# How many valves per cylinder (revised) – 0, 1, 2, 3, 4, 5, or 8?

## With illustrations and a P.S. on 6

Since 1993 all Formula 1 engine designers have chosen 4 poppet valves per cylinder (2 inlet, 2 exhaust). In 2006 this layout was actually specified in the FIA regulations and the new 2014 rules continue it.

Keith Duckworth, who created in 1966 a cylinder head having 4 valves per cylinder (4 v/c) opposed at a relatively narrow angle and combined them with port geometry and increased valve Lift/Diameter ratio to create in-cylinder "Barrel Turbulence" (aka "Tumble Swirl") to raise combustion efficiency, set a benchmark to which, in time, all competitors conformed and which spread far outside the racing arena.

In most of the past century this unanimity on 4 v/c did not exist. Racing 4-stroke piston engines were built with 2, 3, 4, 5, and 8 poppet valves per cylinder. This article follows the title subject generally from the series of 85 "Grand Prix Cars-of-the-Year", 1906 – 2000, listed in this web site . Specifically this admits only 2, 3, and 4 valves per cylinder so, for general interest, substantial diversions have been included to other racing engines with a wider variety of arrangements

In future references to "valve gear" it is to be understood that it refers to poppet valves opened by cams, directly or indirectly, and closed by steel springs forcing them to ride on the cam, unless otherwise mentioned (Desmodromic gear in Mercedes 1954-1955 (DVRS) and Pneumatic Valve Return Systems (PVRS) post-1990). The spring stress acceptable for the required fatigue life *could* impose a definite "Top-end" limit on crank RPM (see Note 13 Part III and also Note 15).

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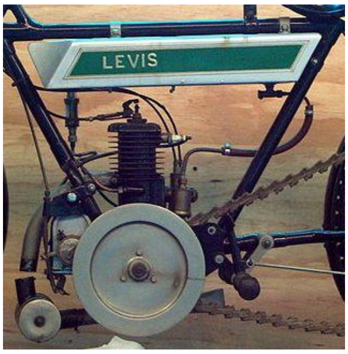
Two-strokes with no valves or 1 valve

If a digression is made to 2-strokes then mention can be made of piston engines with 0 v/c! The simplest 2-stroke has only 3 ports opened and closed by the piston(see Fig. 1).




Wikipedia

Fig. 1. Levis.

A simple3-piston-ported 2-stroke. The picture is a production engine, a/c 67 x 70 mm = 247 cc, representing the works 1922 Lightweight TT winner ridden by Geoff Davison, That was 62 x 82.5 mm = 248 cc (DASO 289.Britain's Racing Motorcycles. L. Higgins. 1952).

The 1922 win was the last in a TT for a Naturally-Aspirated 2-stroke until 1962 (50 cc Suzuki ridden by Ernst Degner).

[A 2-stroke won the Lightweight in 1938, the DKW ridden by Ewald Kluge, but that was supercharged].

The twin cylinder 2-stroke machines designed by Alfred Scott which won the 500cc motorcycle TT in 1912 and 1913, ridden by Frank Applebee and 'Tim' Wood, respectively, actually had a rotary inlet valve to allow better timing (see Fig. 2).

Fig. 2. 1913 Scott 2-cylinder.
Water-cooled cylinders; air-cooled heads (DASO 289).

National Motorcycle Museum

These engines, like all 2-strokes, had the advantage of no "Top-end" limit to crank RPM, but the disadvantage of breathing through the "Bottom-end".

In more recent times the 2-stroke Yamaha OW26 4-cylinder motorcycle, ridden by Giacomo Agostini to defeat the MV Agusta 4-cylinder 4-stroke ridden by Phil Read in 1975 to take the first 500cc premier class Riders' Championship won by a 2-stroke, had more than 3 ports to improve power output. All ports were controlled simply by the piston. From that date until the rules were changed in 2002 to favour the 4-stroke the 2-stroke with highly-tuned exhaust systems reigned supreme in all motorcycle classes, although they were also developed with 1 valve, either a rotating side disc (see Fig. 3) or a rear-mounted reed (see Fig. 4) to control inlet charge timing, plus a variable device to adjust exhaust timing.

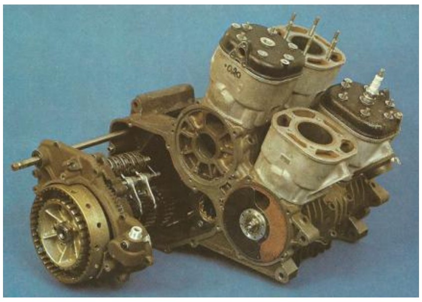


Fig. 3. 1979 Suzuki XR27B 4-cylinder water-cooled (partly dismantled).
The crank-mounted disc valve is shown on the front cylinder. The carburettor was fitted horizontally from a cover plate.

Team Suzuki. R. Battersby. Osprey. 1982.


Fig. 4 1997 Honda NSR500 Vee-4-cylinder watercooled. A reed valve for each cylinder was mounted in the Vee.

Deejay 51

Two-strokes were developed to produce up to 400HP per litre, admittedly with a very narrow power band, only usable in a motorcycle. When the 4-stroke MotoGP class was introduced in 2002 it required a capacity multiplication of 1.98 (990cc) to defeat the 500cc 2-strokes which competed in the same year.

The 2-stroke machines continued in the 250cc twin and 125cc single cylinder classes until the end of 2009 for the former and end 2011 for the latter. The final 2-stroke Championship winner was mounted on the Aprilia RSA125 which had a rear rotary (disc) valve – full circle to the 1912-1913 Scotts! It may have bettered slightly 400HP/litre.

The development of motorcycle racing 2-stroke engines is described in more detail in Grand Prix Motorcycle Engine Development, 1949 – 2008 on this site.

## Car racing 2-strokes with no valves

The only major attempt to use a 2-stroke for car Grand Prix racing was made by FIAT in 1925. Their type 451, conceived by Tranquillo Zerbi, was a supercharged 6 cylinder 1.5 Litre with 2 cranks and opposed pistons, which allowed more latitude in timing (see Fig. 5), aimed at the next year's formula. It was tested to produce over 100HP/litre which would have been competitive but, although watercooled, overheating problems with burnt exhaust pistons and premature ignition could not be overcome.

