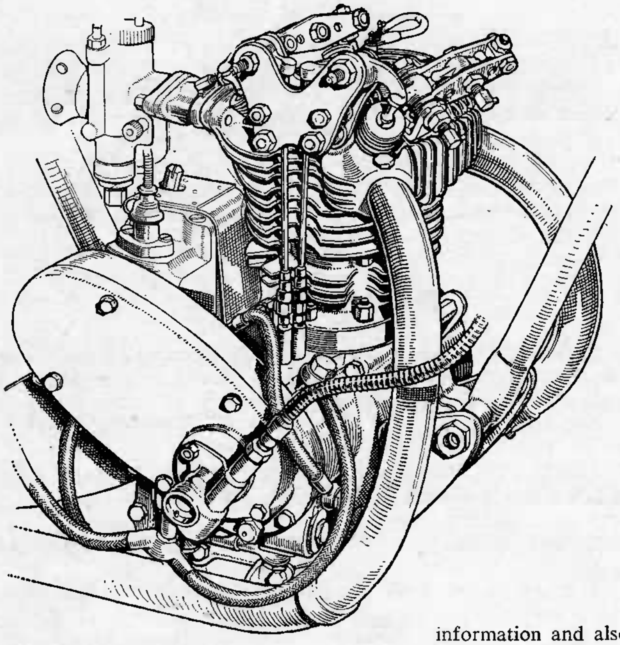
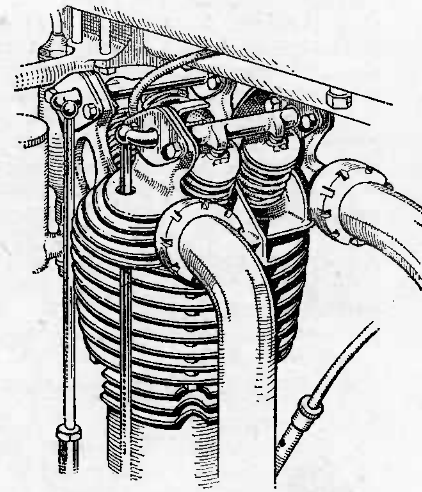
How Many Valves per Cylinder?

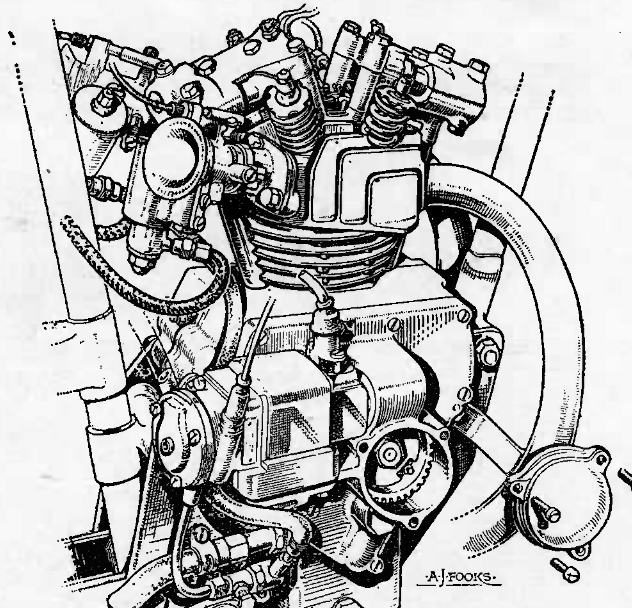
By **PHIL IRVING**, *M.I.Mech.E., M.S.A.E., M.I.P.E*

An examination of a recurring problem in engine design



Outstanding examples of successful racing 4-valve engines include (left) the 1931 Junior T.T. Rudge —scion of a long established line of 4-valvers— and (below) the 1933 250 c.c. T.T. winning Excelsior "Mechanical Marvel." On the right is the famous Ricardo Triumph which achieved much popularity as a touring power-unit in the early 'twenties.





THE adoption of the "four valves per cylinder" principle by the Honda concern for their racing 125 and 250 c.c. engines has naturally revived interest in this layout, and my remark in "T.T. Technicalities" that the decision was surprising in view of past experience has called forth some comment.

