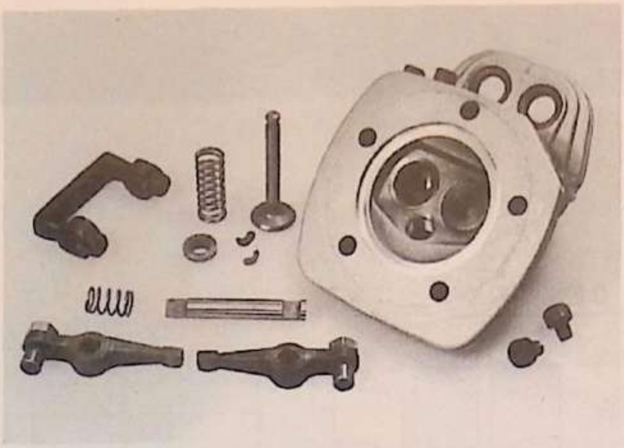
Squish turbulence is more effective. It is obtained by incorporating a *squish* area in the combustion chamber: that is to say, a flat (or very slightly sloped) area which the piston approaches very closely at the top of its stroke, so that the mixture is squeezed from this region into the body of the combustion chamber causing vigorous turbulence during the ignition and burning of the charge.

COMBUSTION CHAMBERS

Theoretically, the ideal shape for a combustion chamber, in the interests of thermal efficiency, would be spherical, since a sphere has the smallest surface area for a given volume and heat

Left: Saito engines feature part-spherical combustion chambers with inclined valves, as in this head from the earliest Saito four-stroke, the FA-30 Mk.I.

Right: Several O.S. four-stroke cylinder heads use shallow "bath-tub" shaped combustion chambers. This example, showing also valve and rocker parts, is from the FS-90.



Left: Enya 60-4C cylinder-head with rocker assembly and inlet valve removed. The same components are used for the 80-4C model.

Right: Cylinder-heads are almost invariably detachable. Exceptions are to be found in some later model Saito engines such as this cylinder from the FA-90T Mk.II which has a steel liner and an integral head.

loss to the walls of the combustion chamber would therefore be reduced to the minimum. (A high temperature is necessary to produce high gas pressure on the piston during the expansion stroke.) In practice, a spherical shape (though possible by forming hemispheres in the cylinder head and piston head) would mean a chamber of far too large a volume, resulting in a totally inadequate compression ratio. If made smaller by surrounding it with a wide squish-band, it would be impossible to accommodate valves of sufficient area.

Fortunately, there are other combustion chamber shapes that will more readily accommodate the essential features of a good head design (large valves, efficient port shapes and a well located ignition plug), yet also promote efficient combustion.

HEMISPHERICAL CHAMBERS

Much favored in full-size high-performance engine circles is the so-called "hemi" or *hemispherical* head. Strictly speaking, a true hemisphere is seldom used: the basic shape commonly employed is more correctly called *part-spherical.* Its main advantages are that the enlarged upper surface area enables larger valves, inclined towards each other, to be used, together with well shaped ports.

PENT-ROOF CHAMBERS

An alternative, allowing similar valve location, is the *pent-roof* combustion chamber. This is even better suited to a four-valves-per-cylinder layout which, although it has not been seen on any production model four-stroke up to the time of writing, has become increasingly favored by designers of full-size high performance motor-cycle and automobile engines since it allows even larger valve areas, while reducing individual valve weights to delay the risk of valve-bounce at very high rpm.

"BATH-TUB" CHAMBERS

Chambers of this type, as their name suggests, take the form of a shallow inverted "bath-tub" shape surrounding the heads of the valves which are placed parallel, side-by-side, in the head. Usually the valves are vertical, but may be slightly inclined, in which case the "bottom" of the "bath-tub" is likely to be sloped to conform with the angle of the valve seats.

A bath-tub chamber can be combined with a fairly generous squish area to aid turbulence. This may occupy part or all of the head area to one side of the bath-tub, while all or part of the other side will normally be sloped to accommodate an inclined ignition plug.

WEDGE CHAMBERS

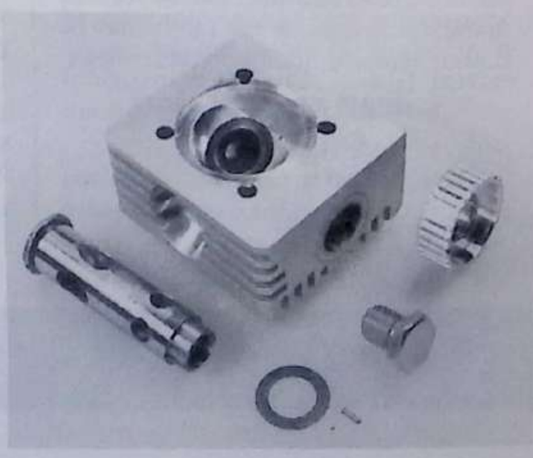
These take various forms but the best type for four-stroke engines usually includes a segment shaped squish area between the thin end of the wedge and the cylinder wall. There may also be a small additional squish area on the opposite side and the overall efficiency of a wedge chamber of this type is similar to that of a bath-tub chamber. The valve heads are usually parallel with the wedge surface, the ignition plug being set into the short side of the triangle.

DISCOID CHAMBERS

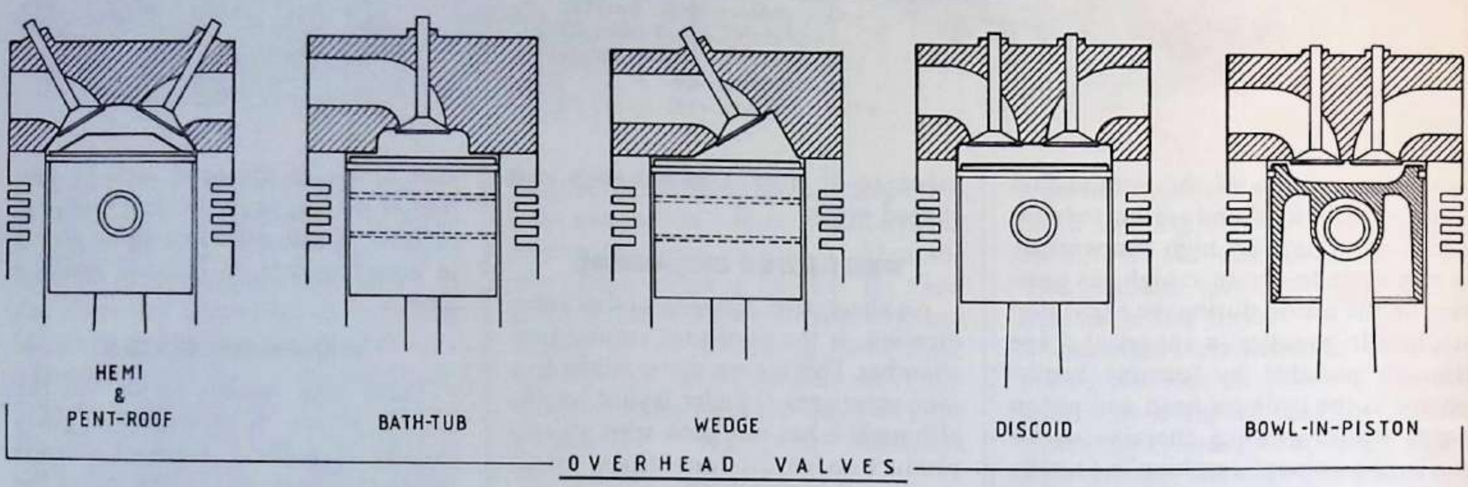
The simplest form of cylinder head has a flat surface which, when combined with a flat piston crown, forms a disc shaped space between the two. This combustion chamber form has frequently been used for model four-strokes in the past, but is becoming less common as designers seek higher levels of performance. It is possible to modify the discoid shape to include

Left: Bath-tub combustion chamber is also used by the Kavan FK-50. The aluminum head screws onto the investment cast steel cylinder with a buttress thread.

Right: Combustion chamber of Webra T4-40 is basically wedge-shaped but is modified by the necessity to accommodate this engine's cylindrical rotary-valve.



COMBUSTION CHAMBER DESIGNS



squish area in the form of a band (as widely used nowadays for two-stroke engines) but in this case the valves must either be reduced in diameter or overlap the squish band.

BOWL-IN-PISTON CHAMBERS

Also known as the Heron head, in recognition of its originator, S.D. Heron, the bowl-in-piston chamber is particularly well suited to engines of low stroke/bore ratio. In effect, it turns the combustion chamber upside-down by using a flat cylinder head with vertical valves and having the combustion chamber machined into the piston head. The chamber normally takes the form of a central bowl surrounded by a squish band. If a very wide squish band is used, crescent shaped cut-outs for valve head clearance can be formed in the squish area, or the valves may be slightly recessed into the cylinder-head.

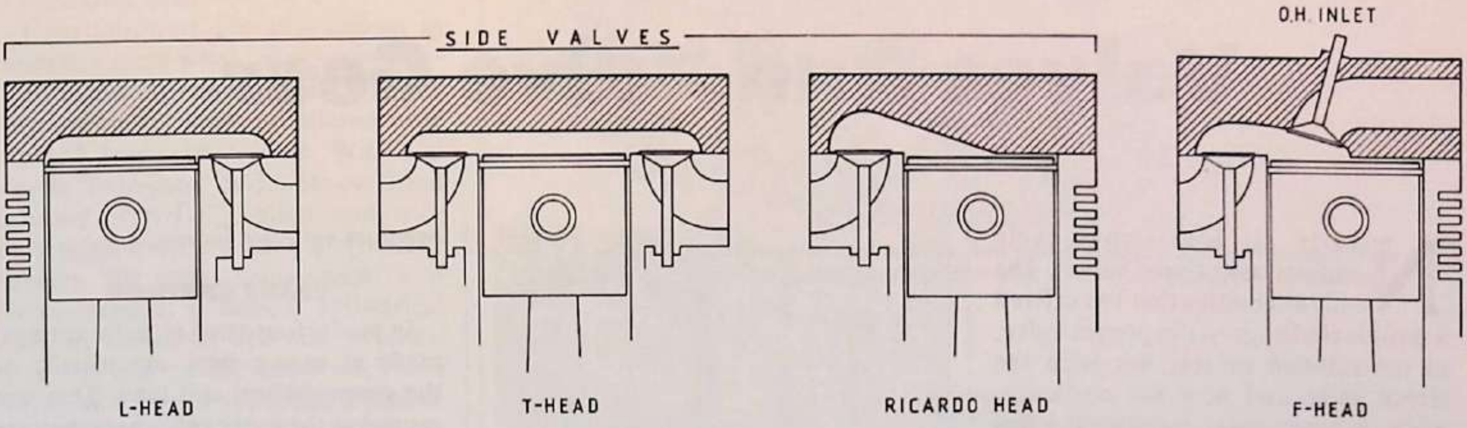
L-HEAD COMBUSTION CHAMBERS

The combustion chambers discussed so far have been of the overhead-valve or valve-in-head pattern. All commercial model four-strokes are of this type, as are most full-size engines. During the first half of the present century, however, the majority of mass-produced four-cycle engines, especially those made in the United States for automobiles and trucks, were L-head designs. L-head engines are still made in large numbers for purposes where high specific power output is not important; for example, most of the four-cycle engines used for lawnmowers, garden tractors, etc. are of the L-head type.

In an L-head engine, the valves are located in the cylinder block alongside the cylinder and open upwards into a combustion chamber which extends across from the top of the cylinder bore. Prior to the L-head, and dating back to the beginning of the twentieth century, there was the T-head engine, in which the inlet valve was on one side of the cylinder and the exhaust valve on the other. Needless to say, the T-head was a poor performer in respect of both thermal efficiency and volumetric efficiency. These criticisms could also be levelled against the early L-heads, but the latter received a considerable boost when the noted engineer, H.R. Ricardo, developed the Ricardo head. Here, the combustion chamber center is shifted towards the valves, the roof of the chamber sweeping down towards the center of the piston head before levelling out to form an effective squish area to substantially increase turbulence and allow a much higher compression ratio to be used.

F-HEAD COMBUSTION CHAMBERS

This unusual arrangement, otherwise known as OHIV (overhead inlet valve) deserves a mention here, if only for historical reasons and the fact that it was used for some years in England by the Rolls-Royce and Rover companies for their passenger cars. Although its combination of a side exhaust valve with an overhead inlet valve made very large valves possible, it was finally abandoned as having no practical advantage over the coventional over-



head valve system. It would not appear to be worth pursuing for model purposes.

MAY "FIREBALL" HEAD

In 1980, an O.S. FS-60 model four-stroke engine, modified by the Australian Orbital Engine Company, was used to power the winning vehicle in the Australian "Mileage Marathon" fuel economy event of that year. At the Warwick Farm motor racing circuit, it averaged a fuel consumption figure of 2,685 miles per Imperial gallon, exceeding the previous record set in England with a modified 50cc Honda engined vehicle by over 1,000 mpg.

To achieve this kind of economy, high thermal efficiency is the number one requirement and so it is no surprise to learn that the engine was modified to run on a much higher compression ratio. What is remarkable, especially as the engine had to run on gasoline instead of an alcohol based fuel, is that the compression ratio was successfully raised to no less than 15 to 1. Even given the fact that spark ignition, rather than glowplug ignition, was used, enabling ignition timing to be optimised, it was clear that something special in the way of cylinder head design was called for.

In fact the special O.E.C. cylinder head was designed against a background of study and experiment connected with O.E.C.'s Orbital engine and the combustion chamber shape chosen was very much along the lines of the May "Fireball" head designed by the Swiss engineer Michael May and introduced in 1981 on the HE version of the twelve-cylinder Jaguar car engine.

As applied to the Jaguar engine, the May head enabled the compression ratio (an already healthy 10 : 1 with the engine's original Heron heads) to be raised to no less than 12.5 : 1, at the same time permitting the use of a substantially leaner fuel/air mixture. The benefits of this were seen in higher torque and lower fuel consumption.

The secret of the May combustion chamber appears to be in the manner in which a relatively lean mixture is persuaded to spin rapidly in the vicinity of the hottest part of the chamber so that the charge is centrifugally stratified, the richer "outside" mixture being more easily ignited, after which the leaner "center" mixture is rapidly consumed. The inlet valve is slightly recessed in the head and the exhaust valve much more so, forming a deep cavity. Between the two there is a curved, inclined ramp and as the piston rises, a squish action forces the mixture up the ramp to rotate in the deep circular cavity below the exhaust valve.

At the time of writing, no commercial model four-stroke manufacturer appears to be moving in the direction of a May type combustion chamber (and to adopt May's design for commercial production could presumably be done only under license) but it would be most interesting to see whether the system has advantges for model sized four-strokes as well as for high performance full-size engines.

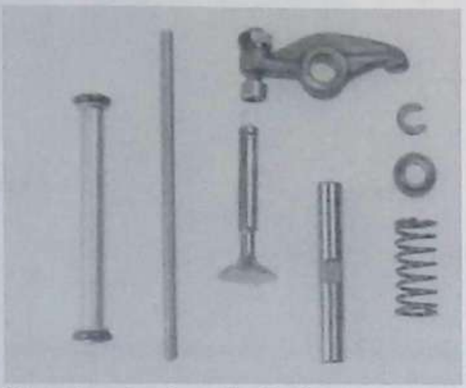
CHAPTER 5

Valves And Valve Gear

Nearly all four-stroke-cycle engines use poppet valves. The only alternative that has offered a serious challenge to the poppet valve, in the full-size sphere, has been the sleeve valve and here the challenge, while, in many cases, technically justified, has made no significant impact on the overall popularity of the poppet valve.

The poppet valve is also widely used for model four-strokes, but here its dominance is a little less complete. The cylinder head rotary-valve, full-scale examples of which have attempted to compete with the poppet valve since the early days of the i.c. engine without much success, has re-surfaced in the model world with rather better acceptance. Up to the present time, of the manufacturers involved in making model four-stroke motors, about a quarter have opted for a form of rotary valve. Actual numbers of rotary valve engines produced, however, are in much lower proportion, as the major Japanese manufacturers of four-strokes have remained committed to poppet valves. The attraction of the rotary valve, so far as the model industry is concerned, is its simplicity (especially in the case of the toothed-belt driven cylindrical type) making such engines much easier and cheaper to produce.

In essence, a poppet valve is simply a disc with a stem, coaxial with it, on one side. The disc, called the valve *head*, closes on a circular port between the combustion chamber and the gas passage. In the early days of the i.c. engine, valves were sometimes flat seated, but in all modern engines the valve seat, forming the edge of the valve port, is ground at an angle (usually 45 degrees) and the edge of the valve head is accurately matched to this to ensure a gas tight seal when the valve is closed



Typical pushrod-overhead-valve components (O.S. FS-40). Left to right and top to bottom: pushrod cover, pushrod, rocker-arm with clearance adjuster, valve, rocker-shaft, valve-spring with cap and retainer.

by the valve spring.

VALVE GUIDES AND SEATS

To center the valve head in the valve seat, the valve stem slides up and down in a *valve guide*. This is usually in the form of a sleeve pressed into the cylinder head (or cylinder block in the case of an L-head engine). Valve guides are generally made of cast-iron or bronze, the latter being the material commonly used for the aluminum heads of model four-strokes. It is also common practice, in model engines, for the guide to be machined in one piece with a cup shaped extension lining the valve throat, the rim of which forms the valve seat.

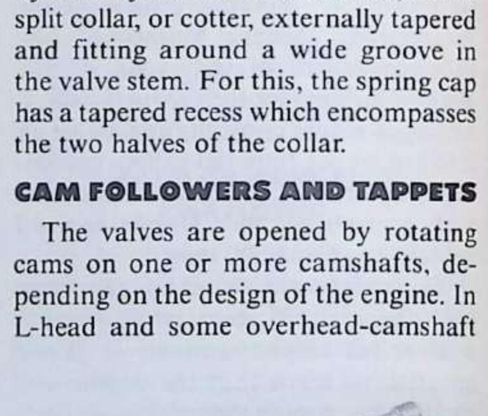
The valves themselves (especially exhaust valves) must be made of a suitably alloyed heat-resistant steel. Both valves, of course, are exposed to the full intensity of combustion but, whereas the inlet valve is considerably cooled, each time it opens, by the flow of air and atomized fuel from the carburetor, the exhaust valve, when open, is subjected to additional heating by the rush of burning gases past the valve head as they leave the cylinder. It becomes very hot indeed.

VALVE SPRINGS

In model four-strokes, valve springs, made of spring steel, are usually of the simple helical coil type. They are capped at the outer end where they are anchored to the valve stem in a variety of ways. A popular method is to use a horseshoe shaped clip, or an E-clip, which engages a narrow groove around the end of the valve stem. This is installed while the valve spring is compressed so that, when the spring is released, the clip is trapped by a recess in the spring cap and cannot slip out. Another method, commonly employed in full size engines, but also featured by the Enya model four-strokes, uses a split collar, or cotter, externally tapered and fitting around a wide groove in the valve stem. For this, the spring cap has a tapered recess which encompasses the two halves of the collar.

CAM FOLLOWERS AND TAPPETS

The valves are opened by rotating cams on one or more camshafts, depending on the design of the engine. In L-head and some overhead-camshaft



Kavan Twin camshaft with four mushroom type c[…] followers (i.e. for both cylinders), plus pushr[…] covers and rocker assembly from one cylinder. (E[…] lobe on camshaft is for driving oil pump.)

engines, the cam may be located immediately below or immediately above the valve stem, but it is not usual for the cam to bear directly on the valve as its wiping action would impose a side thrust. To prevent this, a *cam-follower*, interposed between the cam and valve, is invariably used.

Cam followers are also known as tappets, except when, as in some overhead camshaft engines, they take the form of rocker arms or, alternatively, pivoted levers or *fingers.* With the classic "twin-cam" or double overhead camshaft (DOHC) engine and with some single overhead camshaft (SOHC) engines, the usual arrangement is a *bucket-tappet*, a hollow cylindrical member, closed at one end, inverted over the end of the valve stem and spring and free to slide, like a piston, in a suitable guide.

PUSHRODS AND ROCKERS

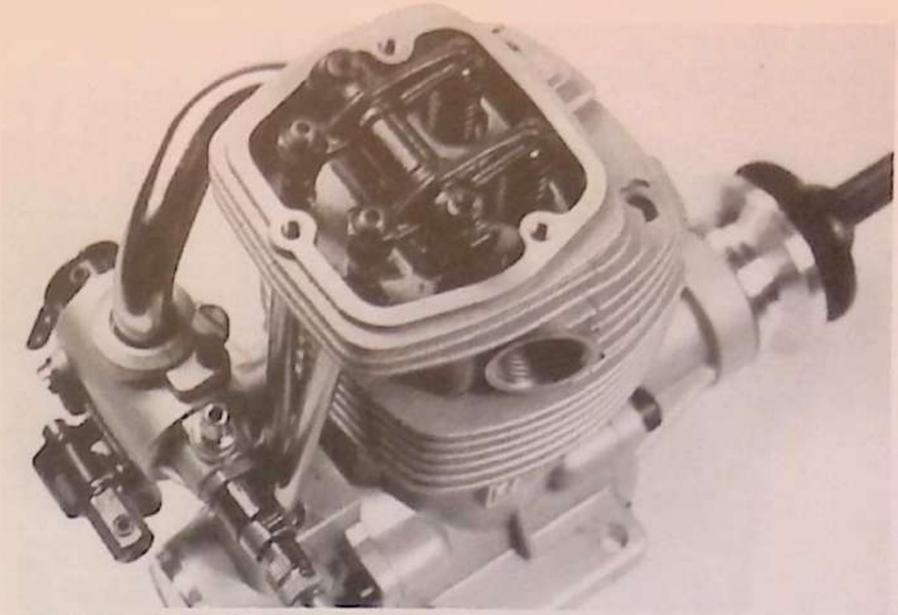
Most of the poppet-valve model four-strokes offered to date have been of pushrod overhead valve (OHV) design. Large numbers of full-size four-strokes are also of this type. In such an arrangement, the camshaft, gear-driven in model engines (but chain driven in some full-size engines) is located alongside, above or behind the crankshaft. Vertical movements of each cam follower are then transmitted to the cylinder head by long *pushrods.*

The pushrods engage *rocker-arms* mounted on top of the cylinder-head. These are pivoted so that, as one end is moved upward by the pushrod, the opposite end pushes downward on the valve stem, causing the valve to open. Rockers need to be a precise wobble-free fit on a hardened steel rocker shaft. In model sizes, they may be made of high-duty aluminum alloy, bronze bushed and fitted with a hardened steel pad at the valve end and a hardened steel socket for the pushrod at the other end, but it is now more common to make the complete rocker of case-hardened cast steel. Pushrods, in the interests of reduced inertia effects, should be as light as is consistent with rigidity, but must have hardened domed ends to resist wear. Sometimes, to lessen weight, pushrods are tubular with solid domed ends.

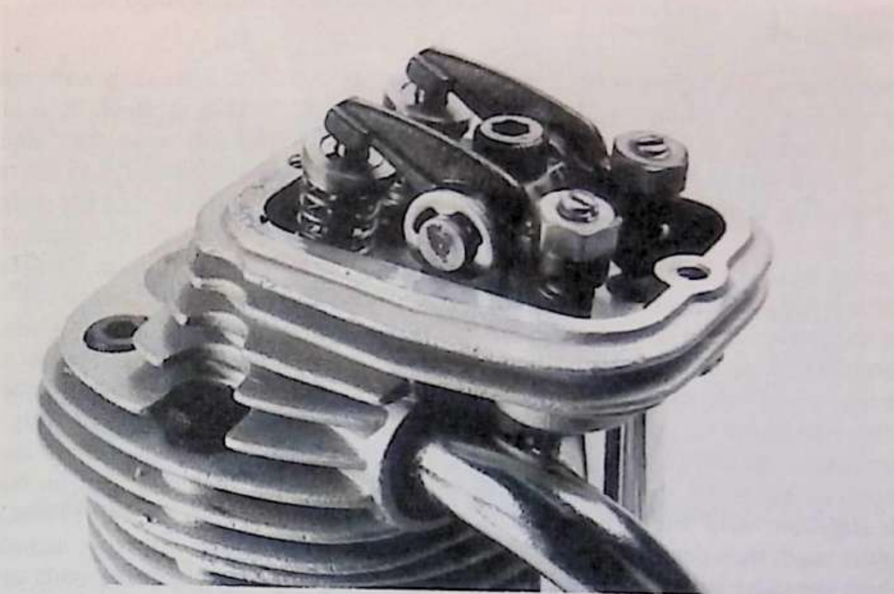
VALVE CLEARANCE

It is essential that, when a valve closes, it does so completely. That is to say, it must be pressed firmly into contact with the valve seat by the valve spring. To make certain that this happens, there must always be a small clearance between the cam follower and the base circle of the cam when the valve is completely closed. This ensures that the cam is not then exerting any lift whatsoever on the valve. The clearances recommended by the manufacturers of model engines are usually between .0015 and .004 in., measured between the end of the valve stem and the adjacent rocker arm or tappet.

The methods of adjusting valve clearances and the consequences of incorrect settings are dealt with in Chapter 12.



O.S. FS-90 with rocker box cover removed to show rocker assembly and valve springs. Note that rocker fulcrum is placed closer to pushrods than to valve stems, in order to increase valve lift.

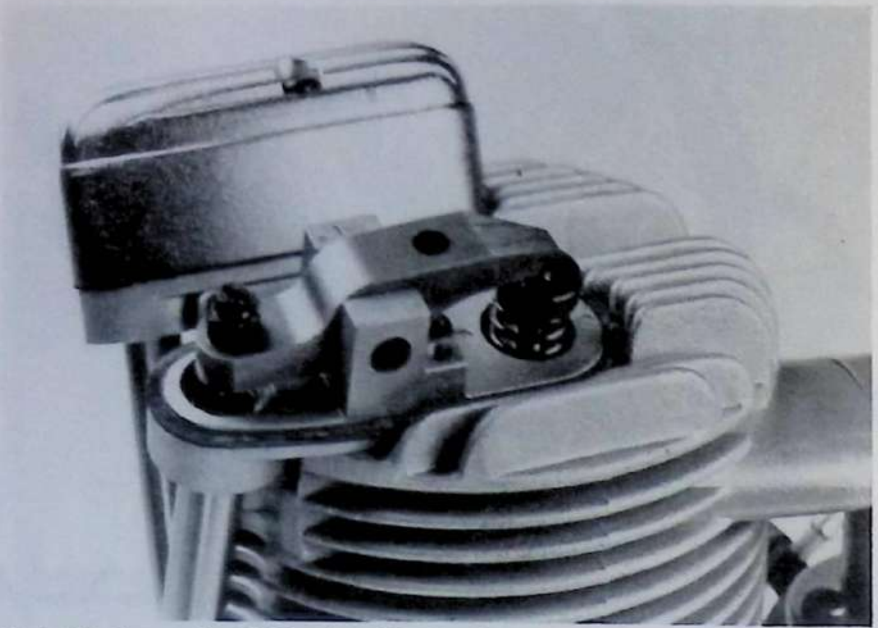


Enya 46-4C rocker-arms are angled to suit this engine's parallel inclined valves. Enya valves feature full-size pattern cotters instead of usual horseshoe or E-clip retainers.

Technopower 'Big-Bore 5' radial engine valve train for just one of its ten valves. Rocker-box is of investment cast aluminum, while cover is of glass-reinforced nylon.

CAMS AND CAM PROFILES

In a four-cycle engine, the crankshaft converts the linear motion of the piston into rotary motion, while the *camshaft* translates rotary motion back into the linear motion necessary to



Early Saito four-strokes (Mk.I version of FA-30 and FA-40) had rather ungainly open rocker gear. Current engines have much more compact design, as in this FA-120 model, seen here with one rocker cover removed.

operate the valves. It might be thought that the latter function could just as easily be performed by another crankshaft. This is not so because, unlike the reciprocating movement of the piston, valve operation is not continuous; there are lengthy periods when the valve must remain stationary. Therefore, the cam lobe is shaped so that its outline is at a constant radius from the camshaft axis over that part of the cycle that requires the valve to be closed, rising to a peak where maximum valve lift is demanded. The precise shape of the cam (its *profile*), together with the type of cam follower used, then determines the rate at which the valve is opened and closed and the length of time, relative to engine speed, that the valve remains open.

The four-stroke engine cam is a deceptively simple looking device. Engines can be made to work satisfactorily with cam profiles that have been arrived at empirically, but the design of cams is, nowadays, a science in itself so far as full-size engines are concerned. Broadly, all that is required of a valve is that it should lift as quickly as possible, remain at that position for the required length of time and close equally quickly. In practice, the attainment of such a state of affairs is somewhat inhibited by the physical problems involved.

For example, if the cam is profiled to raise the valve with extreme rapidity, it will be accelerated to a velocity that may cause it to "take off," lift beyond its designed level and "float." To combat this problem, designers of full-size four-cycle engines try to keep valves as light as possible, consistent with adequate strength. This, incidentally, is one of the advantages of using four small valves per cylinder instead of two large ones. Much depends, also, on the design of the valve springs. These must be strong, but not so strong as to cause excessive loads through the entire valve train from camshaft bearings to valve seat. As helical coil springs are normally used, designers are also concerned with their tendency to vibrate or "surge" at certain engine speeds which may cause the valve to bounce on its seat or for the spring to break. Full-size methods of dealing with this include special springs in which the coils are spaced closer together at one end than at the other, or the use of dual (or even triple) concentric springs or, alternatively, cluster springs or "hairpin" type springs.

When all this is taken into account it is still the cam profile that ultimately determines the performance of the valve gear. We have already observed that, in the interests of high volumetric efficiency, the valve should open and close quickly. It also needs to open fairly widely and remain open for as long as possible, but mechanical considerations demand that the valve should not accelerate too rapidly as it opens. The cam also needs to decelerate the valve gradually during the final stage of closure so that the spring will not return it to its seat too violently.

The cam profile, in conjunction with the type of cam follower used, is required, therefore, to exert progressive and positive control over valve movement throughout the cycle. The various portions of the cam describing the profile shape necessary for this, are known as the *base circle*, the *opening ramp*, the *opening flank*, the *nose* or *peak*, the *closing flank* and the *closing ramp*. The *base circle* is that portion of the cam that is concentric with the camshaft axis (i.e. no valve lift) and will account for less than half the cam's rotation. The *opening ramp* is related to valve clearance or *lash*. It occupies that part of the cam's rotation (usually at least 20 degrees) between the base circle and the point at which lash is taken up and the valve begins to lift from its seat, i.e. the beginning of the *opening flank*, thereafter to accelerate rapidly. As the nose circle of the cam approaches, the valve is decelerated, coming to a halt, briefly, at the peak before accelerating downwards as the tappet or rocker follows the cam over its *closing flank* and *closing ramp*, when the valve must be slowed down in preparation for meeting the valve seat.

In the early days of four-cycle engines, cam profiles were simply drawn as a base circle and a nose circle with the flanks appearing merely as tangents connecting the two. Later, in the interests of higher performance, convex or round flanks were adopted, sometimes in conjunction with a flat or mushroom type cam follower, as a means of providing more rapid acceleration of the valve and a longer effective opening period. This is the type of cam most commonly found in model four-strokes to date. It may be used with a conventional small diameter rounded cam follower, or with a flat or mushroom follower, or with a flat-faced cylindrical tappet whose lift pattern offers a half-way house between the two.

All wearing surfaces of the valve gear should be hardened and this, of course, applies especially to the cams and followers. Sometimes, with a flat-faced cylindrical cam follower, its axis is slightly offset relative to the cam so that it is automatically rotated to distribute wear more evenly.

VALVE SIZE

In the interests of volumetric efficiency, large port areas are necessary and valve heads, therefore, tend to fill most of the space available for them in the cylinder head. One of the advantages of a part-spherical or a pent-roof combustion chamber is that it will accommodate slightly larger diameter valves than can be used with a flat-roofed chamber. In full-scale practice, the need for large valve areas is something that was appreciated even in the days when engine speeds were low and specific power outputs modest. In L-head engines, for example, that part of the combustion chamber accommodating the valve heads was usually wider than the cylinder bore and, in the famous Liberty Twelve aircraft engine of World War-I, which had inclined overhead valves, the cylinders actually widened out above the bore to permit larger valves and ports to be used. However, modern engines, including model four-strokes, have much lower stroke/bore ratios, enabling valves of adequate area to be contained within the bore size.

The determination of valve size begins with calculating the inlet valve throat diameter necessary to keep inlet gas velocity within acceptable limits. In full-size engines it is common practice to make the inlet port 30 to 50 percent larger in area (i.e. calling for a valve 14 to 22 percent larger in diameter) than the exhaust port. This is because the exhaust gases leave the cylinder under pressure and, therefore, faster than the inlet gas.

Nearly all model four-strokes manufactured to date have had inlet and exhaust valves of the same size, the first to use a larger inlet valve being the 1985 Enya R.120-4C.

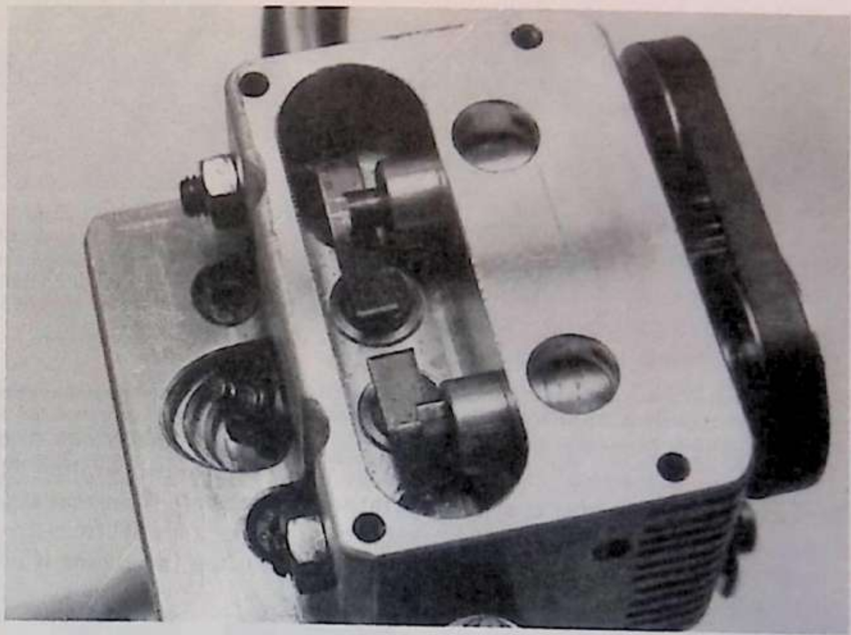
VALVE LIFT

Volumetric efficiency is also dependent on valve lift — i.e. the distance that the valve lifts above its seat when fully open — and it is not unusual nowadays for designers of model four-strokes to use an inlet cam profile that will give a higher lift than that of the exhaust cam. In full-size practice, valve lifts have tended to be in the region of 25 percent of the throat diameter. However, volumetric efficiency has been shown to be steadily improved with lifts of up to 35 percent and many model four-strokes, in fact, use valve lifts of between 30 and 35 percent of throat diameter.

VALVE TIMING AND PERFORMANCE

It has already been explained (Chapter 2) that valves do not open and close to coincide with the reversal of piston direction, but are timed to operate before and after the top and bottom dead center positions because of the need to take account of the inertia of the gases and their changing pressures.

The actual crank positions at which each valve opens and closes, as well as the opening periods of the valves, vary a great deal between different engines but, generally speaking, the higher the speed at which the engine is designed

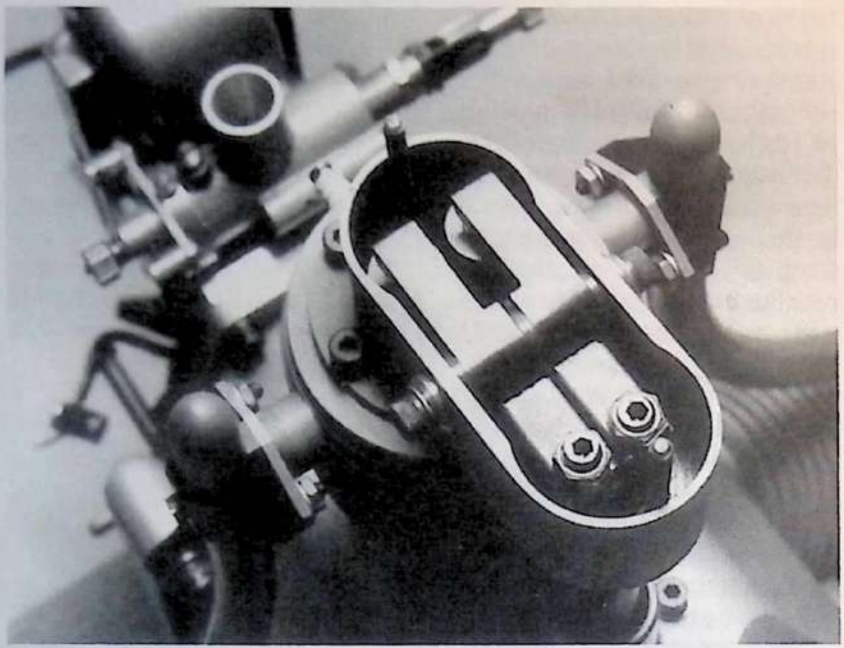


Schillings-PL 10cc engine with valve cover removed to show its twin overhead camshafts and method of operating valves through flat-section steel fingers. Fingers are eccentrically pivoted to allow valve clearances to be adjusted.

to produce its peak power output, the longer its valves will need to remain open and the greater the valve overlap (i.e. the interval between the inlet valve opening and the exhaust valve closing.) For example, a typical passenger car engine might have opening periods of 240 degrees of crankshaft rotation and an overlap of 30 degrees, while a racing engine could have opening periods in excess of 300 degrees and an overlap of over 80 degrees.

In recent model four-strokes, actual measured timings have included inlet periods exceeding 300 degrees and overlaps as high as 100 degrees. It has to be stressed, however, that, especially with the very small cams of model engines, wide discrepancies in valve timing can easily arise. To achieve the intended valve timing, cam profiles must be machined to extremely close tolerances and all other components in the valve train must operate with the utmost precision. Moreover, the designer's intended valve timing can only be met at a specific valve clearance. A typical manufacturer's quoted valve clearance range may be between 0.04 mm and 0.10 mm and if valve timing is measured at a clearance of 0.10 mm (.004 in.) the period that the valve remains open will be very much shorter than if it is measured at a clearance of 0.04 mm (.0016 in.). Theoretically, the valve opening period should begin as the cam rotates from the opening ramp phase to the opening flank phase and end when the cam leaves the closing flank phase and enters the closing ramp stage.

We have noted earlier that clearances are necessary in order to ensure that the valves are properly seated in the closed position. It is commonly supposed that a clearance is required to allow for the expansion of the valve stem when the engine is hot. Actually, this applies mainly to full-size engines and especially to those having water-cooled cast-iron cylinder blocks such as most automobile engines. In a model four-stroke, the opposite is true because the body of the engine is made of aluminum alloy having a much higher coefficient of expansion than the steel parts, as a result of which the valve clearance *increases*, rather than decreases, as the engine warms up to its operating temperature. It therefore follows that the valve clearance of a model four-stroke should be set when the engine is *cold* and, since clearance will increase substantially as the engine warms up, it also follows that there is a case for setting the clearance as close as possible. See Chapter 12 for further information.

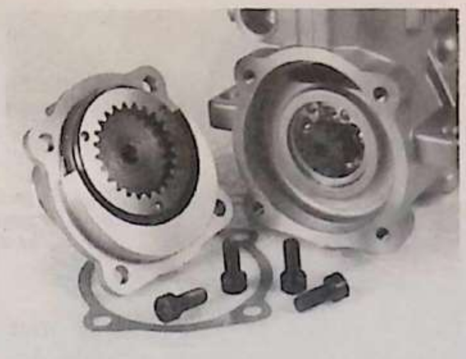


Very unusual feature of the Gerald Smith Osprey 3-cylinder radial engine (see Chapter 3), is its induction system. Mixture from the carburetor is admitted to the crankcase, then passes up through the large diameter sealed pushrod covers to the rocker boxes, from where it is admitted through special ports into the combustion chambers. (Photo: Courtesy Gerald Smith)

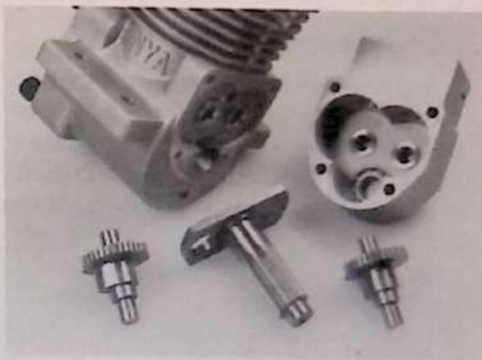
CHAPTER 6

Camshaft Drives

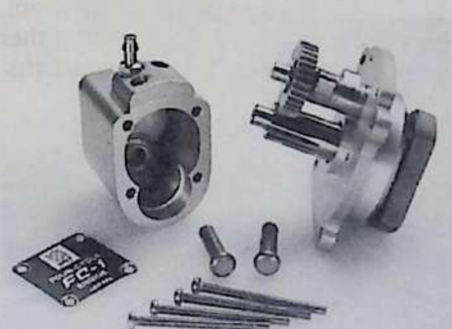
There are numerous positions in which the camshaft can be located in a poppet valve engine. In a single-cylinder motor it can be at the side, in front, behind or above the cylinder. It can be below the crankshaft, as in a horizontally-opposed engine, or above the crankshaft as in a multi-cylinder upright vee type engine. It can be driven from the crankshaft by spur gears, helical gears, bevel gears, by a toothed belt or (mainly in full-size engines) by a roller chain.



In the pioneer O.S. FS-60 the drive pinion, ball-bearing mounted in the rear of the crankcase, engages an internal tooth timing wheel at the front end of the camshaft. The camshaft is supported in two ball bearings. The same arrangement is used in the FS-90 model.



Enya four-strokes use twin rear-mounted camshafts, one for the inlet valve and one for the exhaust valve. The camshafts run in bronze bushes fore and aft. The drive pinion is supported in ball-bearings.



Kalt FC-1 cams and timing wheel rotate on a 5 mm bronze pin above a ball-bearing mounted pinion that is driven, in the usual way, from the crankpin.

Saito engines use front camshafts, driven directly from the crankshaft main journal by spur gears. In the flat-twin Saito models, such as the FA-90T shown here, a separate camshaft is used for each cylinder.

CAMSHAFT LOCATIONS— PUSHROD OHV ENGINES

So far as pushrod OHV model engines are concerned, the simplest arrangement is that used by the Saito engines in which the camshaft is mounted above the crankshaft, parallel to it and driven by spur gears. Strictly speaking, these engines do not have the conventional type of camshaft consisting of a machined and ground steel or cast-iron shaft with integral lobes. Instead, the cams and timing wheel are assembled on a bronze bush which rotates on a fixed shaft. The timing wheel is at the front and meshes with a pinion on the crankshaft between its front and rear ball bearings.

Certain O.S. single-cylinder models (e.g. FS-20, FS-40, FS-61, FS-120) also have the camshaft at the front above the crankshaft main bearing, but here the one-piece camshaft (supported at each end in ball bearings in all except the FS-20 which has bronze bearings) is installed at right-angles to the crankshaft and is driven by crossed-helical (or "skew") gears. The cam lobes are located each side of the timing wheel which is in the center of the camshaft, engaging helical teeth formed directly in the crankshaft journal.

Having the camshaft at the front of a single cylinder engine may be helpful in that, by eliminating the need for a separate timing case at the rear, a more compact engine is possible. In practice this is seldom realised, because the carburetor is usually at the rear and overall length is little changed. However, such a layout still has the merit of simplifying design and construction insofar as a separate timing pinion and shaft assembly, driven by the crankpin and installed in the back of the crankcase, is no longer required.

There are a number of different rear camshaft drive arrangements. In the case of the original O.S. FS-60 and its ultimate FS-90 development (as well as the less well-known FS-75 and FS-80 interim models), the short drive pinion is carried in a ball journal bearing mounted in the rear wall of the crankcase and engages an internal tooth timing wheel attached to the camshaft. The camshaft is supported in two ball journal bearings contained in a separate bolt-on rear housing.

The Enya rear camshaft layout is rather different. Here, conventional spur gears are used, but with two camshafts, one for the inlet valve and one for the exhaust valve, placed side by side, with their timing wheels located one behind the other to engage a long pinion shaft. The latter is supported in a ball bearing at each end, while the two camshafts are carried in bronze bushes fore and aft. A similar layout is used by the British Laser four-strokes.

PUSHROD OHV TWINS

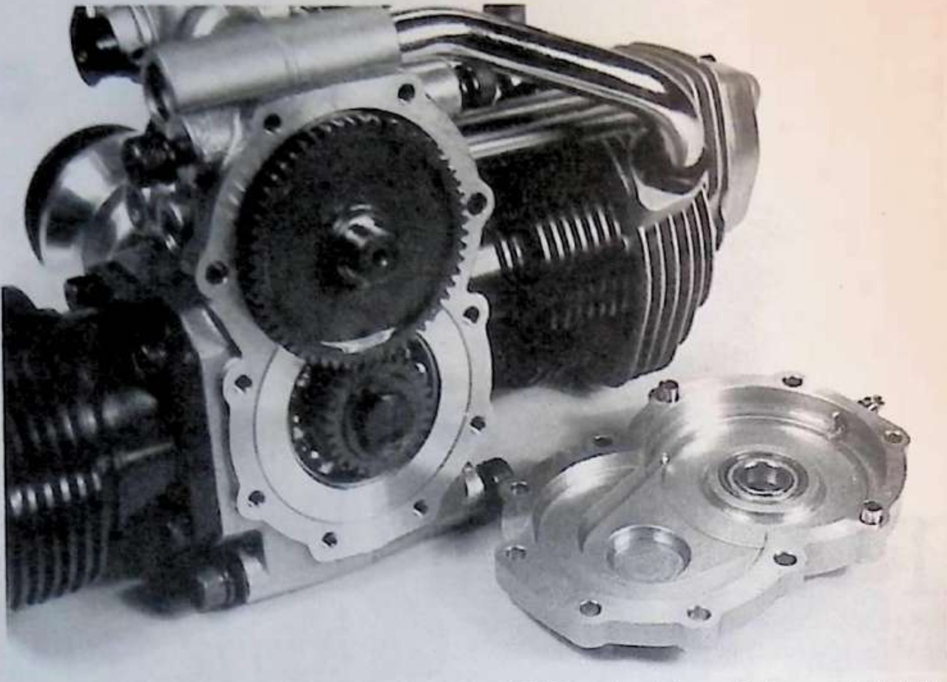
In the case of twin or multi-cylinder pushrod OHV engines of the horizontally opposed type, the most commonly used location for the camshaft is below the crankcase and parallel to the crankshaft from which it is driven by spur gears at the rear. This type of layout is common in full-size horizontally-opposed light aircraft engines and familiar examples in the model world are the O.S. Gemini Series and Kavan FK-50 flat-twins. The camshaft is supported in ball bearings front and rear and has two cams, each of which operates two cam followers, the exhaust cam being at the front.

O.S. engines with front mounted valve gear employ a transverse camshaft driven directly from the crankshaft through crossed-helical "skew" gearing. Example shown here is from small FS-20 model.

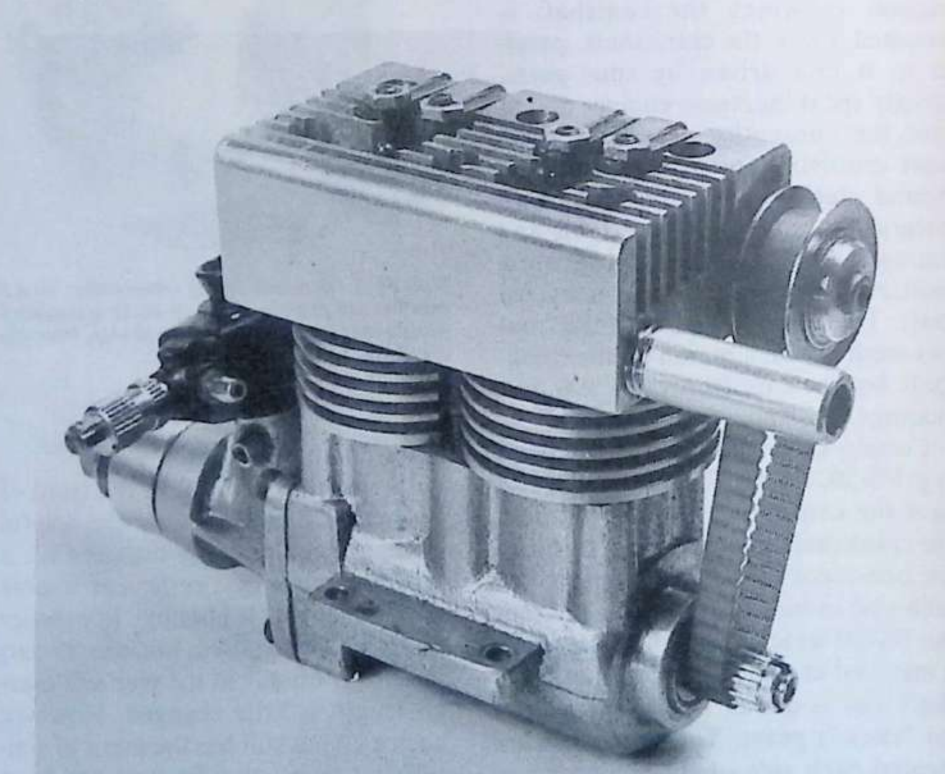
This configuration has much to commend it since it places the valves in a fore and aft arrangement instead of side-by-side and allows the exhaust side of the cylinders and the hot exhaust pipes to be put at the front of the engine where they receive maximum benefit from the flow of cooling air.

For the Saito flat-twins, the manufacturer has been at pains to use as many parts as possible from the single-cylinder Saito four-strokes in order to keep tooling costs down and the price to the customer as low as possible. Accordingly, the Saito FA-80T, FA-90T and FA-270T employ the familiar Saito front camshaft arrangement, as used by the Saito single-cylinder engines, with the pushrods at the front, operating inclined valves. In other words, these twins use two camshafts, one either side of the crankshaft.

In the case of a pushrod OHV vee-twin, the Saito type camshaft arrangement could be employed, i.e. a camshaft for each cylinder at the front, driven directly through spur gears from the crankshaft pinion. However, among the few model pushrod vee-twins built to date, it is more common



Conventional arrangement for a flat-twin pushrod-OHV engine is for a single camshaft to be located below the crankshaft and driven by spur gears. The example shown here (engine inverted) is O.S. FT-240 Super-Gemini. To reduce the diameter of the timing wheel, an intermediate gear may be used, as on the Kavan FK-50.



D.F. Green's unusual prototype parallel twin has a four-lobe camshaft in its cylinder head operating valves through L-shaped rockers. The camshaft is driven at half-speed by a toothed belt.

to find the valve train at the rear, where a camshaft for each cylinder can be geared to a single crankpin driven pinion — as in the Magnum 1.82 cu in. engine illustrated.

Twin overhead camshafts used by Schillings-PL engines are driven directly from a rear crankshaft take-off pulley by a toothed belt. Such a simple arrangement eliminates the need for separate timing gears.

For vee type pushrod OHV engines having more than two cylinders (e.g. the typical pushrod vee-eight automobile engine) the usual place for the camshaft is in the vee between the cylinder blocks. There are no commercial model engines of this type at present.

Also having no counterparts in the commercial model four-stroke world, to date, are the multi-cylinder inline pushrod OHV engines that, in the past, have been extensively used for light aircraft and which are still used for some passenger cars, notwithstanding the increasing popularity of toothed belt driven overhead camshafts.

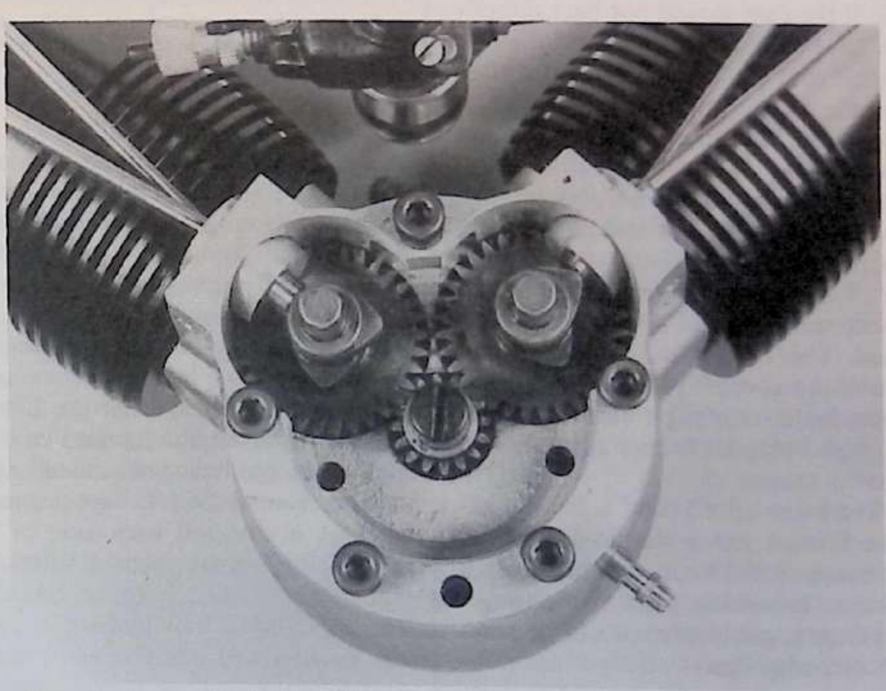
RADIAL ENGINES

For radial engines (at one time the most common type of full-sized aircraft engine) a camshaft, as such, is not used. Instead, the cam takes the form of a large diameter disc or ring, concentric with the crankshaft and carrying lobes on its periphery. These lobes engage cam followers, spaced around the crankcase, which lift the pushrods as the cam rotates. There are two tracks on the cam ring: one for the inlet valves and one for the exhaust valves.

The number of lobes used is related to the speed at which the cam carrier rotates relative to crankshaft rpm. For example, a five cylinder engine might have just two lobes per track, the cam being geared down to rotate at one-quarter crankshaft speed, or, as in the case of the five and seven cylinder Technopower model radials, a three-lobe cam running at one-sixth crankshaft speed could be employed. Full-sized radials of seven or nine cylinders per row commonly have four-lobe cams rotating at one-eighth crankshaft speed. The Gerald Smith 18 cylinder radial illustrated in Chapter 1 has five lobes per track on a cam ring rotating at one-tenth crankshaft speed.

The cam ring is driven from the crankshaft via a train of spur gears and it is most important that concentricity is maintained and that cams are accurately profiled, otherwise the lobes will not provide equal valve lift and there will also be difficulty in setting valve clearances evenly.

It may seem that the obvious place for the camshaft, in any overhead valve engine, is directly above the valve stems. The reasons why the overhead camshaft had to wait for the advent of the toothed belt in order to become more widely used, can be traced back to the earliest T-head and L-head engines. Here, camshafts were invariably placed in the side of the crankcase, parallel to the crankshaft, from which they could be conveniently driven by gears or by sprockets and roller chains and where they were ideally positioned for directly lifting the valves via adjustable tappets. When greater efficiency demanded overhead valves, designers were able to achieve this simply and cheaply by interposing pushrods and overhead rockers between the cam followers and valve stems.



Rear of Magnum Vee-Twin with backplate removed to show twin spur-gear driven camshafts. These run in Teflon-impregnated sintered-bronze bearings.

OVERHEAD CAMSHAFTS

Prior to the invention of the toothed belt and its application to automobile engines in the nineteen-sixties, overhead camshafts tended to be regarded as belonging strictly to expensive high performance and racing type engines, even though they had first appeared in Europe some fifty years earlier. The classic high-performance car engine was and still is a "twin-cam" or DOHC (double overhead camshaft) unit with inclined valves and hemispherical or pent-roof combustion chambers.

The disadvantage of the pushrod-OHV engine is that the reciprocating mass of the valve gear is substantially increased by the addition of pushrods and rockers, and this requires stronger (and thus more power consuming) valve springs to return the valves to their seats. With an overhead camshaft (OHC) engine, lighter springs can be employed or similar springs used in conjunction with revised cam profiles for improved breathing at high speeds.

This is not to say that the pushrod-OHV engine is in any sense obsolete. There are some types of engines (poppet valve radial aircraft engines being a case in point) where pushrods and rockers remain the most satisfactory methods of valve operation and, in the high performance motor-cycle engine field, it is interesting to note that the Honda company, famous for its DOHC engines, elected to revert to pushrods and rockers for its CX-500 four-valves-per-cylinder vee-twin.

SOHC—INLINE VALVES

In the simplest type of single overhead cam (SOHC) engine, the valves are usually placed inline in the cylinder-head, vertically or parallel inclined. As previously stated (Chapter 5) the cam should not bear directly on the valve stem because of the side thrust that the valve stem would then impose on the valve guide. If the camshaft axis is immediately above the valve stem, it is common practice to insert a bucket type cam follower between the valve stem and cam. Alternatively, if the camshaft axis is offset, relative to the valve stem, a finger type rocker arm, pivoted at one end, will be used. This offers the opportunity of providing a simple pivot height adjustment for setting valve clearances and may also be used to increase valve lift relative to cam lift.

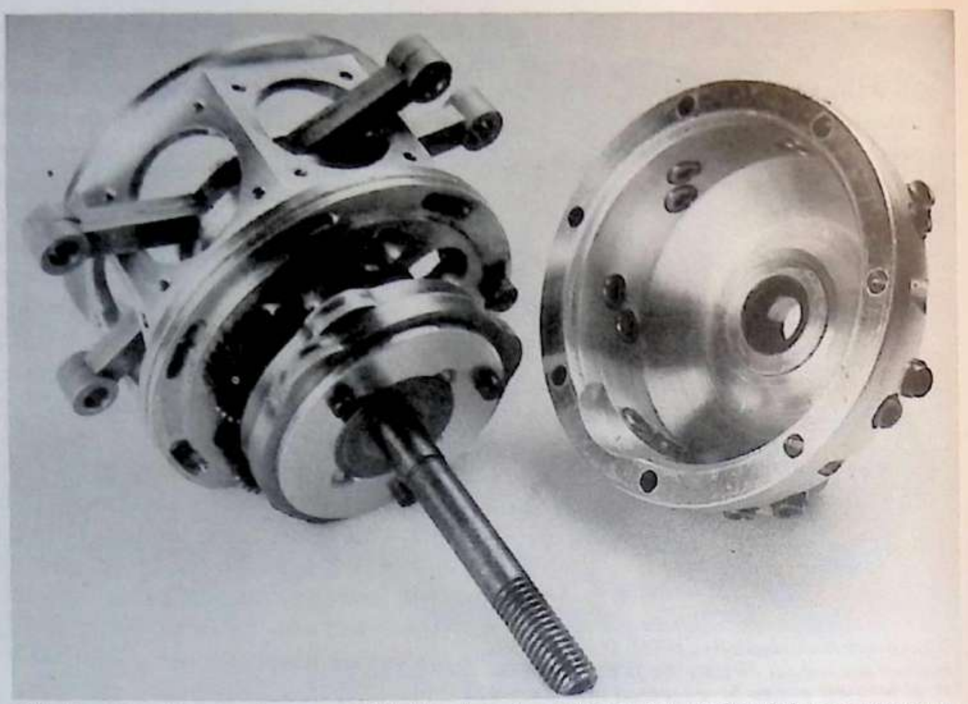
The inline valve SOHC layout is suitable for use with a simple flat-roofed combustion chamber (in which case a concave or bowl-in-piston combustion chamber is preferable) or with a bathtub or wedge head.

