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DIESEL POWER
The full story behind Audi's record-breaking engines

BUMP AND GRIND
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Le Mans 24 Hours
AUDI R18 TDI
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This is an exciting time for motorsport and, according to industry leaders, the changes in racecar design that will take place over the next five years will dwarf those that we have seen in the previous 20.

That is some prospect, and I am honoured to be sitting in the editor's chair of a magazine that will examine these developments in depth. *Racecar Engineering* has built up a solid reputation for bringing you detailed technical analysis across the full spectrum of motorsport, and this month is no different.

Naturally, this issue going to press the week prior to the event, the Le Mans contenders take centre stage. Peugeot and Audi have both produced new cars this year, and the two rival manufacturers have taken completely different approaches to the race. Audi has put its faith in its engine department, and we take the opportunity to look back over the development of its V12 and V10 diesel engines, while Peugeot has concentrated on its aerodynamics. We are undoubtedly in for a fantastic season of endurance racing.

We also feature Georg Plasa's exotic European hillclimber, featuring Judd's fantastic V8 engine mated to a BMW 1-series, bristling with home-brewed innovation. Follow the link on our *Racecar Engineering* website to see this amazing car in action.

Energy recovery systems are all the rage at the moment, and we feature PKM, a French company that is working on a KERS damper system, which we reckon has an exciting future.

Finally, as the world gets its first look at the new IndyCar, we look at the positives and the negatives of one of the most innovative new designs in single-seat motorsport today. We hope you enjoy the coverage.

EDITOR
Andrew Cotton

For more technical news and content go to www.racecar-engineering.com

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GT RACING

ACO boosts petrol LMP cars and GT class stragglers

Efforts to equalise performance in the GT classes has met with approval from all teams, except one – a notably successful German manufacturer...

The Automobile Club de l'Ouest (ACO) made changes to boost the performance of the petrol cars in LMP1 and GT class stragglers ahed of the Le Mans 24 hours, but left the manufacturer cars alone.

In the LMP1 class, petrol cars are to have their air restrictors increased in size by 0.3mm, and are able to shed 10kg, to 890kg. If a car cannot lose the weight, a 0.2mm increase in the restrictor will be allowed. They will also benefit from an increase in the diameter of the refuelling hoses by 10mm to 38mm. The diesel cars have had their refuelling hose diameters decreased by 0.3mm to 25mm, while the older ORECA-run Peugeot has been given a 15kg weight penalty.

Vincent Beaumesnil, ACO sports manager, said: 'Performance is an overall concept that takes into account all the factors that can influence the results. Not only lap times, but also everything that contributes to the final result – power, torque, aerodynamics, cornering speeds, pit stop times, fuel consumption tyres etc are evaluated.'

LM GTE team principals are split over the balance of performance regulations following the ILMC races at Sebring and Spa.

Both the Doran Ford GT and the Lotus Evora were given larger air restrictors, while the Lotus will also benefit from a 50kg weight break. There is also to be a 10mm reduction in the size of the Gurney on the Aston Martin Vantage.

Jan Kalmer, team manager of JetAlliance, which runs the Lotus Evora, said: 'Balancing has made our project viable, and I think that's very important for the sport... if we didn't have this then Lotus would not have joined.'

Sam Hignett, who runs the Aston Martin Vantage, agrees: 'GT2 is very competitive, it's an uphill struggle for new cars, so it's good they can balance performance as it makes for better competition, and that's what everybody wants.'

However, Porsche's head of motorsport, Hartmut Kristen was unhappy: 'The facts speak for themselves,' he said. 'We cannot understand why BMW and Corvette are granted significant advantages over other competitors. Especially for the 24 Hours of Le Mans.

'Everybody knows about the high sensitivity in regards to horsepower/ restrictor diameter. We will cooperate with our customer teams as closely as possible to make the best out of it.'

Kalmer went on to say he hopes the ACO will take another look at the balance of performance in the future, but accepts others are more cautious. 'I think the way they're doing it is correct. It would get very expensive for everybody if it was on a race-by-race basis.'

Lastly, LMP2 cars running to full 2011 regulations will also benefit from an increased fuel hose diameter (by 3.5mm), while the Judd engine will be allowed to run with larger air restrictors.

FORMULA 1

Four-pot cost concerns for Cosworth

F1 engine-builder, Cosworth, has admitted it has concerns over the cost implications of the new-for-2013 four-cylinder turbocharged engine regulations, with its Formula 1 general manager, Mark Gallagher, saying he believes the new engines could lead to a 'financial space race'.

'The one aspect of the 2013 regulations that concerns us is that when we look at our customers and consider the future from the point of view of business in F1, we are here to service customers, and we know customers don't have the appetite to spend money on F1 engines. Costs remain an issue and regulations as currently drafted leave a number of options to spend a great deal of money.'

He added: 'With new regulations, while being welcome from the point of view of innovation, what would never be welcome is creating a financial space race. That is not what we want when we are emerging from the most difficult economic time for many teams. We believe there is a responsible discussion to be had in terms of costs involved in 2013.'

Despite its concerns, Cosworth, which presently supplies powerplants to Williams, HRT and Virgin, is committed to a future in F1. 'We're completely committed to F1 long term,' said Gallagher. 'I said last year when we came back to F1, that the three years Cosworth was away was something we didn't want to see repeated. We are back in F1 long term and we are totally committed to 2013.'

The new engine formula has been subjected to a great deal of criticism lately, with both Bernie Ecclestone and Ferrari saying they are against the introduction. But there has also been some positive reaction from Renault, while an all-new engine supply company named PURE has been set up by former BAR boss, Craig Pollock.

Meanwhile, at a meeting with engine suppliers at the Spanish Grand Prix it's believed FIA president, Jean Todt, made it clear that the governing body is committed to the new engines, although there might be a chance that some teams will be able to run performance-restricted V8s alongside the four pots for the first year.

FORMULA 1

FIA and F1 teams differ on diffuser blowing

A move by the FIA to ban off-throttle diffuser blowing could meet strong resistance from the teams, some of whom have invested heavily in the technology and see it as an important part of their cars' performance package.

The majority of the F1 teams use the technique, which maps the engine to blow exhaust gasses through the diffuser when the driver is not on the throttle, with only Williams, Virgin Racing and HRT running without it.

A ban was put in place in the run up to the Spanish GP, but then rescinded after lobbying by the teams. The issue will now be discussed at the Technical Working Group meeting on June 16.

However, it seems unlikely the teams will let go of the technology lightly, particularly Renault, whose complex, forward-facing exhaust uses 95 per cent throttle opening, whereas the FIA is proposing an upper limit of 10 per cent.

The FIA says blowing exhaust gasses through the diffuser when off throttle is tantamount to a moveable aerodynamic device

Renault's managing director, Jean-Francois Caubet, commented: 'Because we worked over the winter on the exhaust, we did a lot of work, but I think the FIA decision [not to ban it at Barcelona] was a good decision... But probably we will keep it like that... because if you change the rules we will find another solution where we will spend a lot of money for nearly the same thing.'

On the ruling, FIA technical delegate, Charlie Whiting, had this to say: 'It became apparent to us, through examination of data, that what we thought was a fairly benign feature was turning into something that was being used, in our opinion, illegally. An exhaust system is there for exhausting gasses from the engine and, when you're off throttle, it isn't doing that any more. Therefore it's being used to influence the aerodynamic characteristics of the car. We think, arguably, this infringes Article 3.15 of the technical regulations [which bans movable aero devices].'

SEEN: ASTON MARTIN AMR - ONE

Under that central fin lies Aston Martin's 2.0-litre, straight six, mono-turbo engine. The engine is not fully stressed with steel bars carrying significant loading direct to the bellhousing

BRIEFLY

Renault four?

Renault is hoping to supply a fourth team in next year's Formula 1 World Championship, and its managing director, Jean-Francois Caubet, has confirmed the French manufacturer is currently in discussions with the FIA over the possibility. Engine suppliers are currently restricted to three teams and Renault already provides its engines to Red Bull, Team Lotus and, of course, Renault. If the FIA sees fit to lift the restriction it's widely believed Williams will become the fourth Renault team.

DRS code

Formula 1's DRS system will be available for drivers to use twice a lap from the Canadian Grand Prix onwards. The system, which allows the driver to open a flap in the rear wing provided he is within a second of the car in front, has so far only been used at one section of each track, but now the FIA has said it has developed the technology to run multiple sectors. For the Montreal race, the zones will be on the back straight, approaching turn 11, and on the start / finish straight.

Judd for Lotus

The Lotus V6 turbo that is to be used in IndyCar next year is to be developed in conjunction with well-known British powerplant builder Engine Developments, better known as Judd. The company has been working on the Lotus engine since the beginning of the year and the first unit is expected to be run on the dynamometer in September. Judd previously developed an engine for top level US single seaters with Honda in the 1980s, scoring one win with its CART-spec turbocharged V8 in 1988. It was also involved with Toyota in 1996.

Audi on track

Audi's all-new DTM car is set to make its testing debut soon, but Mercedes will not be running its new car for at least another three months. Next year sees a change of formula in the DTM, plus the return of BMW to join Audi and Mercedes to make it a three-way fight. The new cars are to feature reduced aerodynamic downforce and a spec carbon chassis. Neither Audi nor Mercedes have said how many cars they will field next year, though it is known that BMW plan to enter six cars spread across three teams.

• MORE NEWS ONLINE AT WWW. RACECAR-ENGINEERING.COM

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RENISHAW

LE MANS

Highcroft looking for new partner in wake of Le Mans pull out

Out, but not down. Highcroft Racing is looking for opportunities in all areas of motorsport

Highcroft Racing is looking for a new manufacturer to take the place of Honda as it attempts to put its withdrawal from this year's La Mans 24 Hours, and the subsequent ending of its partnership with Honda Performance Development (HPD), behind it.

The team scored a fine second place at Sebring earlier this year, and its HPD ARX-01e LMP1 was expected to be amongst the quickest petrol cars at Le Mans, but it was unable to secure sponsorship for the race. On top of this, with the economic problems in Japan, Honda could not come up with the extra money needed to make the grid, which resulted in the long-running relationship between HPD and Highcroft coming to an end.

Highcroft boss, Duncan Dayton, said: 'We certainly appreciate the massive impact the earthquake and tsunami has had on the people of Japan and the huge challenges facing Japanese business. It appears this may have contributed to Honda's decision and we fully respect and understand their position.'

But the team boss insists this is not the end for Highcroft, and says it is 'actively seeking new manufacturer relationships', both for Sportscar racing and other championships. 'For our future, we need to take the next step in the development of our team,' Dayton said. 'The team is now in a position to start with a clean slate and work towards our next championship assault with new partners.'

He added: 'Our organisation was established as a platform for manufacturers to showcase their technology on the world stage through motorsport. We still have big goals and ambitions - including additional victories in the ALMS, as well as Le Mans and IndyCar.'

Highcroft was part of the HPD Prototype programme from the start, running the original LMP2 car in the ALMS in 2007. It went on to win the 2009 and 2010 ALMS titles.

The team's place on the Le Mans grid is taken by the Kronos Racing Lola Aston Martin. The Belgian outfit is a former World Rally Championship-winning team and currently runs the works Peugeots in the Intercontinental Rally Challenge. The Marc VDS team will be supporting Kronos at Le Mans.

V8 SUPERCARS

Aussie V8 ownership change welcomed by teams

Teams that compete in V8 Supercars, Australia's premier motor racing series, have welcomed the news that the championship is to sell 60 per cent of its shares to a private equity firm.

The new ownership set up will see Australian Motor Racing Partners Pty Ltd (AMRP), a company which is supported by Sydney-based firm Archer Capital, take a controlling interest in the series, at a cost of AUS$300m (£197m).

Sports Entertainment Ltd, which previously owned 25 per cent of the shares, will now leave the series after 14 years in charge, while the teams - which before the deal held 75 per cent of the shares - will now keep 40 per cent. The championship's Car of the Future programme will not be affected by the change.

Speaking on behalf of the teams, Roland Dane, managing director of Triple Eight Race Engineering and V8 Supercars board member, said: 'The teams remain absolutely focused on the championship's sustained growth and to working with AMRP to that aim. We will all continue to support V8 Supercars as management works to further enhance the racing calendar, including introducing new events, and to provide a championship of the highest calibre for our on-track fans and TV viewers alike. Our Car of the Future programme remains firmly on track and will commence with the 2013 season.'

V8 Supercars said the current management team will remain in place, but it will be supported by a new board of directors comprising two representatives of the teams and two representatives of AMRP, with Tony Cochrane becoming chairman.

Meanwhile, a new V8 Supercars Commission will also be set up, which will be an advisory body with a particular focus on racing rules, regulations and formats.

WATCH THIS

If you were wondering where the new Nissan electric racecar shown in last month's news was actually going to race, then the answer is on racecar-engineering.com - late at night, and in the city. So there are some advantages to silent racecars...

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DATA ACQUISITION

GRANT SQ2020 LOGGER

Grant Instruments, a manufacturer and supplier of data acquisition products, recently introduced its new SQ2020 series of high performance, portable data loggers. This flexible, multi-purpose logger has eight differential (or 16 single ended) analogue input channels to measure current, voltage, resistance and temperature, and eight event inputs. All event inputs can either be logged or used as triggers to automatically start or stop logging.

The onboard memory can store up to 14 million readings, as well as retain up to six separate logger configurations, with the memory capable of being extended by using removable MMC/SD cards. The on-board RS232 communications can be connected to a GSM modem and there is a choice between a wireless and an ethernet port to facilitate system networking and the remote transmission of data.

For more information see www.grant.co.uk

MATERIALS

CRP WINDFORM XT 2.0

Rapid prototyping specialist, CRP Technology, has now developed Windform XT 2.0, an evolution of its succesful Windform XT material.

The polyamide-based, carbon-filled powder stock is designed for use in SLS production and prototyping processes and offers higher performing mechanical properties compared to Windform XT. It retains the matt black colour of the previous version but features up to an eight per cent increase in tensile strength, 22 per cent increase in tensile modulus and a 46 per cent increase in elongation at break.

For more information see www.crp.eu

MEASUREMENT

CREAFORM VXtrack

3D optical metrology equipment producer, Creaform, recently released its new VXtrack dynamic tracking software module, for use with the company's dual camera optical sensor. Teamed with this sensor, VXtrack dynamic tracking can be used to simultaneously and continuously measure positions and orientations in space with great precision. Combined with the HandyPROBE arm-free CMM, VXtrack provides a complete portable 3D measuring solution offering both probing inspection and dynamic measurement capabilities. The module has numerous applications such as robot calibration and guidance, monitoring of complex assembly processes, real-time compensation of machining tool-generated errors and monitoring of deformations during testing, so should find applications in the aerospace, automotive and robotics industries, as well as in non-destructive testing.

For more information see www.creaform3d.com

MEASUREMENT

LEITZ LSP-X1h

A new sensor is now available for the Leitz Reference series of coordinate measuring machines, the LSP-X1h. It is able to accept styli lengths of 20-225mm in the axial orientation and up to 50mm in lateral orientation, with a maximum stylus weight of 33g. The sensor attaches to the TESASTAR-m indexable articulated probe heads.

Thanks to this combination of heads, styli and a small external diameter, the LSP-X1h can reach previously inaccessible places.

The LSP-X1h is compatible with the latest Leitz coordinate-measuring machines, the Leitz Reference Xi and Reference XT.

For more information see www.hexagonmetrology.com

SENSORS

EGT SENSOR

US-based Sensor Connections recently introduced its new EGT sensor, geared specifically towards high performance diesel applications. The sensor features a foul proof probe tip that permits operation in bio-fuel and diesel engine applications. Manufactured from high temperature Inconel and 316 stainless steel, this type K thermocouple can withstand extreme conditions, making it ideal for use in R and D and testing, as well as other harsh environments. The sensor is capable of surviving extreme vibration and heat up to 1200degC, while the probe is available in either straight or 90-degree bend models, as shown, to accommodate tight mounting locations. An adjustable, 316 stainless steel, 1/8in NPT compression fitting is included.

For more information see www.thesensorconnection.net

CHASSIS SET UP

INTERCOMP

US-based chassis set up specialist, Intercomp, has introduced the new Microflex system, a family of ultra low deflection RFX wireless scales featuring four load cells per pad. Microflex scales give the user the lowest possible deflection, while providing the highest level of accuracy, repeatability and stability for a more precise chassis set up. Intercomp claim that its Microflex scales represent the industry's first four load cell per scale pad design, while still utilising the same integrated RFX wireless technology used in the company's other systems.

For more information see www.intercompcompany.com

The correct application of money

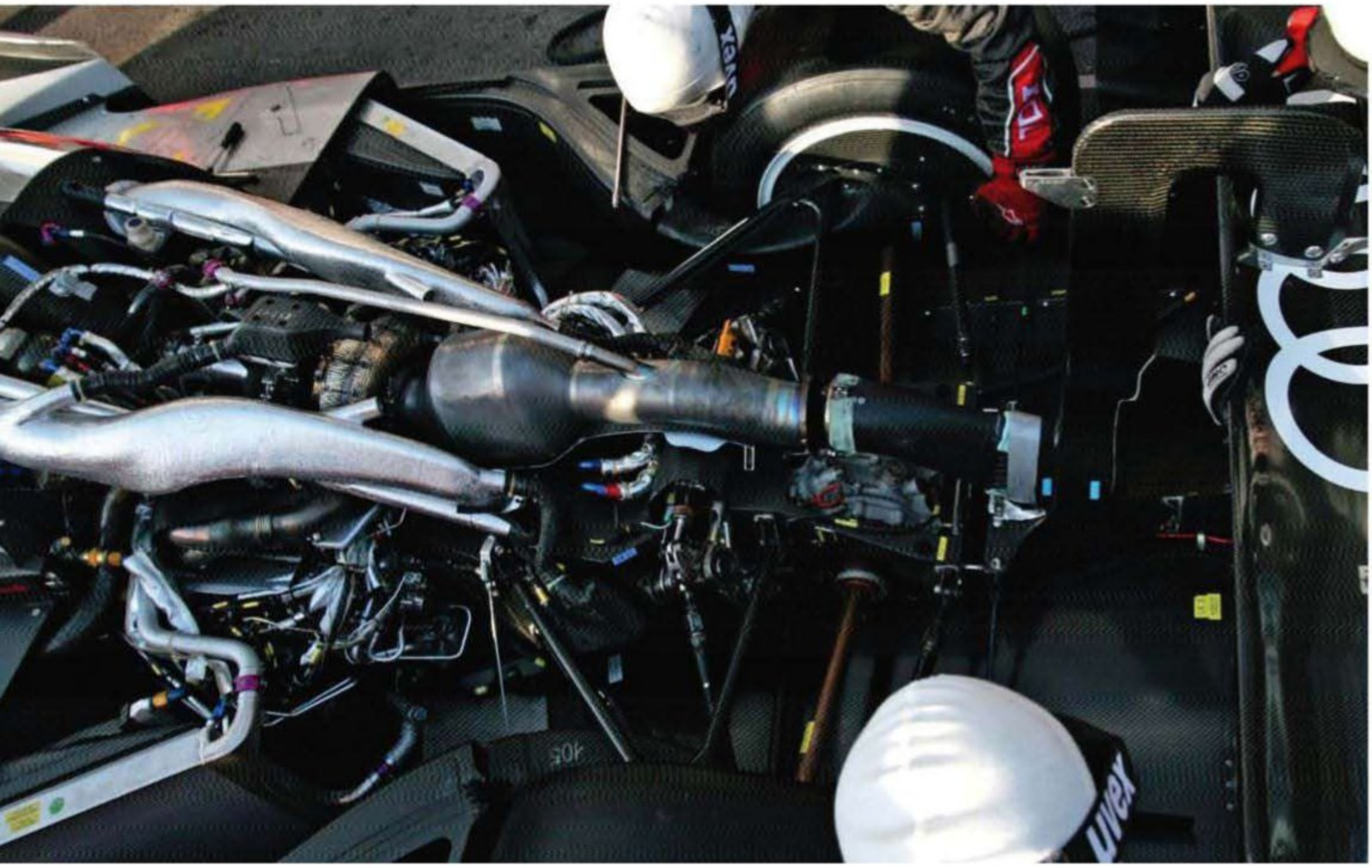
With the emphasis firmly on efficiency, Audi's new closed Prototype is down on power, but a long way ahead on innovation

BY ANDREW COTTON

In 1999, Audi debuted its first closed Prototype, the R8C, at the Le Mans 24 hours. Twelve years later, new regulations have forced the manufacturer to revist the concept with its latest endurance car, the R18 TDI.

The R8C was a sleek machine, powered by a 3.6-litre V8, and looked stunning in its silver livery. It was built by British company racing technology norfolk (rtn), and run by the Audi UK importer under the guidance of Richard Lloyd, alongside the Team Joest-run R8R, the open-cockpit version of the same car.

> The focus is on the Le Mans 24 hours between 2011 and 2014



Audi's mono-turbo V6 engine reduces losses as the air flows straight from the roof-mounted intake through the turbo and out through the single exhaust. Has Audi found an advantage by not loading the suspension through the gearbox casing, therefore potentially allowing a rapid change?

Unfortunately, the R8C was an afterthought - a validation tool if you will - hastily developed after the decision had been taken to stick with the open design.

Out of the R8R, the R8 was born, a car that raced to five Le Mans 24 hour victories between 2000 and 2005 and multiple championship titles. So successful was the car in its open form that Audi continued without a roof through its diesel programme with the R10 and the R15.

The R15 was a complicated car, with a narrow operating window, and a controversial nose that Peugeot contested contained a wing element. Audi had to redesign the car for 2010, and ran it again at the Sebring 12 hours in March 2011 as the new car was not yet ready.

New regulations introduced this year have meant that Audi has been forced back down the closed coupe route with its latest challenger, its third car in as many years; the R18 TDI.

REDUCED CAPACITY

New engine regulations reduced capacity for diesel engines from a 5.5-litre maximum to 3.7-litres, and the resulting loss in torque and power meant teams had to produce slippery body shapes to maintain top speed.

'Obviously, with a change in the rules, especially with the engine size and the reduction of power available, the aerodynamic efficiency has become more and more critical,' says Audi's technical director, Ralf Juttner. 'Parallel to that, there have been some rule changes in the last few years which have changed the balance between the pros and the cons of open or closed cars, and that made us take the opinion that closed was the right way to go.'

Dr Wolfgang Ullrich, head of Audi's Motorsport division since 1993, was a firm advocate of the open design, with its increased appeal to American audiences who could easily identify a driver, and the faster driver changes during the pit stops.

With information from the Bentley programme in 2001-2003, it re-affirmed Ullrich's belief in the open car.

> a huge reduction in performance compared with the V10

However, Audi pulled out of the ALMS after the 2008 season, and new tyre changing regulations reduced the emphasis on fast driver changes.

By the time the new engine regulations were announced for 2011, even he had to concede that closed was better: 'About one and a half years ago, we put a bubble over the cockpit of the R15 and put it in the wind tunnel. The result was clear. It was going to be better, so we knew we had to make its successor a closed car.'

TESTING TIMES

The car rolled out for the first time at the end of November 2011, four months after the Peugeot 908 had its first track test, and since then testing has been both extensive and thorough. From the outset, the Audi R18 has given the team the speed needed to compete with Peugeot, and for the drivers, the confidence to constantly push to find the limits.

'If out of the box, the lap times are quick, you know that it is a good car,' says driver Romain Dumas, '[but] if out of the box you are missing two seconds, you have to find a set up to find that time. This car had a first roll out and was already quick, and there is still a lot to go.'

By producing a closed car, the drag figures immediately improved over the open-cockpit R15, and the reduction in downforce has not been a major factor in the performance of the car. Through the Porsche Curves, and through Eau Rouge, the car is planted, solid and stable.

'You have got to have a balance,' says driver Allan McNish. 'When you have balanced aero, if you take aero off you have the same balance, but less grip. The worst thing, whether in high or low aero spec, is if the car is imbalanced, then you will be slow.'

With less grip, the tyre characteristics are different, and at the Spa 6-hours the difference between Audi and Peugeot was startling. Audi had a big problem with the pick up going off line to pass the slower cars, to the extent that Benoit Treluyer had a hole punched through the wheel arch of his car, and the Peugeot was simply better in the second stint on the same set of medium compound tyres. As a result, Audi went away to re-think its strategy.

"The entire base weight of the car is a quoted 850kg"

WEIGHT REDUCTION

Audi has worked hard on reducing the base weight of the car. The carbon body is made in one piece, instead of upper and lower sections glued together, which makes it torsionally stiffer. The chassis is rumoured to weigh just 72kg, lighter than the R15 chassis despite the addition of a roof, windscreen and doors, and the entire base weight of the car is a quoted 850kg. That is a base weight that Audi has campaigned for the ACO to adopt for non-hybrid cars, rather than a blanket 900kg limit whether an energy recovery system is run or not, though the ACO rejected that plan this year.

This weight reduction comes at a time when Audi's production cars are also on a diet. The latest A6 is 80kg lighter than its predecessor and the new A4 is also lighter, all following the race team's belief that the best way of improving fuel consumption is

AUDI'S CLIMATE CONTROL

Audi has revealed how it has made use of its new climatic wind tunnel, usually only used for production cars, to develop its R18 TDI for this year's Le Mans 24 Hours.

The climatic wind tunnel, which is in the Audi Wind Tunnel Centre in Ingolstadt, creates temperatures between -25 and +55degC, allowing Audi's engineers to generate very hot or freezing cold wind speeds of up to 300km/h (185mph), while it is also possible to simulate sunlight and rainfall.

Audi's R18 TDI is the first of its racecars to use the tunnel, but the manufacturer felt that because the R18 is the firm's first closed Prototype since 1999 it needed to explore the challenges a car with a roof might feasibly face during the 24-hour race.

Work on the R18 in the tunnel focussed on three main areas: optimising the airflow through the cockpit, the windscreen and testing the wipers. 'The results of everything we have tested in the climatic wind tunnel up to now have been confirmed during testing on the race track,' said Christopher Reinke, R18 technical project leader.

Audi also reports that because of the work it carried out in the tunnel it was able to make do without a heavy and power-sapping air-conditioning system in the car, while it was also able to simulate the effects of rainwater and even solid materials, such as sand and rubber, on the body.

SOLAR RADIATION

Dr Martin Muhlmeier, head of technology at Audi Sport, said of the test programme: 'We made many valuable discoveries in this area on the full-scale car in the climatic wind tunnel and modified several things, especially in the airflow area,

'The reflective film on the roof was also validated with findings from the climatic wind tunnel. These are all important details to guarantee a good climate around the driver in the cockpit [of the racecar].'

The silver film helps to prevent the cockpit heating up too much due to solar radiation. ACO regulations state that cockpit temperatures must not exceed 32degC when driving if the maximum ambient temperature is 25degC while, if it is warmer than that, the cockpit temperature may climb by a maximum of seven degrees.

Audi's climatic tunnel was also used to develop an effective windscreen wiper for the R18, and a 'screen that does not fog.

The climatic tunnel is normally reserved for production car test programmes, but proved invaluable for testing cockpit temperature rises in high ambient temperatures and for developing the car's anti-fog windscreen system

by reducing weight.

The new V6 engine is, of course, lighter than the V10. Audi's engineers have cut around 25 per cent from the weight of the unit, plus changed to a lighter gearbox and transmission, which has to cope with less torque. The V6 weighs approximately the same as the petrol V8 that was in the R8 racecar 12 years ago.

EFFICIENCY DRIVE

The engine itself has a 120-degree v angle, rather than the 90 degrees of the previous V10, with a mono turbocharger and single exhaust housed within the v angle.
This lowers the c of g and allows

TECH SPEC

Class: LMP1 Prototype

Weight: 900kg (inc 50kg ballast)

Monocoque: carbon fibre composite design incorporating aluminium honeycomb core

Engine: fully stressed, turbocharged, 3.7-litre V6; 120 degree cylinder angle; four valves per cylinder; DOHC; single Garrett turbocharger; 1 x 47.5mm air restrictor; turbo boost pressure: 3.0bar absolute

Electrics: lithium ion battery, Bosch MS14

Engine lubrication: dry sump, Castrol oil

Power: above 397kW (540bhp)

Torque: above 900Nm

Transmission: rear-wheel drive; traction control

Clutch: carbon fibre

Gearbox: Xtrac six-speed sequential

Suspension:: independent with double wishbones all round; pushrod with torsion bars; adjustable dampers

Brakes: hydraulic dual circuit; monobloc light alloy calipers; ventilated carbon fibre discs front and rear

Wheels: front 14.75 x 18; rear 14.5 x 18

Tyres: Michelin radial, front 360/710-18; rear 370/710-18

Length: 4650mm

Width: 2000mm

Height: 1030mm

Fuel cell capacity: 65 litres

Everywhere on the new car the emphasis has been on improving efficiency and reducing weight. The brakes are lightweight alloy monobloc calipers from Brembo with ventilated carbon fibre discs all round

for more efficient airflow through the turbocharger, which then exits through the single exhaust housed around the mandatory fin on the engine cover.

'We thought about the package with two turbos, but found it extremely compromising in terms of the exhaust and the arrangement,' says Ulrich Baretzky, Audi's head of engine development. 'You cannot do it in parallel, and we didn't like that idea.

'Next to the fact that we have a closed car, we have the intake on the roof, so there is a straight line to the turbocharger, [which is] much easier with one than two. If you have a close look at the Peugeot, the air comes in and is distributed into two, and there are an awful lot of losses. We know from our Bentley years that this cannot be done well.'

With minimal losses, the car produces a quoted 397kW (540bhp) and more than 900Nm of torque. However, Audi's production car department has produced a V6 delivering 600Nm of torque, so few believe the racecar figures are accurate.

Whatever the actual output, there is still a reduction in performance compared with the V10, leaving the drivers struggling for power to pass the production-based GTE cars, and the lower powered LMP2s – a problem that is compounded by a lack of visibility, with the a-pillar obscuring their view.

The low-slung LMP1 cars are difficult for the GTE drivers to see mid-corner, and the Prototypes do not have the torque to pass them on short straights. Though the top speed is higher, they take longer to get there, and that is causing problems. 'I think driver ability will be less of an issue at Le Mans than here or at Silverstone because of the length of the straights and the type of circuit it is,' said McNish at Spa. 'The cars are more spread out, because you have the same number as you do at Le Mans, but on nearly one third of the track distance. In the shorter races [Imola, Silverstone, Road Atlanta and Zhuhai], it is going to be harder.'

> "the best way of improving fuel consumption is by reducing weight"

One potential area of concern is the weight of the R18, and the measures taken to produce such a lightweight car. Everything is lighter, and more fragile, which could make a difference this year.