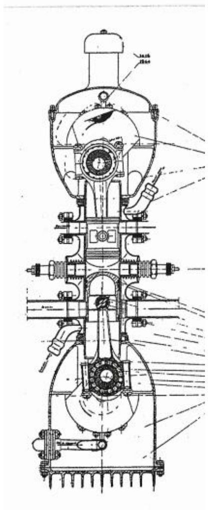


Fig. 5 1925 FIAT 451

DASO 66

Ten years later another 2-stroke racing car appeared in public once, the Count Trossi-financed design of Augusto Monaco with a radial aircooled supercharged double 8-cylinder engine of 4 litres, which would have been eligible for the current 750 kg formula. The paired cylinders with a common combustion chamber allowed the inlet ports to be placed in the rear cylinder and the exhaust ports in the front, so as to improve timing and scavenging .Once again, overheating seems to have killed the project (see Fig. 6).

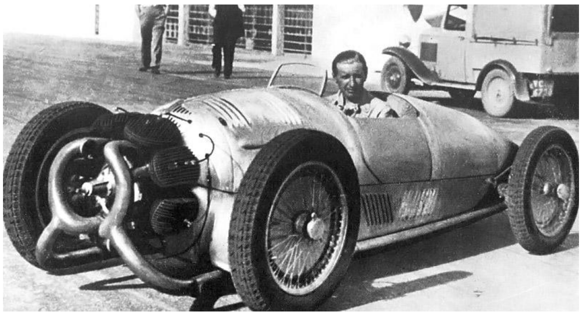
Fig. 6. 1935 Trossi-Monaco

Shown during tests at Monza with its radial cowling removed to improve cooling (which means it was not properly designed).

Count Trossi at the wheel.

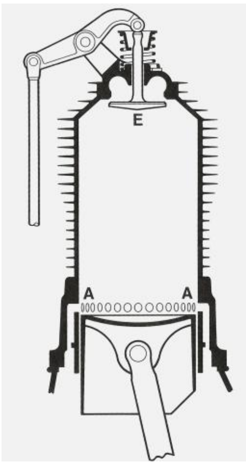
One report suggests that poor handling with front wheel drive and 75/25 weight distribution was a reason for dropping the project.

oldmachinepress



Current FIA rules allow only 4-strokes.

<u>The Gnome “*Monosoupape*” (“One Valve”)</u>




With another digression, a 4-stroke engine was built which had only 1 poppet valve per cylinder plus piston-controlled ports (seeFig.7). This was the Gnome “*Monosoupape*” rotary of 1913 designed by the brothers Laurent and Louis Seguin. Tom Sopwith acquired one early on to power his seaplane which won the 2nd Schneider Trophy race in 1914, piloted by Howard Pixton. In the following war the engine found very widespread use.

Fig. 7. 1913 Gnome “*Monosoupape.*

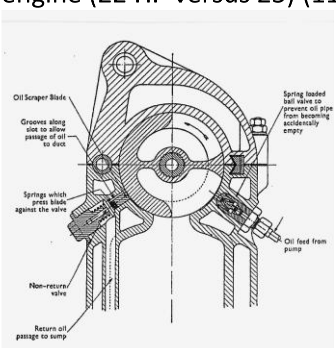
DASO 285 The Rotary Aero Engine A.Nahum Science Museum 1986, describes the operation of the *Monosoupape* as follows:-

On the power stroke the exhaust valve E opens earlier than usual. When the piston uncovers the ring of ports AA at the bottom of the cylinder the pressure is low and little exhaust gas enters them to contaminate the crankcase mixture flowing along the hollow fixed crankshaft. On the ensuing up-stroke the valve E stays open to discharge the remaining gas, and it stays open for 1/3rd of the next downstroke to allow fresh air to be sucked in. It then closes and the further piston movement creates another suction to induce rich mixture through ports AA. A combustible charge is formed with the fresh air and is ignited as usual..

<u>Rotary valves</u>

Other 1 v/c engines tried for motorcycle racing were the single rotary valve type having an internal division which permitted the inlet and exhaust passages to be aligned alternately to a single port in the cylinder. In theory this valve type also removed the “Top-end” limit to crank RPM.

Roland Cross entered two machines with such a valve in the 1935 500cc TT (see Fig. 8) but both retired. Harold Willis, racing engineer of Velocette, tested a rotary valve designed by Frank Aspin (see Fig. 9) on a 350cc engine in 1936 but the unreliable power was less than his standard engine (22 HP versus 25) (1103)(1120).



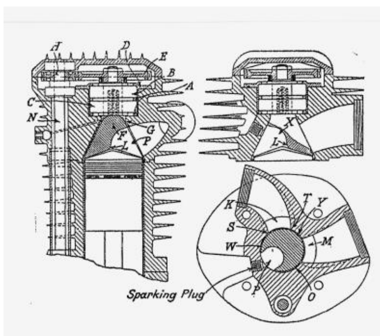

LHS Fig. 8. Cross valve.

RHS Fig. 9 Aspin valve.

DASO 1120 gives a review of Aspin’s engines.

It seems certain that his 1933 claim of 32 HP@ 11,000 RPM from an aircooled NA 249 cc unit (DASO 372) was wrong.

Both Figures:- DASO 372

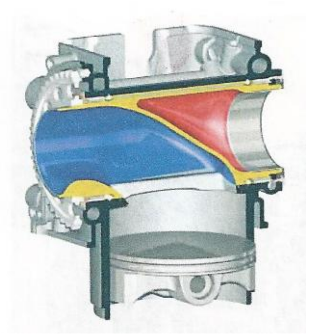


Post-WW2 Laury Bond persuaded Joe Craig, racing engineer of Norton, to test a revised form of the Cross valve on a 500cc engine. In 1954 after development this produced 47HP, similar to the normal engine. It tended to oil its plug when the throttle was shut so it was not raced (1104).

The basic problem with each type seems to have been the loading of the valve by gas pressure while rotating, requiring much oil to avoid a seizure, where the simple poppet valve is just better sealed by the pressure and the valve gear is not affected by it.

The sleeve valve of the Burt-McCollum reciprocating-spiral-action type also comes under the "1 v/c/4-stroke" category but no engine of this type ever raced, although aero engines were made in vast numbers by Bristol in WW2 and some by Napier. They were developed at government expense and then the Bristol production units were x2 as costly per HP as the contemporary *Merlin* poppet-valve engine (DASO 619 p.152).