SOHC WITH ROCKERS

A single overhead camshaft can also be employed in conjunction with rockers to operate side-by-side or inclined valves — the latter usually in a hemispherical or pent-roof chamber.

In the full-size aircraft engine world, for example, both the American Liberty Twelve of the First World War and the British Rolls-Royce Merlin of the Second World War were of this type: each had a single central overhead camshaft per bank of six cylinders. In the Liberty, individual rocker lever assemblies were pivoted either side of the camshaft, where they operated two valves per cylinder, inclined at an included angle of 27 degrees. These were used with either flat or high crown pistons, the latter to increase compression ratio for high altitude operation. In the Merlin, finger type rockers below the camshaft were employed to operate four vertical valves, two inlet and two exhaust, per cylinder. These were used in conjunction with concave crowned pistons.

At about the time that the Liberty engine appeared, the Italian Fiat company was producing an inline engine with a similar SOHC layout having rockers above and each side of the camshaft to actuate inclined valves. An equivalent, today, is to be found in German BMW four and six cylinder car engines and many modern motor cycle engines also use a similar layout.



The front housing, crankcase, crankshaft and master-rod assembly of the Technopower seven-cylinder radial engine, showing the two three-lobe cam rings which rotate at one-sixth crankshaft speed via a train of spur gears.

MODEL SOHC ENGINES

The single overhead camshaft has so far been rare among model four-strokes, but an example of an SOHC engine with direct valve operation is the German Fargen & Joosten "Jupiter," which is made in single and twin cylinder models, having toothed belt driven camshafts actuating inline vertical valves.

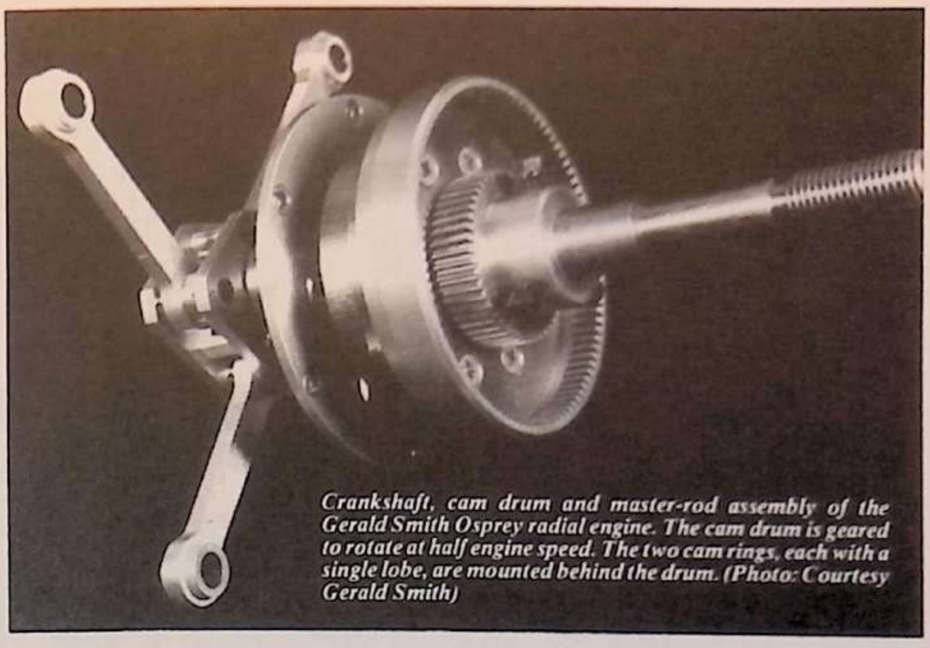
Sole representative, to date, of the single OHC with inclined valves is the single-cylinder 1.2 cu in. OPS 20-OHC from Italy. A central camshaft, toothed belt driven from the rear of the engine, depresses the valves via rocker arms as described above. As befits the first four-stroke from a firm recognised for its high-performance model two-strokes, this new engine is expected to appeal to those looking for above average power in the four-stroke field.

Another single camshaft design — having not so much an SOHC as a cam in-head layout — has been demonstrated by some twin-cylinder .60 cu in. engines built in England by D.F. Green. In these (which include both flat-twin and parallel-twin models) the camshaft is housed in one side of the cylinder head. The engines' vertical inline valves are then operated through L-shaped rockers recessed into slots in the head.

TWIN OHC

The double overhead camshaft (DOHC) or "twin cam" engine is, as we have already said, the classic layout for a high-performance automobile engine. Among the best known examples has been the six-cylinder Jaguar XK engine, in production for nearly forty years, which has hemispherical combustion chambers and two valves per cylinder. Its successor, the AJ6, has four valves per cylinder in pent-roof chambers, an arrangement which, by no means new in the racing world, is now a trend in high performance passenger-car engines as well. This latter arrangement is practically universal in Grand Prix racing and, since vee type designs (mostly V6 and V8) are widely used, most of these engines actually have four camshafts, two to each bank of cylinders. Camshaft drive trains for these engines tend to become quite complex, with numerous sprockets and chains or pulleys and toothed belts, but such mechanical complication is nevertheless justified by the extra power that can be realised.

In commercial model four-cycle engine manufacture, double overhead camshafts are rare at the present time. For the most part, they have been seen only as a means of eliminating the complication of separate timing gears, pushrods and rocker assemblies. For example, all the German Schillings engines have had twin overhead camshafts fitted with large pulleys driven by toothed belts from the rear of the crankshaft.



Crankshaft, cam drum and master-rod assembly of the Gerald Smith Osprey radial engine. The cam drum is geared to rotate at half engine speed. The two cam rings, each with a single lobe, are mounted behind the drum. (Photo: Courtesy Gerald Smith)

No attempt was made with the original Schillings "PL" engines to fully exploit the advantages of a twin-cam layout: the valves were simply placed side-by-side vertically in the head. In 1985, the same manufacturer announced two expensive multi-cylinder DOHC engines using inclined valves: an inline four-cylinder unit and a 90-degree V8. However, with these motors (briefly described in Chapter 1) it is clear that the primary objective was to offer, to four-stroke buffs, engines of classic appearance rather than to take full advantage of the performance potential of a twin overhead cam design.

At the time of writing, it remains to be seen whether more model four-strokes will be of the DOHC type in the future. It is clear, however, that, of the various forms of overhead camshaft drive available, the toothed belt is the obvious choice, there being no justification for adopting any of the traditional and more costly alternatives such as chains, vertical shafts or gear trains. Hopefully, designers would see fit, purely for aesthetic reasons, to enclose pulleys and belts in suitable detachable casings, rather than to leave them exposed as has been seen to date in model engines (notably certain rotary-valve types) using toothed belt valve drives.

In the O.S. FS-90, the camshaft drive is the same as in the original FS-60 but cam profiles are considerably modified and operate special hammer-head shaped cam followers.

CAMSHAFT BEARINGS

Model four-cycle engine camshafts are generally supported either in ball journal bearings (all O.S. four-strokes except the smallest model, the FS-20) or in bushings (most other makes). Bushes are usually made of phosphor-bronze or sintered bronze. A variant of the latter has also been used in the shape of a proprietary steel-backed Teflon-impregnated sintered bronze bearing.

Generally, camshaft bearings are only required to support radial loads. The exceptions are where, instead of being driven by spur gears, the camshaft has a spiral or single helical gear drive. The front camshaft engines in the O.S. single-cylinder range, for example (FS-20, FS-40, FS-61 and FS-120), all have transverse camshafts driven directly from the crankshaft by crossed helical gears. In such an arrangement, the action of the gear teeth introduces an end-thrust requiring suitable bearing provision. This is no problem with the FS-40, FS-61 and FS-120, all of which have their camshafts supported in ball bearings. With the FS-20, which has bronze camshaft bearings, end thrust is taken by a floating steel ball, inserted into the end of the camshaft, that bears against a steel disc in the bearing housing.

CHAPTER 7

Rotary Valves and Sleeve Valves

The Dylla 9cc (0.55 cu in.) rotary-valve four-stroke, one of several engines of this make which featured a rotating cylinder sleeve.

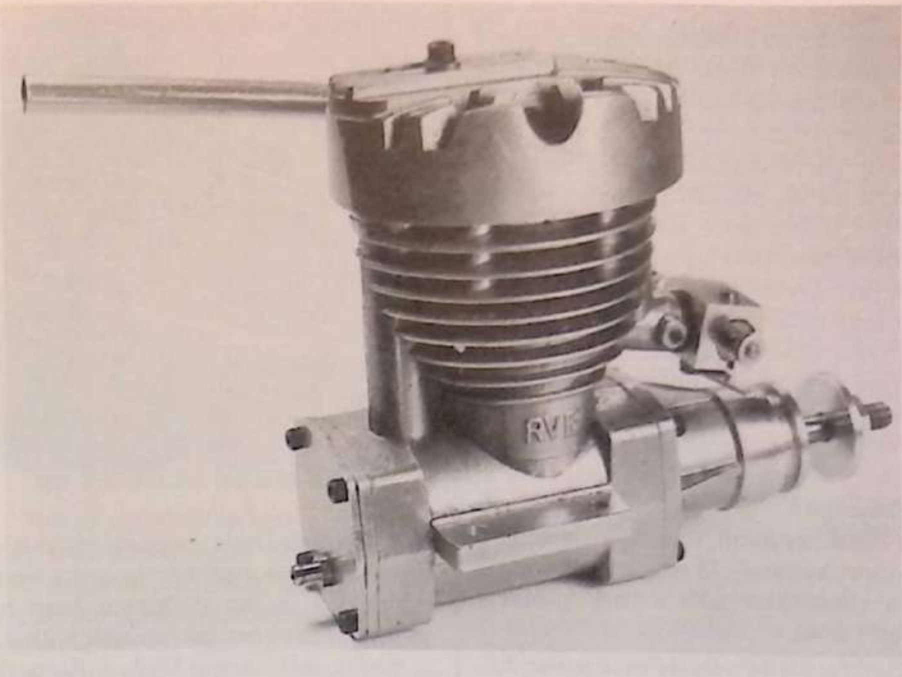
The Dylla 10cc (0.60 cu in.) rotary-valve engine. Dylla engines were made in Austria in small numbers during the late nineteen-seventies.

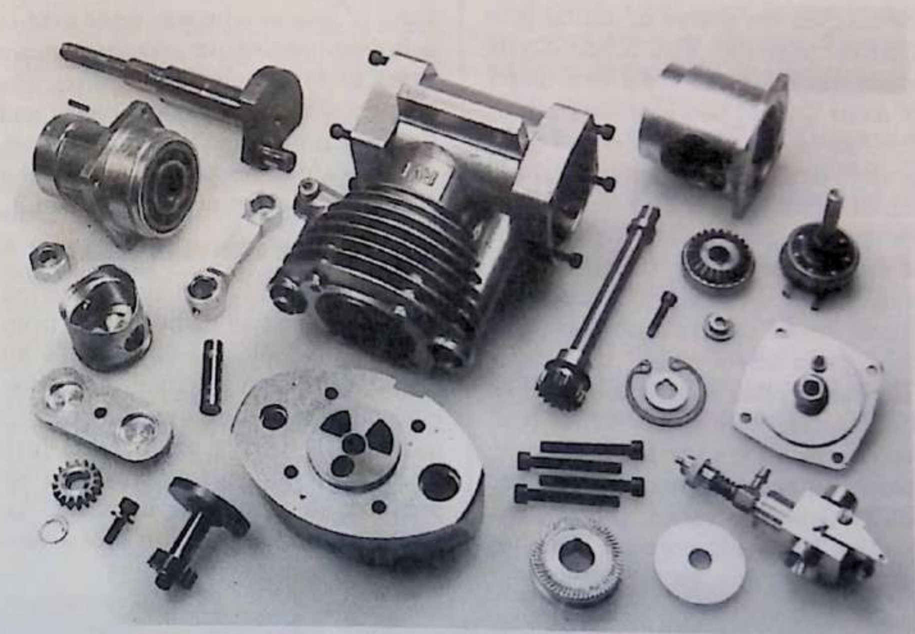
As was remarked at the beginning of Chapter 5, nearly all full-size four-stroke-cycle engines use poppet valves. Despite the fact that no part of the internal combustion engine has been more often criticised as being fundamentally unsuited to its task, the poppet valve continues to be used by even the most brilliant and innovative designers of four-stroke reciprocating engines and all the most powerful racing car and racing motor cycle engines are of this type.

The alternatives suggested by the critics of the poppet valve have been many and varied but, so far as full-size engines are concerned, the only effective commercial challenges have come from sleeve valve engines. Classic car buffs may recall the Willys-Knight. As early as 1905, Charles Y. Knight of Chicago invented an engine in which valve functions were effected by reciprocating ported sleeves between the piston and cylinder wall. First used by the British Daimler Motor Company, which continued to build Daimler-Knight engines for their luxury cars for nearly twenty years, Knight sleeve valve engines were also used by Panhard, Voisin and Minerva in Continental Europe and by Stearns, as well as Willys, in the United States.

The Knight design employed two thin concentric cast-iron sleeves per cylinder. These were moved vertically and independently by small cranks driven at half-speed from the crankshaft, so that the ports in the upper part of the sleeves were timed to open and close, in the correct sequence, for the admission of the fuel/air charge and the subsequent expulsion of spent gases.

Subsequent to the appearance of the Knight double-sleeve engine, single-sleeve designs were developed, independently but concurrently, by Peter Burt in Scotland and James McCollum in Canada. The Burt-McCollum system was used by the Scottish Argyll motor company as early as 1912 and was tried experimentally by several other manufacturers including, in the nineteen-twenties, the American Continental Motors Corporation with a 220 hp 9-cylinder radial aircraft engine. The single-sleeve engine really came into its own, however, when taken up by the engine department of the Bristol Aeroplane Company. During World War II, some large and very powerful sleeve-valve aircraft engines were produced in England in the shape of the Bristol Centaurus 18-cylinder radial and the Napier Sabre 24-cylinder H-type engine. The single sleeve of the Burt-McCollum system combined both reciprocal and semi-rotational movement of the sleeve to open and close the valve ports.





Parts of the Robinson RVE, a complex but interesting design that featured a disc-type vertical axis rotary-valve.

DYLLA ROTARY SLEEVE ENGINES

At the time of writing, no commercial model four-stroke engine uses a sleeve-valve but, in the late nineteen-seventies, an Austrian manufacturer, *Dylla & Rosner Motoren*, of Feldkirchen, near Klagenfurt, produced some engines in which the cylinder sleeve rotated completely, including that portion forming the inside of the head. In fact, the whole purpose of having the cylinder liner revolve was to turn the head portion which, in effect, operated as a disc type rotary-valve. It had a circular port to one side of its crown which uncovered, in sequence, the inlet port, glowplug cavity and exhaust port located in the aluminum cylinder-head above it.

Dylla engines were uniquely different in that the complete cylinder sleeve and head rotated, driven from the crankshaft by spur gears and bevel gears.

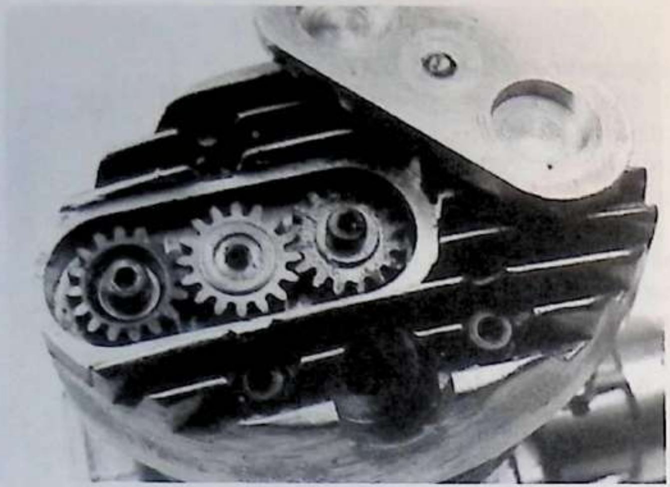
The Dylla rotary sleeve revolved at half crankshaft speed in order to produce the required four strokes per cycle. To achieve this and to pick up the drive from the crankshaft, the engine used both bevel gears and spur gears. The lower rim of the cylinder sleeve was provided with teeth to form the wheel of a pair of bevel gears, the pinion being mounted on a short intermediate shaft above the crankshaft from which it was driven by a pair of spur gears.

It is obvious that the Dylla system carried a penalty as regards mechanical efficiency by reason of the extra frictional losses involved in driving the complete cylinder liner (even at half crankshaft speed) in the surrounding aluminum cylinder jacket. In fact, this penalty was not so severe as might be supposed from turning the engine over by hand. When cold, the thickened oil film between the liner and jacket could make the engine feel very stiff but, when hot, the aluminum jacket would expand away from the steel cylinder and the heated and thinned oil would flow more freely.

The performance of the Dylla was not, it seems, markedly inferior to that of the (admittedly few) model four-strokes produced up to the time that the first Dylla appeared in 1978. According to Dr. Peter Demuth of the German R/C magazine *Modell*, this engine produced approximately 0.39 horsepower at 11,000 rpm, which, for an engine having a displacement of just under 5.9cc (0.36 cu in.) is equal to a specific output of just over 66 bhp/liter. On the other hand, the engine's weight of approximately 18 oz gave it a somewhat less than satisfactory power/weight ratio.

Several Dylla models were made but few reached the status of actual production engines. The 5.9cc Dylla (which was marketed for a time under the name Dymo) was also the basis of a 0.717 cu in. vee-twin model and there were two larger single-cylinder engines, each of which used a 24.5 mm HP 61 two-stroke engine piston. The larger of the two had a 9.90cc (0.6041 cu in.) displacement, while the smaller had a reduced stroke to give a displacement of 8.957cc or 0.5466 cu in.

Both these latter models had another novel feature. With rotary-valves it is necessary that the valve faces are kept in close contact to prevent gas leakage. With vertical axis valves, this is usually done by spring pressure but, for these larger Dylla engines, magnetic attraction was used: two magnets were embedded in the aluminum head to pull the steel liner into contact with it.



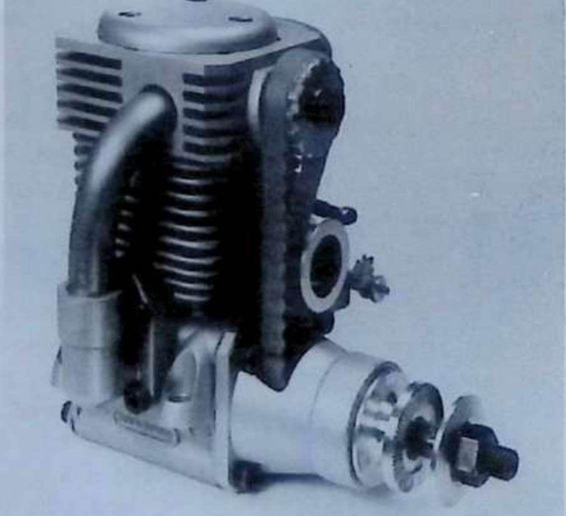
The RVE's disc-valve was rotated via spur gears and a vertical drive-shaft, bevel-gear driven from the rear of the crankshaft.

So far as is known, Dylla & Rosner's form of rotary-valve was never used in a full-size engine. In all other known types of four-cycle rotary-valves, the cylinder liner remains stationary and the valve is placed in the cylinder head, either within the actual combustion chamber, or above or to one side of it.

WEBRA CONICAL VALVE

The Webra T4, sometimes referred to as the T4-91 to distinguish it from the later T4-40, T4-60 and T4-80 models (although it actually has a displacement of a little over 0.87 cu in., rather than 0.91 cu in.) was the first rotary-valve model four-stroke to be produced in reasonable numbers. As mentioned in Chapter 1, it uses a vertical axis rotary-valve of a conical shape. In this respect it resembled the full-size Aspin type valve invented several decades earlier.

An Aspin valve works inside the cylinder and actually forms the roof of the combustion chamber. A single port in the valve uncovers the inlet port, ignition plug and exhaust port in turn. In the case of the Webra, the valve has a 6 mm diameter shaft extension, above the apex of the cone, which runs in a bronze bushing in the engine's large rectangular cylinder head. Where the shaft emerges from the bushing, it is fitted with a 30-tooth hardened steel bevel gear. Obviously, the conical inner surface of the head is carefully matched to the shape of the valve and, to maintain intimate contact between the two surfaces, spring washers are placed under the bevel wheel to lightly lift the rotary-valve against the head. The



Cylinder-head and valve parts of the original Webra T-4. Conical Aspin-type valve is at right. Other parts include bevel gears, bearings and toothed pulley for belt drive from crankshaft.

short shaft carrying the 15-tooth pinion that engages the bevel wheel, is supported in a ball bearing at the outer end and a 4 mm i.d. bronze bush at the pinion end. It is driven by a toothed belt and pulleys from the crankshaft main journal and an adjustable idler pulley is fitted to maintain belt tension.

RVE DISC VALVE

Introduced in 1980, the British made 0.60 cu in. Robinson RVE was another vertical axis rotary-valve engine but here, the valve, rather than conical, was flat; i.e. disc-shaped with a sector shaped cut-out. The cut-out uncovered similarly shaped ports in the head, giving more rapid opening and closing of the valves than was possible with the circular ports of the Webra T4. The RVE also had a more sophisticated drive system than the Webra (more like that of a full-sized Aspin valve engine) involving the use of a rear, bevel-gear driven vertical shaft, with a train of three spur gears in the cylinder head to turn the rotary-valve.

Disc valves have also been used in full-sized four-cycle engines. For example, before the First World War, the Reynolds Motor Company of Detroit produced a four-cylinder marine engine having disc valves that were spur-gear driven from a vertical shaft at the rear of the engine. Disc valves were also employed, at one time, in a car produced by Guy Motors in England. In general, however, disc valves in full-size practice were not too successful. Rapid wear of the valve faces due to combustion pressures was one disadvantage. Another was the difficulty of lubricating the bearings adequately due to the considerable amount of heat conducted from the valve disc through the shaft and bearings immediately above it. This is less of a problem with model engines in which liberal quantities of oil are contaned in an alcohol based fuel which passes through and around the rotary-valve both lubricating and cooling it.

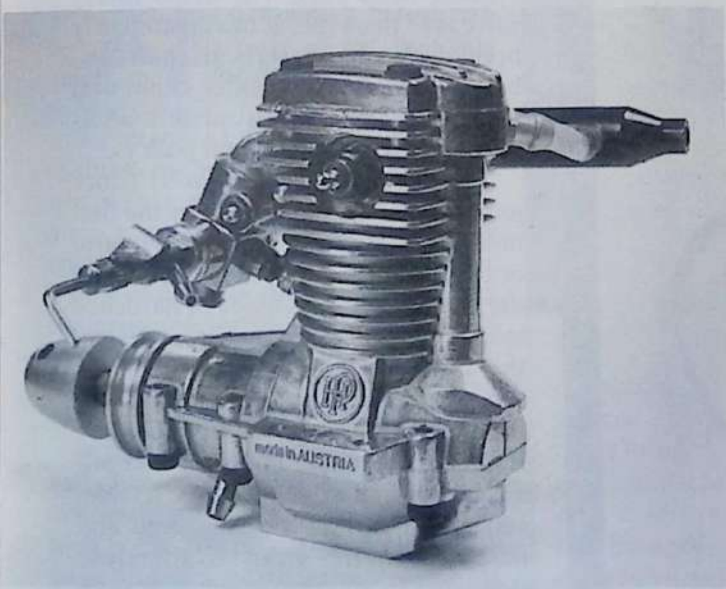
HP VERTICAL DRUM VALVE

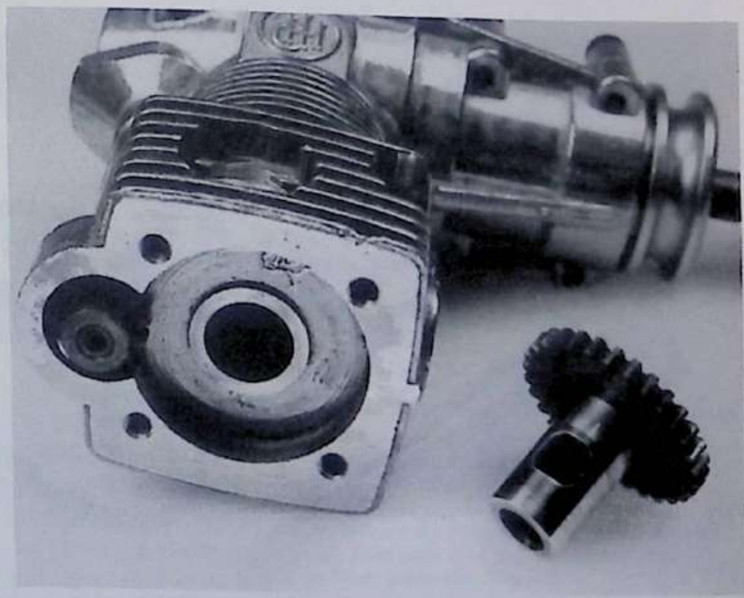
This is another variant of the vertical axis rotary-valve. Developed by the Austrian company, *Hirtenberger Patronen Zundhutchen & Metallwarenfabrik*, for their first model four-stroke, the HP VT-21 introduced in 1982, it is now also used by three other HP four-strokes, the VT-25, VT-49 and VT-61.

As used in the VT-21, the valve, made of brass, has an outside diameter of 9.0 mm, an inside diameter of 5.2 mm and is 14.6 mm long. It rotates in a chromed brass sleeve that extends into the fixed cylinder head. The valve has a rectangular port that registers with, in turn, an inlet port leading directly into the head from the front-mounted carburetor, a slightly narrower exhaust port on the right-hand side and a slot communicating with a horizontal glowplug installed in the left rear quarter of the head.

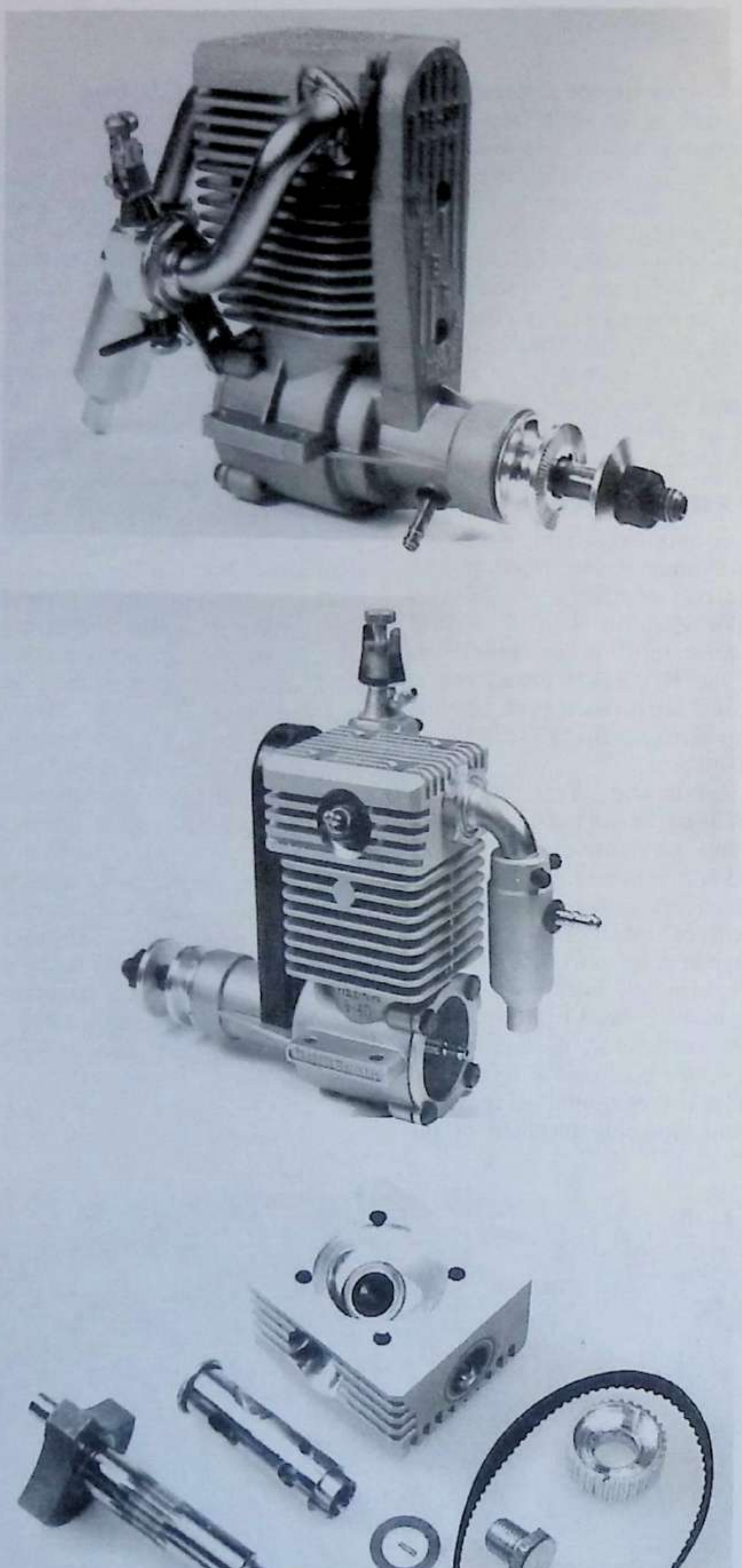
This valve design creates a decidedly odd combustion chamber shape (tall and narrow but with a wide squish-band) that bears little resemblance to the generally recognised "ideal" form. On the other hand, it has the theoretical advantage of adding induction swirl to squish turbulence to improve flame propagation which, as we have discussed in Chapter 4, enables a higher compression ratio to be used before detonation is encountered. The fact that tests of a VT-21 failed to produce any sign of detonation (by running lean or by overloading) despite a high compression ratio of 10.5:1, may be of significance here.

The method of driving the HP rotary-valve is similar to that of the RVE in that a rear vertical shaft is used, with bevel gears at the bottom and spur gears at the top. However, whereas, in the RVE, the necessary 2:1 valve timing is provided by the two bevel gears, while a train of three identical spur gears is used to convey the drive from the vertical shaft to the rotary-valve, the HP has a large spur wheel on the rotary-valve driven directly by a small pinion. This involves running the vertical shaft faster than crankshaft speed and the required 2:1 ratio is restored through a suitably modified bevel gear ratio at the bottom end.





Unusual vertical axis drum type rotary-valve of the HP VT-21. It is driven by a vertical shaft running at 1.25 times crankshaft speed to achieve the required 2:1 final ratio.



Simplest four-stroke engines of all are the Webra T4-40, T4-60 and T4-80. Horizontal axis valve is driven directly from crankshaft journal by toothed belt.

HORIZONTAL AXIS ROTARY VALVES

Horizontal axis rotary-valves have taken various forms in full-size practice. An early type, used by the American Mead rotary valve engine, featured two rotating members, one for the inlet and one for the exhaust. Placed parallel to the crankshaft and rotating at one-quarter speed, they were located across the inlet and exhaust ports each side of the cylinder head and had diametral passages allowing gases to pass through the ports at suitably timed intervals.

Single cylindrical valves, installed above or to one side of the cylinder head, have been of many types and were used by the French Darracq automobile company at one time during its long history. Early valves of this kind had a segment cut away on one side which opened the cylinder to the inlet and exhaust tracts in succession. A disadvantage of this type of valve is that inlet and exhaust gases are alternately passed through the same part of the valve. This means that the fresh charge is prematurely expanded by the hot valve, reducing its density and resulting in a loss of power.

AXIAL FLOW ROTARY VALVES

This is an improvement on the previously mentioned type since the fresh charge enters the valve from one end and the hot exhaust gases exit through the opposite end. The valve is machined in such a way as to completely separate the two passages while allowing their ports to register with a single cylinder head port. The Cross rotary valve is of this type. It has customarily been driven by a vertical shaft and bevel gears, or by a roller chain and sprockets. The obvious modern alternative is a toothed belt and pulleys.

The British-made Condor 91 (since joined by the Condor 120) was the first model four-stroke to use a rotary valve of this type. As with the Cross engine, the Condor's valve is made of hardened steel but, whereas, in the Cross design, the valve is of large diameter, fairly short and centrally located above the combustion chamber, the Condor valve is longer, of smaller diameter and offset relative to the cylinder axis. Its inlet and exhaust ports are staggered and the port in the head is therefore elongated to accommodate each valve port in turn. Fresh mixture enters the valve rotor through a port in its side at the rear, directly from a head mounted carburetor, and exhaust gases exit axially from the front of the valve and thence through a right-angled exhaust pipe.

Horizontal axis rotary-valves in which the valve and crankshaft axes are parallel, have the practical merit of being ideally suited to an inexpensive toothed-belt drive. By the simple expedient of providing twice as many teeth on the valve pulley as on the drive take-off pulley, the need for separate timing gears is also eliminated.

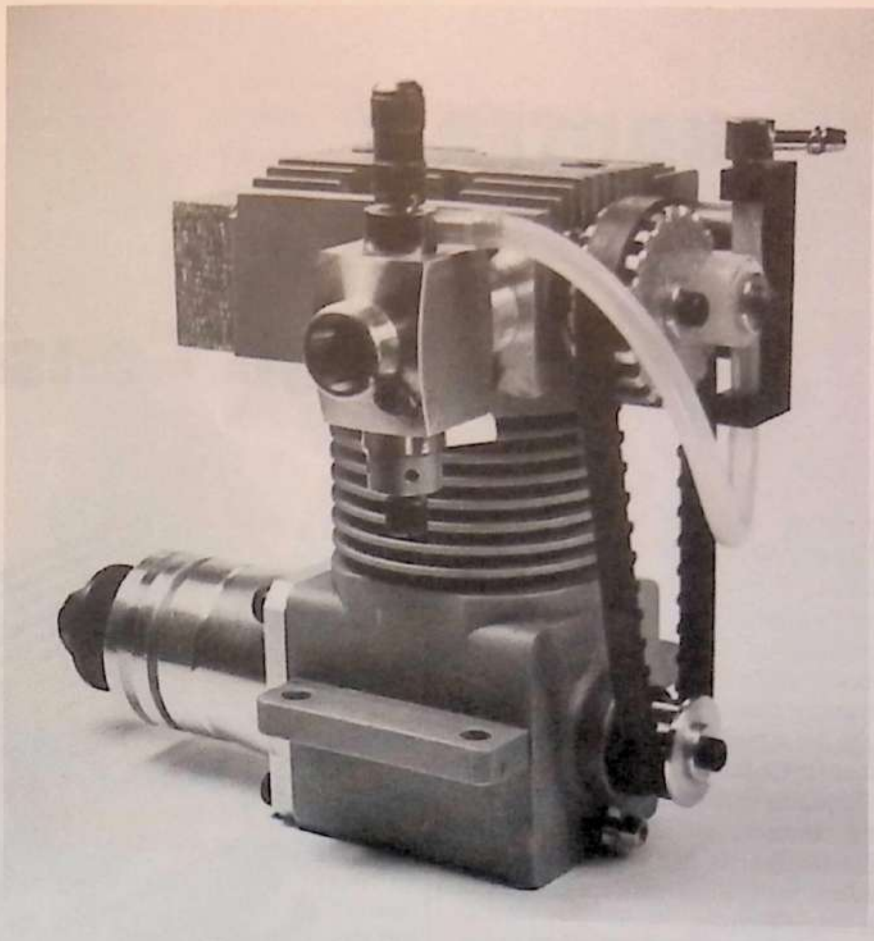
In the Condor engines, the valve drive take-off pulley is mounted on a short shaft installed in the back of the crankcase. The shaft is supported in a bronze bearing and is driven by the crankpin.

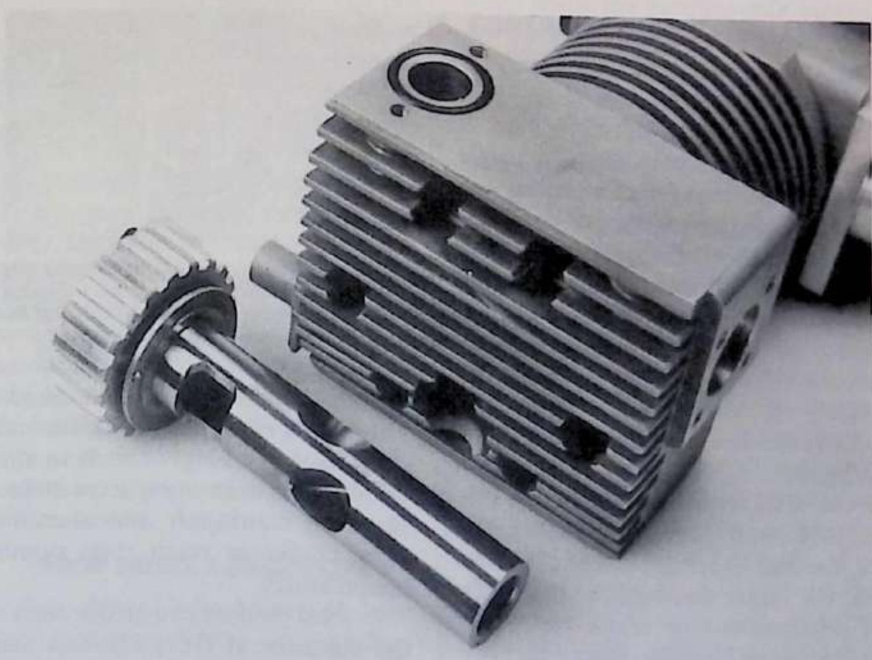
A year or two after the Condor engine first appeared, an even simpler horizontal rotary-valve engine was introduced by the Webra company in the shape of the T4-40 model. Aimed specifically at the sport flyer market where an economically-priced .40 cu in. engine is a popular choice, the 6.44cc (0.393 cu in.) T4-40 reduces the valve gear to just three moving parts: the valve itself, the toothed pulley attached to it and the belt to drive it. There is no separate drive shaft from the crankshaft. Instead, the toothed belt, located at the front of the engine, engages splines formed around the crankshaft journal. The same arrangement is now being used for two intermediate sized Webra rotary-valve four-strokes, the T4-60 and T4-80.

Clearly, so far as model four-strokes are concerned, a rotary-valve engine — particularly one with a belt-driven horizontal axis valve — can be made much more cheaply than a poppet valve engine.

It remains to be seen whether these engines can be developed to the point where they are comparable, performance-wise, with the best poppet valve engines. Almost half-a-century ago, Aspin and Cross rotary valve engines both showed themselves to be capable of specific power outputs equal to those of contemporary high-performance poppet valve engines.

It has been suggested that if, in the early part of the present century, lubrication technology had been at today's high levels, the rotary valve might well have proved a more serious rival and, with subsequent development, moved on to equal or exceed poppet valve popularity. As things turned out, designers' energies were instead channeled into the development of poppet valves and it became increasingly difficult, even after lubrication problems had been solved, to persuade them to abandon a well-trodden path. No such inhibitions need trouble the model engine designer.





The first production model four-strokes to use a horizontal axis cylindrical rotary-valve were the British made Condor 91 and 120. Inlet port is at side of head at rear; exhaust gases exit forward.

CHAPTER 8

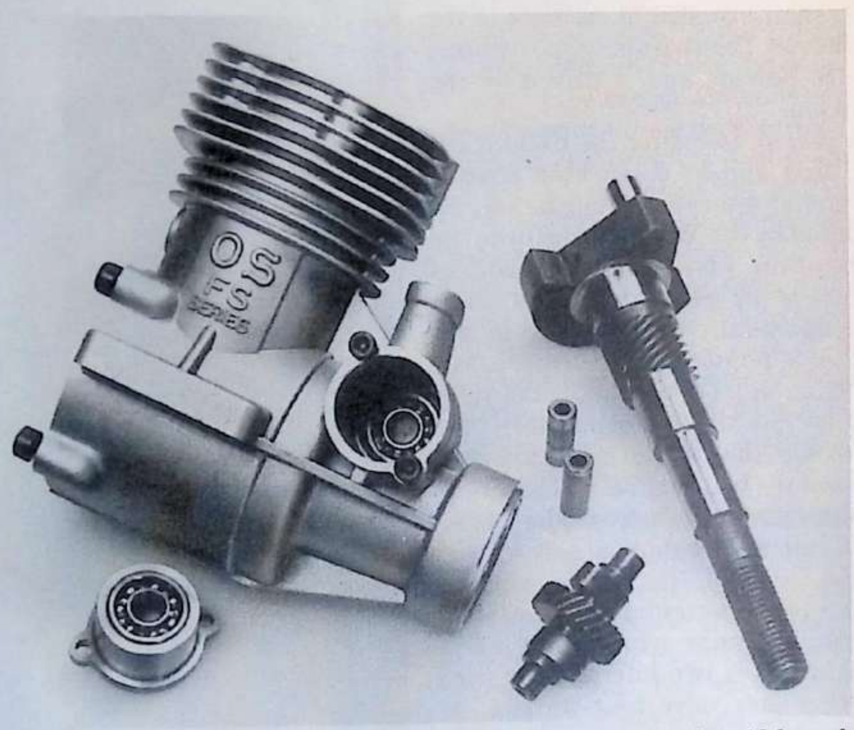
Other Design Considerations

In the previous chapters, all the components that are peculiar to a four-stroke-cycle engine have been covered: camshafts, timing gears, valve mechanisms (both poppet and rotary) and the special cylinder-heads to accompany them. The remaining basic parts, i.e. crankshafts, crankcases and piston/cylinder assemblies are also to be found in two-stroke motors, in one form or another and, since these are more familiar to the average modeler, they are being dealt with collectively in this single chapter.

CRANKSHAFTS AND BEARINGS

The traditional crankshaft for a single cylinder model two-stroke engine is a simple overhung crank type. That is to say, it consists of a shaft, a single crankpin and a web connecting the two. Most single cylinder model four-strokes are also of this type. In a model two-stroke, the shaft may be supported in a plain bearing (usually bronze bushed) or in ball journal bearings or in a combination of both. By contrast, virtually all current production model four-strokes feature at least two ball bearings.

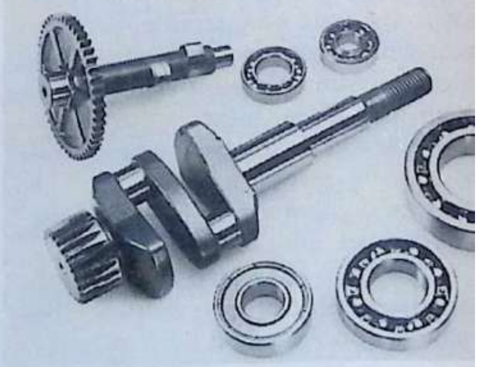
Generally, with a ball bearing engine, the shaft journals (and, therefore, the ball bearings) are of different sizes, the larger one being at the inner end adjacent to the crank web. The smaller, outer, bearing, placed just behind the prop driver, then serves also as a thrust bearing to take the axial loading imposed by the rotating propeller. Customarily, the outer ring of each ball bearing is an interference fit in the crankcase or front housing although, sometimes, the front bearing is also retained by a large internal circlip or snap ring in a groove in the housing immediately in front of the bearing to prevent any risk of forward movement.



An overhung crank, standard with single-cylinder model two-strokes, is also widely used for single-cylinder four-strokes. Typical of modern trends, O.S. FS-61, seen here, also has its crankcase, cylinder casing, front housing and camshaft housing embodied in a single robust aluminum pressure casting.

The crankshaft, on the other hand, is normally a close push fit in the inner rings of the bearings. This is to allow for differences in linear expansion as the steel crankshaft and aluminum alloy crankcase reach their running temperatures.

In most modern two-stroke engines, the diameter of the crankshaft main journal is very large (e.g. 15 to 17 mm diameter in a high performance .61 cu in. motor) since it usually incorporates the rotary intake valve. A large shaft diameter will accommodate a bigger valve port and gas passage to ensure free movement of the fresh charge into the crankcase. Such large diameters are unnecessary in the case of two-strokes having alternative types of intake valve (e.g. rear rotary disc or drum valves) or with four-stroke engines. Here, the main journal for a .61 cu in. engine may, with advantage, be



The O.S. FT-120 Gemini horizontally-opposed twin provides this good example of a two-throw crankshaft. It is carried in three ball journal bearings accurately aligned in a one-piece crankcase casting. Spur gear driven camshaft is supported in two ball bearings.

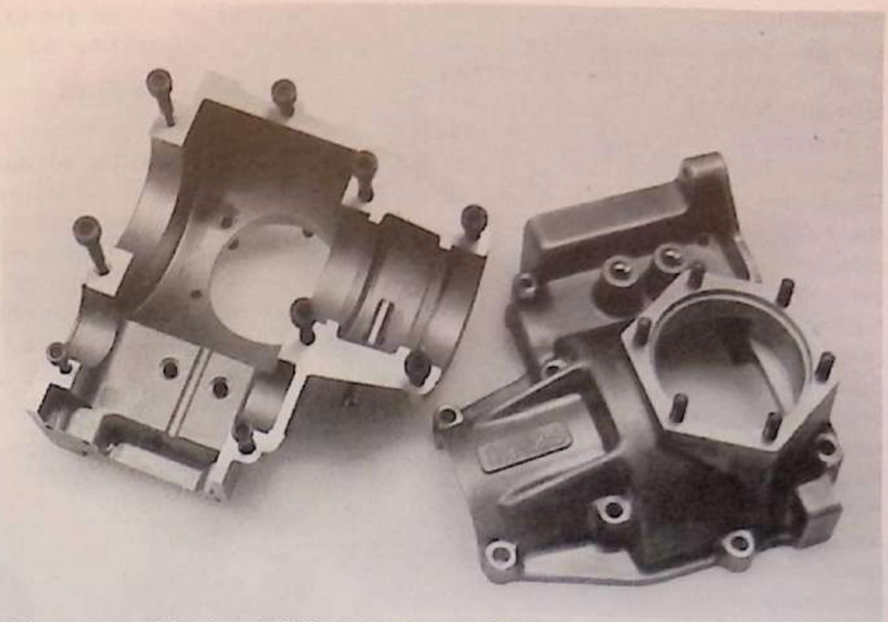
reduced to 12 mm. Exceptions are to be found in the case of some four-strokes having front skew-gear driven camshafts, where the drive pinion is an integral part of the crankshaft, as in certain single cylinder O.S. four-strokes.

Overhung cranks can also be used for vee-twin engines, in which both conrods are coupled, directly or indirectly, to a single crankpin and, as previously discussed, the smaller Saito flat twins (FA-80T and FA-90T) also use a single crank. Since a single-row radial engine also has only one crankpin, here again an overhung crank can be used.

For all other types of twin or multi-cylinder engines, two or more cranks are necessary and this, almost without exception, means that the crankshaft has to be supported at the rear as well as at the front. For the record, the exceptions are the Japanese G-Mark flat twin two-strokes which, by virtue of their very small size (0.6 cu in. and .15 cu in. cylinders) and some clever design, manage to incorporate two overhung crankpins, separated by an additional crank disc. Such an arrangement is practicable only in very small engines developing low cylinder pressures.

Ideally, both ends of a crankshaft having two or more crank throws should be supported in the same casting, so as to ensure perfect main bearing alignment. It goes without saying that the crankshaft journals must be equally well aligned and for this and other reasons, a one-piece crankshaft is to be preferred to a built-up type. In the past, some twin cylinder model engines have employed built-up crankshafts in order to avoid the necessity of using detachable bearing caps on their connecting-rods. Quite the worst of both worlds was experienced many years ago when a small manufacturer elected to use a built-up two-throw crankshaft in a flat twin engine having a crankcase with detachable front and rear bearing housings. On test, a typical production sample of this engine had a struggle to produce more than half its hoped-for power output, thanks to excessive frictional losses created by a combination of both journal and bearing misalignment.

Model engine crankshafts are usually machined from steel bar stock but, occasionally, from forgings and, in rare instances, from castings. Case-hardening is common practice, although this is only necessary for wearing surfaces such as crankpins, gear teeth or (in the case of plain or bushed main bearings) main journals. Hardening of, for example, the front end of the shaft, where this carries the threads for the propeller nut, may cause the threads to become undesirably brittle. To prevent this, parts of the shaft which need to remain unhardened may be protected by a plating of copper before the hardening process. Another solution with engines requiring only the crankpin to be hardened, is for this to be made separately and hardened and ground before being permanently pressed into the crankweb.



The crankcase of the Kavan FK-50 flat-twin is assembled from two halves and contains housings for three crankshaft bearings and two camshaft bearings.

PROP DRIVE ASSEMBLIES

Prop drivers (also known as drive-hubs and, sometimes, drive washers) are mostly made of aluminum alloy and are usually machined. For model four-strokes, they should be of larger diameter than two-strokes of equivalent power, because of the high maximum-to-mean torque fluctuations that occur with four-stroke motors — particularly in the case of single-cylinder units. (See Chapter 11.)

Prop drivers can be mounted on the shaft in many different ways. The simplest is for the driver bore to be shaped to fit a flat (or two flats) on the appropriate portion of the shaft. On the other hand, the familiar split taper collet continues to be favored for its security and elimination of backlash. Keying the driver to the shaft with a square sunk key or (now more widely used) a Woodruff key, positively locates its position relative to the crankpin. This enables the driver to carry a TDC mark which is helpful when checking valve clearances and timing.

CRANKCASES

The crankcase, invariably made of light alloy, is the body of the engine, in and around which the other parts are assembled. In the case of engines that are manufactured in large quantities, the crankcase is usually a pressure die-casting. Alternative methods of production include permanent-mold (gravity-die) casting and investment casting, while, in a few engines, the body components, like most of the other parts of the engine, are machined from bar stock material.

It is common, especially in single-cylinder engines, for the crankcase to incorporate the front housing and/or the cylinder casing. Alternatively, a detachable front housing and an integral rear timing case may be used. An example of how a casting may be designed to integrate all the major parts of the engine is to be seen in the current front-camshaft O.S. engines, in which a single casting includes the crankcase, front housing, cylinder casing and camshaft housing.

The crankcase is usually the component by which the engine is mounted. Beam mounting lugs, cast as part of the crankcase, are the norm with single cylinder and inline engines. For horizontally-opposed and radial engines, bulkhead or firewall mounting is more common, either by means of integral lugs or a separate bolt-on plate or brackets. In the case of the O.S. Gemini 120 and 160 twins and the Pegasus flat-four, an optional cast aluminum mounting plate is supplied that has thrustline reference marks to facilitate accurate alignment with the center-line of the fuselage. This also enables the engine to be quickly removed from the model for servicing, leaving the mount attached to the fuselage.

Another nice touch is the radial mount supplied with the Kavan FK-50 twin. Here, the mount, consisting of three brackets, is bolted to the engine at three rubber-bushed mounting points to provide a resilient attachment that markedly reduces the vibration transmitted to the airframe.

PISTON/CYLINDER ASSEMBLIES

In a two-stroke engine, the piston provides the means of controlling the entry and exit of gases by uncovering ports in the cylinder wall. This means that the length of the piston, in a two-stroke, must be at least equal to (or, for all practical purposes, fractionally longer than) the engine's stroke measurement. If it is not, the bottom of the piston skirt will uncover the lower edge of the exhaust port and allow exhaust gases from the exhaust pipe or muffler to be drawn into the crankcase. This will dilute the fresh charge, causing a loss of power. It will also reduce fuel draw at the carburetor.

In a four-stroke engine there are no ports in the cylinder wall. Therefore, the piston can be made much shorter, which not only reduces reciprocating weight, but means that cylinder height can be shortened. In fact, most of the skirt can be cut away in a four-stroke motor, leaving only an upper band, or ring-belt, sufficient to seal the cylinder bore, plus an intact portion of skirt each side to guide the piston in the bore and resist side thrust due to the angularity of the connecting-rod.

SLIPPER PISTONS

This type of piston is known as a slipper piston and has the additional advantage of reducing frictional losses. Slipper pistons, and modifications of the type, are now in use in some recent model four-strokes. Alternatives are pistons in which large lightening holes are cut in the skirt (as in some O.S. engines) and the hourglass pattern (featured by Laser) in which only the ring belt at the top and a narrow band at the bottom remain in contact with the cylinder bore.

In a well-designed slipper piston, a saving in reciprocating weight can also be made by reducing the length of the wristpin and placing its bosses closer to the connecting-rod as in some Enya engines. Wristpins are invariably full-floating, i.e., in contrast to many full-size engines, the pin is free to move in both piston and connecting-rod. In order to minimise wear in the piston bosses and conrod eye, the wristpin must have a hard, highly polished surface and must be closely fitted to its bearing surfaces.

With conventional pistons, the wristpin is prevented from moving axially and scoring the cylinder wall, in one of two ways. Either its ends are equipped with soft metal or heatproof plastic pads (e.g. brass, aluminum or PTFE) or it is restrained by small circlips or snap-rings in the piston bosses. This latter method is also used for slipper pistons.

Early internal combustion engines, both full-size and model, had pistons made of cast-iron or (sometimes) steel. Some lapped-piston model two-strokes (especially diesels and very small glow engines) still use ferrous materials, but all current model four-strokes, in line with modern full-size practice, have aluminum alloy pistons, usually with piston-rings. W. O. Bentley, the English automobile engineer and designer of the W.W.I Bentley Rotary aircraft engine, was the first to convincingly demonstrate the feasibility of aluminum alloy pistons, using them as early as 1913 in French D.F.P cars which he modified for racing purposes. The main advantage of an aluminum piston is its lightness, which

Three types of modern four-stroke piston. Left to right they are: (a) O.S. FS-90 semi-slipper type with lightening holes; (b) Enya 80-4C slipper type and (c) Laser 75 hourglass pattern.

by reducing reciprocating weight, enables an engine to operate at much higher revolutions and develop more power.

One feature that is virtually unheard of in full-size practice but which is common in model i.c. engines, is the ringless or lapped piston. In the early days (pre W.W.II) of commercial model engine manufacture, most engines were of this type, usually employing a cast-iron piston, ground and lapped to fit a steel cylinder to provide adequate compression seal without the use of piston rings. With the coming of larger high-performance two-stroke engines in the post W.W.II period, ringed aluminum pistons became widely used for the larger controlline speed engines and, since 1960, aluminum pistons have gradually taken over for radio-control engines, first in the .60 cu in. class and subsequently, in both smaller and larger displacements. Along with this later trend came "ABC," originated by the Super-Tigre company in Italy, in which a ringless aluminum piston is used.

The main purpose of a piston ring is to allow for the differential expansion and contraction of the piston and cylinder. When a cast-iron piston is used in a steel cylinder, their similar coefficients of expansion enable the piston to be quite closely fitted to the cylinder bore — sufficiently close, in a model engine, for the ring to be dispensed with. However, when an aluminum piston is used in a steel or cast-iron liner, the clearance between piston and liner has to be substantially increased in order to accommodate the greater expansion of the piston as the engine heats up. A piston-ring (or compression-ring to be more specific) then becomes essential, in order to prevent the leakage of gas past the piston, when the engine is cold, creating starting difficulties.

The ABC type piston/cylinder assembly overcomes this problem in a different way. Here, a material is chosen for the cylinder, or cylinder-liner, that closely matches the coefficient of expansion of the aluminum piston. As originated by Super-Tigre and since used by many other manufacturers, the ABC system features a ringless aluminum piston (A) running in a brass cylinder-liner (B) which, in order to provide a hard, wear-resistant surface,

Kavan FK-50 pistons are made by German Mahle Company and follow full-size practice in having an elliptical skirt section, plus an oil scraper ring. Sturdy forged conrods have I-beam section shanks.

has a chromium-plated bore (C). Some other manufacturers have chosen to use aluminum, rather than brass, for the cylinder-liner, while others have dispensed with the separate cylinder-liner or sleeve and applied the hard-chrome deposit directly to the bore of the aluminum cylinder barrel. These systems are variously known as "AAC" (e.g. for some Saito four-strokes) and "Al-Chrome" (some Enya models).

It might be thought that a ringless aluminum piston would wear rapidly. This is not the case if the components are accurately made from quality materials and operated under favorable conditions. It is usual for the cylinder bore to be made convergent at the top. This means that frictional losses are kept to a minimum over the lower part of the stroke, whereas piston seal improves as the piston approaches top dead center where compression is greatest. Obviously, under such conditions, satisfactory lubrication and the exclusion of any foreign matter that might score the piston and cylinder bore (and thereby cause loss of compression) are essential.

A disadvantage of all ringless pistons is that, when parts have to be replaced, either through wear or accidental damage, it is necessary to fit a complete matched piston and liner assembly. Worse still, in cases where a separate liner is not fitted, a complete replacement cylinder and piston assembly will have to be purchased.

To overcome these disadvantages and also to make piston/cylinder matching less critical during production (a convergent bore being unnecessary) some manufacturers are now equipping their ABC and AAC type engines with piston rings so that only the piston or, in some cases, only the ring, has to be replaced to restore compression and performance. There are still advantages to be gained in that the aluminum piston can be fitted more closely to the cylinder, while heat transference is better than when a ferrous cylinder liner is used.

The pistons fitted to current model four-stroke engines almost invariaby have plain flat heads or crowns. This is in contrast to full-sized pistons which have a wide variety of shapes to suit different combustion chamber designs and provide extra clearance for valve heads.

ELLIPTICAL PISTONS

Another full-size feature that is rarely found in model engines is the "elliptical" piston.

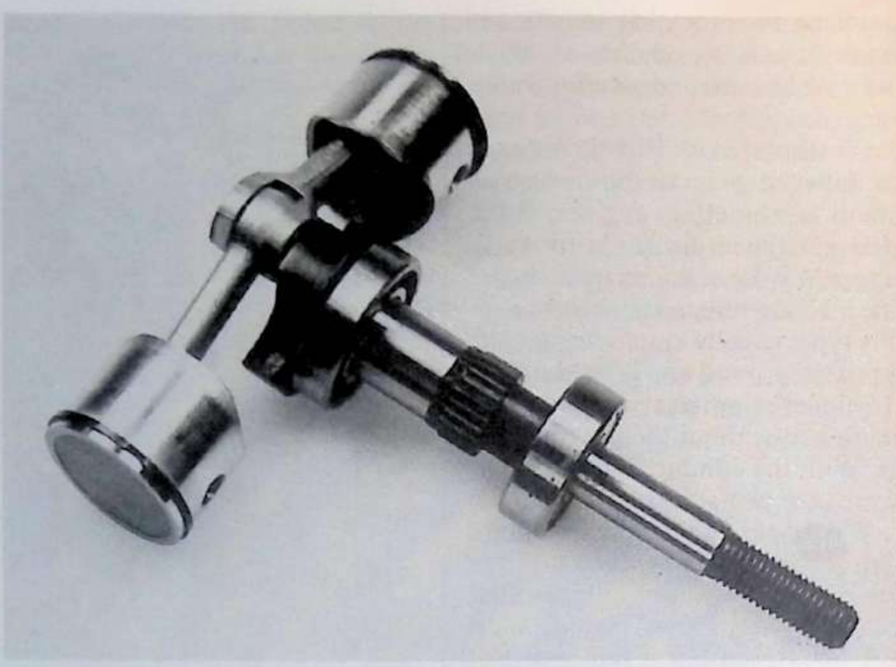
With pistons of conventional design, having orthodox wristpin bosses, heat flow from the piston head causes the skirt diameter to distort to an elliptical shape, with its major axis parallel to the wristpin. Therefore, in full-size engines, it is common practice for pistons to be turned or ground to an elliptical shape in which the major axis of the ellipse is at right-angles to the wristpin. This means that the skirt is expanded to a circular shape as the engine reaches its running temperature.

At the present time, only the Kavan FK-50 has elliptically turned pistons. Machined from forgings by Mahle-Aluminum, the noted German piston specialists, the FK-50 pistons have a nominal diameter of 33.94 mm, giving a 0.03 mm (0.0012 in.) clearance between the top land and the wall of the 34.0 mm bore cylinder, but are tapered, top to bottom, to an elliptical shape. At the bottom of its skirt, the piston measures only 33.64 mm, parallel to the wristpin, thereby increasing cold clearance by an additional 0.15 mm (0.006 in.).