'In the past you can hit the wall, or anybody, and you can still carry on, on three wheels,' says Dumas. '[With the R18], there are smaller details everywhere, and while we don't want to hit anyone as drivers, I am not so convinced that the car is as strong as the old car, but that is also why it is quicker.'

CRYSTAL BALL

The decision to go with the V6 was also influenced slightly by Baretzky's crystal ball. During the life of the V10 diesel engine between 2008 and 2010, turbo boost pressure was reduced by 12 per cent, and the pressure on each cylinder was relieved.

'I am convinced that long term the ACO will restrict the performance of the cars – of the engines because of the speed of the cars, and the barrier of 3m30,' says Baretzky, referring to the ACO's notional lap time limit that it has set for the Le Mans course, and which forms that basis of its performance balancing.

'The concept of the V6 is better than the V8, because in the V8 it is too big for the performance you are getting from it.

'We had the same with the V10 against the V12. When you make 100 per cent performance, you distribute it to more cylinders so every cylinder has to work less. If the power goes from 100 to 90, the load per cylinder is reduced by 10 per cent. Then you come to a point where the amount of cylinders is too big, so the efficiency of each cylinder is not high enough, and that is why we went with a V6.

'It is a bit risky. It has 25 per cent more load than a V8 has but, if the restriction comes, we are in a better position than with a V8.'

The shorter, smaller engine and packaging suited all parties, with the aerodynamicists able to work on a sleeker, more aerodynamically efficient rear, while the engine department will look forward to introducing new technologies to improve efficiency through future 'electrification of the engine'.

'Looking at 2014, Formula 1 is all looking in the same direction – go down with consumption and increase efficiency,' says Baretzky. 'Our demand on the ACO is don't describe any technology by rules. Leave it open. It is expensive, but when we are in motorsport we have to give something back to production, and to do that we have to increase efficiency to reduce consumption. What type of electrification we will have to see.

'You can recover energy from the exhaust gasses. There are a huge variety of systems and you have to find the right solution. If we have something that improves our performance or consumption, then we will use it before 2014. If it is not in the existing rules we have to talk to the ACO, and they are generally open to new ideas, as long as they are going in the same direction.

'If there is a maximum energy allowance, and a minimum weight, and there is a little room for systems beyond an engine, that helps the privateers. If they cannot afford to make these systems, they can afford to make a nice lightweight car and a reasonable small engine, and then you are not in a bad situation. If you invest money as much as you want to fill this little gap, you have the advantage that we always have.'

> **“testing has been both extensive and thorough”**

Peugeot took victory over Audi in the first half of the year and it seemed that the R18 was playing catch up. Audi relied on the R15 to take the fight to its French rivals at the Sebring 12 Hours because the R18 wasn't ready to race, and the new car was soundly beaten at Spa.

Many expected the ACO to penalise the diesels and bring them into line with the petrol cars after two ILMC races. Instead, the ACO demanded that they slow down the refuelling, and have given the petrol cars a performance boost with weight and air restrictors ahead of the Le Mans 24 Hours.

The focus, clearly, is on the Le Mans 24 Hours between 2011 and 2014, when another set of new regulations, currently under discussion come in. These are set to be more radical than anything seen before, and Audi is hoping the R18 TDI will be able to compete against strong opposition until then.

Audi's V10 R15 TDI (left) went through a redesign before the company bowed to the inevitable and introduced a closed Prototype – the V6 R18 TDI

SEEING THE LIGHT

Audi's R18 is the first Le Mans Sportscar to feature full LED headlights, which offer drivers better visibility and the mechanics one less headache.

Light Emitting Diodes were used alongside standard Xenon headlights on the R15 TDI that won in 2010, without a single failure, so the company has adopted them completely for the 2011 R18.

'The light is stronger, and they vibrate less than a normal headlight,' says eight-time Le Mans winner Tom Kristensen. 'This is a clear advantage, particularly at Le Mans, a track that has many dark braking points in the night.'

The standard electric cooling system used on the R15 and Audi's road cars has been replaced, and instead airflow keeps light temperatures down.

'Our colleagues in production car development are very interested to see how we implement this,' says Christopher Reinke, technical project leader for the R18 TDI. 'We have the advantage in motorsport that the car spends less time at a standstill. On the highway, the lights mustn't go out, even if the car is in a traffic jam.'

The R18 is credited with having the brightest diodes currently in use, and these are not at present registered for production car use on the road. Interestingly, the main beam, which is comprised of five LEDs per side, is not brighter than the normal low beam, but uses three extra LEDs to create the *effect* of a high beam by illuminating the track differently through the positioning of the various integral reflectors.

Light fantastic. The R18's headlights use the most powerful LEDs currently available, with the main beam using three extra LEDs to create the effect of a high beam by illuminating the track additionally through reflectors


BOSCH
MAHLE
3


Audi
Vorsprung durch Technik
Le Mans is approaching fast.
This year, arguably the most gruelling endurance race in motorsport takes place on the 11th and 12th of June. At the race, Audi will showcase three new R18 TDIs. Each one is constructed using Audi ultra lightweight technology, the same technology we employ in many of our road cars. To find out more about Audi at Le Mans visit audi.co.uk/lemans

FIRST PRINCIPLES

Simon McBeath offers aerodynamic advisory services under his own brand of SM Aerotechniques – www.sm-aerotechniques.co.uk. In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

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Tel: +44 (0) 2476 355000
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Optimising a sports racer

Starting at the front...

This month, courtesy of ADR Engineering and car owner / driver, Simon Marsh, we turn our attention to the ADR3 sports racer. ADR's principal, Adrian Daniels, and son John, are adamant that sports racers should be capable of accommodating two adults, so their creation is unashamedly a genuine two seater. But whether or not this might compromise aspects of the car's aerodynamic performance was not an issue. The principle aim of this day-long session spent in MIRA's full-scale wind tunnel was simply to obtain the best level of downforce available, with a front-to-rear downforce ratio close to the static weight distribution. With driver and half a tank of fuel aboard, this was assessed at about 48 per cent on the front with this motorbike-engined variant. To work towards this aerodynamic target, Ben Popham and Nick Worsell at Carbon Weezel had produced a van load of parts to test.

The front end featured a two-tier splitter / diffuser arrangement

TABLE 1: BASELINE COEFFICIENTS ON THE ADR3

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.585	0.786	0.018	0.769	2.3%	1.344

Here we can see the smoke plume entering through the left front aperture and exiting via the wheelarch louvres

As usual, the first numbers to emerge from the wind tunnel's data acquisition system helped decide on how to implement the day's plans. Alternative configurations for the front, middle and rear of the car had been brought along, but the baseline data, set out in table 1, below left, made it clear where attention was required first.

REAR-BIASED AERO

This first result showed that the car in 'as delivered' guise had very little downforce at the front axle, and with a fairly potent, full width, dual-element rear wing this made for a very rear-biased aerodynamic set up. It also meant that total downforce and –L/D were also fairly low, but drag was fairly high. However, by session's end, the results in table 2, overleaf, had been obtained. The changes relative to the initial baseline results are shown in counts, where a coefficient change of 0.100 = 100 counts, and in percentages.

As shown, considerable progress was made in creating more front-end downforce, but rear downforce also had to be reduced to obtain the desired balance. Nevertheless, 180 counts of total downforce were gained with a drag reduction of 73 counts, culminating in a 40 per cent improvement in overall efficiency (-L/D) at close to the desired balance. Improvements in

TABLE 2: COEFFICIENTS IN THE BEST CONFIGURATION

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Best config	0.512	0.966	0.458	0.508	47.4%	1.887
Change, counts	-73	+180	+440	-261	+45.1	+543
Change, %	-12.5%	+22.9%	+2444.4%	-33.9%	+1960.9%	+40.4%

NB the seemingly huge percentage changes to the front-end parameters are because of the very low initial numbers

TABLE 3: CHANGES IN COUNTS AFTER PANELLING

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Panel f/chassis	+12.5	-17	+6	-23	0.83	-56.5
Fit new sidepods	0	+43.5	+35.5	+6.5	+4.15 abs*	+73

** abs = absolute change in % front, not relative percentage change*

TABLE 4: WITH WING PROFILE SPLITTER AND DIFFUSER

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Splitter/ diffusers	0.586	1.006	0.314	0.692	31.2%	1.717
Change, counts	-10	+185.5	+251.5	-65.5	+23.6abs	+340
Change, %	-1.7%	+22.6%	+402.4%	-8.6%	+209.9%	+24.7%

times might reasonably be expected from such progress.

The major contributors to these improvements included a different splitter and front diffuser set up, combined with opening up the front of the sidepods to allow air to exit behind the front wheels. Dive planes and splitter end plates helped the front end, too. However, the other major balance contributor was reducing the height of the rear wing, moving it forwards and reducing the angle of the secondary element. We'll go into more detail on some of these changes in subsequent issues, but first we'll look at some of the changes that helped the front end to work better.

FRONT END CHANGES

One of the comments made by the owner / driver during preparations for this session was that, despite good front-end mechanical grip, the car understeered at speed, and the front bodywork could also be seen lifting. It seemed likely, therefore, that air was getting under the front bodywork section from the front and causing lift. Bearing this out, the front bodywork also featured an unusual two-tier splitter and diffuser, with two wide apertures above the splitter either side of the central nose feeding air under the front body section. As such, air passed under and over the splitter (which measured about 200mm front to back) in these areas, while the 'internal' bodywork behind the apertures was shaped into a pair of diffuser sections.

The problem was, there was no easy escape route for the air to follow after passing through these diffusers, except under the front body section and into the cockpit, out through the small gaps between the wheels and the sidepods, or through the wheelarch louvres. So, it was proposed that the chassis sides be panelled in and that modified sidepods, opened up at the front to allow air exiting from under the front end to escape behind the front wheels. These were among the first alterations to be tested, and the changes they brought about are shown in table 3, left, relative to the previous configuration in each instance.

Initially, panelling in the front of the chassis appeared to create a small amount of additional blockage to the air trying to exit from under the front of the car because the results were slightly worse overall (although front downforce increased very slightly, perhaps because less air was packing under the front body top and was now finding its way out past the front wheels). But, combined with fitting the new sidepods, which opened up an exit to air entering at the front, a reasonably significant improvement was measured, with an increase in total downforce of around five per cent – mostly at the front where it was needed – for no change in drag.

Nevertheless, the –CLfront value was still only 0.063, with just 7.6 per cent of the total downforce on the front. Various splitter options were then tried, most of which were variants of the original two-tier arrangement. One of these, which saw the underside of the splitter profiled like a low camber wing, took the –CLfront up to 0.089, or 10.5 per cent front. When the raised, separate diffusers were replaced with a pair of lower-mounted diffusers that integrated smoothly with the lower of this wing profile splitter, the results in table 4 were obtained. It was clear from these that the front end of the car was now working much more effectively and, although there was still a long way to go to obtain the target 48 per cent of total downforce on the front, the combination represented a big step in the right direction.

Next month we will look at further efforts to achieve the target aerodynamic balance.

Modified sidepods provided an unrestricted exit for air passing under the splitter and front diffusers

Connecting the diffusers to the trailing edge of the splitter produced a substantial increment in frontal downforce

Racecar Engineering's thanks to ADR Engineering, Carbon Weezel and Simon Marsh

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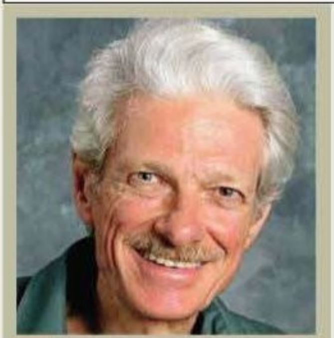

FIRST PRINCIPLES

Mark Ortiz Automotive is a chassis consulting service primarily serving oval track and road racers. Here Mark answers your chassis set-up and handling queries. If you have a question to put to him
Email: markortizauto@windstream.net
Tel: +1 704-933-8876
Write: Mark Ortiz
155 Wankel Drive , Kannapolis
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Talking torque tubes

Q **The car I have in mind is a Mazda RX-7 FD model from the mid-'90s. They run what Mazda term a 'Power Plant Frame', which is a lightweight pressed steel frame tying the gearbox extension housing to the front of the differential casing. The car has independent double wishbone rear suspension. My question is, why would a car manufacturer choose a torque tube to locate the rear of the gearbox and the nose of the differential, rather than a gearbox crossmember and rear subframe?**

If one were to fabricate conventional mounts for the differential nose using a weld-in multi-point rollcage to tie the 'shell together more rigidly, and then something similar with a different but similarly sited engine and gearbox (I'm thinking something with pistons for circuit race usage), what disadvantages can you think of, handling-wise? My personal take on this is that it may have been instigated to allow compliant differential mounting to reduce noise, vibration and harshness (NVH), yet control unwanted differential nose movement to control drivetrain wind up and wheel hop.

THIS MONTH:

Q Why would a manufacturer choose a torque tube to locate the gearbox tail and the differential nose?

A Usually to isolate the linked components from the frame, or unibody, and to resist torque twist in response to axle torque

There are basically two reasons for tying vibration-isolated components together with subframes. The first is to allow soft mounts for good isolation, without incurring undue movement of the individual isolated components. The second is to unite the isolated components as one large mass, which can then be used to achieve a measure of inertia damping by tuning the natural frequency of this mass to interfere with the natural frequencies of the sprung structure as a whole.

> **"suppress side-view wind up of the diff in response to axle torque"**

In the case of a torque tube, or similar structure, tying a front engine and transmission to a sprung differential, not only do we suppress side-view wind up of the diff in response

Torque tubes were common on vintage cars with transverse leaf spring suspension, but such as the Mazda RX-7 use a development of the idea with its 'Power Plant Frame'

This Renault F1 car was fitted with a tuned mass damper at the 2006 German Grand Prix. Unsurprisingly, it was banned immediately after that race

to axle torque, we also create a structure that resists front-view rotation of the engine and diff relative to each other due to driveshaft torque – the same torque that creates torque roll and torque wedge when the diff is unsprung. This relieves the frame or unibody of the need to resist this torque.

In most cases there is a penalty in space efficiency and weight efficiency for using subframes, although to some extent this can be recovered in the main structure by either eliminating loadings, or spreading them among a smaller number of more widely separated points.

INERTIAL DAMPING

When the suspension is softly damped, in pursuit of soft ride, inertial damping from major isolated components can actually help handling, as well as ride, at least in terms of the car's behaviour on irregular surfaces. But in racecars we normally use stiffer shocks, which make all tuning of natural frequencies less important. And we want light weight and a stiff overall structure much more so than good NVH characteristics.

Therefore, traditionally, we build racecars with little or no isolation of the engine, trans and diff. In fact, we solid mount everything to try and get some structural stiffness gain from the components, and deal with any NVH issues by having a loud exhaust and wearing ear plugs.

“ in racecars we want light weight and a stiff overall structue much more so than good NVH characteristics ”

If the shocks are stiff enough for good handling, there won't be much oscillatory behaviour from the suspension.

However, in recent years racecar designers have taken a fresh look at inertia damping, as readers who have followed inertia damping's recent introduction, and prohibition, in F1 will know. The reason for the renewed interest is that modern, high-downforce racecars have such stiff springing that tyre deflection becomes a significant portion of the total 'suspension' compliance. This tyre deflection does not displace the shock absorbers, so the shocks can't damp it, though there is some internal damping in a tyre, but nowhere near as much as we'd like. That's why a very stiffly sprung car can bounce or pitch on the tyres like a tractor (although with smaller amplitude and higher frequency). The shocks can't suppress this, hence the interest in inertia damping.

So if the car is going to have ground effects and wings, and very stiff suspension, there could be a case for using compliant mounting to get some inertia damping. This could involve using a torque tube, or not. It is common practice in live axle passenger cars to use the engine / trans assembly for inertial damping, without a torque tube. It would be quite possible to do that in a racecar with a sprung diff and solid mount the diff. The only downside would be that the engine / trans assembly will undergo rotational displacement on its mounts when it applies torque to the propshaft, and all packaging, plumbing, wiring and linkages will have to accommodate that, though this can be mitigated somewhat by wide spaced motor mounts.

It should also be mentioned that we don't necessarily get inertia damping from compliant mounting of a major mass. If the frequency is not tailored to the tyre and suspension frequencies, it is possible to get reinforcement of suspension and tyre oscillation, rather than interference. So this would not be something to be undertaken lightly. For most of us then, the most prudent recommendation is still to go for rigidity, lightness and simplicity, and solid mount everything.

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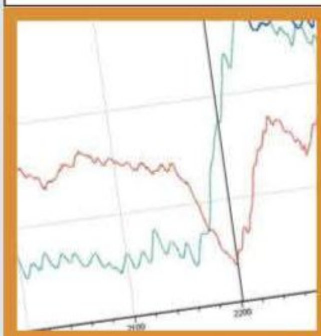


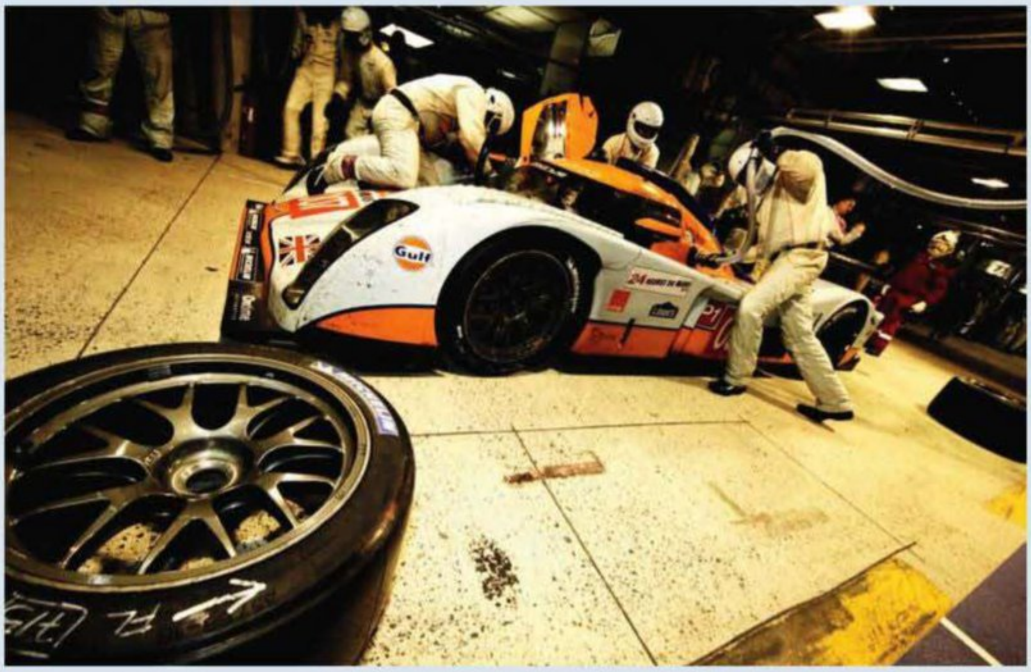
FIRST PRINCIPLES

Databytes gives insights to help you improve your data analysis skills each month as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems. Plus we test your skills with a teaser each month.

To allow you to view the images at a larger size they can now be found at www.racecar-engineering.com/databytes

Calculating fuel strategies

A few simple equations to get you started



Like most things in racecar engineering, having accurate, up-to-date information is the most important thing

Coming up with clever race strategies is something many race teams spend a good deal of time on, and for good reason. After all, a successful strategy can turn what might appear to be a mediocre racecar into a front runner, or even a race winner. Although refuelling is currently banned in Formula 1, there are many race series that require refuelling pit stops and, in those cases, a carefully thought out pit stop strategy needs to be set up. Often the fuel strategy will be a very complicated plan, but it is quite possible to create a good but fairly simple version.

The key to any fuel strategy is fuel consumption. It is therefore vitally important to have accurate and up-to-date information about how much fuel is left in the tank and how much is being consumed. Luckily, most modern racecars have the ability to record the exact amount of fuel being used by the engine, either by using the fuel pulse width or a flow meter in the fuel delivery line, so fuelling information is generally easy to come by. Once we know how much fuel the car uses, and how long our race will be, we can start formulating our strategy.

> "the key to any fuel strategy is fuel consumption"

Using the fuel information and race distance we can calculate how many pit stops are needed and the fuel pit stop window(s). See equation 1. This number should always be rounded up to the next whole number.

Fuel required to complete the race is our estimate of how much fuel is needed based on average consumption and race distance. The useable fuel in a car is how much is in the tank at the beginning of the race. This could, for example, be different to the car tank capacity if the car is under *parc fermé* conditions between qualifying and the race.

Next we need to estimate our pit stop windows, starting with

EQUATIONS

1. $$\frac{\text{Fuel required to complete the race - useable fuel in car}}{\text{car tank capacity}} = \text{number of stops}$$

2. $$\text{Current lap} + \frac{\text{useable fuel in car}}{\text{fuel consumption per lap}} = \text{last lap to pit with current fuel level}$$

3. Last lap - Number of laps per tank = first stop of last pit stop window

4. First lap of pit stop window - number of laps per tank

Fuel information displayed as graphs and in tabular form. This is an easy way to determine average consumption and, if telemetry is used, the fuel level can be monitored live

the last lap we can stop based on the current fuel level in the car. This number could be updated every lap if a telemetry system is in use. See equation 2.

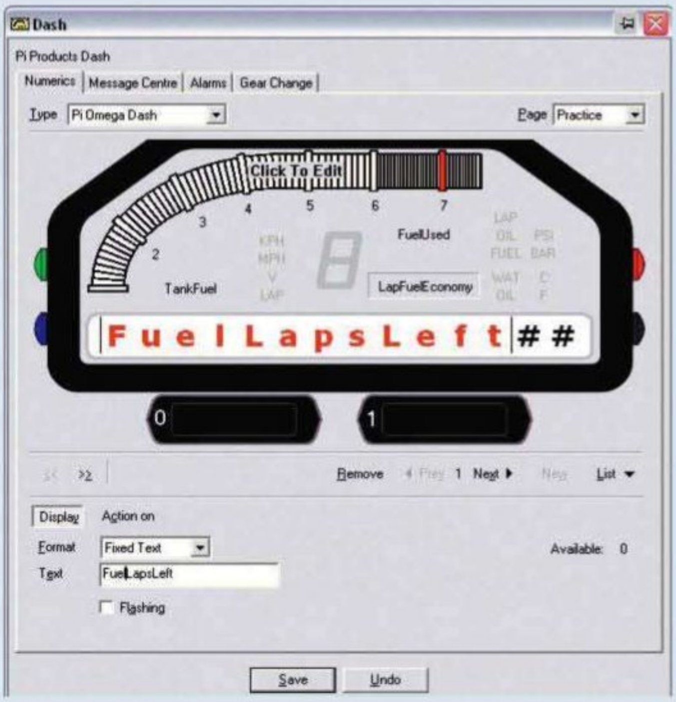
If the number of laps possible per full tank of fuel is added to this number, we can create a prediction for what lap will be the last possible lap per stint that the car can come in for fuel.

In order to find the first possible lap per stint for each fuel window without running out of fuel in the last stint, we need to work backwards from the last lap of the race and subtract the number of laps possible on a full tank. See equation 3. Continuing backwards, the first lap of the next pit stop window is then calculated by equation 4.

Using this information, it is possible to come up with an initial plan for the fuel pit stops during the race. But, as with any good plan, it must be updated during the course of the race as many things will effect consumption. And this is where having live telemetry really comes into play. Having live information from the racecar gives us the opportunity to adjust our strategy to exactly what is going on in the race. This, in turn, means the strategy can adjust automatically to how much fuel is being used. For example, during safety car periods the racecar will need less fuel so the strategy needs to change.

It is possible to adjust the strategy manually if there is no live information available, but to do this well you need information about how much fuel the racecar uses under various circumstances. With that, it is simple to use those numbers to update the strategy. Some data systems are able to calculate some fuel channels live and also display them on the driver display in the car. This feature makes the system more robust as the driver then has the same information as the pit crew, in case there is a radio communication problem.

The fuel strategy is only one part of an intricate plan to win a race and there are other factors that have more influence on when to do a pit stop but, if the fuel strategy is good, then it is possible to work it around these factors to create an overall race-winning strategy.



Giving the driver automatic updates is a feature of some data systems

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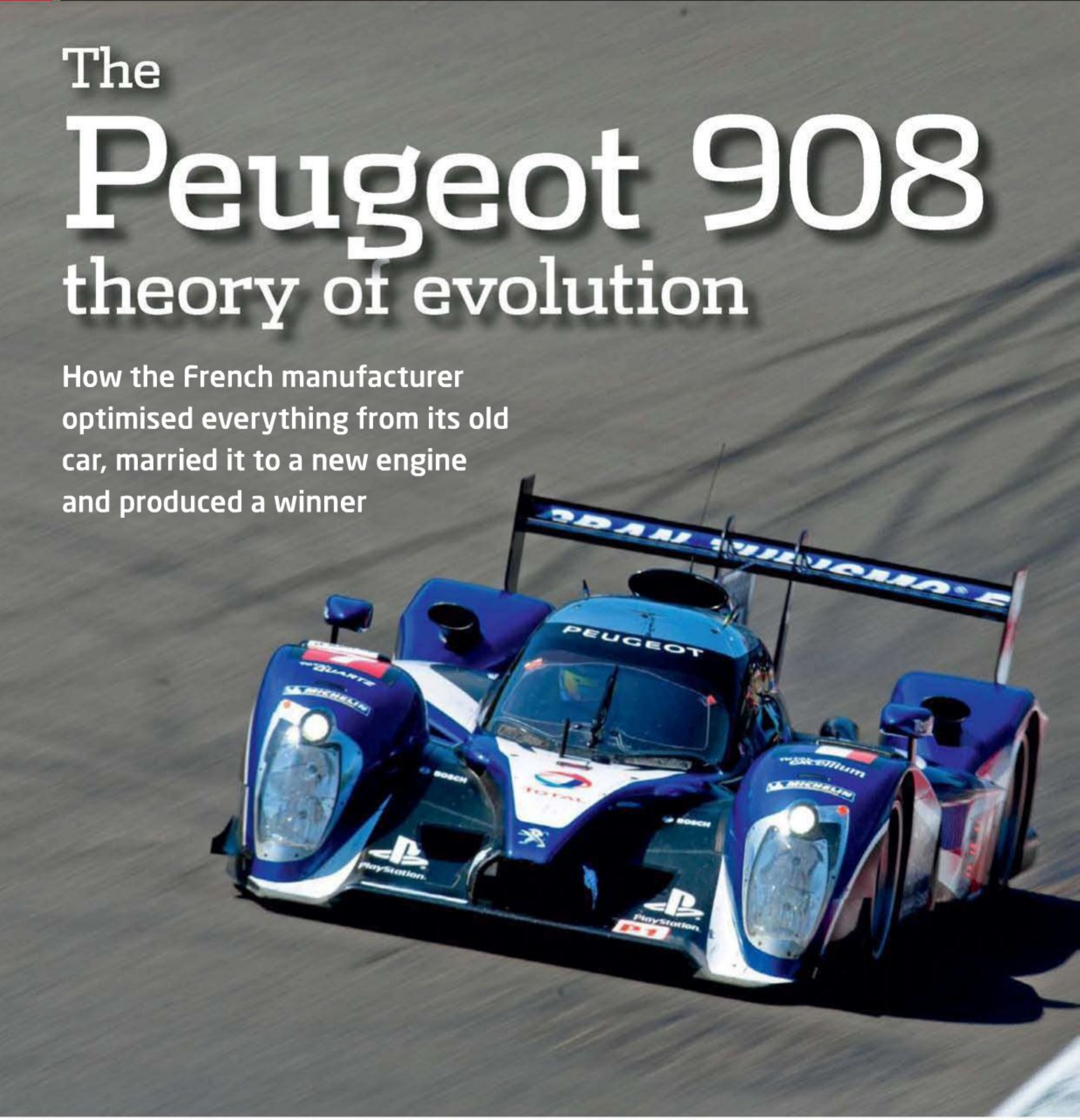
The Peugeot 908 theory of evolution

How the French manufacturer optimised everything from its old car, married it to a new engine and produced a winner



Peugeot's return to endurance racing, 14 years after it won at Le Mans in 1993, heralded the start of a new era of Sportscar racing. The French manufacturer developed a diesel coupé and took on Audi, winning at Le Mans in 2009, an event that served as a catalyst to the board agreeing to fund the build of a new car.

With the button pressed and the rules outlined early by the ACO, Peugeot began work immediately. The first engine ran on the dyno barely six months later, on 25 January 2010. The programme progressed quickly after that, the first track test being last July, with the car's race debut made at Sebring in March this year.

Unfortunately, so good was the previous 908 that, in customer hands, the French ORECA team was victorious at the US event but, at Spa in May, the new 908 found its true form, and finished first and second in its first encounter with Audi.

This was a crucial result, for political pressure on the team is huge, particularly after what happened last year, when Peugeot had the speed to win at Le Mans, but lacked the reliability to deliver the result. As a result, when Peugeot's director of sport, Olivier Quesnel, went to ask for a budget to continue this year, the board made their position very clear: 'What happened at Le Mans last year, the board said

TECH SPEC

Vehicle type: LMP1 Prototype

Weight: 900kg

Monocoque: carbon fibre composite

Engine: stressed twin-turbo 3.7-litre V8; 90-degree cylinder angle; four valves per cylinder; two 33.5mm air restrictors

Engine lubrication: Total oil

Power: 550bhp

Torque: 900Nm+

Clutch: ceramic multi-plate

Gearbox: Xtrac six-speed sequential

Suspension: double wishbones with pushrod and rockers for all four wheels; torsion bar

Brakes: hydraulic dual circuit; monobloc light alloy calipers; ventilated carbon fibre discs front and rear

Wheels: front 14.75 x 18; rear 14.5 x 18

Tyres: Michelin radial, front 370/710-18; rear 370/710-18

Length: 4640mm

Width: 2000mm

Height: 1030mm

Fuel cell capacity: 65 litres

> **"the board said, 'we want to be sure that we can win'"**

no problem to carry on, but we want to be sure that we can win,' recalled the Frenchman.

And with the new 908, Peugeot has done just that, setting a winning precedent with a car that the team hope will see it through the next three years, before new regulations are introduced for 2014. By then, a petrol hybrid engine is the most likely solution for the company, housed in another coupé body to increase aerodynamic efficiency.

