

Shapes of things to come

Road car engine technology is going to change and, as a consequence, so will racecar engines. Here's what to expect

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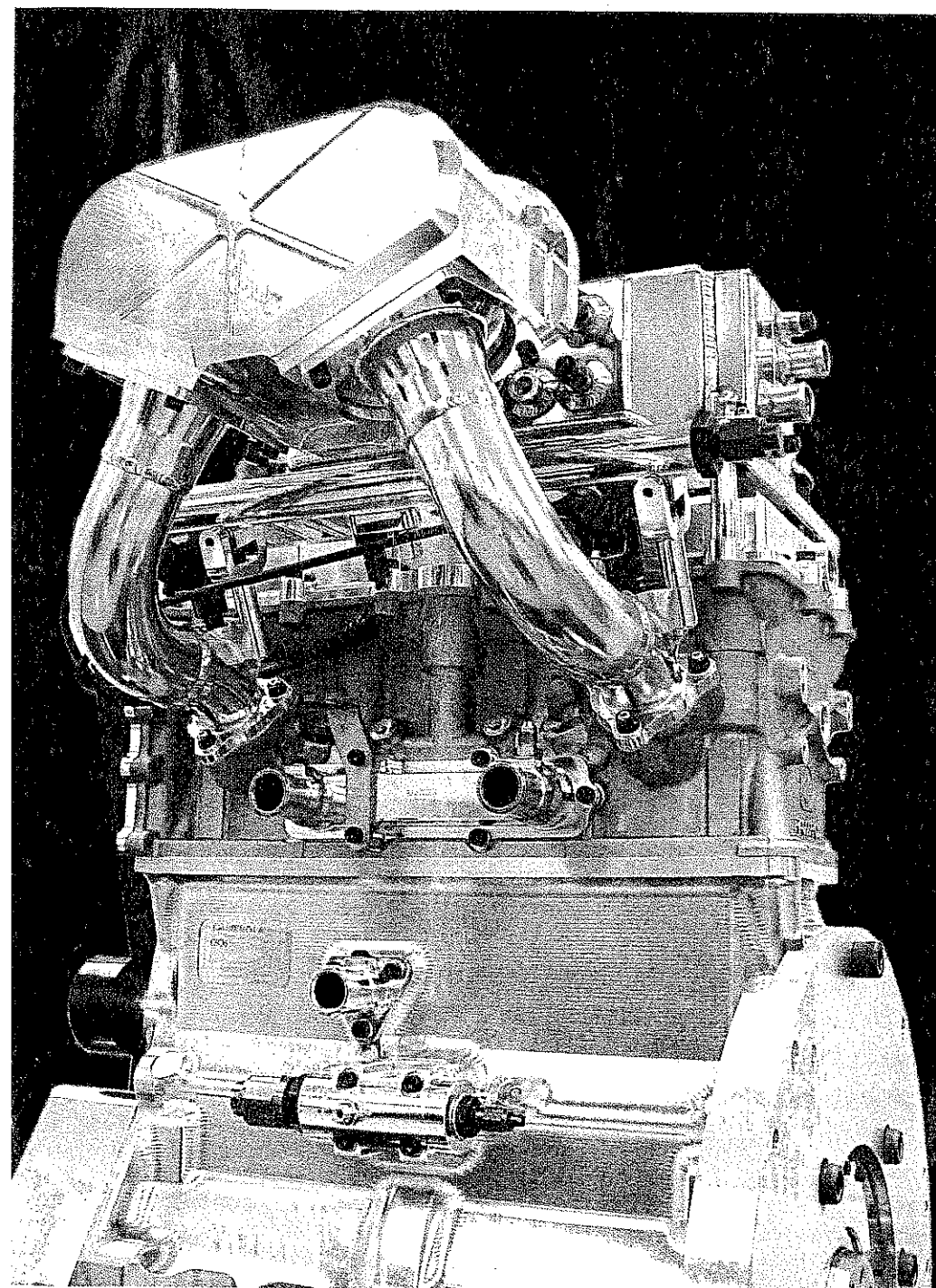
The basic layout of racing engines hasn't changed much in four decades and, in the last two decades, road car-derived race engines have also adopted a pretty common architecture. But very soon all that may change. Dwindling fossil fuel supplies are driving a new generation of internal combustion engine technologies and new patterns of engine design. But motorsport has always accounted for a drop in the ocean of the world's energy consumption, so surely these will be an irrelevance for a long time to come? Think again.