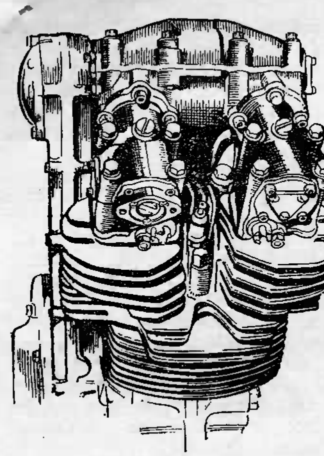
Well, so it should. On the face of things, a quick glance at the two-valve head reveals two large areas which could usefully be employed to accommodate two more valves, leaving a space in the centre which would provide a better location for the plug than the off-centre position normally adopted with two valves.

Many very successful engines have been made on just these lines, and many eminent designers have utilized the idea from time to time. Nevertheless, it is still true to say that, whatever has occurred in other fields, so far as racing motorcycles are concerned (and, for that matter, cars also), any supremacy the four-valve engine has had has been of limited duration, and the two-valve system has reasserted itself.

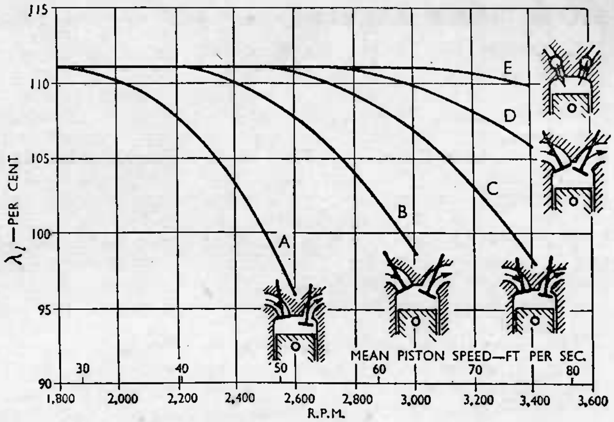
This is contrary to certain experimental information and also to some theories; but when an apparent conflict of this kind occurs one is driven to the conclusion that either the theories or the experiments have not gone far enough, or the results obtained are not strictly applicable to the subject in hand.

After all, racing can be regarded as at least a type of experiment; and, viewed in this light, it is not very logical to reject the results of racing as inconclusive whilst upholding findings obtained under conditions which, though more scientifically controlled, do not always duplicate those to which the results are subsequently applied by other investigators.

For instance, a correspondent, Mr. John Treen, has drawn attention to a most informative article by Dr. Hanz List, published in the Proceedings of the Automobile Division of the Institution of Mechanical Engineers, 1953. This deals with the subject of gas-flow, mainly in two-stroke engines but also in four-strokes, and one of the graphs included shows the relative breathing ability of five valve arrangements—two two-valve schemes, two four-valve schemes and one with a pair of rotary valves—the cylinder size being 6.38 x 7.08 in.



Though discontinued for commercial reasons, the A.J.S. 7R3 engine achieved some notable success in its short racing life. It used two exhaust valves and one inlet with chain drive to the o.h. camgear; a shaft drive was also tried experimentally.



Comparison of different types of valve gear by tests on models. Supercharge pressure, 21.35 lb. per sq. in. absolute. Engine, 12 cyl. V form; bore 6.38 ins; stroke 7.08 ins. A: 2-valve gear, normal design. Inlet valve, 3.18 ins. diameter. B: 2-valve gear, optimum design. Inlet valve, 3.46 ins. diameter. C: 4-valve gear, normal design. Inlet valve, 2.34 ins. diameter. D: 4-valve gear, optimum design. Inlet valve, 2.6 ins. diameter. E: 2 rotary valves, half engine speed: valves 3.34 ins. diameter.

At first glance, both the two-valve schemes are very much worse than the four-valves. However, the graph could be a little misleading to a layman in this respect; if both the horizontal and vertical lines of origin are re-drawn in their zero positions, instead of at 90% and 1,800 r.p.m. respectively, the disparity does not appear to be nearly so great.

However, taking actual readings of the best two-valve and best four-valve arrangements, the latter shows an improvement of 11% at 3,000 r.p.m. and is 7% better at 3,400 than the two-valve is at 3,000. These gains in volumetric efficiency are by no means inconsiderable and cannot lightly be disregarded, but whether the data are *directly* applicable to some other form of engine is open to doubt.