For now, though, the new 908 is a safe option, not a revolutionary car, though Peugeot says it has optimised every area of the old car it is based upon. The decision to stick with diesel was a given, as was the development of another coupé body shape, leaving the company able to draw on previous experience, rather than take Audi's route of a completely new concept. 'We stuck with diesel because we know diesel,' said Peugeot's technical director, Bruno Famin. 'We started with a 100 per cent new car, but this Peugeot team has no experience of petrol engines. We would have to learn from zero – direct injection, all kinds of very sharp technologies – and it would have been a waste of time. Much better to capitalise on what we already knew.'

Although Audi says its V6 is better equipped to deal with the performance balancing that will surely come within the next three years, Peugeot has opted

Peugeot has optimised everything on the new car, including the suspension system, which has allowed the drivers to attack the kerbs and look after tyre wear. Proving its worth, at Spa, Pedro Lamy triple-stinted a set of Michelins

Cockpit ergonomics have been improved and the air-conditioning system is gone, thanks to a change in regulations regarding cockpit temperatures.

for a 3.7-litre V8, saying that turbo boost pressure problems are limited to engine capacity, and that both will be similarly affected when the restrictions come anyway. However, after two ILMC (Intercontinental Le Mans Cup) races, the ACO elected not to restrict the diesels, a decision that Famin fully supports: 'We thought the balance was okay for everyone,' he said. 'There was no objective to change anything because there was nothing to say that the balance was not good. When you look at who was at Sebring, Le Castellet and Spa there are not enough facts. At Sebring, the HPD (Honda Performance Developments) car was very good. The cars have to be within two per cent, and at Sebring the HPD was within one per cent. If the HPD was in Spa, there would be no reason to change anything. In Le Castellet there were no diesel cars, and in Spa the HPD was not there.'

The characteristics of the eight-cylinder engine are similar to those of the large V12 housed in the previous car. The v angle has been decreased – from 100 degrees to 90 in the V8 – to help with packaging, but the new engine is still producing an immense amount of power.

"Peugeot has opted to put its faith in its aerodynamics department"

The new 908 has a top speed comparable to the factory cars in 2010, which, even given the advances in the aero package, mean the engine is producing impressive power. The weight distribution is better than the old car, due mainly to the new engine. Dropping from a 5.5-litre V12 to a 3.7-litre V8 has meant a much smaller package, and the cooling systems and gearbox are also more compact.

'The sidepods are smaller and lighter because the radiators are smaller,' explains Famin. 'We have saved weight, and drag. The gearbox is much smaller, and is completely new because the torque is lower. [But] because the engine is shorter, we had to find a way to maintain a reasonable wheelbase. It is a more compact car.' The six-speed gearbox is cast aluminium, saving further weight at the rear, and Peugeot is believed to have switched chassis supplier this year, and worked on improving driver visibility.

With the reduction in power, Audi has chosen to put its faith in its engine department recouping losses, whereas Peugeot has opted to put its faith in its aerodynamics department, reducing drag while maintaining downforce.

AERO TRADE-OFF

'Given the big reduction in engine power resulting from the 2011 regulations, we had to take a fresh look at the trade-off between aerodynamics, drag and downforce,' says Famin. 'The latter has been significantly reduced in order to maintain a reasonably high top speed.' Airflow through the cockpit has been improved and, with a slight change in the regulations, Peugeot has dispensed with the air conditioning system that worried the team so much on the old car. Now, instead of a set maximum temperature in the cockpit – previously 35degC if the ambient temperature was above 32degC, or less than or equal to external temperature below 32degC – the new rule is that the temperature must be no higher than seven degrees above ambient up to 25degC,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and 32degC at any other time. A seemingly small change perhaps, but one which means air conditioning is no longer a necessity as the temperature can be better controlled with airflow into and out of the cockpit, removing the significant power drain offered by an air conditioning pump.

Like Aston Martin and Audi, Peugeot has opted to run the same size tyres front and rear, eliminating the understeer from the old car, though that has placed more emphasis on rear-end stability. 'The front suspension we have adapted to the bigger tyre, and nothing else,' explains Famin. 'The parts are new and we re-designed the wishbones because the chassis is different, so the drivers are accommodated better. The differences are not big, but we have capitalised on everything we have learned from the 908, the Aston Martin and the Audi!'

The scoops over the rear wheels are now cooling the brakes, while the engine scoop is placed over the cockpit and leads to the fin that runs from the cockpit to the rear wing. The fuel tanks are smaller this year – down from 81 to just 65 litres for diesel and from 90 litres to 75 for petrol cars. Hybrid cars get a further reduction of two litres per tank, and clearly these size reductions require new cars to optimise the space available.

TESTING TIMES

With the focus on aerodynamic solutions, Peugeot has pushed the boundaries, and in pre-season testing suffered large accidents. Ironic, as in the past it has been Audi that crashed as it sought to catch up with the old 908. Marc Gene was the first, in November at Aragon in Spain, destroying one of the new cars, while Nicolas Minassian crashed at the Paul Ricard circuit in February. 'In Le Castellet, we were testing a new aerodynamic package, and we didn't do all the set up that we needed for that,' says Peugeot's director of sport, Olivier Quesnel.

The fact that the cars took off in these crashes re-opened the whole debate on Prototypes but, despite initially claiming that it would hand its documents over to the FIA and to the ACO, the fact that the company hasn't done so suggests it has found the problem and fixed it itself. Peugeot Sport has worked on the set-up to avoid such accidents like Minassian's to happen again.

However, with nine square metres of floor, there is always a danger of an LMP1 car taking flight, but Peugeot and other manufacturers are working with the ACO and the FIA to reduce the risks in the 2014 regulations. As one engineer put it, 'LMP cars are lighter and have a larger area than a light aircraft, and travel faster than the aircraft at take-off speed...'

Peugeot, it seems, has pushed the aerodynamics further than anyone else with this car, and has found the limit.

Certainly, it appears that the finished product is an excellent car. Not only does it have the power and the balance to race well on circuits all over the world, it also appears to be kinder to its tyres. In the heat at Spa in May, the 908 appeared to have the upper hand over Audi in terms of tyre management, with Pedro Lamy able to triple-stint his Michelin rubber mid-race. This is a trick that the Audi couldn't match at the Belgian race.

Audi was also slightly concerned that the Peugeots were faster in their second stint on the same tyres than they were in the first.

Little is known about the Peugeot's suspension system, but it appears that the layout is conventional, with a third spring and torsion bars. The old 908 could run a set up soft enough to attack the kerbs in a way that the R10 and R15 could not, and the new 908 continues that trend

Famin, at least, appears to be comfortable with the way the car handles but, understandably, has reservations about reliability. 'My main worry is not performance,' he says. 'You ask the drivers, they are confident of performance and so am I. The problem is reliability. We have to solve all the problems that we have discovered, and solve all the problems that we have yet to discover. We planned seven 24-hour tests before Le Mans, but every year we go to Le Mans, we find new problems.'

The weakness of the new 908 appears to be its operating window, which is narrower than the old car. That means the three cars have to work on set up in practice and qualifying, and share the information between them to achieve the optimum race set up.

'One day you will see a car that is doing badly, but it will be doing something different to the other cars,' says driver, Nicolas Minassian. 'We are working hard and developing faster. The window is narrower, but it is not too narrow. The car is a good car, but it needs to be set up.'

'It is a consequence of technical choices and we would not be surprised if Audi had the same problems,' says Famin. 'During the race at Spa, the Audi was not working so well. It is down to the concept of the car. We have to work closely with Michelin in the future. We have

The new 908 ran into problems at Sebring, with a crash delaying one car, and a turbocharger problem the other. Peugeot has since developed the aerodynamics, introducing a new nose structure at the Le Mans test day in April

> **"The weakness of the [new] 908 is its operating window, which is narrower than the old car"**

to adapt the car to the tyres, and the tyres to the car.'

Peugeot is not alone though. Audi is facing a similar problem, and it is undoubtedly a worry for both teams. Temperatures at Le Mans can vary by up to 25degC between the day and night, and the car needs to be able to cope with this. It also needs to work in very different conditions around the world, from the undulating Road Atlanta circuit to the flat track at Zhuhai in November.

HYBRID THINKING

Peugeot has said that it expects to have to run a hybrid system in the 908 before the end of the year. With the PSA group shortly putting on sale battery hybrid cars to the general public, the race team has also developed a 908 with batteries instead of a flywheel, partly because that technology is a step too far at this stage.

'To integrate a flywheel is very difficult,' says Peugeot's technical director, Bruno Famin. 'Mechanically speaking, the flywheel is quite a big issue. As a first step, it was quicker and easier to go with batteries, and the decision was already made to do that at the beginning in 2008.'

The regulations demand that the power is delivered back to the wheels from which the energy is collected, and Peugeot has opted to keep things simple and concentrate everything on the rear of the car. 'You need more batteries, a bigger electrical machine, and everything is more difficult,' says Famin, explaining the reasoning behind not collecting and delivering power to the front wheels. '[besides] we think we can collect all the energy that we need from the rear wheels.' The French manufacturer was instrumental in reducing the amount of stored energy from 1MJ to 0.5MJ, which also helps to keep control of the costs, needing less capacity storage and regeneration of energy to recharge the battery.

> “The ACO has to be very careful to give a bonus to new technologies”

'The bigger the energy you have to store, the more the cost, and it is not linear.'

With all the work concentrated on the rear axle, the system is lighter and less complicated than Porsche's GT3 flywheel hybrid, for example. Peugeot's system, which will weigh around 35kg, is expected to deliver a further 80bhp to the rear wheels between braking zones, and will meet the ACO's condition that it can run the entire length of the pit lane on battery power alone.

There seems to be little doubt that the Hybrid will be given a performance break, and that it should be capable of delivering more performance than the standard diesel engine. The ACO has mandated that the system be used only for improving economy, hence the smaller fuel tank and the regulation stating that the power may only be delivered when the car is going in a straight line. However, Peugeot would not be doing this unless it was sure to be a racing advantage in the future.

'We believe the ACO has to be very careful to always give a bonus to new technologies, or there will be no interest,' concludes Famin. 'New technology costs a lot of money. If there is a true equivalence between all the technologies, no one will invest. Nobody knows what will be an interesting technology in three or four years, but hybrid is interesting now.'

SHORT TRAVEL SUSPENSION

Racecar Engineering's chassis expert, Mark Ortiz, on the 908's rear suspension: 'It appears to have torsion bars for the main ride springs, with rotary dampers. There is a ride-only third spring mechanism with a compression coil and a rubber snubber. The small device on top of the bellhousing forward of that appears to be an anti-roll bar, presumably with a compound torsion bar extending down into the bellhousing. From the size of the links, it appears to be a small portion of the roll resistance, and does not appear to be adjustable for rate, except by changing bars?

As for the third spring not being coplanar with the rockers, they usually aren't as normally the rockers aren't coplanar with each other, so nothing else can be coplanar with both of them. The layout shouldn't cause any bad behaviour, unless the spherical rod ends run out of misalignment capacity and bind. The system does seems designed for very short travel indeed but, up to a point, that's normal for this type of car.

BY MIKE FULLER

When OAK racing brought an update kit for its LMP1-specification Pescarolo 01s to the Le Mans test few took notice, yet the rear wing was a radical design.

Since the 2004 LMP1 regulation changes (and even before that with the LMP900 regulations), the ACO has mandated a Gurney on the rear wing flap that is 90 degrees to the plane, connecting the top of the wing to the trailing edge (see FIA Drawing 258-8 in Article 3.6.3 of the ACO regulations). Initially, the mandated height was 15mm, but in 2009 this was raised to 20mm.

Then 2011 saw engine capacity reductions for LMP1, resulting in the loss of about 100bhp for the top diesel LMPs. This has led to a trend shift in aerodynamic development, from pure downforce generation to drag reduction and efficiency first, downforce second.

While it is only a small detail when looking at the entire car, the mandatory Gurney is now even more of a liability than before. But there's precious little that can be done about it. Or is there?

Oak Racing, it seems, has hit upon a clever design that manoeuvres around the Gurney regulation. Ultimately, the concept is a regulatory work-around and nothing more, though it shows there are always ways to push the boundaries and come up with new concepts. But arriving at this conclusion was not a straightforward task.

Initially, it was suggested that the protuberances were designed purely with aerodynamics in mind. Discussions in the pit lane were rampant about the bumps acting as vortex generators, and there was even mention that the bumps were utilising an aerodynamic concept seen in nature on, of all things, whales.

Apparently, scientists have long puzzled over the agility of whales in the water and, when researched, took note of bumps on the leading edge of whales' fins. They came to the conclusion the bumps help reduce span-wise leading edge flow migration, and locally better organise the water flow, leading to a much more efficient fin (or wing, as the case may be with racecars).

THE CALL OF NATURE

Apparently the research is three-years old but, up until recently, nobody had shown up on an F1

grid with a wing that had bumps or similar on its leading edge. Ferrari has experimented with 'riblets', or a 'shark skin' finish, on the underside of its front wing, but that's as close as F1 has come to replicating nature.

Ultimately, the Oak solution is pretty simple. But first you have to think about the wing in cross section. The mandatory 20mm Gurney has to be perpendicular to the line connecting the top of the wing to the trailing edge. But Oak Racing has increased the height of the wing opposite the 'conventional' cross section in an alternating pattern (of bumps). And when you connect the top of the bump to the trailing edge, the perpendicular Gurney is leaned back relative to the conventional section. As the top of the wing is relatively insensitive (note: the low-pressure side is untouched), any loss from the bumps is more than made up for by the alternating Gurney angle reduction.

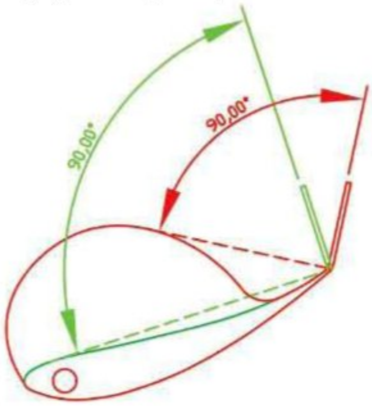
Oak Racing's technical director, Christophe Chapelain, confirms this is the reason for the concept: 'At Oak we have a design office. We have our own tunnel model, but the main focus is on aerodynamics, especially the front splitter and rear wing. On an aero car the diffuser is the most important element, but on these cars it is so restricted you have to focus on the front splitter and nose diffuser.

DRAG REDUCTION

'On top of that, you have the rear wing, which is important to balance the car. If you are able to generate a lot of downforce from the body, you decrease the rear wing and you reduce drag. If you are not able to do that you need to put more angle on the rear wing,' he explains. 'The Gurney is one of the most important pieces for drag. The idea for the bumps came from a sort of brain storming.' Team aerodynamicist, Nicolas Clemencon, utilised CFD to flesh out the concept and followed that up with wind tunnel testing at RUAG in Switzerland. The result, according to Chapelain, is the same level of downforce for slightly less drag. And it seems to be just on the edge of improved L/D, too. The flap wasn't used at Spa because for higher downforce levels it's more efficient to use a standard flap without any bumps.

Interestingly, Oak Racing's concept hasn't been dismissed outright, and both F1 teams and rival LMP outfits are considering the possibilities. 'It depends on how big the negative effect of the flap top surface modification is... I will know more after trying it, possibly in a nicer way,' commented one aerodynamicist for a current LMP project. One wonders, though, if there's been enough time between the Le Mans test and the race...

The row of bumps technically leans back the Gurney angle on the rear wing and, says Oak Racing, produces the same level of downforce as a regular Gurney for slightly less drag penalty



The architecture of a diesel

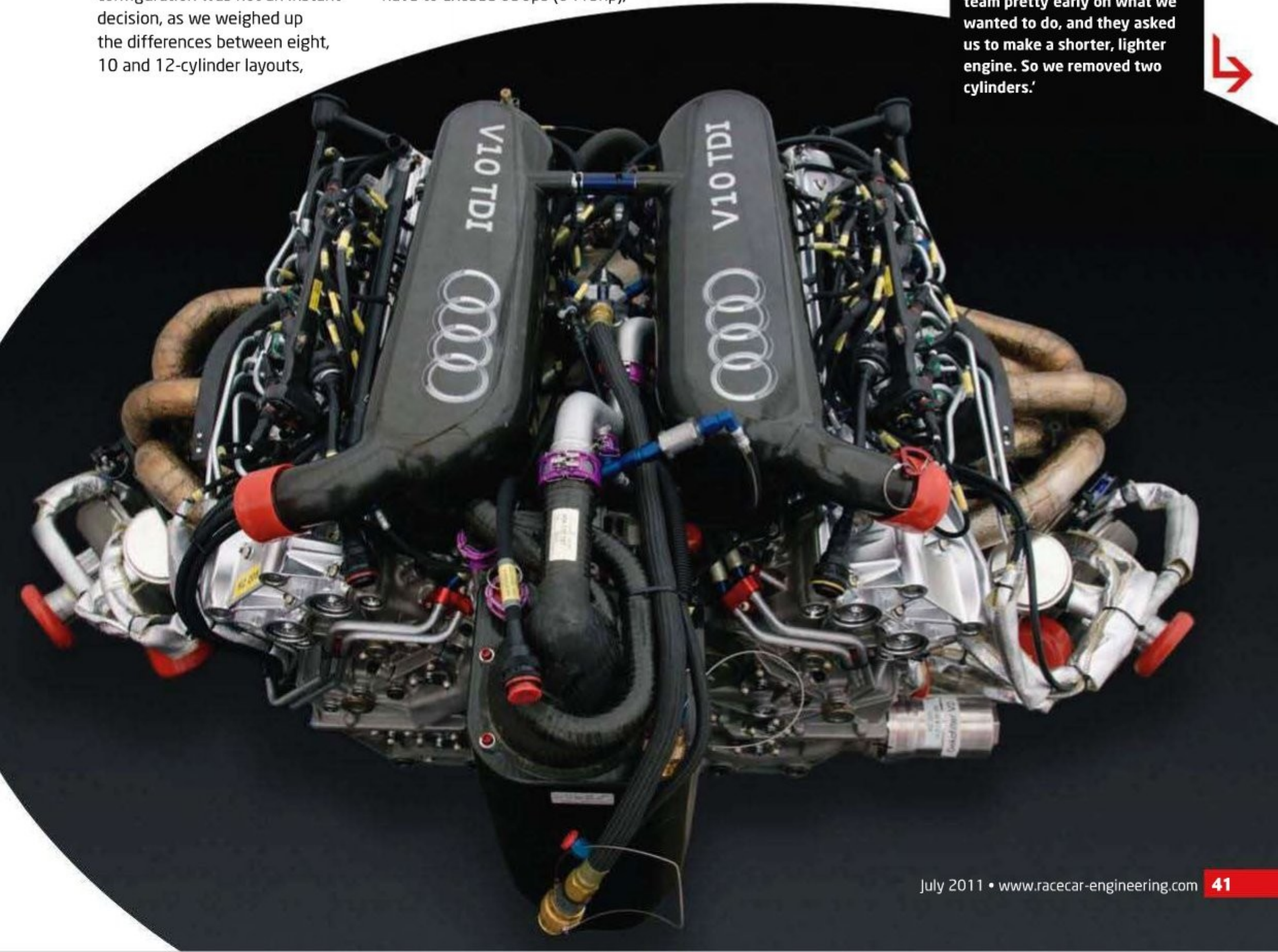
Audi Sport's head of engine technology, Ulrich Baretzky, explains the thinking behind the company's all-conquering powerplants

It was said to be the engine Ulrich Baretzky had wanted to build for years, and once the V12 diesel engine fitted to the Audi R10 TDI had proven itself he was given the green light to progress with his concept for the new R15 chassis. The story starts after the decision was taken to replace the R10 TDI with an all-new Le Mans Prototype, with an all-new engine.

'Choosing an engine configuration was not an instant decision, as we weighed up the differences between eight, 10 and 12-cylinder layouts, taking the following factors into consideration: vehicle packaging; displacement; engine weight; c of g position; overall length; specific piston loads; vibration behaviour; development potential and transfer from / to production car engines,' says Baretzky.

Computer simulation of the complete car on the Le Mans track produced a clear set of design requirements for the new powerplant: the power would have to exceed 650ps (641bhp), with more than 1100Nm of torque in a wide, usable rev range and to be able to use a five-speed gearbox. It could also not weigh more than 220kg and it had to be fully stressed.

'Many of the targets for the new engine resulted from the demands to reduce the engine's overall length, and to be able to change the car's weight distribution as a consequence. The overall dimensions for



The V10 TDI unit produced more than 600bhp and had a maximum torque of over 1050Nm. It was 100mm shorter than the V12 used in the R10, on the request of Audi's chassis department who, Baretzky says, were much more involved with the early development of the R15 than they were on the R10. 'In the past [read: with the R10], the engine came first and they built a car around it. With the R15 we showed the chassis team pretty early on what we wanted to do, and they asked us to make a shorter, lighter engine. So we removed two cylinders.'

Comparison: restrictor, boost pressure

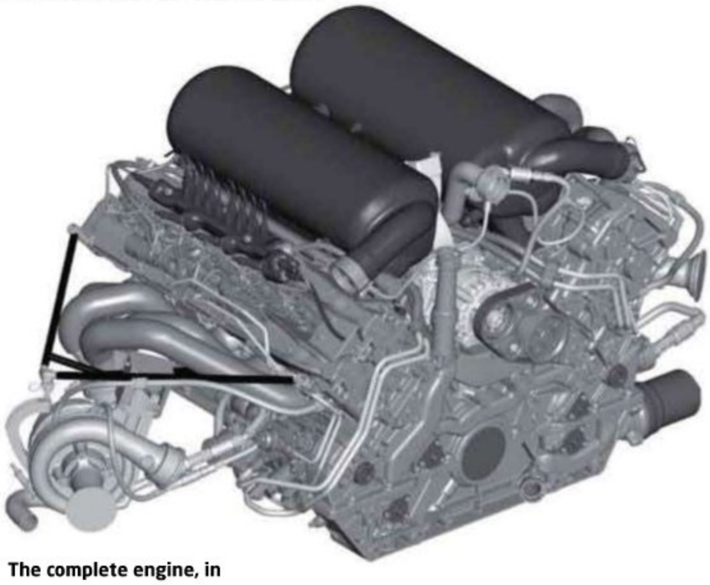
Year	Restrictor size	Change	Manifold pressure	Change	Capacity	Configuration
2006-2008	2 x 39.9mm		2940mbar		5.5-litre	V12
2009	2 x 37.9	-9.8%	2750mbar	-6.5%	5.5-litre	V10
2010	2 x 37.5mm	-11.7%	2590 mbar	-11.9%	5.5 litre	V10

Evaluation of V10TDI and V12TDI concepts

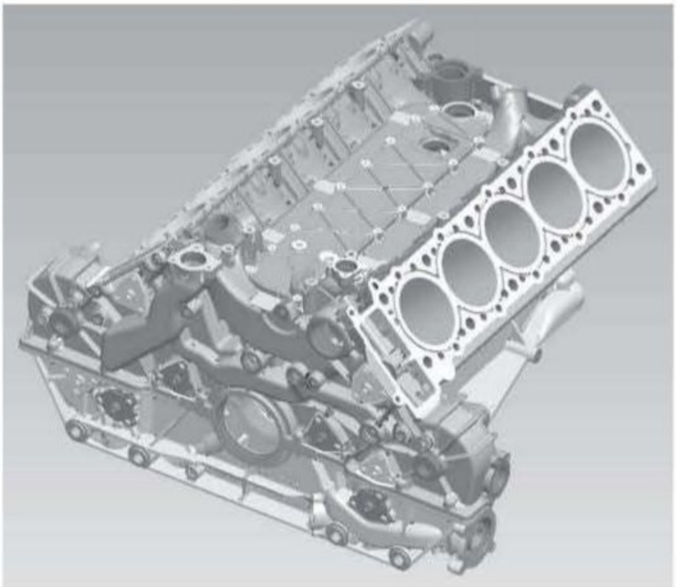
Base V12 TDI = 100%	V10 TDI 5.5-litre
Length	-13%
Width	4%
Height	4%
Weight	-12%

Increase in swept volume for 5.5-litre engine concept

Cubic capacity	5500	5500	5500
No of cylinders	12	10	8
Single cylinder volume	458.3	550	687.5
Increase in cylinder volume		20.00%	50.00%

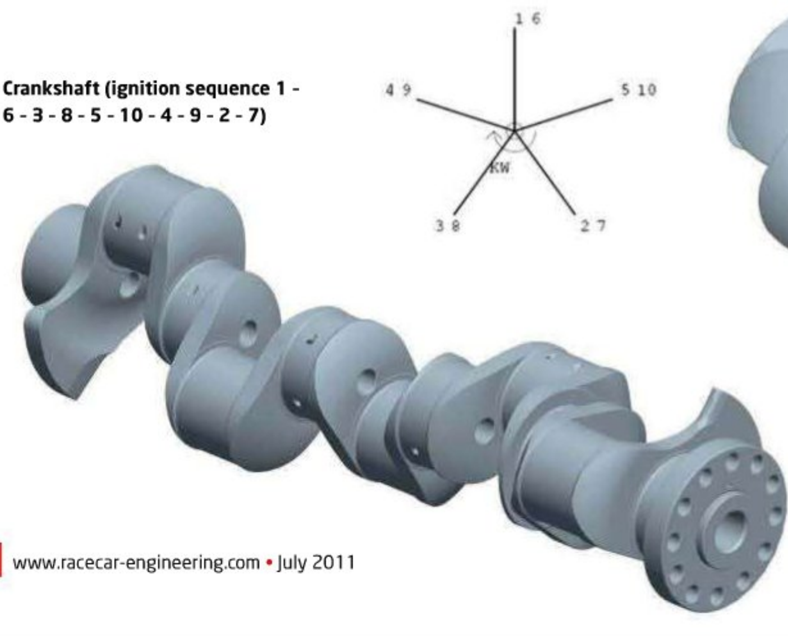


The complete engine, in CAD format



The R15 TDI's fully stressed, all-aluminium cylinder block

Crankshaft (ignition sequence 1 - 6 - 3 - 8 - 5 - 10 - 4 - 9 - 2 - 7)



a 5.5-litre V10 TDI engine demonstrated the 10-cylinder concept's length advantage, but the V12 TDI could be installed lower in the car and achieves a lower height advantage, too. An eight-cylinder configuration was ruled out due to the high single cylinder capacity and the combustion process of the larger cylinders.'

Taking all this into account, the format chosen for the new engine was a 5.5-litre V10 twin turbo diesel. Visually similar to the V12 used in the R10 TDI, the new engine was clearly based on the same concepts but with some clear differences – not least the number of cylinders. 'When we made the V12 we effectively made a V10 too, so on this engine we changed the bore and stroke but the engine is actually not much different. The 90-degree cylinder bank angle was retained, since it represented the best compromise regarding torsional stiffness, overall height and c of g position for the R15 chassis. The resulting uneven angular ignition spacing for a crankshaft with continuous, single axis crank pins has no influence on the wider car. Some people say because it is a V10 perhaps a 75-degree bank angle would be more suitable, but this is a diesel. It's not very high revving, so 90 degrees is just fine.'

The carry over from the V12 was clear to see in other areas too, including the cylinder spacing and the layout of the pump and camshaft drives.

CRANKCASE DETAIL

'The fully stressed, all-aluminium alloy cylinder block was made using a low pressure sand casting method. Each of the 10 cylinders was coated with Nikasil to reduce wear and friction, while for piston

The exits from the titanium exhaust system on the R15 were in an unconventional location - on the rear deck ahead of the rear wing. The car's complex aero package means that the area around the exhausts and turbochargers is incredibly tight. 'Getting the exhausts and the filters into such a tight area was not easy because they run very hot, around 900degC,' reveals Baretzky. 'If you look at the road car, it's a similar idea. You always have to have the particulate filter very close to the engine to use the maximum heat to get it operating as soon as possible. It also helps keep the engine compact.'

The R15 TDI used steel H-beam rods by Pankl and steel pistons with specially developed combustion bowls

cooling purposes corresponding oil grooves with cut-off control valves are integrated in the block. The integral cast water channels with a junction to the heat exchanger have only the connection to the water coolers in closed circuits.

'The crankcase below the main bearing centreline – the so-called bed plate – is manufactured using an identical process to the one used for the R10 V12. It's a complex, heavy duty, cast component and, due to directional solidification, the precision casting has equally high strength (Rm 35Mpa) and ductility, with a minimum wall thickness less than 2mm.

'The side-mounted dry sump scavenge port and ribbings connect the bearing blocks with one another, making a very stiff unit when assembled together with the upper crankcase. This means the engine and chassis have almost equal stiffness.

'The engine's installation height in the Dallara-built, Audi-designed chassis was influenced significantly by the stroke. Although the stroke was increased by nine per cent, the distance between the crankshaft centreline and the bed plate was actually reduced by four per cent, resulting in a lower installation height and a correspondingly low c of g.

'On the drive side, a light steel flywheel transmits torque to the clutch, while an incremental toothed gear integrated in the clutch supplies the impulse for the Bosch Motronic rotational speed signal.'