A major proportion of the cars on racetracks are derived from road cars and, as new technologies appear, much of the engine architecture will have to be carried over. We already have one race series mandating an emissions constraint on its cars in line with the road versions and much work has been done on drafting a fuel flow formula as a means of constraining performance. Suddenly it's looking like the blue sky engine concepts of today are to become essential race technologies, not of the far distant, but of the immediate future.

Remarkably, many of these new technologies are being conceived by organisations with a motorsport track record. With all this in mind, we decided to take a walk through this nursery garden of fresh thinking.

FIVE STROKE

Ilmor is well known as the company that delivered race-winning engines in some of the



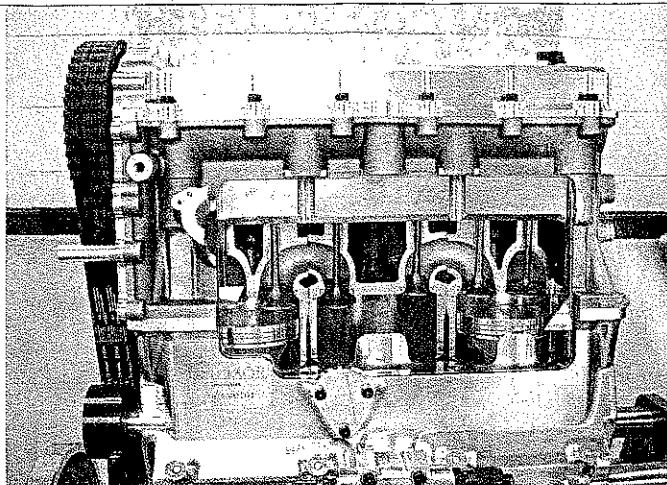
Prototype Lotus Omnivore engine is a complete and working package

world's most demanding series, including IndyCar and Formula 1. Following the death of founding partner Paul Morgan, the majority of the company was bought out and re-branded by Mercedes. But a division of the original concern lives on as Ilmor under the control of surviving partner Mario Illien. Its exploits have been broad, ranging from karts to powerboats, but at the 2009 Engine Expo in Stuttgart the company unveiled the first working example of a five-stroke engine.

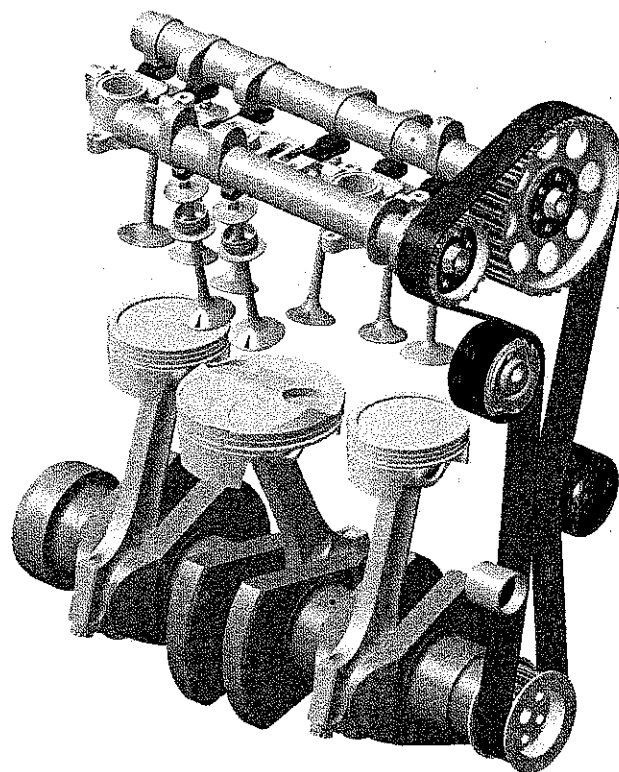
Gerhard Schmitz invented this concept and its name alone is enough to give those brought up on two and four-stroke engines a headache trying to work out what it means. In fact, the challenge it aims to address is that, at atmospheric pressure, the volume of gas before ignition is much smaller than the volume of gas afterwards. That means that ideally you would design the compression stroke of an engine differently from the expansion stroke. A high compression ratio causes unnecessary stresses and can initiate detonation. A low expansion ratio, on the other hand, fails to extract all the available work from the expanding gasses. Unfortunately, the geometry of a piston engine makes it impossible to engineer much difference between the two cycles, with the result that at least one, or usually both strokes, are compromised.

