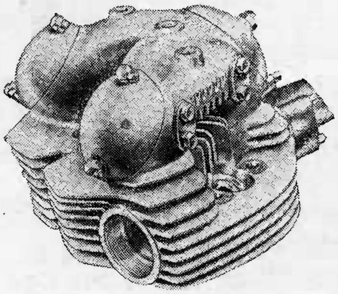
MOTORCYCLE ENGINEERING—22



Heading picture shows the light-alloy cylinder head of Norton's 1960 "Dominator" twins.

Aluminium Alloy Heads

Modern practice and the story behind it

By PHIL IRVING

THE adoption of aluminium alloy for the cylinder heads of side-valve and two-stroke engines presents few problems, because in neither type are there any valve seats, guides or ports to worry about, and the fin design can be quite simple and straightforward—even though at times it is somewhat less effective than it appears to be.

To be of any real use as a heat dissipator, a fin should spring from the hot metal actually surrounding the combustion chamber. Placing vertical fins on a horizontally projecting fin is of very little use except to make the head impressively large and to provide a symmetrical appearance. The original Villiers system, with some vertical and some radially disposed fins, avoids this situation, but does not lend itself well to die-casting in permanent moulds, which is probably the reason why it has been discarded on some models.

Almost any aluminium alloy can be employed, provided it is not too soft and ductile, otherwise it will distort between the bolt-holes and may also eventually give trouble through wearing or stripping of the sparking-plug threads. For racing use, however, with compression ratios running well into double figures, it is advisable to use an analysis such as Y-alloy or RR53, both of which possess great strength at high temperatures, otherwise cracking may occur round the plug-boss.

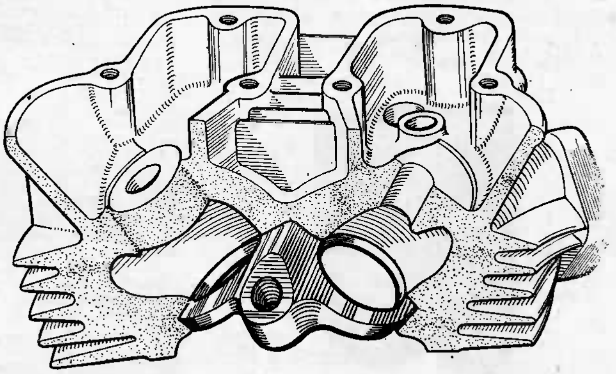
Four-stroke o.h.v. Problems

Four-stroke o.h.v. heads are a different kettle of fish, partly because of the necessity for providing durable valve seats and partly because the structure is complicated—and, in places, weakened—by the presence of the ports.

One method of providing suitable valve seats and retaining rigidity was the original Norton system of first casting an aluminium-bronze "skull," forming the entire wall of the combustion chamber and the first inch or so of both ports. It also had two projecting bosses through which the valve-guide holes were subsequently drilled, and was provided with a number of small ribs which formed keys for the aluminium shell cast round the skull after the latter had been placed in the mould.

This method permitted deep cooling fins to be used without the weight penalty incurred by an all-bronze head, while the contact between the skull and shell was so intimate, and the heat conduction consequently so good, that a compression ratio of 10 : 1 could be employed with pre-war 50-50 petrol-benzole mixture. The head was, however, costly to manufacture in small quantities and did not lend itself to quick production methods in the foundry. Further, the cast metal of the skull was prone to rapid inlet-seat wear which, moreover, could not be repaired by welding and re-machining, as could a solid bronze head, because of the almost certain liability to melt the aluminium shell locally and thus destroy the vital close contact between the two components.

Another approach aimed at reducing weight and making better use of the high-conductivity aluminium was to cast in a pair of seat-rings, either of aluminium-bronze or of austenitic cast iron, relying upon the cooling contraction of the light metal to ensure gas-tight joints between the rings and the head. Unfortunately this was not always achieved, and pressure leakage took place down the sides of the rings, while the thin metal between the rings, or between the plug-hole and the exhaust ring, sometimes cracked, rendering the head useless because repair was impossible.



In the light-alloy heads of the later Ariel "Red Hunters," valve seats and plug boss formed a single cast-iron insert of "spectacles" shape; its edges had a slight reverse taper.

