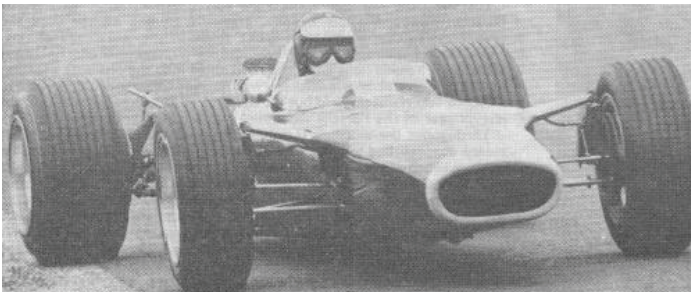


The end achieved - Jim Clark winning the Dutch GP of 1967, first time out with the Cosworth-Ford-V8-engined Lotus 49

means to an end

A comparison of the Cosworth-Ford V8 and the new Matra V12 engine

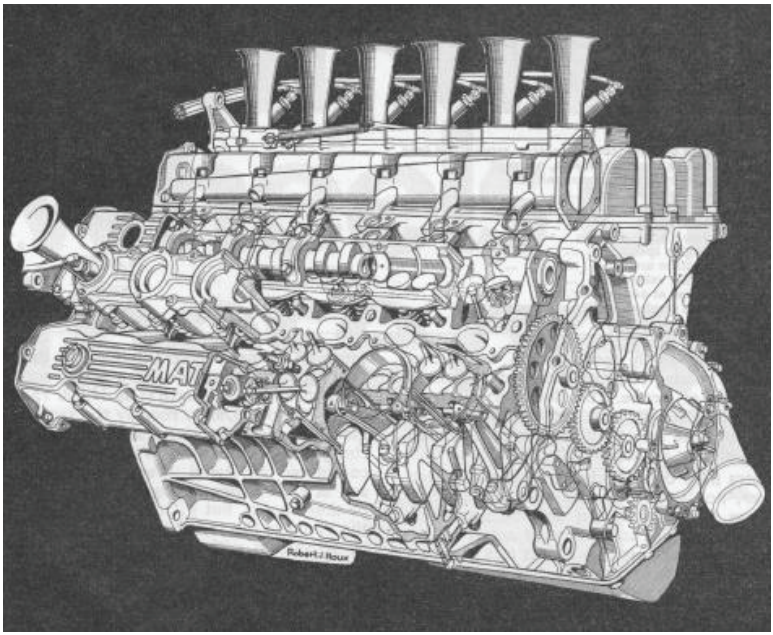
By L.J.K.Setright

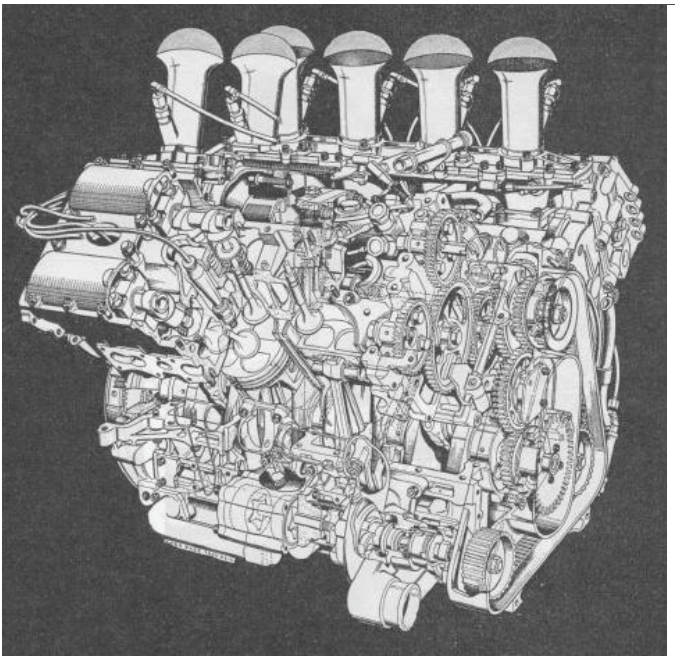
The recent unveiling by Matra of their new Formula 1 engine briefly described in these pages last month, does more than provide a fresh stimulus and additional interest for the forthcoming year's Grand Prix racing. It also makes possible an intriguing comparison of what may be considered opposing schools of thought in engine design, if it be compared with the Ford-sponsored Cosworth V8 that similarly hit the headlines last May. Make no mistake about it, the new Matra is an extremely interesting design, not simply to be categorised along with all the other V12s by BRM, Ferrari and Westlake; its resemblance to these is merely superficial. Within its dimensions reveal a train of thought that follows from the postulate that ample piston area and high rates of crankshaft revolution are the means to power, whereas Cosworth in their V8 have concentrated on good breathing and efficient combustion in pursuit of that same end.