The five-stroke engine is a simple twin-cylinder, spark-ignition engine operating on a four-stroke cycle. However, the cylinders exhaust into a third, two-stroke cylinder that uses the expansion of the gases to do more work. This means both the compression stroke and the two-stage expansion system can be optimised for performance.

To achieve this trick, conventional poppet valves are used and the camshaft for the pair of four-stroke cylinders runs at half engine speed, while the cam for the third cylinder runs at engine speed. In operation, this third cylinder only expands and exhausts, but doesn't induct or compress. In that sense, it only completes half the cycles of a two-stroke engine and could be dubbed a one-stroke engine, making the five strokes of the



A cutaway display version of Ilmor's five-stroke engine. One attraction of this design is its use of entirely conventional engine technology...



...the clever part is how those internals work. The firing cylinder valvetrain turns at half crank speed while that for the third cylinder turns at full speed

engine's name. In reality, it is effectively operating like a steam or compressed air engine, turning the expansion of the gas into work.

As well as those already mentioned, Ilmor claims a

expansion, while the lower compression ratio in the firing cylinder reduces the risk of knock.

Because the firing cylinders are much smaller, pumping losses - the work done pulling a vacuum

both the compression stroke and the two-stage expansion system can be optimised

number of further advantages for the concept over conventional engines: the overall ratio can be as high as 14.5:1, which is approaching diesel levels of

against the throttle - are also significantly reduced. Yet the fuel consumption does not rise as rapidly with brake mean effective pressure (BMEP) as retarding

rejects more energy into the expansion cylinder rather than wasting it down the exhaust.

Ilmor expects a turbocharged 700cc engine to be delivering 130bhp at 7000rpm and 166Nm of torque at 5000rpm, with a power density of 150bhp/litre. Impressive figures for such a small unit that, being smaller and up to 20 per cent lighter than a conventional engine of equivalent output, will contribute to the overall efficiency of any vehicle it powers. In addition, the engine is expected to generate fuel efficiency savings in the region of 10 per cent over current four-stroke designs.

All the technology employed in the design is mature and conventional, so no intensive research and development programs are necessary to make any key parts of the design operational. A working prototype has already been designed and manufactured in-house and is undergoing initial testing. The plan now is to build a second-phase prototype for testing in real world figures and to forge development partnerships with vehicle manufacturers.

OMNIVORE

Lotus has long been a famous brand in motorsport, although competition has been a very minor part of its business for a long time now. Even the new Lotus Formula 1 team is related in name only. Today Lotus Engineering is famous within the road car industry as a capable and groundbreaking consultancy company. Seeing high efficiency car engines as a commercial opportunity, it has been looking closely at the problem.