To start with, the readings were obtained under steady-flow conditions using air at 6.6 p.s.i. above atmospheric pressure, and though Dr. List states that steady-flow readings are useful and can be relied upon for comparative purposes, he admits, in reply to discussions on the paper, that "the dynamic conditions in the adjoining channels and in the cylinder must, however, be considered in order to obtain best results." Therein lies, possibly, one of the keys to the paradox, for the conditions existing in a very high-speed engine, with vast overlap and with the inlet and exhaust systems tuned to come mutually into resonance over a narrow speed-band, are a long way from being steady, either as regards the velocities or pressures of the gases.

Further examination of the graph and the valve sizes quoted reveals that the curves do not rate the various arrangements, as one might expect, in ascending order of merit on the basis of total circular area of the valves, but do rate them in the expected order calculated on the basis of the total circumferences.

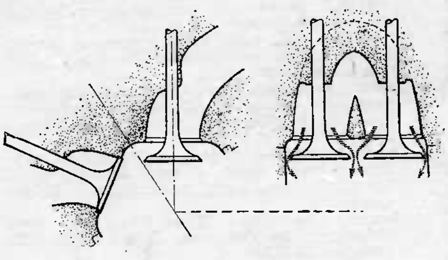
Now, disregarding for simplicity the effect of seat widths, the area available for gas-flow is equal to the circumference multiplied by the lift, up to a height equal to one-quarter of the diameter; and this, in conjunction with the relative ratings of the various schemes, gives rise to the supposition that the figures were taken at comparatively low lifts.

In supercharged aero engines (in connection with which the graph was derived) a designer has to seek a good combination of power per pound of engine weight, allied to the best possible fuel consumption, because every extra pound of fuel you have to carry means a pound of something else you can't. With several pounds' pressure difference between the inlet pressure and the atmosphere, overlap must be limited to prevent loss of mixture through the exhaust valves with detrimental results on consumption, and a comparatively late exhaust opening-point is necessary to extract the largest percentage of useful work from the heat of combustion.

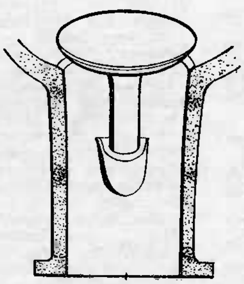
All this means that the breathing ability of these valves at low lifts is extremely important and underlines the need for the largest possible valve-head circumference. It is notable that the four-valve system has been retained and reached its pinnacle of perfection in aircraft engines, such as the Rolls-Royce "Merlin;" an additional point in its favour so far as the exhaust side is concerned being that for the same circumference the area exposed to flame is halved, and so the problem of valve-cooling is somewhat eased.

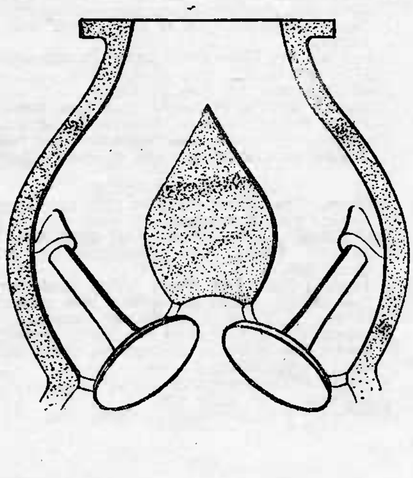
These remarks might apply also to touring road engines, and call to mind the Ricardo Triumph, an early (though by no means the first) four-valve motorcycle engine, which was not particularly fast but was outstandingly economical and flexible.

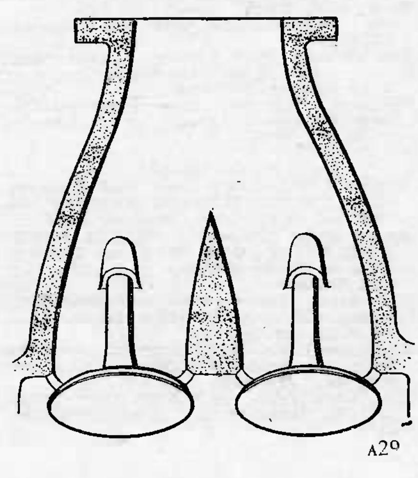
(Continued on page 518)



A section through parallel valves in a pent-roof head shows that gas-flow interruption occurs in corners and between valves.







