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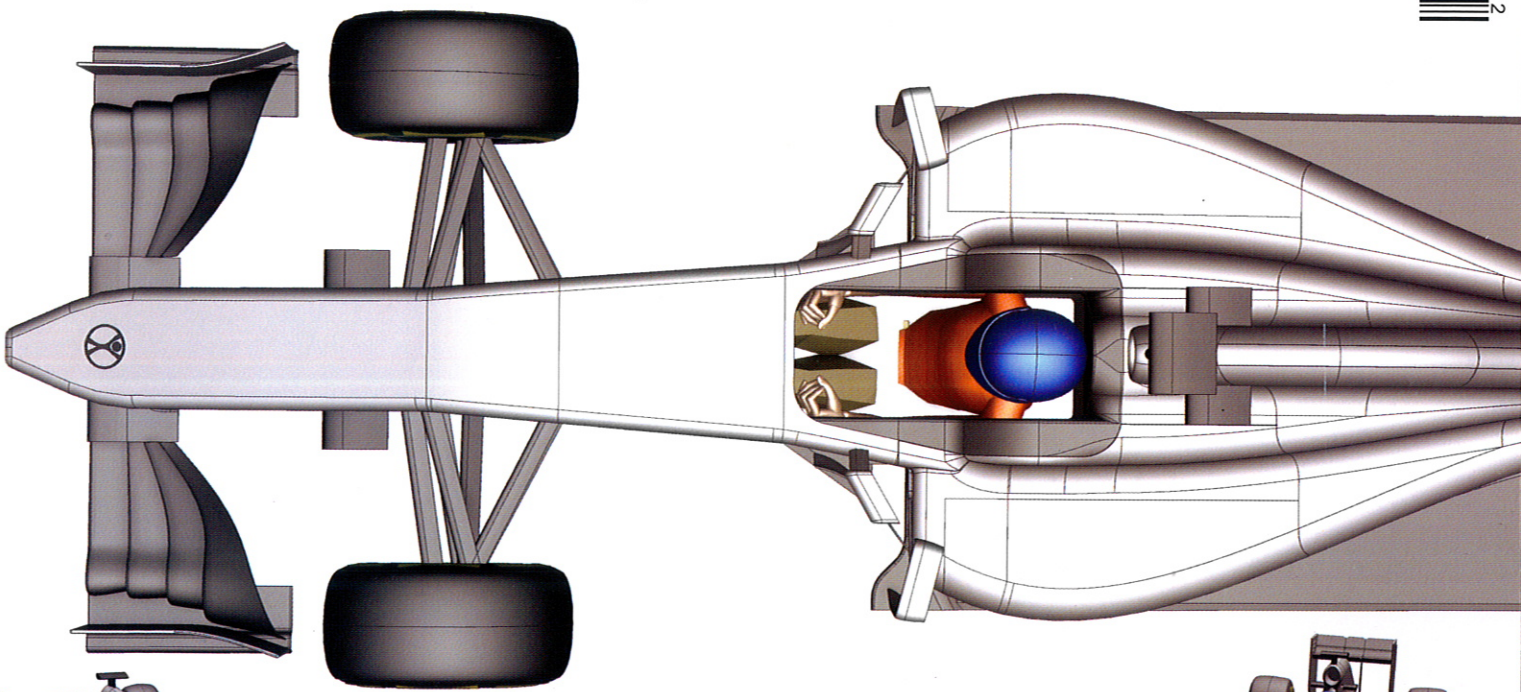