The solution, according to the company's chief engineer of powertrain research, Jamie Turner, is homogeneous charge compression ignition (HCCI). This technology, which Turner describes as, 'the third way,' came out of the Japanese motorcycle industry in the late 1970s. Currently, cars use either spark ignition or diesel engines, which initiate combustion by an electrical spark or the injection of fuel respectively. With HCCI the homogenous charge (a mixture of fuel and air as in a spark ignition engine) is compressed until it

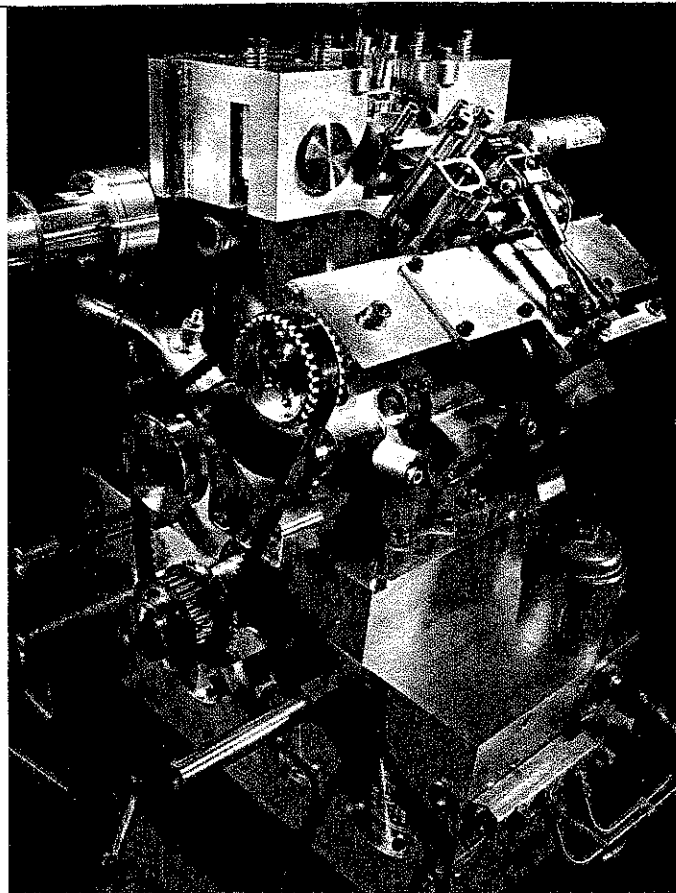
combusts spontaneously. This has major advantages in the efficiency of the combustion. Firstly, it does not rely on a flame front because the reaction takes place spontaneously throughout the charge. Consequently, it can run an exceptionally lean mixture and accommodate a very broad range of fuel grades. Secondly, it burns a lot cooler than conventional combustion, at less than 2000degC. Crucially, this is below the temperature at which oxides of nitrogen form, keeping the critical NOx figures very low.

Achieving this does present a couple of significant challenges, however. Spontaneous combustion requires very high compression ratios, up to 40:1, which are extremely hard to achieve while allowing space for sufficiently large valve sizes and duration without metal hitting metal. Also, without an event to trigger combustion, how do you control the ignition timing? The solution from Lotus is a two-stroke engine fitted with a moveable 'puck' in the cylinder head that can control the compression ratio very precisely.

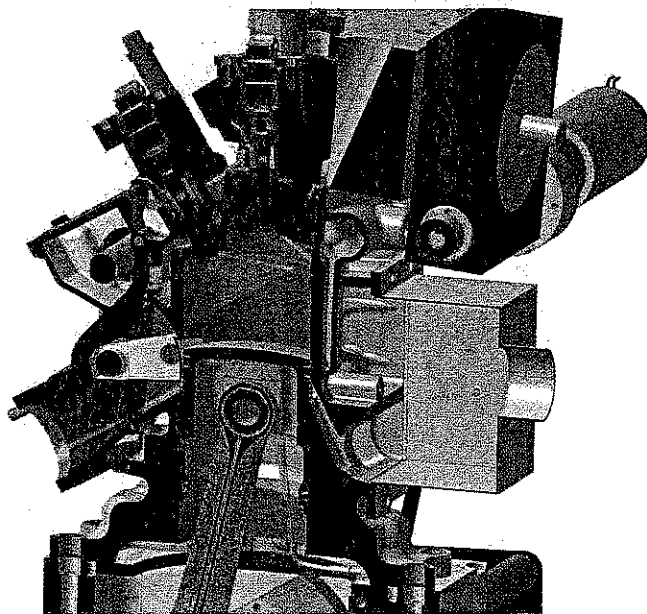
Traditionally, two-stroke engines have a poor reputation for refinement and the image of motorcycles trailing blue oil smoke is not a good fit with the clean aspirations of the project. But Turner insists all these preconceptions are unfounded and born of prejudice. He points out that crankcase compression is not essential and can easily be replaced by another form of forced induction preventing any oil entering the charge.