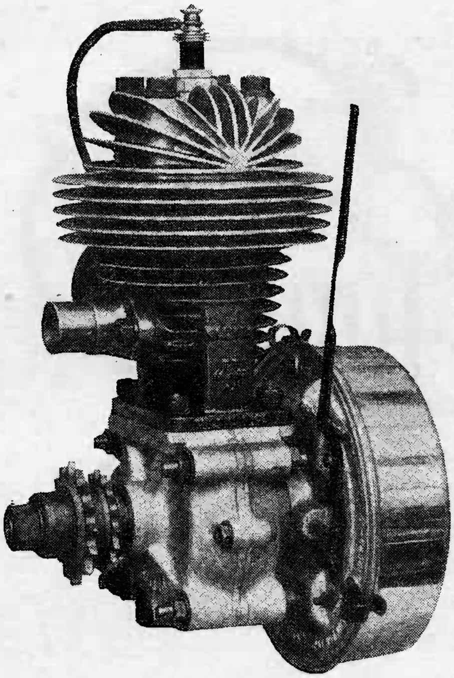
A more satisfactory solution to these difficulties was found by combining both the seat-rings and the plug-boss into a single iron casting resembling a pair of "spectacles"; the design employed in the later models of the 500 c.c. Ariel "Red Hunter" single is a good example. The ring portions are formed with a reverse taper, so that circumferential contraction of the aluminium pulls them firmly back into the rear surface, and the exterior shape of the iron is relatively smooth and not broken up by the ribs which were originally thought to be necessary. In fact, the smoother the surface, the better the contact will be, and it is the general shape rather than the surface finish which retains the whole thing in place.

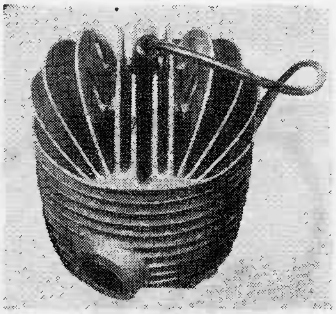
In the Foundry

The construction is, however, rather a tricky one from the foundry angle. The iron casting must first be heated before being placed in the mould, and the latter must then be closed and the metal poured very quickly, otherwise there is a chance of poor contact between the parts or, in extreme cases, voids existing between the two due to water which has condensed on the iron flashing off into steam when the aluminium hits it. Such defects, unless of a gross nature, are difficult to detect.

Still, the "spectacles" plan does at least localize most of the production difficulties within the walls of the foundry, and improved methods have made the process satisfactory both technically and price-wise. But the machine-shop still has to overcome the difficulty of machining the sphere nicely, since austenitic iron should be turned at a low speed with a heavy depth of cut, whereas aluminium is just the opposite and requires a high speed and light cut to obtain the smooth surface finish desired. This, in fact, is one of those situations mentioned in an earlier article, where the demands of the designer temporarily outrun normal production procedure, which eventually catches up with the demand.

Another school of thought preferred to keep all its troubles under its own control by adopting separate valve-seat inserts, fitted mechanically instead of by casting into recesses machined in the head. This scheme had been exploited in the aircraft industry as the only possible method of fitting wear-resistant valve-seats to a forged (as opposed to a cast) head.





Two-stroke heads lend themselves to radial finning. The Villiers sports engine of the mid-1930s (left) employed light alloy for both the head and the muff round the upper barrel. Very deep and almost ideally disposed are the fins of the modern Zündapp alloy head (above).

Holding the Inserts

All sorts of fancy methods have been devised and used to retain the rings—such as screwing them in with the head at a high temperature, or pressing-in below the surface and peening the soft head metal over the edge—but the least expensive and best method happens to be simplest. It consists of machining the recesses accurately parallel and square to the bottom with the finest possible finish, and machining the inserts with similar accuracy and finish to a diameter sufficiently large to ensure that the rings will not come loose at running temperature (which in a well-designed head should not exceed 250° C.).

The first engine to be built on these lines was the Mk. V KTT Velocette. As a precaution, the recesses and inserts in this motor were formed with a very slight reverse taper, amounting to two or three thou. on the diameter—just sufficient, in fact, to permit the large rear ends of the inserts to pass through the small outer ends of the recesses when the inserts were cold and the head heated to 200° C. This stratagem provided an insurance against the inserts dropping out; but boring back-tapered holes to an accurate size is an awkward proposition. Further, if a seat ring *does* come loose you are in trouble, whether it can drop out or not; it just goes on getting looser with continued running. So eventually parallel holes were employed.

A parallel ring in a parallel hole will never—well, hardly ever, as W. S. Gilbert would have said—come loose if the machining standard is high, the interference (or tightness) correct in relation to the metals employed, the general proportions of the ring are right and—a final but quite valuable detail—the ring, when fitted, is slightly "under flush" with the sphere surface instead of being level or standing proud.

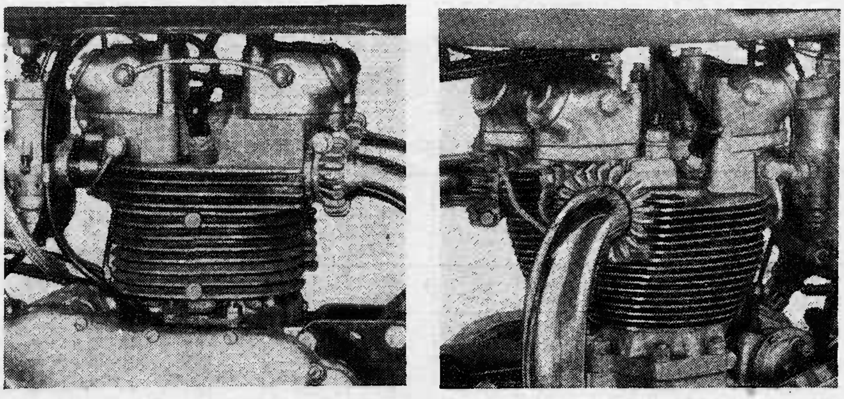
Aluminium-bronze and austenitic cast iron have approximately the same thermal coefficient of expansion, but the former has a higher conductivity. Austenitic iron has a low rate of seat-wear, and while wrought aluminium-bronze in the form of extruded tube is better in this respect than cast metal of the same analysis it is not so resistant as iron, especially on the inlet side. Consequently, in racing engines it is usual to employ the yellow metal for exhaust seats, while austenitic iron is used for the inlets. On sports engines, where long life is of more importance than high conductivity, austenitic iron is generally used on both sides.