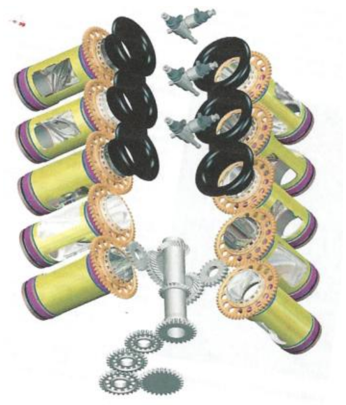
Forty-three years after the Bond valve was dropped another improved version of the Cross valve designed by Bishop Innovation of Australia began development with Ilmor Engineering in 1997. By mounting the valve cylinder with a clearance from the housing in needle roller bearings at each end and with modern materials to seal the gap (see Fig.10) this overcame the excess oil problem. It was sufficiently promising as a single cylinder to be tried by Mario Illien on full F1 3 litre V10 engines, the latest in 2003 (see Fig. 11). However, having learnt of this work, in late 2004 the FIA wrote the rules for the forthcoming 2.4 litre V8 engines to permit only 4 reciprocating poppet valves. While Mercedes-Benz had been prepared to fund the Ilmor-Bishop innovation other makers did not wish to spend money to follow suit and the FIA agreed with that. Consequently six years of development which had yielded power competitive with poppet valves, *with no "Top-end" RPM limit to further increase*, were wasted. Therefore there is no evidence of how reliable the new rotary valve would have been in racing service (1105,1106).



LHS Fig. 10

RHS Fig. 11

Both Figures DASO 1105



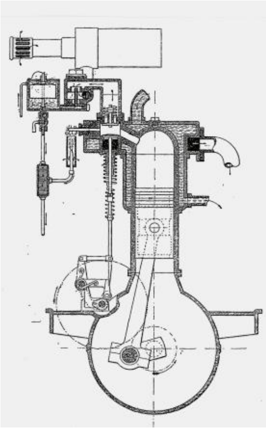
Refs. [where not in Appendix 3].
1103. Velocette. I. Rhodes. Crowood, 1990.
1104. Built for Speed. J. Griffith. Temple Press, 1962.
1105. The Bishop Rotary Valve. T. Wallis. www consulted April 2012.
1106. Race Engine Technology No. 048, August 2010. Interview by Ian Bamsey with Mario Illien.
1120. www.villiers.info/Aspin.

Early engines

Having discussed 1 v/c types, of course the usual minimum for a 4-stroke was 2 v/c, right from the first Daimler motorcycle engine of 1885. The inlet was sucked open but the exhaust had to be opened mechanically and, with an offset combustion chamber, the valves were disposed inlet over exhaust to permit easy operation of the latter from a crankcase-mounted camshaft (see Fig.12 on P.5).

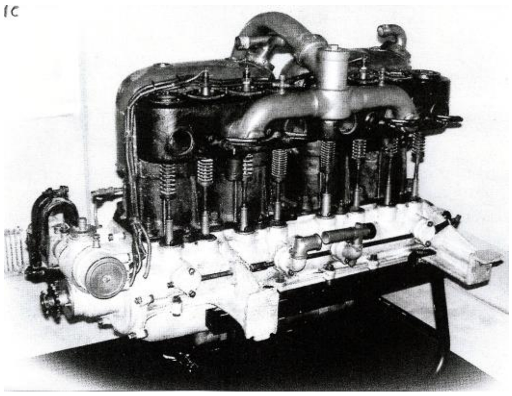
Mechanically operated inlets soon appeared and in the successful Renault type A of 1902 they were first placed side by side with the exhaust alongside the cylinders to allow operation from the same crankcase camshaft. This arrangement was used in the Renault type AK which won the first "Grand Prix de l'Automobile Club de France" (hereafter FGP) in 1906 (see Fig. 13 on P.5).

Except for side exhausts in the 1908 Mercedes, side valves then disappeared from GP winners and all valves subsequently should be understood to be overhead.



LHS Fig. 12. 1890 Daimler.

RHS Fig. 13
1906 Renault AK.
[The engine shown was adapted for airship use].



DASO History of Technology, Vol. V, Oxford 1958

DASO 1094 *French Racing Blue* D. Venables I.Allen 2009

First 4 valves per cylinder in Grand Prix racing

In 1910 the 10.1 litre FIAT type S61 won races with an engine which had 4 v/c placed vertically (2 inlets, 2 exhausts placed alternately in the head, i.e. in the 4 cylinder engine there were 4 inlets and 4 exhausts on each side (although the ports were cored through the head to group the inlets and exhausts to opposite sides) – an arrangement never repeated until BMW used it in their unsuccessful Formula 2 Apfelbeck engine in 1966). They were operated by a single overhead camshaft (SOHC).

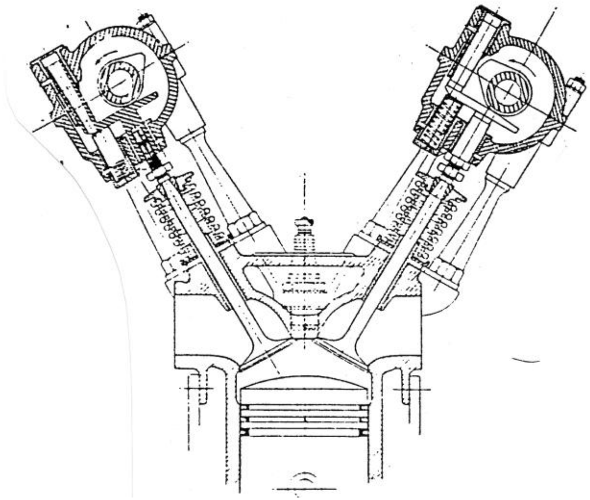
A 4 v/c engine has substantial theoretical advantages over 2 v/c with the same valve area:-

- The valve gear can be run at √2 higher speed for the same spring stress because of the lower individual valve masses;
- With the same seat widths the smaller exhaust valves run cooler than the larger.

Whether FIAT considered these points is unknown and they may just have thought it easier to produce reliable smaller valves at a time when material technology was in its infancy.

FIAT made a 14.1 litre version of this engine, type S74, in 1911 and it was this which was defeated (just) in the 1912 FGP by the 7.6 litre Peugeot L76, the new conception of Ernest Henri. This also had 4 v/c (2 inlet, 2 exhaust) but in 2 opposed rows with an angle of $60^0$ between them (VIA), each row operated by its own overhead camshaft (DOHC) (see Fig. 14)

Fig. 14 1913 Peugeot 3Litre L3
Essentially the same as the pioneering 1912 engine architecture. DASO 597B



. DOHC became the "classic" way of operating valves, regardless of the number of valves per cylinder, which was used for the great majority of later racing engines and is now a common feature of ordinary production engines.

So as to minimise the pressure loss in the inlet ports, i.e. obtain a high Volumetric Efficiency (EV), Henri fitted valves which were so large that they overlapped the cylinder bore, giving what would now be described as "Negative Squish", a bad feature affecting Combustion Efficiency (EC), and moreover reducing the inlet Mean Gas Velocity (MGV) to only 30 metres per second (m/s). This low figure would have prevented good mixing of the fuel/air mixture and again prejudiced EC and flexibility.