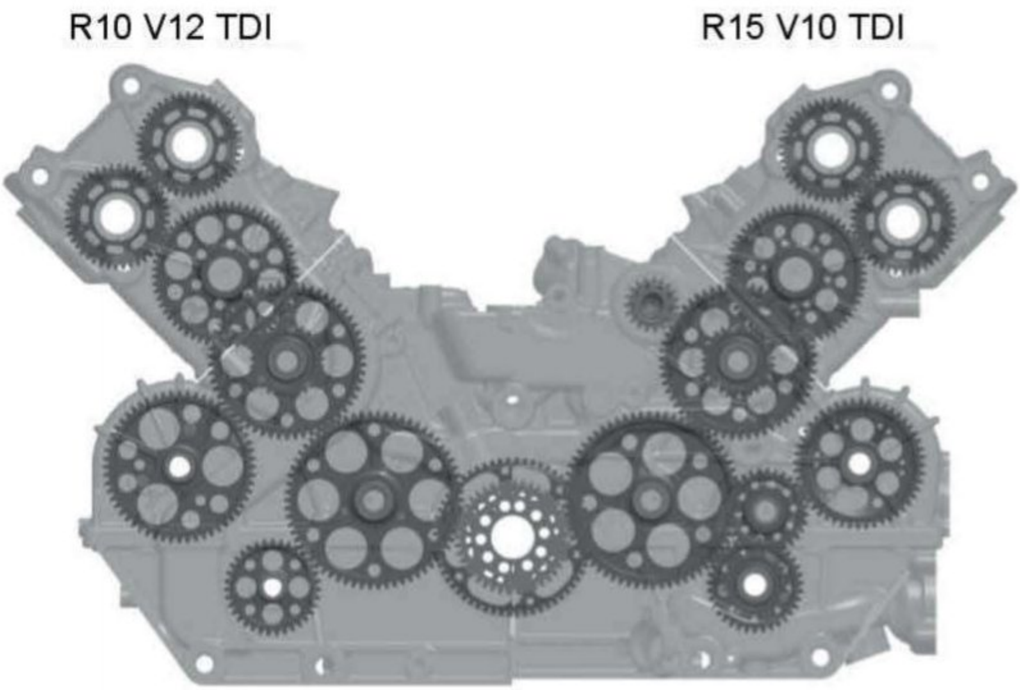
STEEL PISTONS

One of the big steps forward in the new engine was the use of steel pistons, developed with technical partner Mahle. On the V12, aluminium pistons with fibre-reinforced bowl lips were used, but these saw reduced service life and an increase in the probability of failure. So, in cooperation with Mahle, heat-treated steel pistons were tested in the V12 and found to offer both high temperature resistance and good machining properties, leading to the V10 being designed exclusively for such pistons. The higher temperature resistance of the steel means the pistons can be shorter than the aluminium versions, resulting in a lower cylinder block height and a resultant decrease in installation space. Owing to the greater transferable force in the

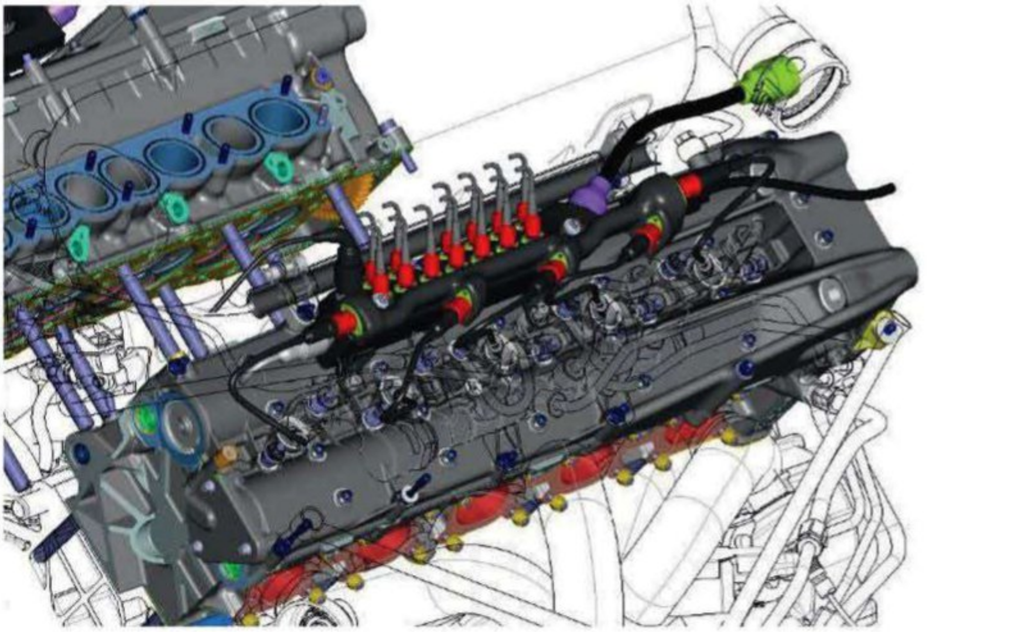
> **"its steel piston can equal or even fall below the weight of its aluminium version"**

SCHEDULE

Concept studies start:
Summer 2007
Project decision made:
September 2007
Single cylinder tests for combustion process development
End of 2007
First engine start of V10TDI:
July 2008
First track test:
December 2008
First race:
12 hours of Sebring, 2009
First victory:
Le Mans 24 Hours, 2010



Comparison of gear train layout in V12TDI and V10TDI engines



The R15 TDI's single piece, aluminium alloy cylinder head, showing the location of the Bosch CRS 3 fuel injectors

pin bore, the gudgeon pin in the steel piston is also considerably shorter, leading Audi Sport to claim that its steel piston can equal or even fall below the weight of its aluminium version.

'The pistons have a combustion bowl developed specifically for the R15 engine, and due to the greater bore size of the V10, the piston surface area load increases by approximately 12 per cent for the same ignition pressure. The high thermal loads made using two piston spray nozzles necessary - one for the piston base, the other to supply the cooling channel.

'The Pankl-supplied connecting rods in obliquely divided steel are manufactured with an H profile, as per the R10 rod, and were optimised with regard to stiffness and minimum weight by FEA calculation.'

CYLINDER HEAD

Like the block, the cylinder head is a single piece aluminium alloy casting, developed using knowledge gained from the V12 head design. Initially, the concept was tried on a single cylinder test rig with the engine adapted from the V12 development parts, using components created through rapid prototyping. The single cylinder took over the main tasks in combustion process development and was also used for durability tests. In parallel to the single cylinder test unit, the head and complete engine were designed and simultaneously calculated.

'The injector duct housing the in-line Bosch CRS 3 piezo high-pressure injectors is positioned centrally in the cylinder head, well supported by ribs in the oil chamber ensuring a stable combustion chamber plate. Two inlet valves and two exhaust valves are positioned parallel to the cylinder axis, with the valve seat rings manufactured from sinter alloys, which were specially designed for the high loads. The valve guides are produced from copper-beryllium alloy, while the valve actuation parts consist of sodium-filled steel valves, conical valve springs and finger followers. The valve arrangement in the combustion chamber was changed and the valves enlarged to use the bore size best.

'The camshafts are steel and are hollow drilled for weight reasons, while the cam contours were renewed compared to the R10, with a larger valve lift and valve timing necessary to optimise the combustion process.

'The cylinder head cover with the engine mounting points is machined from a solid billet for strength and, due to the integration of the camshaft bearings in this cover, the cylinder head has a particularly high stiffness level in the upper area. This allows the introduction of suspension forces via the monocoque and / or the gearbox.

'Positioning of the gear drive on the engine's front face also brings advantages to the combined vehicle stiffness.'

In addition to the camshafts, the oil, water and high-pressure fuel pumps are all driven by

DUCTING

Due to the air ducting, the installation of a turbocharged engine is significantly more complex than a normally aspirated engine. The charge air and water cooler are located on both sides of the monocoque in close proximity to the engine, resulting in low loss flow for low duct volumes. The car-side cooling air ducts to these were optimised in the wind tunnel to ensure very efficient cooling of the charge air and water.

The unfiltered air side of the engine intake system is as per the predecessor. The snorkels, with integrated air filters protruding from the bodywork, provide excellent flow to the restrictors, while exploiting the dynamic pressure at high vehicle speeds causes a marginal increase in mass flow rate.

The air is compressed to the permitted boost pressure in the compressor and enters the intercooler at temperatures of up to 200degC. After cooling, it reaches the intake system through a short carbon fibre connecting pipe. The intake manifolds and plenum chambers are also manufactured from carbon fibre for weight reasons.

gears, with an idler gear and ratio step integrated to achieve the required ratio change. The needle roller bearing steel gears are supported in the housing with floating axles, one per cylinder bank, simultaneously assuming the function of compensating for tolerances and height differences in the cylinder head.

The two Bosch high-pressure fuel pumps are mounted above the oil pumps, no longer driven by the camshaft drive idler gear, but by the oil pump drive gear.

Scavenge ports for the windage trays for dry sump / oil pump system components are on the right-hand side of the bed plate, while the oil and water pumps are located on both sides of the crankcase. The external gear pressure stage is positioned on the left, together with a scavenge stage for the turbocharger and gear shaft, while all scavenge pump stages for the crankcase, gear shaft and turbochargers are arranged on the right-hand side. The cylinder heads are scavenged via the gear shaft. The subsequent intermediate gear to the water pump allows the spiral housing to be positioned close to the engine, permitting easy adjustment of water pump speed.

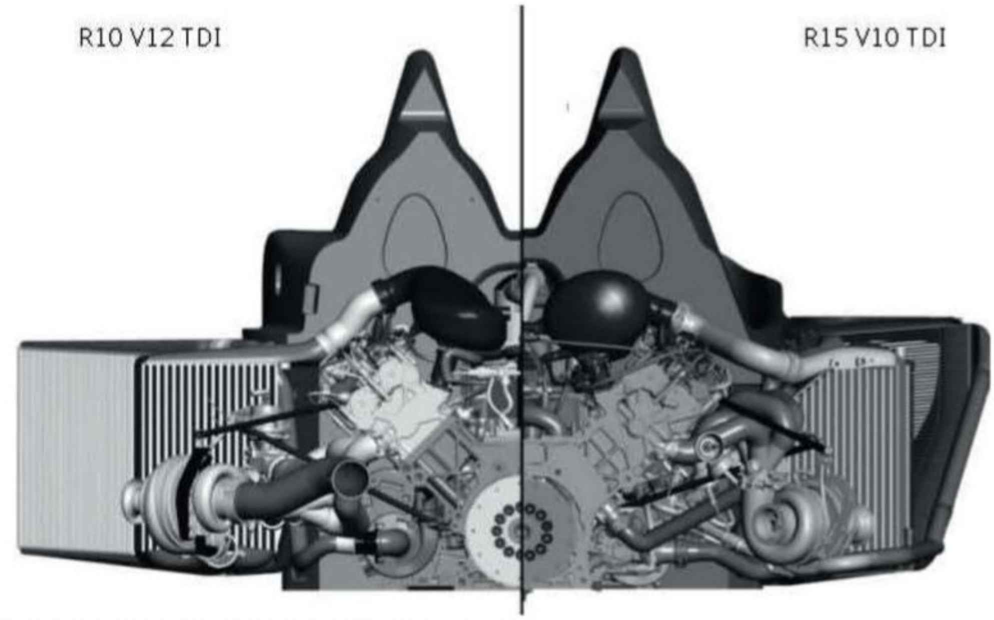
The alternator is positioned behind the oil tank on the front side in the v, with the drive output from the camshaft gear drive made by a short poly v belt. As a result, the unit is decoupled from crankshaft vibrations.

The starter motor is found on the engine's left-hand side, where it can be changed easily in an emergency through an access panel in the under floor.

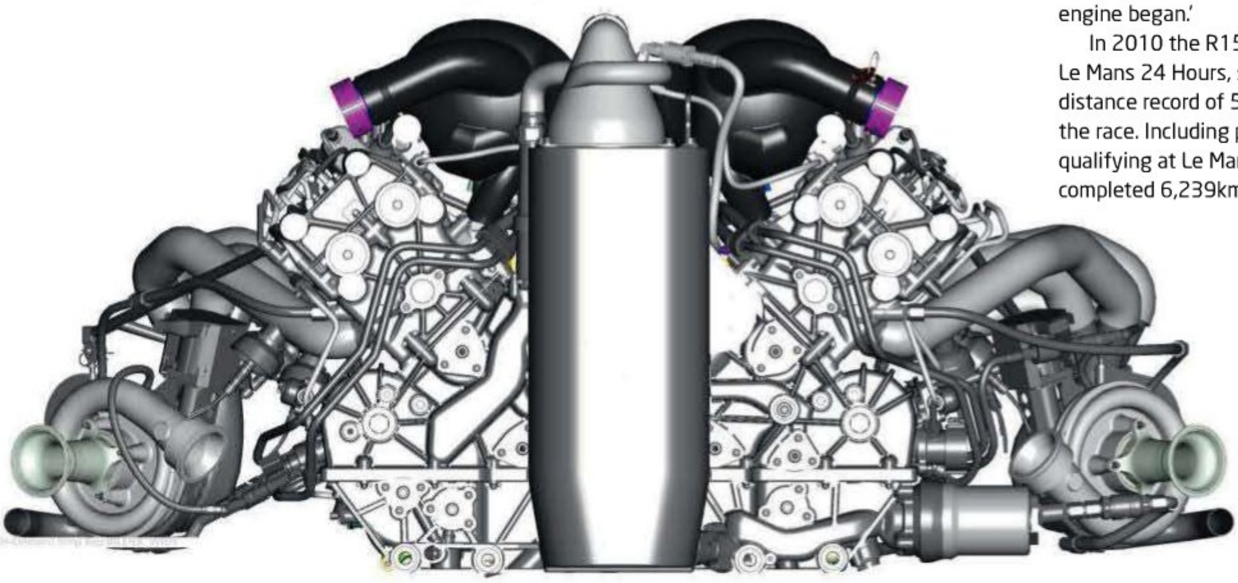
'The new Bosch Motronik MS 14.1 was operated for the first time with the new engine, with testing taking place in both steady state and transient condition, including a race-like endurance test.

'Owing to all this preliminary work, the first roll out and vehicle test was completed without problems, then the short period of time that remained before the Sebring race was used for vehicle tests to implement the final modifications in dynamic operation. Final production of the race engines consumed the short time frame afterwards before Le Mans. During this time, development of the 2010 engine began.'

In 2010 the R15+ won the Le Mans 24 Hours, setting a new distance record of 5,410.7km in the race. Including practice and qualifying at Le Mans, the engine completed 6,239km.



Comparison of ancillaries in R10 TDI and R15 TDI engine bay


Front view of engine with oil tank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Slipped discs

The Swiss Hy-Tech ORECA, run by Hope Racing at Le Mans this year, features the latest in hybrid technology from Flybrid Systems

BY SAM COLLINS

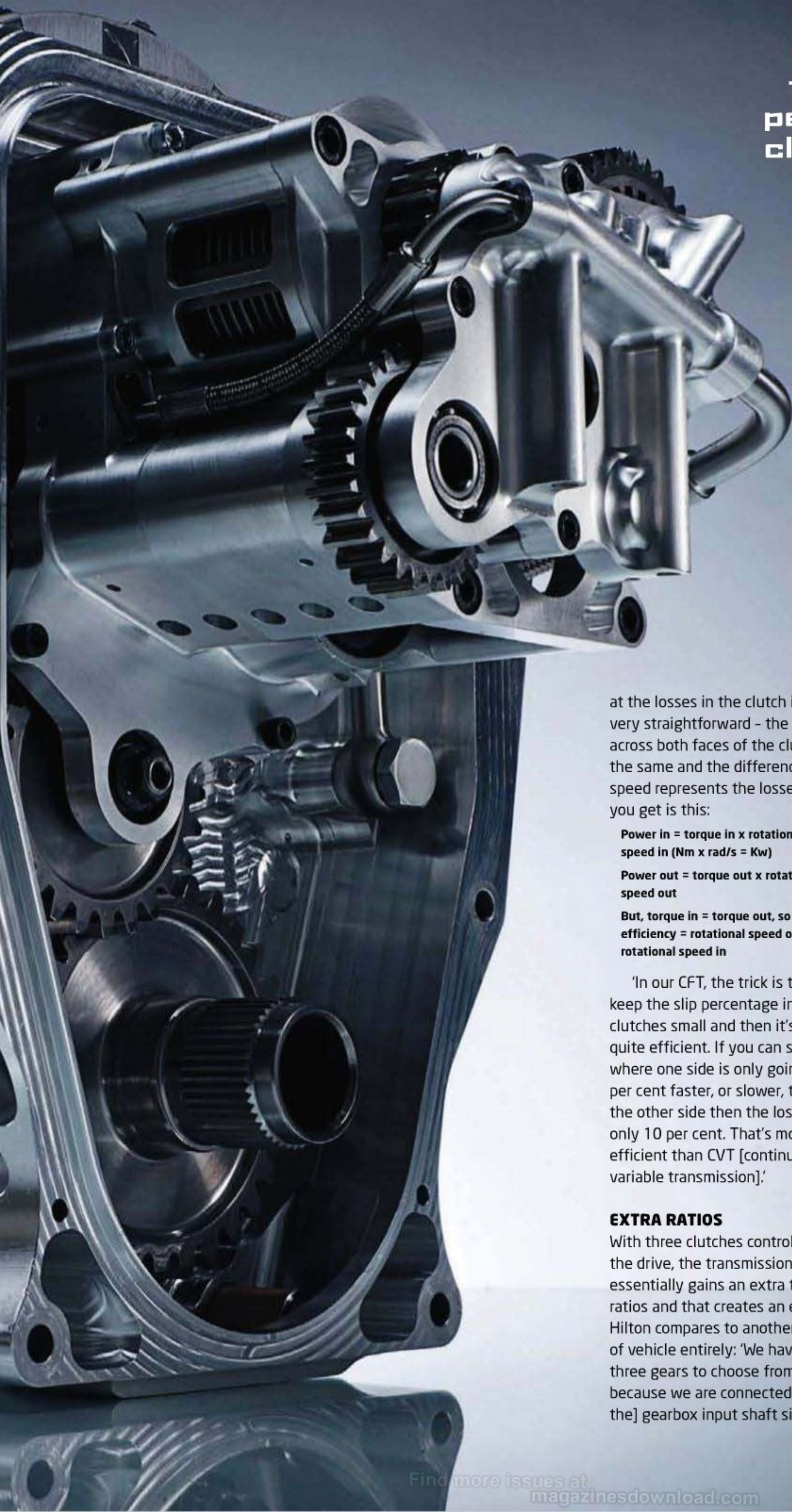
Fitted to the Hope car is the latest innovation from English firm Flybrid Systems, which it has dubbed the Clutched Flywheel Transmission, or CFT KERS. The core principle of the kinetic energy recovery system is essentially the same as previous offerings from the company, in that a flywheel is used as the storage medium. However, where the CFT system differs is in the way it transmits the drive from the flywheel to the rear wheels.

The CFT uses a number of discrete gears and high-speed clutches that perform a controlled slip to transmit the drive. When connected to an engine-speed shaft within the vehicle transmission, the three gears in the CFT KERS are multiplied by the number of gears in the main vehicle transmission to provide a large number of available overall ratios between flywheel and wheels. 'The idea came from Doug Cross, our technical director,' reveals Jon Hilton, managing director of Flybrid. 'It actually came from a proposed road car solution, and I asked Doug to see if he could make it for £10 and fit it to every Tata Nano. The next day he came back with this idea for transmitting drive through a slipping clutch. He thought it would be cheap, but rubbish. We did a quick analysis and almost straight away realised it was not rubbish at all!'

Hilton and Cross then set about taking the idea from vague concept to reality and, in a short period of time, patents had been applied for and motorsport applications were under discussion.

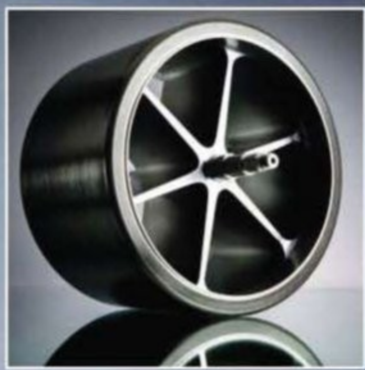
'There are a number of good reasons for it not being as bad as you think,' Hilton continues. 'Everyone imagines that clutches suffer with a lot of losses. This is because people are used to using them in the condition when you have the car stationary with the engine revving and you slip the clutch to pull away until you can close it and stop losing energy through the clutch. But that is an extreme case, where one side is not moving and the other is moving quickly. The moment you let the clutch out, the losses are 100 per cent – all of the energy turns into heat until the car starts to move. In fact, when you look

> "the transmission essentially gains an extra three ratios..."



> the trick is to keep the slip percentage in our clutches small

Like other Flybrid Systems offerings, the CFT KERS uses a flywheel as the storage medium. However, it uses a slipping clutch mechanism to transmit drive to the rear wheels



at the losses in the clutch it is very straightforward - the torque across both faces of the clutch is the same and the difference in speed represents the losses. What you get is this:

Power in = torque in x rotational speed in (Nm x rad/s = Kw)

Power out = torque out x rotational speed out

But, torque in = torque out, so efficiency = rotational speed out / rotational speed in

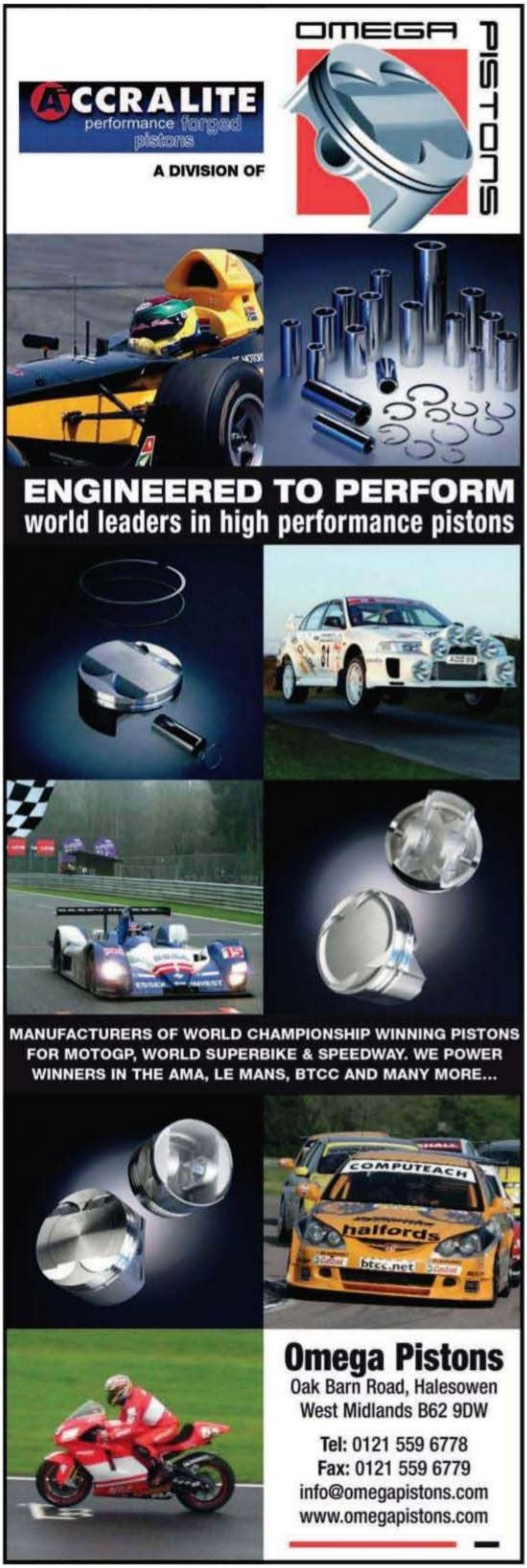
'In our CFT, the trick is to keep the slip percentage in our clutches small and then it's really quite efficient. If you can slip where one side is only going 10 per cent faster, or slower, than the other side then the loss is only 10 per cent. That's more efficient than CVT [continuously variable transmission].'

EXTRA RATIOS

With three clutches controlling the drive, the transmission essentially gains an extra three ratios and that creates an effect Hilton compares to another type of vehicle entirely: 'We have three gears to choose from but, because we are connected [to the] gearbox input shaft side rather than the wheel side, we multiply our three ratios by the six in the gearbox already to give us 18 speeds effectively to choose from. It's like a mountain bike with three gears on the front and six on the back - some of those ratios overlap each other, but we have a wide range to play with, and this means there is always a reasonable efficient gear available. We then choose to close the right one by computer to minimise the slip across it. It's hydraulically actuated, but is controlled electronically, and we write all the software to get the right clutch instantaneously, to choose the one with the least slip. Then, before it grips solid, you change to the next closest and it automatically does that.

'If you can arrange your ratios properly and set it up in the car so the slip across the clutches is relatively small, it's actually a pretty efficient method of doing the power transfer.'

A Flybrid-developed computer controller selects the most appropriate gear by partially engaging the high-speed clutch associated with that gear. The control system then uses hydraulic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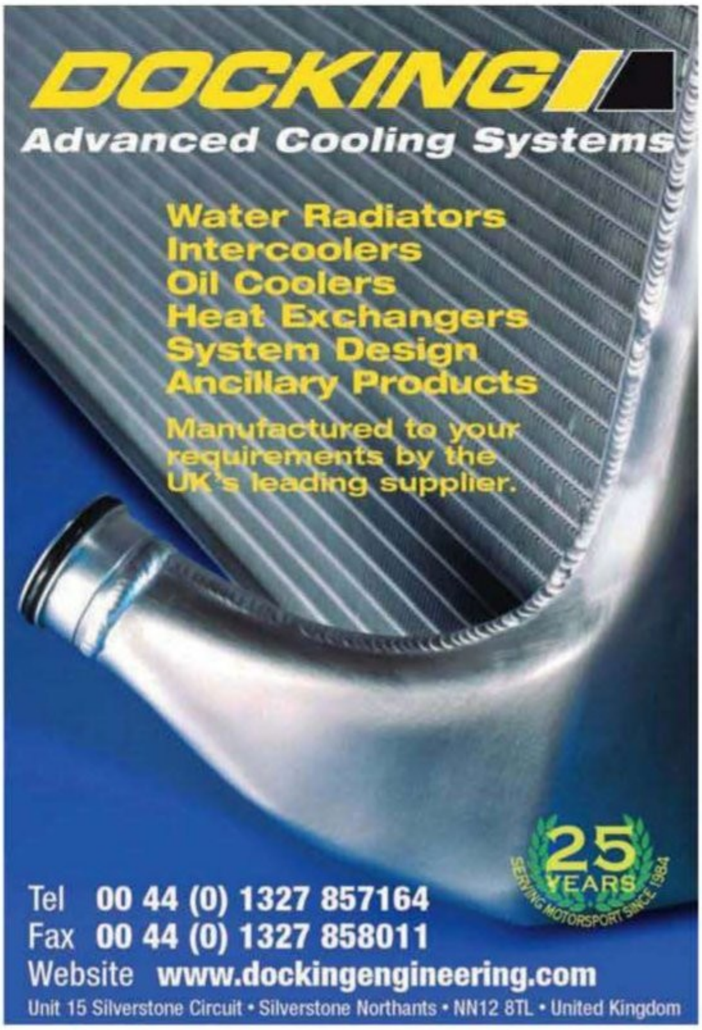
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pressure to close the normally open clutches and transmit the drive, seamlessly changing from one gear to another with no torque interruption as the speed across the engaged clutch reduces to near zero.

The total system cost is a significant amount lower than previous offerings from Flybrid, itself significantly cheaper than other manufacturers' battery-based KERS. 'In terms of a cost comparison with our previous CVT-based systems, it's about 70 per cent of the cost, even in low volumes. Part of the reason for that is there's a lot of commonality – all the clutch packs are identical and all the hubs are the same, so we are making larger quantities of the same components, which helps us control the price. In comparison to electric hybrid, it is massively cheaper. I'd say our system is half the price of a comparable electric system.'

Due to commonality of parts, the CVT KERS is significantly cheaper than current electric and battery-based systems on the market, which should see it gain more widespread use among smaller teams in the future

LMP1 APPLICATION

The entire CFT system is mounted in a bespoke housing that, in the case of the ORECA 01 used by Hope Racing, sits between the car's Xtrac transmission and a turbocharged, 2.0-litre, in-line four developed by Lehmann. But the CFT can also be located elsewhere on the powertrain (see fig 1, right).

Despite looking quite sizeable, the addition of the CFT has not increased the wheelbase of the ORECA, something that highlights the versatility of the concept. 'In this case it does not impact the wheelbase. Originally, the chassis was fitted with a Judd V10 and the wheelbase is the same as it was. It would be more of a challenge with a longer engine but, if you look at the installation, the flywheel sits *above* the clutch of the car, but not overlapped with it at all. There is 200mm or so of shortening you could do relatively easily. We have designed the gearing that sits between the CFT and the car gearbox so there are several options of gears available on the same centres, so the same hybrid system will suit a high revving N/A engine or a low revving turbo diesel.'

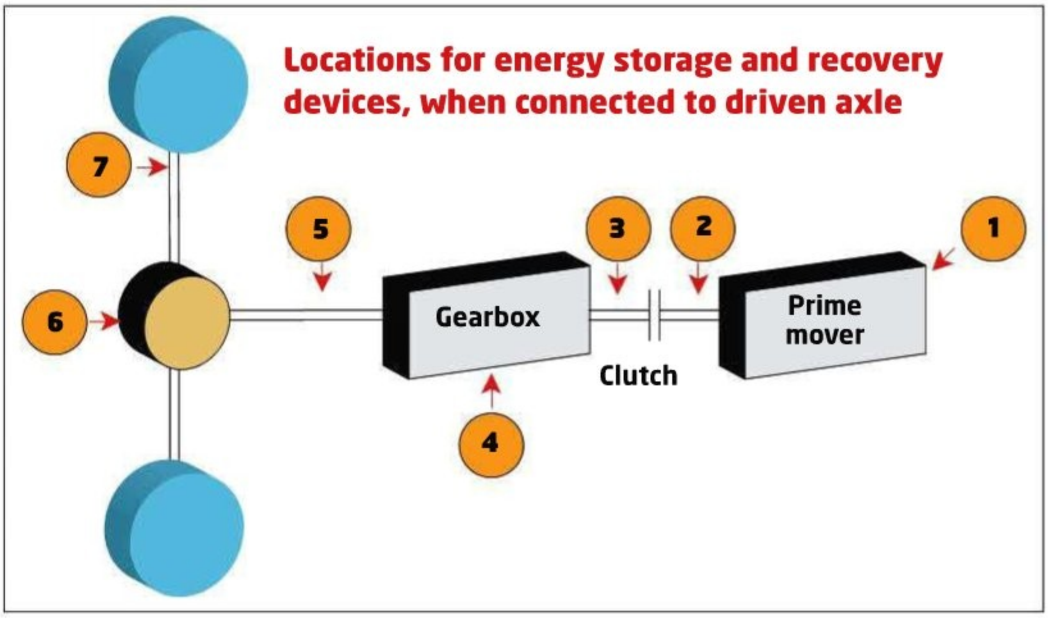
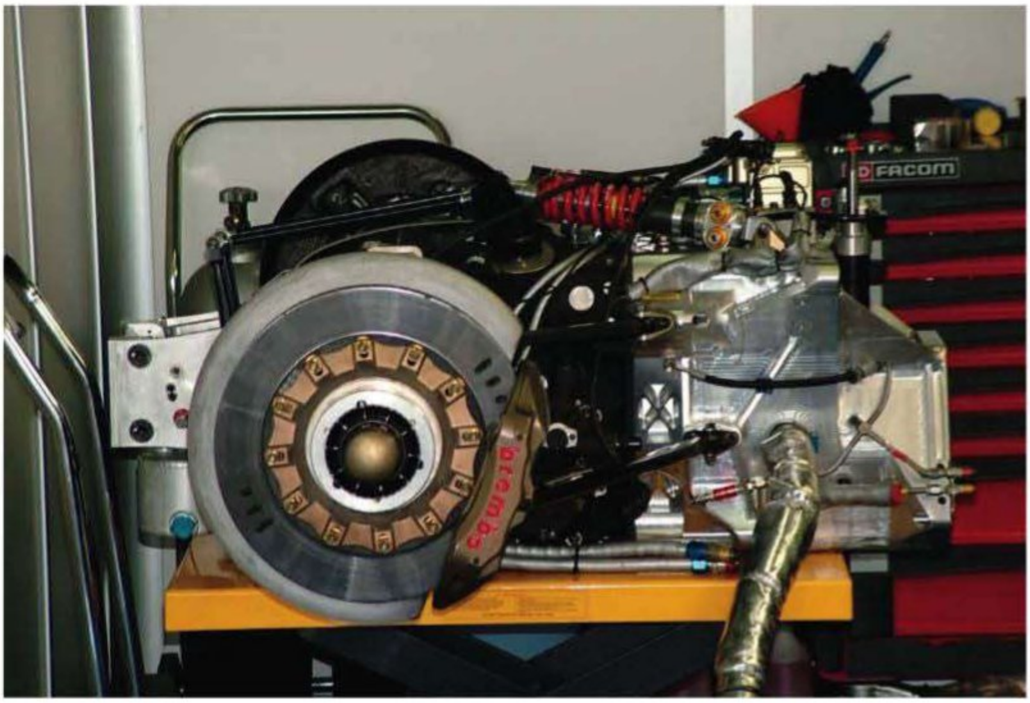


Figure 1: the CFT KERS device may be connected to a vehicle's transmission in any of the locations numbered 1 to 7. When using connection locations 1 to 4, there is the advantage of multiplying the number of gears in the CFT by the number of gears in the vehicle gearbox. In locations 5 to 7 the CFT KERS may be configured with more than three gears, and the round trip losses for kinetic energy recovery are lower due to the proximity to the vehicle wheels

Despite this apparent versatility, the CFT cannot yet be described as a fully off-the-shelf system, as it requires significant work to integrate with the other systems on a car. 'Off the shelf is a funny term,' says Hilton. 'In terms of the hybrid system, yes, it is 'off the shelf' but, in terms of vehicle integration, it is not. Every car requires its own bit of work to make the software talk to the other elements of the car, so on the ORECA we are interfacing with a Bosch ECU, a Megaline control unit for the gearshift and a Cosworth logging box for the ACO. So we have four control units all talking to each other. On other vehicles, which may use McLaren, Marelli or other systems, there is different work involved. It also requires a new bellhousing, but any customers who have bought an Xtrac 1059 2011 Sportscar gearbox, with the standard main case, already have one that is KERS ready, and effectively we can supply them with a kit of bits to turn it from a standard car to a hybrid car. The only thing the chassis team need to do is fit a new bellhousing and find a location for the hydraulic block and KERS controller.'