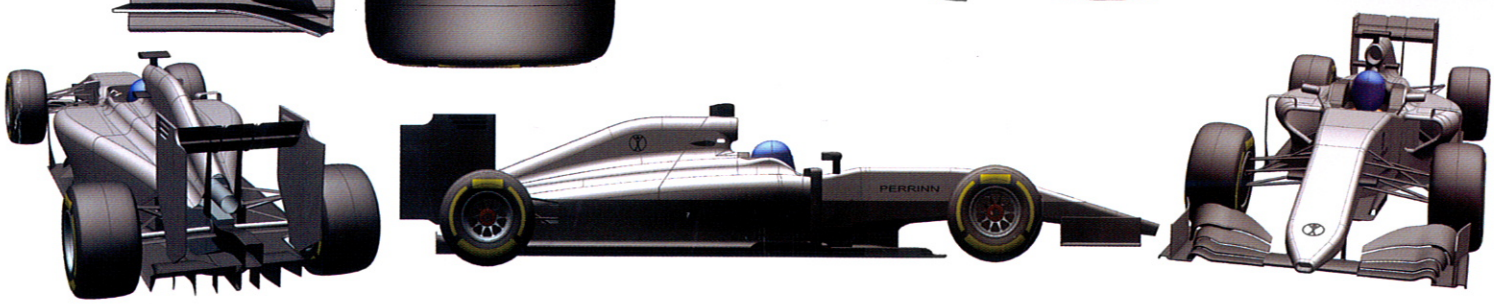

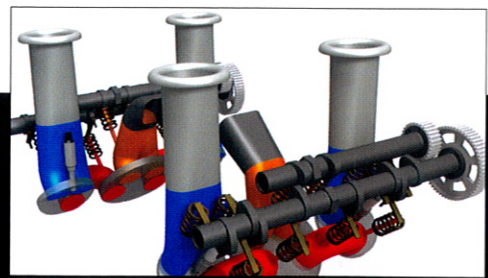

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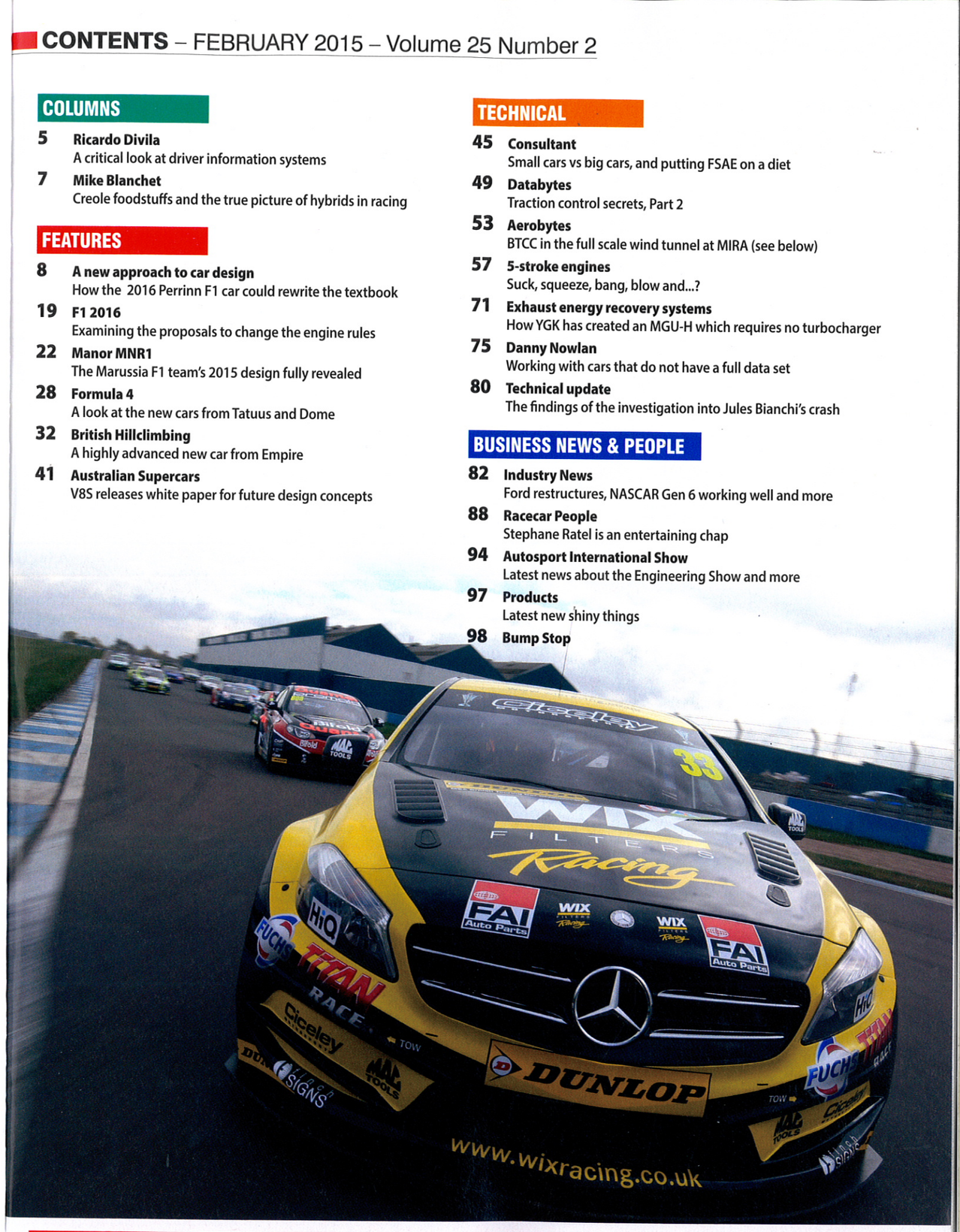