PISTON RINGS

Engines, model and full size, vary a good deal in the number and type of rings fitted to their pistons. In the early days of the automobile, it was common practice to use a very deep ring belt with, perhaps, four rings and, sometimes, one or two extra rings would be located at the bottom of the skirt. Nowadays, pistons are seldom fitted with more than three rings, two of which will be compression rings and the third an oil-control or "scraper" ring — all located above the wristpin. Most model engines used to be fitted with two rings but, since the late Fifties, single rings have been the norm.

As the piston is exposed to the full heat of combustion, it becomes very hot and it continues to soak up heat during the expansion and exhaust strokes, as do the cylinder walls and cylinder head. But, whereas the latter are cooled by contact with the surrounding air (or water-jacket in the case of a liquid-cooled engine) the piston can only lose heat through conduction or radiation, apart from that lost to the fresh charge during the induction phase. Most of the piston's excess heat is, in fact, given up to the cylinder wall: which would seem to be a good argument in favor of using a deep ring belt with several rings and lands. Actually, this advantage is outweighed by the considerably greater frictional loss entailed, hence the drift towards fewer (and, incidentally, narrower) piston rings.



A common method of fitting two connecting-rods to a single crankpin is with a fork and blade type bearing arrangement as shown here.

Piston-rings do not rely solely on their springiness to seal against the cylinder wall. Gas, forcing its way between the piston and cylinder wall, penetrates the ring groove and forces the ring downward and outward. This is further exploited in the low-pressure L-section Dykes type piston ring used by a number of model two-strokes. Here, ring springiness exerts very little pressure on the cylinder wall. Dykes rings are seldom used in four-stroke engines; exceptions being the Austrian HP rotary-valve motors and the German Kavan Mk.II twin. Nor is it usual to pin four-stroke engine rings against rotation. This is only necessary in a ported (i.e. two-stroke) cylinder having wide ports into which the ring gap might rotate and cause damage.

A separate function of piston rings in full-size four-stroke engines, is to allow oil from below to lubricate the cylinder bore but to prevent an excessive amount getting past the piston and into the combustion chamber where it will be burnt, causing excessive oil consumption and carbon build-up. As previously noted, full-size engines normally have two conventional compression rings and, below them, a special oil-control or scraper ring, the purpose of which is to glide over the oil film on the upward stroke, but to scrape off all but a very thin layer on the way down.

Scraper rings are not normally fitted to model four-strokes. An exception is the Kavan FK-50 which, like most full-sized engines, has a crankcase sump from which a mechanically driven pump draws oil to lubricate the bottom end. The FK-50 has two rings and, in its latest Mk.II version, these consist of a Dykes type compression ring and, below it, a stepped oil scraper ring. This revised piston also follows full-scale practice in having a series of oil return holes through the piston skirt to drain the excess oil, collected by the scraper ring, back into the crankcase.

Piston rings are generally made of cast iron and are very brittle. Preferably, they should not be removed from pistons except for the purpose of replacement.

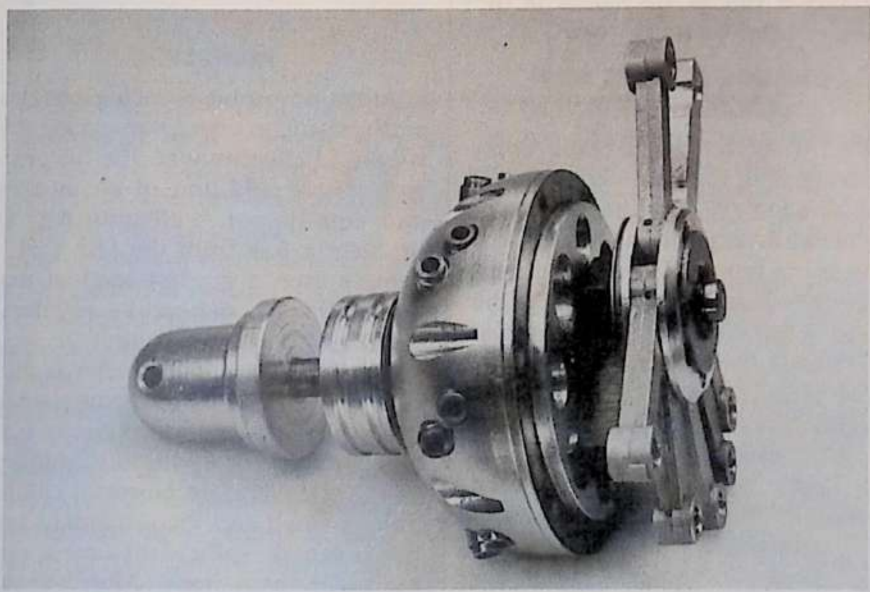
CONNECTING RODS

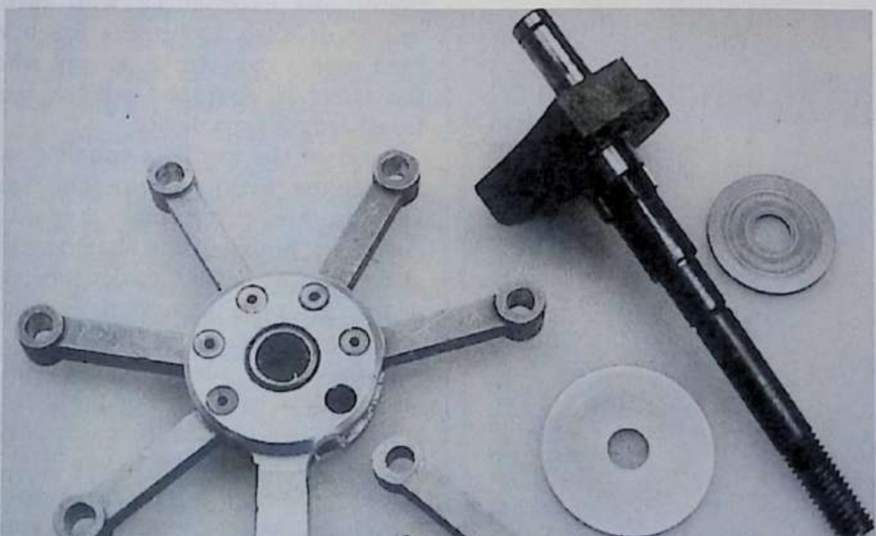
Connecting-rods for model engines are generally made of aluminum alloy. In the simplest and cheapest engines, rods may be die cast but, for four-strokes especially, it is usual for the conrod to be forged or machined from a high duty alloy. In a four-stroke engine, the rod is subjected to much wider fluctuations in load, ranging from tensile to compressive forces and needs to be stronger than for a two-stroke engine of similar power. Although the aluminum alloys used for conrods are commonly quite satisfactory as bearing materials, it is also more common for four-strokes to be provided with phosphor-bronze bushes for the crankpin and piston-pin. Generally speaking, needle bearings are neither necessary nor desirable.

In all model engines having an overhung crank, the connecting-rod is invariably made in one piece: i.e. with closed eyes at both ends, whereas, in the case of twin or multi-cylinder engines having more than one crank-throw and a one-piece crankshaft, the lower end of the rod has to have a detachable bearing cap. The bearing cap is customarily secured with two socket-head cap screws (sometimes specially made for the purpose) rather than with bolts and nuts as used for full-scale engines. With, for example, a flat-twin having a barrel type crankcase, this enables the caps to be tightened by means of an Allen key inserted from the opposite side, before the cylinders are installed.

The width of the connecting-rod shank, i.e. the dimensions at right angles to the bearing axes, should be greater than its thickness. This is because the compressive forces on the rod will tend to bend it more easily sideways due to the fact that it can pivot at each end. For this reason, a rod having a machined circular section shank is not the ideal shape, although such rods have been used by manufacturers of small model two-strokes for many years. Forged rods sometimes have an I-beam section in recognition of the desirability of extra stiffness in the plane of crank rotation.

Connecting-rod lengths vary considerably. In keeping with the steady reduction in stroke/bore ratios that has taken place during the development of the internal combustion engine, there has obviously been a reduction in connecting-rod length, but the ratio of

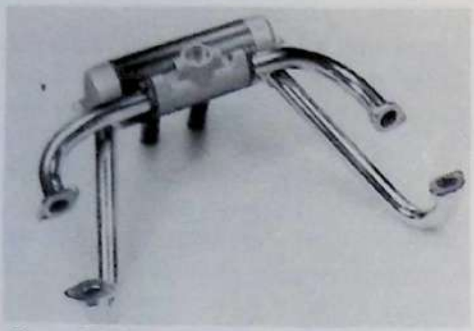




The master connecting-rod, to which the other six rods are articulated, as used by the Technopower 7-cylinder radial engine. The large washers and E-clip are for retaining the assembly on the crankpin.

Three typical examples of prop driver attachment. Top: split taper collet (O.S. FS-60). Center: Woodruff key (O.S. FS-61). Bottom: prop driver bore shaped to fit flats on crankshaft (Enya R120-4C).

Most model four-stroke engine mufflers are simple non-baffled expansion chambers. Improved O.S. type shown has internal diffuser and gives better noise attenuation with minimal power loss.



Kavan FK-50 exhaust pipes discharge into transverse expansion chamber at rear of engine. Engine also boasts an exhaust-heated inlet manifold to aid fuel vaporization.

rod length to stroke has also been reduced. It is now comparatively rare for the conrod measurement, between centers, to exceed twice the engine's stroke measurement.

There are advantages to making the connecting-rod as short as possible. Obviously a short rod will be lighter and more rigid than a long one and, since it also enables the cylinder height to be reduced, the engine can be made lighter and more compact. On the other hand, for a given piston stroke, the angular movement of a short rod is greater than for a long one, increasing piston side-thrust, frictional losses and vibration. As with so many aspects of engine design, rod length has to be a compromise, but placing the wristpin as high as possible in the piston, so as to enable a slightly longer rod to be used without increasing cylinder height, is a practice now fairly widely used by model engine designers. Connecting-rod lengths are mostly in the region of 1.8 to 1.9 times stroke.

CONRODS FOR VEE AND RADIAL ENGINES

With a vee (or single-crank twin) type engine, in which two connecting-rods have to be fitted to one crankpin, one of two arrangements may be used. First,as in a typical V8 automobile engine, the two rods may simply be placed side by side on the crankpin. Alternatively, as in many large vee type aircraft engines, one conrod may have a widened forked end that fits either side of a narrowed plain or "blade" rod. This second method is also used by the Saito FA-80T and 90T single-crank flat twins.

As noted in Chapter 3, radial engines have a master connecting-rod with an enlarged central boss to which the rods from the other cylinders are articulated. In the Technopower five and seven cylinder radials, for example, the master rod is mounted on the crankpin by means of a 6 x 10 mm caged needle-roller bearing containing 10 rollers. The articulated rods are coupled to the master rod with 5/16 inch diameter floating wristpins and the wristpins are held in place by two large steel washers on the crankpin, one each side of the master rod. The complete assembly is retained by an E-clip that engages a groove on the end of the crankpin.

Flange-fitting of curved exhaust header to cylinder, as on this Enya R120-4C, has the advantage of being less likely, than a screw-in type, to loosen and rotate under the effects of heat, vibration and muffler weight.

MUFFLERS

A major problem facing the scale enthusiast who uses a two-cycle motor is how to effectively muffle his engine without the addition of an unsightly and totally non-scale muffler. The problem arises from the fact that, to achieve even a modest level of noise attenuation, a two-stroke requires a muffler of very large volume.

The four-cycle engine user is much better placed. Some of the smaller and less powerful four-strokes can be operated without the addition of mufflers. Even with the more powerful engines, quite a small and inconspicuous muffler is usually sufficient to meet existing noise regulations. Moreover, any power loss experienced with such a muffler is likely to be very much less than with a two-stroke, except where the latter is equipped with a large, tuned-length type device.

Most of the mufflers supplied with (or for use with) current four-stroke engines, are either plain expansion chambers, or expansion chambers with some kind of baffled outlet tube such as the O.S. type illustrated. Few manufacturers have taken the trouble, as yet, to design silencers that can be slung below or hidden within a scale type cowling. One of the exceptions is Kavan, whose FK-50 flat-twin is assembled complete with a transverse muffler at the rear between the engine firewall mounting brackets. Exhausting both cylinders into a single chamber helps to lower noise levels and the muffler outlets consist of two downpipes for ejecting spent gases clear of the model.

CHAPTER 9

Carburetors and How They Work

The speed at which an internal combustion engine runs under a given load is dependent on the amount of gas that is burned in its cylinder. Therefore, control of engine speed would appear, at first sight, to be quite easy. All that seems to be required is a valve to alter the quantity of gas fed into the cylinder.

Unfortunately, this is not so simple as it sounds. Our engines run on a mixture of liquid fuel and air. The liquid fuel has to be atomized in air to make a combustible mixture. This is the primary function of the carburetor. However, in order to ensure that the resulting mixture is, in fact, a *combustible* gas, the ratio of liquid fuel to air, the *mixture strength,* must be held to within certain limits. Therefore, the carburetor must also be capable of correctly matching the supply of fuel to the amount of air passing through it.

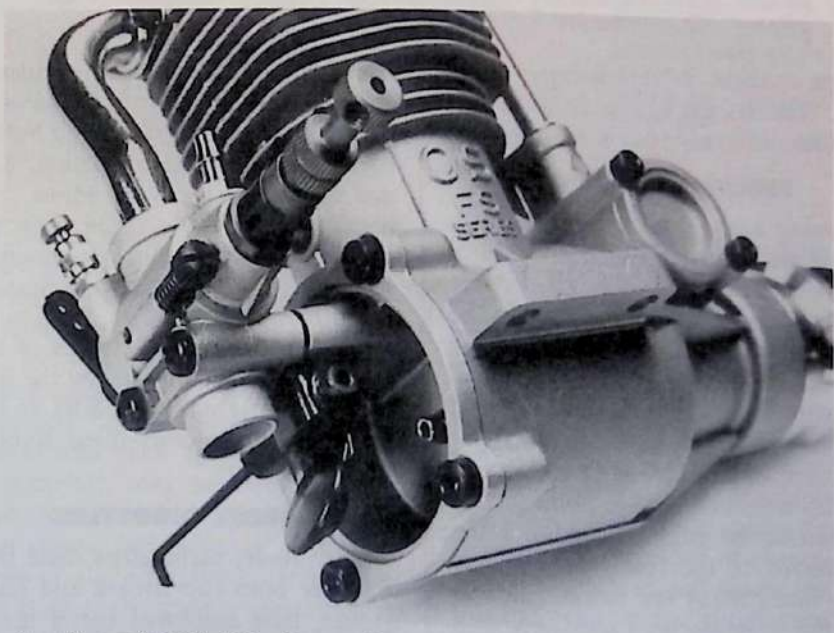
This is easy enough with a "one-speed" engine, such as a stationary or industrial engine, designed to run at a steady speed under load and consuming air at a constant rate. The same applies in the case of a *non*-throttle-equipped model engine — e.g. a free-flight or controlline speed type. All that is required here is that the amount of fuel delivered is correct for the operating speed of the engine (a function of the propeller size used) and all such model engines are equipped with a needle-valve enabling the flow of fuel to be adjusted to match the amount of air admitted. The needle-valve also makes it possible to compensate for other variables, such as different fuels and climatic conditions.

The situation changes, however, when the rate of air flow, through the carburetor, is varied in order to control the engine's power output. This is because air is compressible, whereas liquid fuel is not.

When the flow of air through the carburetor is speeded up, its pressure drops — in other words it becomes less dense — as it passes through the carburetor venturi tube or choke. This means that the suction at the fuel jet (situated in the narrowest part of the venturi) is increased and more fuel is drawn into the venturi. As the combustible mixture strength is dependent on the respective *weights* of air and fuel, rather than on their *volume,* and as the density of the fuel, being a liquid, does not vary, the mixture then becomes too rich.

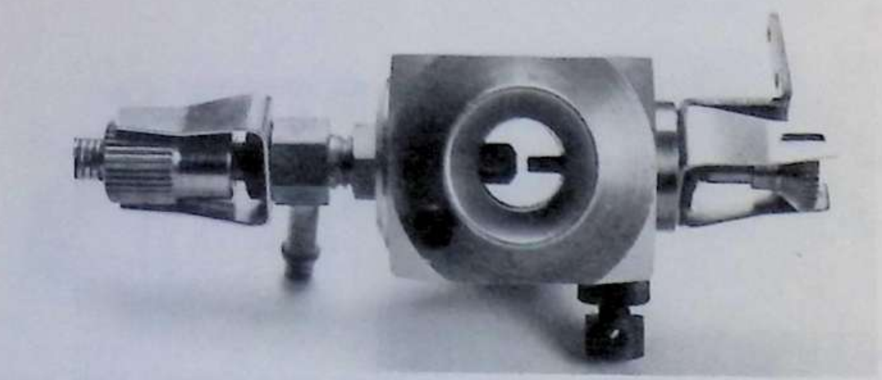
If the carburetor is adjusted so that the mixture strength is suitable for economical operation at moderate speeds, opening the throttle valve will make the mixture progressively richer until, at full throttle, the mixture might become so rich that the engine would no longer continue to fire.

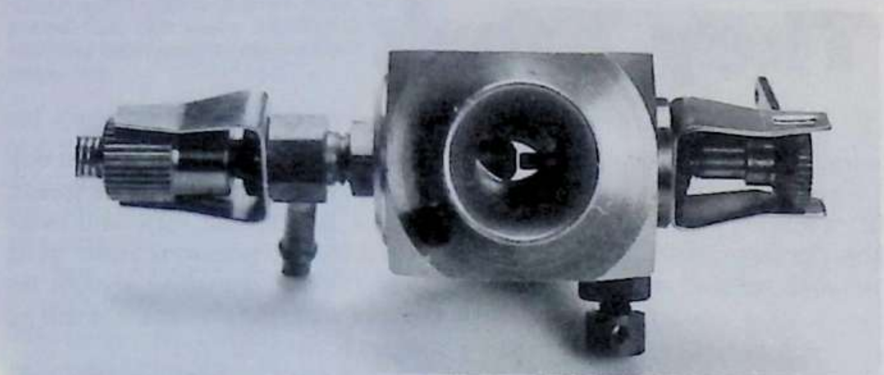
In full-sized carburetors, this problem is dealt with by various types of built-in compensating devices which automatically reduce fuel flow at large depressions. This is obviously necessary in the interests of fuel economy as well as engine performance.



A modern adjustable airbleed type carburetor, as fitted to the O.S. FS-61. The airbleed hole can be seen in the rear of the carburetor body and adjustment is by means of the black slot-head screw behind the needle-valve. Also shown is the self-reopening choke valve.

With model engines, we are usually less concerned with fuel consumption than with the need for the engine to continue to function reliably over a wide range of speeds and through





The Webra TN (the original "two-needle" carburetor) in its full-throttle and half-throttle positions. Note how the secondary needle has moved closer to the fuel jet-tube. When closed to the idling position, the secondary needle enters the jet, automatically reducing fuel flow.

abrupt changes in fuel delivery pressure. This has led to the development of rather different types of carburetors.

THROTTLE VALVES

Among early, unreasoned attempts to provide a degree of speed control for model (two-stroke) engines, were pivoted flaps or butterfly valves in the mouth of the air intake. Such crude devices simply restricted the amount of *air* admitted to the carburetor and were capable of effecting only a slight reduction in power. Reducing air admission beyond a certain point merely resulted in the engine's suction being transferred to the fuel jet (as occurs when one chokes the intake prior to starting) creating an excessively rich mixture on which the engine would not continue to run.

Someone then had the bright idea of coupling a second butterfly valve to the first, the second one being behind the jet so as to reduce suction. This was better but tricky to adjust. The breakthrough really came with the barrel throttle, the first commercial example being Ernie Kratzet's Bramco carburetor introduced in 1955 to fit various American two-strokes of the period. This was followed by the first engines (notably by K&B) to be equipped with factory-fitted throttle type carburetors.

BARREL THROTTLES

Most model carburetors since that time, for both two-strokes and four-strokes, have employed barrel throttles. The barrel, or rotor as it is sometimes called, takes the form of a solid cylinder, usually of brass or steel, located across the venturi and bored through diametrically to line up with it at full throttle. In its simplest form, this type of carburetor has the barrel drilled axially to take a spraybar or jet tube so that fuel is discharged into the center of the choke.

Rotating the barrel towards the closed position decreases the size of the opening on the "upstream" side to limit air admission but, at the same time, the opening in the "downstream" side is also made smaller so that suction is reduced, lessening the tendency for the engine to run rich. Nevertheless, if both openings are reduced by the same amount, there is still a tendency for the engine to run rich when idling.

The solution to this particular problem is to make the upstream opening larger than the downstream one. It can be accomplished in a number of different ways. For example, the bore of the carburetor can be made larger above the throttle barrel than below it. Or the bore of the barrel itself can be made convergent, or it can be elongated or notched at the top.

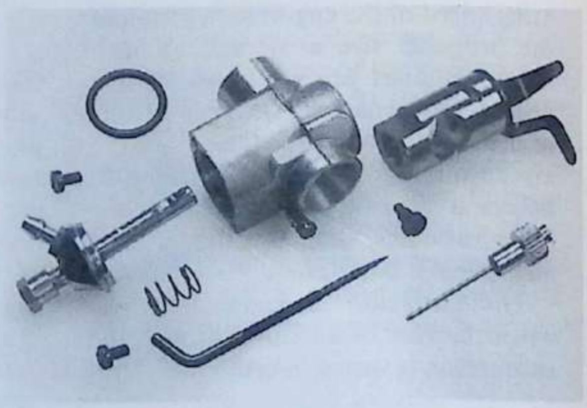
Another method of preventing the engine from running too rich at idling speeds is to drill a small hole through the carburetor body so that this is uncovered by the upper opening of the throttle barrel as it rotates towards the closed position, thereby allowing more air to "bleed" into the system at low speeds.

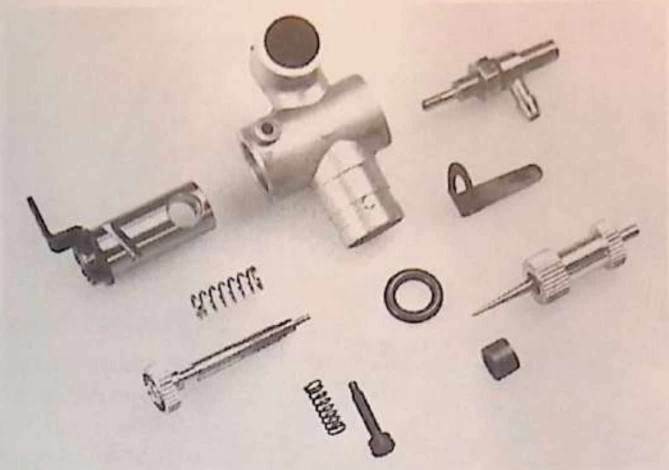
ADJUSTABLE AIRBLEEDS

None of the above systems, however, actually allows the idling mixture to be altered independently of the optimum full-throttle mixture as fixed by the needle-valve setting. This facility came with the introduction of the adjustable airbleed type carburetor. Here, the carburetor body has a relatively large diameter bleed hole through it and the

***Left:** Parts of the Webra TN carburetor. Note the cam slot in the throttle barrel which causes the barrel to move inwards as it rotates towards the closed position.*

***Right:** Parts of the Super-Tigre "Mag" series carburetor which works on the same principle as the Webra TN but has a parallel secondary needle that moves axially within the jet-tube to vary the length of a slit type fuel jet.*





Another two-needle type carburetor as fitted to the Saito FA-30 engine.

Enya "G-Series" carburetors have non-adjustable mixture control (i.e. no secondary needle) via a tapered fuel metering slot in the surface of the throttle barrel. Fine tuning of the idle mixture is then achieved with an airbleed screw.

effective area of the hole is then controlled by a screw. The screw usually enters from the side or top and, when fully screwed in, will blank off the airbleed hole completely. The optimum setting is usually with the airbleed hole about half-way open, thereby giving a wide range of control over idling mixture strength.

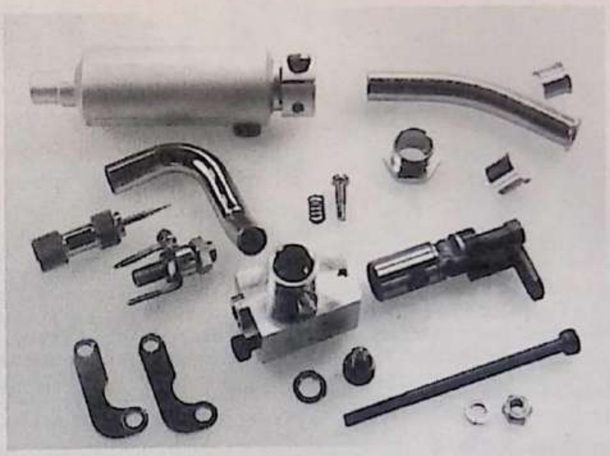
VARIABLE JET SYSTEMS

A good airbleed type carburetor, properly adjusted, can be very reliable and many such carburetors are still used by a number of modern and well respected engines, both two-stroke and four-stroke. However, its principle has been looked upon with disfavor by some designers because of its fixed jet size.

The fixed jet works well so long as fuel draw is primarily dependent on the depression created by a high speed flow of air through the carburetor venturi. But, as already explained, when the airflow past the jet is drastically reduced — i.e. when the throttle is in the idling position — it is the engine's suction that assumes an increasingly important role in pulling fuel to the jet. As we have seen, it is to prevent this suction resulting in an excessively rich mixture at idling speed that an airbleed is used.

This said, it has to be admitted that to have to reduce fuel suction, in this manner, is unfortunate because it is when the engine is idling that it is most vulnerable to small variations (e.g. through aircraft attitude) in delivery pressure. Ideally, pressure should remain high to reduce the risk of the engine being starved of fuel and consequently cutting out.

The answer to this is to keep fuel suction at a high level by eliminating the airbleed and to employ a device for reducing the *quantity* of fuel actually released through the jet.



The Enya "GC Type" carburetors are similar to the standard G-Type but have the addition of a built-in choking device. Pulling the throttle barrel sideways at the idling position blanks off the air intake while uncovering a special priming jet.

This is the principle upon which many modern model engine carburetors now operate. Mechanical design varies and such carburetors which, collectively, may be referred to as "automatic mixture control" (AMC), "automatic fuel metering" (AFM) or "two-needle" (TN) types, are produced by most of the leading manufacturers of both two-stroke and four-stroke engines.

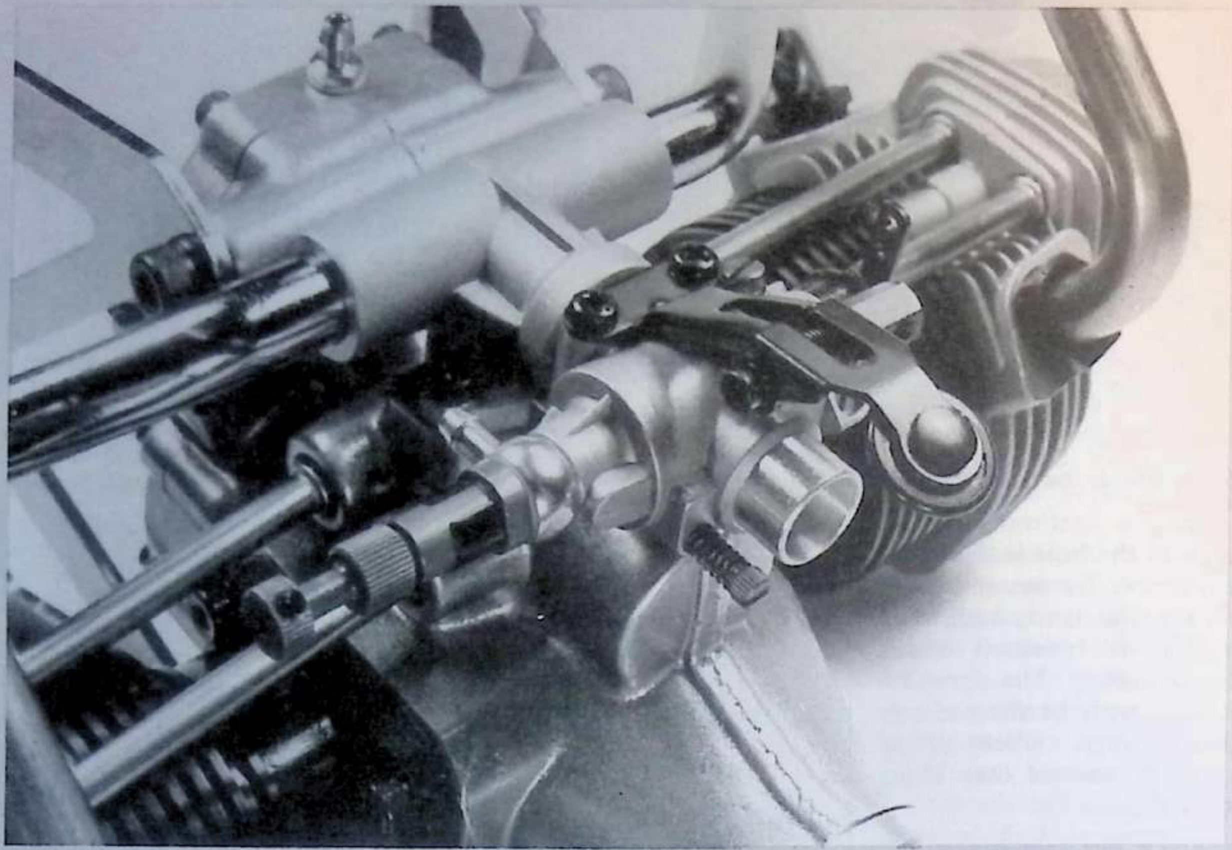
SINGLE-JET TWO-NEEDLE SYSTEMS

This type of carburetor was pioneered by the late Gunther Bodemann in 1967 and has since been used on numerous Webra engines, both two-stroke and four-stroke. Known as the Webra TN type, it has its idling mixture controlled by a second needle fitted in the throttle barrel itself.

The main needle-valve is mounted in one side of the carburetor body. Its open-ended jet tube, concentric with the throttle barrel, projects into the center of the barrel choke. The barrel, inserted from the opposite side of the body, is internally threaded for a concentric secondary (idle) needle.

By means of a cam arrangement, the throttle barrel is moved axially inwards as it is rotated towards the closed position. This carries the secondary needle towards the open end of the jet tube, which it enters at just below the half-throttle position and progressively reduces fuel flow as the engine slows down to its idling speed. The actual amount by which fuel flow is reduced, at the idling speed, is easily adjusted by screwing the secondary needle in or out.

Over the years, numerous other types of carburetors have been devised, including some with two, and even three, separate jets coming into operation at different throttle openings. However, most of the carburetors now fitted to model four-strokes are either of the simple adjustable airbleed type (which generally work rather better



Close-up photograph of the underside of the twin-cylinder O.S. Super-Gemini. A special adjustable automatic mixture control carburetor is fitted to a T-pattern inlet manifold from which mixture is conveyed to the cylinders through chromium-plated inlet pipes. Note adjustable banjo union type fuel inlet and spring-loaded choking device. The carburetor incorporates a sleeve type automatic mixture control valve that can be very accurately set by means of a cam-and-peg adjustment. See sketch for details.

with four-stroke engines than with two-strokes) or are based on the two-needle system. Among examples of the latter fitted to four-stroke engines are HP, Condor and some O.S. and Saito models.

ENYA "G" SERIES

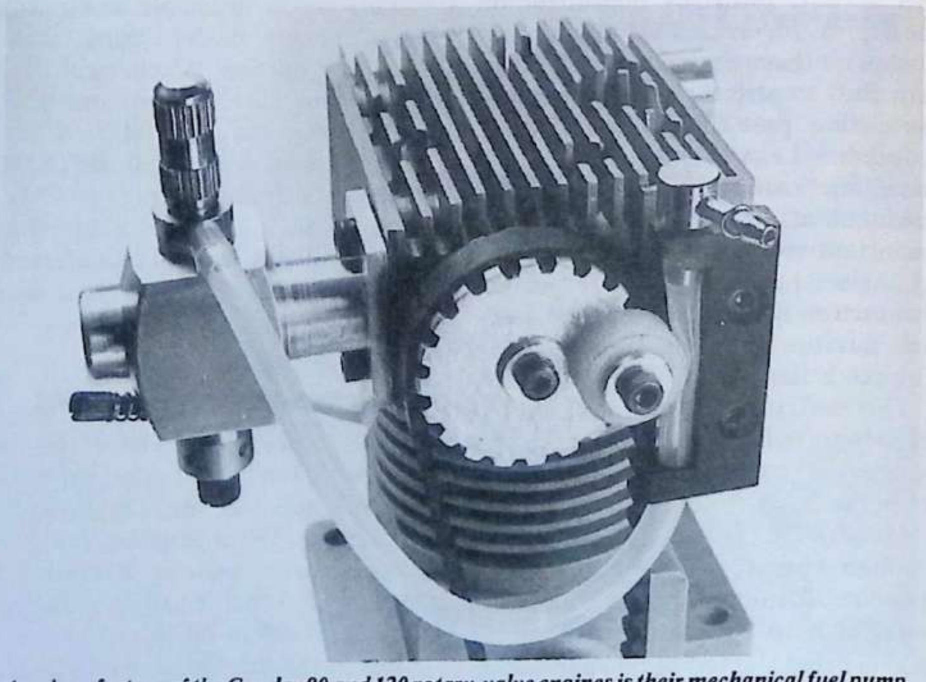
Another method of automatically metering fuel flow is to employ a tapered channel or groove in the surface of the throttle barrel itself.

An example of this is to be found in the Enya G-Type carburetors. Here, fuel is fed through the carburetor body to the interior of the throttle barrel (and to a jet tube fixed in the barrel) via a radial hole in the barrel. Extending a short distance from the hole, around the surface of the barrel, is a tapered groove, so that, when the barrel is rotated towards the idling position, fuel flow is progressively reduced by this taper.

With the Enya G-Type, the amount by which fuel flow is restricted is not adjustable, but an adjustable airbleed is provided to enable the all-important idling mixture to be fine-tuned to the requirements of the engine.

SAITO CARBURETORS

A similar method of fuel metering is used for the Saito FA-65, except that, here, fuel is fed into the barrel through a groove in its flat end surface. Again, an adjustable airbleed is fitted for establishing the best idling mixture. The same system is used on the bigger



A unique feature of the Condor 90 and 120 rotary-valve engines is their mechanical fuel pump, an ingeniously simple device that enables the fuel tank to be located in any convenient position.

FA-120 and FA-270T twin, but here the automatic fuel metering can also be manually adjusted by rotating the separate carburetor body end-plate containing the fuel inlet and main needle-valve.

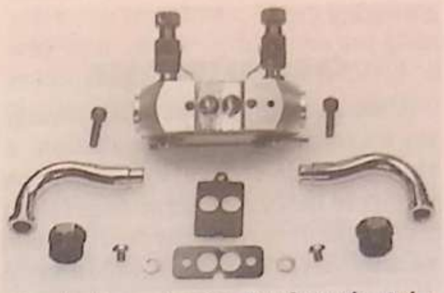
CARBURETOR ADJUSTMENT

A modern model four-stroke usually leaves the factory with its carburetor set up so that it will start and run without further attention, apart from needle-valve adjustment. However, to obtain optimum throttle response and reliable idling may call for readjustment of the low-speed mixture and/or throttle stop.

Basic procedures are as follows:

Start the engine, remove the glowplug lead and set the needle-valve with the throttle wide open. The advised needle adjustment is slightly on the rich side of the setting at which the engine runs fastest, i.e. enough to reduce speed by about 200 rpm. The actual amount by which the needle will have to be reopened to achieve this varies. It will probably be about one-eighth of one turn (i.e. about 45°) but will be more where the carburetor is equipped with a needle-valve having very fine threads and/or a very finely tapered point.

The idea of having the engine run a little on the rich side at full throttle is to ensure that there is a safety margin when the mixture weakens in flight—that is, when the fuel level drops as the tank empties or when the model is in a steep climb. (This can be checked prior to take-off by pointing the model's nose upward.) Having the needle-valve set too lean can result in overheating and detonation. (See sections on "Breaking-in" and "Thrown Props" in Chapter 11.)



The duplex carburetor fitted to the twin-cylinder Saito FA-90T is of the adjustable airbleed type. A separate air intake, needle-valve and airbleed are used for each cylinder. The two throttles are linked together and a slide type choke valve closes both intakes simultaneously.

IDLING

Having established the correct needle setting, close the throttle to the idling speed. As a general rule, the lowest safe idling speed that can reasonably be expected with a single-cylinder four-stroke motor is around one-quarter of its full throttle revolutions on a given prop, e.g. 2,500 when the full throttle rpm are 10,000. Good twin and multi-cylinder engines should do a little better due to their more even torque delivery.

If the engine stops immediately on throttling down, make sure that you are not attempting to run it too slowly. If necessary, screw in the throttle stop screw to raise the idling speed.

AIRBLEED ADJUSTMENT

If the engine continues to cut out when throttled down to its idling speed, it is most likely that the fuel/air mixture is too lean at idling speed. In this case, the procedure to be adopted depends on whether the carburetor is an airbleed type or an adjustable automatic mixture control type. In the case of the airbleed type carburetor, turn the airbleed screw, say, one-half turn clockwise to reduce the amount of air admitted at idling speed. Restart the engine and try again. Repeat if necessary.

The other possibility is that the idling mixture is over-rich. If, for example, the engine will continue to idle if the glowplug battery is left connected, but immediately stops when the plug lead is removed, the indications are that the mixture is too rich. In this case, the airbleed screw should be gradually turned counter-clockwise to admit more air until a satisfactory setting is arrived at.

Rear view of the Saito FA-45 showing its two-needle carburetor. The slide type choke control is not self-reopening.

SECONDARY MIXTURE CONTROL ADJUSTMENT

In the case of carburetors having a separate control for metering fuel delivery at idling speeds, such as the TN (two needle) type previously described, one follows exactly the same initial procedure as for the adjustable airbleed type. That is to say, one first sets the main needle valve for full throttle performance, then tackles the idle performance.

The symptoms of lean or rich running are, of course, the same as for an engine fitted with an airbleed type carburetor but the methods of dealing with them are different. Instead of closing an airbleed to correct lean running, the secondary (idle) needle is opened to admit more fuel. Conversely, an over-rich idle is corrected by closing the secondary needle.

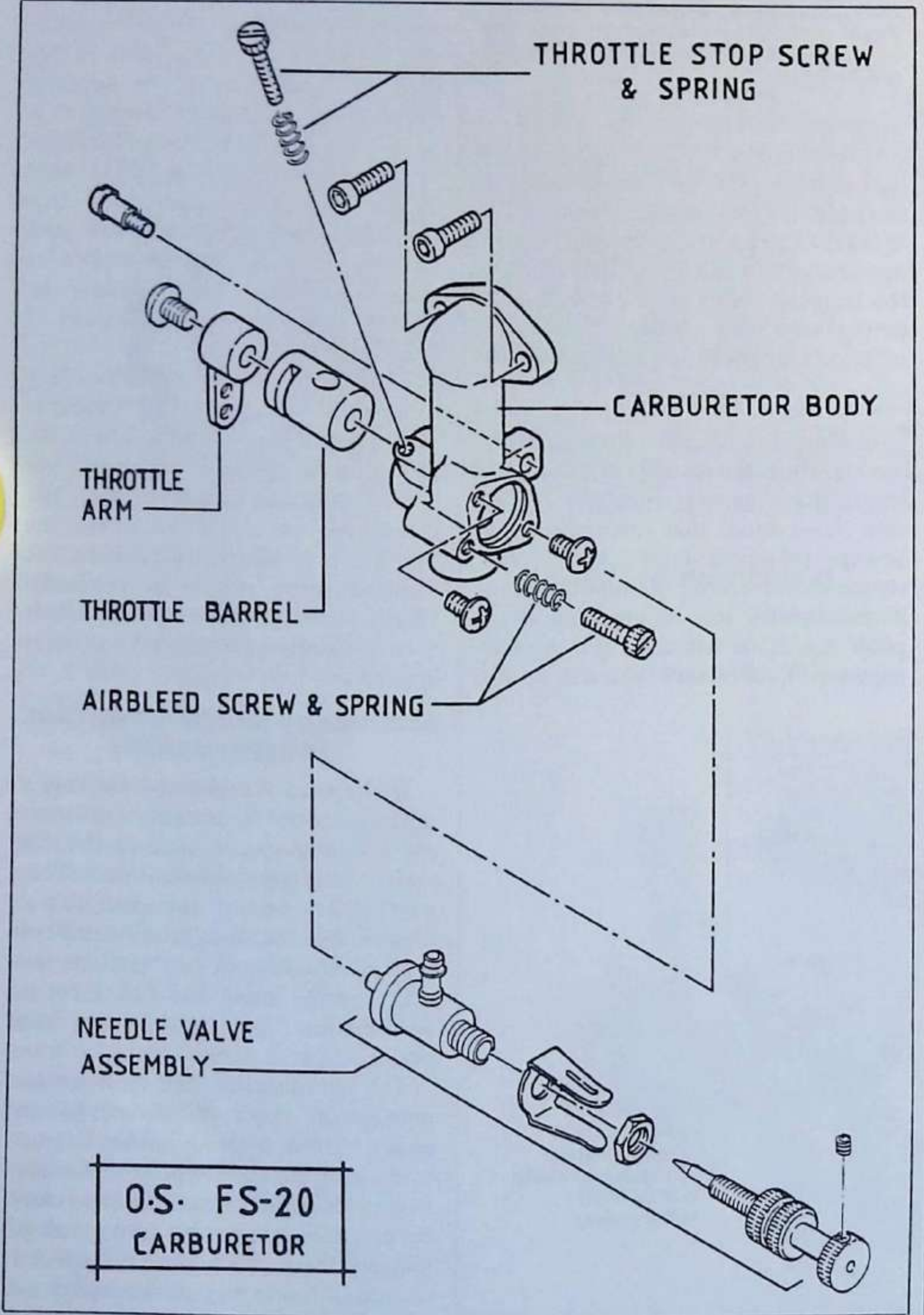
Actually, these adjustments are even easier to remember than those of the airbleed type, since the idle valve works in the same direction as the main needle valve: clockwise to weaken the mixture; counter-clockwise to enrich it.

The amount by which the idle valve should be turned varies with different engines: therefore follow the manufacturer's instructions. If in doubt, turn the valve about 30 degrees at a time and check the effect before making a further adjustment.

With some engines it is possible to adjust the idle mixture while the engine is running. *Do not attempt this unless the carburetor is located at the back of the engine* or, at least, well back from the prop. *Never* use a screwdriver near a rotating prop.

CARBURETOR CARE

Once a carburetor has been properly set up for a particular installation, it should not be necessary to make any change to the established settings (apart from minor corrections to the main needle valve to cope with different atmospheric conditions, fuels or prop sizes) provided that it is kept clean.



An airbleed type carburetor, as fitted to the small O.S. FS-20 engine. In addition to screw adjustments for regulating mixture strength, idling mixture and idling speed, this carburetor has provision for adjusting the throttle-arm and fuel inlet position and for installing a needle-valve extension. It is also supplied with a choke valve assembly (not shown). (Drawing: Courtesy O.S. Mfg. Co., Ltd.)

Always remember that it takes only a minute particle of foreign matter to partially block a fuel passage or jet, especially a slit type jet. By "foreign matter" is meant dirt, fluff or even the waxy precipitate that can appear in some castor-oil fuels after storage. The rule is to employ at least two filters: one in the delivery tube used to transfer fuel from fuel container to fuel tank and another between tank and carburetor. Do not rely solely on the filter in the fuel line to the carburetor. It is all too easy for this to become partially clogged, restricting fuel flow and causing the engine to run lean or to quit.

Other enemies of the carburetor are dust, grit and vibration. These can combine to cause wear in the moving parts, resulting in air leakage which will upset idling and throttle response.

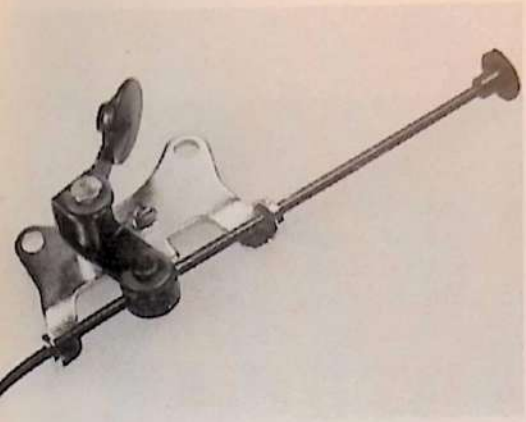
In this connection, some cheaper types of carburetor, especially those used in the past on two-stroke engines, have lacked the qualities necessary to ensure consistent performance over a reasonable period. It is essential, for example, for the throttle barrel to be a close sliding fit in the carburetor body. Any sloppiness or unevenness here can result in air being drawn in, upsetting the engine's idling. The same applies to the fit of the needle-valve and idle valve and to the fit between the carburetor itself and the intake boss or inlet pipe.

CHOKE AREA

The choke area of a carburetor at the fully open position can have a marked effect on the power output of an engine. Effective choke area can be calculated from the simple formula: $B^2 \times 0.7854$ (where B equals the carburetor choke diameter) minus the area of any protrusion into the choke such as a spraybar or jet-tube and needle valve.

In the interests of high power, the choke areas of high performance model two-stroke engines are very large, often requiring a pressurized fuel supply because the velocity of the air through the venturi is insufficient to maintain a steady fuel draw and overcome variations in fuel "head" through maneuvers, etc.

A four-stroke motor does not need such a large choke area. In a four-stroke, mixture from the carburetor is normally drawn straight into the cylinder instead of via the crankcase and a four-stroke's cylinder is a much more efficient pumping chamber than a two-



Simple spring-loaded choking device is an optional extra for the O.S. FS-40. Press-button protruding from side makes for very easy operation.

stroke's crankcase. Also, the inlet valve remains open for a longer period than the piston-controlled port or rotary valve of a two-stroke. This is the reason why four-stroke carburetors are often much smaller than the ones fitted to similar displacement two-cycle engines.

CHOKE VALVES

The traditional method of choking a model engine, prior to starting it, is to use a finger tip over the air intake, but this may be awkward, or even impossible, if the engine is cowled, as in a scale model.

Several four-stroke engine manufacturers are, therefore, now equipping their engines with choke valves that can be operated by an inconspicuous control extension from outside the model. Such devices are fitted to or supplied as optional extra items for all the current O.S. and Saito engines and most Enya models. The majority of these take the form of a hinged flap (O.S. and Enya) or slide (Saito) operated by a semi-rotary or push-pull control.

It is vitally important that a choke flap or slide should be closed only for the two or three turns of the prop necessary to draw fuel into the carburetor. If it is left closed and an attempt made to start the engine—especially if an electric starter is used—an excess of fuel will be sucked into the cylinder causing an hydraulic lock and, possibly, damage to the engine. (See Chapter 11.) All O.S. choke valves are sping-loaded to automatically reopen when released.

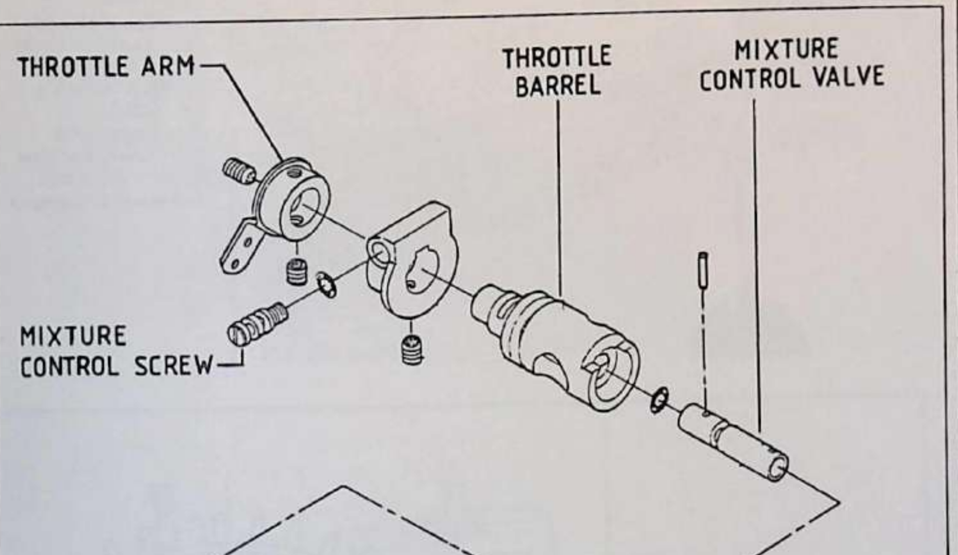
A different choking system is used with the new Enya GC-Type carburetor fitted to certain recent Enya four-stroke motors. The GC-Type is similar to the G-Type in that it features non-adjustable automatic fuel metering with an airbleed to fine-tune the idle mixture. However, it also embodies a special choking system.

To operate this, when starting the engine from cold, the throttle barrel is rotated to its idling position and, by means of an extension rod provided, is also pulled sideways. This simultaneously blanks off the air intake while uncovering a priming jet in the carburetor body above the barrel, enabling fuel to be sucked into the cylinder as the prop is rotated.

The barrel is then pushed in again and rotated fractionally to just above the idle position for starting.

The sideways movement of the barrel (it moves approximately 3 mm or ⅛ inch) is controlled by a small spring-loaded ball-ended plunger that engages a vee-shaped groove around the barrel. The plunger is contained in a screw in the bottom of the carburetor body which can be raised or lowered to adjust contact pressure.

As the Enya GC-Type choke does not automatically reopen, it is still necessary to remember to reopen it before attempting to re-start the engine but, on test, it was found that there was slightly less risk of flooding the engine than with conventional choking methods and the GC-Type carburetor worked well in all other respects.



A modern AMC (automatic mixture control) type carburetor as fitted to the twin-cylinder O.S. Super Gemini engine. As the throttle barrel rotates towards the closed position, the mixture control valve automatically reduces the effective area of the fuel jet. The amount by which it does so can be adjusted to within very fine limits by means of the mixture control screw. (Drawing: Courtesy O.S. Mfg. Co., Ltd.)

CHAPTER 10

Rotary Combustion Engines

There is one model internal combustion engine which, in the sense that it is not a reciprocating piston engine, is neither a two-stroke nor a four-stroke.

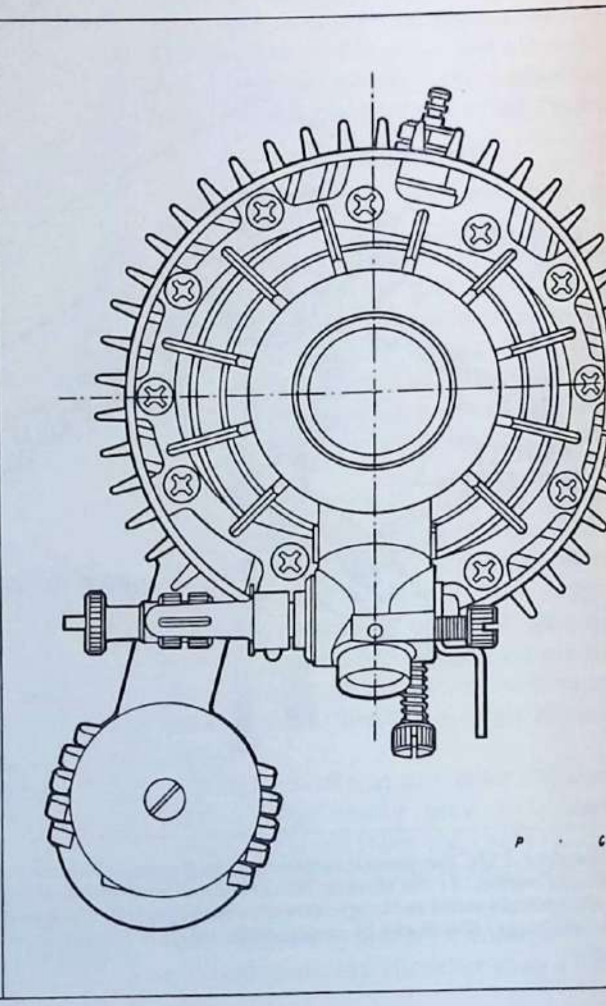
This is the O.S. Graupner Wankel motor. Wankel engines do not have a piston travelling up and down inside a cylindrical chamber. Instead, they have a triangular rotor with curved flanks that moves around in a specially shaped housing. However, although, like two-stroke motors, they produce one power impulse per revolution of the output shaft, Wankel engines have an operating cycle in which each combustion chamber progresses through four distinct phases; induction, compression, expansion and exhaust, as in a four-stroke reciprocating engine. Because of this, it is generally agreed that, if the Wankel motor needs to be aligned with one or the other type of reciprocating engine, it should be with the four-stroke rather than the two-stroke.

The O.S. Graupner Wankel engine actually predates the current generation of model four-stroke reciprocating engines by quite a few years. The story of the Wankel engine was told in a two-part article in *Model Airplane News* by the author at the time of the introduction of the O.S. Wankel motor and, since much of what was then said is of equal significance today, the words that follow will include some edited extracts from that original article.

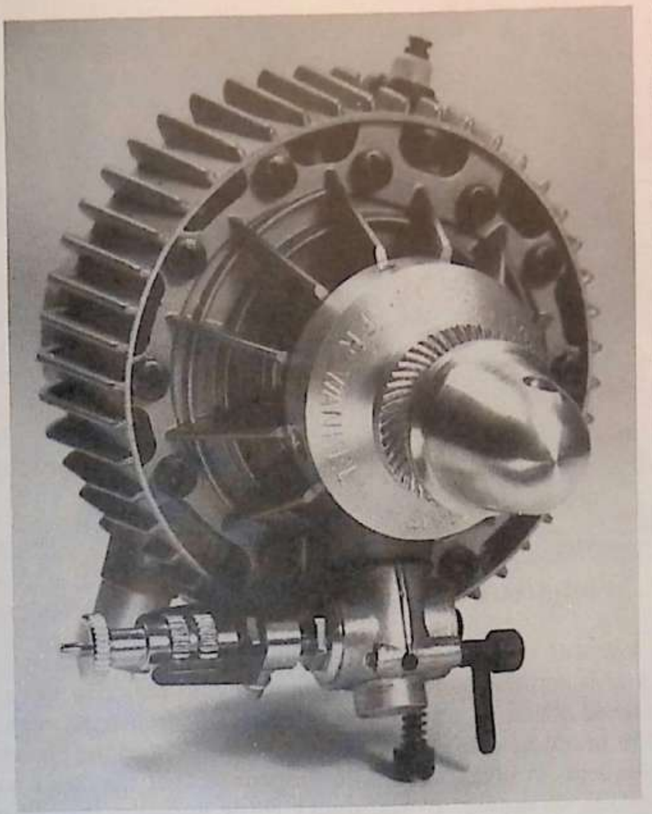
First, a brief word about the origin of the reciprocating piston engine.

In 1794, an Englishman, Robert Street, built and patented the earliest gas engine on record. Used to drive a pump for raising water, it operated on a mixture of vaporized turpentine and air and employed a sliding piston within a cylindrical chamber as a means of converting the pressure of the burning fuel charge into mechanical energy.

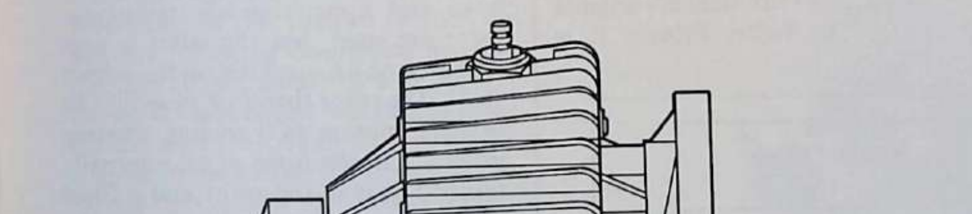
The Schaegg-designed experimental Wankel engine of 1967 installed in the Graupner "Taxi" model in which it was publicly demonstrated in Europe at that time. (Photo: Courtesy Johannes Graupner)



Although, at the time of its introduction, the O.S. Wankel motor was quiet compared with two-strokes of similar power, subsequent production motors were supplied with a muffler which made it even quieter. This drawing is of the 1971-2 version which, with minor modifications, remained in production until superseded by the 49-PI model in 1982.



The Japanese-built O.S. Graupner Wankel engine of 1969. This was one of fifty pre-production models. Many subtle improvements were incorporated in the first year of production.



Other inventors followed with developments of this idea in the early part of the nineteenth century culminating, as explained in Chapter 2, in the first really practical i.c. engine, the Lenoir gas engine introduced in France, in 1860. This paved the way for Otto's four-stroke-cycle engine of 1878 and Clerk's two-stroke-cycle motor of 1881 and their modern successors.

The point about all this is that, although modern applications demand power units that, almost invariably, call for a rotary output, the development of positive displacement internal combustion engines has been entirely based on early linear output engines, thus necessitating the addition of rods and cranks to convert the reciprocating motion of the piston into the rotary motion required to drive wheels, propellers, etc.

The well-known alternative, of course, is the gas turbine. However, this is rather different in that it derives its power, not from gas pressure, but from the inertia of the gases issuing from the combustion chamber at high speed and impinging on the turbine blades. Gas turbines have not shown themselves especially well suited to supersede positive displacement (piston) engines where (as in road vehicles in particular) rapid and wide changes in power output are constantly in demand.

ROTARY PISTON ENGINES

The reciprocating piston has always been recognised as a somewhat roundabout method of translating the energy of expanding gases into rotary motion and it is a fact that the idea of a purely rotary type positive displacement engine is by no means new. Rotary piston configurations for pumps and compressors were an obvious starting point for the development of a rotary piston internal combustion engine, but it was not until Felix Wankel, in Germany, undertook a comprehensive study of the whole field of rotary piston machines, that a practical line of approach to the question of developing such an engine became clear.

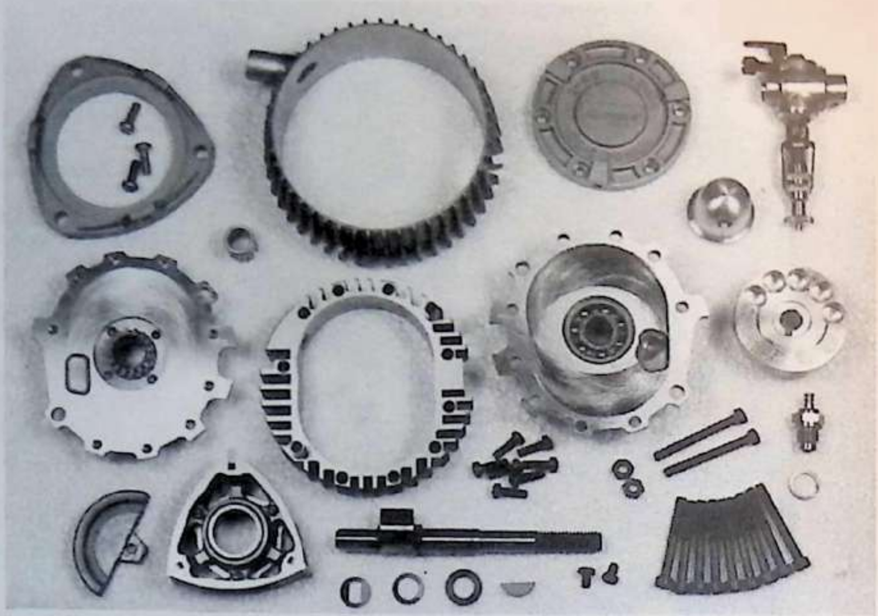
In 1954, Wankel first saw the feasibility of the rotary combustion engine as we now know it. He discovered that, by rotating a triangular piston or rotor within a housing having an epitrochoidal shape, the three chambers, formed between the flanks of the rotor and the sides of the housing, varied in volume in a manner such as to provide induction, compression, expansion and exhaust phases, as in a four-stroke reciprocating engine.