Regarding proportions, a shallow thin-walled ring holds in better than a thick, deep one, partly because it has a little more "give" in it to accommodate variations in the fit which are bound to occur with changes of temperature, and partly because, for a given valve size, there is more parent metal surrounding the recess. Occasional cases of ring-loosening have been traced to the excessive tightness of a thick-walled ring, which, when it has expanded under heat more quickly than the head, has stretched the recess permanently, so destroying the original interference. The opposite thing can happen with a bronze ring, which may shrink under excessive compressive stress, but the final result is the same.

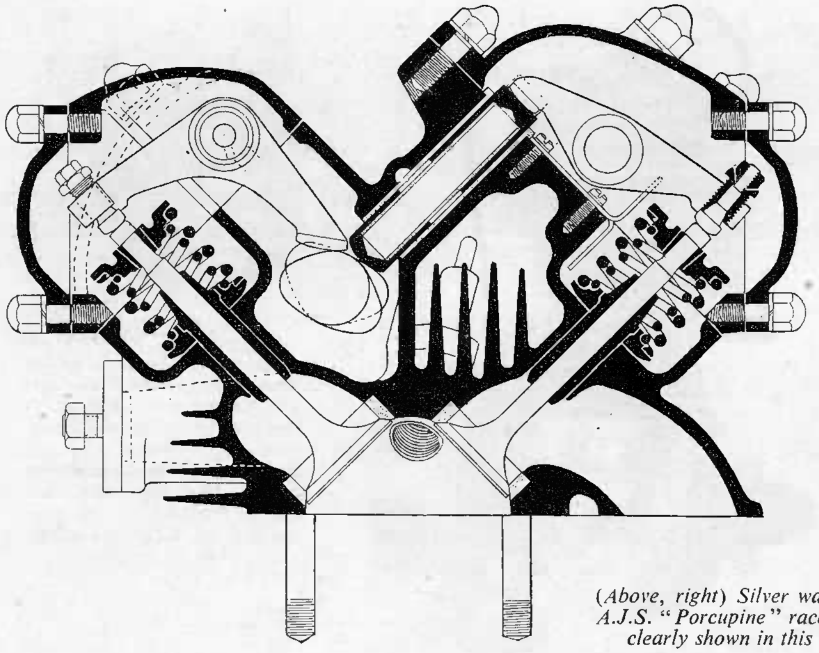
In general terms, the radial wall-thickness of a ring should be around 10% of the port diameter, and its depth should be about 1½ times the radial thickness. The exact proportions are not vital, but those quoted produce rings which will hold in well, without occupying too much of the combustion-chamber area or making the amount of metal between the two inserts dangerously small. Fortunately, with inclined valves the recesses diverge sharply, so there is always more metal between them than there appears to be on the surface.

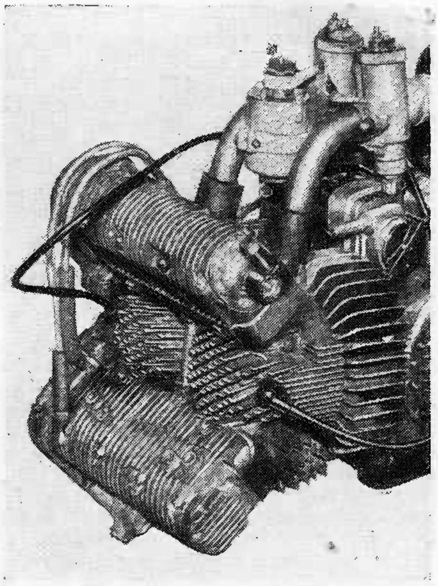
However, as the inserts must be larger than the valves, separate inserts impose a greater limitation on the maximum sizes of the valve heads than does the "spectacles" pattern of cast-in insert or the now disused "skull" arrangement. This limitation could be serious in a long-stroke small-bore engine, but becomes less so as the cylinder proportions become square or over-square and there is more room for the valves.