Building energy

Exhaust gas recovery on a normally aspirated engine has brought application potential at Le Mans, WEC or on the commercial market

By SAM COLLINS

The laboratories of Tokai University contain many interesting projects for the motorsport engineer. Sitting on a four-post rig in one room, for example, is a 1990 Honda Formula 1 car, designed and built in secret by the Japanese firm's engineers. In recent years the establishment has risen in prominence by heavily re-working a Courage LC70 LMP1 car and entering it in the Le Mans 24 Hours in 2008.

The Le Mans project was headed by engine specialist Dr Yoshimasa Hayashi, who had designed and developed his own 4.5 litre V8 engine via his company YGK for use in the project. Once attempts to race the Courage had come to a close little was heard of the programme other than vague reports that it was being used to develop a new hybrid technology. The reports, it turns out, were true.

'I was looking at some basic details of the otto cycle one day and I noticed that there was no progress on working with the heat loss from the combustion process' Hayashi explains. The Otto cycle of the theoretical cycle, the ratio of gas specific heat:

Equation:

$(Cp/Cv) = \kappa$, compression ratio $= \varepsilon$

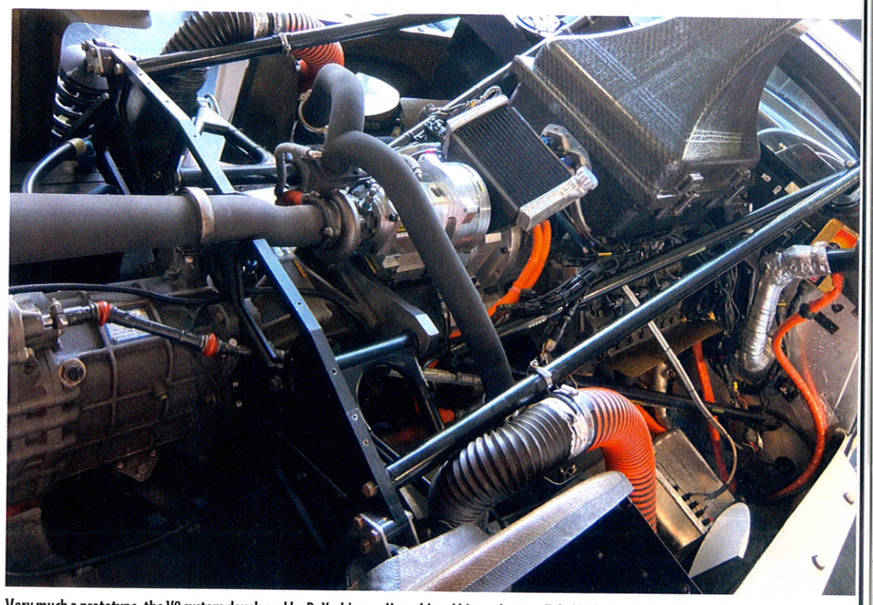
Then indicated thermal efficiency

$\eta = 1-1/\varepsilon^{\kappa-1}$.

'Looking at the values for κ-1, the exhaust loss, I thought why not use the energy recovered from such a big loss?' says Hayashi.

So a little under a year after the Tokai Courage had run at Le Mans, Hayashi, enthusiastically assisted by the engineering students at the university, started to look at ways of improving this. Of course this was something that had already been solved to some extent with the latest generation of competition engines, the four current F1 designs as well as the Porsche LMP1 all feature motor generator units on their turbo chargers, aimed at recovering some of the wasted energy heading down the exhaust pipe.