Optimum MGV

The subject, of the optimum value of MGV to produce the highest value of the product EV x EC, is discussed at length in the web site at Note34. To anticipate, and enable readers to judge the following values of MGV, it was fairly well established by the late Brian Lovell (former MD of

Weslake Developments) that the optimum for Naturally Aspirated engines *with individual and tuned* inlet systems and with fuel entering before the inlet port is around 72 m/s. With the *tortuous* inlet systems which were the norm before 1952, having high drag, the optimum would have been lower. It would also have been lower where a supercharger or turbocharger was "mashing" the fuel before it reached the inlet valve. Generally the temperature rise through a compressor was mostly taken out by alcohol fuel evaporation or an intercooler so was not available to give much help to the mixture.

The calculation of the velocity assumes incompressible flow using the relation:-

MGV = [Piston Area/Valve Head Area] x Mean Piston Speed.

The figures are given at rated or peak power RPM.

<u>Post-WW1 rejection of 4 v/c</u>

<u>Duesenberg's novel 3 v/c</u>

The first World War interrupted Grand Prix racing for 6 years and when it was resumed in 1921 the FGP was won by an American car – a feat never since repeated by that nation - which owed nothing to pre-war Continental practice. This was designed by Frederick Duesenberg and had been built originally for the 1920 Indianapolis 500. It had SOHC operated 3 v/c at VIA = $60^0$, I inlet and 2 exhausts which was logical for cooler valves (as described above) at a time when heat-resisting alloys were only just being developed .

Whether by intention or fortuitously the single inlet gave MGV = 46 m/s, a large improvement over Henri's approach in terms of EV x EC product.

However, the 1 inlet and 2 exhausts valve arrangement found no adherents subsequently (until AJS produced in 1954 a successful 350 cc racing motorcycle with that layout).

<u>FIAT's return to 2 v/c</u>

In 1922 FIAT won the FGP with an engine, type 404, in which Guilio Cappa reverted to 2 v/c with DOHC. He inclined the opposed valves at VIA = $102^0$ and they produced an MGV of 44 m/s. The layout gave a near hemi-spherical combustion chamber of better Surface Area-to-Volume ratio at low compression ratio than the pent-roof Henri design, to the advantage of EC (see Fig. 15).

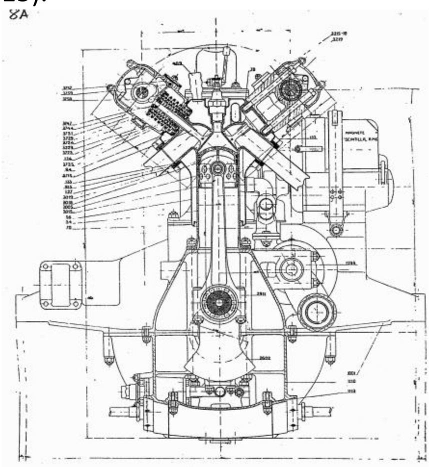


Fig. 15. 1922 Fiat 2Litre type 404.

The success of this engine and its cheaper construction compared to 4 v/c led to many imitations over the next near-half century, although later 2 v/c tended to VIA = $90^0$ or even $60^0$.

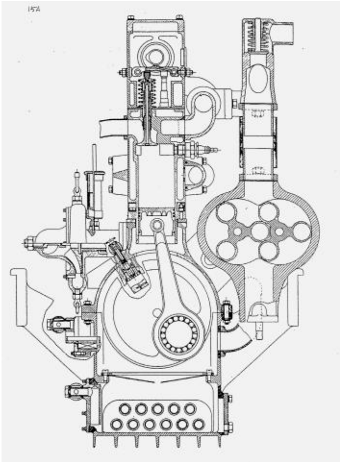
DASO 4

<u>Bugatti 3 v/c</u>

However, Ettore Bugatti could never be accused of being a copyist (until 1931, of which more later). His long string of victories, 1926 – 1930 were obtained with engine types having 3 v/c with 2 inlets and 1 exhaust, all placed vertically with somewhat crude ports into a disc-shape combustion chamber, operated by SOHC (see Fig. 16 on P.7).

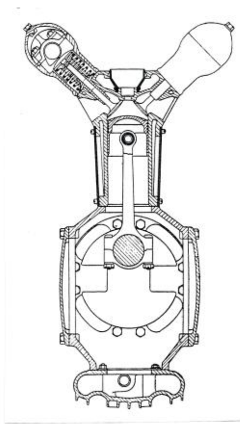
The values of MGV were around 45 – 48 m/s.

No particular merit came from this arrangement and the many Bugatti successes are generally attributed to a superior chassis with neutral to understeer characteristics where contemporary rivals had oversteer.



LHS Fig. 16. 1929 Bugatti 35B
DASO 28

In 1931 Bugatti was led by test experience of a purchased 1927 Miller engine to change his cylinder head. The 1.5 litre Miller, influenced by the 1922 FIAT in a preceding 2 litre unit, had 2 v/c at VIA = $94^0$ with DOHC (see Fig. 17 on RHS)



DASO 6

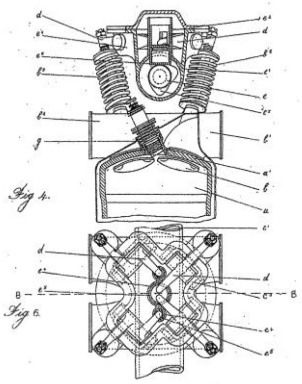
. Bugatti's type 51 only changed VIA to $96^0$ and was otherwise very similar in thermodynamic features. MGV was up to 64 m/s. The power gain with this new head on the well-tried type 35B 2.3 litre bottom end was from 147HP to 185 (+26%), using the same supercharge. This rather showed up the inadequacy of the previous layout. The T51 was another winner.

<u>Rudge Whitworth radial 4 v/c</u>

A very interesting application of 4 v/c in the racing motorcycle world had just appeared in 1930. Rudge Whitworth had adopted 4 v/c some years earlier when others used 2 v/c. The new design by George Hack for a 1 cylinder aircooled 350cc had placed the 4 valves radially, i.e. their axes if prolonged would meet at a point in the cylinder. Operation was by pushrods from crankcase cams and 6 rockers overhead (see Fig. 18)

LHS Fig. 18 1930 Rudge 350 cc.
DASO 193 *Classic Motorcycles* V Willoughby Hamlyn 1975.

RHS Fig. 19 Elliott's patent SOHC 4-radial-valve scheme (adapted with 2 plugs for Rolls-Royce C*ondor).*
DASO 1097 R-RHT Historical Series 43 2011.



. A much more elegant solution had been designed by Albert Elliott for the 4 radial valves of the Rolls-Royce *Condor* aero engine in 1918, employing SOHC (see Fig. 19 above), but perhaps this was too expensive for Rudge.