As an interesting sidelight on this facet of head design, it may not be generally known that the A.J.S. racer which subsequently came to be known as the "Porcupine" was originally intended to be supercharged and to be able to run at manifold pressures of up to 20 lb. above atmospheric. To handle over twice as much air as when normally aspirated without incurring too much pumping loss, the largest possible valves would be required; and to minimize the ill effects of the much greater heat-loss to the walls, a head material of the



Sand-cast barrel of a 1948 Triumph "Grand Prix" engine (left) contrasted with one of the same maker's early die-cast barrels on a touring engine, some four years later.





(Above, right) Silver was too expensive. . . . Complex head of the 1948 A.J.S. "Porcupine" racer. (Left) Disposition of pressed-in valve inserts is clearly shown in this section of an experimental Sunbeam alloy head.

highest available conductivity was essential.

One solution, which received much more than a passing thought, was to cast the head in silver, the thermal conductivity of which is three times as great as that of pure aluminium, and to utilize thin-walled, shallow inserts, silver-soldered in position to provide both a thermal and a mechanical bond with the head without, in themselves, placing any restriction on valve size.

This project even got as far as a visit by Joe Craig to Hatton Garden, from which two major facts emerged. One was that the head casting alone would cost about £350, though the silver merchants were prepared to buy back any machining swarf and scrapped or unwanted heads at the ruling market price for the metal.

The other revelation was that in order to be castable in the intricate sections demanded by the general construction, and to be hardened sufficiently for mechanical strength, the silver would have to be alloyed with a high proportion of copper. This would have the effect of dropping the thermal conductivity to a figure not much better than that of aluminium, though size for size the silver head would have been 3½ times as heavy as an aluminium one!

So the idea was smartly abandoned as impracticable (even if the frantically high price could have been accepted) and the head reverted to Y-alloy. In any case, the whole head design had subsequently to be drastically altered, since the porting system adopted for supercharging was totally unsuitable for atmospheric induction with normal carburetters.

Y-alloy, containing 92% aluminium and 3½% copper as its main ingredients, was one of the first high-strength light-weight casting alloys to be discovered and it is still one of the best materials available, particularly as it retains its strength well at high temperatures. This invaluable property is shared by RR53, which some consider to be easier to cast, and many high-performance heads made in England have been manufactured from one or other of these two metals.

Both have to be heat-treated to bring out their full strength. This means that should any repair work, such as welding-up holes caused by over-enthusiastic port enlargement, be carried out by oxy-welding, the metal in the vicinity of the weld will be only in the annealed or soft condition and its strength will have gone down from 18 tons to about 10 tons/sq. in., which may have serious effects. Small welds can, however, be made by the argon-arc process without deleterious results, as the welding heat is applied only locally and very briefly.

As can be seen from the table of physical properties, the coefficient of expansion of these two alloys is fairly high, so they tend to expand away from aluminium-bronze or austenitic iron inserts. An interference of .002 in. per inch of diameter is, therefore, necessary to retain them without loosening at running temperature.

Alloys containing a high percentage of silicon, such as "Lo-Ex" or L33, have a coefficient almost identical to those of bronze and austenitic iron, so slightly less interference can be used. For "Manx" Nortons, which employ this variety of light alloy, a total interference of .003 in. is quoted.

After allowing for the thicker sections required in stressed areas, an aluminium head scales about half the weight of an iron head of the same overall dimensions. Even so it is more expensive in material cost, especially when the high-strength metals just discussed are used.

However, it has been found that except for out-and-out racing these are not really necessary, and less-expensive commercial alloys, particularly DTD424, which came into use during the war as a general-purpose metal, can be employed satisfactorily. Moreover, DTD424 can be die-cast in permanent metal moulds with a reduction in labour cost, greater dimensional accuracy and a better surface finish than can be obtained with conventional sand moulds.

These factors, allied to the high speed at which aluminium can be machined, all tend towards bringing the overall cost down to a figure which is low enough to permit the use of light-alloy heads on touring engines, with benefits to the rider which not so long ago were enjoyed only by those who could afford the more exotic types of motorcycle, and in the past few years there has been a very noticeable trend towards greater adoption of the scheme by all manufacturers.

Next week's Sports Machine Number will contain a special article by Irving on competition engines.

PHYSICAL PROPERTIES OF LIGHT ALLOYS

Commonly Used Nomenclature	British Standard (B.S. 1490)	Ultimate Tensile Strength tons/sq. in.		0.1% Proof Stress tons/sq. in.		Ultimate Tensile Strength at 250°C. tons/sq. in.	Coefficient o Expansion (20°C. — 100°C.
		Sand Cast	Chill Cast	Sand Cast	Chill Cast	Sand Cast	
DTD424	LM 4	9.0	10.0	5.0	5.0	8.1	21×10^{-6}
L33	LM 6	10.5	12.0	3.5	4.5	5.0	20×10^{-6}
Lo-Ex	LM 13WP	11.0	16.0	12.0	17.0	10.0 (Chill Cast)	20×10^{-6}
Y-Alloy	LM 14WP	14.0	18.0	13.0	15.0	14.2	23×10^{-6}
RR 53	LM 15WP	18.0	21.0	16.0	19.0	13.8	22×10^{-6}
RR 50	LM 23P	10.0	12.5	7.0	8.0	6.2	22×10^{-6}