There are, he notes, significant advantages to a two stroke - for instance, the absence of throttling losses. On a four-stroke engine at closed or part-throttle, the engine is pulling a partial vacuum in the cylinders, consuming energy that is never recovered, whereas a two-stroke has forced induction so never sees cylinder pressures lower than atmospheric.

When it comes to HCCI, the two-stroke cycle has some very real advantages over the four stroke. Without poppet valves intruding into the combustion chamber, the compression ratio can be pushed as high as you could want without any clearance



The prototype of Lotus Engineering's Homogenous Charge Compression Ignition (HCCI) engine, Omnivore



A cylindrical puck intrudes into the combustion chamber and controls compression and ignition timing. Note also the exhaust trapping device

issues. Also, without the valves cluttering up the head, space is available for the adjustable compression ratio device. On Lotus' development engine, this is a cylindrical puck that can be edged in or out of the combustion chamber to fine tune its volume and the moment of combustion.

Turner also points out that when it comes to HCCI, the

four-stroke engine's superior scavenging is actually a disadvantage. Allowing time for the cylinder to cool is a disadvantage, while retaining some of the burned gasses in the charge has two advantages. 'They have a beneficial effect with HCCI because they put more heat into the charge, and can also still be chemically active

during the compression phase,' he explains. 'They also slow down the burn rate and stop a rapid compression rise.'

The Lotus engine manages the amount of burned gases with its charge-trapping valve in the exhaust port that allows it to be precisely controlled. 'If you can trap some of the residuals and control that separate to the amount of compression heat you put in, you have two separate levers which get you back to the point where you can control the ignition timing,' explains Turner.

All these features have been incorporated into the company's Omnivore development engine that was unveiled at the Geneva Motor Show early in 2009. Since then, work has progressed, and the first results from tests are due to be published soon. However, the company has already received interested calls from major OEMs wanting to know more about the concept.

2/4SIGHT

Ricardo is well known for its work in motorsport, from manufacturing gearboxes to its consultancy work for the FIA, employing some of its world-renowned software. But this is a small part of its work compared with the consultancy expertise it provides OEMs.

Compared with Lotus, Ricardo could be accused of being in two minds about the benefits of two-stroke engines. Why else would it design an engine that can run as both a two stroke and a four stroke? In fact, the thinking behind it is that the engine can use the switch to overcome the problems of downsizing.

Smaller engines have lower friction and lower losses and a common approach to improving efficiency is replacing a large, normally aspirated engine with a smaller, forced induction alternative. That way, you have the volumetric efficiency of the large engine with the parasitic losses of the small one. Turbocharging is the most common way of achieving this, but due to the inertia of the turbo impeller, throttle response is poor. Even if this can be overcome with greater boost at low revs, the cylinder pressures needed to produce enough

ENGINE MAJEUR

Energy supply is a concern that has loomed for several decades but, until now, has not driven a fundamental change in engine architecture. However, all that seems destined to change. In 1998, ACEA, the European Automobile Manufacturers Association, signed an agreement with the European Union (EU) to reduce the average output of its ranges of vehicles to 140g CO₂/km by 2008. In exchange, the EU agreed not to impose any legislation in this area. However, since the manufacturers failed to meet this target, the EU has tabled legislation due to be introduced in 2012 that will impose crippling fines on manufacturers who fail to meet a new target of 130g CO₂/km.