Only a single carburetter was fitted, somewhat reducing the breathing advantage one would have thought, although there were separate exhaust pipes. Anyway, the machines took an overwhelming 1st, 2nd, and 3rd victory in the TT, led by H.G. Tyrell Smith. Scaled down to 250cc Rudge took 1, 2 in that class the following year. Ike Hatch for Excelsior copied the 4 radial valves idea for a 250cc TT win in 1933. His single used twin carburettors. After Rudge gave up racing in 1933 a private syndicate continued to race their machines and a win by Jimmy Simpson in the 1934 250cc class with 4 radial valves leading another 1, 2, 3 was the last victory for 4 v/c in the TT for 27 years.

In 1954, twenty years after the last radial-valved TT win, Bert Hopwood conceived and Doug Hele detail-designed and developed for BSA a single cylinder 250cc motor-cycle engine with 4 radial v/c, operated by overhead camshaft, which produced 132HP/litre (see Fig. 20)

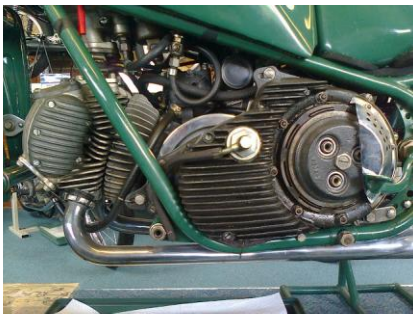


Fig. 20 1954.BSA MC1
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. However, by then NSU were racing 250cc twins of higher power so BSA decided not to enter their MC1.

Mercedes return and 4 v/c again

The return of Mercedes-Benz to unrestricted Grand Prix racing in 1934 soon brought 4 v/c back to the winners' rostrum. The firm had adopted 4 v/c, following Peugeot, for their all-conquering 1914 FGP car designed by Paul Daimler although with SOHC. After WW1 from 1922 to 1924 DOHC were used for their Roots-supercharged engines. Fig. 21 shows the modified 1924 4-cylinder engine which powered the Targa Florio winner of that year. Ferdinand Porsche then designed the M218 8-cylinder engine for the 2 litre formula, although it only competed once outside Germany.

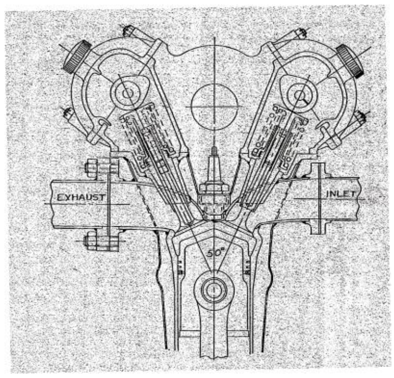



Fig. 21 1924 Mercedes

Motor Sport May 1969

The 1934 M25 engine was based to some extent on the M218; VIA was $60^0$ and MGV 50 m/s. With the carburetter placed *after* the supercharger, which could otherwise have provided some "mashing" of the mixture, and with the supercharger temperature rise mostly taken out by alcohol fuel, this MGV was not helpful to EC. This placement was rectified for the M125 engine in mid-1937, which had MGV of 57 m/s.

From 1935 to 1939 Mercedes took most of the major laurels, interrupted in 1936 by Auto Union with a 2 v/c mixed OHC-cum-pushrod engine with VIA = $90^0$ and MGV = 52 m/s, based on an original Porsche project. As this was a design intended for sale, bought by the new Auto Union group for advertising purposes but not being so well endowed as Daimler-Benz, the valve layout was probably chosen for cost reasons (see Fig. 22).

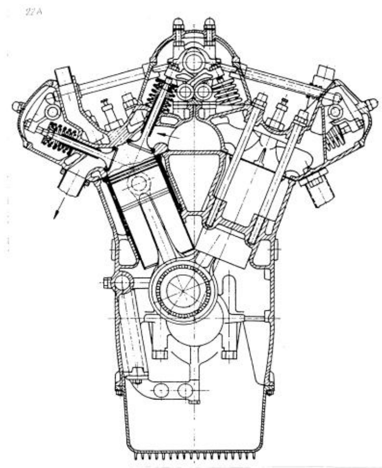


Fig. 22 1935 Auto Union type B/C
DASO 4

The 1938 – 1939 Mercedes engines were V12 and somewhat restricted in RPM by their valve gear so that MGV in the 1939 M163 was only 42 m/s. By then the carburetter had been placed ahead of the 2-stage superchargers so that their action on the mixture would have been beneficial.

Back to 2 v/c again for 20 years

Alfa Romeo type 158/159

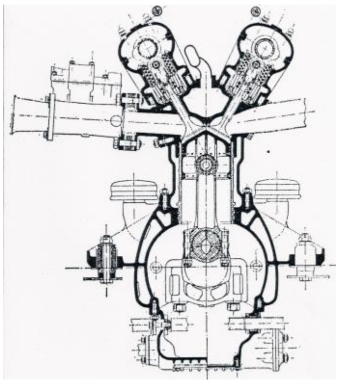
In 1937 the Alfa Romeo type 158 1.5 litre voiturette had been designed by Gioachino Colombo. As a "graduated pupil" of Vittorio Jano, who had employed 2 v/c since his famous P2 of 1924 which had VIA = $102^0$ like the FIAT from whose design office he had emigrated, Colombo also chose the "Continental" VIA, $100^0$ actually (the successful Delage of 1926 -1927 and Jano's type B (P3) of 1932 had all used VIA= $100^0$). By necessity, after WW2 the158 became a Grand Prix car and with continual increase of supercharger pressure proved extremely hard to beat. In its last specification MGV was 55 m/s, having of course the supercharger benefit.

Ferrari type 375 4.5 litre NA

Taking up the alternative formula of 4.5 litre Naturally-Aspirated (NA), in 1950 Aurelio Lampredi designed for Ferrari a car which, when stretched to the full capacity, gave Alfa a considerable shock and then, in 1951 beat it 3 times in succession. The V12 engine had 2 v/c, VIA of $60^0$ to obtain a more compact combustion chamber but, on alcohol fuel with high compression ratio, needing a high humped piston which spoilt EC, and in its final 2 plugs per cylinder form a value of MGV at 71 m/s which was too high for a tortuous inlet system.