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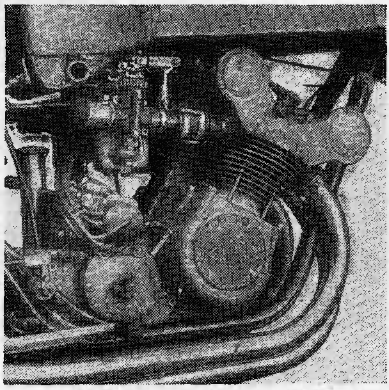
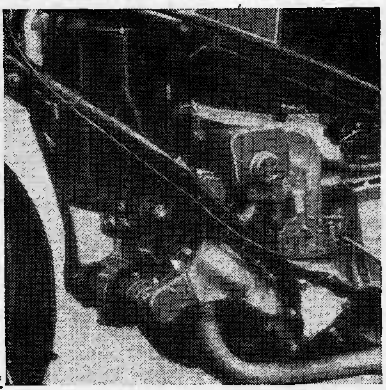


Air v. Water Cooling



—from the two-wheeler designer's angle

by PHIL IRVING

WHY is it that nearly all motorcycle designers retain air cooling, when the majority of internal-combustion engines in other types of vehicle are water-cooled?

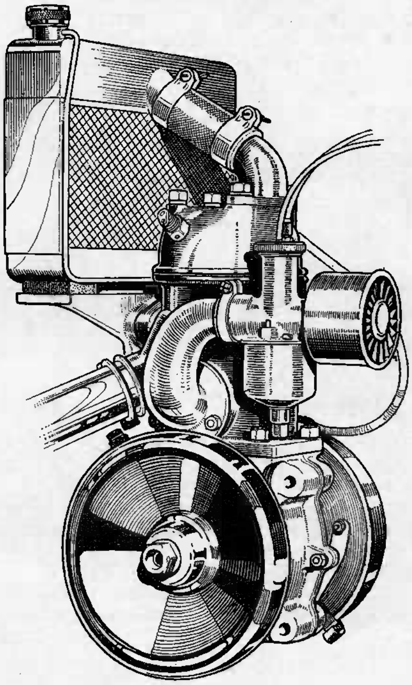
There is no doubt that water cooling does confer some advantages, particularly on an engine whose design is such that (a) adequate cooling fins cannot be provided at vital places, or (b) no draught can reach those fins which are there.

The first conditions may exist in a four-cylinder engine of the in-line or V type which has its cylinders closely packed together in order to reduce its block bulk. The second exists in any side-valve cylinder, where it is extremely difficult to guarantee that air will reach the hot-spot between the barrel and the exhaust port in sufficient quantity to keep the local temperature within bounds even at perceptible road speeds, whilst at low speeds or a standstill air cooling at this point may cease entirely and heat can be dissipated only by conduction to cooler areas.

Water cooling can clearly be a great help in reducing local high temperatures due to these and similar causes, if the water passages are correctly designed.

Four cylinders, in line or in a square arrangement, can be incorporated either integrally or in the form of inserted wet liners into a single casting of great rigidity, and so long as the barrels are not actually touching they will be cooled substantially equally all round and consequently will be free from thermal distortion. Some car blocks have even been made with the barrels "siamesed"; that is to say, with alternate pairs joined together so that there is no water-space between. This is not really a sound scheme; it is usually adopted in order to shorten an over-long cylinder block and so save a little weight, but that is its only justification.

A V-four, inherently a bad design for air cooling, can be constructed with a pair of linered aluminium blocks on the lines pioneered by the 1939 A.J.S. racer. This was originally designed for air cooling, but cylinder distortion and other troubles made the change-over imperative when supercharging was adopted.



The 250 c.c. Villiers of 1936 was offered as a unit with ready-mounted radiator. Heading pictures compare the water-cooled Gilera engine of 1938 with its post-war descendant.

At this stage it may be as well to consider just what the cooling system has to contend with. In terms which are necessarily generalized because of the variation between designs, only 30 to 35% of the heat generated by combustion is converted into mechanical work at the piston; a little of this is lost in piston friction and reappears as heat which is absorbed by the barrel. A further 30% of the heat is absorbed by the surfaces bounding the combustion chamber. Finally 35 to 40% is lost in the exhaust gas, one of the advantages of a high compression being that this type of loss is reduced and more heat is converted into work.

However, the rate at which heat is absorbed by the head is very far from being constant over the whole area, even in an open, unobstructed hemispherical head, because during the exhaust stroke the surfaces adjacent to the exhaust valve are being scrubbed with gas at a high temperature, and even when that valve is shut the port is still full of hot gas. In a squish-type o.h.v. head with vertical valves located in a bath-tub-shaped recess, the flat squish area is largely protected from the worst of the combustion heat—or, to be more exact, is purposely designed so that little or no actual burning takes place in the narrow gap between it and the piston crown—so this area keeps very much cooler than the exhaust-valve region.