It would be a mistake to accept old-fashioned notions that these two techniques cannot be combined. Equally it would be mistaken to suppose that no other extrinsic requirements affected the two designs. The Cosworth engine had to be built within certain overall dimensional limits in order to fit into the Lotus chassis for which it was intended, and it had to have ample stiffness in all planes to allow it to form a stressed portion of the chassis, taking suspension and other loads through its structure, and passing them at appropriately distributed points into the monocoque hull to which it, in turn, was attached - and all this without being deflected so much as to endanger the alignment and load-bearing capacity of the crankshaft bearings. It was thus reasonable to make it short and broad, in fact nearly 5 inches wider than it is long; and if reasonable space is to be allotted to comfortably curved exhaust pipes and sufficiently long inlet pipes, then a 90-degree V8 configuration becomes eminently reasonable.

Nor is it unreasonable for the crankshaft to be a simple single-plane device, despite the fact that such a shaft renders perfect secondary balance impossible. The resultant vibrations need not be considered insupportable in a racing engine, least of all when that engine is rigidly mounted and subject to the constant hammering pounding and wrenching of suspensory tractive and braking loads. After all there are advantages to be gained in turn; where the shaft has its throws spaced 90 degrees apart, the main bearing loads may be much smaller, but balance requirements make full counterweighting necessary, resulting in a heavy crankshaft; and although in a flat-crank engine secondary harmonic forces originating in the two banks of pistons may lead to serious vibration, at least the exhaust systems can be clustered and combined into a pair of tailpipes, without any need for complicated cross-coupling of the pipes from opposing cylinder banks. There is also the point, often overlooked, that a V8 with a single-plane crankshaft and employing the right firing order can be better off than the other type in terms of torsional vibration in the shaft; in fact, the amplitudes of certain orders of torsional vibration are reduced to only one-third of what could be obtained with the conventional two-plane shaft.

The considerations affecting Matra's choice of a V12 configuration were utterly opposed to those that determined Cosworth's design, virtually perfect mechanical balance, both primary and secondary, were essential, for the engine is eventually to find its way into some sort of super-duper road going car, the well-heeled purchaser of which would not tolerate a continuous high-frequency vibro-massage of his delicately nurtured derriere. Such balance is afforded by the V12, which also has the advantage of narrowness and small frontal area, appropriate to its insertion, largely unstressed, into a fully enveloping monocoque chassis. Nevertheless, the Matra crankcase is





Previous page: *Twelve cylinders, four overhead camshafts, 48 valves, the new Formula 1 Matra engine, X-rayed by French artist Robert Roux.*
This page: *Eight cylinders, four overhead camshafts, 32 valves, the Formula 1 Cosworth-designed Ford engine, X-rayed by British artist Theo Page.*

extremely stiff, the liberally webbed skirts extending a good distance below the crankshaft centre line, while the main bearing caps are fully cross bolted to keep everything in its proper place. By contrast, the Ford crankcase only descends as far as the centreline of the crankshaft, though it must be conceded that the unusually substantial sump adds considerably to the stiffness of the whole unit when bolted into position.

We thus have two engines of fundamentally different construction, yet they are remarkably closely comparable. There is no significant difference in their weights nor in their power output; Ford claimed 400-410 bhp for the V8 last summer, Matra propose to begin racing with 420 bhp this spring. If one takes into account the probability that Matra are thinking in terms of cv or metric horsepower, whereas we British are accustomed to a horse which is 1.387 per cent more powerful, that 420 may be reduced to 413 bhp - whereupon the difference becomes less than the tolerances permitted in any of the recognised testbed procedures.

Still, we must not be nasty to the French if only because they might think we were following their example, and promptly proclaim themselves pioneers of yet another new movement. Let us give them credit for a full 420 bhp developed at 11,000 rpm, a clear 1,000 below the limit they have admitted for the engine. This is the equivalent of a brake mean effective pressure of 166 lbs per square inch and if you think that's good you haven't been concentrating. Levels of peak-power bmep have admittedly declined since the inception of the 3-litre limit for Formula 1 engines, but the Matra figure is lower than those of the Westlake or the 48-valve Ferrari, for example, and considerably lower than that of almost any engine of the 1.5 or 2.5 litre years.