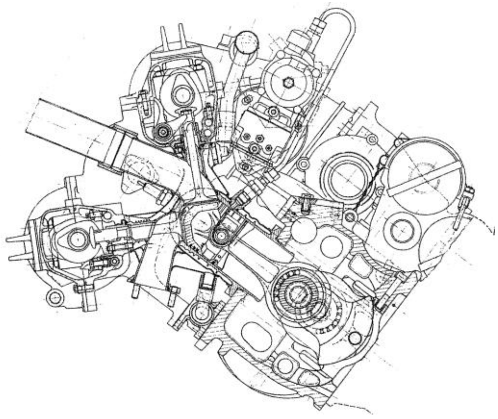
The introduction of individual and tuned inlet and exhaust systems

In 1952, again of necessity when Alfa retired, GP racing adopted the second category formula, effectively 2 litres NA. For this, Lampredi produced an IL4 2 v/c Ferrari engine with VIA = $58^0$ which, for the first time in GP competition, introduced individual and tuned inlet and exhaust systems (see Fig. 23)



LHS Fig. 23 1953
Ferrari type 500
DASO 80

RHS Fig. 24
Mercedes-Benz M196
DASO 468



. However, with MGV at 58 m/s in the 1953 model, the F500 did not take full advantage of this new approach but it became the standard for future engines.

Mercedes-Benz made their second return to GP racing after a World War in 1954 and then for the M196 engine adopted 2 v/c at VIA = $88^0$. With direct fuel injection into the cylinders to ensure good fuel/air mixing they were able to fit large valves with MGV only 44 m/s to give good EV. These valves were closed mechanically (“desmodromic” operation, DVRS). The high VIA with a compression ratio of 12.5 meant a high hump on the piston crown which gave a particularly “orange-peel” combustion chamber with high Surface Area/Volume ratio and which also hindered flame front development, both spoiling EC (see Fig. 24 above).

Reconsideration of 4 v/c

Grand Prix engine designers continued to use 2 v/c until 1967 but they began to reconsider 4 v/c from 1959 when Honda appeared on the motorcycle racing scene with that configuration. With wide VIA this became that company’s trademark during all their single-track participation and then into cars until 1968. Their motorcycle success was attributable mostly to their use of more cylinders than rivals (see Fig. 25 and Note 78 chart 115/DST).

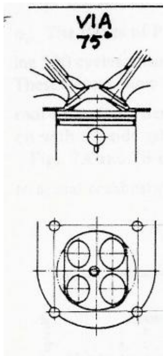
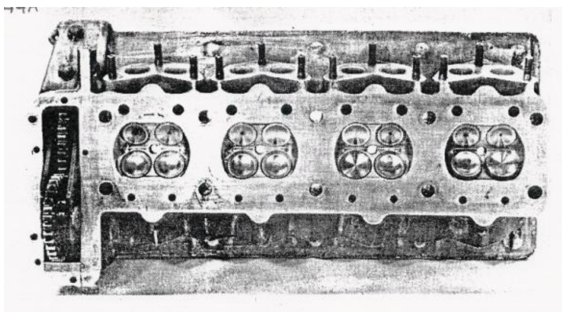



Fig. 25. Typical Honda 4 v/c cylinder head.
This is the 1965 RC114. DASO 453
2 cylinders, B = 34 x S = 27.4 mm  V = 49.8 cc!

. The 125cc and 250cc Championships were first won in 1961, including the 1st win of a 4 v/c engine in a TT since 1934. This seems to have triggered car designers to take a serious interest in 4 v/c. Ferrari, BRM and Coventry Climax all produced such engines over 1962 – 1965 but only the latter was raced , securing 3 wins for Lotus in 1965 (see Fig. 26)

Fig. 26. 1965 Coventry Climax FWMV Mk 6.
4 v/c cylinder head. DASO 34



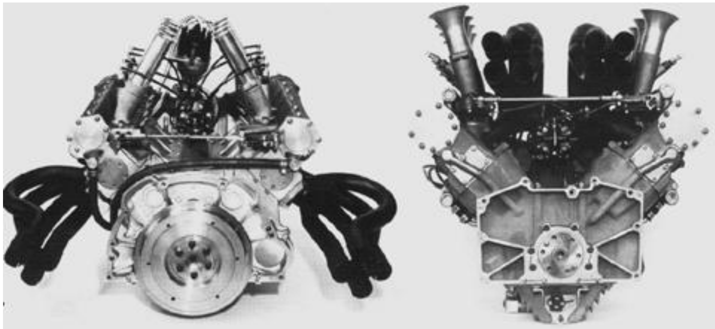
. The trouble seemed to be that all retained the wide-angle VIA – $60^0$ or more – of their 2 v/c heads. The BRM 4v/c design with VIA = $68^0$ is shown below on Fig. 30.
With high compression ratios now possible on 102RON petrol this spoilt EC, as described above for the M196.

The anomalous Repco engines

A successful anomaly in Grand Prix engine design occurred in 1966 at the start of a new 3 litre formula and also in 1967. Jack Brabham, building his own cars, obtained from the Australian Repco firm engines, based on the discontinued Oldsmobile V8 light alloy production unit and revised by Phil Irving, which had 2 v/c but parallel and nearly vertical to the cylinder axis, i.e. VIA = 0, and with only SOHC. MGV was nearly 76 m/s in 1966. With other teams either struggling to develop or introduce new engines these simple and light engines enabled Brabham in 1966 and his driver Denny Hulme in 1967 to "steal" the two Championships (see Figs 27 & 28).

Fig. 27. 1966 REPCO 620 Fig. 28. 1967 REPCO 740

DASO intothered.dk



Ferrari did introduce in 1966 for their all-important Italian GP an engine with 3 v/c (2 inlet, 1 exhaust), which took then its only win (see Fig. 29)

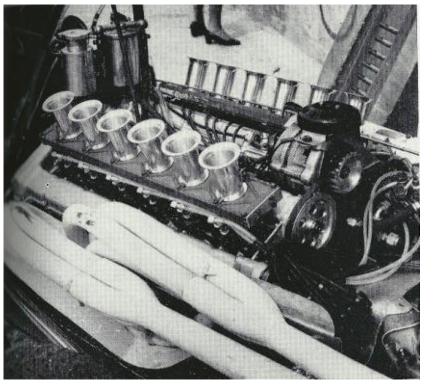


Fig. 29. 1966 Ferrari 312 3 v/c.

DASO *Motor Sport* October 1966

. Maserati in 1967 also redesigned to 3 v/c (2 inlet, 1 exhaust) placed axially.