EARLY TESTING

The initial running on the ORECA did not go entirely to plan, with a number of electronic system issues preventing the team completing all the testing they had hoped for. Also an issue with



The Flybrid Systems CFT installed on an Xtrac gearbox in the ORECA chassis. The engine will then connect to the CFT

the engine's vibrations at idle speeds caused a resonance in one component in the CFT, which led to a failure. That part has since been re-designed, and such are accepted as simply teething problems on what is still a new technology in racing.

'The biggest problem we have had is getting all of the systems working together before we can turn it up to a significant level of performance. The challenge is that it is capable of delivering 100kw in either storage or recovery and, if it did that at some poor moment on track, you can cause the car to crash. So you have to be a bit circumspect about running it flat out at first. You have start and make sure everything is working with it turned down to a very low level. So we had it on at the Le Mans test day but at very low power levels, just 10kw or some tiny number. We did that to test all the things you can think of and cannot do on the rig, like running a high kerb or with the sharp torque spikes that result when the driver locks a wheel and you get some unusual speed sensor readings. You have to prove none of those things cause the system to do something you were not expecting. We know it works perfectly at full power on the test bench but we cannot put it to full power in the car until we know all those control systems work.

"It's like a mountain bike, with three gears on the front and six on the back"

'During the running we have done we have had a lot of electronic communication problems. We found that the Bosch ECU and the ACO logger both use the same CAN channel, but for different information, and neither supplier wants to move off that channel. That channel is the throttle pedal signal from the Bosch unit, which we need, and the ACO information messes that up. It required engineers from the team, Flybrid, Cosworth and Bosch to work together to resolve the problem, as without a clean throttle pedal signal we can't get the system to work reliably. And we cannot just add an extra sensor and loom because the signal the Bosch unit puts out has already been processed for safety, so this means that if the driver presses the brakes and throttle at the same time they send us a signal that says idle throttle rather than what the pedal says. All of that safety software is in the Bosch ECU and we intended to use that, but it's the processed signal that goes to the engine not the raw throttle position data.'

PIT LANE TEST

Another unique challenge with the Le Mans hybrids is the so-called 'pit lane test'. The regulations require all hybrids running in the race to be able to drive the length of the pit lane (400m) at Le Mans on its hybrid system only at 60kph. It was thought this test would involve a car leaving the pits, doing an out lap, then driving through the pits on hybrid power alone, the system fully charged from the out lap. At the test day both hybrids present were summoned to a straight on the infield circuit at Le Mans and told to do the 400m from a standing start.

'The pit lane test was not what we expected. With an electric hybrid system you can arrive fully charged after plugging it in in the pits, but you can't do that with a mechanical system. Even if you could spin it up in the garage, it would slow down by the time you have pushed it to where it needs to be tested. It's the case for our system as well that the amount of storage you need to work well on the track is not that much – maybe 300kJ – but that is not enough to pass the pit lane test, so the flywheel is sized for the pit lane test and is only just big enough to do that. Any bigger and it is just dead weight, as it is already oversized. It is not the same problem for a battery car because they are power limited rather than energy limited. So the battery is sized by the power requirement and the capacity is many times bigger than required.'

"capable of delivering 100kw in either storage or recovery"

Even before this discovery, the pit lane test had thrown up another issue, as Hilton reveals: 'This is where the devil is, in all of this detail. The first time we tried to run the pit lane test, when the driver hit the engine kill switch it turned the Bosch ECU off and, in turn, the throttle pedal signal, so the KERS didn't work! It's these small simple things that you need to resolve. You can't just put one of these systems on the car and have it working in 10 minutes. It's not plug and play, it's not easy, it's hard-won data and proper engineering, and it's not free!'

It is for all these reasons that hybrid racecars are genuinely difficult to develop, claims Hilton. And what happened at Le Mans this year bears this out. Of the three hybrids scheduled to run at the test day, only the Flybrid-equipped ORECA took to the track. Zytek's petrol / electric hybrid did not leave its garage and Peugeot Sport's diesel electric 908 was withdrawn ahead of the event.

The Hope Racing-run Hybrid ORECA 01 took part during the test day and completed 22 laps, the first time a hybrid has taken part in official running at Le Mans since the Zytek-developed Panoz Q9 in 1998. It was also the first public run for a car equipped with KERS developed by Flybrid but, with the development work that has gone into it, it's looking likely not to be the last.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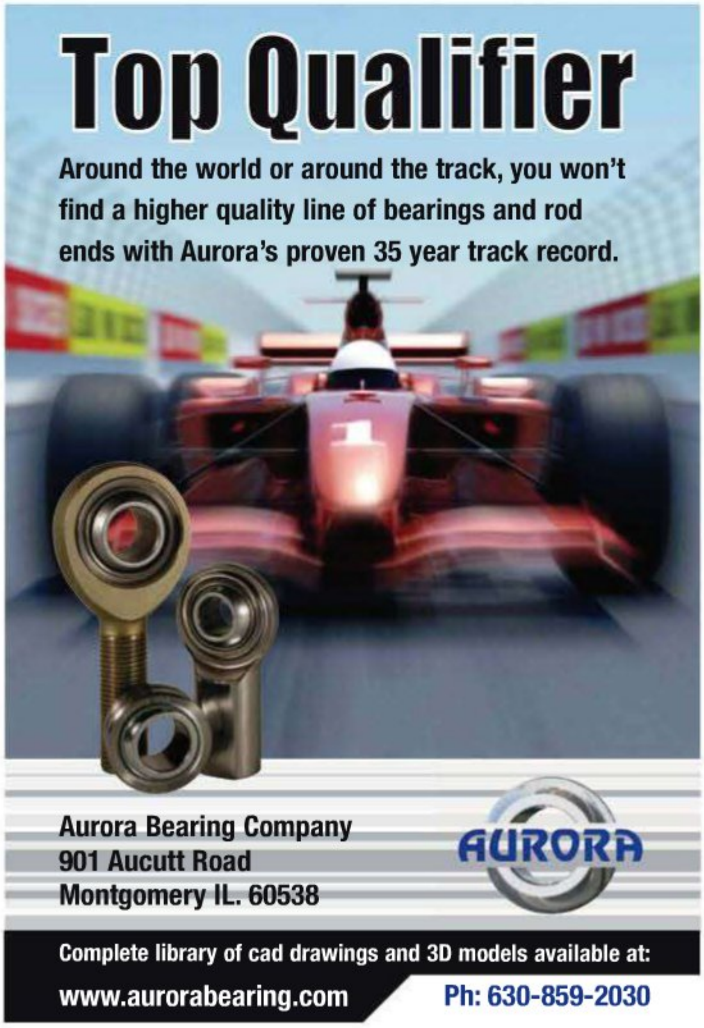
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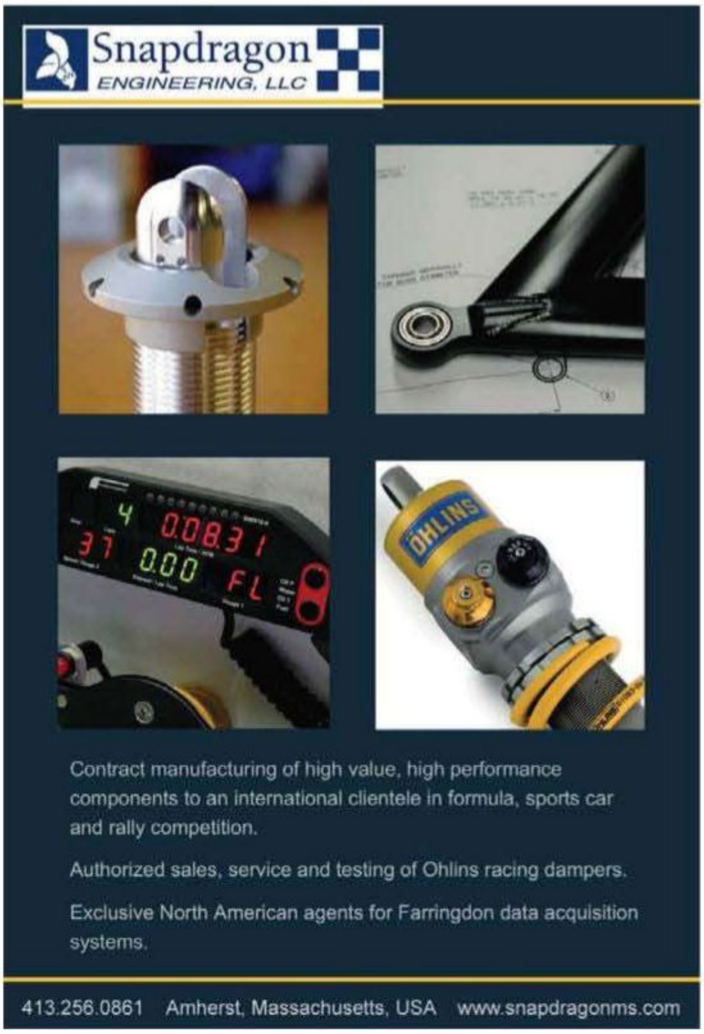
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The original development mule was a long travel Rally Raid damper, but since then the technology has been developed for applications in other forms of motorsport

Speed bumps

A revolutionary new method of energy recovery, utilising dampers as the power source

BY LAWRENCE BUTCHER

Tucked away just east of the French port of Marseilles, near the Paul Ricard circuit, a small damper consultancy company, PKM Consulting, has developed an energy recovery system that is a major departure from the powertrain-based set ups that have found favour in recent years.

Until now, the few systems present in racing have focused on the recovery of energy generated by the forward motion of a car, normally through a direct connection to the engine or transmission. There has been a lot of talk regarding recovery of thermal energy from engines but a viable system has yet to appear, and packaging in a motorsport application still presents many problems. PKM's system takes a more lateral approach to the energy recovery process – instead of recycling wasted energy from the powertrain, it harnesses the kinetic energy generated as the car's wheels move over bumps.

The first seed of an idea was sown while the company was developing a damper system for use in the Paris Dakar rally, in competition with another damper manufacturer. After several days of testing under exceptionally harsh conditions, a decision was made to assess the ultimate reliability of the heavy duty units. This was to be achieved through setting the dampers to provide maximum damping, and then running them to destruction. Raphael Venu of PKM takes up the story: 'After 20 minutes there was so much temperature in the damper that we thought, "why are we not doing something with this energy?" And from there we began to imagine ways that we could recover this energy.' Once they had returned from the desert, the team of engineers set about devising a way to harvest this potential energy source.

> “harnesses the kinetic energy generated as the car's wheels move over bumps”

Two key design parameters were identified. Firstly, any system needed to be able to generate power without compromising the primary role of the damper. Secondly, there could not be any significant increase in weight or packaging requirements that would negate any power gains.

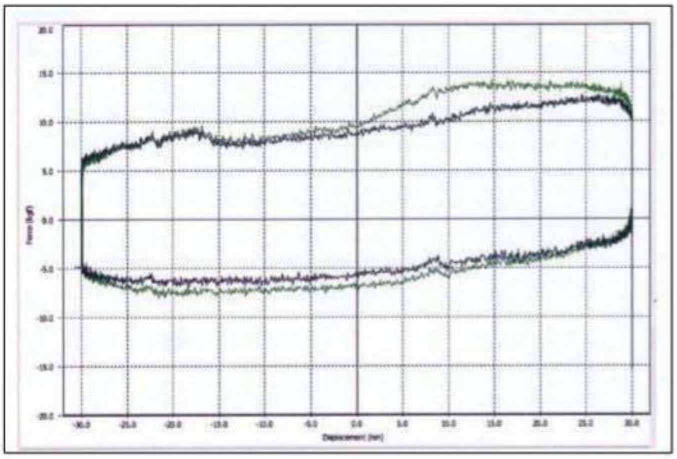
The majority of modern suspension dampers (excluding such curios as friction plate units) create resistance to suspension movement by utilising a piston that moves through a viscous fluid. This resistance is then varied through the use of either adjustable valves or pre-set shim packs to control fluid flow through the face of the piston. The team realised that the displacement of this fluid could be used to generate power, with the key being to develop a system that harnessed this while not altering the damping performance or response rate.

The device PKM settled on is based around a system that diverts the damping fluid through a small hydraulic pump during compression and rebound strokes. This pump is linked to a small electrical generator that, in turn, is mated to the parent vehicle's wiring harness.

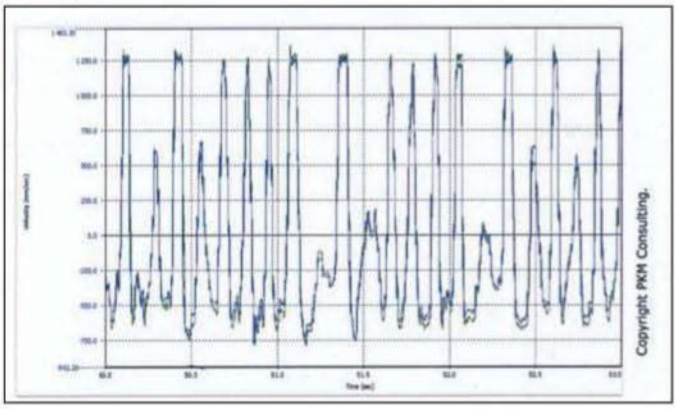
SCIENTIFIC EXPERIMENTATION

With the method of generating electrical power decided upon, the engineers at PKM did not just dive straight into producing hundreds of different iterations in order to refine what had by then been dubbed the 'Powershock'. Instead, the company based its methodology firmly in scientific experimentation. Venu: 'We began to design the product and, after designing the first prototype, we signed a contract with a French university to produce a mathematical model. This would allow us to understand where we would be likely to find problems with the product. Our methodology is science based. Rather than start with prototypes and make and re-make them, we prefer to create correct mathematical models to find the problems and then find solutions in order to gain efficiency and performance. After this point we were clear. Yes, we will have some modifications in production, but that is to be expected.

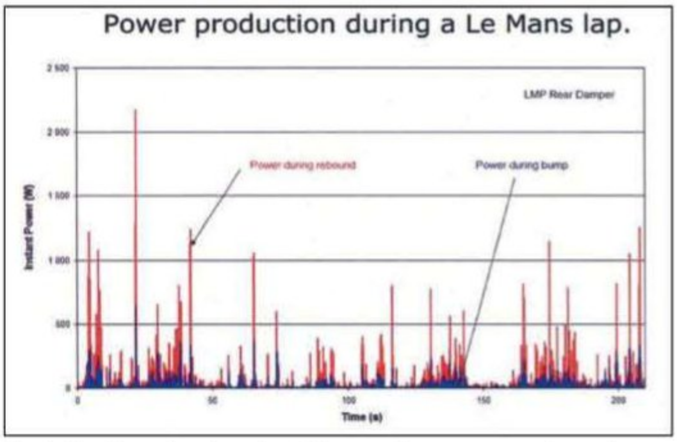
'We developed the first prototype for a specific vehicle type and data set.' And for that first iteration of the system, the company looked to its recent Rally Raid experience, basing the prototype on the requirements of a desert racer. The reasoning behind this was there was a large amount of data on the Rally Raid set up already available, allowing for direct performance comparisons between old and new. The core areas addressed with the first prototype were fourfold: efficiency and performance of the system in terms of hysteresis; ease of adjustment of the damping properties; the spectrum of adjustment available and the packaging requirements. Happy the proposed system would work, the design of the prototype was finalised and the technology patented, before an extensive test programme was started on PKM's in house Roehrig damper dyno. This enabled the company's engineers to fine tune the unit for maximum efficiency and to tie down key parameters for future versions. 'With the results that we gained from that first damper we were then able to validate and modify the mathematical model. From here, we were able to start doing computations to develop the next generation of the system.' explains Venu.



PKM worked hard to ensure the Powershock did not increase hysteresis in the damper fluid due to the addition of a hydraulic pump and generator



Even with the added complexity of the fluid routings in the hydraulic pump, the Powershock retains the same response rate as a standard damper



Simulation shows the planned LMP damper will generate up to 2Kw of power instantaneously, with a useful level produced throughout a complete lap

PKM's Powershock has won a number of awards, including the illustrious 2010 Autosport Engineering Show Best Technical Innovation award

POWER LEVELS

During testing with the Rally Raid-based prototype, power levels of up to 2KW were achieved without affecting the normal operation of the damper. In real world terms, this would allow for the majority of a vehicle's lighting system to operate on the power supplied by the dampers, greatly reducing the load on the on-board alternator, and its consequent load on the engine.

Obviously, in the case of a desert racer, the magnitude of the suspension travel is considerable, whereas for circuit racing applications the degree of movement will be much smaller. However, PKM has run a number of simulations on the proposed second generation Powershock, which show impressive power levels could be generated on much shorter travel units. 'Our target is preparing for the 2011 LMP1 regulations relating to cars with hybrid powertrains. So we are looking at the whole spectrum, from Rally Raid to LMP cars. For LMP cars it is obviously not the same damping levels, or packaging requirements.' PKM's engineers say that so far, results on the LMP-type damper are encouraging. The simulation (left) for a single damper during a lap of Le Mans shows that a useful quantity of power can be produced – up to 1.5KW during certain damping events.

With the ACO tweaking its regulations to allow energy to be recovered from the dampers, combined with the fact that a car would need a minimum of modification to fit the units, this new technology could prove very attractive to teams unable to resource a full hybrid system. Equally, it would provide an extra source of power on a vehicle running other energy recovery systems, without compromising the overall package.

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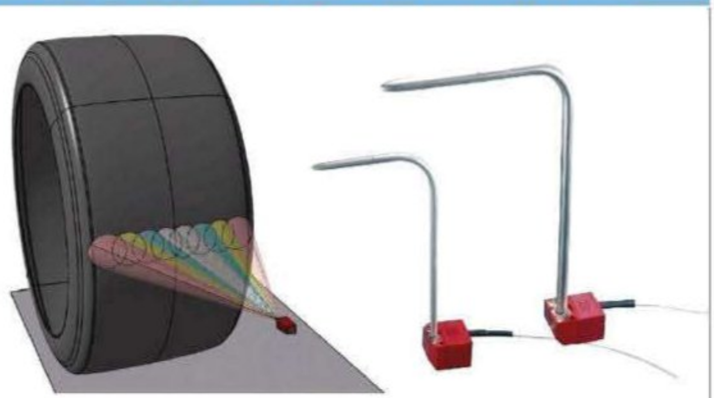

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Climb every mountain

'Silhouette' regulations often produce some great racecars, and this FIA European Hillclimb contender is definitely one of them

BY SIMON MCBEATH

The immensely popular FIA European Hillclimb Championship is dominated on pace by ex-Formula 3000 chassis and by single and two-seat sports racecars. But while these cars are restricted by technical regulations, there is another group where technical freedoms are greater and where outright pace can be pretty amazing. This is Group E2-SH, the 'silhouette' class.

In recent years German motorsport engineer, Georg Plasa, has campaigned his Rennsporttechnik BMW 320 E36 Judd V8 to a string of successes in this class. And the car was immensely quick. At the April 2009 Rechbergrennen (the Austrian Mountain Grand Prix), for example, the winning Reynard 95D clocked a best time of 1m59.523s, while Plasa's BMW stopped the clocks just 4.992 seconds slower.

CUTTING EDGE CONCEPT

But what to do next? Plasa explains: 'I hate to repeat things I've already done, so the new car had to be more sophisticated and cutting edge, and include things like a transaxle gearbox, less weight, better weight distribution and lower c of g. Because modern cars tend to grow from one edition to the next, neither an E46, nor an E92, nor any hatchback E87 were options. Furthermore, very complex (read: heavy) suspension systems are commonly used nowadays, so a double wishbone arrangement appeared logical. And I wanted to stick with more or less 2700mm wheelbase. Then the E82, the 1 series coupé, with a wheelbase of 2660mm appeared…'

All that remained then was to turn a 1 series coupé 'shell into a racecar and install the Judd V8 again. So this is where the story really begins.

It's clear from the outset that this is one very sophisticated racecar, but then so was its predecessor, so how did Plasa develop the concept for the new car? 'One of my ideas was to recruit young mechanics and engineers to give them the opportunity to realise themselves and to get experience. We all should do this in time to avoid all our experience and knowledge getting lost. At a later stage HABO Engineering became a partner, so CAD design with Catia V5 and FEM calculations also became possible.'

'CAGE FIGHTER

A visit to recruit Avon tyres as a crucial partner set the project in motion, but the first physical tasks were the preparation of the shell and the construction of the rollcage. In-house engineer, Matthias Roeger, mapped the interior of the bare bodyshell using a Faro laser-digitising arm to provide the design space in which the 'cage could be created in CAD. The aim was nothing less than 'the ultimate CAD design of the 'cage and the mounting points.' The rollcage design was structurally modelled using finite element analysis, but only to attain the requisite homologation certificate from the German ASN.

The complex tasks of generating the scanned data and doing the CAD design, which was performed by automotive engineering student Eva-Verena Ziegahn, and the construction of the 'cage by fabrication experts Lockid, all took longer than expected. But Plasa expressed himself very satisfied with the outcome in terms of weight reduction and safety, commenting that 'on the national and international mountain race tracks, there will be a few cars with such a perfectly

The ex-ALMS LMP2 3.4-litre Judd KV V8 was chosen for its compact dimensions as F3000 engines were not for sale

> “with five litres residual fuel, target weight is 780kg, according to the rules”

With a wheelbase of 2660mm, the 1 Series BMW coupé offered the perfect body shape to replace Plasa's previous E36 BMW

manufactured rollcage.'

The car's strict diet was also applied to the 'shell, from which an astonishing 144kg was removed, so that the 'shell with 'cage and most of the carbon body panels, including paint, weighed in at 206kg, 52kg less than the bare production 'shell.

AERODYNAMICS

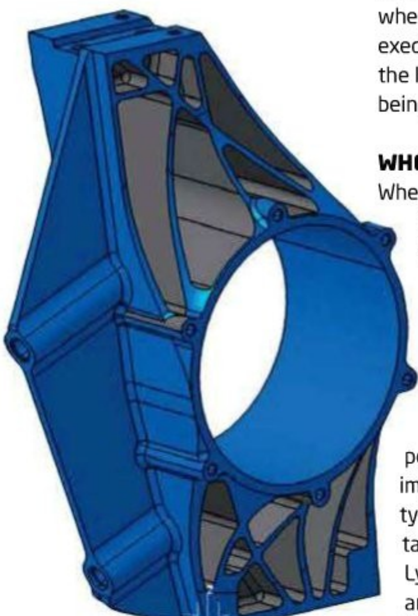
Meanwhile, a second 'shell was set up at Flossman Auto Design, essentially as a full-scale model on which to design, manufacture and fit the body panels and downforce-inducing appendages, and Flossman produced all the external panels in vacuum consolidated CFRP sandwich construction. The team, aided by Flossman, designed its own aerodynamics, some of which was based on that developed on the E36 racecar.

'Thanks to a good friend we have been able to use a wind tunnel at BMW, and we gained many ideas during about 60 hours of testing on the E36,' remarked Plasa. So the 134 became superficially similar to the E36 in exterior detail, but a 10-hour session in the wind tunnel towards the end of the build in late December 2010 showed that the 134 was already at the level of its predecessor in terms of downforce and efficiency (2900N at 160km/h, or 100mph and -L/D greater than 2.0). Nevertheless, Plasa candidly added, 'we always struggle for more front downforce. At the rear it's not so much a problem to just add more wing, drag not being so much of an issue on hillclimbs.' So we can expect to see further development at the front end, and more wind tunnel time was planned for late April 2011.

In outline, the car features a sizeable front splitter with front diffusers beneath, a flat underside, double rear diffusers and a dual tier rear wing assembly with upper dual element and a lower single element sections. Details include front wheelarch louvres, exits behind the front wheels, rear wheelarch flip ups and neatly executed front radiator ducting, the latter (and the engine airbox) being the work of KVH Hartung.

WHEEL SYSTEMS

When it came to the suspension, Plasa again brought his experience to bear on the design, which he alone performed utilising Win Geo software from Bill Mitchell, together with Catia to create the geometry. 'I realised at a very early point in the design how important it would be to obtain tyre data to set the correct targets. So my thanks to Mike Lynch at Avon, who organised, among other things, dyno runs with our tyres at different slip and camber angles and supplied us with all the data.'



Win Geo and Catia were both used to design the all round double wishbone suspension, which uses modified E36 magnesium front uprights and fabricated rear uprights. Adjustable coilover dampers are by KW Automotive

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Plasa also employed his own theories regarding dynamics and roll centre heights: 'In brief, the requirements I believe are right for the European hillclimbs are that the suspension should only be as stiff as necessary, and that you should have good dampers and good frequency control.'

The front uprights were adapted from the E36's magnesium STW units, but the team couldn't find anything 'off the shelf' for the rear that incorporated the required wheel bearing hub assembly, plus they had their own ideas concerning caliper position, caster and weight. So HABO Engineering was contracted to design the rear uprights, which it optimised using FEA for minimum weight and strength before machining them from aluminium. All four fully assembled uprights complete with bracketry amount to less than 25kg.

Interestingly, the brake system uses non-ventilated carbon ceramic SICOM discs, in spite of the course lengths and multiple braking events. But, as Plasa explained, 'cooling isn't an issue because of the materials used and the relatively low weight of the car.

'We also use a Teves competition ABS system and regularly achieve up to 2.4*g* longitudinal on the bumpy and commonly low friction public road surfaces where European hillclimb events take place.'

A healthy ongoing relationship with damper supplier, KW Automotive, was another important part of the 134 project, and Plasa paid glowing tribute to the company's support. As well as supplying bespoke, three-way adjustable, 'upside down', lightweight struts, the team was also able to make use of KW's seven-post test rig to optimise settings.

Plasa: 'We initially used only four posts but, thanks to the wind tunnel data we collected, we could run with the fifth post, and then after the pre-season test at Verzegnis in Italy, with numbers six and seven, which enabled track data replay. This is really cool technology for a hillclimber!' Indeed, but was this not an expensive exercise?

Having used BMW's own wind tunnel to develop the previous car's aerodynamics, this information was used as a baseline for the new car. Carbon composite exterior body panels were manufactured by Flossman Auto Design

Fabrication specialist Locklid built the 'cage, which was modelled using FEA and features CAD design work by engineering student Eva-Verena Ziegahn

Plasa's response reflected the benefits of most kinds of simulation: 'We chose this "in-house" solution because in two days of methodical testing we achieved what would have taken a week of track testing, with all the associated costs that would have involved. So in fact we reduced the costs, avoided the environmental impact and saved time.' And, he may just as well have added, the testing was carried out under uniform conditions, too.

> **"One of my ideas was to recruit young mechanics and engineers"**

DRIVETRAIN

The engine choice was governed by Plasa's wish to install an F3000 unit, which obviously offers fairly extended rebuild intervals, even in terms of European hillclimb events, and ultimately by the dimensions of the Judd (Zytek) compared with the other options. 'Only the Judd was small enough at its front end because of water pumps and so on to avoid clashing with our suspension pick-up points,' Plasa continued. 'The Cosworth and Mugen engines were too wide. But because of the FIA leasing contract at that time, which was to avoid extra testing by the F3000 teams, the engines were not for sale. Then an option to buy a 3.4-litre ALMS LMP2 engine came up. Two weeks later I was at Engine Developments Ltd in Rugby, UK, and thanks to Barry Smith at EDL the story started.' Running without air restrictors and mapped on a MoTeC M880 ECU, rather than the EFI Euro 6, the engine now makes somewhat more power than in its original Sportscar guise.

After a successful 15-year relationship with Hewland Engineering, it was natural that this company would be Plasa's first choice for the new car, too. The TMT was selected because of its ideal torque capacity to match the Judd KV, its crown wheel and pinion height, the overall weight (which is 42kg with the magnesium casing option) and the integral semi-automatic selection capability, which, Plasa reports, 'works brilliantly with our MEGA-line automatic gear shift system.'

The car utilises the same version of the MEGA-line system as the Audi R15+, the OEM II system, not the simpler but heavier 'family' system. The combination of gearbox and semi-automatic shift system was expected to produce gear change durations of just 25 milliseconds.