By contrast the Cosworth V8, in developing 410 bhp at 9,000 rpm, rates a peak power bmep of 197 lbs per square inch, bettered by no other petrol -burning Formula 1 racer, and inferior only to the 1957 Vanwall among the earlier unblown alcohol-fuelled engines. In this we see the truest measure of the Cosworth's greatness, for to sustain a bmep as high as this at peak-power revs, a bmep only 8.5 per cent lower than the peak torque level, is an achievement only exceeded by the Ferrari 555 to which I referred last month. That engine, you will recall - and if you do not you may refer to page 22 of the February issue of *Motor Racing* - also ran at 197 lbs per square inch bmep at maximum power, and this was only 3 per cent lower than the peak of the curve. When the Ferrari was delivering its maximum torque, its bmep was no less than 207 lbs per square inch and this was a little lower than the 215 of the Cosworth - which has only been equalled in Formula 1 engines of the past 14 years by the 1957 Maserati when fuelled by an extremely potent alcohol mixture laced with nitro additives.

However, brake mean effective pressure is but one facet of engine performance, and ultimately it is bhp that counts. For all its wonderful volumetric efficiency, the Cosworth is no more powerful than the Matra or sundry other rivals, for what it gains in bmep it loses in rpm, being limited to little more than 9,000, less than any of its rivals save the Repco. Quite why this should be so is not quite clear, especially in view of the claim made when the engine was first made public knowledge, that it was stressed to be safe up to 11,500 rpm. This prompts the chastening thought that at this rate the mean piston speed would be no less than 4,900 feet per minute.

This may be a valuable clue. At 9,000 rpm the mean piston speed of the Cosworth is already 3,830 fpm, a figure that bears closely upon the commonly accepted practical limit of 4,000 beyond which very few engine designers ever dare to go. Since 1960 only the 1.5-litre Honda has reached 4,000 fpm and only the 3-litre V12 Maserati has exceeded it in running up to 4,150. Yet one can't help wondering whether this almost universally accepted limit is justified, or whether it be some sort of superstitious nonsense akin to our Ministry. of Transport's stone-age notions of braking efficiency. What hazards lurk unknown in the giddy regions beyond 4,000 feet per minute? What champions of engineering development are these who dare not transcend a mere rule of thumb?

After all, the modified Alta engine of the 1956 Connaught ran up to 4,130 fpm, the 2.5 litre BRM to 4,200, the Vanwall to 4,250, the. Ferrari 625 to 4,400. My friend Tony Hutchings never had any trouble from his 328 BMW, whose engine is partly Bristol, despite taking it beyond 4,500 fpm in club racing; and the Type 159 Alfa Romeo knew 4,750 fpm in 1951!

And what do Matra propose? Pusillanimous as all the rest of them, they will limit their V12 to 12,000 rpm, at which rate the mean piston speed will be 3,940 fpm.

But we did not say earlier that the Matra was designed with revs in mind? So we did, and so it is, as can be seen from the unusually short stroke, and from the unusually long connecting rod. The stroke:bore ratio of the Matra is a mere 0.628:1, the lowest yet, lower by the tiniest of fractions than the last of the 1.5-litre Coventry Climax V8s. A short stroke enables high crankshaft speeds to be achieved without exceeding a limiting piston speed and also ensures that piston area will be commensurately large, this in turn making it possible to have valves of generous size.

All this Matra have undoubtedly achieved. The piston area of their V12 is higher than that of any rival, higher than that of the H16 BRM. Indeed, you have to go back to the 4.5-litre Ferrari 1951 to find an engine with more piston area, and even further back to the 1937 Auto Union or failing that to the 1912 Fiat (6 and 14.1-litres respectively!) to find engines with considerably more piston area. Matra have also done the decent thing, by the valves, duplicating them after the modern idiom in order to have as much valve area as possible area and making them of such size that the total inlet valve area is 24.7 square inches, no less than 27.7 per cent of the piston area. To achieve this, they have adopted a tall pent-roof combustion chamber with the valves steeply inclined in opposing banks whose included angle is virtually 56 degrees.