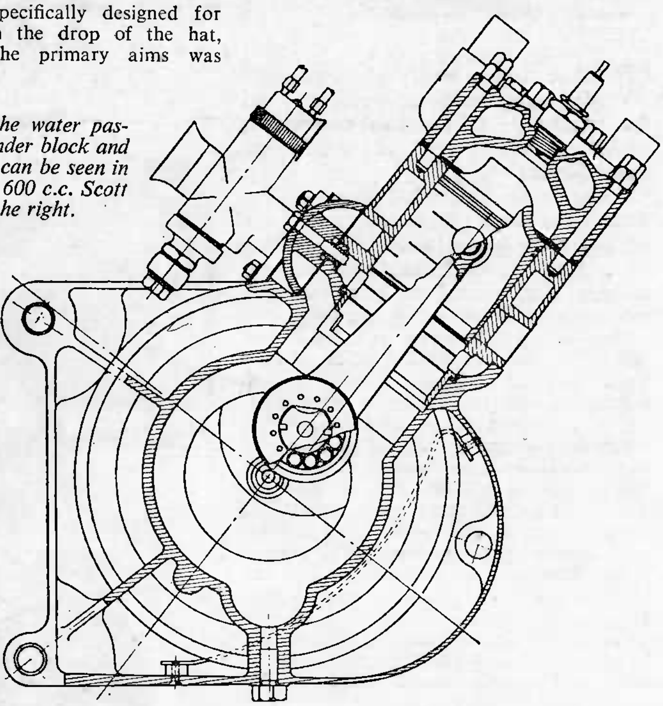
The area around the inlet valve in any shape of head is the coolest of all, not so much because it absorbs less heat as because it is kept cool by the ingoing fresh mixture and by conduction back to the cold inlet port.

Now what one requires in the combustion chamber is, as in many other instances, a compromise between two extremes—not too hot, not too cold, but just right. The colder the surfaces and the higher the conductivity of the metal, the greater the absorption of heat and the reduction of power (hence some of the sluggishness of an engine when first started up). On the the other hand, if the walls, or parts of them, are too hot, trouble will arise through (a) detonation, which causes "pinking" and can be very destructive; (b) pre-ignition, which may cause a dull knock and, even if inaudible, reduces power through excessive pressure-rise towards the end of the compression stroke; or (c) "running-on," i.e., an annoying refusal to stop when the ignition is switched off.

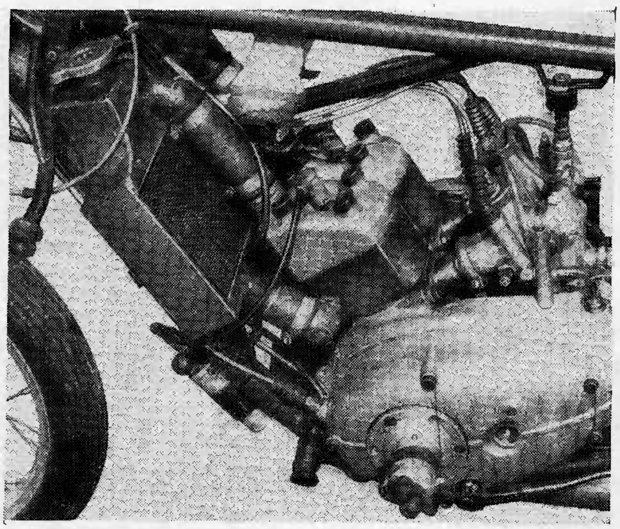
These faults, it must be borne in mind, are all due to *surface* temperatures, and it is clear that the local high rate of heat absorption around the exhaust valve is less likely to lead to uncomfortably hot surfaces in this region if the thermal conductivity of the metal is high, so that part of the excess heat can be conducted swiftly away towards the colder areas to equalize the surface temperatures, and part can be transferred rapidly to the external surface from which all the heat has eventually to be dissipated, irrespective of whether finning or water-jacketing is employed.

The exhaust valve, assailed as it is on both sides by hot gases, has to do what it can to keep cool by conduction through the seat and also down the stem and thence to the valve-guide, which itself is partly exposed to high-temperature gas. Conduction through the seat can only occur while the valve is actually closed, and the longer the valve-opening period the less the time available for the process; so, in racing engines particularly, cooling via the stem and guide becomes the main outlet and great care is necessary in the design of this locality to achieve valve reliability.

In any good water-cooled engine, care is taken to provide ample water-spaces round the valve-guide boss and adjacent to the seat, while pipes are often included to direct the flow of water towards these danger areas. Unless some such provision is made, or the jackets are skilfully designed to bias the water-flow in this direction, local boiling accompanied by the formation of steam pockets may occur.



Disposition of the water passages in the cylinder block and detachable head can be seen in the section of a 600 c.c. Scott engine on the right.



Radiator of the 1959 250 c.c. Adler racer (left) is placed high in relation to the cylinder block and equipped with a pressure-cap.