In due course, Felix Wankel's first rotary combustion engine was built by *NSU Motorenwerke AG* in West Germany and was run for the first time in February 1957. It had a displacement of 125cc (7.6 cu in.) and, after minor modifications, developed nearly 29 bhp at 17,000 rpm—a highly impressive beginning.

ROTATING PISTON AND ORBITING PISTON ENGINES

This original engine was, under the terms of Wankel's own system of rotary engine classification, a DKM *(Drehkolbenmaschine*—literally "rotary piston engine") in which the rotor *and* its surrounding epitrochoidal casing both rotated (but on different axes), the former at two-thirds of the speed of the latter by means of appropriate phasing gears. Power take-off was via spur gearing from the rotary casing rather than from a central shaft.

Since both moving parts of the DKM (also known as a "single rotation engine") revolve about their own centers of gravity, such a motor can be completely balanced and is eminently suitable for ultra high speed operation. It has, however, certain practical disadvantages and subsequent Wankel engines, including the O.S. Graupner unit, have belonged to the KKM *(Kreiskolbenmaschine)* category.

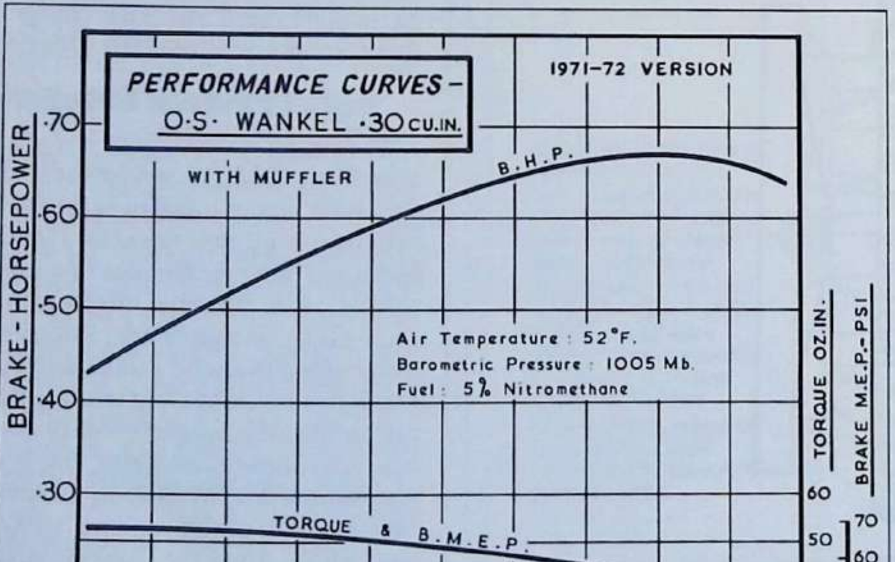


Parts of the 1971 O.S. Wankel motor.

The KKM ("orbiting piston engine" or "planetary rotation engine") was developed from Felix Wankel's original design by Dr. Walter Froede. It is simpler, requires fewer parts, is cheaper to manufacture and easier to service.

The essential difference between the single rotation motor and the planetary rotation motor, is that the latter has a stationary rotor housing, instead of a rotating one, and power take-off is via a central shaft instead of from the rotor housing. The elements of the engine are the same in that an epitrochoidal bore and approximately triangular rotor are used, but the latter is now mounted on an eccentric on the output shaft. The rotor therefore describes an orbiting motion as it rotates. Phasing gears are in the form of an internally toothed gear in the rotor and a fixed pinion mounted centrally on the end cover. The output shaft rotates at three times rotor speed.

The one disadvantage of Froede's development, compared with the Wankel original design, is that the rotating parts are no longer in perfect balance since the mass of the rotor moves eccentrically. However, with a single rotor engine, counterbalancing weights are fitted to the shaft outside the housing and, while this means that the balancing forces are not in the same plane, it does reduce the problem to one of providing adequate shaft thickness and good bearings. In full size Wankel engines, it is common to use twin rotor chambers in tandem with the shaft eccentrics located 180 degrees apart to maintain good balance. Such engines are renowned for their smoothness.



A power output of 0.67 bhp at just over 16,000 rpm, with muffler, for the 1971 O.S. Wankel, when running on 5% nitromethane fuel, was very good for a .30 cu in. displacement engine.

ROTOR OR PISTON?

Incidentally, it may be thought that the word "piston" is not a particularly appropriate one for describing the Wankel engine's rotor. "Pistons" are, after all, widely understood to be cylindrically shaped components that move up and down or back and forth in a tubular chamber or cylinder. On the other hand, the Wankel engine is a German invention and its rotor is referred to as a *kolben*—the German for "piston." Therefore, both "rotor" and "piston" may be regarded as acceptable English usage.

HOW IT WORKS

Understanding how a Wankel engine works is not easy to absorb without a practical demonstration of how the parts move in relation to one another. The Audi/NSU/Auto-Union company were obviously very conscious of this difficulty when they began producing cars powered by Wankel engines and they took the trouble to issue to their agents a pocket-sized plastic demonstration model of a Wankel epitrochoidal housing and rotary piston, complete with phasing gears, shaft and ports, to show the complete cycle of operations. Hopefully, in the absence of such an aid, the following description and the diagram (pages 80-81) of a peripheral intake Wankel engine will enable those readers who are unfamiliar with rotary engines to understnd something of the *modus operandi* of the Wankel motor.

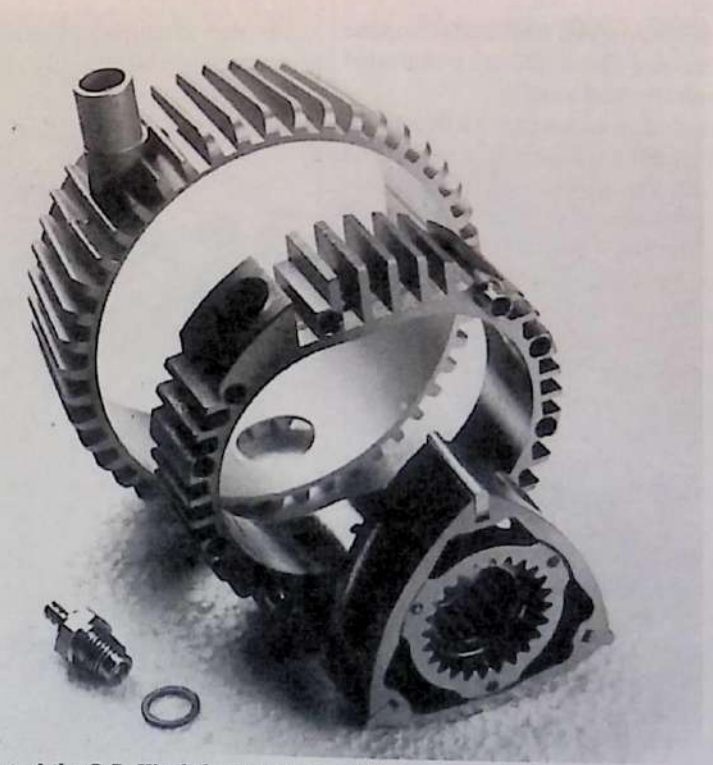
First, let us imagine that the end cover (rear housing) of the engine is transparent so that we can look into the epitrochoidal center housing complete with rotor. Strictly speaking, a rotary combustion engine has neither top nor bottom but, for the purpose of this explanation, let us assume that the wide-waisted figure-of-eight shape of the housing is seen with its major axis horizontal and with the ignition plug at the bottom, as in the diagram. Assuming that the rotor moves clockwise when viewed from the rear, this will mean that the exhaust port is at the top and somewhat to the left of the minor axis, while the inlet port, also at the top, is located to the right of the minor axis.

All three tips of the rotor are, of course, in constant contact with the bore of the epitrochoidal housing and three chambers are therefore formed between the flanks of the rotor and the housing. For simplicity, let us consider the thermodynamic cycle of just one chamber.

Prior to the beginning of the induction phase, the appropriate rotor flank will be approximately horizontal at the top of the housing, a position (1) that corresponds to the top of the stroke in a reciprocating engine. As the rotor revolves in a clockwise direction, the chamber volume (2 & 3) increases and the fuel/air mixture is drawn in through the point of maximum compression, the mixture is fired by the ignition plug (7) and the expansion (power) phase begins (8). Expansion continues (9) until maximum chamber volume (left lobe) is reached (10).

At this point, the leading tip of the rotor begins to uncover the exhaust port which remains open (11, 12, 1) while the spent gases are forced out and the rotor begins its second revolution (1 & 2).

While this has all been happening, precisely the same process has been



The heart of the O.S. Wankel motor is its orbiting rotor and epitrochoidal rotor housing. Note the rotor's spring-loaded tip seals, internally toothed gear and the roller bearing by which it is mounted on the shaft eccentric.

the inlet port. This continues while the rotor completes 90 degrees of rotation, at which point the chamber volume (4) now in the right lobe of the trochoid, is at its maximum. (This corresponds with the bottom of the stroke in a reciprocating engine.)

Beyond this point, the chamber volume begins to diminish as it enters the compression stage. (There is a slight delay before the inlet port is closed by the trailing rotor tip, in order to take advantage of the inertia of the incoming charge—as in a four-stroke reciprocating engine.) As the flank approaches (5 & 6) the bottom of the housing, i.e.

initiated at 120 degree intervals in each of the following two chambers. The rotor therefore receives three torque impulses per revolution. This, when set against the fact that the engine's output shaft revolves at three times rotor speed, means that a single rotor Wankel engine is, in effect, the equivalent of a twin-cylinder four-stroke reciprocating engine (or a single-cylinder two-stroke) as regards torque fluctuations.

PORTING

All Wankel engines employ peripheral exhaust ports, i.e. through the wall of the center housing. This type of port is also used for induction in many engines, the alternative being a suitably shaped port in one of the end covers. The latter was the system used by the O.S. Wankel until the appearance of the "PI" model in 1982.

SEALING

It will be appreciated that, for the rotary piston engine to work, efficient gas sealing must be maintained at all times. In a reciprocating engine, this is the job of the piston rings (or the close lapping of the piston to the cylinder bore in a ringless model engine) and is fairly simple to achieve. The satisfactory sealing of a Wankel engine is a much more compex problem, since the oddly shaped "piston" has to be sealed both radially and axially.

The solution adopted with most full-scale Wankel engines is to provide the rotor with a complete sealing grid made up of strips of cast-iron let into slots in the apices and sides of the rotor and backed by light springs. As with a normal piston-ring, spring pressure is necessary only to improve sealing for starting. Thereafter, the grid relies mainly on gas pressure.

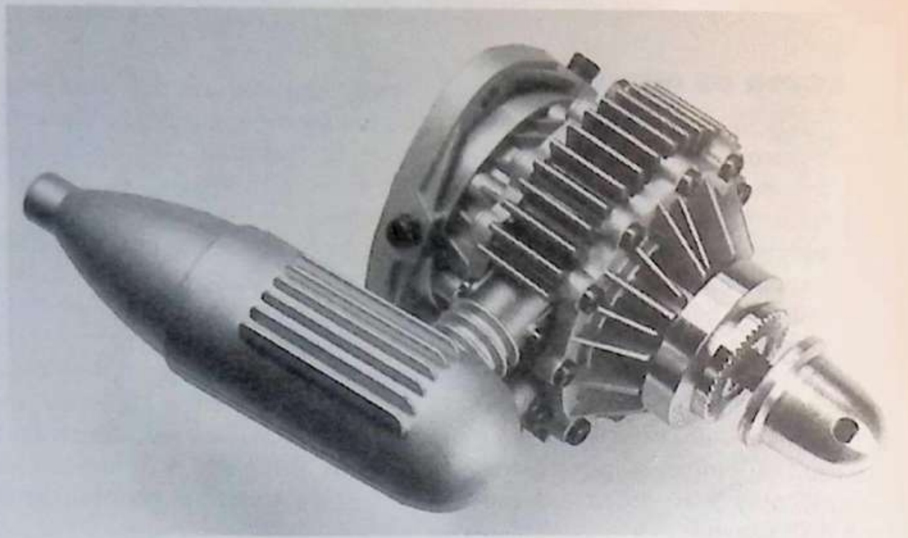
A complete sealing grid for a typical Wankel rotor employing double side seals may consist of as many as fifty-four parts, some of them very small. This is apt to become exceedingly difficult to duplicate when rotor size is reduced to model engine proportions.

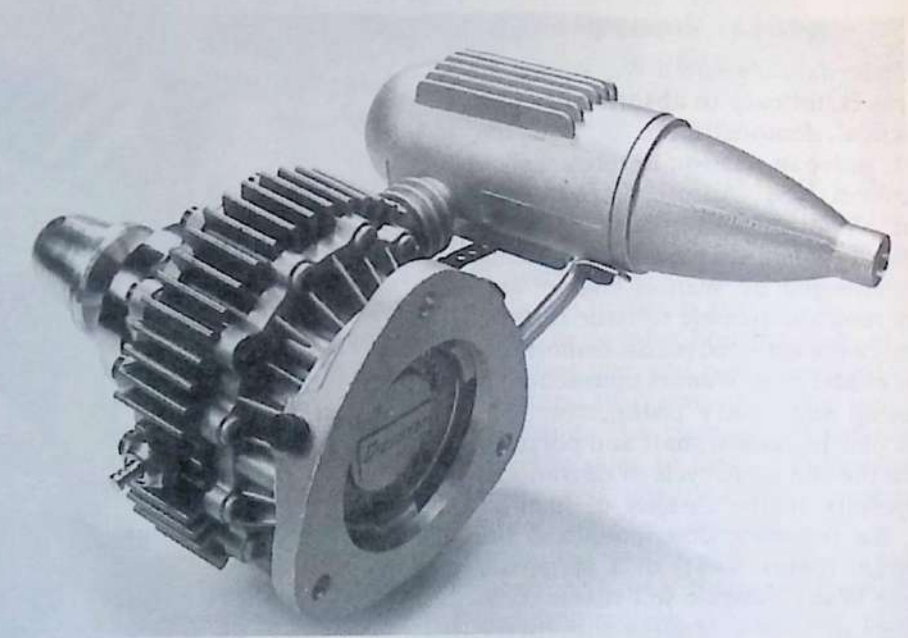
In the O.S. Graupner Wankel motor, therefore, only apex seals are used. For side sealing, O.S. depends on highly precise surface grinding of the rotor side and the housing end covers and axial clearances are held to the minimum, consistent with the thermal expansion ratios of the rotor and center housing.

AXIAL CLEARANCE

A characteristic of all Wankel engines is that, whereas the rotor is successively exposed to the heat of combustion and the cooling effect of fresh gas on each of its three flanks and thereby maintains an even thermal expansion, the rotor housing receives very much more heat on one side only, i.e. the expansion and exhaust side.

This does not matter too much in a full-size Wankel engine where coolant flow can be more easily controlled and where, in any case, axial sealing grids are used.





Two views of the current peripheral inlet O.S. Wankel Type 49-PI. It has the same displacement as the earlier models but is considerably more powerful.

The situation is rather different with a model Wankel engine that depends on the maintenance of intimate contact between two flat ground surfaces. Here, an increase in axial clearance between the rotor and the hotter expansion/exhaust side of the housing will allow gas blowby and a reduction in power as the engine warms up. It will also make hot re-starting difficult.

This was a problem with the early O.S. Wankel engines, but was quickly solved by the deceptively simple device of introducing differential axial cold clearances. On the induction/compression side of the rotor housing, the axial clearance (cold) between the rotor and rotor housing end plates was established at between 0.008 and 0.010 mm (i.e. between 3 and 4 ten-thousandths of an inch) greater than on the expansion/exhaust side. Axial clearance (cold) on the expansion/exhaust side is held to the absolute minimum and is of the order of 0.002 mm (less than one ten-thousandth of an inch).

TWIN AND MULTI-ROTOR ENGINES

Most of the Wankel engines made for automotive applications have been of the twin rotor type, i.e. a second rotary piston in its own sealed chamber is added in tandem with the first. The output shaft is suitably lengthened and the additional eccentric is located at 180 degrees to the first so that the second rotor is phased to fire alternately with the first, thereby reducing torque fluctuations and further increasing smoothness. It is perfectly feasible to extend this idea to three or four rotors for greater power and a smoothness that rivals that of a gas turbine. In 1970, for example, Daimler-Benz built a 350-horsepower four-rotor Wankel engine which powered their C.111/1970 experimental sports car to a maximum speed of 186 mph and a 0-60 acceleration time of 4.7 seconds. In the model field, O.S. and Graupner experimental twin-rotor Wankel motors have also been built.

DISPLACEMENT AND NOMINAL VOLUME

Some years ago it became accepted practice, for purposes of classification alongside four-stroke reciprocating engines, to rate Wankel type motors at (since slightly modified) twice their true displacement. In other words, a twin rotor Wankel engine in which each rotor displaced, say, 500cc per output shaft revolution, was rated at a "nominal volume" of 2,000cc, not 1,000cc.

This practice was adopted because, whereas a single-cylinder four-cycle reciprocating engine piston receives the benefit of only one expansion phase for every two revolutions of its output shaft, the Wankel piston receives two. But, of course, in delivering a torque impulse twice as often as the reciprocating four-stroke, the Wankel not only delivers more power; it also consumes twice as many charges of fuel and air. Therefore, by doubling the Wankel's swept volume per output shaft revolution and using this "nominal volume" figure to classify the engine, it is, in effect, more readily comparable, in terms of power output and fuel consumption, with reciprocating piston four-strokes. So far as automobiles are concerned, this puts the engine on a footing more easily understood by the prospective purchaser but, equally important, it gives an acceptable basis on which a rotary-engined sports car, like the Mazda RX-7, can be homologated for racing purposes.

When the 5cc (0.30 cu in.) O.S. Graupner engine was about to be introduced in 1969, there was a suggestion that it, too, would have to be artificially uprated and put in the 10cc (0.61 cu in.) class. This, quite rightly, was successfully resisted on the grounds that, at that time, all production model engines were of the two-stroke cycle type which, like the O.S. Wankel, also fired once for every revolution of the output shaft.

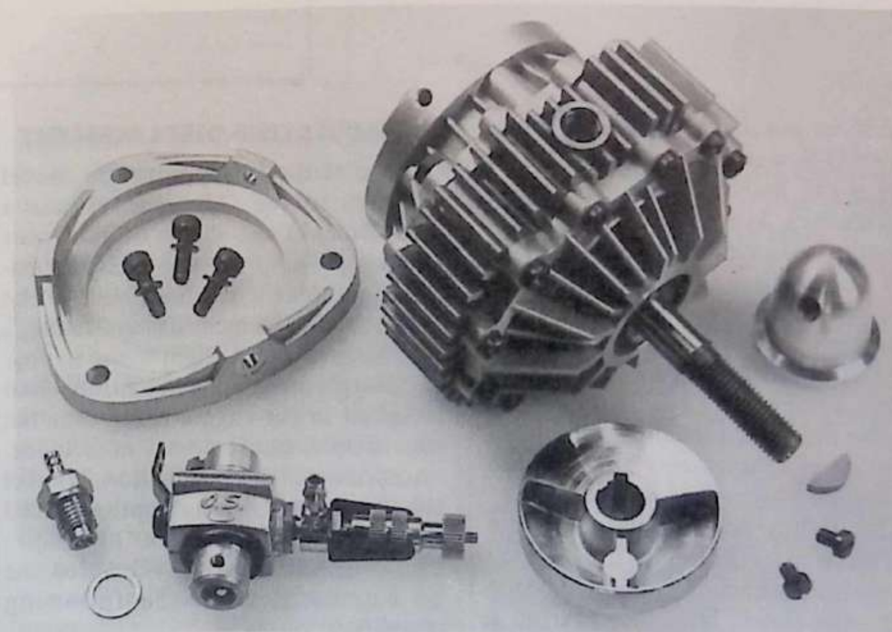
THE SCHAEGG INITIATIVE

Early in 1961, the West German Johannes Graupner company, the largest model firm in Europe, decided to sponsor the development of an air-cooled Wankel type engine for radio-controlled model aircraft use. It was laid down that the engine should operate on glowplug (rather than spark) ignition, use standard alcohol-based model engine fuels, have a displacement of about 5cc (0.30 cu in.) and be capable of around 12,000-14,000 rpm on a 25 cm diameter, 10 cm pitch (i.e. approx. 10 x 4 in.) propeller.

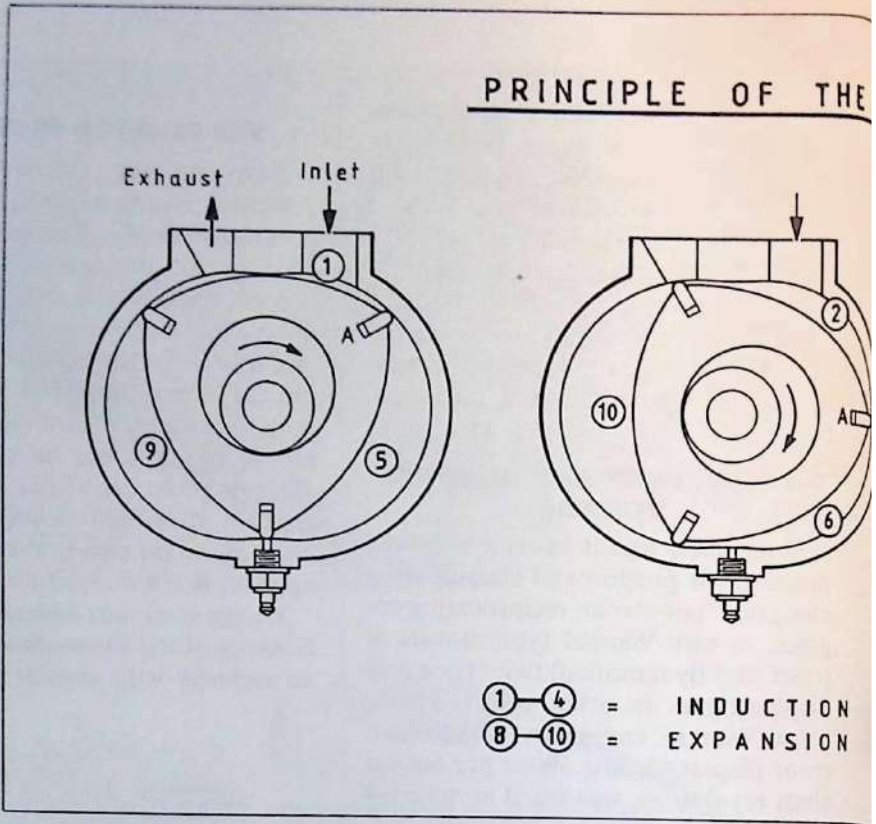
Design work was undertaken by Ing. Schaegg of the Frauenhofer company, an engineer with considerable experience in Wankel engine development. Not surprisingly, in view of the problems involved, it was not until the end of 1964 that an engine was built that would actually run. This first working model had a displacement of 0.22 cu in. and turned a 22 x 10 cm prop at 11,000 rpm. In 1966, a more powerful motor was developed which turned the specified 25 x 10 cm prop at 10,500 rpm and this was test flown in September of that year in a Graupner *Caravelle* R/C model weighing 7 pounds. It was followed by a further improved engine in the spring of 1967 and now, for the first time, Graupner's interest in Wankel engines was made public as this latest motor, installed in a 59-inch Graupner *Taxi* high-wing trainer, flown by the late Fred Militky, was widely demonstrated, including flights in Corsica on the occasion of the 1967 World R/C Championships.

THE MIHARA ERA

Commercial exploitation of the NSU/Wankel System is legally restricted to Audi/NSU/Auto-Union AG of Neckarsulm, West Germany. Graupner was granted a license in 1967 covering model Wankel engines of up to 3 horsepower. Hans Graupner then approached the O.S. model engine company in Japan with an invitation to take over the development and eventual production of the engine and, following a visit to Germany by O.S. president Shigeo Ogawa and his noted chief engineer (now vice-president) Kazuhiro Mihara, the O.S. experimental department began an intensive program of redesigning the engine for production. Numerous problems were encountered but, by April 1968, Mr. Mihara had several experimental engines on test and, six months later, O.S. was demonstrating prototype .30 cu in. single-rotor and .60 cu in. twin rotor engines in regular pattern type R/C models.



Of smaller diameter than the earlier models, the Type 49-PI has extra integral fin area and dispenses with the earlier design's separate cooling ring.



Almost another year was to elapse before O.S. was ready to begin making a pilot-run batch of fifty pre-production engines. Much special tooling for quantity manufacture of the engines was designed and built in the O.S. factory, including a special machine for accurately grinding the epitrochoidal bore of the rotor housing. Some processes completely new to the model engine industry, including the metal-spraying of steel wearing surfaces onto aluminum die-castings, were adopted.

One of these pre-production engines was received by the author in July 1969 for evaluation and, in addition to bench tests, was flown, later that year, in a Bill Northrop designed *Apprentice* 72 inch trainer from M.A.N. plans. The engine was difficult to re-start when hot, by hand (electric starters were not generally in use in 1969) but performed quite well, with commendable smoothness and a much quieter exhaust note than typical two-strokes of the period.

PRODUCTION ENGINES

By the time the first production models became available in 1970, several modifications had been incorporated and some significant improvements were added over the next twelve months so that, by the time the 1971 model was tested for M.A.N., it had become a conspicuously better engine in every way. The production improvements are summarised in the following paragraphs.

CALCULATING DISPLACEMENT

One of the first production model changes to the O.S. Wankel was a reduction in the depth of the rotor housing. The prototype and pre-production models had been built to the same trochoid dimensions as Schaegg's 5cc engine, but a slight error in Ing. Schaegg's original calculations had resulted in the engine being over the 5cc displacement limit, at 5.144cc. Accordingly, the production Wankel had its rotor housing depth reduced from 15.0 mm to 14.5 mm.

The displacement of a Wankel engine is calculated from the following formula:

$$V_s = 3\sqrt{3}Reb$$

where V_s = swept volume

R = generating radius

e = eccentric radius

b = rotor depth

The production model O.S. Wankel has a generating radius of 22.0 mm, an eccentric radius of 3.0 mm and a rotor depth of 14.5 mm which, using the above formula, indicates a displacement of 4.973cc or 0.3035 cu in.

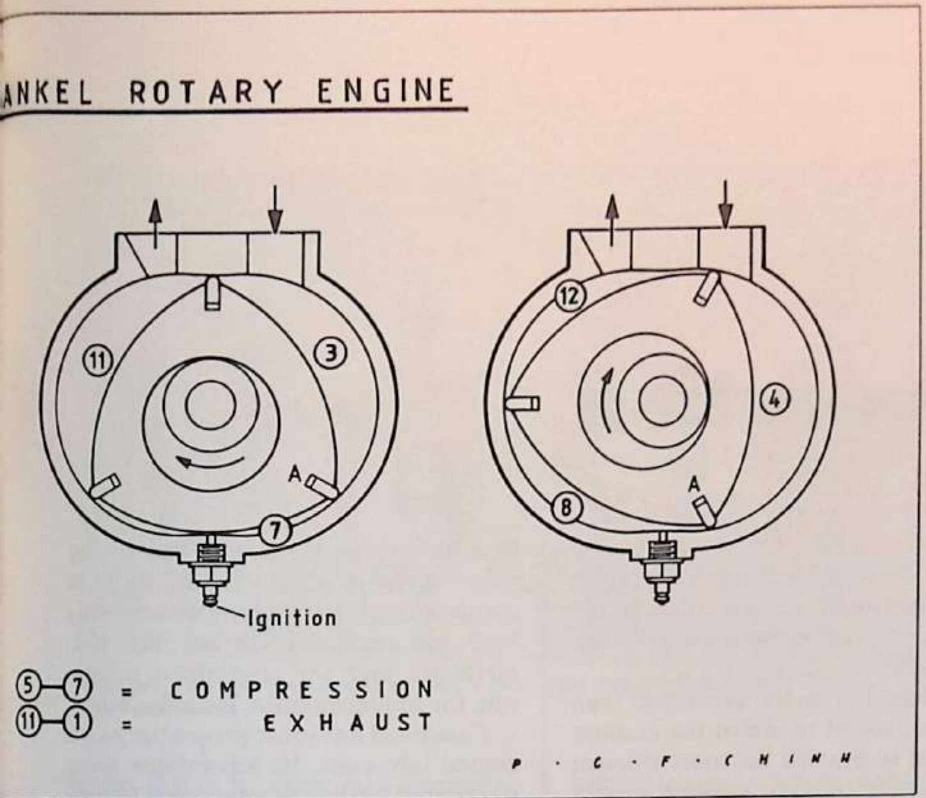
ROTOR HOUSING

As has already been mentioned (see "Axial Clearances") the problem of gas blowby, due to the unequal expansion of the rotor housing on its induction/compression and expansion/exhaust sides, was very successfully dealt with by introducing a cold clearance differential. This simple but very precisely executed modification had a marked effect, not only in virtually eliminating power loss, but in vastly improving the engine's idling, throttle response and hot restarting qualities.

Other modifications included a revised (circular) exhaust port and a slightly relocated and enlarged (2.2 mm instead of 1.8 mm) ignition hole. A little later, the exhaust port diameter was reduced from 5.5 mm to 5.0 mm. The peripheral exhaust port on a Wankel engine is, of course, open for a full 360 degrees of shaft rotation, compared with around 140 degrees for a typical two-stroke model engine.

END PLATES

Although early versions of the O.S. Wankel engine had the complication of a metal-sprayed steel coating on the end-plates as wearing surfaces for the rotor, experience later showed that this was unnecessary and that a plain aluminum alloy surface could be used equally satisfactorily. Changes were also made to the intake porting, the ports being reshaped and placed closer to the outside of the chamber to give a much longer induction period extending through something like 330 degrees of shaft rotation in contrast to the 180-210 degrees maximum of a high performance two-stroke engine. The carburetor continued to be mounted in a boss in the front plate.



ROTOR

Originally machined from Meehanite cast-iron bar stock, the rotor was later machine finished from a shell molding. All rotors were equipped with special cast-iron apex seals, each backed by a pair of high carbon steel leaf springs, and were mounted on the shaft eccentric by means of a 12 mm caged needle bearing. The shaft itself, carried in a single ball journal bearing at the front and a caged needle bearing at the rear in the pre-production engines, was provided with an extra front ball bearing in the production models. The phasing gears were of case-hardened nickel-steel in all models.

COOLING RING AND MUFFLER

All the pre-PI model O.S. Wankels were equipped with a clamp-on finned aluminum cooling ring. This also provided a means of mounting an exhaust muffler. Because the discharge of exhaust gases from a Wankel is virtually continuous, instead of in a succession of separated bursts (as in a single cylinder two-cycle engine) the muffler does not have to be very large, nor does it need a big outlet pipe to prevent excessive power loss.

Not surprisingly, the muffler equipped Wankel turned out to be by far the quietest model aircraft engine of anywhere near its size and power in 1970-71 and for several years later, prior to the introduction of the O.S. FS-60. It still compares quite favorably with four-strokes as regards actual sound level, although the frequency of its exhaust note remains high.

Tests carried out on a production model O.S. Wankel in 1971 indicated a power output of 0.67 bhp at 16,000 rpm running on standard 5 percent nitromethane content fuel and with the muffler fitted. Power loss caused by the muffler was very slight, being the equivalent of only about 200 rpm on a 10 x 6 prop. Typical rpm recorded on various maple wood props included 10,300 on an 11 x 6 Power Prop, 11,300 on a 10 x 6 Top Flite and 12,600 on a 9 x 6 Top Flite. Also showing a big improvement on the earlier models was the engine's throttle response: the Wankel idled steadily at around 2,500 rpm when propped for a full-throttle static speed of around 12,000, with excellent recovery, smooth progression through the throttle range and steady intermediate speeds.

O.S. WANKEL TYPE 49-PI

After twelve years of production, the original O.S. Graupner Wankel engine was replaced in 1982 by an entirely new design carrying the type number 49-PI. Unlike the original design, which featured a front mounted carburetor with induction through a port in the front plate controlled by the side of the rotor, the new engine has a peripheral inlet port (hence "PI") over which the rotor's apex seals pass and through which induction takes place virtually without interruption.

The new rotor housing has integral radial fins and the separate clamped-on aluminum supplementary cooling ring has been dispensed with. The muffler has been redesigned and is now attached directly to the rotor housing. The same also applies to the carburetor which, of course, now projects from the side of the engine, alongside the muffler.

A great deal more fin area has been added to the expansion/exhaust side of the rotor housing and also to the expansion/exhaust sides of the front and rear end plates. Externally, the body of the engine (less carburetor and muffler) is considerably more compact. The rotor housing, no longer circular in shape, is 65.5 mm x 55.5 mm instead of 69.5 mm diameter across the cooling fins and the engine's length, from prop driver face to the rear face of the radial mounting ring, is reduced from 66 mm to 60.5 mm. The engine is fractionally lighter than the previous model at 12.3 oz or 13.4 oz with muffler.

The Type 49-PI is very much more powerful than its predecessor. It is rated, by the manufacturer, at over 1.2 bhp at 17,000 rpm, compared with a maximum of 0.75 bhp for the final production models of the previous design.

The O.S. Graupner Wankel engines have the rare distinction of having remained the only model sized rotary combustion engines manufactured to date.

CHAPTER 11

Operation

The best advice that can be offered on operating a four-stroke engine is to first read the instruction sheet that comes with it. This might sound obvious but it has to be said that many modelers do not pay sufficient attention to manufacturers' instructions. Often this is because they have had experience with other engines and tend to rely on that knowledge and disregard what they may think of as information for beginners only.

When a user has had experience of a few four-stroke engines, he will have assimilated the basic principles of operating them, but there is always the possibility that a new engine coming into his hands will have certain characteristics that require special attention. This attention may relate to subsequent care or it may be such that, to ignore it, may result, at the very outset, in damage to the engine itself, or even personal injury. Some manufacturers try to guard against such eventualities by including special warning notices with their engines. Never ignore them.

By and large, makers' instructions are adequate and accurate although, as most four-strokes are of foreign manufacture, English translations sometimes contain anomalies. More important, however, there are many points which require amplification for the wider understanding of the user.

The purpose of this chapter, therefore, is to promote such understanding, to make additional recommendations and to point the user in a direction that will give him greater satisfaction and fewer problems in the operation of his four-cycle engine.

For easy reference, this chapter is divided into a number of sections with appropriate headings.

FUEL MIXTURES

Like most model two-strokes, nearly all current model four-cycle engines operate on a methyl-alcohol (methanol) based fuel mixture. The reasons for using methanol, rather than gasoline, are several.

Methanol is more expensive than gasoline, added to which the amount required to provide the most efficient combustible mixture strength (about one part methanol to 9 parts of air, by weight) is much higher than for gasoline (about one part to 15 parts of air) which, of course, means that the engine's fuel consumption is increased. But the extra cost of running on methanol is offset by a number of points in its favor.

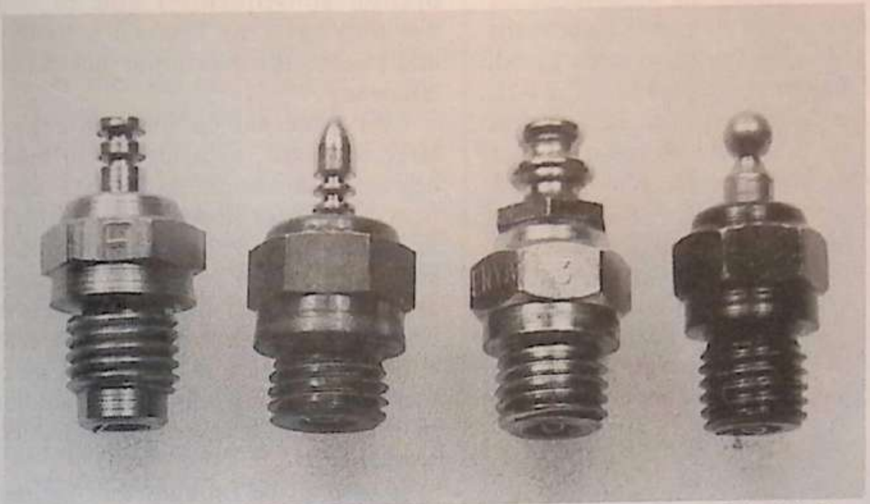
First, engines run cooler on methanol. They can be operated at higher compression ratios and deliver more power. Second, there is a greatly diminished fire risk when handling methanol, compared with gasoline. Third, the majority of model four-strokes, like model two-strokes (i.e. true "model" two-strokes as distinct from converted chainsaw type gasoline engines) use glowplug ignition. Glowplugs work best in the presence of alcohol, their platinum alloy elements having a catalytic effect which aids ignition and enables the engine to continue to operate through wide variations in mixture strength.

LUBRICATION

In full-size four-stroke engines, it is usual for the lubricating oil to be carried to the working parts by a pumped lubrication system, either from a separate oil tank or a crankcase sump. Crankcase-charged two-strokes, on the other hand, are lubricated by having a quantity of oil mixed with their fuel and this is also the method of lubrication used with most current model four-stroke engines. In the case of gasoline fueled spark-ignition two-stroke motors, the lubricant is usually of a conventional petroleum (motor-oil) type, but such oils will not mix with methanol and the traditional substitute for model engines, is castor-oil.

Castor-oil has great properties as an engine lubricant. Its advantages were discovered by the manufacturers of full-sized engines before the First World War and, despite the great strides that have been made in the development of special synthetic alternatives, castor-oil continues to be widely favored for mixing with alcohol based model engine fuels and justifiably so. To date, no substitute has been found that offers better protection against damage in the event of a "lean run" condition in which the quantity of lubricant is diminished, the engine overheats and the protective qualities of the oil are tested to the maximum. Castor-oil also gives better protection against corrosion than most synthetics.

The oil content of a typical *two-stroke* model engine fuel mixture is usually between 20 and 25 percent. Some of this oil is consumed with the fuel, but by far the larger part of it is ejected, unburnt, with the exhaust gases. In this way the oil performs the secondary function of helping to cool the engine by picking up heat from the hottest parts. Because a four-cycle engine has a firing stroke only once for every four strokes of the piston and runs cooler than a two-stroke, it is generally agreed that a four-stroke fuel mixture can contain a somewhat lower proportion of oil. Most model engine makers recommend a maximum oil content of 15-20 percent for four-stroke engines and some approve lower percentages (10-15 percent) although there has been a trend upwards again from the 5-8 percent figures that were sug-



Glowplugs used for four-stroke engines. Left to right they are: O.S. Type F, Saito P-1, Enya No.3 and Webra No.3.

gested earlier by some manufacturers. The lowest proportion approved at the moment is the 2 percent recommended for the Kavan FK-50, but here the oil acts as an upper-cylinder lubricant only: the rest of the FK-50's moving parts are lubricated with oil that is pumped over the working parts, from a crankcase sump, by a camshaft driven pump.

Synthetic oils are approved as alternatives to castor-oil by some manufacturers. Others recommend that, where a synthetic oil is used, a proportion of castor-oil should still be included as a safety measure. The Saito company, for example, specifies that castor-oil should comprise at least 30 percent of the total lubricant content.

NITROMETHANE

The addition of nitromethane to model two-stroke fuels has long been known for its beneficial effect on power output: hence its use (where rules permit) in large quantities — 50 percent and upwards — for high-performance racing engines. It is also used as a means (in smaller quantities) of improving flexibility and throttle response in all other engines.

Engine makers are, nevertheless, divided in their views as to the desirability of having nitromethane in four-stroke fuels. When manufacturers began introducing model four-strokes to the market in the late nineteen-seventies, most of them recommended the use of between 5 and 15 percent nitromethane. As a result, a 10 percent nitromethane content has become widely recognised as the norm for four-strokes and as the standard fuel for comparative testing of four-stroke engines, except when a factory may specifically recommend otherwise.

By contrast, some manufacturers do not advise the use of nitromethane at all, on the grounds that it increases the risk of corrosion occurring within the engine. For example, the makers of the high-performance Laser four-stroke engines disapprove of the use of both nitromethane and synthetic oils and recommend a straight 80/20 blend of methanol and castor-oil instead.

It is true that four-cycle motors are more prone to suffer bottom end cold corrosion than two-strokes. The reasons for this are explained in Chapter 12, but cold corrosion can also occur without nitromethane having been added to the fuel. Measures for guarding against such corrosion are also explained in Chapter 12.

COMMERCIAL FUELS

The above comments on fuel mixtures are made partly on the assumption that the modeler is able and willing to obtain the materials to blend his own fuel. In some cases this will not be so and the user may well find it more convenient to purchase a ready-mixed commercial model engine fuel from his local hobby dealer. In this case, the four-stroke owner is advised to take note of the previous remarks and to select a fuel mixture that approximates to the maker's recommendations. Several fuel manufacturers are now offering fuels that are blended specifically for four-stroke engine use. For example, K&B "125" four-cycle fuel is blended with castor-oil and contains 12½ percent nitromethane. Sig "Premium" four-stroke fuel is also blended with castor-oil and is available in a choice of 10 percent or 15 percent nitromethane. Both manufacturers also offer straight methanol/castor-oil fuels that can be substituted where the engine manufacturer specifies such mixtures.

GLOWPLUGS

When four-stroke model engines were first introduced, it was commonly believed that special glowplugs would be necessary in order for them to retain sufficient heat through the four-cycle engine's two extra non-firing strokes. The original O.S. FS-60 engine was, in fact, fitted with a special plug, the O.S. Type F, which is still standard equipment on O.S. four-stroke engines. However, most model four-strokes operate quite satisfactorily on ordinary (usually "hot" rated) model two-stroke plugs.

The main difference between conventional glowplugs and the O.S. Type F is that the latter has a longer body

In the heyday of the spark-ignition model two-stroke, miniature spark-plugs were provided by many leading manufacturers, including Champion (example right), AC, KLG, etc. Production ceased with the rapid acceptance of the glowplug after 1948. Modern successor (left) is the Japanese NGK ME-8.

and the portion containing the heating element extends, in a reduced diameter, below the threads. In this way, the threads in the cylinder head do not have to break through into the combustion chamber. This can be helpful in the design of a small engine where space is limited by the need to find room for two valves and a glowplug within an acceptable combustion chamber shape. In fact, in all FS-60 engines, with the exception of the very earliest (1976) production model, the plug was contained in a socket above the combustion chamber and ignition took place between the socket and combustion chamber through a hole having a diameter of only 3.5 mm — a little more than half that of a normal plug hole.

In regard to the choice of glowplugs, the user is advised, once again, to follow the engine manufacturer's instructions. To date, glowplugs have shown a tendency to last longer in four-stroke engines than in two-strokes but if, in an emergency, it becomes necessary to replace a burned-out plug and another of the same type is not readily available, some caution may need to be exercised.

For instance, any attempt to fit a conventional long-reach plug to an FS-60 will result in the plug "bottoming" in the plug hole, instead of seating properly in the head. The use of an idle-bar type plug would make matters even worse; in fact, bar type plugs, in general, are not suitable for four-stroke motors. On the other hand, while O.S. Type F plugs have been successfully used in many four-strokes, their extra reach makes them totally inappropriate for some other four-stroke engines.

An example of the importance of making sure that plug reach is correctly matched to the engine, is to be found in the Austrian Hirtenberger HP VT-21 rotary-valve four-stroke. This engine uses a conventional long-reach ($^{7}/_{32}$ in.) plug, but with a special *extra-thick* (1.5 mm) washer. Standard plug washers are only half this thickness and will actually allow the plug to bottom against the chromed brass sleeve in which the vertical cylindrical rotary-valve revolves. It is very probable that, if the plug is tightened under these conditions, it will distort the valve sleeve. Unfortunately, in this particular engine, such distortion would call for the replacement of the entire cylinder and crankcase assembly, an expensive mistake which emphasizes the need for caution when dealing with some engines, even when changing such a simple item as a glowplug. (See also Chapter 12.)

Typical glowplug clip and battery leads. This version has switch and indicator light for checking glowplug element.

BREAKING-IN

"Breaking-in" or "running-in" can be defined as the process of aiding an engine's transition from a newly assembled assortment of metal parts to an efficient working machine.

It means running the engine under carefully controlled conditions at the beginning of its life in order to avoid the risk of immediate damage to certain components (or their premature deterioration subsequently) and to help working parts to become smoothed and aligned for maximum mechanical efficiency.

Every internal combustion engine, large or small, to a greater or lesser degree, needs some extra care when new. No matter how well an engine is made, its working surfaces are microscopically "rough" when new and parts are apt to distort from the effects of combustion pressure and excessive heat. Rough surfaces and distortion mean increased friction and the generation of still more heat to make matters worse.

It used to be thought that the best way of dealing with this problem was to first "motor" the engine by coupling it to an external power source. Certainly, this used to be helpful in easing the very tightly fitted babbitt-metal bearings used in the early days of automotive and aeronautical engineering but, with model motors, such preliminary procedures serve no useful purpose and have no effect on the length of the full break-in time. This is because, in a model engine, the most critical parts are the piston and cylinder and it is necessary for these to be subjected to normal working pressures and temperatures, for brief periods, to enable running-in to take place properly.

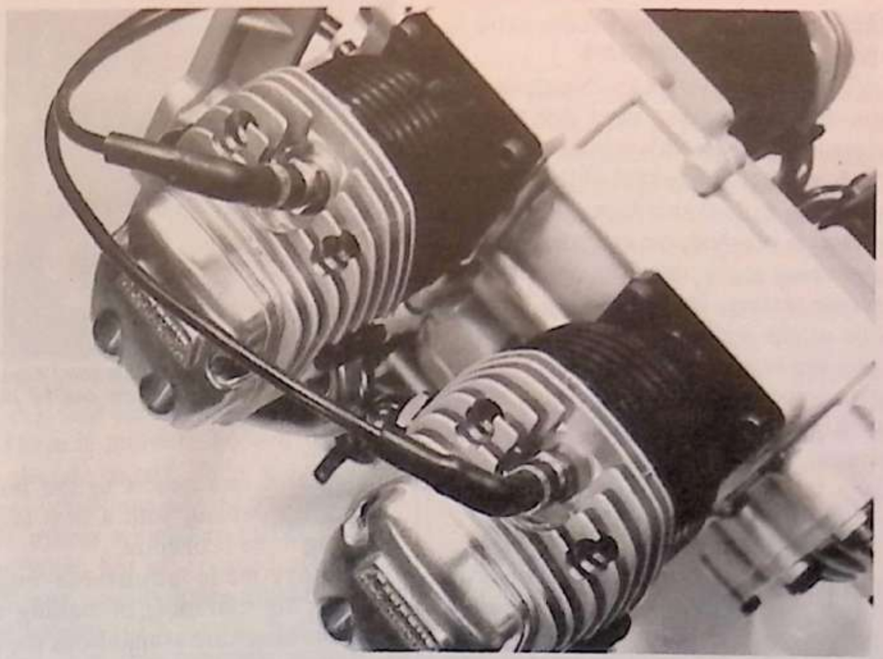
One cannot be dogmatic about what goes on inside an engine when it is running. It is impossible to see or measure all the changes that different parts undergo while the engine is operating at, perhaps, a hundred cycles per second for a model four-stroke engine and upwards of double that number in the case of model two-stroke engines.

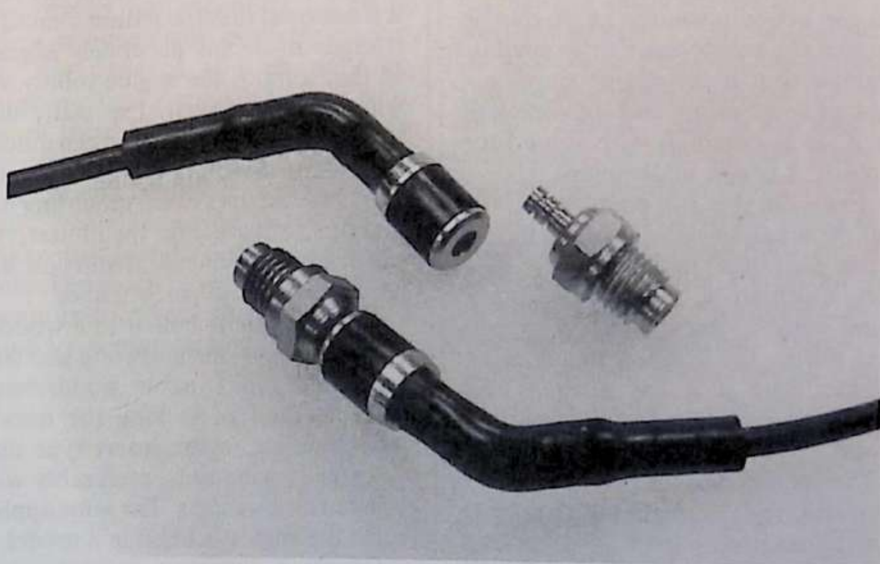
Certain processes are, however, self-evident. We know that, although the surfaces of newly manufactured working parts may appear to be beautifully smooth to the naked eye, they are actually a succession of hills and dales when examined under a microscope and that, as they rub against each other, the high spots are worn down and "fit" is thereby improved. We must also understand that different components, and even different areas of those components, distort in varying degree, according to the thermal and mechanical stresses imposed upon them and that these movements, minute as they may be, must also be accommodated by additional "wearing-in" at those points where clearances would otherwise be reduced to below the safe minimum when the engine is hot.

To help the engine through this critical period in its life, one thing stands out as all-important: heat must not be allowed to build up excessively. Too much heat means excessive expansion, a reduction in clearances, more friction and, thus, more heat, thereby entering into a spiral in which clearances are eventually reduced to the point where friction overcomes the power available and, if lubrication then breaks down, the engine is brought to a grinding halt.

We can prevent this excessive heat build-up during breaking-in in three ways:

1. Use a fuel which contains an adequate proportion of (preferably) castor-oil and a minimum of power-boosting additive (nitromethane). A straight mixture of four parts methanol and one part castor-oil will suit most four-stroke motors for breaking-in.
2. Open the needle-valve so that the fuel/air mixture strength becomes over-rich. This will cause less of the fuel to be burnt and the remainder to pass through the engine, acting as a coolant.
3. Run the engine for short periods of the time, especially at the beginning of the break-in process, with a cooling off period between each run.
4. Do not overload the engine with a big prop. Choose one of the medium sizes recommended in the instructions.





For twin and multi-cylinder engines, or enclosed installations where permanently wiring of plug/s to a single outlet point is desirable, compact, firmly-fitting connectors are essential. These neat O.S. spring-loaded push-on connectors are here fitted to the O.S. FF-240 Pegasus four-cylinder engine.

Model engines, in general, vary a good deal in regard to breaking-in requirements and, happily, four-strokes are rather less critical to break-in than two-strokes. There is no doubt, however, that all engines benefit during breaking-in from being brought up to normal operating temperatures for brief periods and then allowed to cool off. This is borne out by the experience of many years of testing hundreds of new engines, each of which has had to be properly broken-in before it could be subjected to the rigors of testing for power output. It is of little or no use, for example, to run an engine at a reduced throttle setting or at a rich setting for hours on end, in the expectation that this gentle treatment will have the desired effect. It will not.

The reason for this is that the components have, in effect, to become "acclimatized" to the environment in which they will eventually be called upon to operate. The minor distortions that engine parts suffer are, themselves, subject to certain changes and it appears that stability is only achieved after the parts have progressed through several cycles of heating and cooling and the necessary permanent clearances achieved.

About one hour of total break-in time is usually sufficient to bring the average engine up to the point where it can be safely run at full power continuously. This generally holds true for engines having .60-.90 size cylinders. Bigger engines may need rather more time whereas, with smaller ones, 30-40 minutes running time may be sufficient.

The throttle should be kept wide open during the break-in (although it may be slightly closed for the first few runs if the new owner prefers) using the rich setting of the needle-valve to reduce rpm.

The rule is to start the break-in with the engine running very rich and to close the needle-valve gradually with each successive tankful of fuel. By the time the end of the nominal break-in period is reached, the engine should be operating at, or near to, its optimum needle setting, i.e. slightly on the rich side of the setting at which maximum rpm are achieved. (See Chapter 9.) If the engine will not hold a steady speed at this stage, it is not fully run-in and should be operated at a richer setting for a few more runs.

IN-FLIGHT BREAK-IN

The advantage of a bench break-in is that the operator has complete control over the engine at this critical stage. If the engine begins to overheat and slow down, he is on hand to take corrective action instantly: i.e. to quickly reopen the needle-valve or to snap the throttle shut if the engine shows any sign of overheating and tightening up or if, as is common with some four-strokes, it begins to detonate.

This said, it is still possible to carry out the break-in (or, at least, all but the initial part of it) in flight. There is, in fact, much to be said for bearing in mind basic in-flight break-in procedures during the first few flights of the engine, even if it has already been broken-in prior to installation in a model.

The idea here is to use the throttle control at regular intervals, combining it with maneuvers, so that the engine is alternately put under load, then allowed to cool off on a reduced throttle setting in a shallow dive. A Cuban-8 maneuver is often recommended as a good one for alternately loading and unloading an engine in this way.

If the engine has had little or no bench running prior to being flown, the needle-valve should be set as rich as is practicable without endangering the aircraft through lack of power. It is not advisable to attempt Cuban-8s at this early stage. It will be sufficient simply to throttle back at intervals for a shallow cooling off dive.

MOUNTING

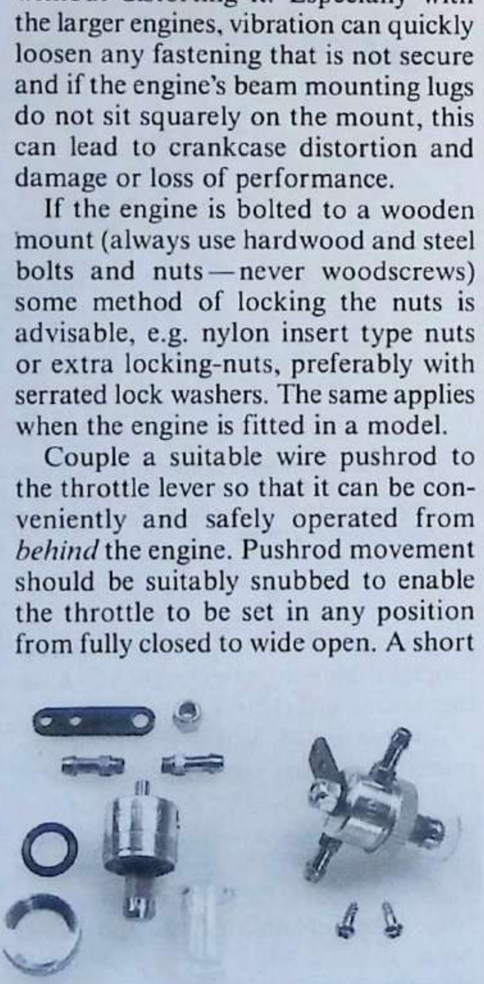
Generally speaking, it is more convenient to learn to handle an engine while it is fitted to a bench mount than in a model. This is particularly so in the case of newcomers to the hobby and when dealing with a new engine needing to be broken-in.

Fuel filters are essential. This good example from the Fox Mfg.Company can be taken apart for cleaning.

Factory-made adjustable engine mounts for clamping or bolting to a suitable bench are available, or the user can devise his own mounting to which the engine can be bolted. In either case, it is essential that the mount should be strongly made and accurately aligned, so that it holds the engine solidly and without distorting it. Especially with the larger engines, vibration can quickly loosen any fastening that is not secure and if the engine's beam mounting lugs do not sit squarely on the mount, this can lead to crankcase distortion and damage or loss of performance.

If the engine is bolted to a wooden mount (always use hardwood and steel bolts and nuts—never woodscrews) some method of locking the nuts is advisable, e.g. nylon insert type nuts or extra locking-nuts, preferably with serrated lock washers. The same applies when the engine is fitted in a model.

Couple a suitable wire pushrod to the throttle lever so that it can be conveniently and safely operated from *behind* the engine. Pushrod movement should be suitably snubbed to enable the throttle to be set in any position from fully closed to wide open. A short sleeve of silicone fuel tube slipped over the wire and fixed to the rear of the engine mount or bench, slightly squeezing the pushrod, will serve here.



An alternative type of fuel filter from Saito. It has a detachable transparent sediment bowl.

FUEL SUPPLY

A conventional model fuel tank of molded polyethylene should be located behind the engine in such a position that its upper fuel level is slightly below the carburetor fuel jet. There is no need to pressurise the fuel tank. If the manufacturer advises pressurising the tank for certain applications when the engine is installed in a model, pressure should be tapped from the exhaust system (or any other recommended source), *not* from the crankcase. Most four-stroke engines are fitted with a crankcase nipple, but it must be emphasised that, unlike the crankcase nipples fitted to some two-strokes, this is *not* for the purpose of pressurising the fuel tank. It is there simply as a breather and to enable excess oil, that would otherwise collect in the crankcase, to be drained away.

Sullivan "Hi-Tork" 12-volt electric starter will start most engines of up to 1.2 cu in. displacement. To avoid stalling starter with a big engine, prop should be rotated backwards 1½ turns from compression before applying starter.

POWER SUPPLY

The majority of glowplugs are intended for operation on a nominal 1.5 volts and this can be supplied by a heavy-duty dry cell, but a more practical power source is a rechargeable battery. There is nothing more irritating than to find that one has a flat battery and, although a rechargeable battery is more expensive to buy, it will outlast numerous dry cells and, if kept charged between flying sessions, will ensure that there is always a healthy starting glow at the plug.

Two types of rechargeable glowplug battery are in common use: 1.25 volt nickel-cadmium cell and 2 volt lead-acid cell. The former should have a minimum rating of 1.2 ampere-hour per plug and should be used with short, low-resistance plug leads to avoid voltage drop.

O.S. safety locknut type prop fastening (left) as supplied with O.S. Gemini, Sirius and Pegasus engines. With a through-bolt type fastening (right) it is essential to use props with adequately proportioned hubs and to keep screws and propnut tight at all times.

The 2-volt cells which, nowadays, are of the sealed type, are available for glowplug use in various capacities up to 10 Ah. They should be equipped with long leads in order that the voltage reaching the plug is suitably reduced. The actual lead length required will, of course, depend on the resistance of the wire. A typical example would be about six feet of 0.75 mm^2 twin lead, but exact requirements can easily be determined by trial and error. Alternatively, a short length of nickel-chromium resistance wire can be interposed between one of the battery terminals and the plug lead. If an alligator clip is fitted to the latter, the current reaching the plug element can be adjusted to give the required "glow" at the plug, according to the type of plug in use and the state of charge of the battery.

An excellent commercial example of a self-contained power source, adjustable for all types of glowplugs, is the "Fire-Plug" unit which was introduced several years ago by the Fusite Division of the Emerson Electric Company. It consists of a rechargeable 2 volt 5 Ah sealed cell, rheostat and ammeter within a high-impact polypropylene case.

ELECTRIC STARTERS

The traditional method of starting a model aircraft engine (except in the case of controlline speed engines which, because of the inadequate inertia provided by their tiny propellers, have invariably required some form of powered starter) is by flipping the prop. From about 1970, however, hand-held electric starters began to come into use for radio-controlled models and are now widely used.