This search for the ultimate in valve area has forced Matra to accept a shape of combustion space that is far from ideal, so although the engine undoubtedly breathes extremely well, it burns indifferently. Cosworth, by contrast, would not allow themselves to be led astray, reasoning that their engine's general proportions allowed four valves of adequate size to be fitted into each combustion chamber without inclining them at all. They thus limited themselves to a total inlet valve area of only 21.9 square inches; and although they did, in fact, incline the valves outwards at an included angle of 32 degrees, this was rather to provide better access to the spark plug than for any other reason.

Now we know that it works, we can commend their choice as a reasonable one, but really, they were rather brave to make the decision. in the first place. See, though, how extremely cunning they were, how well contrived their design is: by keeping the valves almost vertical, the pent-roof shape of the combustion chamber recesses in the cylinder heads. is a very flat pent-roof, and the piston crowns are similarly almost flat. The result is a combustion space that may fall short of the theoretically ideal hemisphere but is still a great deal better than the scrappy misshapen space in the Matra.

At the same time, although the Cosworth V8 has much less piston area than the French V12, it has not such a handicap in inlet valve area; so the ratio of the latter to the former is greater in the English engine than in the French The result, of course, is that the Cosworth not only breathes exceedingly well, but also burns the compressed charge most efficiently,

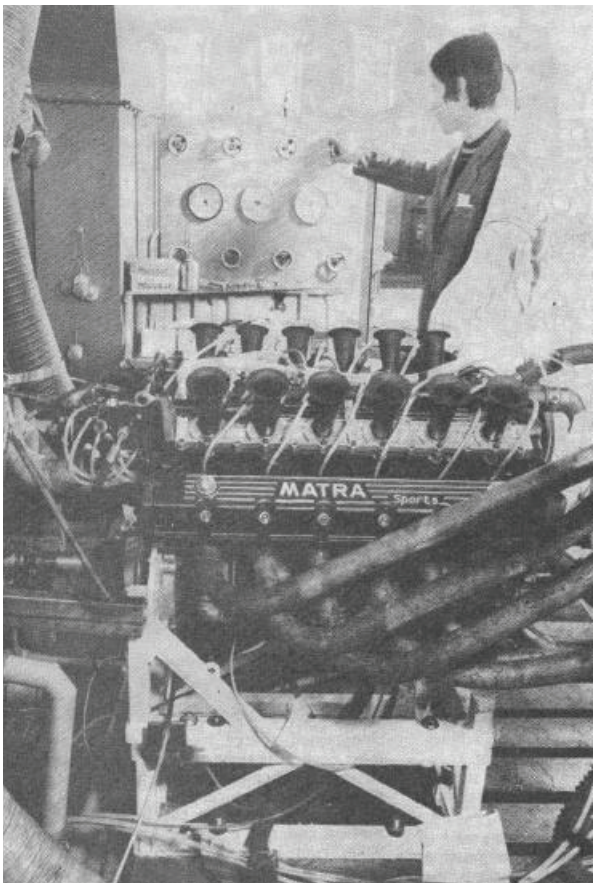
and we must never. lose sight of the fact that both these factors influence volumetric efficiency, of which bmep is our measure.

Here then, we have the basis of our comparison and our contrast. On the one hand 9,000 rpm isn't much, on the other hand neither is 166 psi and on both hands we have engines of about the same weight and power. So where do we go from here? Which engine has the more scope for development, which is likely to prove the more successful in the long run (all other things being equal, which they seldom are!) and which is therefore the more meritorious design?

There are two courses open to both manufacturers if they are to increase their engines' power output. One is to increase the rate of revolution, the other to increase the volumetric efficiency. Obviously, the former is the more obvious for the V8, the latter for the V12. Here we must consider the limit to which the engines are supposed to have been stressed, where upon the mooted 11,500 rpm of the V8 becomes the most interesting proposition. As I pointed out earlier, it connotes an unprecedentedly high mean piston speed, but I have not yet touched upon another design factor which will also be pushed to extremes the little matter of piston acceleration.

This is the bane of all short-stroke high -revving engines, for it has been widely argued that the true criterion of safe maximum engine speeds is not mean piston speed but maximum piston acceleration. Not only does it increase as the square of the engine's rotational speed, but it is also affected by the length of the piston stroke, and the ratio of this figure to the length between centres of the connecting rod.