As Jamie Turner of Lotus Engineering points out, 'In 2015, each gram over will be 95Euros (£85 / \$143) on a car. Just 25g will be the thick end of £2000 (\$3300). That cost will be passed on to the customer, ultimately driving buying decisions in the future. To remain competitive in the market, manufacturers are expected to introduce radical new technologies in pursuit of efficiency. These are the technologies that are likely to impact on motorsport in a number of different ways.

torque at low revs puts a great load on the bearings, requiring upsizing and more losses of the type you were trying to avoid in the first place.

A two-stroke engine, however, having twice the power strokes per revolution than an equivalent four stroke, can deliver the same torque with half the bearing

overcome the compression ratio barrier to further downsizing,' explains Ricardo group technology director, Professor Neville Jackson. 'By running the engine in two-stroke mode under low-speed / high-load conditions, the torque produced by each cylinder every power stroke is about half of that, which

reduced fuel consumption and, possibly, better launch feel.'

DISSIMILAR ARCHITECTURE

It's a great theory, but could it be achieved in practice, considering how dissimilar the typical architecture of the two engines is? The team at Ricardo was undaunted. Its 2/4SIGHT engine uses the conventional four-valve cylinder head architecture. Under most driving conditions, this runs a normal four-stroke cycle with forced induction from a turbocharger. Then, when there is sufficient demand at low revs, it switches cam profiles and spark frequency to run as a two stroke. Doubling the frequency of the valve opening and with forced induction, the normal poppet valve architecture can be made to run as a reasonably efficient two stroke.

The first development engine used a block and heads taken from a Jaguar V6, but equipped with an external supply of pressurised air for simplicity. It also utilised an electro-hydraulically actuated valvetrain to simplify the development of the different cam profiles and the switch between the two. To make the switch smoothly it has to be done during the part of the cycle when the valves are closed for the longest. On a multi-cylinder engine though, this is going to be at different times for different cylinders. That entails being able to switch cylinders over individually - a simple task with electro-hydraulic actuation. However, such a system is not practical on a production road car and conventional mechanical cams need to be used. Ricardo is confident that it has a system worked out that will do the job without too much complexity.

In fact, it has already designed the first development engine ready to install in a car, a Jaguar XF. Incorporating direct injection fuelling and two forms of forced induction - a turbo for normal driving and a supercharger that kicks in when the engine switches to two stroke, ensuring good scavenging. Behind the wheel, the team expects the switch to be perceptible but not unpleasant, merely a prompt response to the throttle on demand at low revs.

an engine that operates like a turbocharged four stroke but, at low revs, switches to two stroke

loads. The people at Ricardo then thought, what if we have an engine that operates like a normal turbocharged, four stroke most of the time but, at low revs, switches to two stroke?

'When we first conceived the 2/4SIGHT engine we realised that we could potentially

would need to be produced by a four-stroke engine under the same duty. Two-stroke operation effectively offers a means of boosting low-end performance, in the process further increasing the opportunity for downsizing in spark ignition engines. The main benefit to the driver would be

2/4SIGHT

Figure 1

Topology of the 2/4SIGHT concept: a three-cylinder direct-injection engine with turbocharger and supercharger

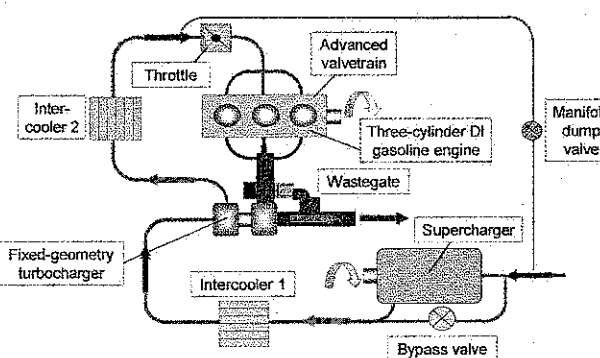


Figure 2

The difference it makes in practice compared with an equivalent baseline conventional engine