Notably the Porsche solution does not ever act as a motor to spin up the turbo – rather it is simply a generator unit (GU-H). This is the closest design in concept to what Hayashi was working on, but he wanted to apply it to his normally aspirated V8 engine. With no turbo to connect a GU-H to he had to come up with an alternative way of recovering the energy.



Very much a prototype, the V8 system developed by Dr Yoshimasa Hayashi and his students at Tokai University, in its Jaguar chassis

The YGK EER-Hybrid, as the Japanese concept has been branded, is at least on paper quite simple. A turbine is added to the exhaust pipe which is driven by the exhaust gasses up to 126,000rpm. This in turn drives a generator unit at around 18,000rpm via a reduction gear. But as this is a normally aspirated engine there is no compressor; the turbine is purely there to generate electricity. That electricity then passes via an inverter to a capacitor pack mounted in the passenger seat area of the cockpit. Unlike other LMP1 systems the energy store on the YGK solution is very compact, because the electricity is fed almost constantly to a traction motor mounted between the transmission and engine, though this could theoretically be positioned at the front or rear axle, though with this layout the electric motor acts on the engine's crankshaft, increasing rpm but not fuel consumption. The small size of the energy store is due to the fact that the energy is supplied constantly from the turbine at any point when the engine is running, while most hybrid systems used at Le Mans or in F1 rely on recovering brake energy then having to store it until needed.

The potential energy that can be recovered in such a system is much higher than that of a turbocharged engine due to the much higher exhaust gas velocity, but the lack of turbo in turn creates its own challenges, particularly in terms of thermal management. Hayashi will not be drawn on the exact details but admits that the generator unit runs at about 80degC while the turbine runs at 800degC or more.

Hayashi says one of the system's biggest advantages is its light weight and simplicity: 'The major components of EER-Hybrid are an exhaust turbine, a reduction system for ultra high speed revolution, an intermediate device,

"A turbine is added to the exhaust pipe which is driven by the exhaust gasses up to 126,000rpm. This in turn drives a generator at 18,000rpm"

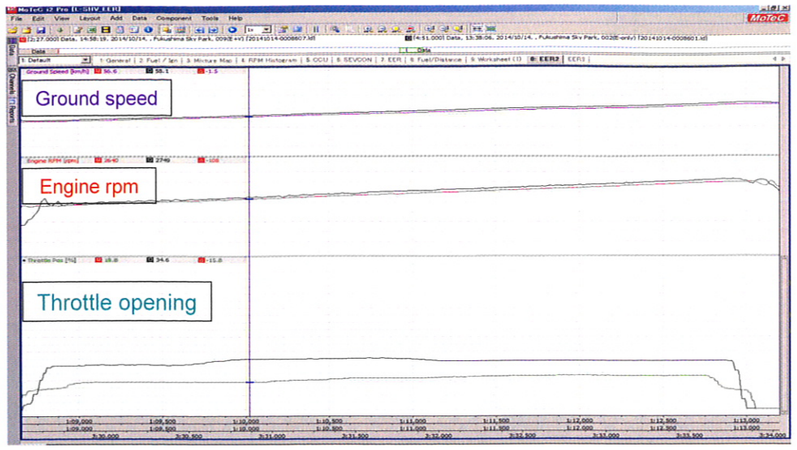


Figure 1: the same engine rpm and vehicle speed could be achieved with a smaller throttle opening. The black trace is from the run with the EER-Hybrid system deactivated and coloured traces are from the runs with the system switched on

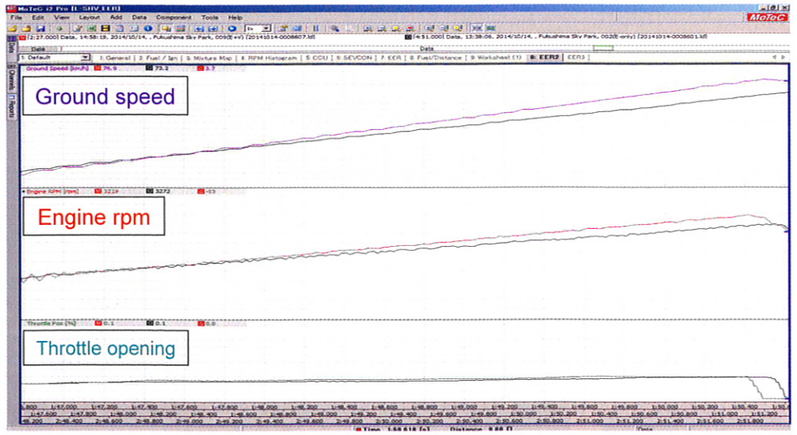


Figure 2: with a constant throttle position the Jaguar was notably faster with the hybrid system engaged