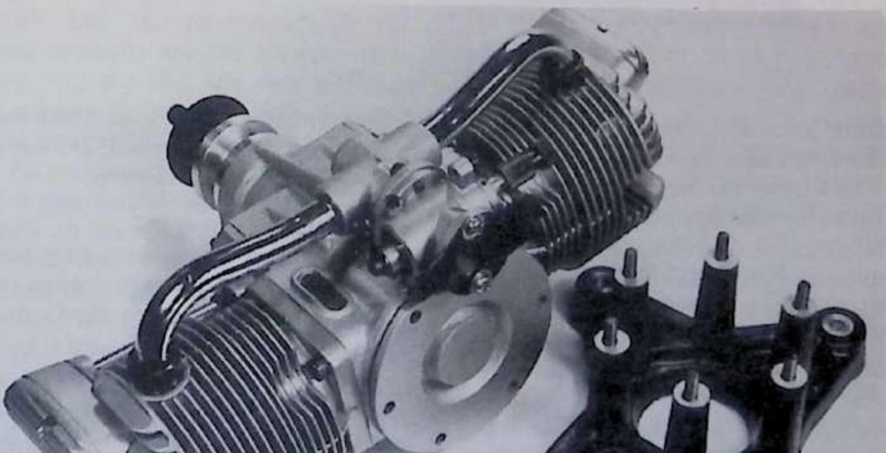
There is much to be said for using an electric starter. There are some engines which are easy to start by hand and others which are rather less co-operative, but all respond at least as well and usually more quickly, to the application of a starter. It should be added that this generally applies to engines having individual cylinder displacements not exceeding 1.2 cu in. Most commercially available starters are not designed to cope with very large engines. Fortunately, the majority of these big engines, aided by the inertia of large diameter propellers, are not difficult to start by hand. Incidentally, "hand" starting should not be taken too literally here: for safety, a "chicken-stick" or heavy glove or gauntlet (*not* bare fingers) should be used to swing the prop.

PROPELLERS

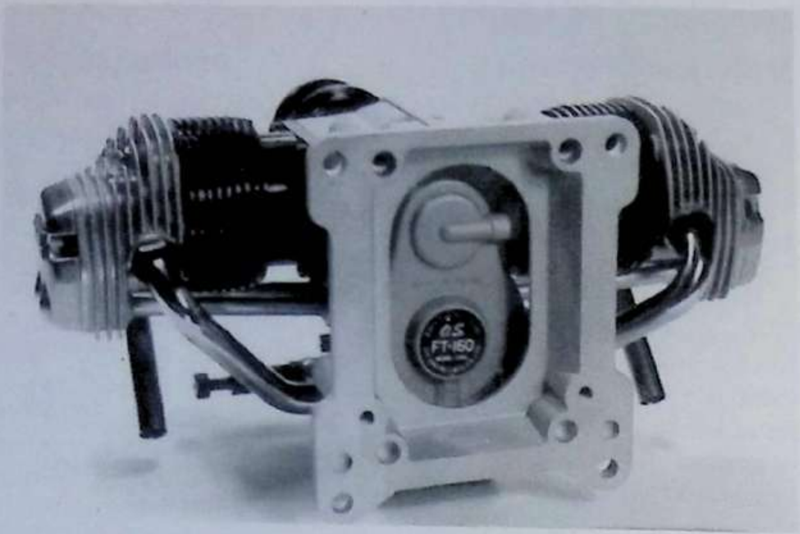
For most engines, the user has the option of fitting a machine-made wooden propeller, or a molded plastic type. Wood props are generally made of maple or beech. Molded props are mostly made of nylon, glass-reinforced nylon (GRN) or of epoxy resin reinforced with glassfiber, carbon-fiber or polyester fabric material. Each type has certain advantages and disadvantages and the user should be careful to select the type that is best suited to his engine and the purpose to which it is to be put.

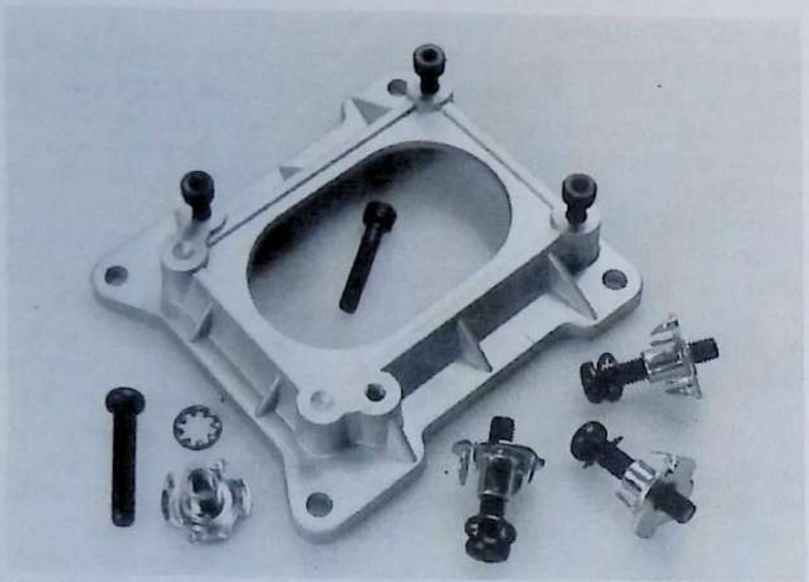
Nylon

First, it must be stated that props made of plain nylon and other non-reinforced plastic materials are not recommended. These propellers, the first examples of which were seen in the late Forties and early Fifties, are adequate only for the very smallest low-powered two-cycle engines such as the .049 cu in. "Half-A" class. When used on more powerful engines, such material has insufficient tensile strength to withstand the high centrifugal forces generated at normal revolutions and th will result in blades fracturing a being thrown off at high speeds. Sin propeller tip speeds may exceed 6 feet per second, or more than 400 mph, it can be readily appreciated that a



Good heavyweight cast-aluminum radial mount for the big 2.75 cu in. Saito FA-270T twin.





Excellent pressure-cast bulkhead mounting plate is supplied with O.S. Gemini 120 and 160 and Pegasus FF-240. It can be permanently fitted to the aircraft firewall with screws and blind-nuts supplied, enabling the engine to be quickly removed by unscrewing four hex headed cap screws.

sharp piece of propeller blade can inflict severe injury on anyone in its path.

To a lesser extent, similar objections can be levelled against glass-reinforced nylon props, particularly those using powdered glass filler rather than glassfiber filaments. When such props were first introduced, some twenty years after the earlier plain plastic types, they were supposed to be safe, but it was soon demonstrated that they could not be relied upon to absorb the power of many of the newer engines. More recently, however, improved GRN props have been put on the market which appear to be capable of remaining intact at somewhat higher speeds.

In some cases, these more recent GRN props are packaged with specific recommendations listing the largest displacement engines with which each sized prop should be used. *Do not ignore such recommendations.*

Calculating safe rpm

Also aimed at discouraging users from fitting GRN props to engines that are too powerful for them, the German Graupner company has issued a warning that the maximum propeller tip speed, in the plane of rotation, should not exceed 180 meters per second (i.e. 590 fps) with the Graupner "Super-Nylon" range of props.

To aid calculation, Graupner suggests the use of a simple formula which can be expressed as follows:

$$\text{rpm} = \frac{3{,}438}{D}$$

where D = diameter of propeller in meters.

Using this formula, if we take a 12-inch (0.305 meter) diameter prop, its safe operating speed will be seen to be:

$$\frac{3{,}438}{0.305} = 11{,}272 \text{ rpm}$$

Alternatively, the formula can be rewritten to show the maximum prop diameter that can safely be used when it is desired to match prop size to a given rpm (such as when the user wishes to employ as much as possible of the engine's maximum power output) i.e.

$$D = \frac{3{,}438}{\text{rpm}}$$

In this case, assuming the required operating speed to be 10,000, the maximum allowable prop diameter would be:

$$D = \frac{3{,}438}{10{,}000} = 0.3438 \text{ meters} = 13.5 \text{ in.}$$

If the power of the engine is such that safe rpm are likely to be exceeded for the chosen prop diameter (remember to allow for build-up to higher rpm in flight) the user has a choice of two options: (a) use a propeller of greater pitch or blade area to reduce speed or (b) change to a wood or epoxy propeller.

Epoxy

Epoxy props usually have their reinforcing materials (mostly glassfiber but sometimes carbon fiber) extending from tip to tip and are extremely strong. Being partially hand made, they are more expensive to manufacture and rather costly to buy although, as they are highly resistant to impact damage, as well as to blade shedding, they far outlast all other types of prop. These props are heavier than wooden ones, but that is an advantage with a four-stroke engine where the inertia, or "flywheel effect," of a heavy prop is a worthwhile aid to even running. The main disadvantage with epoxy props is that the range of sizes available is very small at the present time.

Wood

Wood props offer the most extensive selection of types and sizes and are widely used for the larger displacement engines. They are somewhat less resistant to accidental damage, such as nicked blades or tip damage on take-off or landing, but have good tensile strength to resist blade shedding at high revolutions.

A disadvantage of some wood props, when used on certain large displacement four-stroke engines, is the relative weakness of the propeller boss. Four-strokes, in general, are more prone to detonation and all four-strokes (especially single-cylinder examples) suffer from considerable variation in torque delivery through the cycle (see Chapter 3), both of which can result in the prop slipping, especially if the diameter of the prop driver or the prop boss is small and the frictional contact between the two surfaces is inadequate. Deep serrations in the prop driver face do little to help matters here: if it slips, the serrations will simply gouge material from the back of the prop.

Pinned and Through-Bolt Prop Fixtures

To prevent such movement, some manufacturers have resorted to keying the prop driver to the propeller itself. This usually takes one of two forms. The simplest is to fix dowels or pins (usually two at 180 degrees to each other) in the face of the prop driver, projecting forward, so that they engage suitably drilled holes in the back of the prop boss. The pins are most commonly pressed-in steel roll pins or screwed-in studs.

The other method is to use full length screws through the front prop retaining washer, through the prop and into the prop driver behind it. Four or six screws, spaced at equal intervals, may be used, the assembly being basically similar to the through-bolt type hub commonly used in the past for fixing wooden propellers to full-sized aircraft. The normal prop nut is, of course, retained for securing the complete assembly to the crankshaft.

These two methods of retaining the prop work satisfactorily only so long as the prop nut is kept tight. It is advisable, in fact, to check the prop nut for tightness every time that the engine is started. Preferably, a self-locking stop-nut or an extra, jam nut should be used.

If the nut is not kept tight or the slightest movement develops between the prop and prop driver, the fact that the prop boss has been drilled to accommodate drive pins or through-bolts will prove to be a source of weakness.

Under such conditions, detonation or, alternatively, the severe mean-to-maximum torque fluctuations that occur with a powerful single-cylinder four-stroke engine, can actually cause the prop to split apart, especially if the locating holes through the prop boss are aligned with the grain of the wood. It is worth bearing in mind here that, if two holes are used, they should be positioned so that a pencil line, drawn through their centers, is across the grain of the wood, not parallel to a line connecting the two tips of the prop. If the boss requires four holes, two should be aligned across the boss as just explained.

Prop Slippage

Often overlooked, a further problem arises when the prop does not have a sufficiently large diameter boss to safely accommodate the pins or screws. It has to be admitted that there has been a certain lack of appreciation, by prop manufacturers and engine manufacturers, of the need for co-operation in this area.

The types of four-stroke engines most commonly equipped with pinned or through-bolt prop fixtures, are the larger motors of 1.20 cu in. and upwards, but tests have indicated that these methods are not always necessary. Nor are they the only methods of preventing prop slippage if such a problem exists.

As previously mentioned, the type of engine with which prop slip is most likely to occur, is a powerful single-cylinder four-stroke where torque variations through the cycle are at the highest levels. With a twin-cylinder engine of similar power output, the ratio of maximum to mean torque is much reduced (and even more so in the case of multi-cylinder engines) so the tendency for the prop to slip and suffer damage is greatly reduced.

Here it is significant that, although the O.S. company originally introduced the 1.62 cu in. Gemini-160 and 2.44 cu in. Super-Gemini twin-cylinder engines with through-bolt type prop driver assemblies, these were superseded, shortly afterwards, by a locknut type assembly in which resistance to prop slippage reverted to the traditional model aircraft engine method of depending solely on static friction between the prop driver face and the rear face of the prop boss. This works perfectly satisfactorily with these smooth-running alternate-firing twin-cylinder engines.

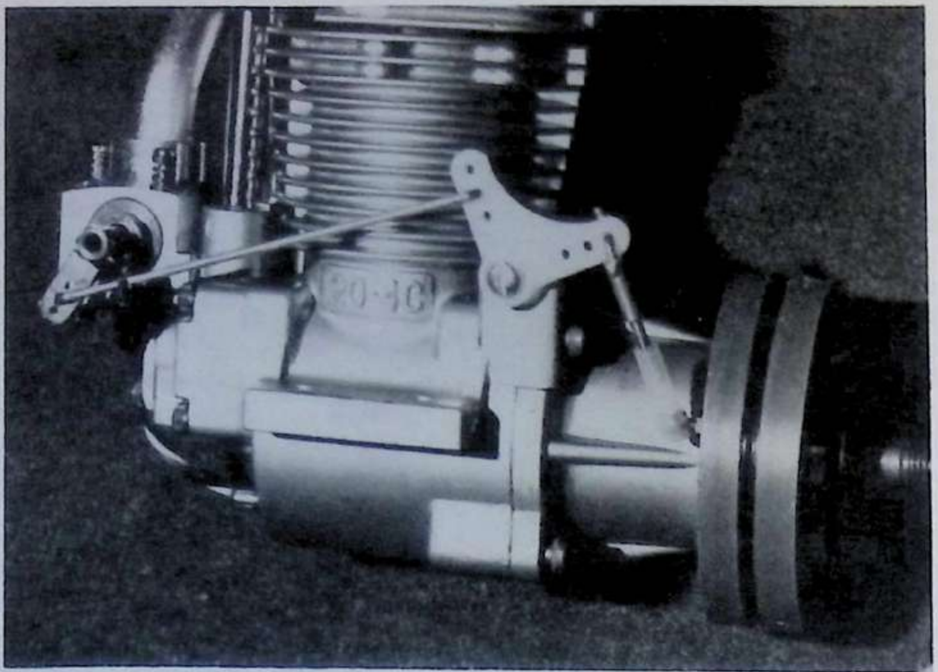
Torque v. Prop Driver Diameter

If, however, resistance to slippage is to depend solely on such contact, the adjoining surfaces must not only be in firm contact, they must also be of sufficiently large diameter to deal with the torque impulses transmitted through them. In other words, *the prop driver must be of a relatively large diameter and the prop must have an equally large diameter boss.*

This is not always the case. Some four-stroke manufacturers appear to have overlooked the need to match prop driver diameters to the levels of torque that they are required to transmit. Most small and medium sized engines have prop drivers that are big enough but, in the larger engines, prop drivers are usually much smaller relative to those engines' torque levels. It is with these engines that a tendency for the prop to slip is most frequently encountered.

An examination of large and small single cylinder four-strokes illustrates this situation quite graphically. Two of the smallest four-strokes tested, the 0.21 cu in. HP VT-21 and the 0.22 cu in. O.S. FS-20, have prop driver face diameters of approximately 23 mm. These are called upon to transmit, respectively, mean torque levels of approximately 23 oz-in. and 28 oz-in. and both did so, on test, without any tendency for their props to slip.

By contrast, a powerful 1.22 cu in. engine of another make tested at the same time as the O.S. FS-20, had a 35 mm diameter prop driver that had to transmit mean torque levels in excess of 200 oz-in. with, of course, very much higher peaks occurring every 720 degrees. This, despite a heavily serrated prop driver face, it could not do without prop slippage (and consequent damage to the rear face of the prop boss) unless its optional screw-in drive pins were used and these could not be accommodated by some makes



An Enya 120-4C fitted with C.H. Electronics capacitive discharge ignition and throttle-coupled spark advance. The bell-crank linkage between the carburetor throttle-arm and the timing plate containing the pulse-switch automatically matches the ignition timing to the throttle opening. (Photo: Courtesy C.H. Electronics, Inc.)

of prop having small sized bosses.

The Solution

The standard prop drive assembly of a model aircraft engine can be likened to a single dry plate disc type automobile clutch. The formula for calculating the torque that can be transmitted by such an assembly depends on four variables. These are (a) the mean radius of the disc, (b) the pressure between the contact surfaces, (c) the coefficient of friction of the contact surfaces and (d) the number of contact surfaces.

(a) The contact area of a model engine's prop driver or hub, is usually in the form of a raised flat ring like the lining of an automobile clutch but having a serrated surface and, since one of the laws of mechanics is that friction is independent of the area in contact, it is the *mean radius* of the ring that is significant, not its area.

(b) The pressure between the contact surfaces is determined by spring pressure in a clutch and by the pressure exerted by the retaining nut in a prop drive assembly. To some extent, and especially with wood props, the pressure that can be applied is limited because this tends to crush and weaken the prop boss.

(c) The coefficient of friction or "grip" depends on the nature of the surfaces in contact. The serrated face of a prop drive hub improves grip but, if torque is sufficient to break this contact, the serrations will only serve to damage the prop.

(d) The number of contact surfaces is *two* in the case of a single dry plate automobile clutch because there are friction linings on *both* sides of the clutch plate sandwiched between the flywheel and the pressure plate. This *doubles* the torque that can be transmitted by the clutch.

This raises an interesting point so far as large single-cylinder four-strokes are concerned.

It can be shown, mathematically, that, with such engines, employing existing friction drive methods and conventional prop materials, very much bigger diameter drive hubs and prop bosses are required — preferably twice as large. There is, however, another possibility. As we have seen, part (d) of the equation reveals that torque transmission can be increased 100 percent by doubling the number of contact surfaces — as in a double-sided clutch plate. Therefore it would seem to be a wise move to use the prop retaining washer, also, as an additional driving surface.

To do so will require that the washer is *keyed* to the shaft so that, while free to move axially, it cannot rotate. Obviously, the washer should have the same type of driving surface as the propeller hub. (See drawing p. 96-7.)

Fine-Pitch Props

Before leaving the subject of prop drive assemblies, a word of warning concerning fine pitch propellers.

Fine pitch props customarily have thinner bosses than medium and high pitched props. Always check that, when such a prop is fitted, some threads still remain when the prop is pulled up tight. If necessary, add an extra washer between the nut and the prop washer. The same applies when the engine is equipped with a sleeve-nut or spigot-nut type fitting. Check by fitting the nut and prop washer to the engine to make sure that, when the nut is tightened, the space between the prop driver face and the prop washer is smaller than the thickness of the prop boss.

Failure to make these checks may mean that the prop is not fitted as tightly as has been supposed and will slip and, most likely, be damaged when the engine is started.

Balance

In the interests of smooth running, props should not have one blade heavier than the other. Most modern commercially made props are reasonably well balanced, but simple balancing devices are available to enable this to be checked. If necessary, trim the heavier blade until the prop balances, like a wheel, in any position. After trimming, seal the tips of wooden props with a fuel-proof finish, applying to both tips to maintain balance.

STARTING & RUNNING

There are various starting techniques with model four-cycle engines — rather more so than with two-strokes. Some engines respond best to one particular starting drill; others are less critical. Some are easy to start when cold and less responsive when hot. With others the reverse is the case.

Obviously, the first thing to do when a new four-stroke has been acquired is to follow the manufacturer's instructions in regard to starting procedure.

Generally speaking, no difficulty in hand starting will be experienced. However, as with two-strokes, some engines start more easily than others and it is not always the smaller engines, supposedly more suited to the beginner, that are the least foolproof. The new owner may have to persevere for a bit. Later, when the engine is broken-in and he has unconsciously adapted to its idiosyncrasies, he may wonder why he had problems at the beginning.

The alternative to patience and perseverence, in such cases, is to buy an electric starter. No engine that has a glow at the plug and sufficient (not too much) fuel at the carburetor, should fail to respond to being spun over with an electric starter. If it does, there is something wrong. We will come to this in a moment.

Check List

Let us suppose that a new engine has been set up, ready for running, as described earlier in this chapter. The basic check list should read as follows:

1. Engine firmly mounted and propeller fitted *securely* to shaft. Refer to maker's instructions for appropriate prop size. Usually, a choice of several prop sizes will be given. Avoid the use of the smallest diameter recommended: medium sizes have higher inertia and make for easier hand starting, without overloading the engine when new.
2. Fuel tank properly positioned and filled with recommended fuel mixture. Use silicone fuel tubing for "plumbing" and install a fuel filter in the delivery line from fuel tank to carburetor. It is even more important to fit a filter in the outlet from your fuel container as this will trap most foreign matter before it reaches the fuel tank.
3. Remove glowplug from engine, attach battery leads to it and check that plug glows a bright red color by adjusting rheostat, resistance wire or lead length. Re-insert plug, screwing in with fingers to ensure that it is not cross-threaded, before tightening with plug wrench.

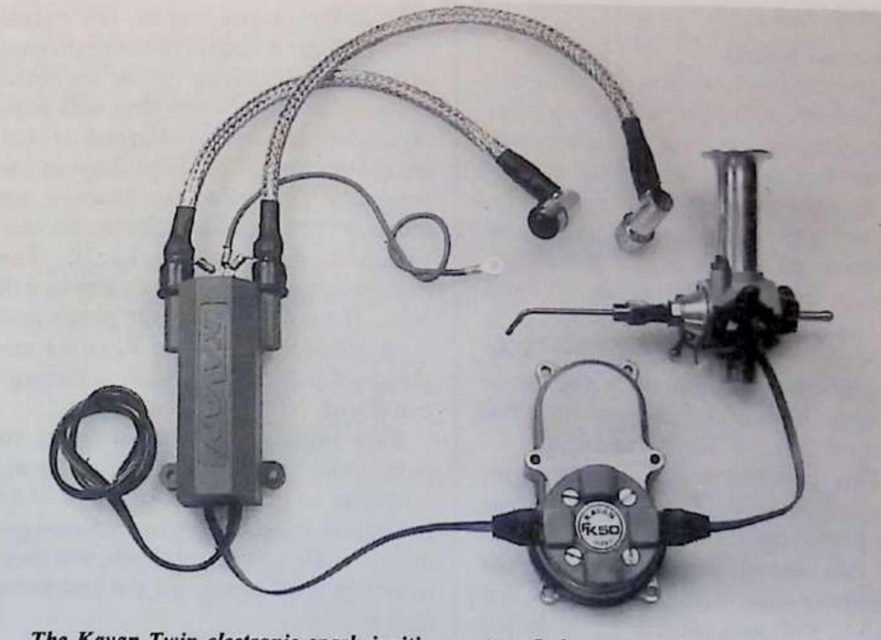
Basic Starting Procedure

Now to the actual starting. First, try whatever method or methods are advised in the manufacturer's instruction leaflet. Generally, such instructions can be relied upon, although it has to be admitted that, occasionally, makers' instructions can be needlessly detailed and complicated so that the user may well become a trifle confused if he lacks experience of four-strokes.

If the engine does not appear to respond to the maker's instructions as well as might be expected, the following simple procedure may be tried instead.

1. Open needle-valve to starting setting and fully open throttle.
2. Choke carburetor intake and rotate prop just sufficiently to draw fuel through delivery tube to carburetor.
3. Release choke, close throttle to about one-quarter open and turn prop through two complete revolutions (i.e. to include one suction stroke) to draw mixture into cylinder.
4. Turn prop over compression to make sure that not too much fuel has been drawn into cylinder. (This is unlikely if the above procedure has been followed, but if excessive resistance or a hydraulic lock occurs (see below), turn prop backwards to eject excess fuel through exhaust.)
5. The engine is now said to be "primed." Energize glowplug, grasp prop blade very firmly and pull through top dead center on compression stroke. You should feel a slight "kick" as the mixture fires, indicating that the engine is ready to start. (If on the other hand, a sharp metallic knock is heard, check that the prop-nut has not loosened.)
6. Apply starter or flip prop vigorously. (Beginners are advised to first practice "prop flipping" without the glowplug energized, in order to become familiar with the "feel" of the engine.)

If the engine does not start immediately, keep the starter engaged for a few seconds or continue to flip prop. If the engine still refuses to start, disconnect glowplug battery and repeat prestart procedure, choking the intake for one extra suction stroke. Engines with updraft (rather than horizontal) carburetors, may need this extra choking because some fuel will drip from the intake before it can be sucked into the cylinder.



The Kavan Twin electronic spark ignition system. It has two Hall Effect pickups, one advanced and one retarded, with selection via a microswitch actuated by the throttle.

In cold weather — and provided that you have a fully-charged battery — it may help to leave the plug energized for 15 or 20 seconds to warm the cylinder and assist in vaporizing the fuel before attempting to start the engine.

Hopefully, when the engine starts, it will run steadily with the throttle at the quarter-open position as previously set. Most engines will do this, as received from the factory, provided that the idle mixture control or air-bleed screw has not been tampered with. It certainly feels more civilized to be able to start an engine at part-throttle (or even idle) instead of at full throttle.

However, if, at this early stage, the engine will not keep running on a part-throttle setting, it is probably better for the beginner to opt for the once traditional "full throttle" start, as it is much easier to set the primary mixture control (i.e. main needle-valve) first. One can then carefully readjust, as necessary, the idle controls, after which there should be no difficulty in making subsequent starts with the throttle at its idle setting.

The procedure to be adopted varies according to the type of carburetor fitted to the engine and is described in Chapter 9.

Bounced Starts

An alternative method of hand starting a four-stroke often recommended (especially by Japanese manufacturers) is the "reverse-flip" or "bounced start." Here, after priming the engine as described above (sometimes the direct injection of fuel through the exhaust pipe is recommended as an optional method of priming), the prop is brought up to compression, then flipped vigorously *clockwise* (i.e. in the opposite direction to normal rotation) to start.

This procedure has been recommended as being less likely to cause the engine to "bite" the operator and, for this reason, has been favored for beginners and also for others when dealing with very large engines. When the prop is flipped backwards, it rotates through 1½ revolutions and the operator's hand (or "chicken stick") is well out of the way before the partially compressed mixture is fired by the glowplug and the piston is kicked smartly back in the right direction to start the engine.

Hydraulic Lock

A mixture of liquid fuel and air is compressible. Liquid fuel on its own is not. Therefore, if so much fuel is induced into a cylinder that it occupies more than the quite small volume of the combustion chamber on the compression stroke, the piston will be unable to pass over top dead center.

Propeller bosses should fit prop shafts accurately. Excellent tool for this purpose is the Fox Prop Reamer for the popular ¼ in., 5/16 in. and ⅜ in. shaft sizes from Fox Mfg.Co.

This is called "hydraulic lock" and it can occur if the engine is over-choked or over-primed. It can happen with a two-stroke engine, but is much more likely to occur with a four-stroke because the four-stroke draws its fuel directly into the cylinder, instead of indirectly via the crankcase. If one over-chokes a two-stroke, the excess fuel will simply collect in the crankcase (assuming the engine to be mounted upright) and the worst that will happen, when the prop is flipped, is that the glowplug will be doused by an excessively rich mixture thrown up through the bypass port, to the accompaniment of a sizzling sound. The same treatment with a four-stroke will arrest the movement of the piston and if an attempt is made to start the engine in this condition, serious damage can occur.

It is important, therefore, not to over-choke a four-stroke prior to attempting to start it and to check — as indicated in the starting procedure above — that the crankshaft will pass over top dead center on the compression stroke.

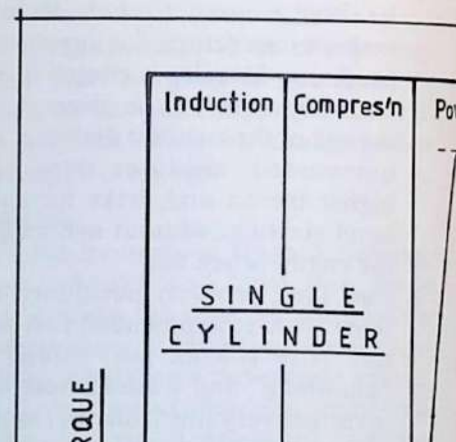
If the engine is equipped with a choke valve, it is essential for this to be reopened before an attempt is made to start the engine. Preferable, in this respect, are choke valves of the spring-loaded self-reopening type as fitted to the O.S. four-stroke engines.

Thrown Props

It is not unknown for model engines (occasionally two-strokes, but more often four-strokes) to perform a somewhat disconcerting trick; i.e. to emit a sharp crack and come to an incredibly abrupt halt. If the prop is not keyed to the prop driver, its inertia usually results in its kicking the prop nut loose and (unless a locknut is used) the whole assembly; prop nut, washer and propeller disappears in a flash. At one moment the engine is running at several thousand revolutions. One second later, it is stationary, seemingly none the worse for what appears to have been an attempt at self-destruction — or, possibly, the attempted destruction of its owner by hurling its prop assembly at him.

From various observations and investigations, this awesome phenomenon can result from one or more of a number of conditions.

First, it has been observed that such occurrences are usually preceded by audible detonation, i.e. a high-pitched "knock," or "*ping*" as it is descriptively known to U.S. auto mechanics. Detonation will occur if the engine's compression ratio is too high. As explained in Chapter 4, the highest practicable compression ratio is determined by (among other things) the design of the combustion chamber, the fuel em-



Although the torque produced by an i.c. engine is normally expressed in terms of the average or mean torque throughout the cycle, it actually fluctuates widely. It reaches a peak during the power stroke but varies between negative and small positive values during the "idle" strokes when ployed, the mixture strength and the ignition timing relative to the speed of the engine under load.

Early automobiles suffered a good deal from detonation. It was dealt with by providing the driver with a manual ignition timing lever, by which means the spark could be retarded when the engine began to labor and knock when climbing a hill, for example. Nowadays, so long as the right grade of gasoline is used, we rarely encounter detonation in our cars, partly because of improved engine design and better fuels, but mainly because ignition timing is automatically controlled, either mechanically or as part of a complete electronic management system. In the future, such systems will continually monitor all the conditions under which the car is operating, including atmospheric conditions and fuel quality and will control spark timing, air/fuel ratio and even inlet turbulence, accordingly.

Unfortunately, we have very little control over ignition timing with our glowplug-ignition model engines. It is quite remarkable, in fact, that glow ignition works as well as it does. However, there are things that can be done — or at least borne in mind — to reduce the risk of detonation and its consequences.

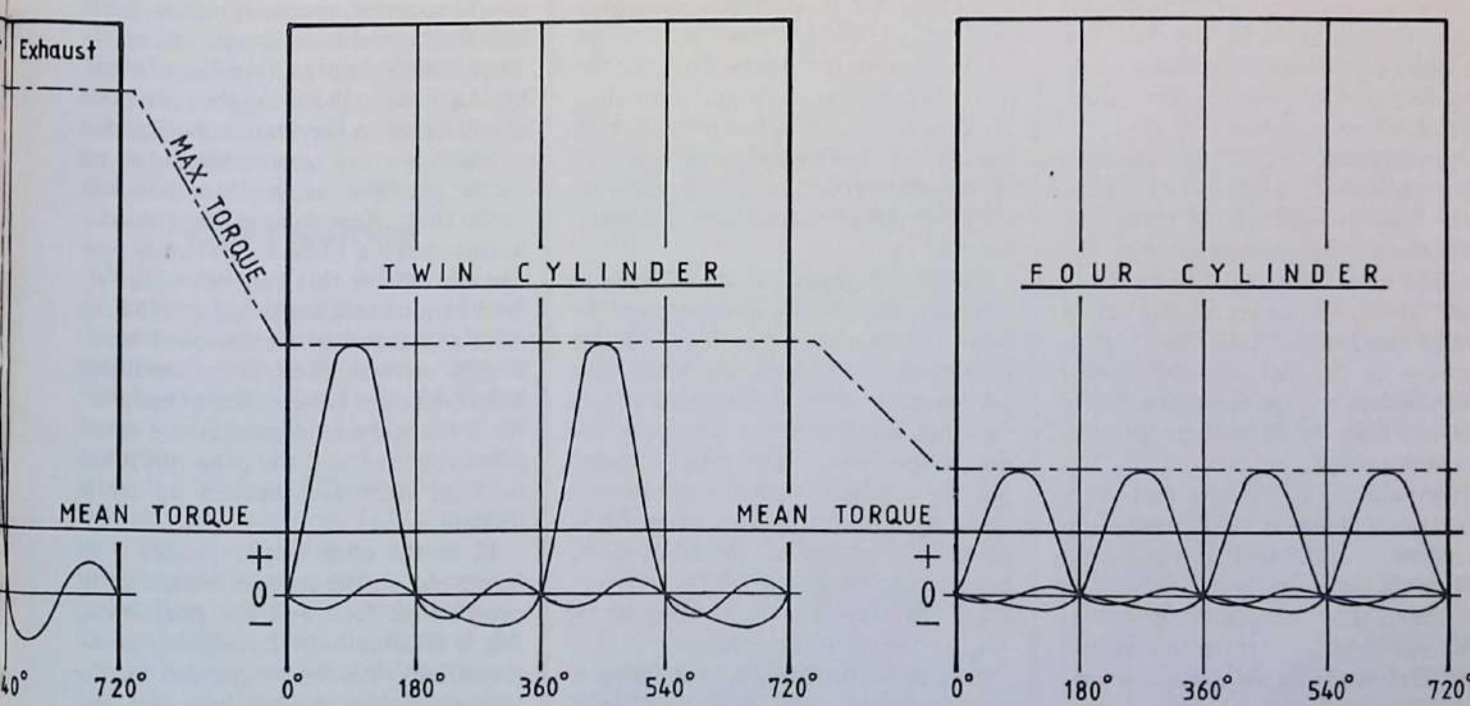
Firewall mounting brackets for Kavan FK-50 are of aluminum alloy plate and incorporate resilient three-point attachment to engine using rubber bushes.

The most important of these is not to run the engine too lean. Detonation most frequently occurs when, after the engine has warmed up, the operator is tempted to try to extract the last hundred or so revs from the engine by closing the needle-valve a little more. Either of the following may then occur.

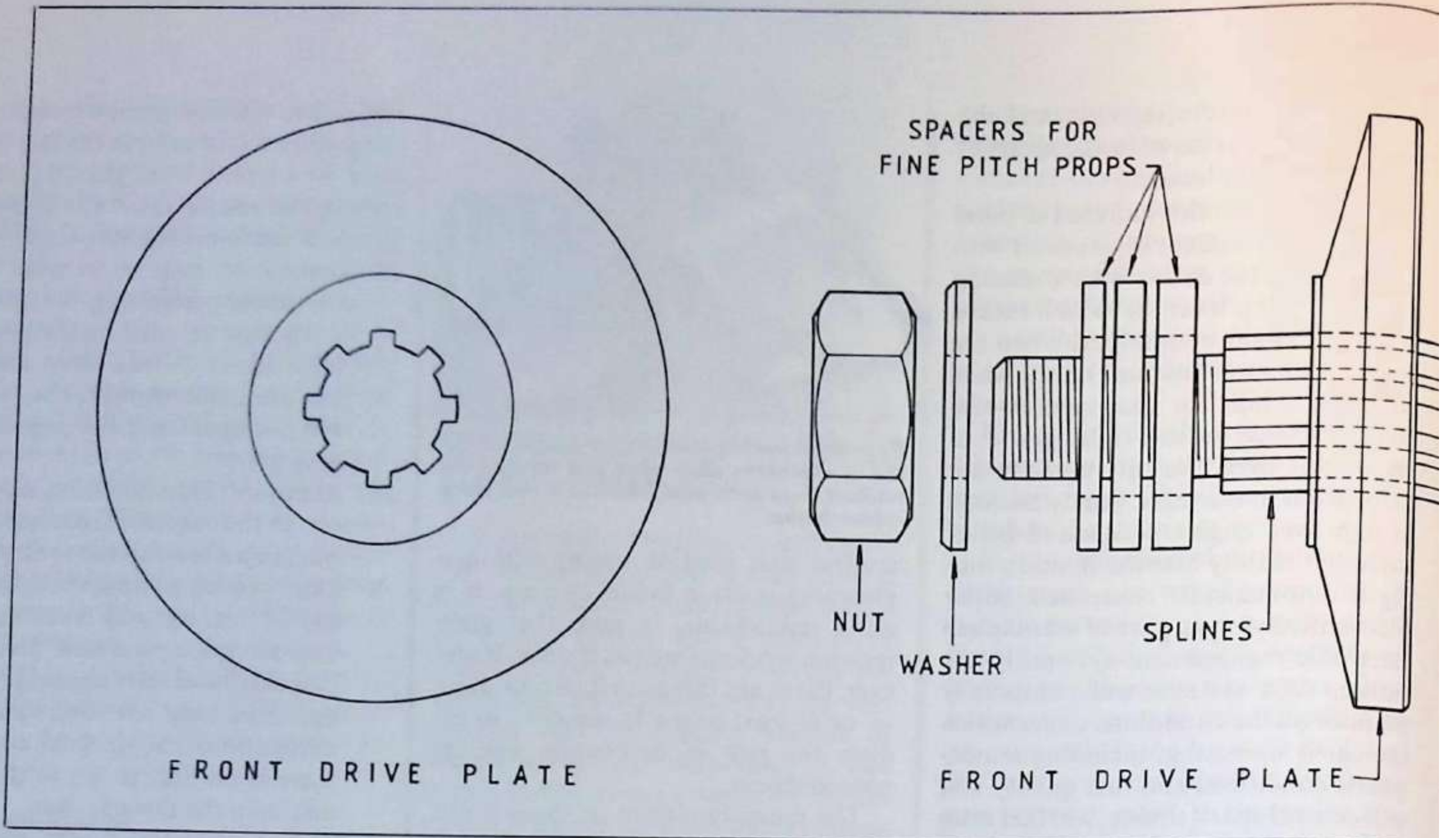
(a) Detonation may set in while you are actually adjusting the needle. If you hear it, open up the needle-valve again *immediately* and, if you are quick enough, the "ping" will disappear and the engine will keep going.

(b) Alternatively, detonation may occur as the engine is continuing to warm up a few moments after you think you have found the optimum needle setting and have turned your attention elsewhere. This time you may have little opportunity to act. You may not even hear the detonation but, if you do, and there is no time to get to the needle, snap the throttle shut.

Detonation rarely, if ever, happens when the engine is running at part



the piston is drawing in the fresh charge and compressing it and expelling the exhaust gases. As these diagrams show, there is an extremely wide variation between mean and maximum torque levels in a single-cylinder four-stroke engine and this violent fluctuation is a major cause of prop slippage with the larger and more powerful single-cylinder model four-strokes. By dividing the engine's displacement between two alternate-firing cylinders, the ratio of maximum-to-mean torque is greatly reduced. With a four-cylinder engine of the same total displacement, the magnitude of torque fluctation is still further reduced. It is these reductions in torque variation that, with better engine balance, are also responsible for the much smoother operation of twin and multi-cylinder engines.



A suggested method of reducing the risk of prop slippage with powerful single-cylinder four-strokes, based on the principle of the automobile clutch. By replacing the standard prop washer with an additional drive plate keyed to splines on the crankshaft, frictional contact is doubled. Since the front plate cannot rotate on the shaft, this also prevents it from loosening the prop nut if the engine should detonate or "backfire."

throttle. It is also less likely when the engine is running at full throttle but reasonably lightly loaded; that is, running on a normal size propeller rather than on an oversized one.

Atmospheric conditions can also affect an engine's propensity to detonate. Engines which have tended to detonate all too readily in hot dry weather, have been found to be much more amenable under cooler, more humid conditions. Too much nitromethane in the fuel can also induce detonation and some users have found that too high an oil content can also increase the risk.

It should not be thought that every four-stroke engine is ready to frighten its owner by suddenly emitting a bang and throwing its prop off. This was something that was almost unknown with early mild-performing model four-strokes. It first became recognised as a four-stroke hazard when certain manufacturers began looking for more performance. There was a period, for example, when fitting decompression gaskets to certain Enya engines became recognised as "a good thing." In more recent years, the Enya factory has introduced new models that are more powerful, yet do not detonate.

Many other four-strokes have also been tested which show little or no inclination to detonate even under extreme provocation. If an engine simply cuts out cleanly when over-leaned, even when running on the largest recommended prop size, it is unlikely to suffer detonation problems at other times.

The development of new combustion chamber shapes appears to have been of some benefit in reducing the incidence of detonation, while the adoption of more positive methods of securing propellers has not only reduced the risk of the prop actually parting company with the engine but also, by preventing the prop from being able to slip on the crankshaft, has enabled its kinetic energy to overcome the tendency for the engine to stop as a result of detonation.

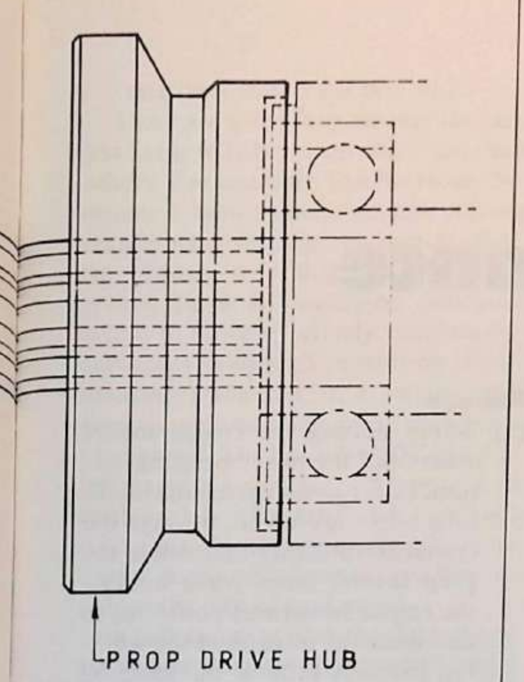
It used to be thought that fixing a prop so firmly to the crankshaft that it could not slip in an emergency, would be likely to cause the crankshaft to break. In the early days of model (two-stroke) engines, there was some justification for such fears. The lightweight engines of those times often had quite flimsy crankshafts and it was not unknown for them to break in normal use. In contrast, modern engines, both two-stroke and four-stroke, are much more sturdily built and the risk of shaft breakage through having the prop positively keyed to the shaft, is negligible.

There is every reason, therefore, to fix the propeller as solidly as possible to the shaft. Repeating earlier remarks in this chapter, there are basically two ways in which this can be achieved. Both require that the prop itself should have a generously dimensioned boss. If pegs or through-bolts are used, the prop boss must have sufficient material for it not to be weakened by the extra holes required and the prop nut must be kept tight and backed up by a locknut.

If, on the other hand, reliance is to be placed on the friction between the prop driver face and the prop boss, this is feasible only if contact is commensurate with the torque that has to be transmitted. As has been demonstrated, prop drivers are generally adequate in the case of small engines, but very marginal in the case of some large single cylinder engines.

Effect of Two or More Cylinders

Dividing a four-stroke engine's total displacement between two or more cyl-



inders is, as previously shown, desirable in the interests of improved balance and a reduction in torque fluctuations. But these conditions not only make for smoother running qualities. The torque impulses, much less violent and occurring at closer intervals, are markedly less likely to cause the prop to slip. Detonation, if it occurs, will also be less violent in its effects.

SPARK IGNITION

Before leaving the subject of (a) detonation and (b) slipping props and the implications thereof, it needs to be mentioned that there is one way in which these problems can be eliminated in the case of (a) and reduced or overcome (b). This is by abandoning glowplug ignition in favor of variable-advance spark ignition. This gives precise control of ignition timing and thereby enables any tendency towards detonation to be forestalled by delaying the point at which the firing of the charge is initiated. Since detonation is also one of the causes of prop slippage, it follows that this may also be lessened.

Spark ignition was the only type of ignition used by model engines prior to World War II. It became outmoded by post-war European compression-ignition and American glow-ignition engines only because of its weight, relative complexity and the fact that it was the cause of 90 percent of the starting problems experienced by users in those days.

The spark ignition situation is now rather different, especially with modern electronic systems. These dispense with the long familiar mechanical contact-breaker or timer-points assembly and utilize, instead, optical or magnetic trigger systems which function without the need of frequent cleaning, adjustment or replacement. A good electronic ignition system can be relied upon to go on functioning, without attention, almost indefinitely, providing an intense spark at the plug over an extremely wide speed range. Weight is not a problem since spark ignition would not normally be contemplated for small engines. These systems normally run from a 500 mAh 5-volt rechargeable nickel-cadmium power pack, instead of the dry cells used in the early days.

Very few model four-cycle engines are produced at the present time with ready-installed spark-ignition systems, but conversion kits, manufactured by C.H. Electronics Inc., of Riverton, Wyoming, are obtainable to enable existing engines to be converted to this form of ignition. In Europe, the West German Graupner company is offering spark-ignition systems for O.S. four-stroke engines including the twin cylinder Gemini and four-cylinder Pegasus models.

A feature of all but a few of the very earliest of commercially produced model engines of the Thirties and Forties, was manually adjustable spark timing. This enabled the spark to be retarded for safe and easy starting and then advanced, when the engine was running, to suit its operating speed under load and thereby produce the best performance.

Curiously, not all modern electronic systems for model engines have such provision. It would appear that the adoption, in the early Seventies, of small industrial type two-stroke magneto-equipped gasoline motors (i.e. ex-chainsaw, weed-eater, leaf-blower, etc.) for large scale model aircraft, was influential here. Such engines seldom had manual ignition control. As originally introduced in 1982, the C. H. system also had fixed spark timing, but it subsequently became available with the addition of variable timing linked to the engine's throttle control. Known as TCTA (Throttle-Coupled-Timing-Advance) this rotates the plate carrying the magnetic (Hall Effect) pickup, automatically retarding the ignition for starting and advancing it again as the throttle is opened for full power. (The magnet that triggers the system is mounted in an aluminum disc, normally located between the prop driver and prop, or forming the spinner backplate.)

A different system of automatically advancing and retarding the spark is used on the Kavan electronic ignition system that is an optional extra for the Kavan FK-50 twin-cylinder four-cycle engine. Here, two Hall Effect pickups are installed, one located to advance the ignition through 15 degrees. A microswitch, mounted on the carburetor, switches the ignition timing from the advanced pickup to the retarded one as the throttle is closed to the idling position for starting. There is also provision for manually altering the timing so that the advanced setting can be adjusted to achieve the optimum spark advance according to the prop size and operating rpm. This is achieved by rotating the housing containing the two pickups so that they are triggered earlier, or later, by the magnets embedded in the camshaft timing gear.

Spark ignition has two disadvantages. First a good system adds considerably to the cost of the engine — too much so, perhaps, for it ever to become universally adopted for the smallest and least expensive types of four-stroke motors. Second, it is easier to "oil-up" a spark plug than a glowplug if the engine is overprimed when starting. The latter is not a serious problem and the user will soon learn how to deal with it and, later, to avoid it. As regards cost, this is much the same for large engines as for small ones (but more for twin or multi cylinder motors) and for large engines the extra expense seems to be more than adequately outweighed by spark-ignition's advantages.

CHAPTER 12

Care and Maintenance

The care of a model engine is, first and foremost, dependent on its being operated correctly. This chapter, therefore, should be read in conjunction with the previous one in which some of the pitfalls that await the unwary are touched upon.

This is not to say that four-strokes are more troublesome than two-strokes. From the beginning (i.e. from the appearance of the O.S. FS-60) four-strokes have proven remarkably reliable. At their present stage of development, component failure is comparatively rare. Whether this happy state of affairs will continue, as future four-strokes become more highly stressed in the pursuit of increased power output, remains to be seen but, for the moment, such problems as may be encountered with four-strokes are mostly due to ignorance or carelessness on the part of the operator.

CORROSION

Corrosion, i.e. the rusting of the internal ferrous parts of the engine, is something that can develop without the owner being aware of it and needs to be guarded against at all times. The problem arises from the fact that combustion of the fuel/air mixture in an i.c. engine produces certain corrosive gases which, when condensed, form acids that can attack, in particular, certain steel parts of an engine or, in the case of full-size engines, its exhaust system.

Most of the corrosive products of combustion are, of course, expelled through the exhaust port. However, there is, inevitably, an escape of exhaust gases and contaminated lubricant between the piston and cylinder wall and into the crankcase. This happens with two-strokes as well as four-strokes but, with the former, the crankcase is continually purged of such contaminants by the action of the induction system. In a two-stroke, remember, the fresh fuel/air mixture is drawn from the carburetor into the crankcase on the upward stroke of the piston and then transferred, via the bypass passage, into the cylinder as the bypass port opens during the downward stroke of the piston.

No such cleansing of the crankcase with fresh gas occurs in a conventional four-stroke engine. Fresh mixture is drawn directly from the carburetor into the cylinder via the inlet valve and the exhaust gases that leak past the piston and into the crankcase are not entirely expelled through the crankcase breather. When the engine is cold, some of the acid products of combustion will remain to attack crankshaft and camshaft surfaces, ball-bearings and timing gears, unless action is taken to prevent this.

Much can be done, in fact, to reduce or eliminate the risk of corrosion. Suggested preventative measures include the following:

After Use

(a) At the conclusion of a flying session, or any other period of use, do not allow the engine to idle for a long period prior to stopping it.

(b) Similarly, do not run the engine excessively rich before stopping it. This will not only over-cool the engine; it will also allow unburnt fuel to enter the crankcase and further increase the risk of bottom end corrosion.

(c) Instead, open the throttle and allow the engine to run at full power for about 30 seconds, then shut off the fuel supply — preferably by pulling the fuel delivery tube from the carburetor.

Storage

(a) Before putting the engine/model aside until the next operating session, inject some corrosion-inhibiting oil, or lay-up oil, through the crankcase breather and rotate the prop several times while holding the engine in various positions, to distribute the oil around the working parts. A little of the same oil through the plug hole (or through the exhaust pipe with the exhaust valve open) is not essential but will do no harm and may be of benefit, under severe conditions, if the engine has a plain steel cylinder liner. (Make sure, however, that any excess oil is drained out of the combustion chamber before the engine is next used.)

(b) Try to store the engine in reasonably dry conditions — not in a damp garage, for example.

(c) If the engine is to be out of use for several months, there is a good argument for adopting a policy of more positive protection. Some manufacturers recommend removing the engine from the model and washing out the interior with gasoline or kerosene before injecting liberal quantities of preserving oil and sealing it in a plastic bag. With certain engines that have their camshafts at the front (such as some O.S. and Saito models) the crankcase backplate can be removed, without disturbing the timing gears, to give easy access to the working parts. With most others, rinsing out the interior can usually be done with a syringe, through the crankcase breather. (If the breather nipple has a very small hole, it can be carefully removed for this, but take care not to strip the threads on re-fitting if the nipple is installed directly in the relatively thin crankcase wall.

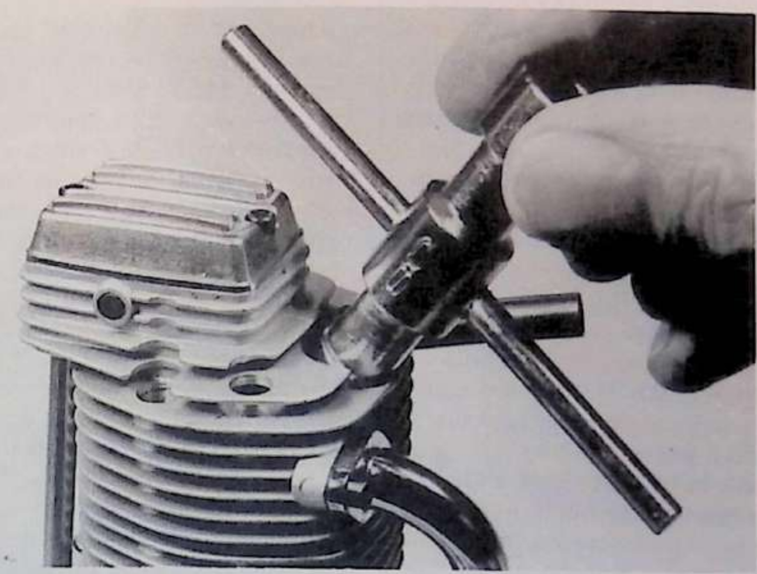
There are some four-strokes that are less liable to suffer from corrosion than others. For example, in a horizontally-opposed twin-cylinder engine having crankpins at 180 degrees to each other, the pistons, travelling in and out together, have an increased pumping action to more effectively ventilate the crankcase (although protection is still necessary) whereas, in a single-crank twin, the volume of the crank chamber is unchanged. The Saito FA-80T and FA-90T engines are of this rare type and, as explained in Chapter 3, are equipped with a small rotary pump to pressurise the crankcase with fresh air and thereby reduce the risk of acid attack.

In radial engines, also, the crank chamber volume does not change and it might be supposed that these engines are at considerable risk from the effects of blowby gases. Actually, this is not necessarily so because most model radial engines to date, such as the Technopower series, have utilized their crankcase as an induction chamber. Inlet pipes radiate from the crankcase to each cylinder head, drawing fresh mixture from a carburetor in the center of the crankcase backplate. Thus, blowby gases are swept out with the fresh charge, as in a crankcase-charged two-stroke engine. (An exception to this arrangement is that of the O.S. Sirius, which has a separate inlet manifold.) Moreover, blowby gases have less opportunity to condense in a radial engine because the crankcase tends to become quite hot due to the fact that it picks up heat from so many cylinders bolted to it.

CLEANLINESS

Generally, model four-stroke engines keep cleaner than two-strokes, although the exhaust pipe of a four-stroke, which gets very hot indeed, is apt to accumulate a disfiguring external coating of baked-on oil. However, where, as in the case of the O.S. four-strokes, the exhaust pipe is made of stainless steel, it is quite easy to clean it. Simply detach the pipe from the engine and use hot water, detergent and fine wire wool to remove the deposit. The stainless steel surface will soon be restored to its original bright semi-matte surface.

The rest of the outside of the engine, when it becomes soiled, will benefit from being scrubbed with an old toothbrush dipped in kerosene or gasoline. If the engine has to be operated under less than ideal conditions, try to avoid allowing dirt to accumulate around the valve gear. Most engines have enclosed pushrods and rocker gear, the main exceptions being some early models such as the O.S. FS-60, Enya 35-4C and 40-4C and Saito FA-30.



When fitting a glowplug, insert and rotate it with the fingers. If the plug is too deeply recessed to be dealt with in this way, use a plug wrench but gently rotate the wrench between finger and thumb to ensure that it is not cross-threaded, before tightening with T-bar.

Try to keep the engine reasonably clean externally when you are using it. Make a point of having the front end wrapped with a piece of clean cloth when your model is parked on the airfield. In dry conditions, dust blown by the wind or the slipstream from other aircraft, can quickly accumulate on the engine and if it is run in this condition, some of this external dirt may well become baked on, while other abrasive particles settling in and around the air intake may be drawn into the cylinder when the engine is started, with harmful effects.

It is rather surprising, in view of the fact that model aircraft are often operated from less than ideal runway surfaces, that so little has been done, over the years, to fit effective air filters to carburetor air intakes. Practically every other type of i.c. engine is so equipped. We are all familiar with the air-cleaners fitted to our cars, lawn-mowers, etc. and (particularly in regard to the latter) are left in no doubt as to their effectiveness when we have to change or clean a filter element.

There are, admittedly, some practical objections to the use of air cleaners on model engines. To be effective without restricting performance, an air cleaner must be large and it must be located above the intake so that there is no risk of its becoming soaked with fuel. Alternative methods of choking or priming the engine may also have to be devised. But air cleaners are now widely used (and very necessarily so) for the two-stroke engines of radio-controlled model racing and off-road cars. This may possibly hasten the day when manufacturers give serious thought to such devices for model four-stroke engines.

VALVE GEAR LUBRICATION

With exposed-rocker engines, the application, each time the fuel tank is filled, of a drop of oil to the wearing surfaces of the valve gear may be advisable, unless these surfaces are obviously receiving all the lubrication needed. As model four-strokes usually run on a fuel and oil mixture, there is always a tendency for oil to travel up the valve guides to the rockers from the combustion chamber and also past the cam followers to the lower pushrod ends. With enclosed valves, this usually eliminates the need to manually lubricate the valve gear, since an ample supply of lubricant accumulates in both rocker box and pushrod covers.

FITTING GLOWPLUGS

The importance of fitting the correct glowplug and the damage that may be caused to some engines by not using a plug of the correct thread length, has already been emphasised (Chapter 11).

It is also vitally important to insert the plug correctly. The consequences of cross-threading a plug in a four-stroke head are likely to prove a great deal more costly than the same mistake in a two-stroke motor. Yet, because plug holes in four-strokes are customarily in unfamiliar locations and at odd angles, accidental cross-threading is actually more likely in a four-stroke than a two-stroke. The rule, therefore, is always to insert the plug and rotate it in its first few threads with the fingers. If the plug is deeply recessed, a tubular wrench may be used, but it should first be lightly rotated between finger and thumb to ensure that the threads are properly engaged. Only tighten the plug with the wrench when it has been screwed fully home.

COWLING AND COOLING

It has been mentioned that four-cycle engines tend to run cooler than two-strokes, but this does not mean that the provision of an adequate flow of cooling air is less important with a four-stroke. Four-strokes are frequently installed in scale models, which may mean that the engine is contained within a close-fitting cowl; in fact, if the original full-sized aircraft was powered by a liquid-cooled engine, there may be a temptation to almost totally enclose the engine.

Just as much thought needs to be given to a four-stroke, as to a two-stroke, in regard to cooling and cowling with, perhaps a little more attention to admitting a flow of air to the whole engine rather than just concentrating on the cylinder and head — the real hot-spots of a two-stroke. In a two-stroke, the cylinder becomes very hot because it has to deal with twice as many firing strokes for a given operating speed. On the other hand, its crankcase remains at a much lower temperature, relative to its cylinder temperature, due to the continual passage through it of air, methanol and oil, all of which have a considerable cooling effect. In a four-stroke, on the other hand, the heat that is transferred, by conduction, from the cylinder assembly to the crankcase and lower end, is not (except in comparatively rare crankcase-charged engines) dissipated so effectively.

Obviously, a radial cowl enables a large volume of cooling air to reach the engine and a horizontally-opposed type cowl, also, will usually provide an adequate supply. If a single-cylinder engine is being used on its side in a horizontally-opposed type cowl, the opposite air inlet can be utilized, if need be, to duct air to the crankcase.

Whatever type of cowl is used, remember that a full flow of air through the cowl is only possible if the air outlet from the cowl is bigger than the inlet. Air entering a cowl is heated by the engine, is thereby expanded and so needs a bigger escape area. This is worth bearing in mind when an engine has to be contained in a "liquid cooled" type cowl (and some deviation from scale is inevitable) since it is usually possible to more easily disguise air outlets than inlets. In such an installation, the total outlet area can, with advantage, be up to twice as large as the total inlet area. With traditional scale air-cooled engine cowls, scale inlet and outlet areas will normally be quite adequate.

As with two-strokes, mufflers should not, as a general rule, be enclosed. An advantage of the four-stroke engine is that it does not need such a large muffler as a two-stroke to achieve a satisfactory level of noise suppression. Consequently, the type of muffler supplied for a typical four-stroke looks less unsightly than the typical two-stroke equivalent.

If, however, the true scale buff finds it unacceptable to have even a small non-scale muffler sprouting from the nose of his model, it may be permissible to utilize an unused space within the cowl to house a suitably proportioned muffler, *provided* that an ample supply of cooling air can be directed over it. It may also be possible to install a simple heatproof shield to protect the engine from radiated heat from the muffler.