There is then a grave danger that an iron head (or block, in the case of a side-valve) may crack, either simply through getting too hot or through rapid cooling off and contraction should conditions suddenly ease and the pockets rapidly fill with cold water. (There is a system known as "vapour-phase" or evaporative cooling, in which boiling followed by condensation outside the engine is intentionally allowed to occur; but this method can be used successfully only in power-units with water passages expressly designed or inherently suitable for it.

Most water-cooled car and truck engines are fitted with pumps to provide a flow of coolant adequate for all demands, a thermostat to reduce the flow for quick warming-up and to avoid over-cooling under easy conditions, a radiator to transfer heat to the air and a fan to provide an air flow when the forward speed is insufficient. All these things, plus a pressure-cap on the radiator to raise the boiling-point slightly at sea-level and maintain it at the same temperature at altitudes, are necessary to cope with every possible set of running conditions.

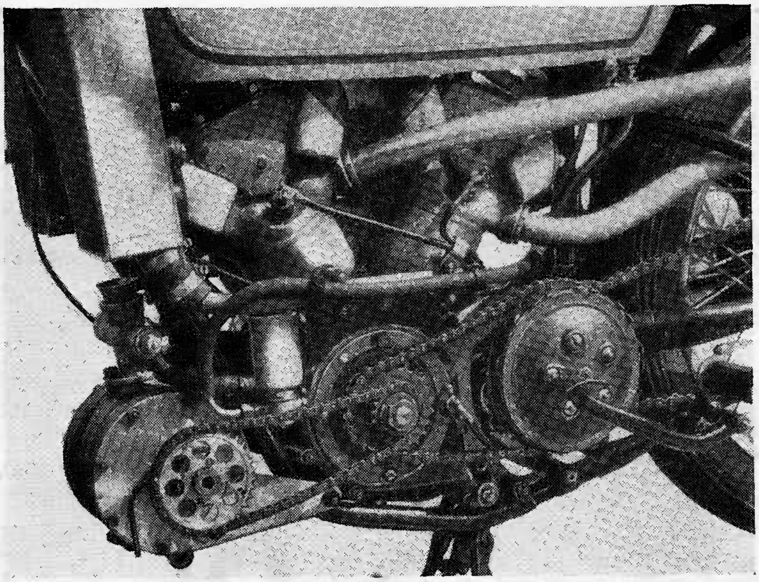
On a four-wheeler there is usually enough space for these ancillaries. The situation is different on a single-tracker which is sufficiently cramped for space already unless the engine is either small in itself or has been arranged to leave some free space within the frame, as on the LE Velocette. This model was specifically designed for water cooling from the drop of the hat, because one of the primary aims was longevity—a feature which could not have been attained with small side-valve cylinders due to the difficulty, already noted, of eliminating local high temperatures and distortion between the exhaust ports and barrels. The problem is not present in the o.h.v. variant of this engine which is satisfactorily air-cooled.

Nevertheless, from time to time, designers have produced water-cooled models, some of which, notably the Scott, have been highly successful.

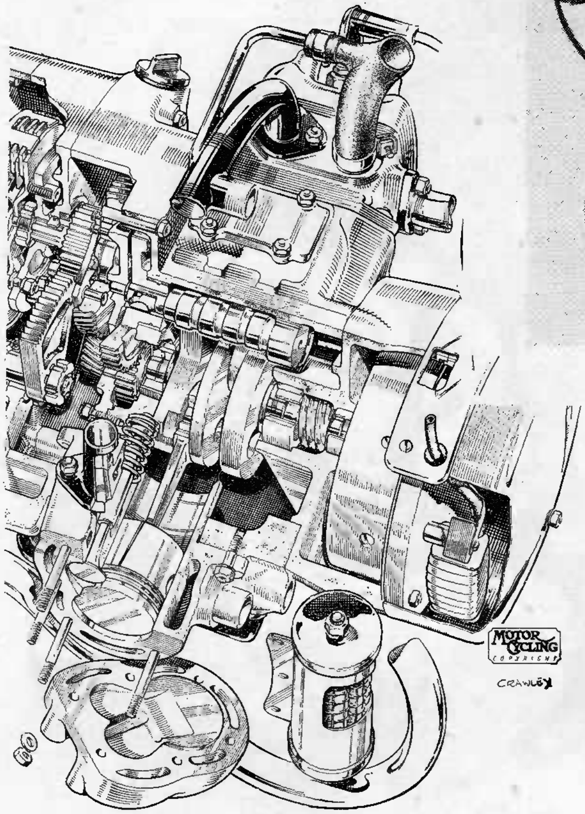
A two-stroke barrel suffers very intensely from big temperature differences in areas which are close together and therefore prone to cause cylinder distortion. Differential cooling to cure this effect at least partially can be provided by the simple expedient of feeding the cool water into the jacket immediately adjacent to the exhaust port (or between twin ports) and, if necessary, deflecting the flow away from the transfer-port region by internal baffling or similar means. This scheme was adopted in the 250 c.c. Villiers of the mid-thirties which had two exhaust and four transfer ports; whereas the air-cooled version of the same engine could be overdriven on a hot day, it was impossible to tire the water-cooled model provided, of course, the radiator was adequate.