The Four Valve Renaissance

The "Four Valve Renaissance", as the late Brian Lovell (former Managing Director of Weslake Developments) termed it, had really begun in 1964 with a Shell-financed Weslake research unit, the WR22 375cc twin cylinder with 4 v/c and *narrow VIA of* $32^0$ (see Fig. 30)

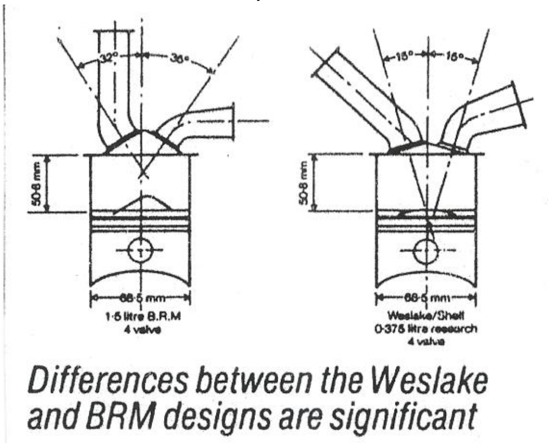



Fig. 30. 1964 Weslake WR22 2-cylinder. Being then part-owned by BRM this experimental unit was built to BRM 1.5L dimensions; B = 68.5 x S = 50.8 mm.

DASO 836 Letter by Brian Lovell in *Motor* ca 16 May 1987.

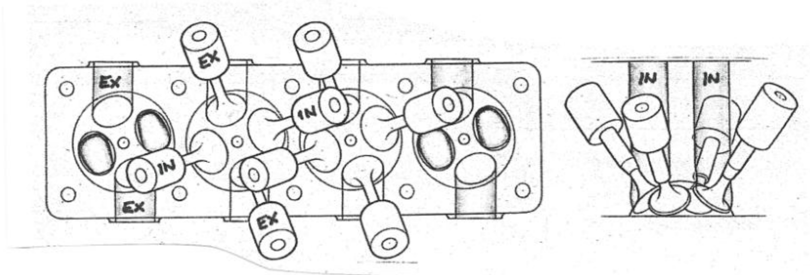
. Enlarged to 500cc with VIA = $30^0$ it became the basis of the Gurney-Weslake "Eagle" V12 Grand Prix engine, designed by Aubrey Woods, which first raced in September 1966. This therefore appeared more-or-less simultaneously with the Cosworth FVA described below.

See also Note 78.

The Apfelbeck 4 radial v/c of 1966

Before describing the Cosworth FVA and DFV advances, a sideways look at the contemporaneous BMW Apfelbeck Formula 2 IL4 1.6 litre engine is interesting. This had 4 radial v/c (see Fig. 31).

Fig. 31. 1966 BMW Apfelbeck.
DASO 165 *Autocar* 13 April 1967.




The designer concentrated on gaining high EV by a Inlet Valve Head Area/Piston Area ratio of 0.445, obtained with VIA of $74^0$, so that MGV was only 46 m/s. This VIA resulted in an "orange peel" combustion chamber, spoiling EC as described above. Although peak power was equal to the FVA (220HP) the low MGV resulted in an inflexible engine, like the pre-WW1 Peugeots. The RPM range from Peak Power to Peak Torque was only 11% where the 1966 FVA had 22%. The engine was easily beaten by the FVA.

The unique Cosworth DFV

In October 1965, after Coventry Climax decided not to make an engine for the new formula, Colin Chapman persuaded Ford of Britain to fund Cosworth Engineering to build one. Cautiously, Keith Duckworth agreed to design first in 1966 a 1.6 litre engine for a new Formula 2 in 1967 with a new head on a modified production Ford bottom end. His design also re-introduced 4 v/c but with VIA reduced from the prior wide-angle engines to $40^0$. Apart from the advantages already listed for 4 v/c this narrow angle provided a compact combustion chamber with a flat-topped and therefore light piston which could run to higher Mean Piston Speed for the same stress as previous humped-piston 2 v/c units. The valve area was chosen to give MGV = 68 m/s (Valve Head Area /Piston Area = 0.3) (see Fig. 32).

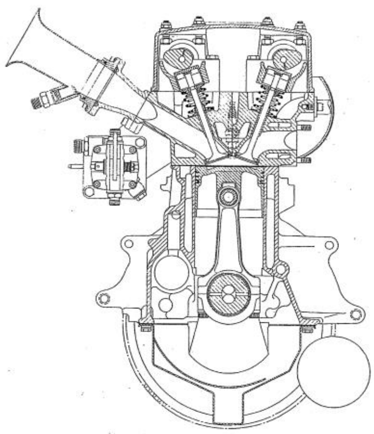


Fig. 32. 1966 Cosworth FVA.

Even more significantly, although kept secret at the time, Duckworth chose a combination of downdraft, port angle relative to the valve head and higher-than-usual valve Lift/Diameter ratio to provide in the cylinder what he called "Barrel Turbulence" – a *vertical* rotation of the inlet charge which was greatly magnified by conservation of its angular momentum as the piston rose to compress it into the unobstructed combustion chamber. This gave rapid burning after ignition to enhance EC more than the loss of EV involved in creating the rotation. When this effect became more generally known it was called "Tumble Swirl", to distinguish it from the less effective *radial* swirl which had been used frequently since Bill Heynes and Harry Weslake introduced it in the Jaguar XK120 in 1948 (see Note 26).

The result was a performance greatly superior to previous 2 v/c or wide angle 4 v/c engines. The "Four Valve type A" (FVA) engine powered all F2 Champions bar one over 1967 to 1971 and after BMW copied the head for their later post-Apfelbeck 2 litre F2 engines they powered Champions 1973 – 1975 inclusive plus 1978,1979 and1982.

Having satisfied himself that the new narrow angle 4 v/c head was a winner, Duckworth applied it to his complete new full 3 litre V8 – named "Double Four Valve" (DFV) engine, with a reduction to VIA = $32^0$ After a victorious debut in June 1967 this went on with steady improvements to take 154 Grand Prix wins up to 1982 (a 1983 win sometimes listed against the DFV was actually taken by a substantially redesigned engine, the DFY).

John Judd assisted DFV development for Williams in later years. By raising its RPM the value of MGV in 1982 with larger valves was 75 m/s.

The Duckworth architecture was very soon copied for nearly all subsequent racing engines – not always with the "Barrel Turbulence" feature – and it is now common in even bread-and-butter production engines. The VIA trended down to around $20^0$ with higher compression ratios.

Cosworth development is given in greater detail in The Unique Cosworth Story.

5 v/c: Yamaha and Ferrari

An exception to DFV-like 4 v/c heads came from Japan in 1985 where Yamaha introduced a 5 v/c (3 inlet, 2 exhaust) concept on their 750cc sports-racing motorcycle and then their OX66 Formula 2 engine (see Fig. 33).

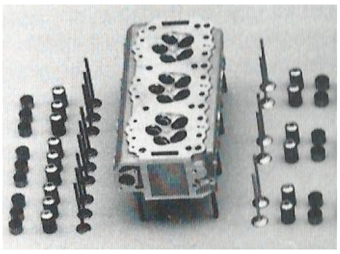


Fig. 33 1966 Yamaha OX66.
DASO 62

These were quite successful and Cosworth for 1988 entered into an agreement with the firm to provide their head design for a permitted 3.5 litre NA alternative to the previously- dominant but now boost-restricted and fuel-rationed Turbocharged (TC) engines. The forecast power gain, which it was hoped would make the Benetton B188 car competitive, did not appear and the engine had to be hastily changed back to a 4 v/c layout (the DFR). This did not produce a serious rival to the last Turbocharged McLaren Honda.