Two on the test-bed: **This page:** *the new Matra V12 at Velizy* **Next page:** *the Cosworth-Ford V8 at Northampton, anxiously watched by Bill Brown, Keith Duckworth (centre) and Mike Costin (right)*

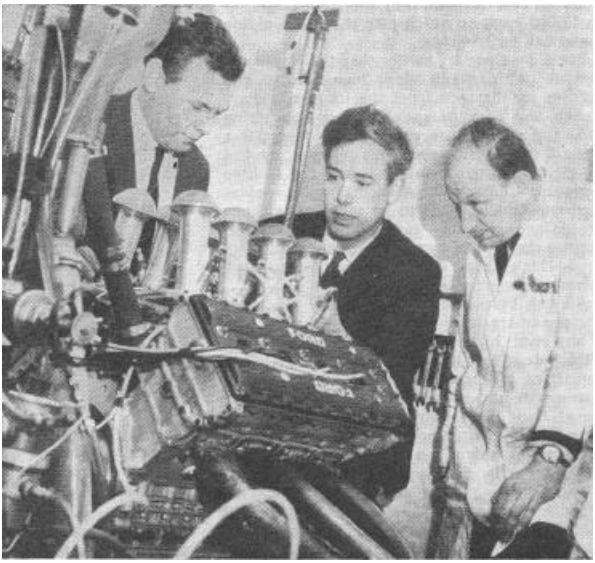


How they compare

DATA	*COSWORTH-FORD*	*MATRA*
Stroke: bore ratio per cent	75.5	62.8
Piston area, sq ins	71.7	92.6
Inlet valve area, sq ins	21.9	24.7
Ratio of distance between conrod centres: stroke, per cent	205	219
Ratio of inlet valve area: piston area, per cent	30.5	27.7
Ratio of exhaust: inlet valve areas, per cent	74.7	87
Claimed maximum bhp	410	420
Peak power engine speed, rpm	9,000	11,000
Equivalent bmep, sq ins	197	166
Claimed maximum torque, ft / lbs	270	-
Peak torque engine speed, rpm	7,000	8,000
Bhp per sq in piston area	5.72	4.14
Bhp per sq in inlet valve area	18.7	17
Mean piston speed at peak power, fpm	3,830	3,610
Maximum piston acceleration at peak power, fpsps	139,400	156,500

For decades it was accepted that the conventional proportions of a conrod involved a length between centres twice as great as the length of piston stroke; but in recent years there has been a tendency to whittle away this figure in an effort to make shorter and stiffer engines. Cosworth resisted this temptation manfully, coming out with a conrod 2.05 times the length of stroke. This does very little to reduce acceleration and stress so that at 9,000 rpm the maximum acceleration suffered by pistons is about 4,300 g.

Matra have conrods that are relatively even longer, not simply because they are hunting for low stress levels but also because their engine is designed to be opened out at a later stage to about 4-litres for sports cars or whatever.



The obvious way to do this would be to lengthen the currently very short stroke, and to accommodate the longer crank throw without a complete rebuild of the entire engine the conrods would be shortened. If you are going to shorten the conrods later you'd better make them pretty long to start with, and this is what Matra have done, rod centres being 2.19. times the stroke. Despite this, Matra pistons still suffer

more severe accelerations than the Cosworth's: at 11,000 rpm the figure is about 4,860 g, roughly the same as the maximum piston acceleration of the old super-charged 1.5 litre BRM V16 that was once considered an Awful Warning to designers and at 12,000 rpm the figure climbs to 5,780 g or thereabouts. But if Cosworth were to push the V8 up to the 11,500 rpm that it's supposed to be able to withstand, then stresses would jump by 53.5 per cent and acceleration to over 7,000 g, a figure quite beyond present experience.

Nevertheless, it is clear that the V8 can safely be speeded up somewhat, and more power in consequence. It also seems that the Matra cannot be speeded up much, but it is painfully evident that there is plenty of scope for improvement in volumetric efficiency, and a little subtle work in the breathing and burning departments might easily see the bmep and bhp figures elevated by perhaps one-eighth. Even then the peak power bmep of the Matra would be lower than that. of Cosworth, but the bhp would rise to over 470, which would make it 'formidable indeed. This is how the greatest of classical racing engines has been developed in the past; with examples such as the 7R AJS and overhead-camshaft Norton among motorcycles, the DB3S Aston Martin and the Maserati 250F among cars, to bear witness to the great things that can be achieved. The attainment of high volumetric efficiency is still something of a black art, not yet an exact science; and therefore, Matra have a very good chance of succeeding in a task to which they must urgently apply themselves.

Matra V12 first time out, Monaco 1968