It is perhaps significant that nearly all examples of water cooling in recent years have been two-strokes intended purely for racing, where the air-speed is high for most of the time and the lowness of the engine, and particularly of the exhaust system, not only allows enough space for a radiator large enough to handle a relatively modest horsepower, but permits it to be mounted at such a height that thermo-syphon circulation is adequate.

This system, which does away with the need for a pump, depends upon the fact that hot water is lighter than cold. It has the advantage that circulation does not commence until the engine itself is fairly warm, and thereafter automatically adjusts itself to demand. However, it will not provide a sufficiently rapid flow unless the top of the radiator is well above the outlet from the cylinder jacket. Even then, if for any reason the radiator ceases to reject heat as fast as it receives it, the water temperatures on the hot side and the cold side will tend to equalize, the thermo-syphon action will slow down and cease, and boiling will commence soon after.



Water cooling for performance: the fabulous 500 c.c. A.J.S. supercharged V-four racer of 1939. Only one of the twin radiators was actually used.



Water cooling for longevity: engine section of the 200 c.c. Velocette LE power unit. The LE is the only two-wheeler now in large-scale production to be designed specifically for water cooling.

The most probable cause of this condition is a lack of cooling air travelling in the right direction, which is of course, square to the main radiator surface, whereas the fins of an air-cooled cylinder can reap a benefit from whatever direction the breeze arrives. At a standstill, neither can keep going indefinitely, though the air-cooled cylinder is at an advantage, because the rate of pure radiation (as opposed to transfer of heat to the air in contact with the fins) increases as the fourth power of the temperature, and consequently a moderate rise in temperature results in a greatly increased rate of rejection by this means, which is quite evident to anyone astride a machine in traffic on a hot day.

A radiator, despite its name, cannot make use of this phenomenon because it cannot rise above boiling-point, and this it may attain very quickly in the absence of air from straight ahead. One method of assistance is to incline the radiator forward so that air can move through the core by natural convection; this is a feature of the Scott, but if overdone may reduce the efficiency at high speed.

The whole problem could be solved by fitting a fan. This, however, is bulky, difficult to drive on a conventional motorcycle and, unless carefully guarded, is likely to inflict physical injury on an unsuspecting mechanic—altogether something to be avoided in this application, although it is a perfectly feasible proposition when flywheel-mounted and cowled, as is now common practice on many scooters.

Thermo-syphon circulation operates with only a few ounces per square inch pressure differential, and therefore requires large areas in order to promote an adequate rate of flow. These can be provided easily in a two-stroke, but not so easily in a four-stroke, especially in the danger areas round the exhaust valve and sparking-plug boss.

By fitting a pump the water can be forced to go where it is most needed, and it even becomes possible to use ethylene-glycol, which is more viscous than water, to keep the general temperature of the engine higher. This circulation system was used on the A.J.S. racer but, besides providing an extra component to drive, it complicates the pipework and is a potential source of water leaks.

The geared-twin, supercharged racing Velocette (" The Roarer "), which was at the paper stage when the A.J.S. first appeared in its water-cooled form with twin radiators, was originally intended also to be water-cooled, but Harold Willis was so horrified by the apparent bulk and complexity of the Woolwich product that he instantly reverted to air-cooling, despite the fact that the exhaust ports were at the rear and thus deprived of any direct air-blast. He did not know, of course, that only one of the A.J.S.'s two radiators was in use and that the apparently enormous pump-casing contained an impeller of exactly the same size as the one he had intended to fit.

On the score of cost, water cooling is probably the more expensive, partly because a radiator with the stylish appearance necessary on an open motorcycle is not a cheap item and some extra parts and work are entailed in assembling and coupling-up the cooling system. Some benefit is to be expected in mechanical silence because the water-jacket acts as a sound-deadener, but advances in cam and valve-gear design and the adoption of pistons which can be run with very close clearances have resulted in some air-cooled engines being so quiet that there would be little gain from water-cooling them.

All in all, therefore, it would appear that for everyday use with conventional o.h.v. engines, in single or twin-cylinder form, air cooling is as good as, and in some respects better than, water cooling. It also results in a motorcycle which is easier to build and subsequently to work upon; and it has no freezing troubles in winter-time.

For racing, water cooling is unnecessary except for engines with tightly packed cylinders, but it may be of great advantage for two-strokes of very high specific output. Another worth-while application might be for a record-breaker using a very compact, heavily supercharged four-cylinder unit with a skin-surface radiator forming part of the shell and offering very little extra air resistance; the idea has been tried on cars and aeroplanes and certainly offers possibilities which have not so far been exploited for a two-wheeler.

IRVING NEXT WEEK
How the cylinder head gets rid of heat: the theory behind effective fin design.