Another long-term partner who made a special contribution to the project is the Compton Technology Group (CTG) who, as Plasa explained, 'did a brilliant job of making a two-piece CFRP propshaft that can deal with the permanent high revs arising from the rear transaxle arrangement.' Drexler lightweight tripod driveshafts are employed in the last leg of the drivetrain.

ELECTRONICS

Bavarian aerospace electronics support company, Stock Flight Systems, was contracted to create the on-board electronics control and communications hardware and software. Plasa: 'Michael Stock's self-developed software package, with proprietary hardware-based operating system, is implemented on multi-processor architecture, and provides an extremely high data transfer rate. Any control command or sensor value will be processed in real time via the central gateway computer to the respective controllers and components with the appropriate scaling, so that the signal input to control output is achieved in under one millisecond! The origin of this technology lies in the company's main field of operation in aerospace. Now they have established the practice in motorsport, offering both performance and reliability.

'Stock Flight Systems tested the 'gateway computer' in the laboratory to simulate extreme operating conditions, and among other things a heat soak test was carried out for several hours at 80degC (176degF). The gateway computer manages the communication of CAN buses in the car. This allows us to link all the systems such as the MoTeC ECU, the data logger, the dash display, the MEGAline gear shifter, the Teves ABS, the steering wheel and an almost unlimited number of additional components to each other and to exchange data.

'And all this with, in simple terms, four cables. This saves on weight, brings flexibility and reflects the latest state of the art, according to the standards we set for the new racer. Our self-developed wiring harness comprises numerous aerospace quality multi-pin connectors, yet thanks to the CAN technology and to the reduced amount of cable it permits, weighs less than 3kg.'

Even the alternator was a bespoke design. 'My old friend Hans Lehner of Lehner Motoren Technik built the alternator,' said Plasa. 'The design is a modified version of a generator used in the military field in UAVs. It provides 40 amps output, is 70mm long and weighs just 450g (1lb).'

It will be evident by now that every component was pared down to the lowest weight possible, in order to achieve the ambitious target weight of 780kg. Plasa: 'In the summer of 2009, when the project was conceived, our specification included the simple sentence, "with five litres residual fuel, car weight 780kg, according to the rules." Every effort was then made in terms of weight, weight distribution, safety, materials to be employed and questioning of each component in detail, even with simple screw connections.'

The end result was actually 748kg. 'For a race car of this type, moreover, a private hillclimb team, this seems unimaginable. So much tension and stress has paid off,' said a proud and obviously very relieved Plasa.

FIRST RUNS

Early April 2011 saw 134 Judd rolled out at Verzegnis, northern Italy, for testing. A few days later, the first round of the FIA European Hillclimb Championship took place at Col St Pierre in southern France where Plasa won his class. Typical of an experienced designer / constructor, though, Plasa expressed a degree of disappointment afterwards:

'I wasn't really satisfied but that's normal if you have to develop a car when you're used to having better results...

'Nevertheless, I was not far from the times of the old car, so that's not too bad after a short time.' Immediately afterwards, Plasa started on the updates: brake pads; discs and master cylinder; rear springs; gearbox set up; differential set up; front anti-roll bar; front camber; traction control and gear ignition cut mappings, plus some minor aero upgrades.

And you can expect a lot more in the months to come from this spectacular racecar.

TECH SPEC

Class: FIA European Hillclimb Championship E2-SH

Chassis: Modified BMW E82 1-series coupé 'shell, CAD-designed, 25CrMo4 rollcage

Body: Flossman carbon composite

Engine: Judd KV

Configuration: V8, 90 degree

Capacity: 3400cc

Valves: 32

Power: 565bhp at 10,250rpm

Torque: 410Nm (302lb.ft) at 8250rpm

Clutch: Sachs 5.5in triple plate pull-type

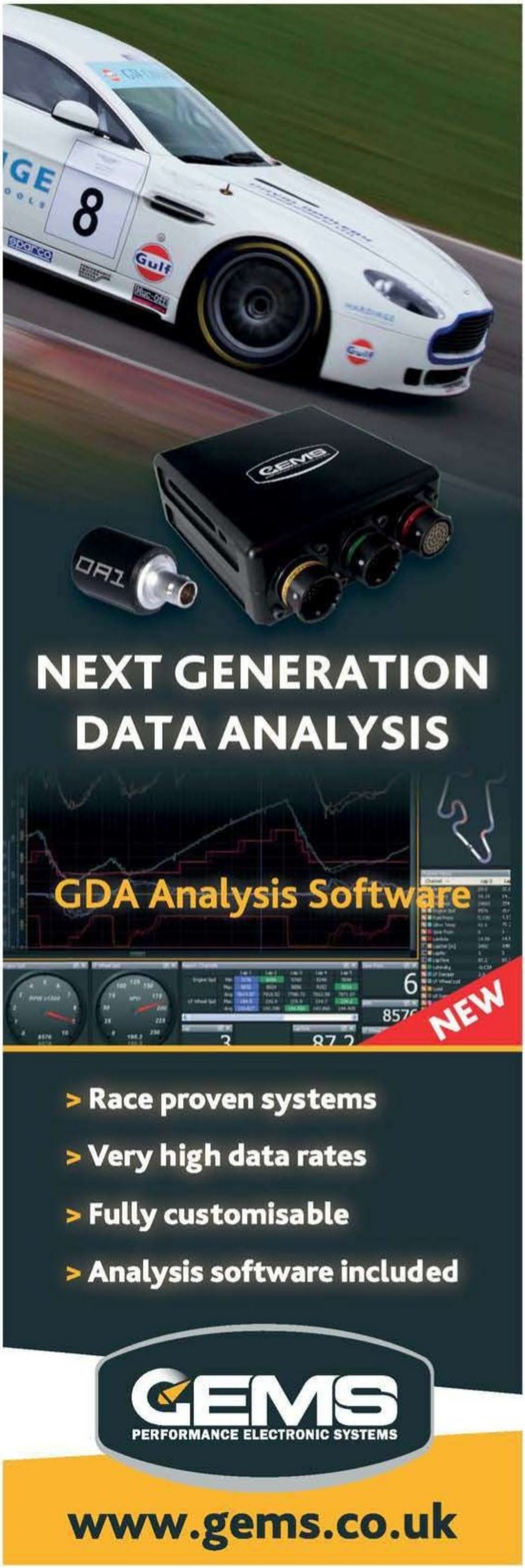
Exhaust: Inconel, 8-1

ECU: MoTeC M880

WATCH THIS

To see more of this incredible, home-built racecar visit www.racecar-engineering.com

Aerospace electronics specialist, Stock Flight Systems, was contracted to create the on-board electronics control and communications hardware and software, which links to a MoTeC M880 ECU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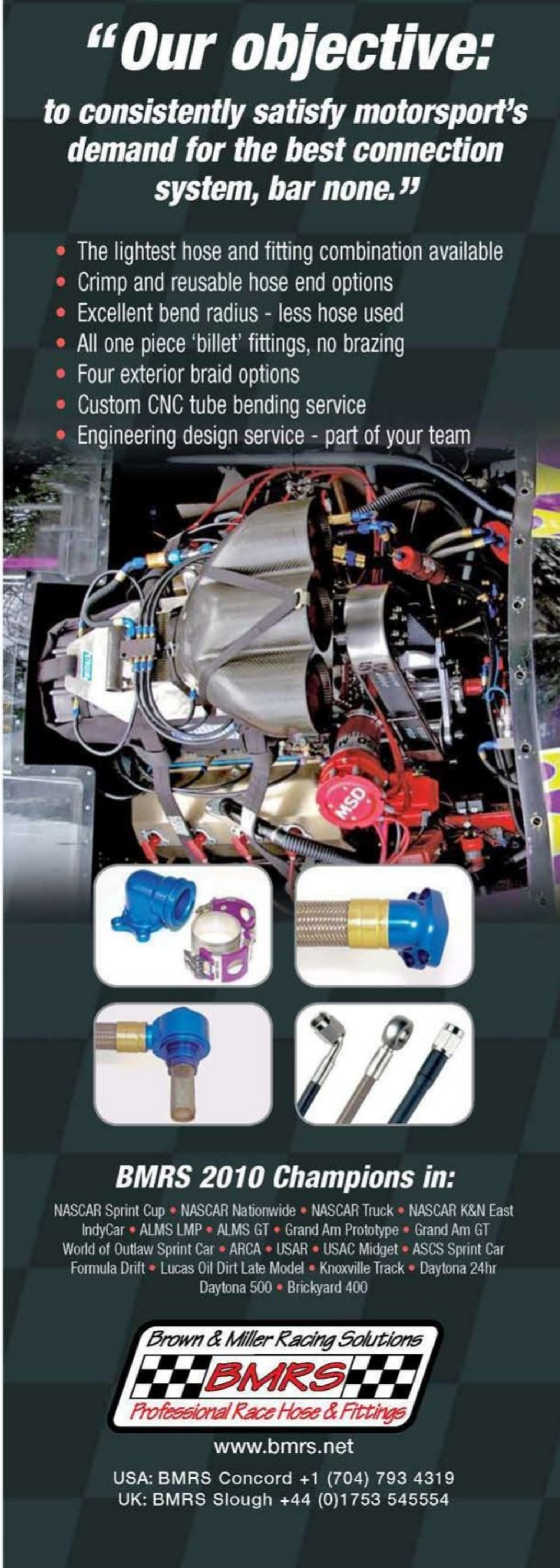
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IndyCar 2012

The unveiling of the two new concept cars provoked mixed reactions, but most found at least something they liked amongst the new ideas on show

BY IAN WAGSTAFF / COLLINS

Shortly before the 100th running of the Indianapolis 500, two very different looking cars appeared at the famous Speedway. It was the first time the racing world had been given a chance to see the new-for-2012 Dallara IndyCars, and the response to them was fascinating.

The two concept cars were built up around real 2012 monocoques or, as they are described by IndyCar, 'safety cells'. Immediately obvious is the wider cockpit, bringing the new car closer to FIA standards – something IndyCar is very keen on – and giving a clear indication of one of the main design objectives, namely improving safety.

Around the rear of the cockpit aperture, energy absorbing EPP (expanded polypropylene), the same material used for headrests, is used. Behind the driver it is 3in (76.2mm) thick, underneath it is 1.5in (38.1mm). The monocoque construction beneath the driver has full sandwich construction of carbon, honeycomb and carbon. 'When there is open chassis competition, it is usual to have a recess in this area that is just carbon, but for us safety was the number one priority,' explains Andrea Toso, Dallara's head of R and D, the man who headed up the 2012 IndyCar programme.

> the current car, fully equipped, costs around $700,000. The new car will be $385,000

The tub also features an enlarged anti-intrusion panel that runs from the front bulkhead to the engine bulkhead, protecting the fuel cell, a substantial increase on the current versions.

Impact protection is also increased, with the roll hoop conforming to the same crash test loadings as current Formula 1 cars, which represents a 40 per cent increase over current cars.

PEDAL-OH!

At the front of the tub, only two pedals are accommodated, the throttle being drive-by-wire and the clutch being steering wheel-mounted, as is common practice with European single seaters. 'It means more room for the driver and less risk of the feet getting trapped in the event of a crash,' reasons Toso.

But it is not a view everyone subscribes to, Ganassi engineer, Andy Brown, suggests that it may actually hinder drivers who right-foot brake: 'The trouble is that these [pedals] are rather large, and spaced well apart, like some automatic gearbox American road car. And this has the right-foot brakers (especially Dario Franchitti) rather worried, as trying to get across from one pedal to the other is going to lose them a lot of time.

'I'm told that this is for safety reasons – less clutter down there – all very commendable but, in the interests of pleasing the great and almighty "spec racecar" gods, the teams aren't allowed to

The two new chassis that were rolled out at Indianapolis Motor Speedway wore two proposed aero kits - one for street circuits and one for the high-speed ovals

change the pedal arrangement. It would be very easy to incorporate the option for current-style brake and throttle pedals, then have a smoothly moulded 'dead pedal' on the left side. That's just as safe [especially considering there's going to have to be a dead pedal on the left side anyway so drivers can brace themselves in fast turns without riding the brake pedal with their left foot].

'The powers that be seem very intransigent, though. Why are two smaller pedals with the brake offset more to the right less safe? Shouldn't IndyCar be trying to build up this series, not doing its best to drive away some of the star drivers?'

The safety theme goes beyond the tub, too. Both of the new concepts feature wider bodywork. Indeed, all of the concepts produced by the various rival bids did, and this is designed to prevent interlocking wheels in side-by-side racing and reduce the high speed aerial accidents that have dogged IndyCar for a number of years.

Will Phillips, vice president of technology at IndyCar, is keen to point out that the aero kits are not the final designs, and that the series' organisers are still listening to all suggestions

A great deal of thought has gone into the design of the sides of the car to try and prevent cars rolling or taking off when they slide sideways

> **Safety was the first priority, cost the second, styling third**
> **Andrea Toso, Dallara**

'Another key aspect of safety is the aerodynamic stability,' adds Toso, 'so we have designed the underwing and the shape of the car so that when a driver loses control and the car starts to slide sideways, the tendency to roll over and fly up into the air will be reduced.

'Also, when you run over a piece of debris the car will go up in the air and we have to minimise this. We have devoted a lot of time to analysing this to reduce this tendency. It is something the fans do not see.'

Will Phillips, the newly appointed vice president of technology at IndyCar, reveals that, despite these measures, more could still be done to keep the cars grounded. 'There's concern that a couple of Peugeot 908 LMP1s have flown recently (see p35). Why did that happen? And what were the circumstances? It is hard to get that sort of information. Yet there is a car with the latest thinking the FIA safety commission could generate.

'Communication with Dallara is open almost daily. There is concern that, as we generate large amounts of downforce in the tunnel, what is the effect when you go backwards? Does it make it worse? Do we need to put flaps in tunnels? Or a NASCAR flap? These things are not there yet but we are open to suggestions. Things could be added even after the car has been launched. We are still constantly working with Dr Terry Trammel, looking ahead on safety.'

> **wider bodywork... designed to prevent interlocking wheels**

'The second priority was cost,' reveals Toso. 'We had a stringent target from IndyCar that the current car, fully equipped, must cost around $700,000 (£430,000). The new car will be $385,000 (£237,000).' To achieve this, a large number of components on the car will be spec, including the radiators, radiator boxes, the fuel tank and internals, suspension – wishbones and pushrods – the steering, the nose box and the rear attenuator. Notably, the electronic system from Cosworth is designed to suit all the engine installations (currently Honda, Chevrolet and Judd).

CARRY-OVER PARTS

In another move to keep costs down, the wheels, Mega-Line gearshift and dampers can be carried over from the current car. 'They won't fit straight on because the eyelets might be different,' said Phillips. 'There might be a couple of changes in the shaft lengths and things like that, but the bulk cost and investment that a current team has in its damper inventory will be able to be carried over. If one team currently has every damper available, that will help with cost. You can't get away from a historic carry over like that.

'It is a great opportunity for the small teams to invest in their engineering resource to try and compete with the bigger teams. A team is about a group of people. It is all about the personnel. If you don't invest in them, it does not matter what product you are going to get.'

The rest of the suspension will be spec, with Dallara supplying all components, but it is designed to give teams scope to tune the cars. 'It will have a lot more adjustability than the old one, in terms of being able to achieve the right cambers, ride heights, roll centre options and geometry options,' reveals Phillips. 'A lot of thought went into listening to what the requests were, and also what is realistically achievable. Within one gearbox, for example, there are a given number of pick ups that you can use, but it is the intention it is all stock Dallara parts. Understanding how the car works within its aero maps – that is where the performance will come to start with, as well a picking the right engine.'

A reduction in the inventory of new parts will also help keep costs down, and this thinking shows up all over the concept cars. The Brembo carbon brake package is a good example of this, with the same calipers and discs used for both road and oval courses (at the moment steel brakes are used for road courses and carbon for the ovals). A maximum of two sets of discs and pads per season is now all that will be needed.

Likewise, both the speedway and road course cars share the same nose box structure (the current car has two separate specifications), and the rear impact structure follows a similar single version concept.

'What we want is that the first thing that fails when you are hit from behind is the front wing of the following car,' says Toso, 'otherwise you can go crazy, you push and you damage the car in front. The second thing to fail is the side structure, the third the big wing and the fourth thing is the attenuator. This is what we call progressive deformation.'

Perhaps unsurprisingly, this very restricted specification, where teams can only really change the seatbelts, steering wheel, dampers, wheels and maybe the wing mirrors, has attracted criticism from some of the teams.

'There are a few things that I disagree with about the whole concept,' argues Chris Mower, Panther Racing's team manager. 'One of these is that Dallara will produce everything. I think this is a bad thing for the series, and for competition. It allows them to

rake us over the coals. We have seen in the past that parts we were only able to purchase from Dallara have been expensive.' However, it may be argued that as much of the supply will come from Dallara's under-construction facility in Indianapolis, the costs will reduce.

VISUAL IDENTITY

One area where teams and manufacturers will be able to do very different things is the bodywork, with its controversial aero kits. 'At the end of the priority list came style,' says Toso. 'It has to be different. It has to please the fans.'

The fans had demanded different cars, but the ICONIC group decided not to leave the comfort zone of spec racing. They did, however, agree to allow the teams and manufacturers a visual identity, as Phillips explains: 'Wings, bargeboards, sidepods, sidepod extensions, the engine cover, all those kinds of bit and pieces of kit will all be within the realms of the aero kit. It's often perceived as just one configuration, but that isn't correct.

'The aero kit will allow the car to run on a super speedway, a short oval and a road or street course. You obviously might need more front downforce if you have a big road course wing on the back, so you will generate that with either end fences, flap extensions or the flaps themselves. Those are the kind of items that could be within that aero kit.'

A number of firms have expressed interest in supplying these kits next season, including Lotus, General Motors, Honda and ORECA, but the team owners have not been all that receptive.

> **"the pedal layout could force some established drivers to retire"**
> **Andy Brown, Ganassi**

In fact, at the start of the season, the team owners voted against introducing the kits in 2012, and the topic is still hotly disputed. 'I hope, especially following the public outcry against the team owners voting not to have manufacturer-funded aero kits next year, that we see more developments along these lines,' says Brown.

'The body kits are needed in order to sustain the fan interest and build this series back up to where it should be. As different as the new cars look now, after a few races with 20 or so of them all looking the same as this, interest will soon fade.'

Others are not yet clear on the scope of adjustment the teams will be allowed to make with the aero kits, as Ganassi engineer, Julian Robertson, reveals: 'If IndyCar allows you to change the body kits as much as the show cars have in terms of differences, giving room for such as sculpting end plates and sidepods, that will be a good thing.

'But if they hammer it down so there are only limited things we can do, it will not give us much scope to make a difference with the body kit.' The cars rolled out at Indianapolis had two different sets of bodywork fitted to them, one an outlandish road course package, the other a far more realistic speedway kit. It was intended to show the teams what could be done with the new car, but it elicited a very mixed response: 'They could have done a better job with the appearance and aesthetics of the car,' complains Mower, 'but if it works, and if it looks like that because it is going to work, then fair enough. If a car comes on the market and is ugly but then performs well and meets all the criteria, people start to think it is a nice looking car.

'I would like them to have gone more down the road of a modern F1 car. Those cars do have a lot of downforce and they would look a lot different to the cars we run at the speedways. I think an F1 car these days is a work of art, not only through performance but also appearance.

'I know what they're doing with regard to a lot of the bodywork they have added on – the big wheel flips that they have and the big pods behind the wheels. That is all for reducing the drag and improving straight-line speed. But the back of the car looks almost like a Group C Sportscar, or a street legal open-wheel car. I am not going to make a judgement on it until I know how it performs, but when the current car came out a lot of people thought it was ugly, especially with the raised sidepods going up towards the outer sides of the car.'

One thing that is certain is that Dallara itself will not supply an aero kit in 2012, only a default body for the car. 'We will supply the first body,' reveals Toso. 'At some time, I do not know when and it is not my decision, IndyCar will open the doors for new aero kits. Teams will then be able to buy other kits and use theirs or ours. It could be that Dallara will eventually design and manufacture an aero kit for somebody else, but not for

Teams will eventually be able to run cars with their own visual identity through the aero kits. When they will be able to do so is open to discussion

AIR BOX

One thing that caught many by surprise was the appearance of an air box, as opposed to the now traditional open roll hoop. Andrea Toso, Dallara: 'It is not really an air box. Inside, yes, there is a duct and a filter, and past the filter it will go to either the single turbo or the twin. So really it is an engine inlet.

'We had to find a common location for the three new engines. IndyCar has set rather free rules for them, so there could be a single or a twin turbo, and among the three manufacturers they will exploit both. To get air for the turbo, you could do this at the side or at the top but, if you do it at the side, it will be close to the fuelling receptacle, which would be dangerous if drops of fuel get into the inlet. So we thought the safest place would be to put it at the top.'

Pods behind the rear wheels are intended to improve straight-line speed, but give the cars an air of Group C Sportscars

COMMENT

'I am surprised to see the air box because they have made it look like a Formula 1 car again, while I thought the idea was to give more the identity of an IndyCar. The traditional IndyCar was a turbo with no air box but a roll hoop, which distinguished the body lines. This is not very exciting and the lines are very simple.

'I can understand the brakes being spec but I am not so sure you can make carbon work financially. If it is a very hard, low grip carbon set then it is possible that you will be able to get the mileage out of it. Theoretically, the idea works, but as carbon gets hot it eats itself, so on a road track you can just gobble your way through carbon. On an oval though they are very safe.

'I am also surprised by the clutch mechanism. It just seems an expensive piece to mandate onto the cars. It is a very exotic system for an F1 car, so I am surprised they are building an automatic clutch into a spec car. I am also disappointed by the paddle shift, as any time you make another step between open-wheel racing and NASCAR, you make it more difficult for the NASCAR drivers to drive an IndyCar, or vice versa. I really do not see the point of it. I think it makes the race quite boring because the cars are becoming easier and easier to drive.

When the cars were exciting to drive, the good drivers were able to overtake the poor drivers, though they could still qualify further up the grid. Then, during the race, the good drivers would always come to the fore. Now you get processional races because the poorer guys can maintain the race pace but they cannot overtake, so they block and the good drivers are stuck.

> **I think this fashion of making the cars easier to drive is what is hurting the race**

'I think this fashion of making the cars easier to drive is what is hurting the race. It is a shame to keep quoting NASCAR, but those cars are difficult to drive and they put on a good show.

But I do think most of the safety elements really make sense – wide cockpits to get the drivers out, anti-intrusion panels, I like all of that.

'I have more of an issue with making the engine benign, the aerodynamics, the paddle shifting and making the car easy to drive. The engine needs to have loads of horsepower and the tyres do not necessarily need to have lots of grip. The aerodynamics need to be difficult – not flat bottoms, but just pitch sensitive so that you need a real expert to drive them.

'I do wonder how they are going to do this bodywork performance thing while still containing the costs though. If they were to have a template, as in NASCAR, with about three different styles, then it is the series that is doing the development not the manufacturers.

'I think they are doing exactly the same as CART did with the Panoz. They promised everyone it would be a different type of racecar and it ended up being just a different *shaped* car to the one that it replaced.'

Bruce Ashmore, Ashmore Design

2012 as it would not be fair. It could be for 2013 though.'

For the time being, the issues surrounding the introduction of the aero kits remain unresolved, and Phillips explains that when the dust has settled a decision will be made: 'I cannot give you an answer as to when the alternative aero kits will be used. Randy Bernard will make an announcement when it is the right time.

'Right now he is making sure he is listening to all sides of the argument. Then it will be up to IndyCar to issue the rules as we see it right for progress. Not everyone is happy with every decision – of course they never will be with any regulations – and the fans must have an important vote, too. Ultimately, IndyCar needs to do what is right for the future of IndyCar.'

INTERESTING FEATURES

'They have some interesting aerodynamic features that will hopefully make the cars more raceable on the ovals that are an important part of our product,' enthuses Panther Racing chief engineer, David Cripps. 'Going forward, I would like to see more of what we are seeing in F1, with the adjustable wing and KERS. I am a big believer in any kind of energy recovery, and it would be hard to argue that the adjustable wing system has not had an effect on F1.

'An adjustable flap could be a problem on the ovals, but I think you should have an adjustable front wing for them. The adjustable flap would be ideal for the road courses. More toys to play with on the car makes it a far more fascinating and challenging project and gives the drivers more to adjust.'

But, as well as looking across the Atlantic, both Toso and Dallara hope the looks will be exchanged in the other direction, too. 'I hope the FIA in Europe will catch up and adopt some ideas and the concept of this car. It is still open-wheel, open-cockpit, but it has brought to the table new concepts. I really hope the Europeans will look at it.'

That remains to be seen, but the concept could have particular resonance in classes like Formula 3. Watch this space.


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How to establish a test programme

What should you really be considering when you're testing?

How should you go about testing? I've worked both as a race and data engineer, and also as a simulation engineer and developer, so feel that I am in a pretty unique position to offer a perspective. In a lot of cases I have only had track data to work with and, if you're smart, you can get quite a bit out of this.

The purpose of this article is to share with you the lessons I have learned from this and outline what I consider to be some important boxes you need to tick when establishing a test programme for yourself. I also want to outline some of the pitfalls you should try and avoid when preparing for an upcoming season.

BY DANNY NOWLAN

Too often I have seen people sorting through data that tells them nothing whatsoever about the car. The two biggest traps that people fall into are:

1) You get so wrapped up in topping the timesheets during testing that you forget to run the car through a number of different set up options to build a complete picture of what the car is actually doing. The corollary of this is that if everyone does this and the car is really weird, you wind up in an engineering dead end.

2) You spend a fortune on test programmes that are completely useless and give you very little real and tangible information about the car's capability.

We are going to see that if you do a little bit of forward planning, you can actually tell quite a bit about the car from the data you amass.

The first step, believe it or not, is to read the racecar manual and / or measure up the racecar, then determine the downforce the car is running. Most racecar manufacturers should give you some indication of the level of downforce, but if you don't have this you can always approximate it from the data. I am going to talk about this in great detail shortly, but initially you want rough ballpark figures of downforce (CLA), drag (CDA) and aero balance.

Once you have an idea of the aero, your next goal is to come up with a rough approximation of the range of lateral load transfer distributions you are going to deal with. For this you need to know your suspension geometry and your different combinations of springs and bars. This will give you a rough idea of the load envelope of the tyre you need to be testing on. Effectively, what you are looking for is to populate a spreadsheet that looks like table 1, shown right.

You don't have to reproduce table 1 in its entirety, but it gives you a tool that tells you all the possible tyre load situations, and this will tell you what to try when you test your tyres. We will discuss this in detail shortly.

The next step in this process is to calibrate your sensors properly. This might sound an incredibly obvious thing to say, but I have seen testing reduced to nothing because the data acquisition system wasn't taken care of properly.

Make no mistake, this is a critical area on any racecar and you have to stay on top of it. There are no exceptions to this, so don't skimp or cut corners. If you do that, it will come back to bite you.

Table 1: sample of a spreadsheet that returns lateral load transfer at the front with estimated tyre loads

Roll centre front (m)	-0.0254
Roll centre rear (m)	0.0445
Front weight distribution (%/100)	0.43
Front tyre spring rate (N/mm)	260
Rear tyre spring rate (N/mm)	290
Front spring rate (lbf/in)	1300
Front bar rate (N/mm)	1738
Rear spring rate (lbf/in)	1300
Rear bar rate(N/mm)	500
C of g height (m)	0.3
Front track (m)	1.63
Rear track (m)	1.529
Mean track (m)	1.57243
All motion ratios are damper / wheel	
Front motion ratio	1.03
Front roll bar ratio	0.5869
Rear motion ratio	0.8696
Rear bar motion ratio	0.621
Front main spring wheel rate (N/mm)	241.5285
Front roll bar wheel rate (N/mm)	598.6569
Rear main spring wheel rate (N/mm)	172.1603
Rear roll bar wheel rate (N/mm)	192.8205
rcm	0.014443
hsm	0.285557
rsf at spring	840.1854
rsr at spring	364.9808
rsf at tyre	198.5558
rsr at tyre	161.5993
Prm	0.567072
Roll distribution (%)	**48.94622**
Weight transfer calculation	
Car mass total (kg)	712
Car speed (km/h)	113
Lateral acceleration (g)	2.3
CLA	3.2
Air density (kg/m^3)	1.225
Aero distribution	0.43
Total aero force (kgf)	197.0525
Front aero force (kgf)	84.73256
Rear aero force(kgf)	112.3199
Total lateral force (kgf)	1637.6
Static load front (kgf)	195.4463
Static load rear (kgf)	259.08
Load FL (kg)	348.3707
Load FR (kg)	42.52183
Load RL (kg)	418.5891
Load RR (kg)	99.57079

AERO PROGRAMME

After we have done our prep work, we then need to consider whether we require a proper aero test programme. As a rough rule of thumb, if the CLA obtained from either the manual or your hand calculation is greater than, or equal to, 1.5, you have to do an aero test programme. Again, there are no exceptions to this.

I would love to say just read the racecar manufacturer's manual and you'll be fine, but I have lost count of the number of times exploiting an oddity in the car's pitch sensitivity has literally meant the difference between winning and losing. It's that simple.

How in depth you need to go will be determined by your simulation correlations to your data when you shakedown the car. This is an example of why, at least as far as I am concerned, if you are not using lap time simulation, you are committing professional suicide.

If your damper displacement correlations are close throughout the speed range then you don't need to do pitch sensitivity testing, but often you won't be that lucky. So during aero testing you should also log the following:

- Vehicle speed, rpm, gear and accelerations
- Damper displacements (take this at the damper)
- Strains (if you have them)

I know this is obvious but I thought I'd mention it anyway.

When doing your aero testing, your goals are as follows:

- Start with a nominated front and rear wing and appropriate ride height. Take this either from the racecar manual or experience
- Determine the ride height sensitivity map by sweeping the ride heights
- Once you have done this, return to the nominated ride heights and sweep the wings

Bear in mind you might very well have to do this depending on the wing configuration options you have available. As a rough rule of thumb, if there are jumps of CLA of 0.3-0.4 between the different configurations then it's a good idea to do it.

That said, if time is at a premium, formulate the pitch sensitivity map on the configuration you will use the most. This is not ideal but it will be enough to get you by.

The most important job you are going to do in aero testing is constructing the front and rear ride height sensitivity map. You can be forgiven a multitude of sins if you get this right.

When we run a racecar and resolve the forces on the data you obtain a thin sliver of the aeromap. This will look something like figure 1. Our goal is to collect as many of these slivers as possible. When we are done, we are after a plot of front and rear ride height for all our different slivers that look like figure 2. Effectively, the more points you have in figure 2, the better the aeromap is going to be.