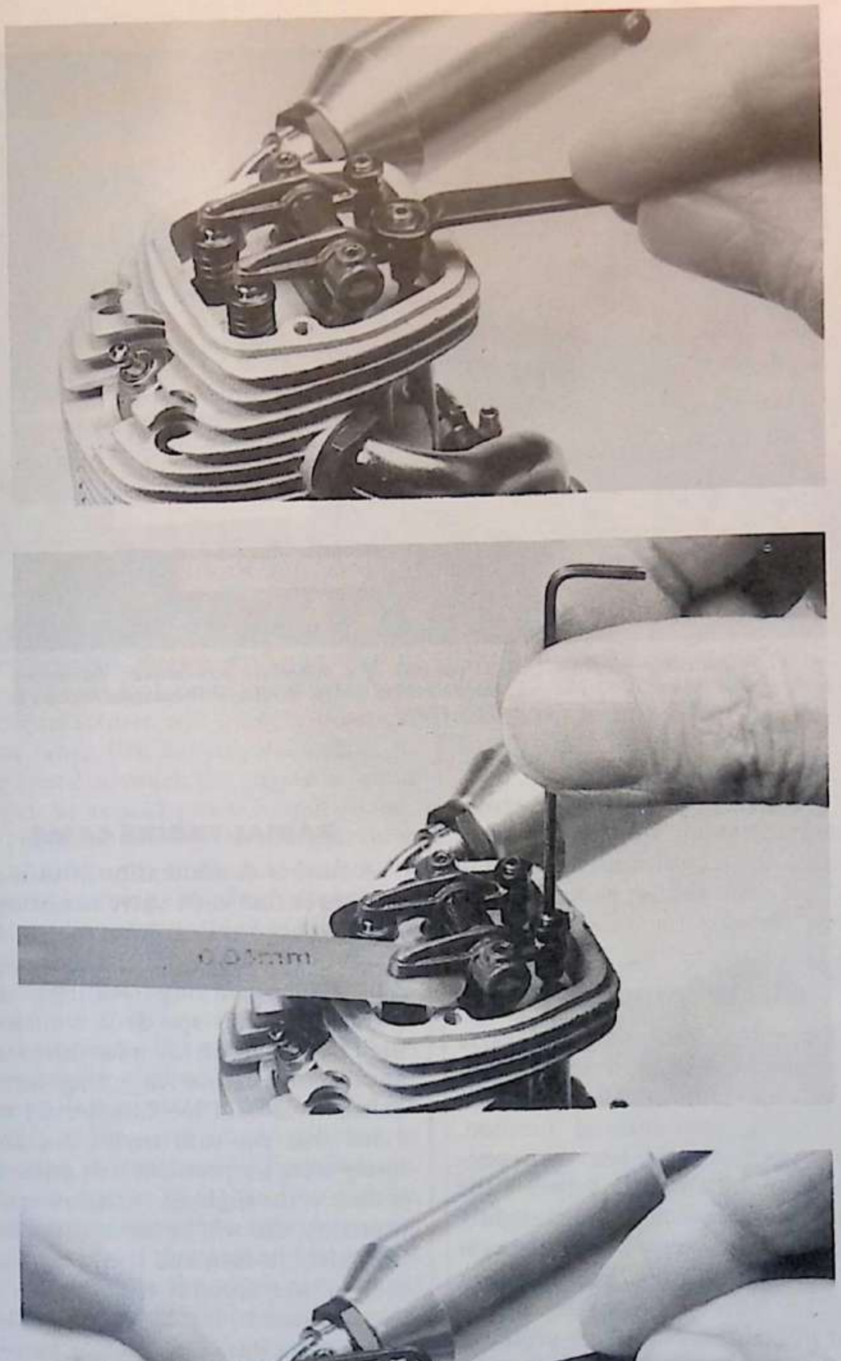
VALVE CLEARANCE ADJUSTMENT

Valve clearance or tappet adjustment is something that is necessary periodically with all conventional poppet valve engines, large and small, with the exception of those having self-adjusting hydraulic valve lifters, as featured by most American automobile engines.

As explained in Chapter 5, it is necessary to maintain a clearance between the base circle of the cam and the cam follower so that the valve is in firm contact with its seat when in the closed position. It was also pointed out that the clearance should be as small as possible because (especially with pushrod-OHV model engines having aluminum alloy body castings) the clearance increases when the engine is hot.

Valve clearances are (usually) correctly set before the engine leaves the factory but will increase with normal wear. It has been observed, in the course of many years of testing model four-strokes, that, with recent high-quality engines, wear in the valve train takes place more slowly and, as a result, the need to readjust clearances has become less frequent. Measurable widening of the clearance will usually occur during the break-in period, as the many wearing surfaces between camshaft and valve become polished but, thereafter, it is quite possible for a well-made, well-maintained engine to go through a full season's flying without further need of adjustment.

The suggested procedure is to check clearances when the engine is new (or has had only a few minutes running) and to re-check them at the end of the break-in period when the engine has logged one or two hours of total running time. If the clearances have increased by more than .002-.003 in., it would be advisable, after re-setting them, to check again after, say, another two or three hours. It is probable that the rate of wear will be less than this and that the second recheck will reveal no significant increase in clearance. In this case, there is unlikely to be any



Basic valve clearance adjustment. Top: slacken locknut. Center: gently rotate adjusting screw until feeler gauge is lightly nipped between rocker arm and valve stem. Bottom: hold adjusting screw at required setting and tighten locknut. Recheck. See text for full description of procedure.

need to recheck the clearances more than once or twice during the season, unless you are an "everyday" flyer.

It will not be a disaster if the valve clearance exceeds the recommended maximum. The worst that can happen is a slight loss of power. This is because, due to the extra lash in the system, the valve will not lift quite so far and will be open for a shorter period. Different engines react unequally to this, depending on whether their designed valve lift and timing are in keeping with other design parameters. During tests of one early model four-stroke, no less than 600 rpm were recovered on resetting the valve clearances after breaking-in, but this is rare. Generally speaking, no significant difference in performance will be noticed from routine readjustments, unless the clearances have been allowed to widen excessively.

The maximum valve clearance usually specified by model four-stroke engine manufacturers is 0.10 mm or .004 inch. Minimum recommended clearances are mostly between 0.03 mm and 0.05 mm or 0.001-0.002 in. Clearances are invariably measured between the end of the valve stem and the rocker pad face and the actual setting is established with the aid of thin shim steel strips appropriately called thickness gauges or "feeler" gauges. Most engine manufacturers supply (with the engine or as an accessory) either one or two such gauges. If one gauge only is supplied, it will be the one that establishes the minimum clearance. If two feelers are included they should be used as "go" and "no-go" gauges.

Checking and adjustment are quite simple. Some earlier model four-strokes utilized eccentric bushes between the rocker and rocker shaft, as a means of raising or lowering the whole rocker arm, to adjust valve clearances, but all current production pushrod OHV models follow familiar full-size practice in having a screw adjuster at the pushrod end of the rocker.

When checking and adjusting rockers, use only the correct small tools for the job. Usually, the engine manufacturer supplies (either with the engine or as an optional extra) the correct size Allen key or screwdriver for turning the adjusting screw and a small wrench for the locknut. Also, adjustments must be made only when the engine is *cold.*

Basic procedure is as follows:

1) Remove rocker-box cover (if fitted) and slowly rotate prop until compression is felt (do not remove the glowplug), then turn it approximately one quarter revolution. The piston will now be at the top of its stroke and both valves will be closed, enabling both clearances to be checked. It will be possible to rock the prop each side of the top-dead-center position without the rockers moving. (If, in the case of a conventional 360° firing flat-twin engine, the rockers move, you have chosen the "wrong" cylinder. Rotate the prop through a full 360 degrees or, alternatively, check the other cylinder first.)
2) Check gap between inlet valve stem and rocker-arm with feeler gauges. If clearance is more or less than the recommended range of adjustment, slacken locknut and adjusting screw and insert feeler gauge required for recommended minimum clearance (e.g. 0.04 mm or .0015 in.).
3) Keeping feeler gauge between valve stem and rocker, slowly rotate adjusting screw clockwise with Allen key or small screwdriver, as appropriate, between finger and thumb, until resistance is felt. Do not use force: too much pressure will open the valve. Gently slide the feeler gauge back and forth: clearance is correct when the rocker is just nipping the gauge.
4) Hold adjusting screw in this position and re-tighten locking nut.
5) Remove the feeler gauge, rotate the prop through two revolutions exactly and recheck gap. The feeler gauge should just slide between the two surfaces. (It is possible for the adjustment to be upset when the locknut is tightened. Therefore, reset the gap if necessary.)
6) When inlet valve clearance is correct, follow the same procedure with the exhaust valve.

It will be observed that only the thinner feeler gauge has been used. The thicker gauge (usually 0.10 mm or .004 in.) should not, of course, pass through the gap if the clearance has been properly set as detailed above. It is held in reserve and used, periodically, to check that clearances have not opened up beyond the recommended maximum. It is not necessary to touch the adjustment again until such time as the thicker gauge is found to pass between the valve stem and rocker.

Useful valve adjusting kit from O.S. It consists of a miniature screwdriver, box-ended wrench, Allen key and two feeler gauges with angled tips for dealing with recessed rockers as in, for example, O.S. FS-40, FS-61 and FS-120.

CAM INACCURACIES

Do not be tempted to set valve clearances at less than the recommended minimum in the expectation of increasing valve lift and duration. With a clearance of less than one-thousandth of an inch between the valve stem and rocker, and even slightly less between the base circle of the cam and the cam follower (depending on the rocker ratio), it follows that only a minor inaccuracy in the cam profile is necessary to cause incorrect operation of the valves.

For example, if the radius of the base circle of the cam is not constant, it would be possible for the valve to be momentarily lifted from its seat during the period that it should be closed. Fortunately, this is rare, but has been detected on two occasions in the past.

The conclusion to be drawn from this is that, although the better quality four-strokes currently on the market are unlikely to be affected in this way, it is as well to stay within the valve clearance limits advised by the manufacturer.

RADIAL ENGINE CAMS

A further consideration with radial engines is that each valve is not operated by just one cam lobe. With a five or seven cylinder engine, for example, a three-lobe cam ring (rotating at one-sixth crankshaft speed) is commonly used to operate all the inlet valves with another three lobe cam ring for the exhaust valves. (See Chapter 6.) Provided that the cam tracks are absolutely true, no problem will arise. But if there is the slightest variation in concentricity, this will be transmitted to all the valves in turn and it will be necessary to take account of this when setting clearances. It may be advisable to check the clearance of each valve at intervals of two revolutions of the crankshaft, to make sure that the valve clearances are the same at different points on the cam tracks. If the clearance should be too small at one point on the cam track, it will be necessary to open up the clearance even though this will mean that the gap is slightly greater at other positions.

OVER-SPEEDING

High-performance two-stroke engines are well known for their ability to "rev." As load is progressively reduced, they will go on turning faster and faster until they literally "run out of breath" (not surprising since ports may be opening and closing in less than one millisecond), combined with mounting frictional losses to prevent any further increase in speed.

At such revolutions (which may approach 40,000 rpm with certain small racing engines) the engine is, of course, running well above the speed at which maximum horsepower is developed. Therefore, such speeds are of academic interest only. But the point to be made is that, provided it is adequately lubricated and cooled, the two-stroke need suffer few, if any, ill-effects from such over-speeding.

This is not so with a four-stroke. Most manufacturers of four-strokes quote a "practical rpm range," or warn against allowing the engine to exceed a certain speed. By two-stroke standards, these speeds look quite low. Sometimes a manufacturer will quote a practical rpm range that actually falls short of the speed at which the engine is found to deliver its peak power output on test.

The reasons why the manufacturer is anxious to warn his customers against running their four-strokes too fast are the same as those of the sports-car manufacturer who installs an ignition cut-out to prevent incautious owners from over-revving in the intermediate gears. The operating speeds of four-stroke engines are inhibited by mechanical considerations, i.e. by the ability of the valve gear to continue to function properly and without damage. This is not to say that four-strokes cannot be designed to operate at very high speeds — they can and have been — but, ideally, the valve gear should be designed to match the required operational speed range of the engine. This, in turn, is governed by the different purposes for which engines are intended: for example, a lightplane engine required to turn no faster than 3,000 rpm, or a Grand Prix racing car engine capable of over 10,000 rpm.

Valve float and the risk of the valve hitting the piston are the recognised dangers associated with the over-speeding of four-stroke engines and it is for this reason that model four-stroke manufacturers emphasise the need not to under-prop their engines.

Experience to date suggests that some of the safe speeds specified by manufacturers are somewhat on the low side, but this is no bad thing. If the instruction sheet gives the "practical rpm" limit as 10,000, whereas the engine actually delivers its peak power output at 11,000 rpm and is quite safe at 12,000 rpm, there is a reasonable safety margin if the user actually fits a prop that holds the engine to 10,000 rpm static. In the air, when the load on the prop is reduced with forward speed, the engine will speed up about 10 percent to its peak output in level flight and there will still be a safety margin to allow for some over-speeding in a dive.

This assumes that the user has a tachometer with which to check the ground rpm of his engine. If he does not, he may be guided by the prop sizes recommended by the manufacturer for his engine, although a check with a tachometer is still a good idea. Remember, with its lower frequency exhaust note, a four-stroke sounds deceptively slow compared with a two-stroke. If in doubt, the user should avoid over-speeding the engine in a long power dive, by throttling back.

DISASSEMBLY AND REASSEMBLY

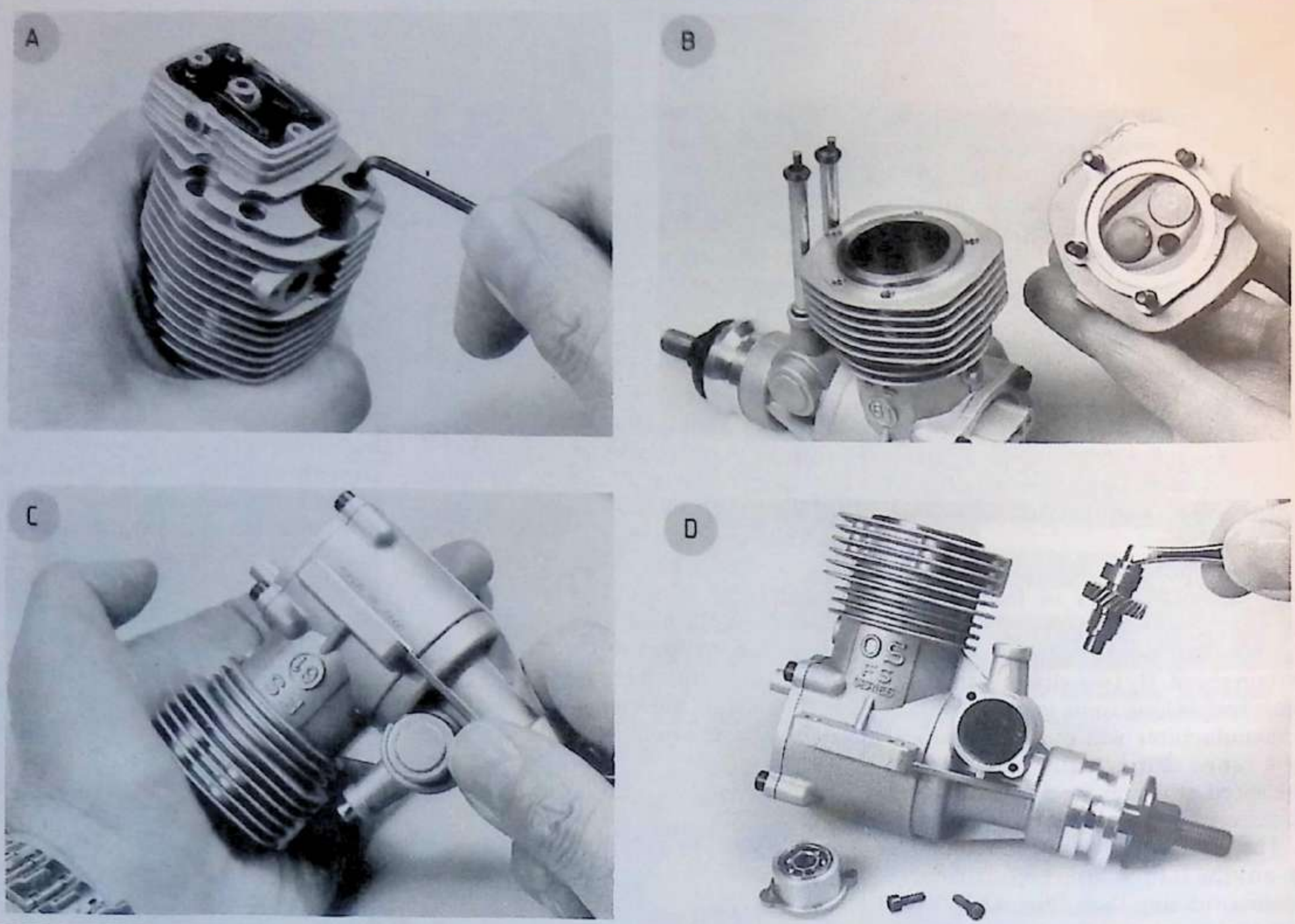
It is widely agreed that the general rule for dismantling an engine is *don't*. Manufacturers and service agents whose job it is to repair model engines have numerous stories to tell about the dreadful condition in which engines are sent to them for attention — especially those that have been tampered with by their owners — thereby proving that the average model builder is the ultimate bonehead, hamfisted beyond belief, who ought never to be allowed within a hundred yards of a model engine.

This, needless to say, is a slight exaggeration of the situation. Mutilated engines may not be exactly rare, but most R/C flyers are patient, conscious that pitfalls may await them and tolerably competent when dealing with something they understand. They would not be successful model builders otherwise. Moreover, any modeler who has sufficient interest in engines to have read this book thus far, should have a good idea of the component parts of an engine, how they work and how they are put together. It is not unreasonable, therefore, for him to feel confident enough to take an engine apart.

Typical small tools supplied with four-stroke engines by manufacturers.

Of course, there is no merit in taking an engine apart without a good reason. Mere curiosity is not one of them. If an engine is running well, it is best left alone. And a good four-stroke is likely to run with no more than routine maintenance, for quite a long time.

In the case of crash damage, it may be preferable to return the engine to the manufacturer or distributor for a complete overhaul and replacement of parts as found necessary. However, if the damage is clearly superficial or if the owner's pride in his ability is such



Typical disassembly sequence (O.S. FS-61 engine). After removing exhaust, inlet pipe, carburetor and rocker box cover, slacken head screws diagonally (A) and lift head (B). Remove pushrods and covers and tap cylinder against hand to release cam followers (C). Remove camshaft end-cover and extract camshaft (D).

that he is determined to look after his engine himself, why should he not do so?

TOOLS

Having the correct tool for every component is essential if screws, nuts, bolts, studs and other parts are not to be damaged. Most of the screws used in modern four-strokes are of the hexagon-socket or Allen type and manufacturers usually supply a set of hexagon section Allen keys or wrenches to deal with these. As the majority of the four-stroke engines on the market are of foreign manufacture, metric sized screws are widely used and it is vital that the correct metric sized hex keys are to hand. Some cross-head (e.g. "Phillips" or "Posidriv" pattern) screws are also used. In either case, make sure that the exactly correct sized key or screwdriver is used, otherwise the screw may become deformed and impossible to remove even with the correct tool.

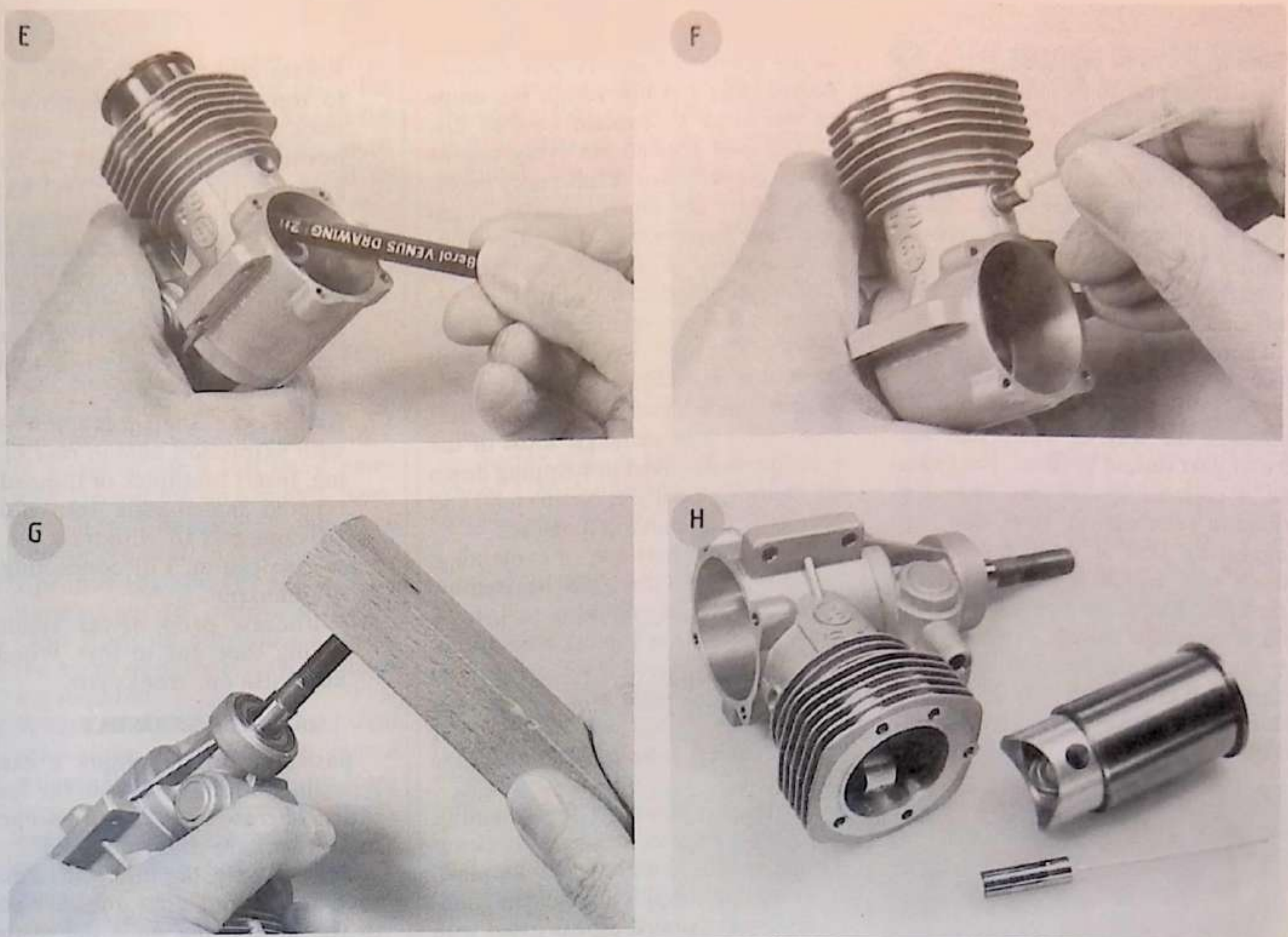
The same goes for wrenches, whether open-end, box-end, socket or tubular. (Incidentally, to avoid confusion with the wording of some instruction leaflets, it should be noted that "English" terminology — as distinct from American — for wrench is "spanner" and that these tools are known, respectively, as open-ended, ring, socket and box spanners.)

Other tools that may or may not be required, depending on the type of engine dealt with and the extent to which it is to be dismantled, include electrician's and instrument maker's screwdrivers; a small soft-faced hammer (e.g. copper, lead, aluminum or plastic) and a brass drift or nylon punch. It is assumed that the owner has a suitable glowplug wrench (most four-stroke engines call for a socket type) and a couple of prop-nut wrenches. Pliers, on the other hand, are tools that are best kept away from model engines, with the possible exception of small needle-nosed pliers that may be useful for extracting the wire snap-rings or circlips often used for locating wristpins in pistons. The alternative tool here is a pair of tweezers and these will also have a use in removing and refitting valve-spring retainers.

THE VALUE OF HEAT

Most model engines can be serviced with the simple tools described above, but it may be necessary, sometimes, to apply heat to certain parts to aid disassembly and reassembly.

This applies particularly to parts that may have been originally assembled in this way — such as a shrunk-on finned jacket over a cylinder-liner — but is also recommended when remov-



Remove crankcase backplate and push up cylinder liner with dowel or pencil (E). After removal of liner, extract wristpin with toothpick through access hole (F) to release piston and lift conrod off crankpin. Withdraw prop driver assembly and push back crankshaft through crankcase. If shaft is tight in bearings, tap out with* soft-faced *hammer or block of hardwood (G). Note: when reinstalling piston, first fit it partly into liner (H), then slide liner into case until wristpin hole aligns with access hole at rear. Align conrod bearing, reinsert wristpin and gently push liner down.

ing parts that may have been pressed together with a light interference fit. For example, expansion of a bearing housing with gentle heat, to facilitate the removal or re-installation of a ball-bearing, is infinitely preferable to attempting to drive out the bearing from within or to reinsert it without the proper equipment.

The method by which heat is applied is important. Excessive localised heat may cause permanent distortion: only just sufficient heat should be applied to allow the parts to be parted. The use of a gas ring or a propane torch, in the wrong hands, can be risky. The readily available alternatives are boiling water, a heat gun, or the domestic oven.

Boiling water is adequate only in cases where, for example, a steel cylinder-liner has been very lightly pressed into an aluminum case. Generally speaking, parts need to reach between 120°C and 150°C (250°F-300°F) for the aluminum to expand sufficiently to free a liner or ball bearing. For this, the domestic cooking oven is convenient since the heat can be evenly applied and at a controlled level. Start at 250°F, leaving the component to soak up the heat for a few minutes after the thermostat indicates that 250°F has been reached. If this is insufficient to enable the parts to be separated, re-set the thermostat to 275°F and try again.

An electric heat gun (as used for heatshrink covering materials) is a really useful alternative. It enables heat to be applied quickly where required and for only as long as is necessary for the surfaces to be freed from each other.

Needless to say, when handling hot parts, some protection for the hands is necessary, such as a pair of oven gloves or soft folded cloths.

CARE AND MARKING OF PARTS

The first requirement before attempting to take your engine apart is a decent working environment, i.e. a clean, well-lit bench or table top (and one that you can sit at, rather than stand), some sheets of clean plain paper on which to work and some suitably sized containers in which to place small parts. Also necessary will be two containers, partially filled with kerosene or a suitable solvent; one for cleaning the parts and the other for rinsing them. The containers should, preferably, have secure lids and where inflammable liquids are in use, remember to keep them well away from naked sources of heat.

Whenever a part is removed, a mental note should be made of the way in which it has to be replaced. If it is possible for the part to be reinstalled back-to-front or upside-down, it should be marked in some way. A small scratch mark is permissible on a non-working surface or, if the surface is wiped clean of oil with alcohol, a spot of colored lacquer can be used. The latter is particularly suitable for hardened steel parts, such as gears, camshafts, etc.

There are some parts which, while it may be possible to replace them wrongly, have some small feature that indicates the way in which that particular part should be fitted. For example, a connecting-rod may appear to be quite symmetrical, front and rear, suggesting that it does not matter which way round it is fitted to the crankpin. But if the lower eye of the rod is inspected closely, it will usually be found that the bearing surface is chamfered at one end only — the end which should always be placed nearest to the crankweb.

If the cylinder liner is too tight to slide out of, or into, case, apply heat to expand aluminum casting.

HEAD SCREWS

It is fairly generally understood that, when a cylinder-head is installed, the screws should be tightened in a diagonal criss-cross pattern, so as to pull the head down evenly and avoid any risk of distortion. The best procedure is to lightly run each screw down (after making sure that the head is sitting squarely on the cylinder) then to begin tightening them in diagonal pairs, a few degrees at a time.

The same reasoning should apply when the head is removed. Do not simply remove each screw in turn. Start by slackening each one a few degrees at a time until all are loose. They may then be unscrewed and removed in any order.

BASIC DISASSEMBLY AND REASSEMBLY PROCEDURES

Four-stroke-cycle engines vary a great deal in design and construction, as the previous chapters have demonstrated, and it is not within the scope of this book to explain how to dismantle and reassemble every engine on the market. Nor is this really necessary. There are illustrations throughout these pages which show the component parts of all the most widely used types of model four-cycle engines and how they are related to each other. The study of these, in conjunction with the words that follow, should be sufficient to guide a competent engine buff and enable him to tackle most of the procedures involved in stripping down an engine (partially or completely) and correctly reassembling it again.

Possibly the best way of explaining, as simply as possible, the disassembly of a four-stroke engine is to list the basic steps with a typical modern engine, backed up by a few more general notes. The following brief summary is based on the procedure for a popular medium-sized four-cycle engine, the O.S. FS-61.

1. Exhaust pipe or muffler assembly. To exchange or remove for cleaning, use 10/12 mm wrench supplied. Note that, on this engine, the stainless steel exhaust pipe is fitted with an aluminum washer but that this is discarded when muffler header pipe is substituted.
2. Carburetor. Remove complete needle-valve assembly to check for possible accumulation of foreign matter in carb body. Remove two screws attaching carburetor to crankcase backplate. Remove two screws securing inlet pipe to cylinder-head, allowing inlet pipe, carburetor and choke valve assembly to be detached from engine.
3. Cylinder head. Remove glowplug and rocker box cover. Gradually slacken, in diagonal sequence, five head screws. (It is not necessary, on this engine, to dismantle rocker assembly to give access to head screws.) Loosen head screws completely and carefully lift head, steadying pushrods.
4. Remove pushrods and covers. Take care not to lose O-ring seals. These parts are interchangeable, left and right, and any small discrepancy on reassembly can be corrected by re-adjusting valve clearances. Invert engine and tap cylinder against palm of hand to release each cam follower.
5. Rotate crankshaft to bring piston to top-dead-center. Remove camshaft housing end-cover and note position of timing mark on timing gear when piston is at TDC. Extract camshaft with tweezers or magnet.
6. Remove crankcase backplate. Using nylon punch, wood dowel or pencil, push up cylinder liner. Extract liner from cylinder casing. Mark piston head and connecting-rod to indicate front or rear.
7. Rotate crankshaft to align wristpin with extraction hole in rear of casing. Insert toothpick or thinned and tapered match-stalk into hole in wristpin pad to withdraw pin and release piston. Lift connecting-rod off crankpin.
8. Withdraw prop driver assembly, taking care not to lose Woodruff key. Push out crankshaft.

REASSEMBLY

Basically, this is simply a case of repeating the above steps in the reverse order. There are just one or two procedures that have to be modified.

For example, because, with a design such as this, one does not have access to the piston-ring once the piston is installed, it is necessary to install the piston and liner together. Slide the upper portion of the piston containing the piston-ring into the lower part of the cylinder bore, leaving the wristpin holes exposed. Then lower the complete assembly into the case, having first attached the connecting-rod to the crankpin. Slide the liner and piston down until the wristpin hole in the piston is visible through the access hole in the casting. Align the upper conrod eye with the hole in the piston and reinsert the wristpin sufficiently to allow the cylinder liner to slide down between the piston skirt and body casting.

It will be noted that, with the FS-61, everything comes apart without resort to heat or special tools. Other engines may call for slightly different procedures. For example:

(a) If the cylinder liner will not push up as described, apply the heat gun to the cylinder fins. This will cause the casing to slacken its grip on the liner.

(b) If a prop driver is fitted to the shaft with a split taper collet, it may, especially after considerable use, become very tight on the shaft. If it is necessary to remove it, use a suitable puller. Alternatively, use a heat gun or place the assembly in an oven to expand the prop driver, then strike the shaft end against a block of wood to release the driver. (To reduce tendency of prop driver to jam on its taper collet, dust tapered surfaces with powdered flake graphite before reassembly.)

(c) If the crankshaft will not push back through the bearings by hand when the prop driver is removed, tap the shaft end against a block of wood or use a soft faced hammer. Do *not* use an ordinary hammer; it will damage the bearings and/or the shaft end.

(d) Apropos (b) and (c) above, it is unnecessary to remove a crankshaft from its bearings except in the event of parts replacement being required.

(e) Where wristpins are retained with snap-rings or circlips, the engine will usually have a detachable front housing or cylinder casing, thereby enabling the piston/rod assembly to be dealt with as a whole.

TIMING GEARS

Nearly all four-stroke engines have marks on their timing gears to ensure that, when the engine is assembled, the gears are properly meshed for the correct valve timing. Always look for these marks before removing the timing gears. They may take the form of round center-punch type dots or small vee grooves. If no marks are visible, the gears should be marked before disassembly.

VALVE REMOVAL AND REINSTALLATION

Unless a valve spring breaks (rare), there is seldom any need to dismantle an inlet valve assembly. With the exhaust valve there will, in time, be a build-up of carbon deposits around the valve and in the exhaust port. In a model four-stroke, these deposits tend to remain soft and can usually be rubbed off from the readily accessible surfaces of the valve head and combustion chamber. To clean the underside of the valve head and the valve throat and port, however, it will be necessary to extract the valve.

First detach the rocker arm assembly if this has not already been done prior to removing the cylinder head.

Valve-spring retainers are of two main types: (a) horseshoe or E-clip or (b) split collar or cotters and, whichever is used, it will be necessary to compress the valve spring. Miniature valve-spring compressors are not available commercially and some method of pressing down on the valve cap, to enable the retainer to be extracted, will have to be devised.

If the valve stem and spring projects from the head, free of surrounding obstructions, extraction does not present too many problems. A flat steel washer or, better still, a narrow metal strip about 1/16 in. thick and 2 inches long, with a hole drilled through the center,

To remove tightly fitted prop driver (e.g. split taper collet type) use a suitable puller. Type shown is an O.S. accessory.

will do the job. The hole needs to be small enough to cover the outer rim of the valve cap, but large enough to allow the valve stem and retainer to pass through. Place the head on a firm surface with a small block of wood under the valve head to prevent it from opening. Place the washer or strip over the valve cap and press down so that the valve stem with its clip or split collar is exposed. Carefully extract the latter with a pair of tweezers or any small sharp-pointed instrument such as a scriber, needle or very small screwdriver. Then gradually release the spring pressure and lift off the valve spring and cap.

If access to the valve stem and spring is more difficult, due, for example, to their being located well down inside the rocker-box (as in the case of the O.S. FS-61) a different method of compressing the spring will be necessary. A suitable solution is to use a length of metal tube, notched at the lower end, so that the clip or cotters can be fished out while the cap is being pressed down.

At this point, it is worth mentioning that valve retainer removal (and replacement) carries some risk of parts being accidentally ejected by spring pressure and possibly lost due to their small size. Therefore, there is a good case for such work being undertaken in "sealed" conditions; for example, with the cylinder-head and hands inside a transparent plastic bag or a box with a sheet of glass on top.

After the valve spring assembly has been removed, the valve can be withdrawn, but it often happens that the valve stem has become burred in operation (this occurs with full-sized engines also) and to try to force it through the valve guide in this condition will cause damage to the guide. If, therefore, the valve does not slip through the valve guide easily, it will be necessary to "dress-off" the obstructing burr first.

This is best done with a fine, triangular-section oiled slipstone or Swiss file. Only a very small amount of metal will need to be removed and the use of a magnifying glass is recommended, to check on this work. The burr is most likely to have been raised on the edge of the annular groove for the valve retainer but, with ball-ended rockers especially, it may occur on the end of the stem.

The soft carbon deposits that will be revealed, when the valve is withdrawn, can mostly be removed with a piece of cloth or with a small wooden scraper fashioned for the purpose. Any hard carbon on the valve that cannot be removed in this way can be carefully loosened with a blunt modeling knife blade. *Do not scrape or scratch the valve seating surfaces, either on the valve itself or the bronze seat in the cylinder head.*

Finally, do not neglect to thoroughly clean all parts before reassembly. A final rinsing in clean kerosene or gasoline should be followed by the application of machine-oil to all ferrous parts and all other mating surfaces. This also includes all screws. As each working part is installed, check to make sure that it is moving freely and smoothly. Constantly check alignment and free movement before tightening assembly screws and do not omit any gaskets. Make sure that the timing gears are meshed correctly. Lastly, check and readjust valve clearances as necessary.

APPENDIX

Specifications, Performance Data & Installation Drawings

The following pages contain specifications, test data and full-scale drawings for twenty-two four-stroke engines commercially available since the O.S. FS-60 first appeared in 1976-77.

Most of these engines have been the subjects of lengthy illustrated reports in past issues of MODEL AIRPLANE NEWS and, for the convenience of readers who wish to have more complete information on any particular model, the date of each appropriate issue is given.

PRODUCTION VARIANTS

In most cases, the engines dealt with have been early production samples. In some instances manufacturers have subsequently incorporated minor improvements, sometimes identifying the modified model as a "Series 2," "Mark III," etc. Such changes are included in the notes accompanying the tabulated data.

WEIGHTS & DIMENSIONS

The advertised weights of model engines are frequently inaccurate. The weights quoted in this appendix are actual checked weights measured to within one gram and then converted to ounces. Cylinder bore and piston stroke measurements also tend to vary — less in some engines than in others — but here the manufacturer is given the benefit of the doubt. The figures are the maker's own and each engine's swept volume, or piston displacement, is calculated from the official bore and stroke dimensions, using the formula: $bore^2 \times stroke \times 0.7854$.

Most manufacturers do not disclose the valve timings of their engines. Timings can, in any case, vary a great deal in a model four-stroke, due to the marked effect of the most minute cam profile inaccuracy or variation in valve clearance. All the figures quoted, therefore, are based on actual measurement of the test engine, usually with the valve clearances set at the practical minimum — generally 0.001-0.0015 in.

PERFORMANCE

All torque and horsepower data are the result of independent tests on single standard production engines and have been gathered under similar conditions using the same equipment and instruments. Such data, therefore, are basically comparable, but it should be understood that individual production examples of any particular model engine can vary quite considerably.

Also, although some typical propeller static rpm figures are included for each engine, it must be emphasised that these are provided solely to enable readers to visualise the propeller sizes that, relative to the diameter v. pitch required for a particular type of model (large diameter, fine pitch for large slow-flying aircraft; smaller diameter, coarser pitch for smaller faster models) are likely to be best for his purposes.

The performance of one engine, relative to another, should never be judged by how fast each turns a given size of propeller — or even what might *appear* to be the *same* prop. Prop rpm readings are a notoriously unreliable method of comparing engine performance, for the simple reason that the torque absorption of different props of the same nominal dimensions can vary enormously. It is not unknown, for example, for there to be 1,000 rpm difference between the speeds that one engine will turn two props of the same nominal size but different make.

Nor is it unknown for two props of the *same size and type from the same manufacturer* to be as much as 500 rpm apart on the same engine — or for a nominally lower pitch prop to turn *slower* than a higher pitched one of the same family. Again, it should not be assumed, when a prop of the same make and size is quoted among the rpm figures for a number of different engines, that the same prop has been used in every case. Literally thousands of props have been used for the M.A.N. tests over the years and many hundreds of different props are in use at any given period. Up to six examples of each size and type may be used, due to the fact that (a) they have to be reamed out to suit a variety of shaft sizes, and (b) wear and tear requires individual examples to be replaced from time to time.

Generally speaking, prop rpm are quoted to the nearest 50 or 100 rpm for, although the tachometers used include ones capable of readouts in whole units, model engines do not hold speeds so steadily as to make such readings practicable. It is common, in fact, for engine rpm to continually fluctuate ± 0.5 percent. Incidentally, it is worth mentioning that the simple photo-tach type instruments sold for hobby use are seldom accurate to within less than 2 or 3 percent.

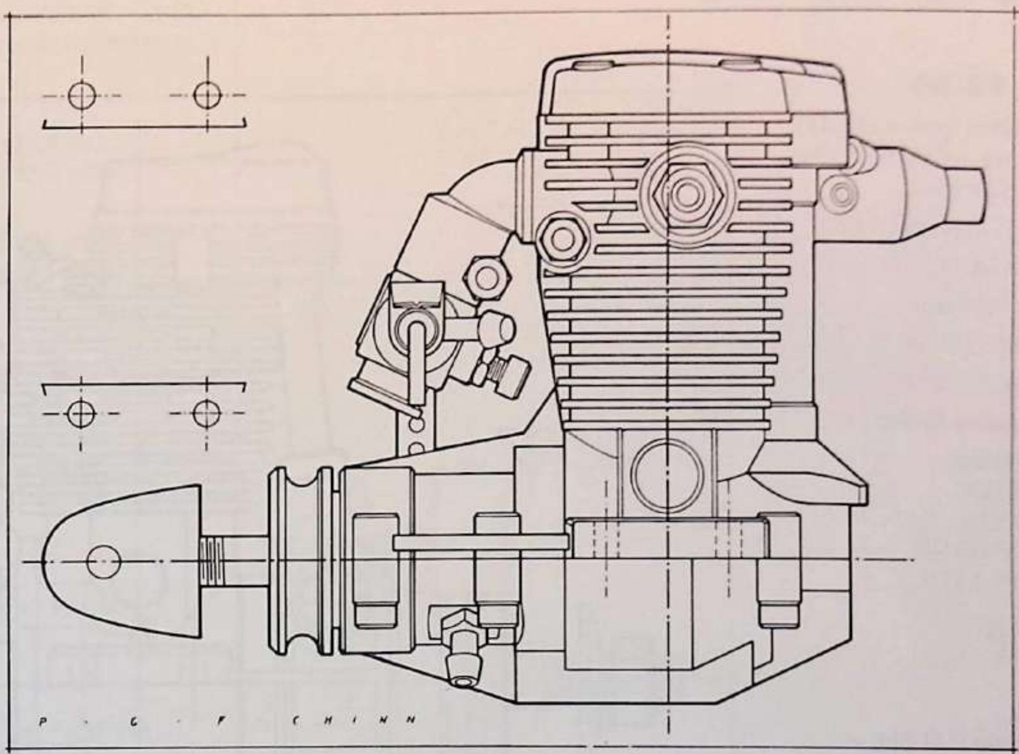
"GROSS" & "NET" FIGURES

Engines manufactured during the first few years of four-stroke production were sufficiently quiet as to be acceptable without mufflers. But, beginning with the higher performance levels achieved by the Enya 60-4C in 1982, it was clear that, for many of the more powerful single-cylinder engines, especially, mufflers would, henceforth, be necessary.

As is well-known, the addition of a muffler usually results in some loss of power, although this may vary considerably and some more recent four-stroke muffler installations have been very much less restrictive than earlier ones, even to the extent of causing virtually no power loss.

For the most part, tests are carried out on the engines "as supplied," i.e. if the manufacturer includes a muffler with the engine, this is used. Therefore, to differentiate between "without muffler" and "with muffler" conditions, performance figures are (following full-size practice) quoted either as "gross" or "net" respectively.

HIRTENBERGER HP VT-21



HIRTENBERGER HP VT-21

Type: Single-cylinder with gear-driven vertical-axis rotary-valve in head. Two ball-bearing crankshaft.

Checked Weight: 322 grams (11.4 oz) including muffler

Displacement: 3.463cc (0.2113 cu in.)

Bore: 16.6 mm (0.6535 in.)

Stroke: 16.0 mm (0.6229 in.)

Stroke/Bore Ratio: 0.964 : 1

Measured Compression Ratio: 10.5 : 1

Measured Valve Timing:
Inlet opens: 45° BTDC
Inlet closes: 45° ABDC
Exhaust opens: 38° BBDC
Exhaust closes: 29° ATDC
Inlet period: 270°
Exhaust period: 247°
Overlap: 74°

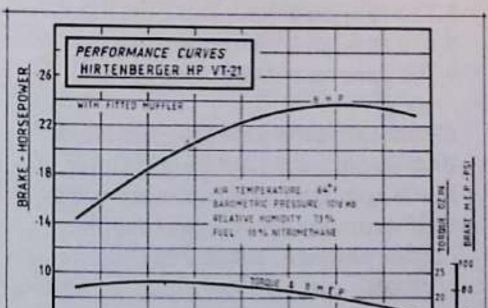
Performance Tests
Power Output, net: 0.238 bhp at 12,250 rpm
Torque, net: 23 oz-in. at 8,000 rpm
Equivalent b.m.e.p.: 86 lb/sq in.
Specific Output, net: 1.13 bhp/cu in.
Power/Weight Ratio, net: 0.334 bhp/lb

Typical prop rpm (with muffler):
8,800 rpm on a 9x6 Zinger maple
9,100 rpm on a 10x4 Top Flite maple
9,500 rpm on a 9x5 Zinger maple
9,700 rpm on a 9x5 Top Flite maple
9,800 rpm on a 10x4 Zinger maple
10,400 rpm on a 9x4 Top Flite maple
10,900 rpm on a 9x4 Power Prop maple
12,400 rpm on an 8x5 Power Prop maple

Establishing itself as the smallest displacement four-stroke on the market when released in 1983, the HP VT-21 is also one of the most unusual of model four-stroke engines. A vertical axis cylindrical rotary-valve in the cylinder head is spur-gear driven from a rear vertical shaft which, in turn, is driven by bevel gears in the rear of a horizontally-divided crankcase. Also unusual is the front mounting of the carburetor and the side exhaust pipe with integral muffler. A pleasant handling little engine of moderate power but very quiet.

Full test report: M.A.N. September 1983

Manufacturer: Hirtenberger Patronen-, Zundhutchen- & Metalwarenfabrik AG., Hirtenberg, Austria.



O.S. FS-20

O.S. FS-20

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Two bronze-bearing camshaft.

Checked Weight: 263 grams (9.3 oz)

Displacement: 3.563cc (0.2174 cu in.)

Bore: 18.0 mm (0.7087 in.)

Stroke: 14.0 mm (0.5512 in.)

Stroke/Bore Ratio: 0.778 : 1

Measured Compression Ratio: 7.2 : 1

Measured Valve Timing:
Inlet opens: 65° BTDC
Inlet closes: 53° ABDC
Exhaust opens: 65° BBDC
Exhaust closes: 28° ATDC
Inlet period: 298°
Exhaust period: 273°
Overlap: 93°

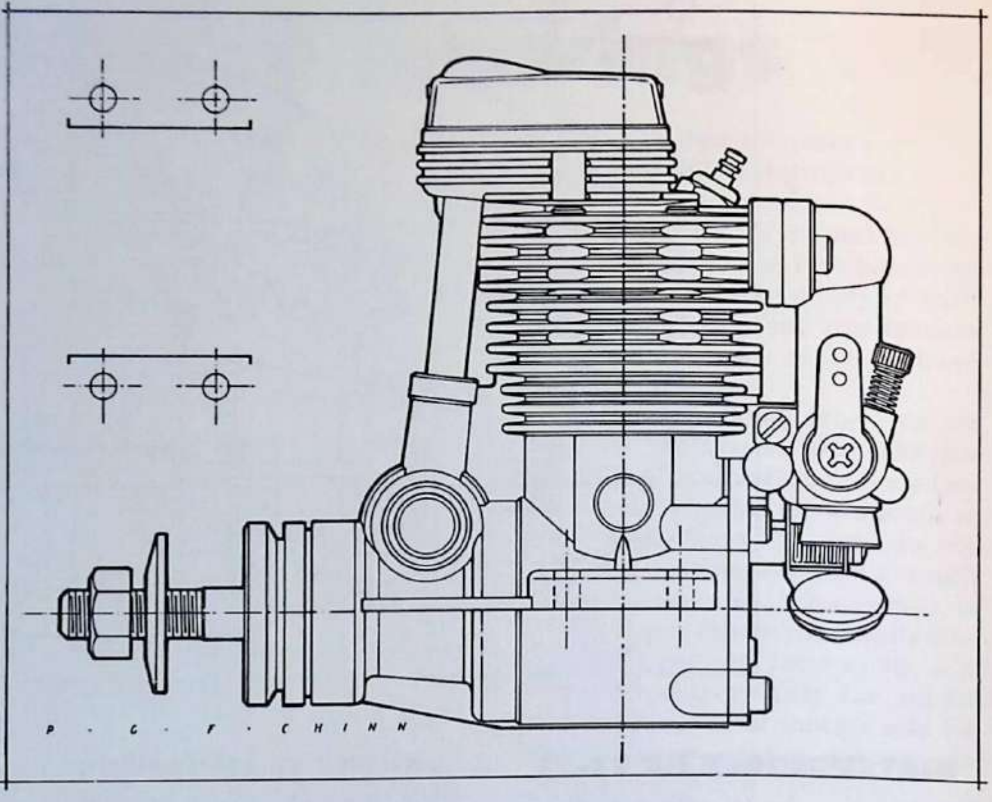
Performance Tests
Power Output, gross: 0.31 bhp at 12,500 rpm
Torque, gross: 28 oz-in. at 9,000 rpm
Equivalent b.m.e.p.: 101 lb/sq in.
Specific Output, gross: 1.43 bhp/cu in.
Power/Weight Ratio, gross: 0.54 bhp/lb

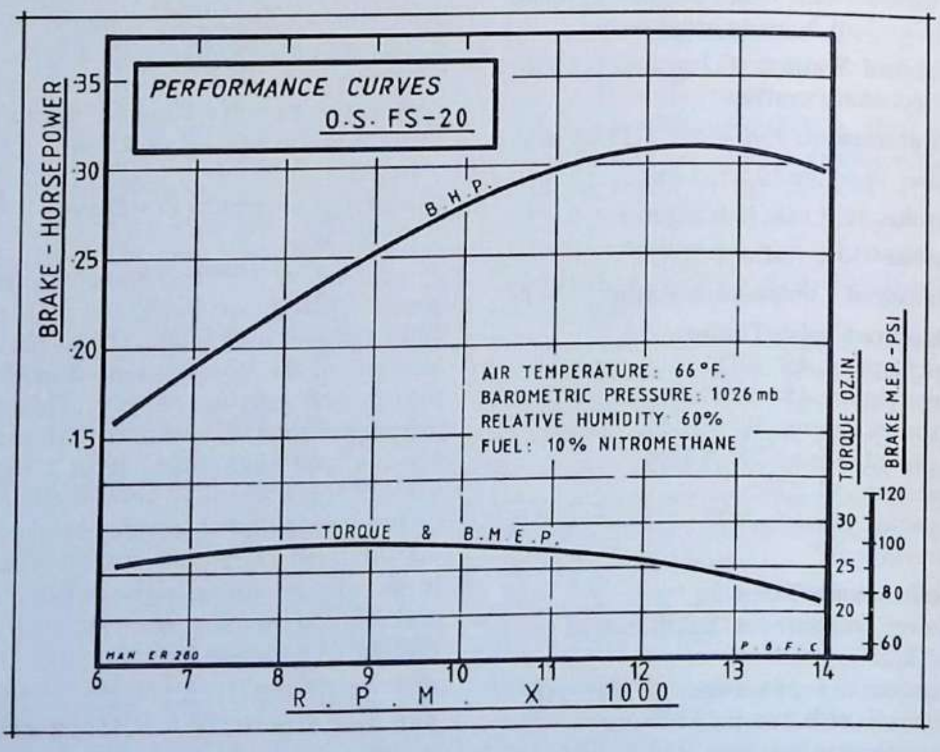
Typical prop rpm (less muffler):
8,750 rpm on a 10x5 Top Flite maple
9,450 rpm on a 9x6 Zinger maple
9,700 rpm on a 9x6 Power Prop maple
10,300 rpm on a 9x5 Top Flite maple
10,400 rpm on a 10x4 Zinger maple
11,100 rpm on an 8½x6 Zinger maple
11,250 rpm on a 9x4 Zinger maple
11,800 rpm on a 9x4 Power Prop maple

The compact, moderately-priced FS-20 became the world's lightest production four-cycle engine when introduced in the summer of 1985. It is similar in design and construction to the FS-40, but benefits from later research and development. Lively and sturdily made. Includes an easy "press-button" self-reopening choke valve.

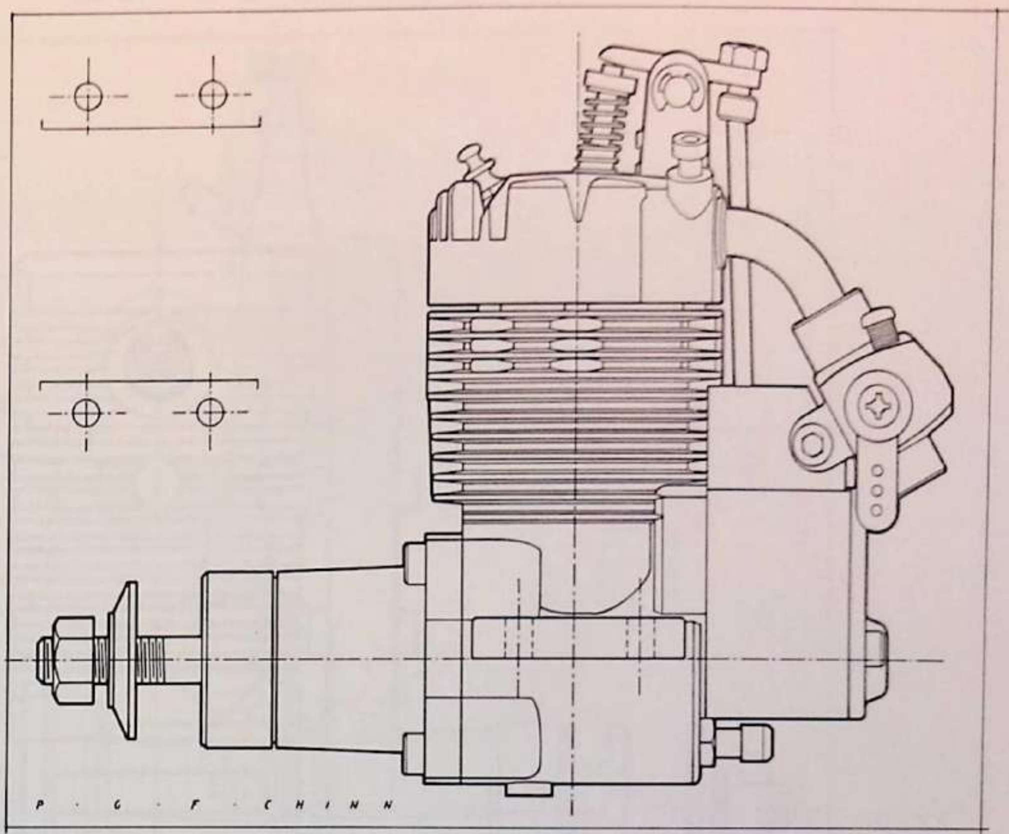
Full test report: M.A.N. February 1986

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan.





ENYA 35-4C & 40-4C



ENYA 35-4C & 40-4C

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin camshafts supported in bronze bearings.

Checked Weights:
35-4C — 352 grams (12.4 oz)
40-4C — 369 grams (13.0 oz)

Displacement:
35-4C — 5.860cc (0.3576 cu in.)
40-4C — 6.640cc (0.4052 cu in.)

Bore:
35-4C — 20.95 mm (0.8248 in.)
40-4C — 22.30 mm (0.8780 in.)

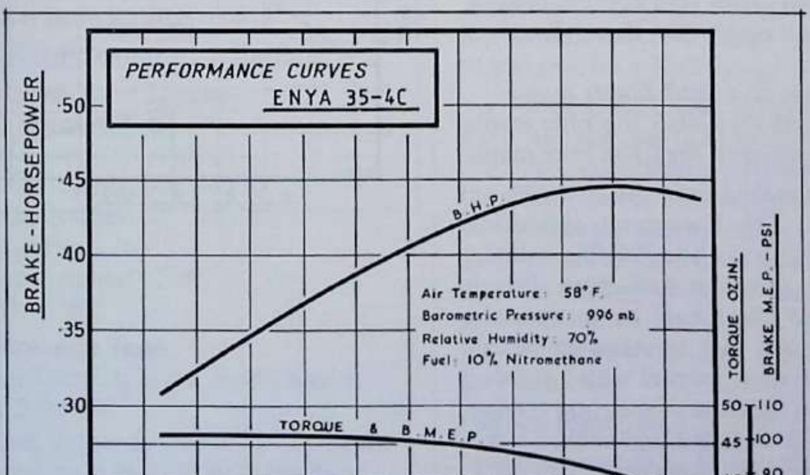
Stroke:
35-4C — 17.0 mm (0.6693 in.)
40-4C — 17.0 mm (0.6693 in.)

Stroke/Bore Ratio:
35-4C — 0.811 : 1
40-4C — 0.762 : 1

Measured Compression Ratio:
35-4C — 8.5 : 1
40-4C — 7.0 : 1

Valve Timing:
Inlet opens: 25° BTDC* (20°)**
Inlet closes: 85° ABDC* (60°)**
Exhaust opens: 57° BBDC* (40°)**
Exhaust closes: 43° ATDC* (40°)**
Inlet period: 290°* (260°)**
Exhaust period: 280°* (260°)**
Overlap: 68°* (60°)**
*40-4C (measured)
**35-4C (nominal)

Performance Tests
Power Output, gross:
35-4C — 0.445 bhp at 11,000 rpm
40-4C — 0.47 bhp at 11,500 rpm



Torque, gross:
35-4C — 46 oz-in. at 7,500 rpm
40-4C — 48 oz-in. at 8,000 rpm
Equivalent b.m.e.p.:
35-4C — 101 lb/sq in.
40-4C — 93 lb/sq in.
Specific Output, gross:
35-4C — 1.24 bhp/cu in.
40-4C — 1.16 bhp/cu in.
Power/Weight Ratio, gross:
35-4C — 0.57 bhp/lb
40-4C — 0.58 bhp/lb

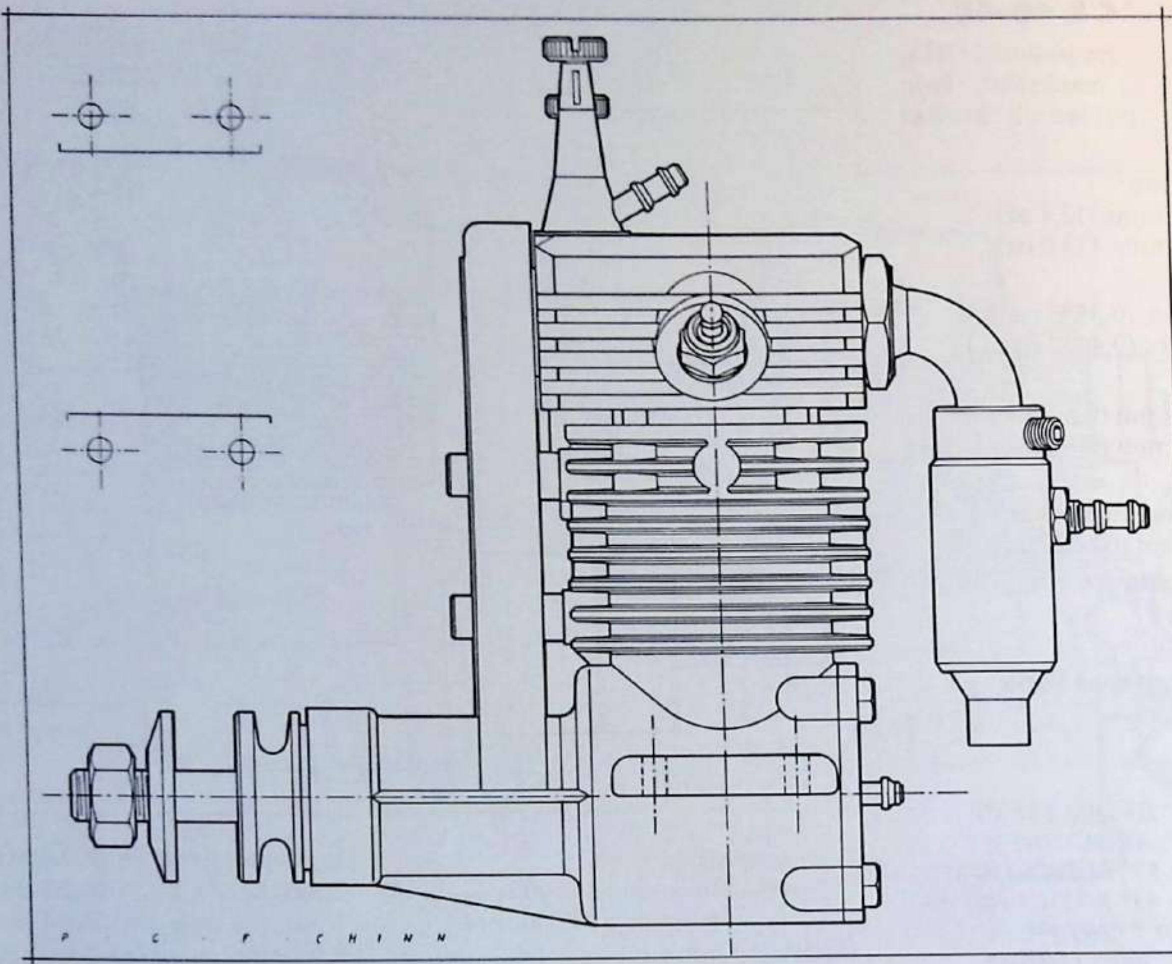
Typical prop rpm (40-4C) (less muffler):
7,500 rpm on a 12x6 Top Flite maple
7,900 rpm on a 12x5 Top Flite maple
9,000 rpm on a 12x4 Zinger maple
9,500 rpm on an 11x6 Power Prop maple
9,500 rpm on an 11x5 Top Flite maple
9,750 rpm on a 10x7 Zinger maple
10,250 rpm on a 10x6 Power Prop maple
10,900 rpm on a 10x5 Zinger maple

The 35-4C, introduced in the summer of 1980, was Enya's first four-stroke and featured twin rear-mounted camshafts as in subsequent model's from this manufacturer. Above average power but had tendency to "knock" and throw props if leaned out too far. The 40-4C, introduced in 1981, is essentially an enlarged bore version of the 35-4C but with much lower compression-ratio. External dimensions and appearance unchanged but with coventional ringed aluminum piston and steel cylinder instead of ringless AAC type.