Port shapes with (centre) radial or (extreme right) parallel inlet valves are more complicated than the simple, straight port of the single inlet (above).

HOW MANY VALVES? - - - - *Continued from page 517*

They apply also to the Rudges which enjoyed a spasm of near-invincibility *circa* 1930 in all forms of racing—road, track and speedway included. However, this was at a time when the possibilities of increasing power by utilizing the kinetic effects of the ingoing and outgoing gases were only beginning to be explored, and the following year the Rudges were outpaced by the Nortons to the tune of 2 m.p.h. in the Senior and 1½ m.p.h. in the Junior. The 250 c.c. model still held its own for a while longer, but subsequently greater power was obtained from two-valve versions.

The point seems to be that, in trying to fill a cylinder at very high speeds with the least pressure-drop across the inlet system, obtaining the largest valve area is only half the battle.

There are three accepted methods of installing four valves: (a) in parallel pairs in a "pent-roof head," (b) with the inlets parallel and the exhausts radial and (c) with all four radially disposed.

In the pent-roof form (used in the original Rudge design and at present by Honda), and also in the semi-radial layout, each inlet valve can be approximately three-quarters of the diameter of a corresponding single valve, and the pair would then have 12½% greater port area and 50% greater circumferential area *at equal lifts* than the single one. However, to obtain anything like a reasonable compression ratio, the valve-heads are unavoidably tucked up into corners at their outer edges and are close together at their inner edges, so that the gas flowing through is impeded more than it is with a single valve opening into a clear space.

Conditions leading up to the valves are no better. If a single carburetter is fitted, interruption to flow and undesirable changes of velocity occur at the point where the port divides. If two carburetters are fitted, for any required induction pipe cross-section there is twice the circumferential area along which the air has to slide, as it were. In fact, whatever you do, the flow conditions are not nearly so favourable as with a single port interrupted only by one valve stem.

With fully radial valves, although their heads are not obstructed by adjacent head surfaces, they cannot, for geometrical reasons, be quite so large as in the pent-roof. Moreover, the higher they lift, the closer their inner edges approach, thus detracting from the flow area, while the converging gas-streams must create some mutual interference. Externally, each port must have some additional curvature if one carburetter is used, and if there are two the same objection holds good as when two are used with parallel valves—the "wetted surface" of two pipes is twice as great as that of a single pipe of equal cross-sectional area and length.

This two-carburetter scheme was used on the Excelsior "Mechanical Marvel" which won the Lightweight T.T. in 1933 (practically its sole racing success) and was tried—in practice only—by Guzzi in the Island in 1952 (as this race was won by a two-valve engine from the same stable, one can only conclude that the more complex model was slower). Both Velocette and J.A.P. have experimented with the idea, using a bifurcated port, but rapidly discarding it. For some reason there always seems to be difficulty in obtaining clean carburation when two carburetters supply one cylinder, either through one valve or two.

It seems, therefore, that the additional obstruction to flow, both inside and outside the head, with two inlet valves more than offsets any possible gains through increased valve area, especially when the pressures concerned are only in the region of atmospheric.

On the exhaust side, where the release pressure is much higher, the increased circumferential valve area might conceivably be very helpful, and with gas going out past the heads instead of coming in, there is less fear of mutual interference between the streams. With parallel valves, however, the dividing wall between the ports is likely to become dangerously hot if both ports blend into a single outlet; if they are separate and widely splayed, this objection is not nearly so serious, but it still may lead to valve-seat distortion, even if not to cracking of the thin metal in the wall.

Some years ago, an Austrian four-valve engine was built with the inlets and exhausts placed at opposite ends of two diameters, instead of in pairs. This arrangement lends to rather complicated valve gear, but gets over the local heating problem very neatly; however, it too has vanished into limbo of lost things.

Taken all in all, a system with two radial exhausts and one inlet valve, which can be even larger than in a conventional two-valve head without fear of fouling the exhausts on the overlap period, seems to offer the best possibilities. This, again, is an idea which has been tried and dropped, the outstanding modern example being the 7R3 A.J.S. which won the 1954 Junior T.T. Mechanical complications are, of course, unavoidable; nevertheless, there are many who viewed the demise of this promising unit with considerable disappointment.