The way we are going to do this is to walk in with a test programme then, after each run, look at the data intelligently. The test programme I will run will resemble that shown in table 2.

These ride heights can be in any units the user wants, though my personal preference is in mm. The ride height deltas are going to be car height specific (on an open wheeler or Sportscar, this will generally be about 5mm, while Touring Cars are usually around 10mm). The best way of determining the appropriate delta is to compare damper or strains from run to run. Start small, then increase the delta until you see about 1mm worth of differential damper displacement. That will determine your delta. As with anything in life, the more you do it, the better you will become at it. It should also go without saying that you should not run your car into the ground.

It's important during this process to review the data in between sessions. In particular, you should be looking at the inferred ride height channels. Ride height can be inferred by the following approximation,

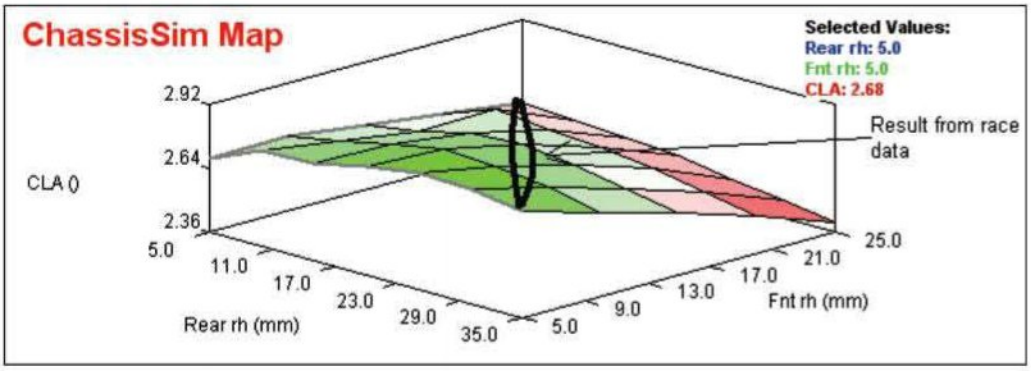


Figure 1: the section of the aeromap you obtain from race data

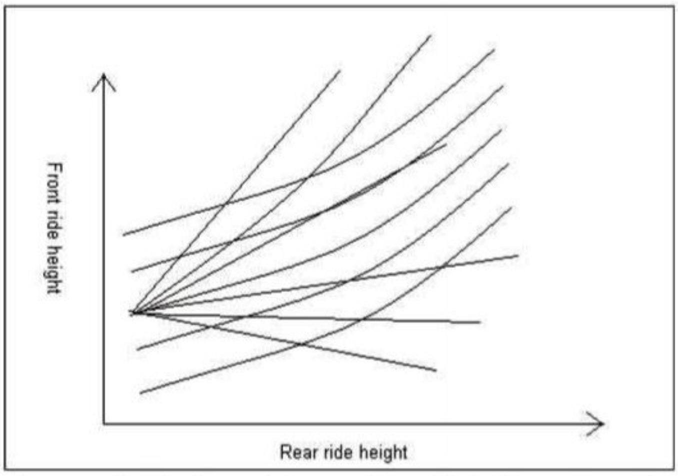


Figure 2: what the locus of front and rear ride height maps needs to look like for aeromapping

Table 2

Test No	Front rh	Rear rh
1	frh0	rrh0
2	frh0	rrh0 + del_rrh
3	frh0	rrh0 + 2*del_rrh
4	frh0	rrh0 + 3*del_rrh
5	frh0	rrh0 - del_rrh
6	frh0	rrh0 - 2*del_rrh
7	frh0 - del_frh	rrh0 + del_rrh
8	frh0 - del_frh	rrh0 + 2*del_rrh
9	frh0 - del_frh	rrh0 + 3*del_rrh

Where,
frh_0 = initial front ride height
rrh_0 = initial front ride height
Del_frh = delta of front ride height
Del_rrh = delta of rear ride height

(1)
$$F_S = \left(k\left(x_s\right) + c\left(\dot{x}_s\right)\right) \cdot MR$$

(2)
$$w_m = \frac{F_S}{k_t}$$

(3)
$$d_i = \frac{x_{s_i}}{MR} + w_{m_i}$$

(4)
$$rh_f = rh_{f0} - \frac{d_1 + d_2}{2}$$

$$rh_r = rh_{r0} - \frac{d_3 + d_4}{2}$$

where,

F_S is the force of the spring damper unit at the wheel

x_s and $\dot{x}_s$ is the movement and velocity of the spring

k is the spring rate or function

c is the damper rate or damper function specified at the damper

MR is the motion ratio of the spring expressed as damper / wheel movement

d_i is the total movement of the corner of the car

rh are the relevant ride heights

To make thing easier on yourself, zero the dampers on the ground. The point of this exercise is so that every time you do a data run you do an xy plot of front and rear ride height. This will give you a snapshot of what you have just done. Alternatively, you can use simulation tools to do this for you. The important thing is to actually look at it so you get an idea of the section of the aeromap you have categorised.

In terms of the practicality of doing this, you can either do runway testing or at the track. Runway testing is ideal but, if you have to do it at the track, it's in and out laps only. In my experience, it doesn't take very long for racecar drivers to get bored and team managers to get grumpy doing this. Also choose a circuit with a long straight (say, 400m and above).

The next step is to reset the car to the nominated ride heights and sweep the wing settings. I generally sweep the wings to the drag polar specified in the racecar manual as it saves you time coming up with a test matrix. It also cross checks what's in the manual. If it hasn't been specified in the manual, I concentrate on sweeping the rear wing, and then add or subtract from the front wing appropriately. That is, if I add two degrees of rear wing, I add two degrees of front wing, and vice versa. This gives you your true drag polar.

Before we leave the topic of aero testing, let us quickly discuss coastdown testing. There are some who are adamant about performing these tests, but my personal view is if you can test your engine on a rolling road dyno, you only need to do this step once to get a snapshot of the aero drag and rolling tyre resistance. Once you have this, the rest can be back calculated from engine power. If you don't have this, I would recommend one coastdown to calibrate your engine losses. If you don't do a lot of coastdown testing, though, it's not the end of the world.

TYRE TESTING

Now that we have the aero side of things out of the way, it's time to focus our attention on the tyres, and our first port of call here is camber testing.

What we do in this situation is set the racecar to the recommended set up and sweep the front and rear camber. How do you determine the deltas you sweep in? Again, this is where a bit of simulation comes to our aid. To illustrate this, consider the plot of cambers for a given lap shown in figure 3.

If you know what camber variation you are looking at, you can plot the deltas you are looking for. To really focus on the effects, I would suggest doing the camber sweeps in isolation. This way, when you compare run to run you can see immediately what is affecting the lateral and longitudinal grip. This also allows you to refine your deltas. A rough rule of thumb here: if you make a change and the change in lateral acceleration is very large, back off the delta.

This information is invaluable for determining camber sensitivity and invaluable for populating this curve. If you are dealing with an open wheeler / Sportscar, use 0.2 degree deltas, Touring Cars use 0.4 degrees. However, the operative word here is a *rough* rule of thumb.

TYRE PRESSURES

Our next area of investigation is tyre pressures. This is often overlooked, yet it is critical in determining tyre temperatures and tyre spring rate. This is what I would do: start with the manufacturer's recommendation and log the data. Advance the front tyre pressures by one psi and log the data. When you're comparing the data, pay close attention to the lateral acceleration and steering trace and, if you can trust them, what the driver has to say. Then repeat the process for the rear. I would love to claim credit for this, but

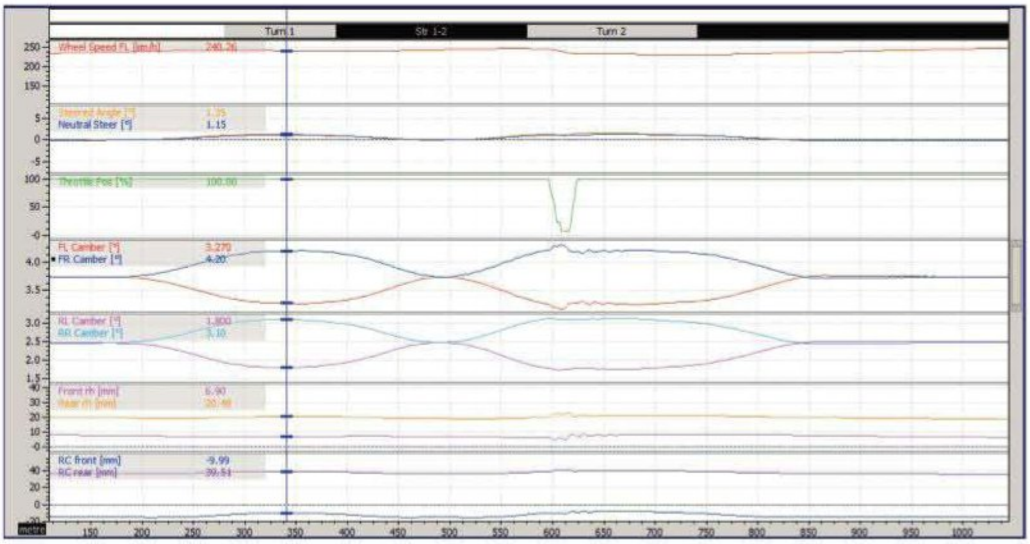


Figure 3: plot of simulated camber

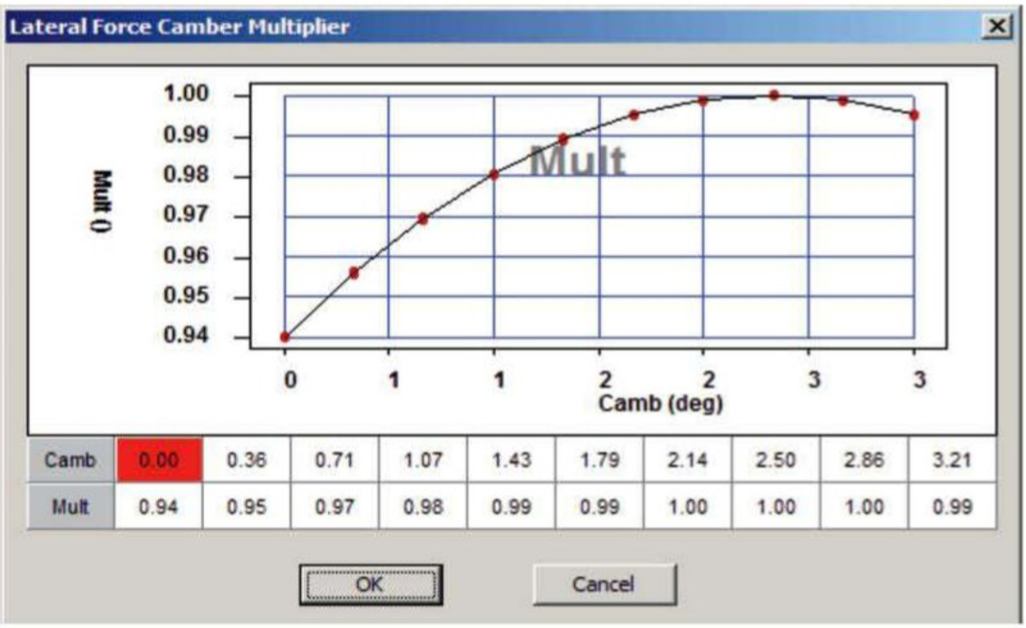


Figure 4: lateral sensitivity vs camber

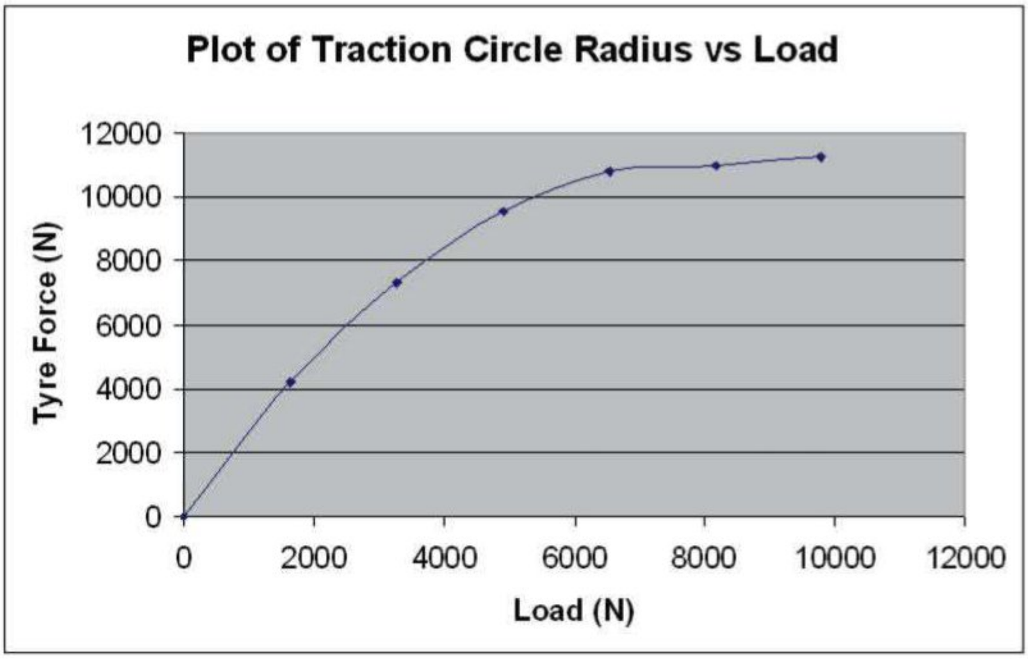


Figure 5: traction circle radius vs load characteristic

this is something a former boss of mine came up with and it worked really well.

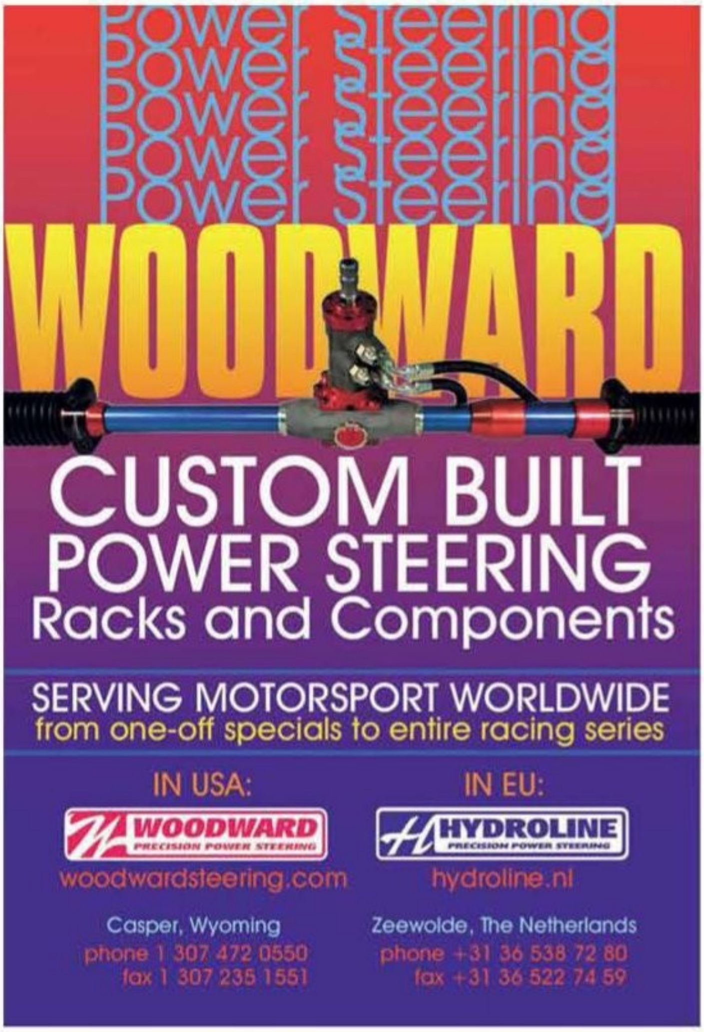
The last step in the process is to throw as many bars and springs at the car to get as much load variation as you can. This is where table 1 comes in again, because what we want is to collect as much information as possible to fill in the maximum traction circle radius vs load characteristic. This is illustrated in figure 5, below left.

When it comes to tyre modelling, you can be a forgiven a multitude of sins if you get this right. This is why we need the lateral load transfer analysis in table 1, because the more load variations we throw at the car, the better idea we are going to have of what the car wants. Also remember, this curve isn't just a simple square function. Due to temperature effects, it can be highly non-linear. With this method of testing we are going to capture this, which is invaluable information.

Once we are at this point, you'll have the information you need to go chasing lap times, regardless of the situation you find yourself in. You can now use simulation tools to reverse engineer the tyres and aero. Alternatively, you can use the techniques on tyre and aero modelling that I've discussed in recent issues and do it manually. Then, you will be in a strong position to know what the car is going to do in a multitude of situations. I also guarantee, once you have this knowledge, your racecar simulator will be transformed into a powerful asset.

CONCLUSION

In closing, preparation and attention to important details is what wins races. The whole point of testing is to learn about the things that count with your racecar. What I have outlined here came as a direct result of being in the trenches and having to tally up what we have seen from the data to the virtual world and understanding why. A friend once said to me, 'if I supply you with both the why and the how, you can cover yourself for any situation'. This is what these techniques will do for your knowledge of *your* racecar.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The F1 scandal

Recidivists, repentant or rehabilitated?

PAUL J WEIGHELL

As mooted in this column a short while ago, the flotation of Williams has not seen a vast rush to push the team's value though the roof. In fact, it now seems it has lost some 20 per cent of its value since the launch and has not been a rosy path for investors.

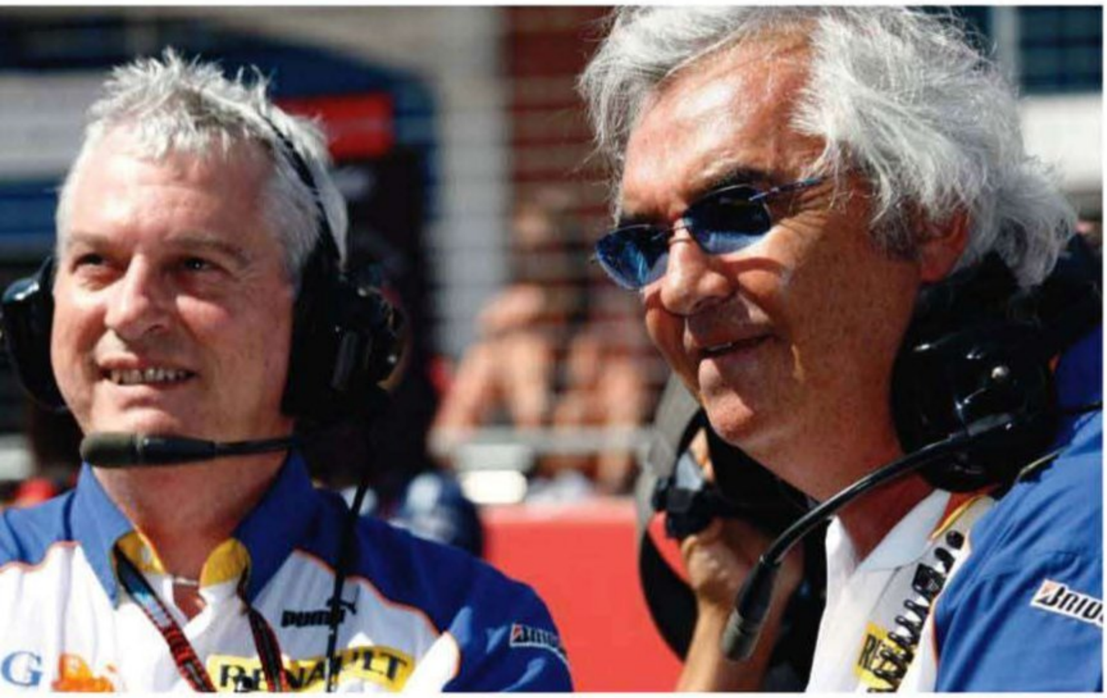
The winter optimism about Williams' performance seems to be late in reaching the track and, as no doubt you are all aware, a number of key people are to leave the team totally, coincidentally, we are told.

More worrying for the longer-term value of Williams, not to mention its sponsorship profile, is a dubious face from the past – one Mike 'please dear, nip down to the copy shop with this stolen Ferrari dossier' Coughlan has been hired.

Williams is not alone. Virgin has recently employed Patrick Symonds as a consultant. He has been in place for a few months, in a post that seems dangerously close to the 'operational role' that he, and other members of the 'F1 Four', are currently barred from. Surely, a consultant who is available at the team on a day-to-day basis to suggest changes that can then be implemented is like any other sort of operational worker? Yet seemingly the FIA don't see it this way.

The FIA states that both Symonds and Briatore recognise their share of responsibility, have expressed their regrets and presented their apologies. Presumably then, they are now deemed rehabilitated. If such convenient rehabilitation works, then perhaps Briatore will eventually oust Sir Frank Williams? A straw poll search of the 'net yields that Briatore in particular would 'not be welcome', and here I have paraphrased public opinion for reasons of language modesty.

The FIA has mooted the addition of a 'fit and proper person' test, but seems not to



Two of the 'F1 Four', Pat Symonds (left) and Flavio Briatore, both now rehabilitated and working in Formula 1 again...

Manufacturing boost for UK

Postgraduates studying for doctoral research degrees in manufacturing at the University of Warwick, UK will soon have an added facility at their disposal, following the decision by one of the university's academic departments, WMG (formerly Warwick Manufacturing Group), to install a seventh machine tool from longstanding technical partner, DMG. The five-axis machining centre, a DMU65 monoBLOCK, will be the first in the UK from this German manufacturer to be fitted with carbon dioxide (CO^2) cooling. The continuous stream of refrigerated gas can be used in place of the more usual fluid coolant to flood the machining area at the point where the cutting tool meets the metal work piece. Roger Bull, technical and facilities officer at WMG, commented, 'Advantages of the technology when machining titanium and other exotic alloys include less contamination of the work piece, better surface finish, longer tool life and the ability to use elevated cutting feed rates to enable higher productivity.'

Composite expansion

Carbon fire composites manufacturer, epm:technology group, has launched an in-house R and D and evaluation department, designed to provide expert and tailored technical solutions for its customers. According to epm, who supply composite components to Formula 1 teams and high-end automotive brands, the facility represents a significant step towards transforming UK composites into a more commercially driven sector, with huge implications in terms of cost efficiency and long-term business prospects.

'Composites are a cutting-edge business that attracts cutting-edge customers, but too often development is focussed too much on perfecting the science and not on realising the commercial potential. It's the difference between making things, and making things happen,' says Graham Mulholland, the company's managing director. Epm's philosophy is that, if composites are to take the next step into mass-market usage, it will require the major players in commercial industry, such as aerospace or automotive, to transform existing processes into scaleable production models.

have implemented it yet. It may be in the next Concorde, but will it be retrospective and weed out unfit persons already employed?

Besides, as the Football League seems to have found, it is not easy to administer such a test. A report in *The Guardian* newspaper highlighted the fact that the 'owners' and directors' test' of the Football League says it is a 'disqualifying condition' for a director of a League club to be 'subject to a suspension... from involvement in the administration of a sport by a sport's governing body'. Briatore is serving out just such an FIA ban – on a voluntary basis no doubt – until 2013 and so should presumably not be an owner or director of a Premier League football club. Yet Companies House details showed Briatore as a director of Queens Park Rangers at the time *The Guardian* printed its report.

President Todt has curtailed all ongoing legal proceedings in relation to Briatore and Symonds because the media coverage was judged to be prejudicial to the image of the FIA and motorsport in general. How much more prejudicial though is allowing the cause of the problems back into the sport? The media coverage already given to the return of Coughlan and Symonds cannot be much less bad publicity than that given to the dry legal wrangles over FIA rights to administer its own sport and serve life bans on the employees of licence-owning teams, as well as its current right to serve such bans on the licence-owning teams themselves. One can apparently ban an entire team for the actions of its employees, yet the employees can remain largely unscathed and then go on to join other teams. One wonders how much one could charge for wrecking a team simply by being there and committing grave acts against their interest? (The editor has my contact details for any such offers!).

> **Who would not say 'I repent' for the chance to return?**

Surely Williams and Virgin both have a duty not to bring the sport into either direct disrepute or indirect disrepute by creating a resurgence of bad publicity through reminding people all over again of the 'regrettable incidents'.

McLaren was, of course, not so lucky. Despite its official announcement, made by Whitmarsh not Dennis, that it has no problem with the employment of Coughlan, one suspects Ron Dennis must be fuming to see someone who cost his company $100m in FIA fines returning close to the scene of the scandal.

In the author's view, it does not say much for the sport's image governance that repentant miscreants may return. They may have served their time, but the stakes in F1 are so high that it can only prompt others to make the cold calculation of the risk of being caught and banned for a few months against the kudos of a championship win? Who would not say 'I repent' for the chance to return? A short sabbatical in NASCAR does not seem much of a penance for the quite staggering nature of the SpyGate and CrashGate offences.

Both Williams and Virgin might like to consider that they are publicly traded companies, with shareholders and sponsors who value business image and company reputation at least equally to on-track performance. If a public traded company hires senior people with widely known reputations for cheating, then those companies should not later complain if their sponsorship income or share price suffers as a result.

Amber light for Honda

Amber Composites' materials have been chosen for extensive use in Honda Racing's British Touring Car programme, and the companies have signed a long-term technical supply agreement. Team Dynamics, who prepare the Honda for racing, are using Amber's pre-preg technology to reduce weight in critical components of the car. Advances have already been made in areas such as the front bumper, the splitter and the floor structure, which sits below the engine bay and extends underneath the driver. 'Our partnership with Amber Composites represents the beginning of a long-term plan to use composite technology in a wide range of parts. Amber's involvement as our sole supplier of composite materials brings a number of important advantages to the programme, including technical support and advice, speed and volume of supply and, most importantly, quality of product. We look forward to working closely with Amber now and in the future as we implement a number of important developments on the car,' commented Peter Crolla, team manager at Team Dynamics Motorsport Ltd.


Pre-preg composite parts feature heavily (lightly?) on the BTC Hondas

BRIEFLY...

Porsche profits increase
Porsche Automobil Holding SE has once again posted impressive profits during the first three months of the 2011 fiscal year. Post-tax profits for the group totalled 691 million euros ($976m), thanks mainly to development of its Porsche and Volkswagen investments.

Cloud 8
Platform Computing, a leader in cluster, grid and cloud management software, recently announced the latest versions of two tools designed to help HPC administrators and IT managers. Platform RTM 8 and Platform Analytics 8 are intended to maximise efficient use of resources in HPC data centres. For more information, look up www.platform.com

Engineered for Racing
Turbo Dynamics has been announced as the official UK and European distributor for Borg Warner's new EFR range of turbochargers. The EFR, or 'Engineered for Racing' turbos have been designed to be capable of high boost levels with extreme durability, while also providing rapid response at low boost levels.

Engineering insurance
Markel, a UK insurance company specialising in offering business insurance for professionals, has launched a new 'direct to market' brand, aimed specifically at engineering businesses. The new brand will allow engineering companies to rapidly arrange employer's liability, public and product liability, directors' and officers' liability, office buildings and contents and business interruption insurance policies. For more information look up www.markeluk.com

continued...

More friction at Bremsen

All Porsche Supercup cars run brakes supplied by bt Bremsen

Brake friction manufacturer, TMD Friction, has formed a new high performance and racing division. Following the takeover of bt Bremsen Technik GmbH (bt Bremsen) in 2010, the company is now combining the high performance and racing activities of TMD Friction and the subsidiary bt Bremsen, under the responsibility of Olaf Schwaier, who was appointed managing director of bt Bremsen in February of this year.

Responsibility for motorsports activities has now been transferred to Michael Spuckti, the new director of motorsports at bt Bremsen. The objective of the increased commitment is to further expand TMD Friction's leading position in the field of high performance brake pads. And for the first time, the brake friction manufacturer is presenting its own racing team this season, in cooperation with German-based GT racers, Black Falcon. The team will run as Black Falcon Team/TMD Friction.

Iconic tracks team up with Toyota

Iconic tracks and a new range of vehicle models are combining to enhance the driving simulator at Toyota Motorsport GmbH (TMG), already one of the most advanced on the open market. The simulator now includes accurate reproductions of the Circuit de la Sarthe at Le Mans and the full Nürburgring Nordschleife. The Hockenheim Grand Prix layout and night racing at Marina Bay Circuit in Singapore have also been added to expand TMG's circuit list, which includes the majority of Formula 1 venues.

This unique selection of circuits allows TMG clients to experience these challenging tracks in completely safe and repeatable conditions, and to gain valuable practice at venues such as Le Mans or Marina Bay, where private track testing is otherwise impossible.

Originally developed exclusively for TMG as a Formula 1 engineering tool, the driving simulator has been further upgraded to feature four distinct virtual vehicle models, with F1, GP2, Super GT and Le Mans Prototype car behaviour now faithfully reproduced.

All circuits are created using precise laser mapping, which defines the track surface with an average point spacing of 0.2mm and height accuracy to less than 1mm.

The high resolution, 220-degree, wraparound screen reproduces every aspect of the circuits, including kerb angles, track surface inconsistencies and external factors such as scenery and even sponsor branding.

Using hardware-in-the-loop technology, TMG's driving simulator allows drivers to hone their skills in an environment that is so precise it even recreates wheel-hop frequency at all racing speeds. Engineers, meanwhile, can experiment with set up changes on the cars and receive immediate driver feedback and evaluation.

An accurate tyre model includes thermal effects, which allows precise modelling of balance variation around a lap, with special modes developed for complete repeatability between laps, guaranteeing like-for-like set up comparisons.

To complete the experience, and really simulate the sensation of racing, TMG's driving simulator features a full-size car body, either formula-style or closed-cockpit, mounted to an electro-hydraulic motion platform with six degrees of freedom.

TMG offers individually-tailored packages for use of the driving simulator with a variety of additional options, including full race engineer support and comprehensive data analysis.

RODAC join Team Lotus

Rodac International, The Netherlands-based supplier of pneumatic equipment to the worldwide automotive industry, has concluded a sponsor agreement with the Team Lotus Formula 1 team. For the next three years Rodac will provide Team Lotus with tools and garage equipment, making the company an official supplier to the Anglo-Malaysian Formula 1 team. The new partnership begins immediately.

BRIEFLY...