Full test reports:
M.A.N. March 1981 (35-4C)
M.A.N. June 1982 (40-4C)

Manufacturer: Enya Metal Products Co. Ltd., Tokyo 176, Japan.

WEBRA T4-40



WEBRA T4-40

Type: Single-cylinder with toothed belt driven horizontal axis cylindrical rotary-valve in head. Two ball-bearing crankshaft.

Checked Weight: 381 grams (13.4 oz) including muffler

Displacement: 6.442cc (0.3931 cu in.)
Bore: 21.0 mm (0.8268 in.)

Stroke: 18.6 mm (0.7323 in.)

Stroke/Bore Ratio: 0.886 : 1

Measured Compression Ratio: 7.0 : 1

Measured Valve Timing:
Inlet opens: 20° BTDC
Inlet closes: 30° ABDC
Exhaust opens: 30° BBDC
Exhaust closes: 20° ATDC
Inlet period: 230°
Exhaust period: 230°
Overlap: 40°

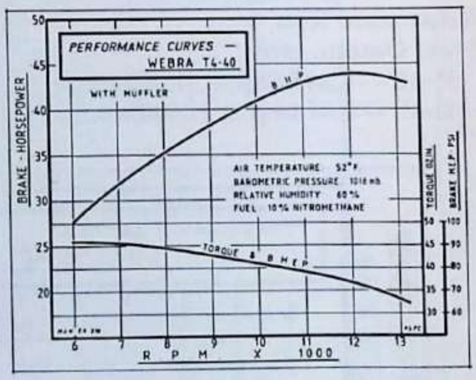
Performance Tests
Power Output, net: 0.44 bhp at 12,200 rpm
Torque, net: 46 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 92 lb/sq in.
Specific Output, net: 1.12 bhp/cu in.
Power/Weight Ratio, net: 0.53 bhp/lb

Typical prop rpm (with muffler):
7,800 rpm on a 12x5 Zinger maple
8,700 rpm on a 12x4 Zinger maple
9,200 rpm on an 11x6 Power Prop maple
9,100 rpm on an 11x5 Top Flite maple
9,400 rpm on an 11x4 Power Prop maple
9,400 rpm on a 10x7 Zinger maple
10,000 rpm on a 10x6 Top Flite maple
10,750 rpm on a 10x5 Top Flite maple

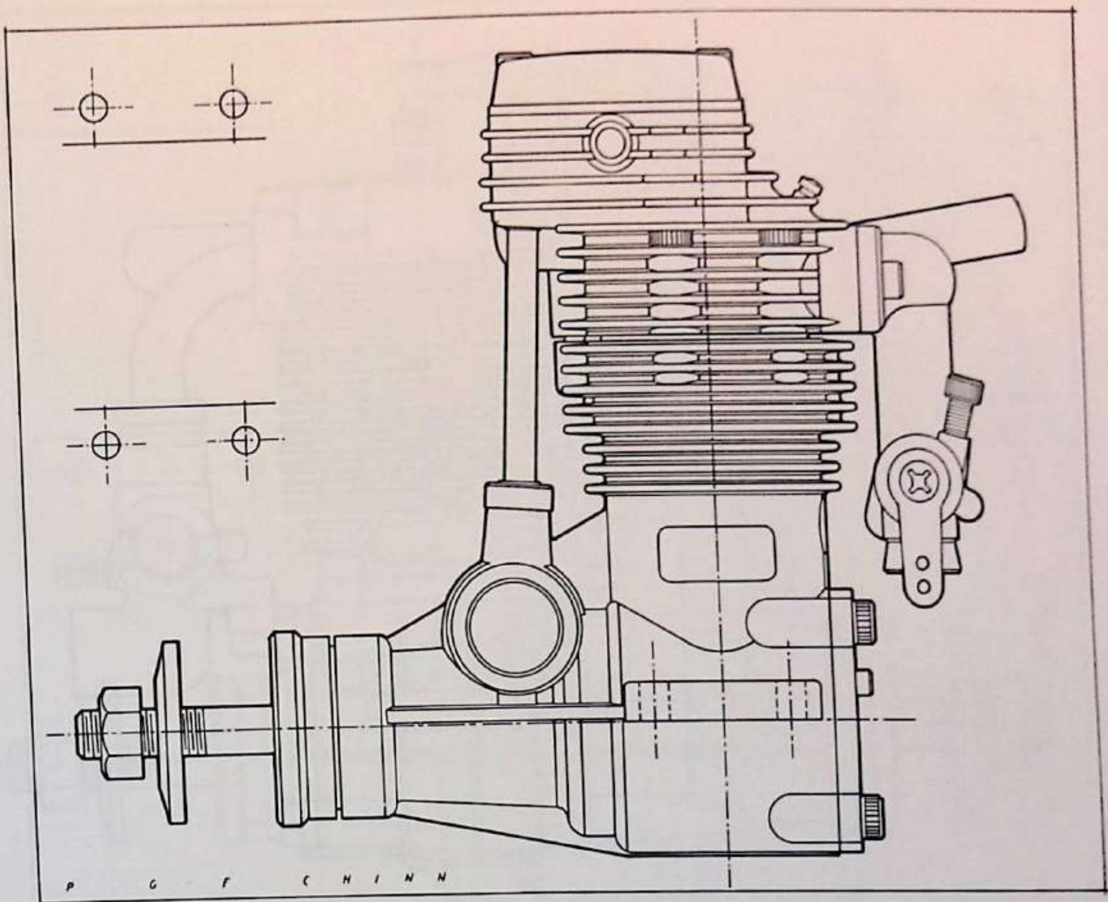
The simplest four-stroke design yet devised. The horizontal cylindrical rotary-valve, in the T4-40's cylinder head, is driven at half-speed directly from the crankshaft by means of a toothed belt that connects splines on the crankshaft journal with a toothed pulley on the front of the rotary-valve. Muffler is included and caused virtually no power loss on test.

Full test report: M.A.N. August 1984

Manufacturer: Webra Modellbau GmbH, Weidenberg, West Germany



O.S. FS-40



O.S. FS-40

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Two ball-bearing camshaft.

Checked Weight: 341 grams (12.0 oz)

Displacement: 6.495cc (0.3964 cu in.)

Bore: 21.2 mm (0.8346 in.)

Stroke: 18.4 mm (0.7244 in.)

Stroke/Bore Ratio: 0.868 : 1

Measured Compression Ratio: 8.5 : 1

Measured Valve Timing:
Inlet opens: 45° BTDC
Inlet closes: 60° ABDC
Exhaust opens: 45° BBDC
Exhaust closes: 45° ATDC
Inlet period: 285°
Exhaust period: 270°
Overlap: 90°

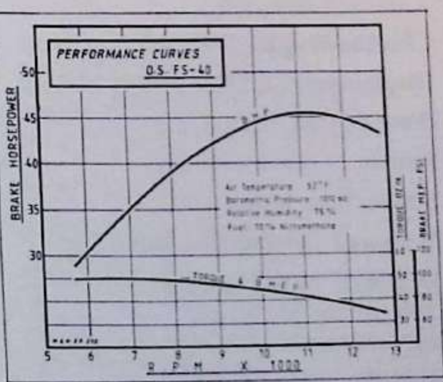
Performance Tests
Power Output, gross: 0.455 bhp at 11,200 rpm
Torque, gross: 50 oz-in. at 7,000 rpm
Equivalent b.m.e.p.: 99 lb/sq in.
Specific Output, gross: 1.15 bhp/cu in.
Power/Weight Ratio, gross: 0.61 bhp/lb

Typical prop rpm (less muffler):
8,000 rpm on a 12x5 Top Flite maple
8,900 rpm on a 12x4 Zinger maple
8,950 rpm on an 11x6 Top Flite maple
9,500 rpm on an 11x6 Power Prop maple
9,400 rpm on an 11x5 Top Flite maple
9,800 rpm on an 11x4 Power Prop maple
10,150 rpm on a 10x6 Zinger maple
10,800 rpm on a 10x5 Zinger maple

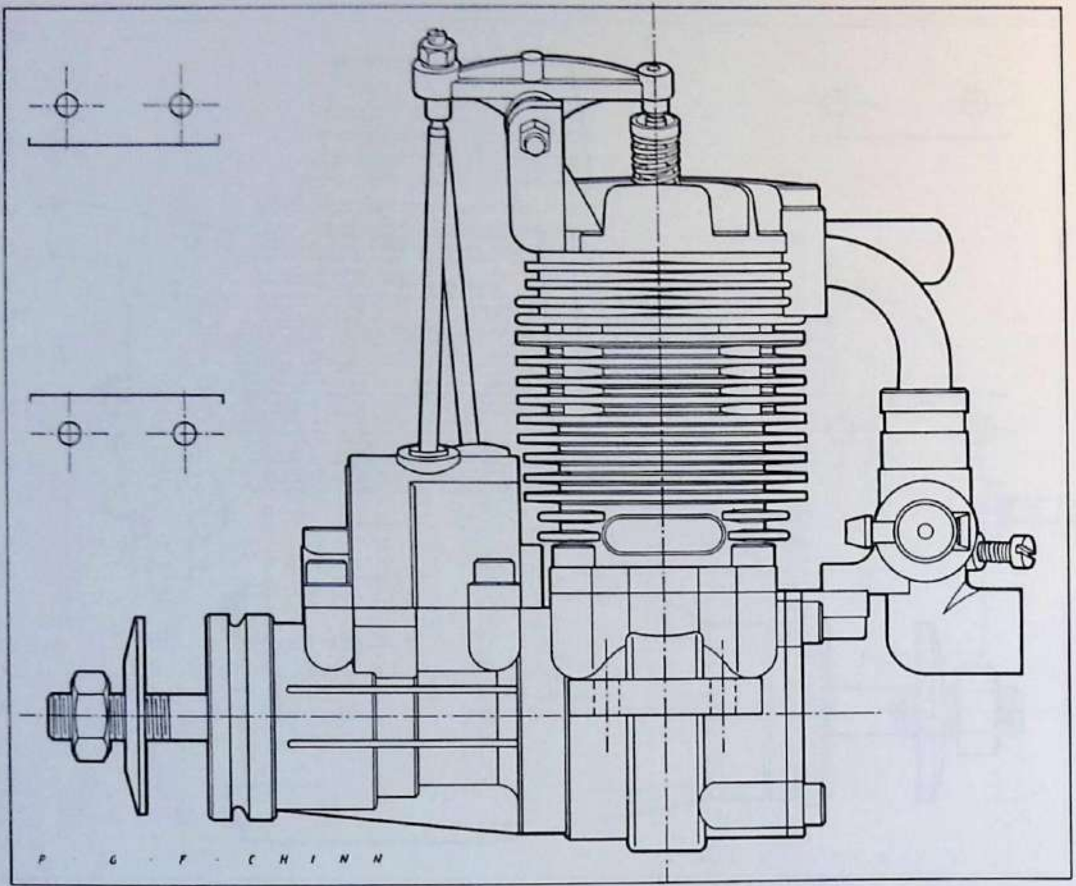
Popular O.S. FS-40, introduced in 1981, was the first O.S. four-stroke to use a crossed-helical gear driven front camshaft. Clean, compact design was also unusual, among single-cylinder four-strokes at the time of its introduction, in having enclosed valves and pushrods, previously seen only on FT-120 Gemini. Modest weight and easy to handle.

Full test report: M.A.N. February 1982

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan



SAITO FA-40 Mk.I



SAITO FA-40 Mk.I

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Bronze bushed camshaft.

Checked Weight: 354 grams (12.5 oz)

Displacement: 6.581cc (0.4016 cu in.)

Bore: 21 mm (0.8268 in.)

Stroke: 19 mm (0.7480 in.)

Stroke/Bore Ratio: 0.905 : 1

Measured Compression Ratio: 7.0 : 1

Measured Valve Timing:
Inlet opens: 33° BTDC
Inlet closes: 38° ABDC
Exhaust opens: 42° BBDC
Exhaust closes: 50° ATDC
Inlet period: 251°
Exhaust period: 272°
Overlap: 83°

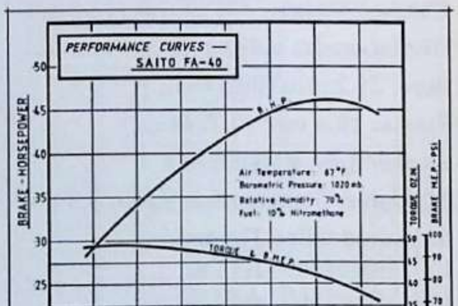
Performance Tests
Power Output, gross: 0.46 bhp at 11,300 rpm
Torque, gross: 49 oz-in. at 6,500 rpm
Equivalent b.m.e.p.: 96 lb/sq in.
Specific Output, gross: 1.15 bhp/cu in.
Power/Weight Ratio, gross: 0.59 bhp/lb

Typical prop rpm (less muffler):
7,950 rpm on a 12x5 Top Flite maple
8,850 rpm on a 12x4 Zinger maple
8,900 rpm on an 11x6 Top Flite maple
9,300 rpm on an 11x5 Top Flite maple
9,800 rpm on an 11x4 Power Prop maple
9,800 rpm on a 10x7 Zinger maple
10,100 rpm on a 10x6 Top Flite maple
10,800 rpm on a 10x5 Zinger maple

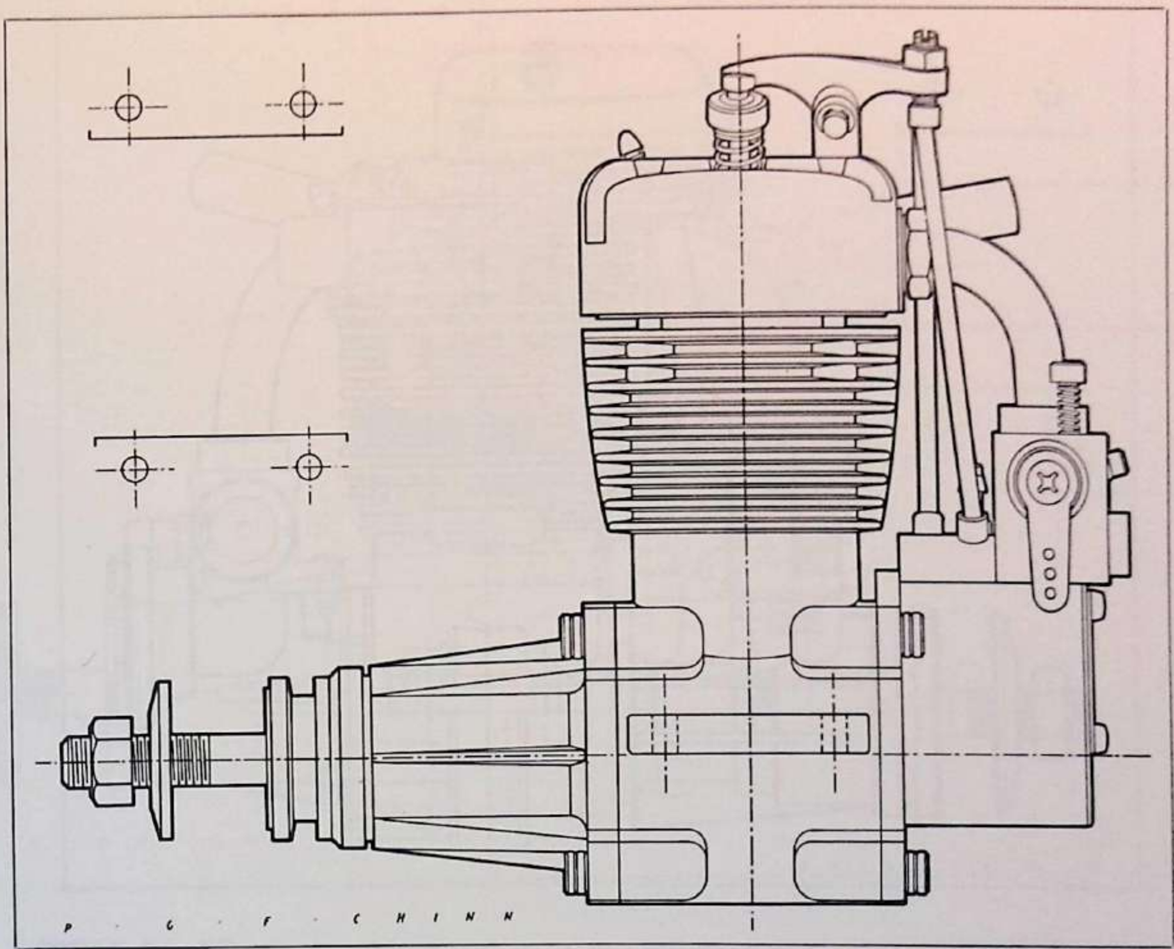
Basically, an enlarged and redesigned version of the Mk.I Saito FA-30 but with separate chromed bore cylinder casting, instead of drop-in chromed brass sleeve. Provision for mounting carburetor directly to cylinder-head or via separate inlet pipe as shown. This Mk.I model, first marketed in 1981, has since been superseded by Mk.II and Mk.III models with enclosed valve gear and having the same appearance as the FA-45.

Full test report: M.A.N. November 1981

Manufacturer: Saito Seisakusho Ltd., Ichikawa-shi, Shiga Pref., Japan.



KALT FC-1



KALT FC-1

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Camshaft mounted on bronze spindle.

Checked Weight: 525 grams (18.5 oz)

Displacement: 7.421cc (0.4528 cu in.)

Bore: 22.3 mm (0.8780 in.)

Stroke: 19.0 mm (0.7480 in.)

Stroke/Bore Ratio: 0.852 : 1

Measured Compression Ratio: 7.7 : 1

Measured Valve Timing:
Inlet opens: 25° BTDC
Inlet closes: 55° ABDC
Exhaust opens: 50° BBDC
Exhaust closes: 15° ATDC
Inlet period: 260°
Exhaust period: 245°
Overlap: 40°

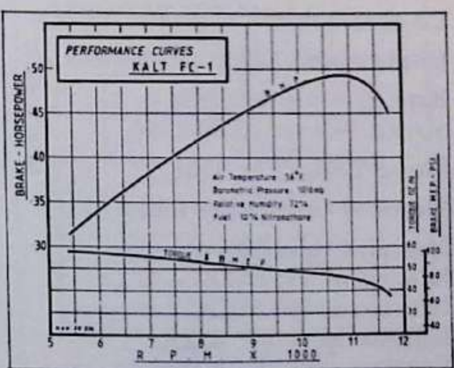
Performance Tests
Power Output, gross: 0.49 bhp at 10,800 rpm
Torque, gross: 58 oz-in. at 5,500 rpm
Equivalent b.m.e.p.: 101 lb/sq.in.
Specific Output, gross: 1.09 bhp/cu in.
Power/Weight Ratio, gross: 0.43 bhp/lb

Typical prop rpm (less muffler):
8,100 rpm on a 12x6 Zinger maple
9,300 rpm on an 11x6 Top Flite maple
9,400 rpm on an 11x5 Zinger maple
9,700 rpm on an 11x6 Power Prop maple
10,000 rpm on a 10x7 Zinger maple
10,500 rpm on an 11x6 Robbe glassfiber-nylon
10,600 rpm on a 10x6 Zinger maple
10,700 rpm on a 10x6 Top Flite maple

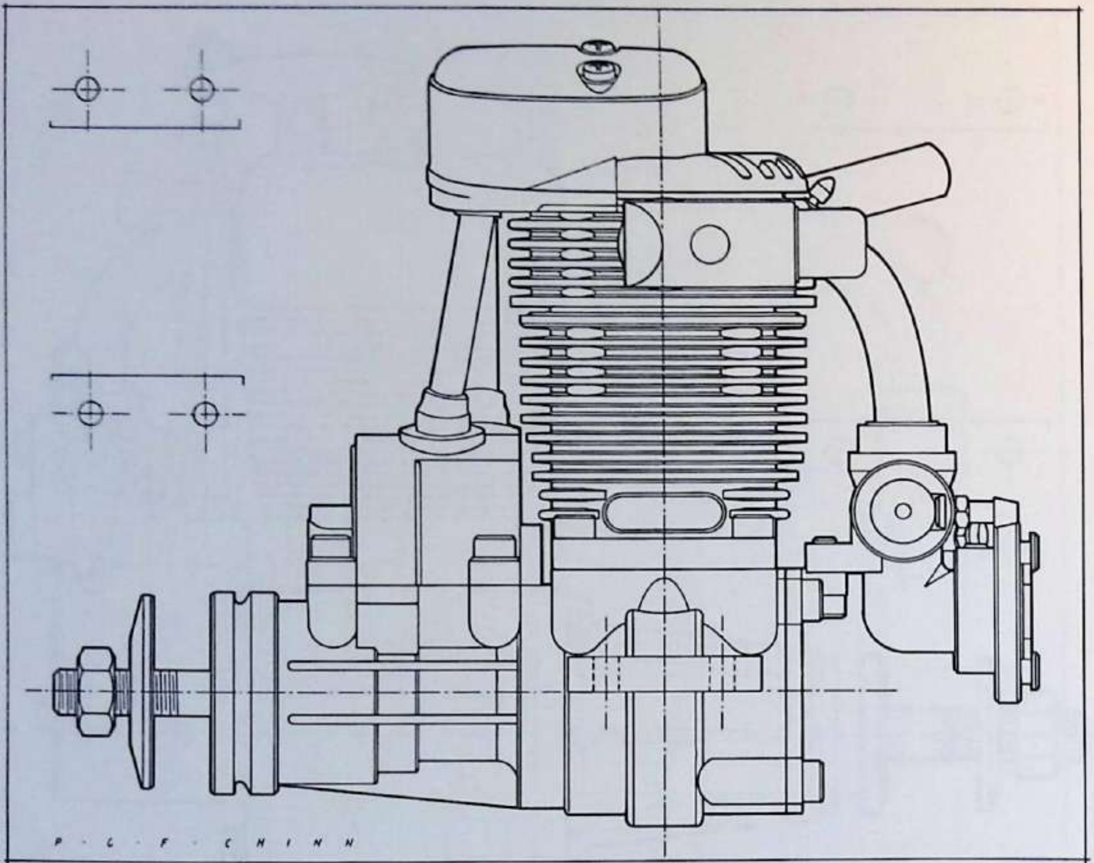
The second Japanese-made four-stroke to appear on the market. Regrettably, the Kalt company, better known for their helicopters, withdrew from the model engine market after only two years; a decision apparently in no way due to any shortcomings in the FC-1 itself, which was well-made and easy to handle.

Full test report: M.A.N. November 1978

Manufacturer: Engine no longer in production



SAITO FA-45



SAITO FA-45

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Bronze bushed camshaft.

Checked Weight: 398 grams (14.0 oz)

Displacement: 7.488cc (0.4569 cu in.)

Bore: 22.4 mm (0.8819 in.)
Stroke: 19.0 mm (0.7480 in.)

Stroke/Bore Ratio: 0.848 : 1

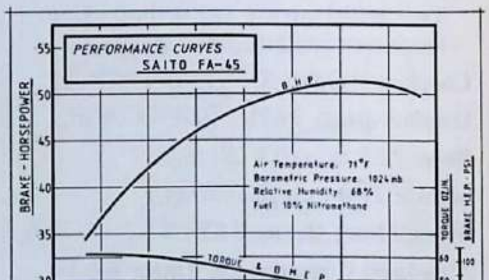
Measured Compression Ratio: 7.2 : 1

Measured Valve Timing:
Inlet opens: 35° BTDC
Inlet closes: 50° ABDC
Exhaust opens: 45° BBDC
Exhaust closes: 50° ATDC
Inlet period: 265°
Exhaust period: 275°
Overlap: 85°

Performance Tests
Power Output, gross: 0.51 bhp at 11,400 rpm
Torque, gross: 61 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 105 lb/sq in.
Specific Output, gross: 1.12 bhp/cu in.
Power/Weight Ratio, gross: 0.58 bhp/lb

Typical prop rpm (less muffler):
7,400 rpm on a 14x4 Top Flite maple
8,200 rpm on a 12x6 Top Flite maple
8,550 rpm on a 12x5 Top Flite maple
9,100 rpm on an 11x7½ Power Prop maple
9,400 rpm on a 12x4 Zinger maple
10,000 rpm on an 11x6 Power Prop maple
10,200 rpm on an 11x4 Power Prop maple
10,550 rpm on a 10x6 Zinger maple

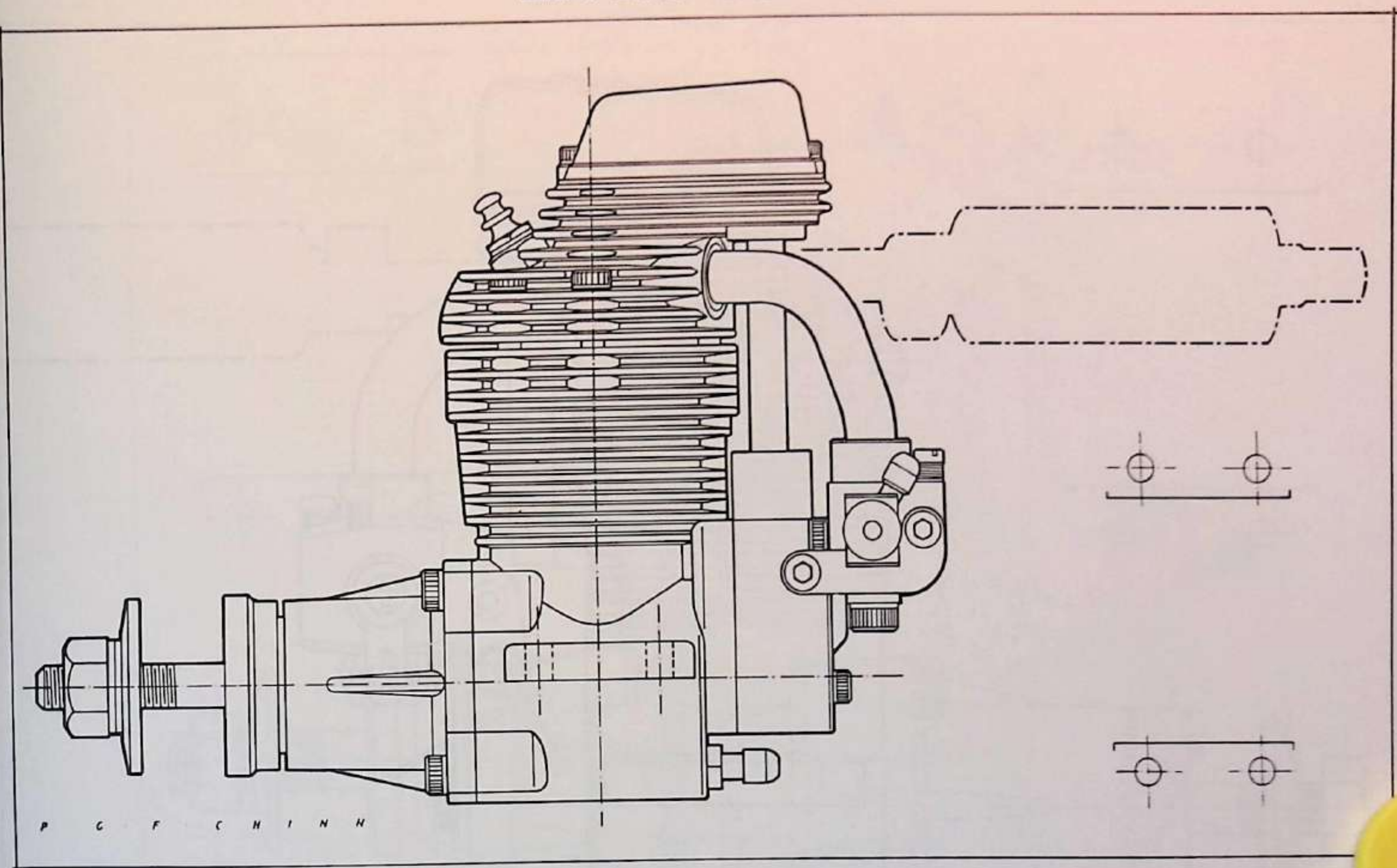
A de-luxe development of the original FA-40, having the same piston stroke but a larger cylinder bore, plus much more compact valve gear (shorter stemmed valves, lowered rocker assemblies and new steel rocker arms enclosed in neat streamlined rocker boxes), enclosed pushrods and a manual choke valve. Current version (FA-45 Mk.II) has ringed piston running in steel linered cylinder with integral head, in place of original ringless-piston AAC design with detachable head.



Full test report: M.A.N. October 1982

Manufacturer: Saito Seisakusho Ltd., Ichikawa-shi, Chiba Pref., Japan.

ENYA 46-4C



ENYA 46-4C

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin camshafts supported in bronze bearings.

Checked Weight: 410 grams (14.5 oz) with muffler

Displacement: 7.499cc (0.4576 cu in.)

Bore: 22.3 mm (0.8780 in.)

Stroke: 19.2 mm (0.7559 in.)

Stroke/Bore Ratio: 0.861 : 1

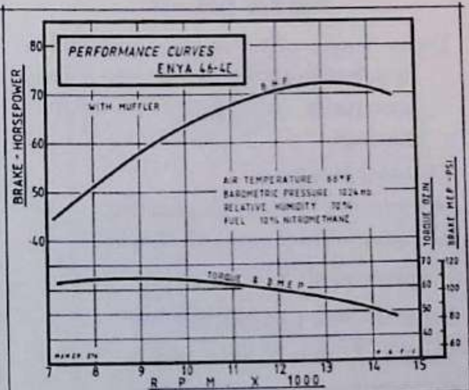
Measured Compression Ratio: 7.8 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 80° ABDC
Exhaust opens: 70° BBDC
Exhaust closes: 35° ATDC
Inlet period: 300°
Exhaust period: 285°
Overlap: 75°

Performance Tests
Power Output, net: 0.72 bhp at 13,200 rpm
Torque, net: 65 oz-in. at 9,000 rpm
Equivalent b.m.e.p.: 112 lb/sq in.
Specific Output, net: 1.57 bhp/cu in.
Power/Weight Ratio, net: 0.79 bhp/lb

Typical prop rpm (with muffler):
8,800 rpm on a 12x6 Zinger maple
9,400 rpm on a 12x5 Top Flite maple
10,200 rpm on a 12x4 Zinger maple
10,400 rpm on an 11x6 Top Flite maple
11,050 rpm on a 10½x6 MK glassfiber/nylon
11,100 rpm on a 10x7 Zinger maple
11,600 rpm on a 10x6 Zinger maple
12,000 rpm on a 10x6 Top Flite maple

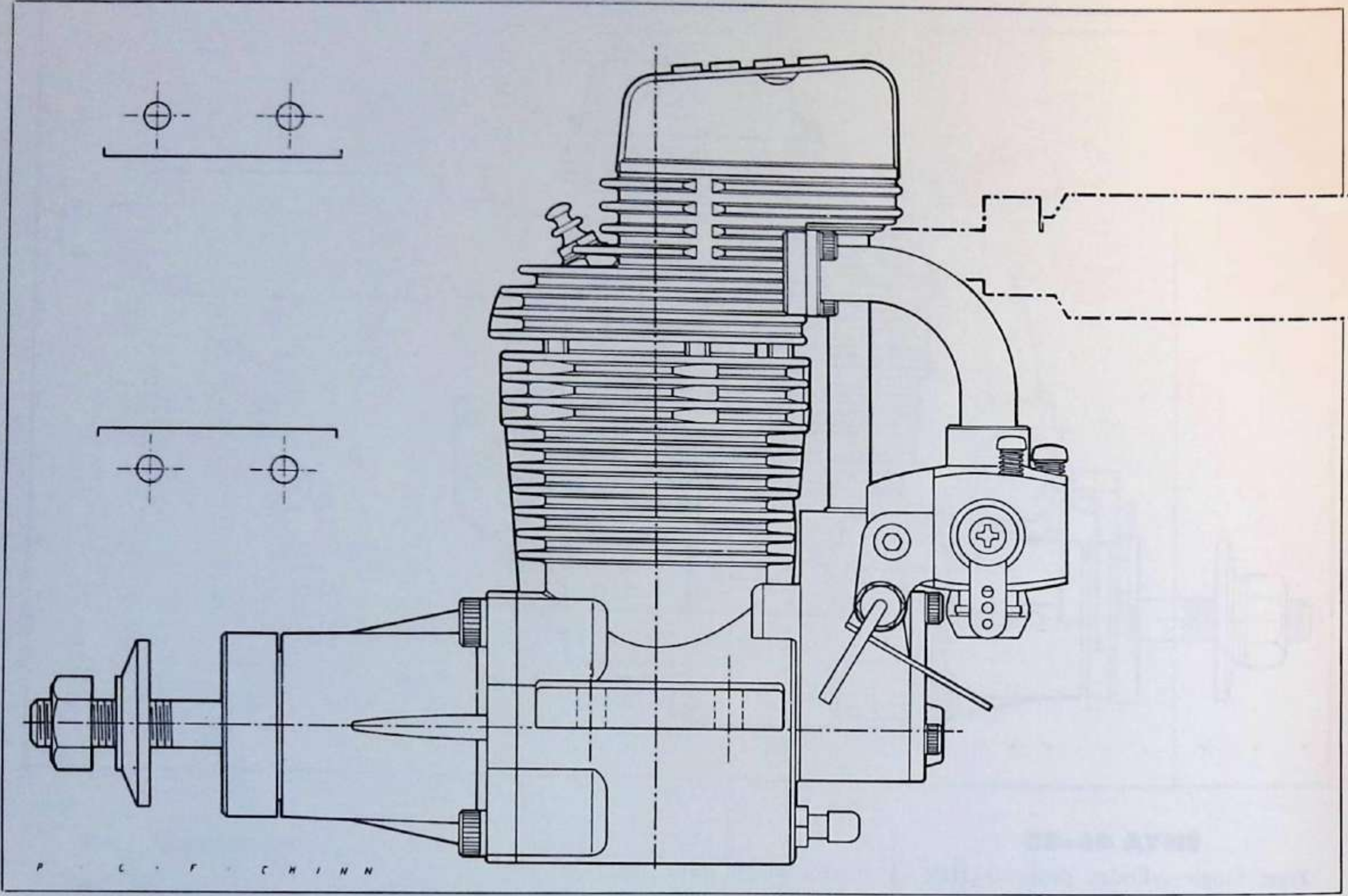
Announced in 1984, the Enya 46-4C set a new performance yardstick for four-stroke engines of this size. Very little larger, externally, than the Enya 40-4C and only very slightly heavier, despite the refinement of enclosed valve gear, a more complex carburetor with built-in choke control and the addition of a muffler. On test, it was 50 percent more powerful than existing .40 size four-strokes. Now manufactured in a Mk.II version with sturdier front end.



Full test report: M.A.N. November 1984

Manufacturer: Enya Metal Products Co. Ltd., Tokyo 176, Japan.

ENYA 60-4C



ENYA 60-4C

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin camshafts supported in bronze bearings.

Checked Weights:
609 grams (21.5 oz) less muffler
620 grams (21.9 oz) with muffler

Displacement: 9.953cc (0.6073 cu in.)

Bore: 24 mm (0.9449 in.)

Stroke: 22 mm (0.8661 in.)

Stroke/Bore Ratio: 0.917 : 1

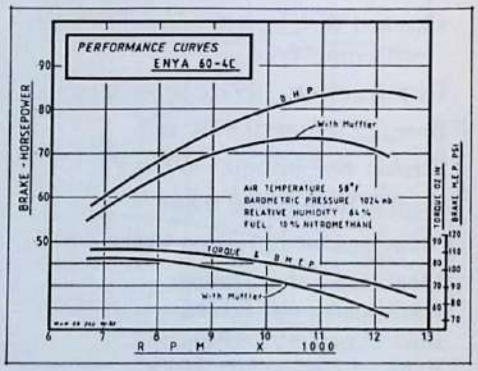
Measured Compression Ratio: 7.7 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 80° ABDC
Exhaust opens: 80° BBDC
Exhaust closes: 40° ATDC
Inlet period: 300°
Exhaust period: 300°
Overlap: 80°

Performance Tests
Power Output, gross: 0.84 bhp at 11,800 rpm
Power Output, net: 0.73 bhp at 10,750 rpm
Torque, gross: 86 oz-in. at 7,500 rpm
Equivalent b.m.e.p.: 111 lb/sq in.
Torque, net: 82 oz-in. at 7,000 rpm
Equivalent b.m.e.p.: 106 lb/sq in.
Specific Output, gross: 1.38 bhp/cu in.
Specific Output, net: 1.20 bhp/cu in.
Power/Weight Ratio, gross: 0.62 bhp/lb
Power/Weight Ratio, net: 0.53 bhp/lb

Typical prop rpm (less muffler):
7,300 rpm on a 16x4 Top Flite maple
8,200 rpm on a 14x6 Top Flite maple
8,400 rpm on a 13x6 Top Flite maple
9,900 rpm on a 12x6 Zinger maple
10,400 rpm on a 12x5 Top Flite maple
10,900 rpm on an 11x7½ Power Prop maple

When introduced in 1982, the Enya 60-4C demonstrated that four-stroke engines did not have to be confined to low-powered sport models. Its specific

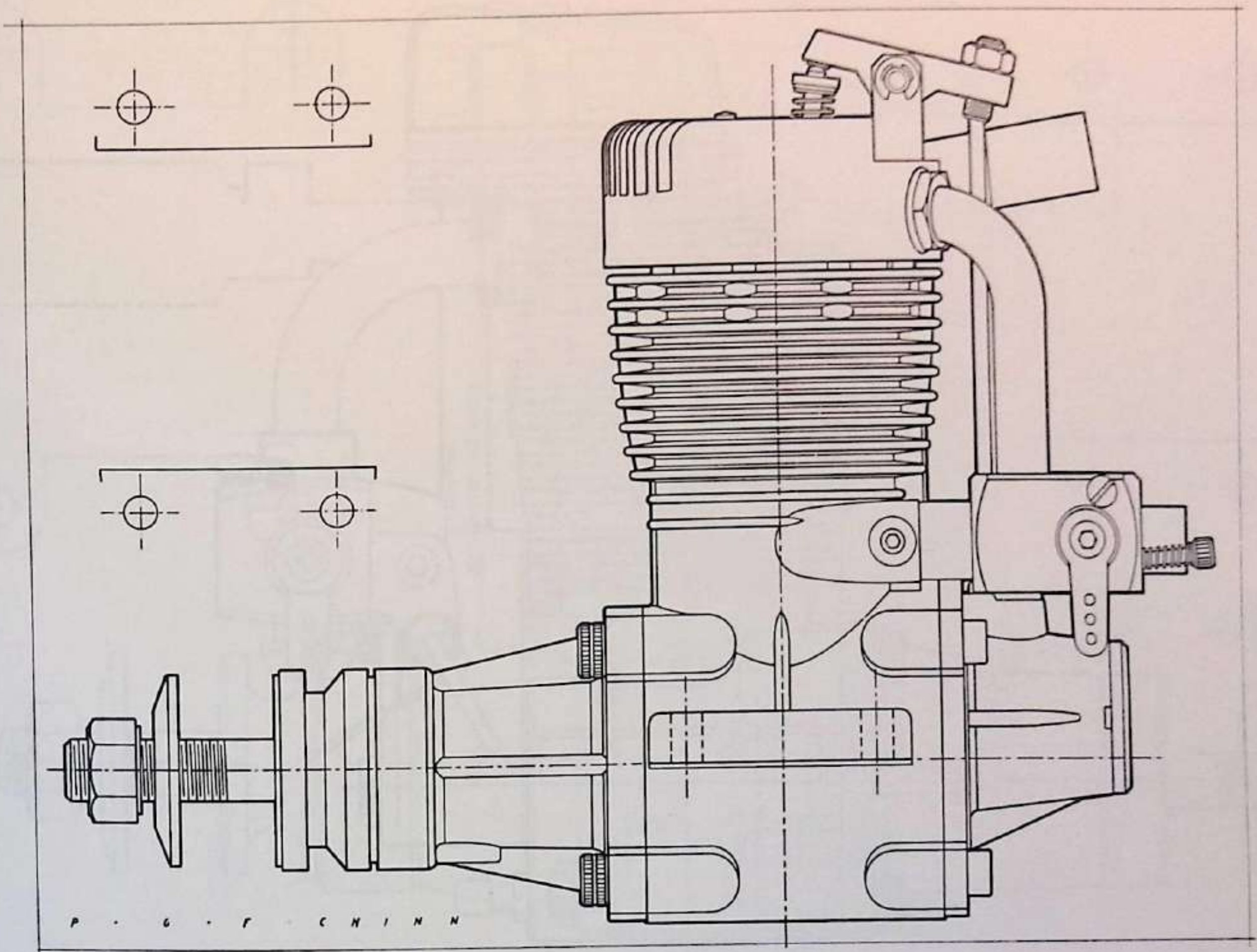


output was the highest for any four-stroke at the time. Noise was also increased, but small outlet of early Enya muffler used in tests reduced power too much and set-screw fastening was insecure. Current type muffler is much better and less restrictive.

Full test report: M.A.N. February 1983

Manufacturer: Enya Metal Products co. Ltd., Tokyo 176, Japan.

O.S. FS-60



O.S. FS-60

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Two ball-bearing camshaft.

Checked Weight: 590 grams (20.8 oz)

Displacement: 9.953cc (0.6073 cu in.)

Bore: 24 mm (0.9449 in.)

Stroke: 22 mm (0.8661 in.)

Stroke/Bore Ratio: 0.917 : 1

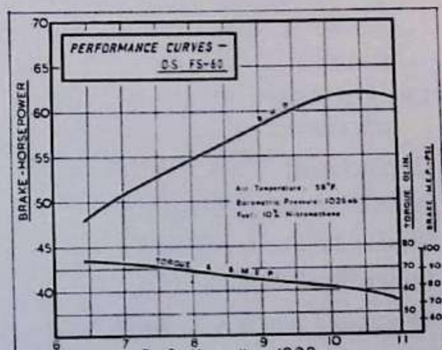
Measured Compression Ratio: 9.0 : 1

Measured Valve Timing:
Inlet opens: 30° BTDC
Inlet closes: 55° ABDC
Exhaust opens: 90° BBDC
Exhaust closes: 28° ATDC
Inlet period: 265°
Exhaust period: 298°
Overlap: 58°

Performance Tests
Power Output, gross: 0.62 bhp at 10,500 rpm
Torque, gross: 74 oz-in. at 6,500 rpm
Equivalent b.m.e.p.: 96 lb/sq in.
Specific Output, gross: 1.02 bhp/cu in.
Power/Weight Ratio, gross: 0.48 bhp/lb.

Typical prop rpm (less muffler):
7,300 rpm on a 14x6 Top Flite maple
8,400 rpm on a 13x5½ Top Flight (old type)
8,800 rpm on a 14x4 Top Flite (old type)
8,900 rpm on a 12x6 Top Flite maple
9,700 rpm on an 11x7½ Power Prop maple
9,800 rpm on a 12x5 Power Prop (old type)

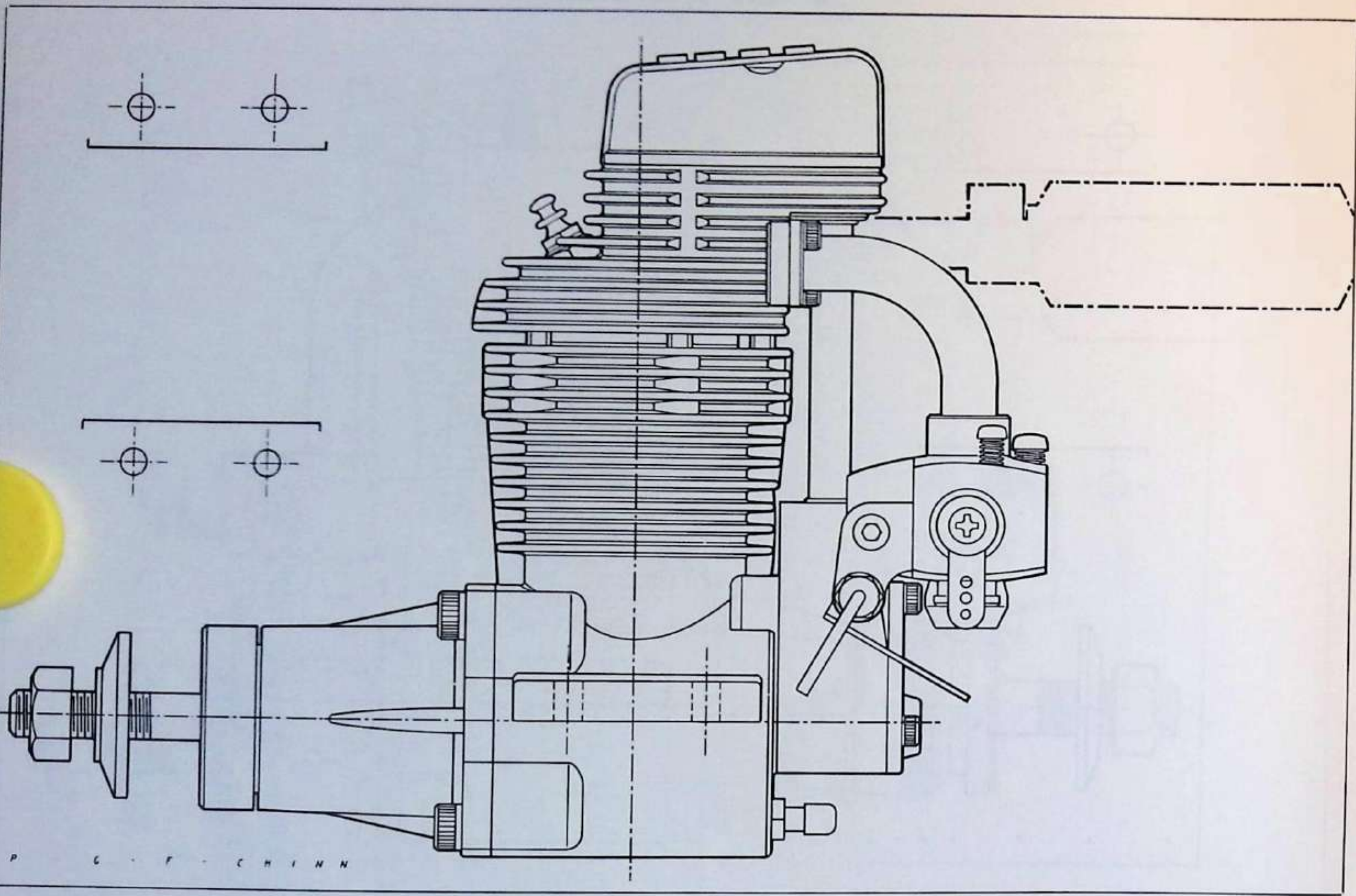
The engine that began the four-stroke revolution. Large numbers still in use. Original model had bronze bushed machined aluminum alloy rocker arms and machined cylinder head and carburetor body. Production modifications during first year included revised combustion chamber and cam profiles, thicker valve stems, followed by cast steel rockers and, later, by a new cast head and automatic mixture control carburetor. Remained in production for seven years until superseded by FS-61.



Full test report: M.A.N. September 1977

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan.

ENYA 80-4C



ENYA 80-4C

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin camshafts supported in bronze bearings.

Checked Weight: 600 grams (21.2 oz) with muffler

Displacement: 12.60cc (0.7687 cu in.)

Bore: 27 mm (1.063 in.)

Stroke: 22 mm (0.8661 in.)

Stroke/Bore Ratio: 0.815 : 1

Measured Compression Ratio: 8.6 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 80° ABDC
Exhaust opens: 80° BBDC
Exhaust closes: 40° ATDC
Inlet period: 300°
Exhaust period: 300°
Overlap: 80°

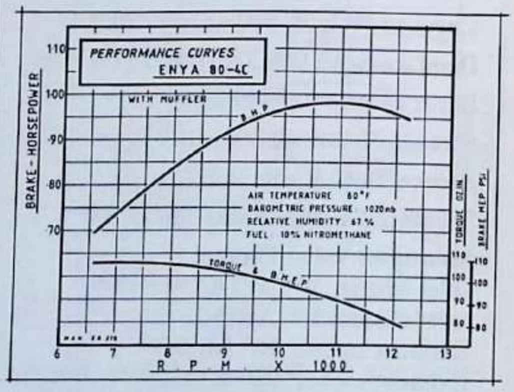
Performance Tests
Power Output, net: 0.98 bhp at 11,000 rpm
Torque, net: 106 oz-in. at 7,000 rpm
Equivalent b.m.e.p.: 108 lb/sq in.
Specific Output, net: 1.27 bhp/cu in.
Power/Weight Ratio, net: 74 bhp/lb

Typical prop rpm (with muffler):
8,300 rpm on a 13x8 Airflow beech
8,700 rpm on a 15x4 Airflow beech
9,000 rpm on a 14x6 Top Flite maple
9,500 rpm on a 14x4 Top Flite maple
9,500 rpm on a 12x8 Airflow beech
10,450 rpm on a 12x6 Top Flite maple

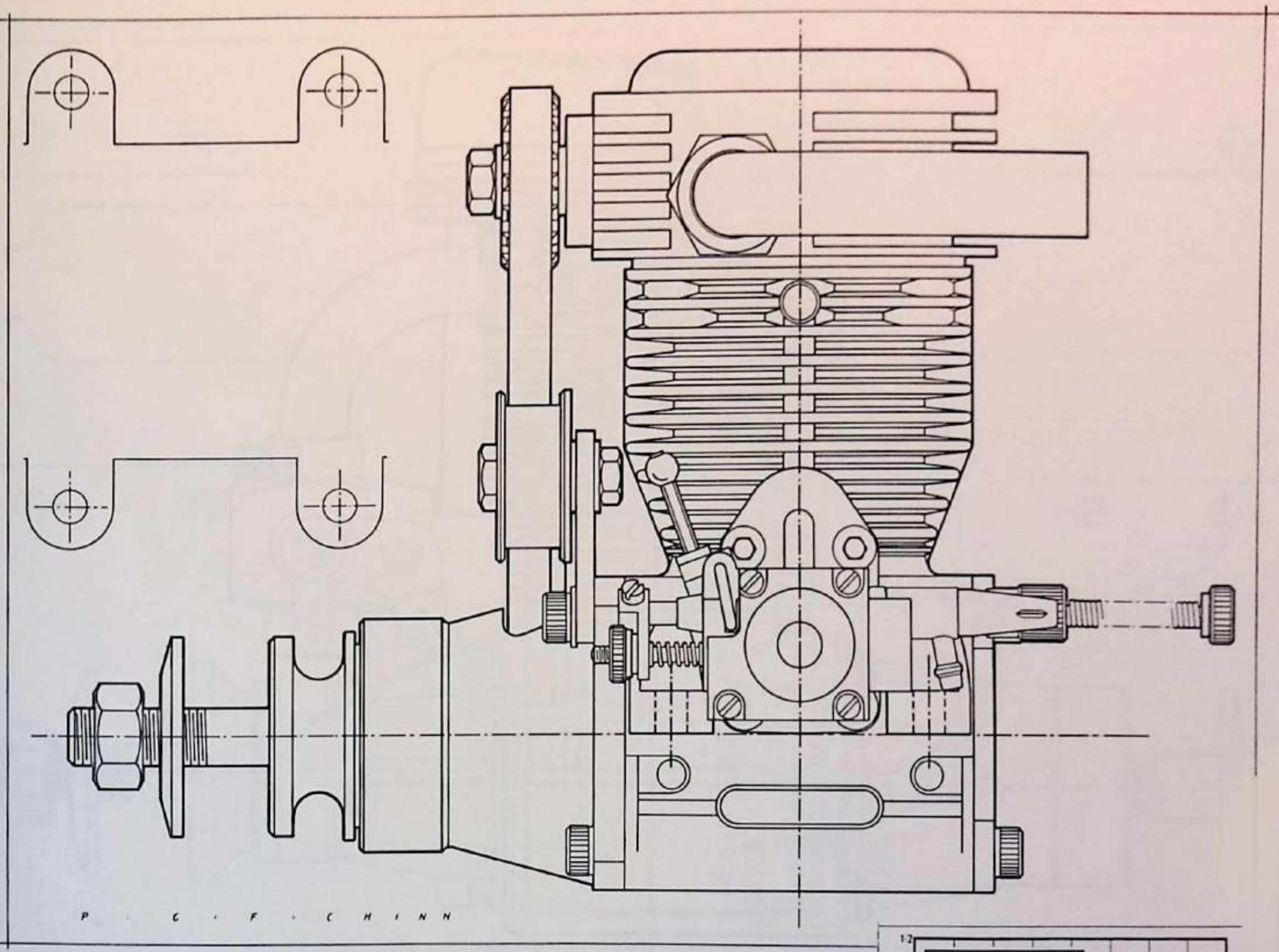
Surprisingly effective "stretch" of 60-4C. Main casting bored out for 3 mm larger bore liner. New lightweight slipper piston. New throttle barrel. All other parts (including cylinder-head) unchanged. Effective new muffler. Total weight fractionally less than for 60-4C, resulting in substantially improved power/weight ratio. Vibration levels still well within acceptable limits.

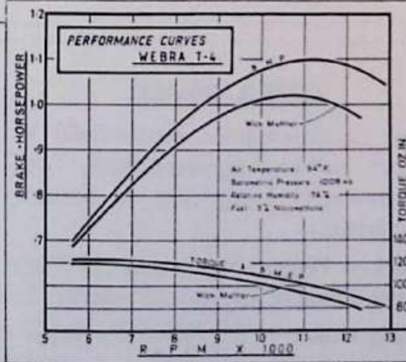
Full test report: M.A.N. April 1985

Manufacturer: Enya Metal Products Co. Ltd., Tokyo 176, Japan.



WEBRA T-4 (0.87)





WEBRA T-4 (0.87)

Type: Single-cylinder with crankcase charging and toothed belt driven Aspin type rotary valve. Two ball bearing crankshaft.

Checked Weight:
998 grams (35.2 oz) less muffler
1,040 grams (36.7 oz) with muffler

Displacement: 14.31cc (0.8735 cu in.)

Bore: 27 mm (1.063 in.)

Stroke: 25 mm (0.9842 in.)

Stroke/Bore Ratio: 0.926 : 1

Measured Compression Ratio: 9.2 : 1

Measured Valve Timing:
Inlet opens: 25° BTDC
Inlet closes: 55° ABDC
Exhaust opens: 65° BBDC
Exhaust closes: 15° ATDC
Inlet period: 260°
Exhaust period: 260°
Overlap: 40°

Performance Tests
Power Output, gross: 1.10 bhp at 11,250 rpm
Power Output, net: 1.02 bhp at 10,750 rpm
Torque, gross: 124 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 112 lb/sq in.
Torque, net: 120 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 108 lb/sq in.
Specific Output, gross: 1.26 bhp/cu in.
Specific Output, net: 1.17 bhp/cu in.
Power/Weight Ratio, gross: 0.50 bhp/lb
Power/Weight Ratio, net: 0.44 bhp/lb

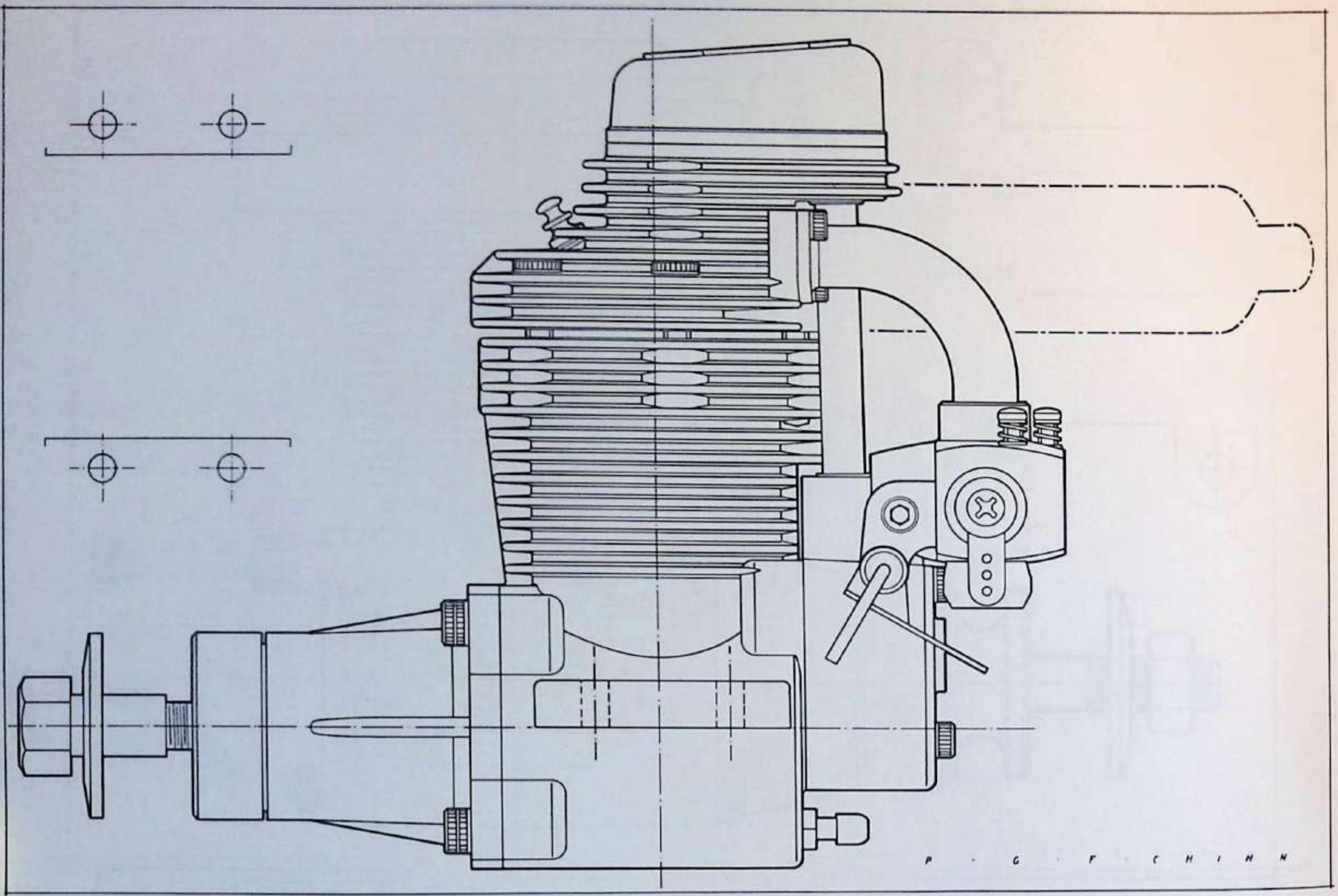
Typical prop rpm (less muffler):
6,100 rpm on a 17x6 Top Flite maple**
6,800 rpm on a 16x6 Top Flite maple
7,200 rpm on a 15x6 Top Flite maple*
8,300 rpm on a 16x4 Top Flite maple
9,350 rpm on a 14x6 Top Flite maple
9,900 rpm on a 14x4 Top Flite maple
* = cropped from 16 in. diameter
** = cropped from 18 in. diameter

Webra's big and hefty original T4 was this company's first four-stroke and the world's first (1980) production model four-stroke rotary-valve engine. Highly unconventional design with crankcase induction via reed valve and external transfer pipe to cylinder head (later Mk.II option reverted to orthodox direct inlet from head-mounted carburetor) and vertical axis conical rotary-valve driven by toothed belt via bevel gears in head. Webra baffled expansion chamber muffler absorbs some power, especially at top end, but is very effective.