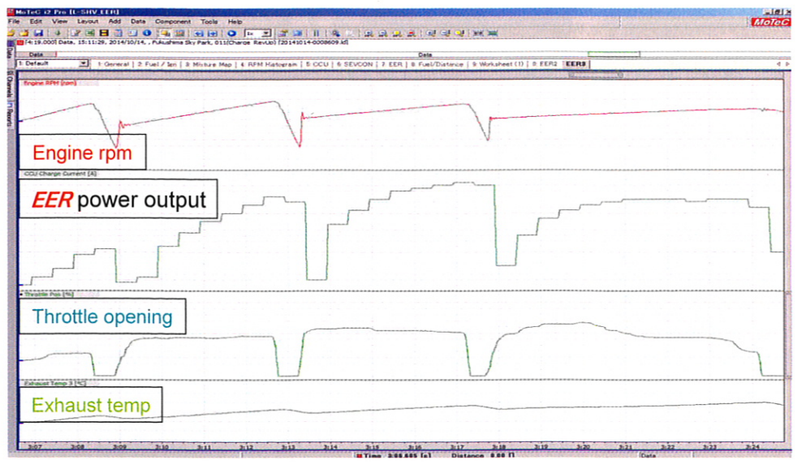


Figure 3: data from Fukushima airport shows the EER-Hybrid's power output and exhaust temperature

Hayashi has discussed the system with the ACO with an eye to it being used at Le Mans

a generator, an MGU, an inverter for generation and drive, and a capacitor, for the development of the test car project. Then we have specially developed the 2kg reduction system and the other parts are not really different from commercial products.'

After seeing early results from the test bench Hayashi decided to resign from his post at Tokai University to continue development of the EER-Hybrid, though still keeps a very close relationship with his former employer. After the bench tests were complete the next stage of the project was to run the system on track so the EER-Hybrid mounted to the YGK V8 was fitted to a Jaguar XJR-15 chassis.

'We had had the car for some time, it was used to for YGK's LMP1 engine 'YR40t' in 2005 for the Tokai University Le Mans project,' Hayashi explains. 'We have still got the LMP1 Courage, but this time we wanted to build the system into something that looked more like a production car. The XJR-15 is a classic car these days but it is still good enough for testing purposes.'

Test runs

During the test runs held at Fukushima airport the Jaguar completed over 100 miles of running and the hybrid system performed well. In the first runs the car was tested at a constant speed and rpm with the hybrid system turned on and off for comparison. These tests showed that the same speed and engine RPM could be achieved with a smaller throttle opening, suggesting an increase in range **(Figure 1)**. The second set of experiments saw back-to-back runs conducted with a constant throttle position, with the hybrid engaged this showed a notable increase in rpm and vehicle speed **(Figure 2)**.

'We found a 25 per cent improvement in efficiency at constant speed, powered by EER-Hybrid. You can make more improvement of fuel economy combined with KERS system using this,' Hayashi states.

Although it is very much a prototype Hayashi hopes the system will become commercially available. 'We will talk to potential customers about the reduction system for ultra high speed revolution. It costs less than 800 euros, but we estimate it will be going down to 10 per cent of the cost if it is put into mass-production as the other parts are similar to typical components,' Hayashi says. With no firm plans for its use in competition yet Hayashi has already discussed the system at length with the ACO with an eye to it being used at Le Mans or in the WEC.

'We do not have a plan for competing in races in 2015, but possibly we will do it the year after,' he says. 'We want to prove the system. It is not difficult to adapt EER-Hybrid to production cars. Nowadays, a Hybrid car already has MGUs, inverters, and batteries, and EER-Hybrid just provides the extra power from emitted exhaust gas energy by a N/A engine. We hope that it will be adopted by any interested world car and engine manufacturer.'