Despite this, when the 3.5 litre NA-only formula began in 1989, Ferrari produced a 5 v/c V12 engine designed by Jean-Jacques His. Over the next 4½ years they retained that arrangement. The car *did* win its first race and won a further 8 times to the end of 1990, but this was probably due more to the advantage of a new semi-automatic gearbox (SAGB) than the valve arrangement. After others caught up with SAGB in 1991 there were no further 5 v/c wins. Consequently, in late 1993 the fruit of a secret agreement with Honda (who had retired from GP competition at the end of 1992) altered the Ferrari V12 engine to 4 v/c. Only one more win was secured before Ferrari threw in their V12 hand and built a V10 for 1996 – with 4 v/c. This copied the configuration which Honda (powering McLaren) and Renault (for Williams) had been using successfully from the start of the 1989 3½L formula.

An interesting aside is that Alfa Romeo in 1985 had built a V10 3½L engine with 5 v/c and the valve layout is shown on Fig. 34.

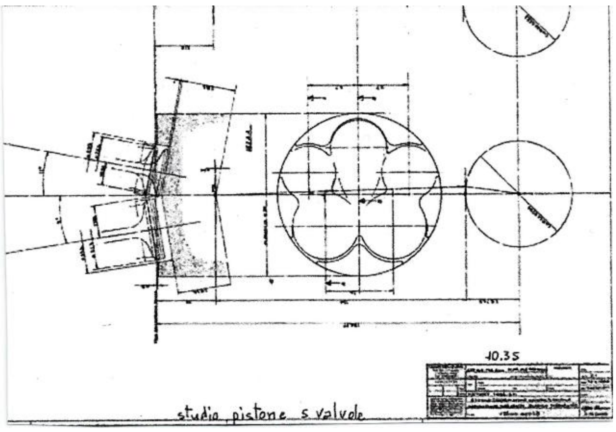



Fig. 34. 1985 Alfa Romeo type 1035.
DASO 1111 Alfa data courtesy of John Cundy

The engine was intended for a Racing-Sports series which did not go ahead. It was considered later for the new F1 but not raced.

The Ferrari 5 v/c engine layout was probably similar.

The Honda 8 v/c

This concludes the saga of "Valves per cylinder", except to describe one other intriguing concept – 8 v/c! Honda re-entered premier 500cc motorcycle racing in 1979, a class which had been dominated by 2-strokes for the previous 4 years, with a 4-stroke. To secure sufficient power required ultra-high RPM and therefore ultra-short stroke. As the rules permitted only 4 cylinders and a huge Bore/Stroke ratio was then thought not to be feasible, lateral thinking led to the distribution of the needed piston area into “oval” bores (a better description would be “race-track”-shaped, the track as at Indianapolis). The required valve area was then provided by 8 valves (4 inlet, 4 exhaust) (see Fig. 35)

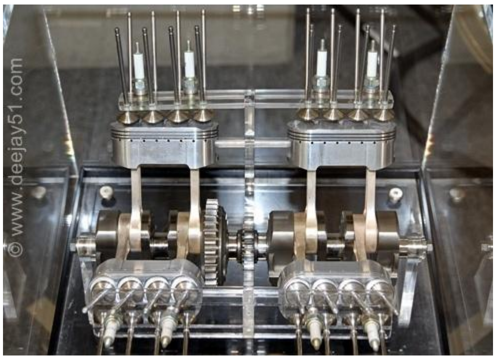



Fig. 35. 1981 Honda NR500D
DASO deejay51

. Honda developed this engine for 3 years and got it up to 268HP/litre but it never looked like beating the rival 2-strokes in major races. Honda had to join them in 1982.

Honda resurrected the 8 v/c “race-track” idea in 1987 for a 750cc sports-racing motorcycle which showed well at Le Mans but DNF. The FIA took fright at this and ruled that car engines must have cylinders of circular section!

## Conclusion

Apart from the USA, where thinly-production-based NASCAR engines have to stick to 2 v/c, 4 v/c reigns supreme for racing engines and, by FIA rule, will stay at least during the life of the 2014 Formula 1. A minor refinement, actually introduced by Porsche in 1984, is to place the valve pairs at a small angle to each other in a longitudinal direction; $6^0$ has been used by Ferrari. This allows a little more area but perhaps the real gain is to open the valves further away from the cylinder wall. This layout is made possible by modern multi-axis machining centres.

## P.S. on 6 valves per cylinder

The main text covers racing engines. As a final digression (only recently known to the author), in 1986 Maserati developed an experimental sports engine with 6 v/c.

This was the Twin Turbocharged 6.36:-

$90^0$V6; Bore(B) 82 mm; Stroke (S) 63 mm; B/S = 1.302; Swept Volume (V) = 1,996 cc.

The two DOHC 6 v/c heads were fitted on the existing production BiTurbo block.

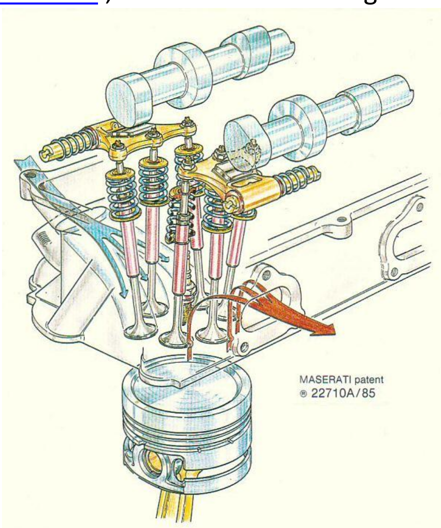
Claimed power was 261 HP @ 7,200 RPM with a boost of 0.8 Bar.

BMPP = 16.25 @ MPSP = 15.12 m/s.

The engine is described more fully in www.maserati-alfieri.co.uk., which includes the figure below:-

VIA of outer valves = $21.75^0$;
VIA of central valves = $5.5^0$

This difference in valve angle was intended to promote In-cylinder turbulence to Improve Combustion Efficiency.




The engine did not go into production. Presumably the advantages were outweighed by the increased manufacturing cost.

The 6 v/c design would have been much more beneficial in a racing engine with much higher B/S ratio – perhaps as much as 2½, permitting very high RPM at material-limited piston speed. A few years later this increased B/S began to happen with PVRS.