Full test report: M.A.N. May 1981

Manufacturer: Webra Modellbau GmbH, Weidenberg, West Germany.

ENYA 90-4C



ENYA 90-4C

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin camshafts supported in bronze bearings.

Checked Weight: 823 grams (29.0 oz) with exhaust header and muffler

Displacement: 14.93cc (0.9110 cu in.)

Bore: 29.0 mm (1.142 in.)

Stroke: 22.6 mm (0.8898 in.)

Stroke/Bore Ratio: 0.779 : 1

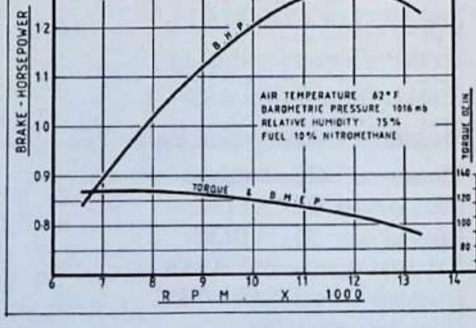
Measured Compression Ratio: 7.5 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 80° ABDC
Exhaust opens: 80° BBDC
Exhaust closes: 40° ATDC
Inlet period: 300°
Exhaust period: 300°
Overlap: 80°

Performance Tests
Power Output, net: 1.28 bhp at 12,000 rpm
Torque, net: 128 oz-in. at 7,000 rpm
Equivalent b.m.e.p.: 110 lb/sq in.
Specific Output, net: 1.40 bhp/cu in.
Power/Weight Ratio, net: 0.71 bhp/lb

Typical prop rpm (with muffler):
7,000 rpm on a 16x6 Top Flite maple
7,800 rpm on a 15x6 Airflow beech
8,500 rpm on a 16x4 Top Flite maple
9,700 rpm on a 14x6 Top Flite maple
10,200 rpm on a 14x4 Top Flite maple
11,500 rpm on a 12x6 Top Flite maple

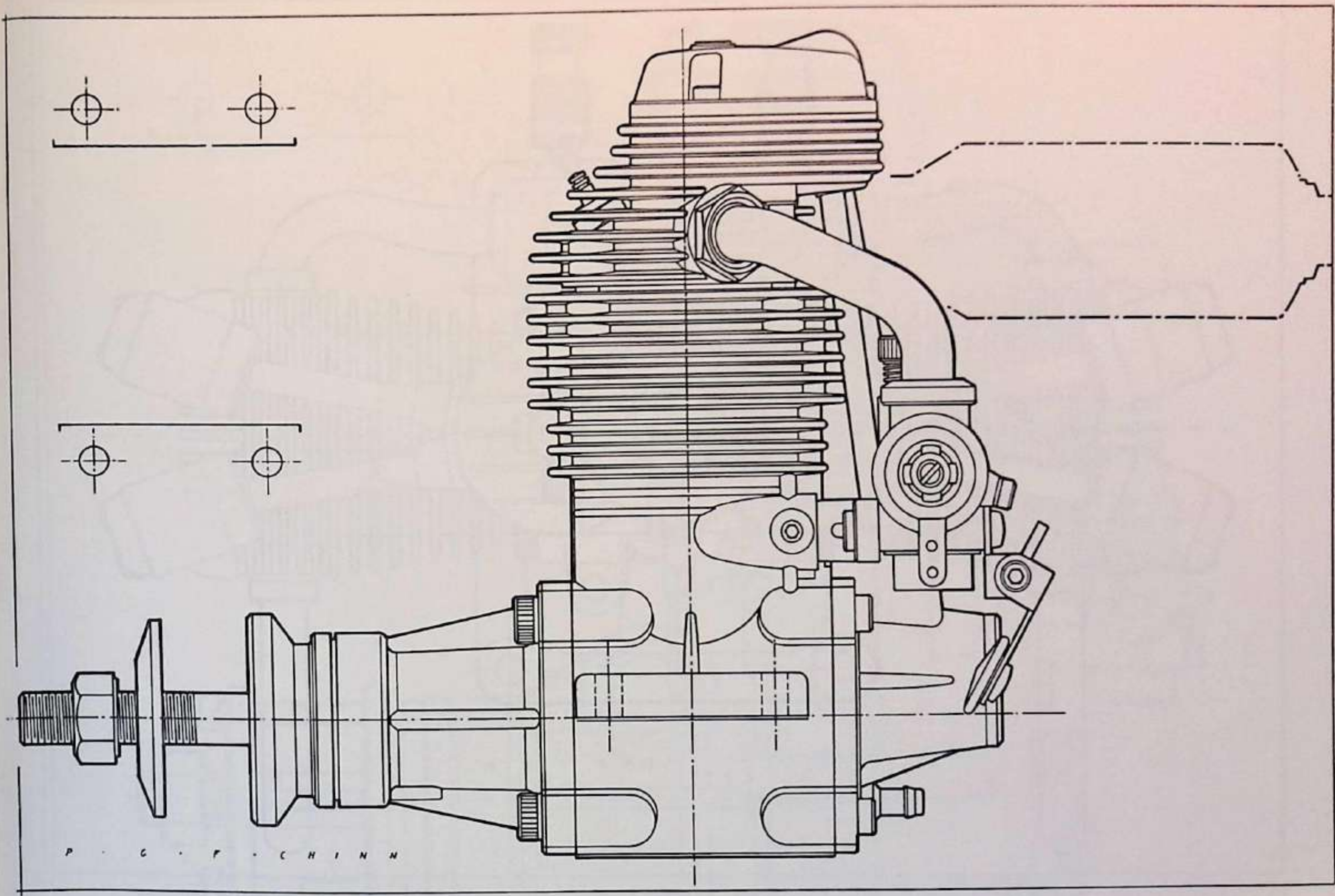
Another trend-setter from Enya when introduced for the 1983 season. Excellent performance with standard muffler (supplied) on wide range of props. Designed to take advantage of 1983 FAI rules as originally formulated to allow 15cc four-strokes for FAI Scale. Rules subsequently amended to 20cc which resulted in the introduction of bored and stroked 120-4C model. (Latter now supplemented by entirely new and more powerful R120-4C).



Full test report: M.A.N. March 1984

Manufacturer: Enya Metal Products Co. Ltd., Tokyo 176, Japan

O.S. FS-90



O.S. FS-90

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Two ball-bearing camshaft.

Checked Weight: 693 grams (24.4 oz) with exhaust header and muffler

Displacement: 14.95cc (0.9120 cu in.)

Bore: 27.7 mm (1.0906 in.)

Stroke: 24.8 mm (0.9764 in.)

Stroke/Bore Ratio: 0.895 : 1

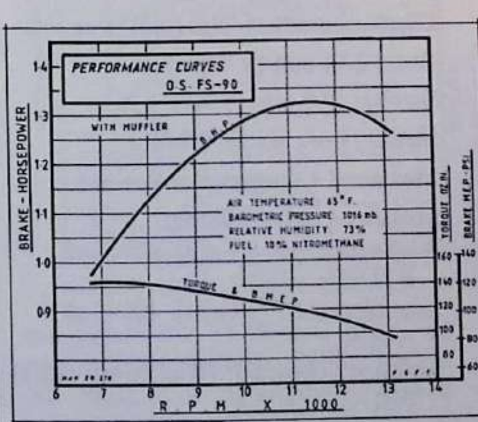
Measured Compression Ratio: 8.8 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 90° ABDC
Exhaust opens: 80° BBDC
Exhaust closes: 40° ATDC
Inlet period: 310°
Exhaust period: 300°
Overlap: 80°

Performance Tests
Power Output, net: 1.32 bhp at 11,500 rpm
Torque, net: 144 oz-in. at 7,200 rpm
Equivalent b.m.e.p.: 124 lb/sq in.
Specific Output, net: 1.45 bhp/cu in.
Power/Weight Ratio, net: 0.87 bhp/lb

Typical prop rpm (with muffler):
6,800 rpm on a 17x6 Airflow beech
7,500 rpm on a 16x6 Top Flite maple
8,200 rpm on a 14x8 Airflow beech
8,800 rpm on a 16x4 Top Flite maple
9,800 rpm on a 15x4 Airflow beech
10,100 rpm on a 14x6 Top Flite maple

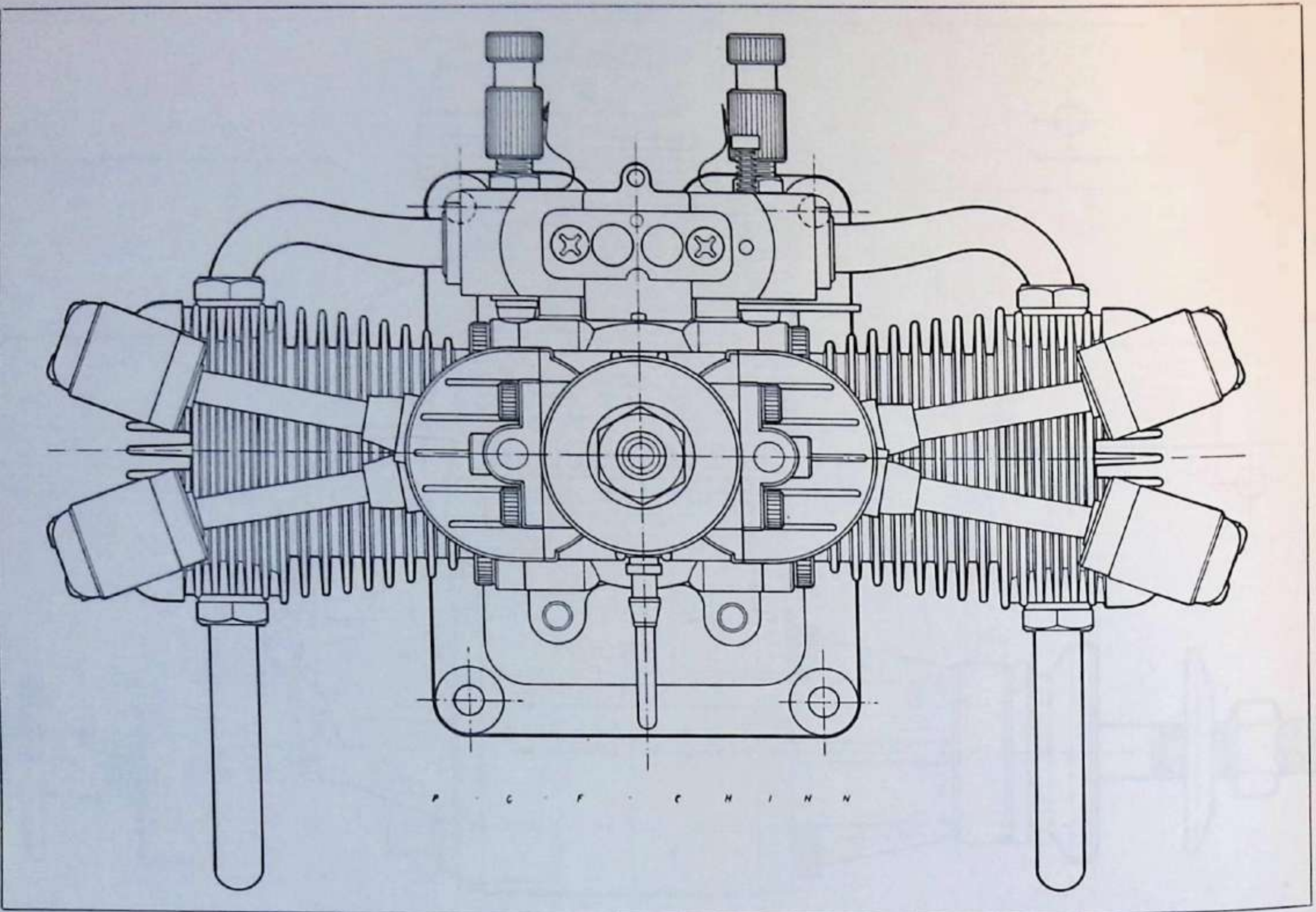
Ultimate development of original FS-60 basic design. Remarkable transformation and vastly superior to FS-75 and FS-80 intermediate models. New engine throughout, combining enlarged valves and ports, further revised cam profiles, increased rocker ratio and 50 percent bigger displacement to boost power by more than 100 percent, for only 4 oz increase in weight including muffler and choke device. Much improved torque also results in above-average performance on bigger prop sizes.



Full test report: M.A.N. April 1985

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan.

SAITO FA-90T Mk.II



SAITO FA-90T Mk.II

Type: Horizontally-opposed, single-crank, twin-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Twin bronze bushed camshafts.

Checked Weight: 805 grams (28.4 oz)

Displacement: 14.98cc (0.9138 cu in.)

Bore: 22.4 mm (0.8819 in.)

Stroke: 19.0 mm (0.7480 in.)

Stroke/Bore Ratio: 0.848 : 1

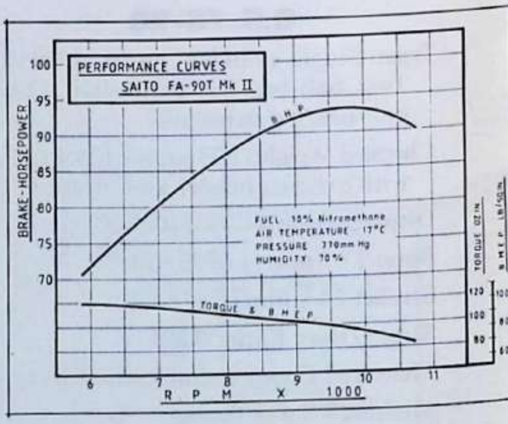
Measured Compression Ratio: 6.6 : 1

Measured Valve Timing:
Inlet opens: 40° (Right), 45° (Left) BTDC
Inlet closes: 35° (Right), 40° (Left) ABDC
Exhaust opens: 60° (Right), 40° (Left) BBDC
Exhaust closes: 50° (Right), 35° (Left) ATDC
Inlet period: 255° (Right), 265° (Left)
Exhaust period: 290° (Right), 255° (Left)
Overlap: 90° (Right), 80° (Left)

Performance Tests
Power Output, gross: 0.93 bhp at 9,800 rpm
Torque, gross: 120 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 103 lb/sq in.
Specific Output, gross: 1.02 bhp/cu in.
Power/Weight Ratio, gross: 0.52 bhp/lb

Typical prop rpm (less muffler):
6,750 rpm on a 16x6 Top Flite maple
7,000 rpm on a 15x6 Top Flite maple*
7,300 rpm on a 14x8 Airflow beech
7,800 rpm on a 16x4 Top Flite maple
8,850 rpm on a 15x4 Airflow beech
9,100 rpm on a 14x6 Top Flite maple
* = cropped from 16 in. diameter

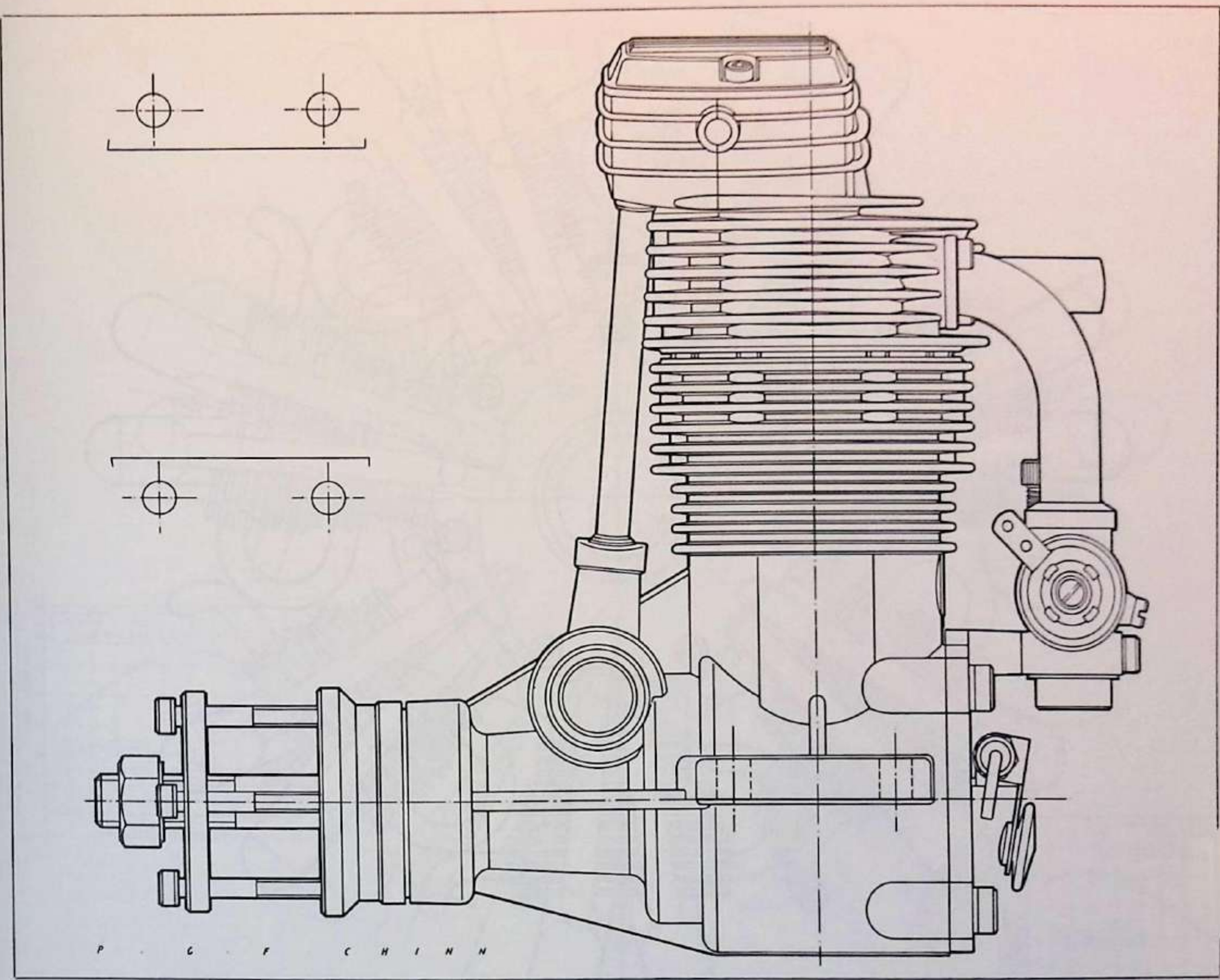
With its unusual single crank design, Saito's moderately priced FA-90T has irregular firing intervals and lacks the conventional flat-twin's balance, but it is smoother than a single-cylinder engine, is easy to handle and runs well. Because it is based on FA-45 Mk.II parts, its cylinders have different valve timings but this, too has no ill effects on its running qualities. The dual choke carburetor, with separate needle-valve for each cylinder, is easy to adjust and works well.



Full test report: M.A.N. September 1984

Manufacturer: Saito Seisakusho Ltd., Ichikawa-shi, Chiba Pref., Japan.

O.S. FS-120



O.S. FS-120

Type: Single-cylinder, pushrod-OHV. Two ball-bearing crankshaft. Two ball-bearing camshaft.

Checked Weight: 770 grams (27.2 oz)

Displacement: 19.96cc (1.218 cu in.)

Bore: 30.4 mm (1.197 in.)

Stroke: 27.5 mm (1.083 in.)

Stroke/Bore Ratio: 0.905 : 1

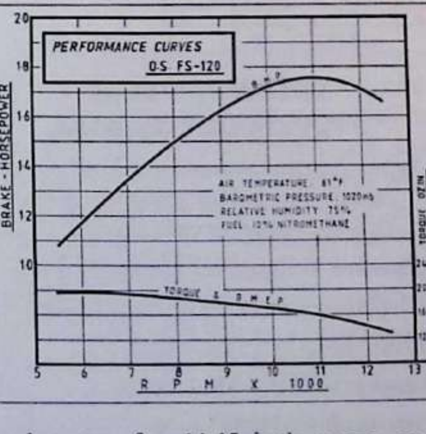
Measured Compression Ratio: 7.7 : 1

Measured Valve Timing:
Inlet opens: 40° BTDC
Inlet closes: 80° ABDC
Exhaust opens: 80° BBDC
Exhaust closes: 40° ATDC
Inlet period: 300°
Exhaust period: 300°
Overlap: 80°

Performance Tests
Power Output, gross: 1.76 bhp at 11,000 rpm
Torque, gross: 195 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 126 lb/sq in.
Specific Output, gross: 1.44 bhp/cu in.
Power/Weight Ratio, gross: 1.03 bhp/lb

Typical prop rpm (less muffler):
7,400 rpm on an 18x6 Top Flite maple
7,800 rpm on a 17x6 Airflow beech
8,300 rpm on a 16x6 Top Flite maple
8,800 rpm on a 15x6 Top Flite maple*
9,000 rpm on a 14x8 Airflow beech
9,700 rpm on a 16x4 Top Flite maple
* = cropped from 16 in. diameter

Originally laid out as a 15cc unit to meet 1983 FAI Scale rules, but redesigned, before production, to take advantage of revised (20cc) limit, hence its modest weight and uncommonly good power/weight ratio. High torque provides good performance on 16-18 inch diameter props for largish scale models, but there is also plenty of top

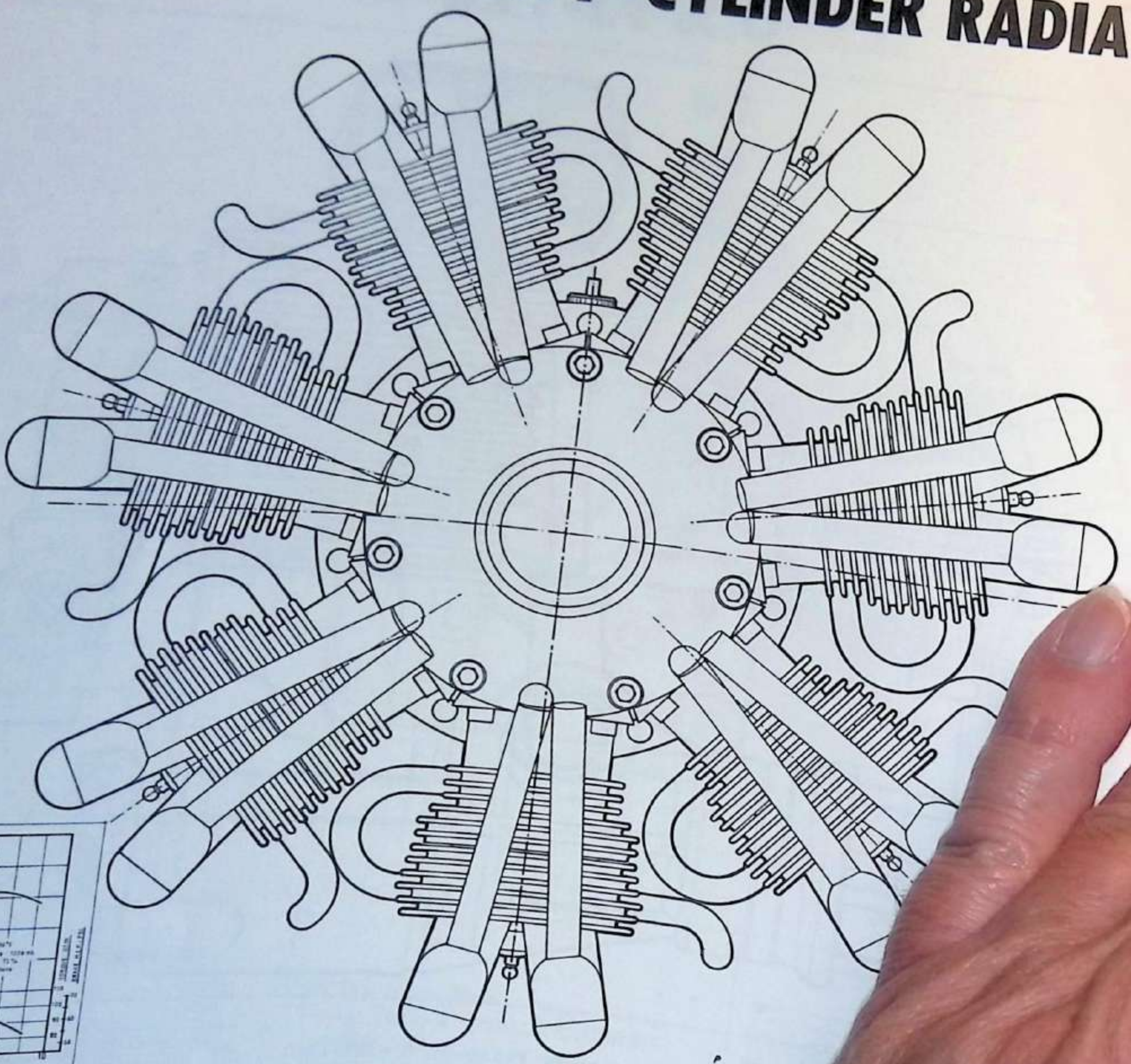


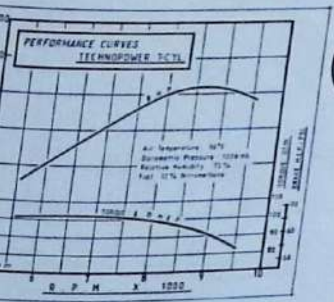
end power for 14-15 inch props on smaller faster aircraft. (Note: 14x6 is too small, allowing engine to exceed bhp peak, especially in flight. 14x7 — not available at time of testing — should be more appropriate.)

Full test report: M.A.N. April 1984

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan.

TECHNOPOWER 7-CYLINDER RADIAL





TECHNOPOWER 7-CYLINDER RADIAL

ype: Seven-cylinder pushrod-OHV radial. Two ball-bearing crankshaft. Two ball-bearing cam carrier.
hecked Weight: 913 grams (32.2 oz)
splacement: 1.353 cu in. (22.17cc)
re: 0.625 in. (15.87 mm)
oke: 0.630 in. (16.00 mm)
ke/Bore Ratio: 1.008 : 1
pression Ratio: 8 : 1
ominal)
ured Valve Timing:
opens: 15° BTDC
loses: 45° ABDC
st opens: 45° BBDC
st closes: 15° ATDC
eriod: 240°

Exhaust period: 240°
Overlap: 30°

Performance Tests
Power Output, gross: 0.82 bhp at 8,700 rpm
Torque, gross: 102 oz-in. at 6,500 rpm
Equivalent b.m.e.p.: 59 lb/sq in.
Specific Output, gross: 0.61 bhp/cu in.
Power/Weight Ratio, gross: 0.41 bhp/lb

Typical prop rpm (less muffler):
6,200 rpm on a 16x6 Top Flite ma
6,600 rpm on a 15x6 Top Flite m
6,900 rpm on a 15x6 Super-Th beech
7,700 rpm on a 16x4 Top Fl
8,300 rpm on a 15x4 Top
* = cropped from 16

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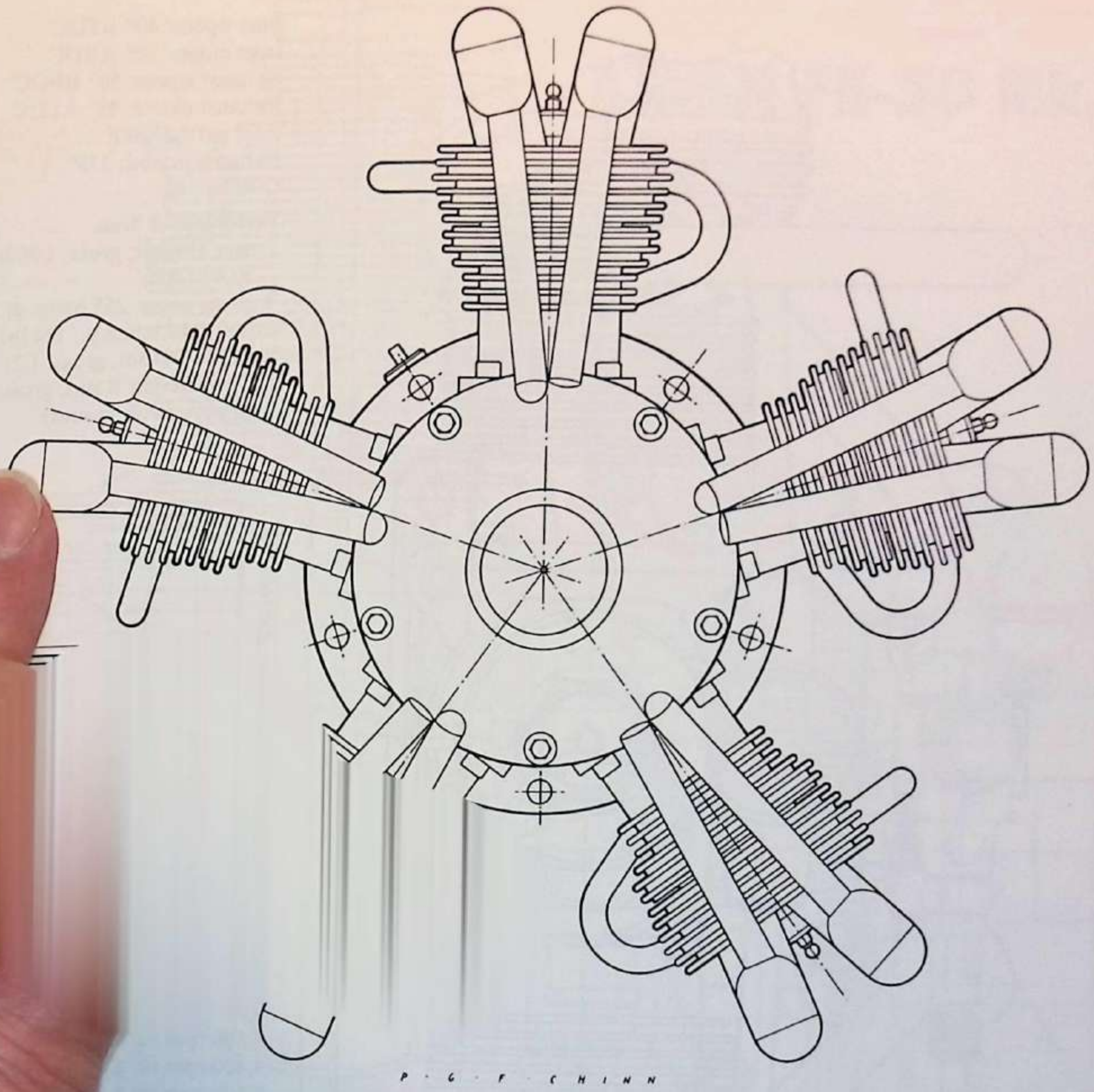
TECHNOPOWER 'BIG BORE 5' RADIAL



OWER
5' RADIAL

ler pushrod-OHV
-bearing crankshaft.
g cam carrier.
717 grams (25.3 oz)
392 cu in. (22.80cc)
9 mm)
. (16 mm)
atio: 0.84:1
mpression Ratio: 6.4:1
lve Timing:
5° BTDC
55° ABDC
pens: 40° BBDC
closes: 40° ATDC
eriod: 250°
ust period: 260°
erlap: 55°

Performance Tests
Power Output, gross: 0.85 bhp at 8,200 rpm
Torque, gross: 116 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 65 lb/sq in.
Specific Output, gross: 0.61 bhp/cu in.
Power/Weight Ratio, gross: 0.54 bhp/lb

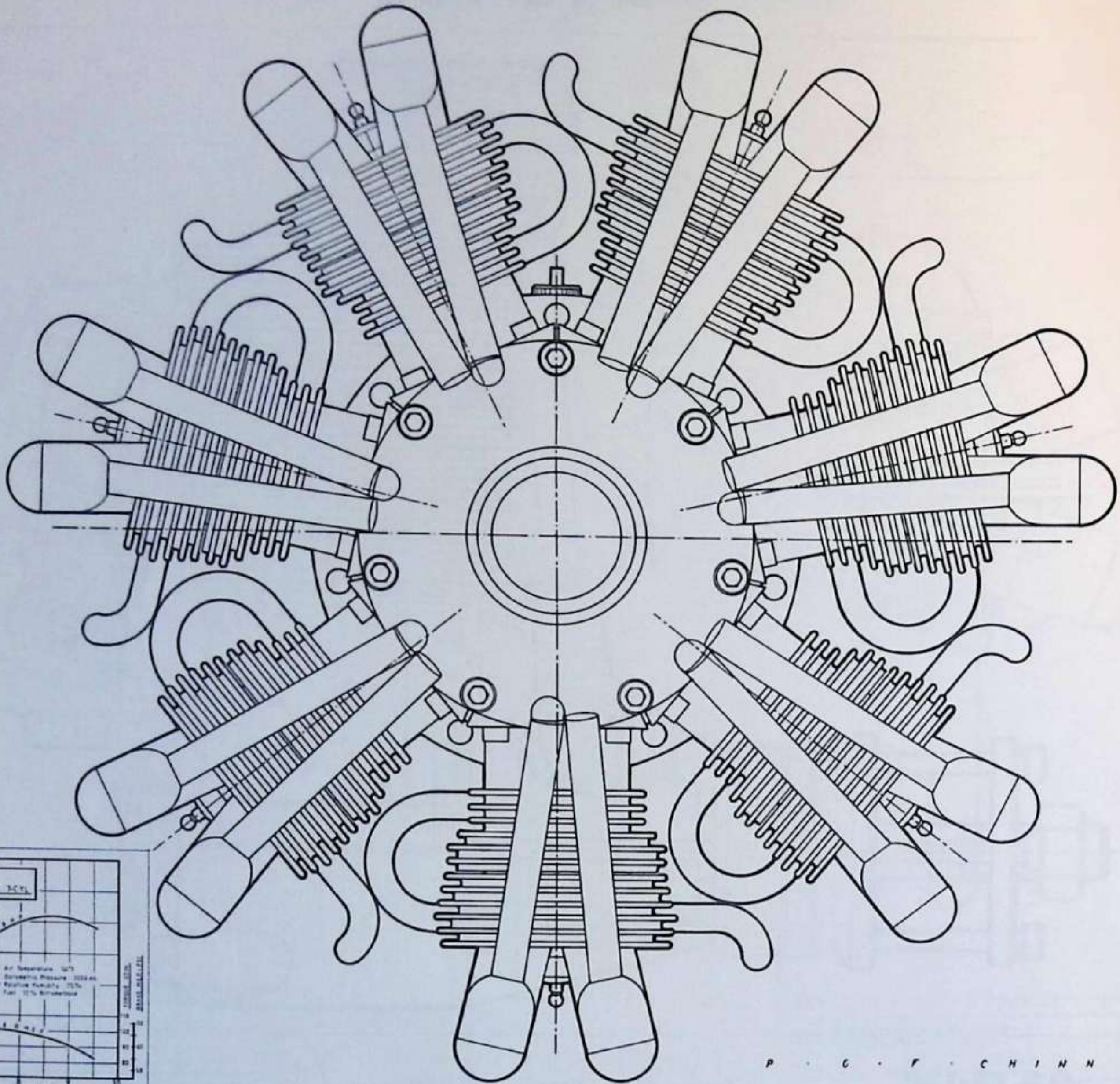
Typical prop rpm (less muffler):
5,900 rpm on a 17x6 Top Flite maple**
6,100 rpm on a 17x6 Airflow beech
6,700 rpm on a 16x6 Top Flite maple
7,100 rpm on a 15x6 Top Flite maple*
7,400 rpm on a 14x8 Airflow beech
7,900 rpm on a 16x4 Top Flite maple
* = cropped from 16 in. diameter
** = cropped from 18 in. diameter

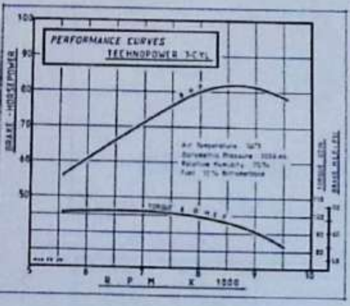
A big improvement on the previous 0.966 cu in. (15.84cc) five-cylinder model. "Big Bore" version increases earlier engine's displacement by 44 percent for substantially higher performance, while the elimination of earlier model's cast-iron cylinder-liners has reduced weight to a remarkably low 25 ounces. Other changes include new investment cast aluminum rocker boxes, a new piston design, a larger diameter shaft front-end and modified valve timing. Definitely a more practical power unit than the earlier Technopower radials.

Full test report: M.A.N. December 1983

Manufacturer: Technopower-II Inc., Chagrin Falls, OH 44022, U.S.A.

TECHNOPOWER 7-CYLINDER RADIAL





TECHNOPOWER 7-CYLINDER RADIAL

Type: Seven-cylinder pushrod-OHV radial. Two ball-bearing crankshaft. Two ball-bearing cam carrier.

Checked Weight: 913 grams (32.2 oz)

Displacement: 1.353 cu in. (22.17cc)

Bore: 0.625 in. (15.87 mm)

Stroke: 0.630 in. (16.00 mm)

Stroke/Bore Ratio: 1.008 : 1

Compression Ratio: 8 : 1 (nominal)

Measured Valve Timing:
Inlet opens: 15° BTDC
Inlet closes: 45° ABDC
Exhaust opens: 45° BBDC
Exhaust closes: 15° ATDC
Inlet period: 240°
Exhaust period: 240°
Overlap: 30°

Performance Tests
Power Output, gross: 0.82 bhp at 8,700 rpm
Torque, gross: 102 oz-in. at 6,500 rpm
Equivalent b.m.e.p.: 59 lb/sq in.
Specific Output, gross: 0.61 bhp/cu in.
Power/Weight Ratio, gross: 0.41 bhp/lb

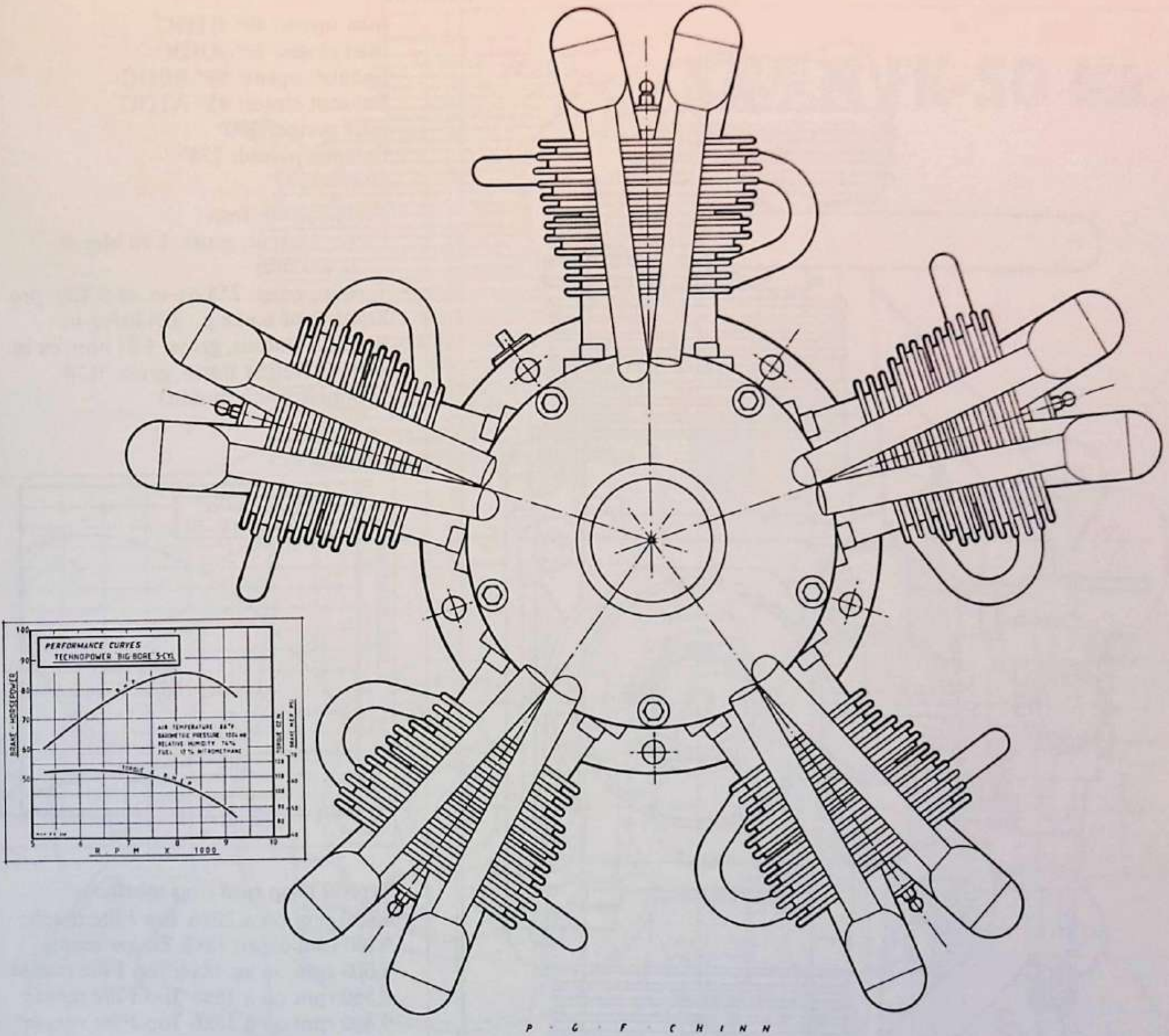
Typical prop rpm (less muffler):
6,200 rpm on a 16x6 Top Flite maple
6,600 rpm on a 15x6 Top Flite maple*
6,900 rpm on a 15x6 Super-Thrust beech
7,700 rpm on a 16x4 Top Flite maple
8,300 rpm on a 15x4 Top Flite maple*
* = cropped from 16 in. diameter

A fascinating engine which looked and sounded very much like "the real thing," but which was not without shortcomings when originally introduced. (See Chapter 1.) 1981 version, shown here, has now been superseded by new "Big Bore 7" model, replacing troublesome GRN rocker box material and with enlarged chromed-bore aluminum cylinders, increasing displacement to 1.92 cu in. (32cc). Should be more powerful, as well as more serviceable. All Technopower radials have full-size radial characteristics and need to be treated accordingly: always remember to check for hydraulic-lock before starting and do not risk overheating by ground-running at full throttle for long periods.

Full test report: M.A.N. March 1982

Manufacturer: Technopower-II Inc., Orland Park, IL 60462, U.S.A.

TECHNOPOWER 'BIG BORE 5' RADIAL



TECHNOPOWER 'BIG BORE 5' RADIAL

Type: Five-cylinder pushrod-OHV radial. Two ball-bearing crankshaft. Two ball-bearing cam carrier.

Checked Weight: 717 grams (25.3 oz)

Displacement: 1.392 cu in. (22.80cc)

Bore: 0.750 in. (19 mm)

Stroke: 0.630 in. (16 mm)

Stroke/Bore Ratio: 0.84:1

Measured Compression Ratio: 6.4:1

Measured Valve Timing:
Inlet opens: 15° BTDC
Inlet closes: 55° ABDC
Exhaust opens: 40° BBDC
Exhaust closes: 40° ATDC
Inlet period: 250°
Exhaust period: 260°
Overlap: 55°

Performance Tests
Power Output, gross: 0.85 bhp at 8,200 rpm
Torque, gross: 116 oz-in. at 6,000 rpm
Equivalent b.m.e.p.: 65 lb/sq in.
Specific Output, gross: 0.61 bhp/cu in.
Power/Weight Ratio, gross: 0.54 bhp/lb

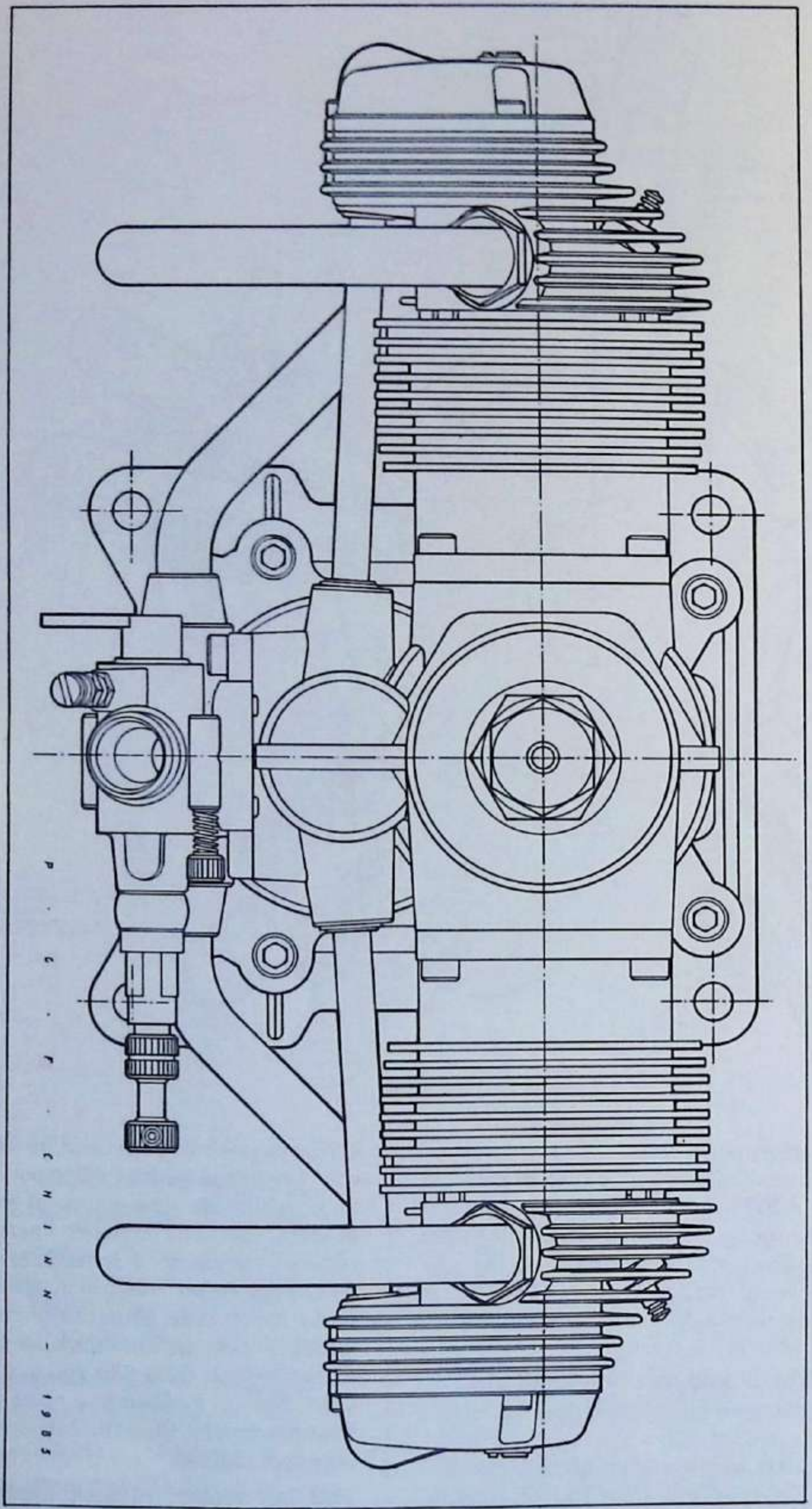
Typical prop rpm (less muffler):
5,900 rpm on a 17x6 Top Flite maple**
6,100 rpm on a 17x6 Airflow beech
6,700 rpm on a 16x6 Top Flite maple
7,100 rpm on a 15x6 Top Flite maple*
7,400 rpm on a 14x8 Airflow beech
7,900 rpm on a 16x4 Top Flite maple
* = cropped from 16 in. diameter
** = cropped from 18 in. diameter

A big improvement on the previous 0.966 cu in. (15.84cc) five-cylinder model. "Big Bore" version increases earlier engine's displacement by 44 percent for substantially higher performance, while the elimination of earlier model's cast-iron cylinder-liners has reduced weight to a remarkably low 25 ounces. Other changes include new investment cast aluminum rocker boxes, a new piston design, a larger diameter shaft front-end and modified valve timing. Definitely a more practical power unit than the earlier Technopower radials.

Full test report: M.A.N. December 1983

Manufacturer: Technopower-II Inc., Chagrin Falls, OH 44022, U.S.A.

O.S. GEMINI-160



O.S. GEMINI-160

Type: Horizontally-opposed, twin-cylinder pushrod-OHV. Three ball-bearing crankshaft. Two ball-bearing camshaft.

Checked Weight: 1,203 grams (42.2 oz) including optional firewall mount

Displacement: 26.52cc (1.618 cu in.)

Bore: 27.7 mm (1.0906 in.)

Stroke: 22 mm (0.8661 in.)

Stroke/Bore Ratio: 0.794 : 1

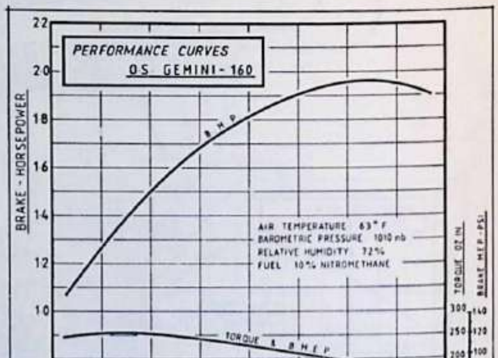
Measured Compression Ratio: 8.0 : 1

Measured Valve Timing:

Inlet opens: 40° BTDC
Inlet closes: 70° ABDC
Exhaust opens: 50° BBDC
Exhaust closes: 45° ATDC
Inlet period: 290°
Exhaust period: 275°
Overlap: 85°

Performance Tests

Power Output, gross: 1.96 bhp at 10,400 rpm
Torque, gross: 255 oz-in. at 5,400 rpm
Equivalent b.m.e.p.: 124 lb/sq in.
Specific Output, gross: 1.21 bhp/cu in.
Power/Weight Ratio, gross: 0.74 bhp/lb (with mount)



Typical prop rpm (less muffler):

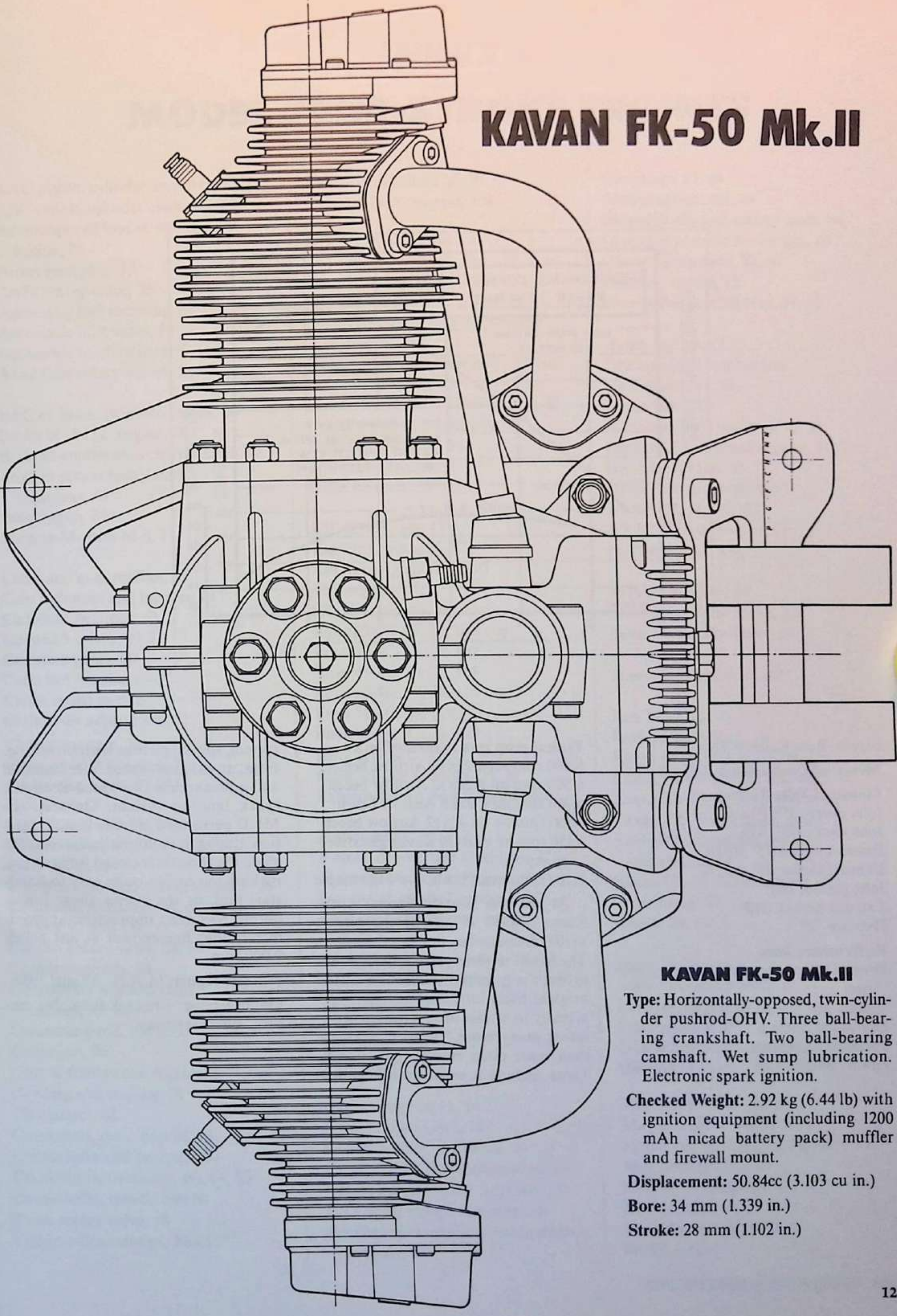
6,050 rpm on a 20x6 Top Flite maple
7,100 rpm on an 18x8 Zinger maple
8,000 rpm on an 18x6 Top Flite maple
8,850 rpm on a 16x6 Top Flite maple
9,400 rpm on a 15x6 Top Flite maple*
9,800 rpm on a 14x8 Airflow beech
* = cropped from 16 in. diameter

Despite its similarity to the original Gemini-120 in layout and appearance, the 160 is a completely new model, a little heavier but slightly more compact. Benefitting from five years further research and development, the Gemini-160 has a more efficient combustion chamber shape, bigger valves and ports, revised timing and other modifications which, together with a 33 percent increase in swept volume, raises the 160's power output to more than 50 percent above that of the original Gemini. An impressive engine; powerful, yet docile, smooth running and flexible.

Full test report: M.A.N. October 1985

Manufacturer: O.S. Engine Mfg. Co. Ltd., Osaka 546, Japan.

KAVAN FK-50 Mk.II



KAVAN FK-50 Mk.II

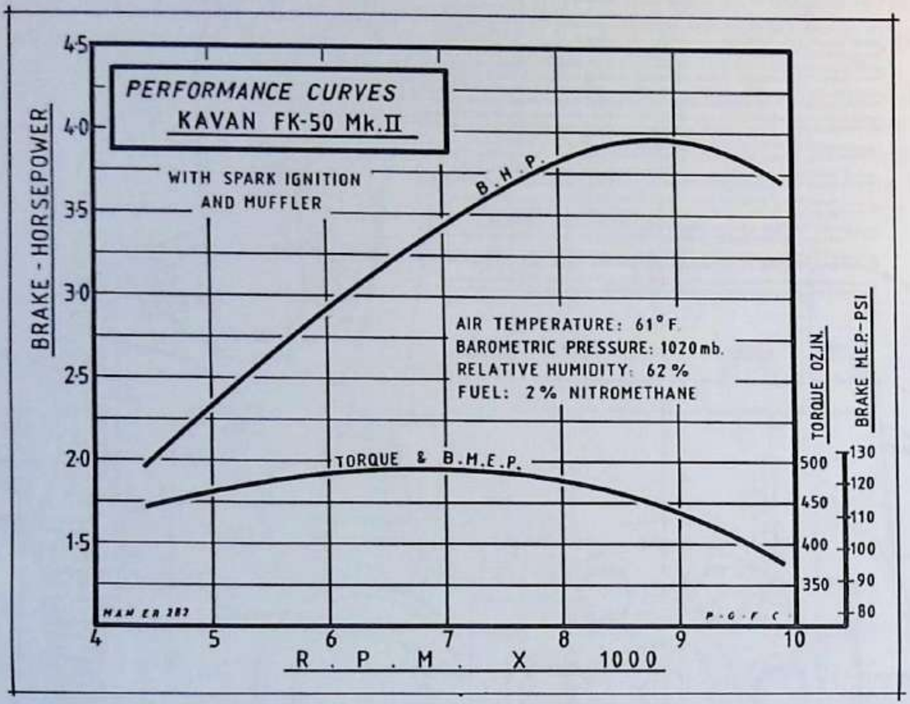
Type: Horizontally-opposed, twin-cylinder pushrod-OHV. Three ball-bearing crankshaft. Two ball-bearing camshaft. Wet sump lubrication. Electronic spark ignition.

Checked Weight: 2.92 kg (6.44 lb) with ignition equipment (including 1200 mAh nicad battery pack) muffler and firewall mount.

Displacement: 50.84cc (3.103 cu in.)

Bore: 34 mm (1.339 in.)

Stroke: 28 mm (1.102 in.)



Stroke/Bore Ratio: 0.824 : 1

Measured Compression Ratio: 8.6 : 1

Measured Valve Timing:
Inlet opens: 35° BTDC
Inlet closes: 75° ABDC
Exhaust opens: 75° BBDC
Exhaust closes: 35° ATDC
Inlet period: 290°
Exhaust period: 290°
Overlap: 70°

Performance Tests
Power Output, net: 3.95 bhp at 8,850 rpm
Torque, net: 490 oz-in at 6,700 rpm
Equivalent b.m.e.p.: 124 lb/sq in.
Specific Output, net: 1.27 bhp/cu in.
Power/Weight Ratio, net: 0.61 bhp/lb.

Typical prop rpm (with muffler):
5,600 rpm on a 22x10 Airflow beech
6,500 rpm on a 20x12 Airflow beech
6,700 rpm on a 22x6 Airflow beech
7,900 rpm on an 18x12 Airflow beech
8,150 rpm on a 20x10 Kavan glassfiber-epoxy
8,300 rpm on an 18x10 Top Flite maple

At just over 50cc displacement, the Kavan FK-50 is one of the largest model four-strokes marketed to date. The Mk.II model, released in 1986, is a substantially improved version of the original Mk.I introduced in 1982 and is really in a class of its own, incorporating many more "full-size" features than most other model four-strokes. These include a separate lubrication system, special pistons with oil scraper rings, an exhaust heated inlet manifold and a breakerless two-speed electronic spark ignition system. On test, the Mk.II performed extremely well. Ignition timing is automatically retarded when the throttle is closed for starting, making the engine quite easy to hand-start and, as the curves show, power output was most impressive: approximately four horsepower at just below 9,000 rpm.

Full test report: M.A.N. August 1986

Manufacturer: Franz Kavan, Nuremberg, West Germany

INDEX
MODEL FOUR-STROKE ENGINES

INDEX

APPENDIX

—TEST DATA ON FOUR-STROKE ENGINES

Including specifications, test data, drawings and performance curves.