CRP revamp

Rapid prototyping and composite specialist, CRP technology, recently launched its new, revamped website (see www.windform.eu). The site has been updated to make it more intuitive to use in relation to product information and to help users find the most suitable material for their applications. Particular attention has been devoted to technical and commercial support, with pages where users can find downloadable documents, including technical sheets and details about buying materials.

India charge ahead

Indian-owned Base Batteries has become the official battery supplier for the Hispania Racing Team (HRT) for the 2011-2013 seasons. Colin Kolles, Hispania Racing team principal, stated, 'for us, India is one of the largest growing markets. By signing Narain, who is the number one Indian driver, we expected that Indian companies would support us. We are very proud to announce another Indian sponsor with Base who will help us to move the team forward.'

Max power

Specialist off-road and waterborne vehicle manufacturer, Bombardier Recreational Products, has signed a sponsorship agreement with the Lotus F1 team and the Air Asia GP2 outfit. Each team will be equipped with a Can-Am Outlander Max 800 Limited, which will sport their respective colours and be present at race events throughout the season, where they will be used to tow equipment between the pits and the garages.

THE BUSINESS

2011, and beyond!

CHRIS AYLETT

Motorsport business is starting to look strong again, but diversification is still the key to success

In January, I said this would be an unpredictable year. How true that has proved to be. Although some businesses have struggled, since the last quarter of 2010, many suppliers cannot recall such an acceleration of business, moving from virtually empty forward-order books to the busiest they have seen for years. The major battle, however, has been to secure supplies of materials to meet those orders.

As we enter the planning phase for 2012, everyone is trying to find a reason for this explosion. A sensible business plan for 2012 is hard to create, when this year remains so impossible to understand. Take a look at the growth and enthusiasm in some GT grids and the race series of Ferrari and Porsche, for example. And there have been recent announcements of new technologies in NASCAR, Grand Am, Le Mans and Formula 1, with promises of more to come. All this suggests we have moved from 'doom to boom' in a matter of months.

It would be easy therefore to think the future is bright, but is it? A business can only be cautious for so long. It needs to invest in new machinery to meet demand. New business is still predominantly in the traditional markets of Europe and the USA, but South America is coming on strongly. The problem is, although new F1 circuits are being built in exotic developing markets, very little is then done to build a motorsport business and often these new circuits lie dormant whilst F1 is away. This is not good for motorsport business.

Diversification helps motorsport companies create a more stable base. The MIA has led businesses into defence, marine, aerospace and, recently, into space, too. Most importantly though, into mainstream automotive. Commitment from the UK Automotive Council, with government backing, to a low-carbon future requires new suppliers capable of research, development and prototype building. This is the perfect environment for motorsport. The automotive industry is entering its most unpredictable future, with no certainty as to which powertrain will be the most successful over the next 20 years. Out of this confusion will come business-for-motorsport companies as specialist prototype builders.

> **we have moved from 'doom to boom' in a matter of months**

Automotive OEMs need to test consumer opinion of their powertrain solutions, perhaps needing just 500 to 1000 cars, which is perfect for motorsport companies. This new business, sitting outside mainstream automotive, will be a boom for motorsport, which is why the MIA has become active in this area.

The UK government has announced a £2.5bn Business Growth Fund, in collaboration with the banks, to provide middle market companies with sales between £10m and £100m, with equity investment. The MIA will run its first 'Invest in Motorsport' event to attract investors, who will see the combination of world-class motorsport income, connected to new engineering challenges, as profitable.

The MIA investment event aims to attract investors into the motorsport world to bring added security to great companies as they emerge from this tough business period. If your company could do with a boost to business or some help, do check out www.the-mia.com and join now – you would be very welcome.

Delta Motorsport is testing alternative powertrain solutions in small volume production cars

Choosing cams the easy way

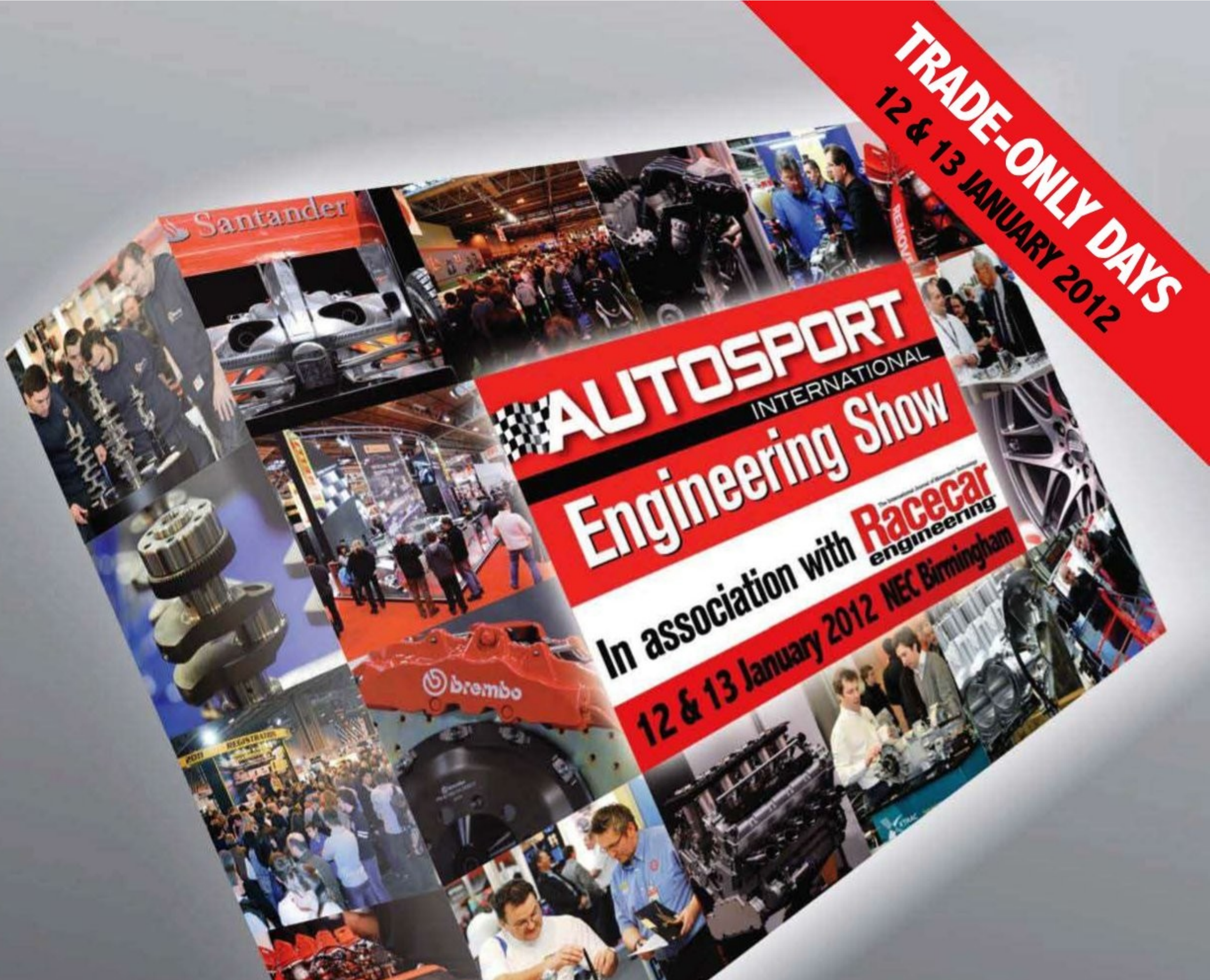
US manufacturer COMP Cams' CamQuest application allows both PC and Mac users to select the perfect camshaft for their engine package, simply by answering 10 application-specific questions. Using straightforward drop-down menus, the easy-to-use, online program then suggests the top matching camshafts based on your application and performance desires. A built-in virtual dyno will even calculate your engine's estimated horsepower and torque, while a print feature displays all this information, including cam specs and 'dyno' results for your records.

CamQuest also suggests matching COMP Cams valvetrain components, such as lifters and valve springs. Once you have found the perfect cam, the program integrates with COMP Cams' online store so you can order everything you need with just a few mouse clicks.

If you need more advanced help, CamQuest also connects directly to COMP Cams' technical support, with either live help or email options

Good thinking, solidThinking

Michigan-based solidThinking Inc has signed Cambridge, UK-based Cadsoft Solutions Ltd to its network of distributors. 'This relationship emphasises the international interest surrounding solidThinking,' said Jim Hassberger, vp of business development. 'Adding a prominent UK distributor such as Cadsoft Solutions to our growing network provides the opportunity to extend our reach within the global design community and highlight how our products can complement the concept development process.'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Exploiting the aerodynamics

Even within the tight confines of IndyCar, there are still detail differences to be seen

BY MARSHALL PRUETT

While the current spec of IndyCar conforms to an incredibly tight set of rules, teams are allowed just enough freedom to experiment with bespoke items like front wing end plates and rear wing mount plates, and to use some of the optional oval package items such as sidepod extensions and rear 'wheel backers'.

Most teams save a special set of 'Indy bodywork' just for the Speedway, which has received weeks of effort to perfect its shape, to fill the smallest gaps and seams and to minimise any areas where air might become blocked or impeded as it travels inside or over the car.

Teams also spend a huge amount of time perfecting the angles of the exposed suspension items, spending time testing up and down long airport runways or automotive proving grounds, doing nothing other than rotating steering arms and sidepod mounting struts in minute increments to find the most aero-friendly angle to use on the super speedways.

For the sections of the body where transitions happen – where the front wings meet the nose, where the radiator blocking panels meet the sidepod and where the front suspension mounts to the chassis – teams use thin and rubbery 'helicopter tape' to smooth airflow and reduce drag. In its thinnest form – about 3mm thick – helicopter tape also helps minimise damage to an IndyCar's carbon fibre body from the inevitable debris that is thrown rearward at over 200mph.

> "finding a few hundredths of a second around Indianapolis makes the time and expenditure here well worth the effort"

With its origin as a pliable tape used to protect the delicate leading edges of helicopter rotor blades, motor racing is a perfect alternate use for the product. But at upwards of $300 (£185) per roll for the highest grade of tape, it is a high consumption item, especially at Indy when it is used every day by every team.

At the front of the spec Dallara chassis, front wing end plates provide the biggest opportunity for teams to produce their own solutions. Most teams simply chose to run with the stock end plates provided by Dallara, but some, like Target Chip Ganassi Racing, have developed their own. While the aero gains may only be minimal, finding an improvement of a few hundredths of a second around Indianapolis makes the time and expenditure here well worth the effort. The front wing end plates are designed to match the wing angle range a team expects to run, which gives a further indication why different teams might choose to produce their own solutions.

Gurney flaps are also open to interpretation, and everything from carbon fibre to old school aluminum Gurneys can be seen up and down the pit lane, in varying size and height. Some teams prefer to use Gurneys with a uniform height, while others opt for ones that are flush in some areas and stand tall in others.

The Dallara's rear wing section is also a place where many detail differences can be found, but those variances are found mostly in the ways the wing is mounted to the chassis.

With teams running their rear wings tilted back as much as five degrees in qualifying, engineers

Front wing end plates are open to development by individual teams and generally match the wing angle range a team expects to run

Rear wing location devices vary significantly from car to car, though the key is ease and speed of adjustability at the track

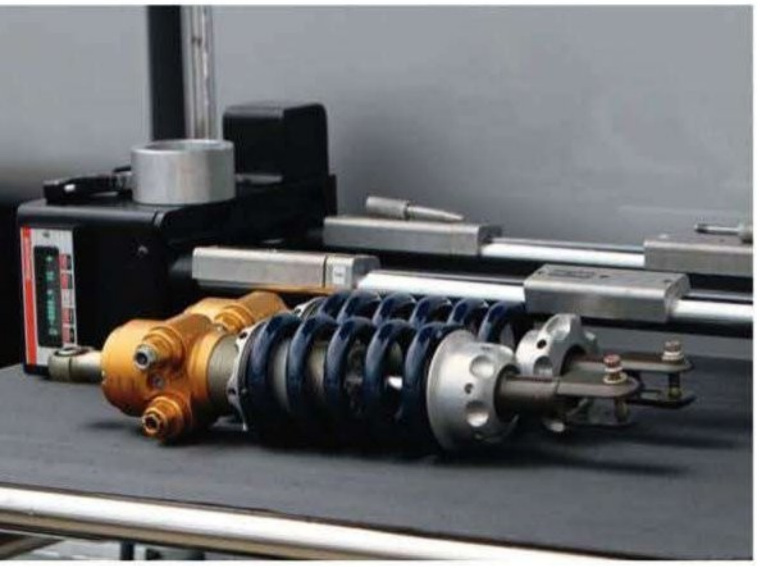
need to be able to make quick adjustments when necessary.

As HVM Racing IndyCar engineer and SPEED.com contributor, Michael Cannon, shared, the extremes teams will go to in order to shed downforce to gain straight-line speed at Indy straddles a fine line: 'The rear wing stops losing drag and starts making lift at about -4.5 degrees. Anything more is truly terrifying, yet you will see people run -5 degrees. Simply because you can flatten out the front wings and there are a variety of ways to shave off just that much more drag, the trade-off for downforce is big. You lose a lot of drag, and gain speed, but the car is almost impossible to hold on to in the corners. The guys running -5 degrees are truly heroes!'

The majority of teams use mount plates that provide a range of adjustment at their base, where the wing is bolted to the crash attenuator, while others use plates with few external adjustment holes, opting to make their wing angle changes inside the wing where it mounts at the bottom of the element. The latter style of adjustment offers small aerodynamic gains, but takes considerably longer than the former style of mount plate.

A few teams have even developed a ratcheting style of angle adjustment – the fastest method of all – but this puts extra items in the airstream.

Rules dictate the rear wing end plates must conform to a specific point of coordinates in relation to rear wing angle and, as a result, when wing angle changes are made, teams usually make an adjustment to the angle of the rear end plates, too.



Damper choice is open in IndyCar but teams tend to follow each other and opt for the ones that are winning most at the time

DAMPER SOLUTIONS

Another area where teams are free to use the product of their choice is dampers. Öhlins, Penske and Dynamic Shocks are three of the most common products used, but Cannon says teams tend to go with what seems to be winning most consistently at the moment.

'It's a case of 'monkey see, monkey do,' he says. 'We've been running around on Öhlins and what we are doing with the Öhlins is better than what we are doing with the Penskes at this point in time. Is one better than the other though? I doubt it. A highly developed and evolved damper is your best option.

'Öhlins makes an excellent and very adjustable damper, the most common one being a through-rod design. This uses a series of springs and shims to generate force. They are very configurable and very light weight, but they are still a through-rod damper.

'They don't offer the same platform or support feeling that a monotube damper like the Penske does. There is a bit of nose pressure with the non-through-rod design, which tends to give the car's platform a bit of stability, and the drivers like that especially as the downforce gets shed off the car.

'There is also a frequency issue. The shim damper can be better at fast amplitude, but that's very high frequency stuff and that's just what you see at Indy.'

What a drag

Mercedes' Ross Brawn on the trials and tribulations of working with DRS

> "we're trying to gain as much performance from the wing being activated as we can"

Formula 1's drag reduction system, or DRS as it is commonly known, has been the focus of a great deal of attention so far this season. Debate continues amongst pundits over whether it adds to the show or makes it too artificial, while engineers discuss whether it really works at all.

At Mercedes, however, there was no debate – the DRS system fitted to its W02 did not work. The problem was not that the wing stuck open, rather that it seemed not to fully close, or at least not return to exactly the same position, causing instability in the airflow.

Team principal, Ross Brawn, explained the issue to the press at the Malaysian Grand Prix: 'When you activate the rear wing and the flap goes up, effectively the airflow stalls. It separates off the wing when the flap comes back, then the flow re-attaches.

'We're having some situations where the flap comes back and the flow doesn't attach immediately, but takes a bit of time before the flow re-attaches. 'We made some modifications after Melbourne, and it looked okay, but it seemed to come back again during qualifying. On both cars during qualifying there were several corners where the flow was unstable, and it happened

The Mercedes DRS wing that was causing all the problems...

...and the revised wing. Can you spot the difference?

GURNEY FLAP DETAIL

Ferrari arrived at the Spanish Grand Prix with extended Gurney flaps on the rear wing. They were promptly banned and the car had to race in its original configuration (below)

in Nico [Rosberg]'s case as well. Obviously, in the qualifying mode, you're operating the system at many points on the track, and in the race you're only operating it in one place on the straight.

'It's aggravated when we get into qualifying because when you're operating it in lots of places [and] in certain conditions we seem to have this separation. It's not a new phenomenon. We all design the rear wings to be at the absolute limit of attachment to get the maximum performance from them. We've seen that many times – a rear wing that's perfectly okay, yet in a crosswind or an unstable condition you get some separation. I think it is the effect of the yaw angle or angle of flow. But that's the balance you're trying to strike.

'Obviously, our wing we've designed with an evaluation of a huge number of elements, not just downforce / drag, but stability and response rate too – all these things are assessed in the wind tunnel. But you're always trying to push close to the limits, and we're trying to gain as much performance from the wing being activated as we can

'The gain in straight-line speed for our wing is quite substantial, but we've just got this bit of instability. It's not unique, it's not new, but it caught us out at the wrong time. I thought we'd solved it with the modifications we made after Melbourne. The issue was not performance, the issue was the drivers having a consistent car, because when the flow doesn't attach, it's not as though you have no rear downforce, but you don't have the downforce that you have when the rear wing is working fully.

'So, you get a 2-3 per cent shift in the balance and the car is not as stable as it would be with the wing attached.

'The parts of the track where we've had the issue are not the parts of the track where we're allowed to use it. With the permitted zone being the main straight, it's not an area where we expect to have a problem. But we'll monitor it.

'We'll have the data during the race, so we'll see whether it's an issue or not. We're still struggling with the consistency of the car and are not giving our drivers the best chance to show what they could achieve. There are times when the car is working well and the pace is evident, but there are too many occasions where things are not functioning properly.'

DETAIL UPDATES

Mercedes introduced a number of detail updates between the Turkish Grand Prix and the race at Monaco and the cars' form improved. Brawn: 'We had a weekend where the car ran pretty smoothly [but] we had a glitch with Michael [Schumacher]'s car in qualifying again. The wing is on the edge of re-attaching when the flap is activated, but on the crucial lap, as is always the case, it did not quite re-attach properly.'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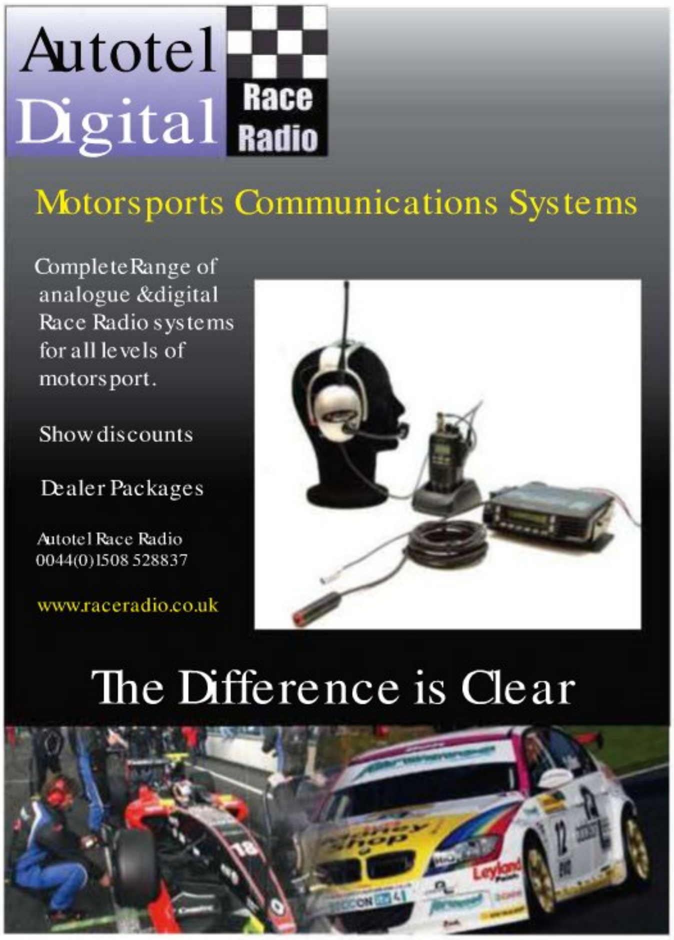
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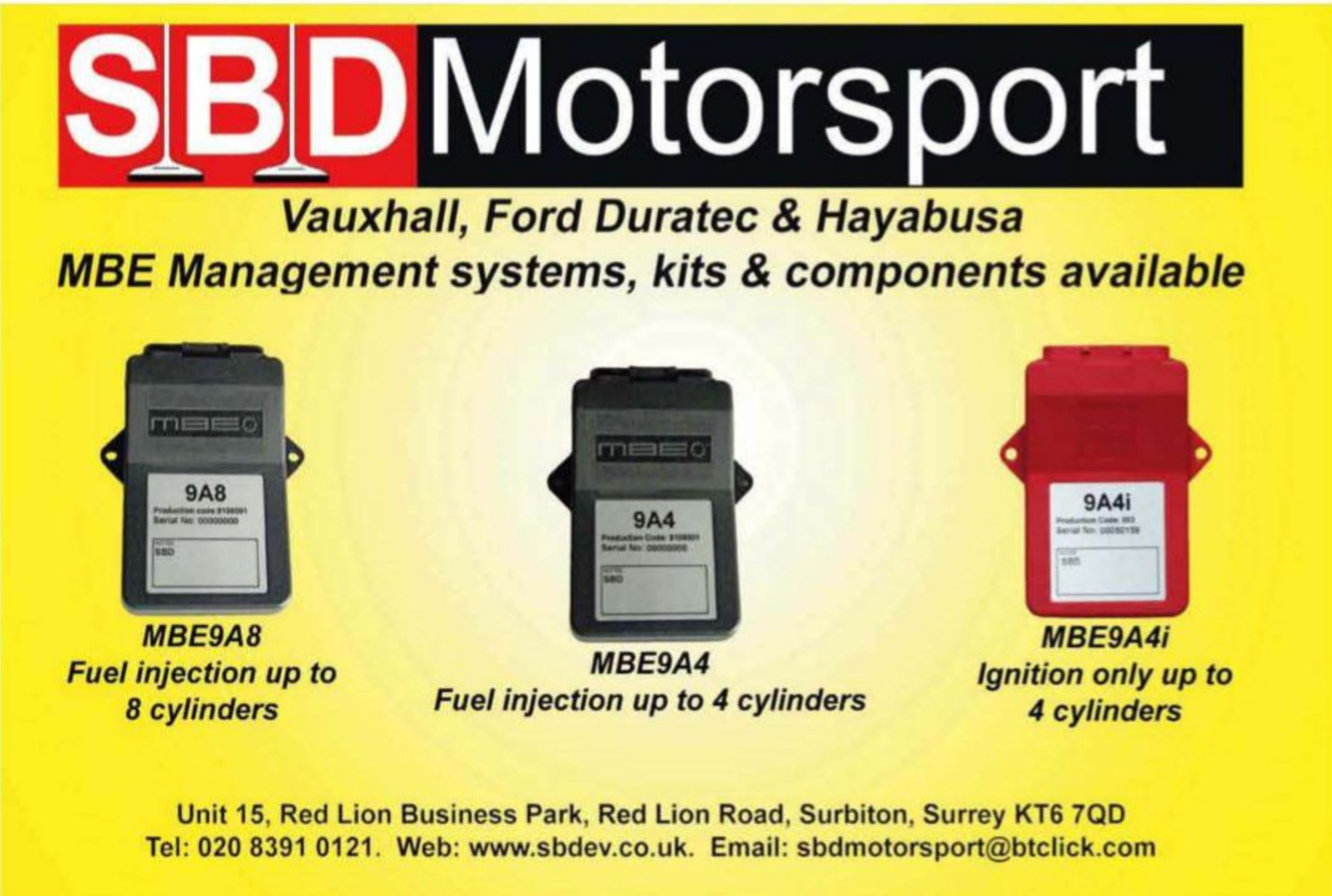
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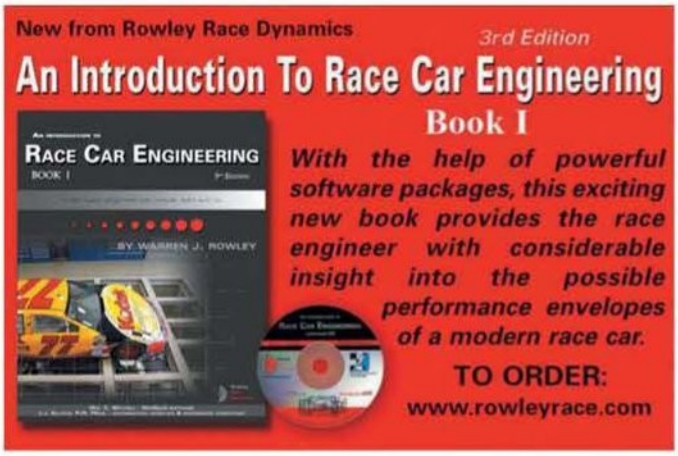
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Chris Saunders
THE INTERVIEW

Q How did you get involved in motor racing?
The first job I ever had was as a forensic scientist, in 1977, so I suppose today I would be called a CSI guy! I was working for the Metropolitan Police out of Lambeth but I decided that I didn't like commuting to London. I was fortunate enough to have the opportunity to move into the field of fluid dynamics at the National Physical Laboratory (NPL).

In the early '80s, NPL was approached by the newly-formed McLaren International F1 team, and I spent a few years working with them, but we also worked on oil rigs, bridges, ships, submarines and missiles – basically anything to do with fluid dynamics. It was fantastic fun. No one does that variety of work any more.

Q You were involved in F1 recently with Red Bull and Toro Rosso, but now you're back at Lola. Why the switch?
Lola was looking to raise their game, so a return to them worked well for us both. I learnt a lot during my return to F1 and enjoyed the challenge.

Q What exactly is your role at Lola today?
I'm the manager of the Technical Centre, which basically covers the wind tunnel, seven-post rig testing and anything else I can apply my skills to. The facility is commercially available, and therefore we look to sell its services (we also have a model shop), but we obviously also put our own product through it. I'm currently involved with wind turbine work, which is very interesting, and it's nice to be working to generate clean electricity rather than consuming it – wind tunnels use vast amounts of electricity.

Q You were responsible for building the 50 per cent wind tunnel at Lola. What is it like to come back?
With my recent F1 knowledge, it's good to know that we're there or thereabouts in terms of what we can offer, and it's refreshing to come back and say, 'okay we did a good job when we built it 12 years ago, as it's still a first class facility'. I find that very satisfying.

I think about six F1 teams have used the tunnel over the years, so there's no doubt it's a tunnel that's good enough to be used at the top levels of motorsport, but we are always looking at ways in which to improve the facility as this kind of technology and the associated testing techniques never stand still.

Chris Saunders, Technology Centre manager, Lola
- **Late 1970s:** worked in fluid dynamics department at the National Physical Laboratory
- **1980:** seconded to McLaren to advise on aerodynamics and wind tunnel work – the first car he worked on was the MP4-1
- **1986-'94:** full time in F1 with Williams, involved in building its first wind tunnel (1989-'91)
- **1994-'00:** Lola, head of aerodynamics
- **2001:** independent consultant, worked with many F1 teams, including leading aero design of still-born Asiatech programme
- **2002-'06:** Lola Technology Centre manager
- **2007-'09:** Red Bull Technology wind tunnel manager
- **2009-'10:** Toro Rosso wind tunnel manager
- **2011:** rejoined Lola as manager of the Technical Centre

Q Tell us a bit about the tunnel's motion system
If you take the model in the wind tunnel you have to move it around as if it was the car on the circuit, and that requires a pretty sophisticated motion system. Our in-house designed system is actually extremely good, such that we have sold the design into two Formula

RACE MOVES

Former Renault F1 managing director, **Christian Contzen**, and aerospace expert, Robin Southwell, have been recruited by the new **Craig Pollock**-headed PURE Formula 1 engine supplier. PURE has been set up to supply customer teams with powerplants for the new 1.6-litre, four-cylinder engine formula, due to be introduced in 2013.

FIA president, **Jean Todt**, has decided against appointing a Formula 1 commissioner – an individual who would look after the interests of F1 – saying there is no need for such a position in Grand Prix racing as **Bernie Ecclestone** already fulfils such a role. Todt has already appointed commissioners for other FIA championships such as WRC, WTCC and GT1.

NASCAR venue, Darlington Raceway, has re-dedicated the track's media centre in memory of former circuit president and NASCAR vice president of corporate communication, **Jim Hunter**, who passed away last year.

Williams' technical director, **Sam Michael**, is to leave the team when his contract expires at the end of the season. Chief aerodynamicist, **Jon Tomlinson**, has also resigned from the Grove-based outfit. The resignations come

Sam Michael

LAT

after a disappointing start to the 2011 season for Williams. Michael has been at Williams for 10 years, Tomlinson for five.

Titanium expert, **Nigel Hoskison**, has joined Dynamic Metals Ltd. Hoskison, a qualified metallurgist and engineer, has over 35 years' experience in the titanium industry, while Dynamic Metals was established at the

Nigel Hoskison

LAT

end of last year and now supplies teams and sub-contractors in F1, WRC and LMS.

NASCAR outfit, Michael Waltrip Racing, has replaced four members of Martin Truex jr's Sprint Cup pit crew after a series of pit-stop blunders. The new line up includes **Eric Maycroft**, **Ricky Coleman**, **Daniel Rankin** and **Jake Brzozowski**, all wheel change men. The only crew members not replaced were jack man, **Brian Chase**, and gas man, **Doug Newell**.

RACE MOVES

Above: Honda has given two of its young technicians in the UK the chance to develop their skills working with the Honda Racing Team at selected rounds of the BTCC this year. The lucky mechanics are **Alex Knight** (19), an apprentice at Gatwick Honda, and **John Couldridge** (21), who works at Glyn Hopkin Honda in Chelmsford.

Former McLaren technical chief, **Mike Coughlan**, who left the team in 2007 after the 'spygate' scandal, has been signed by Williams to work as its new chief engineer. Coughlan's two-year ban from F1 has expired and latterly he had been working in NASCAR at Michael Waltrip Racing.

Mark Smith has started work as technical director at Team Lotus, where he reports to chief technical officer, **Mike Gascoyne**. Smith joins **Lewis Butler** (chief designer), **Marianne Hinson** (head of aerodynamics), **Dieter Gass** (deputy technical director) and **Elliot Dason-Barber** (head of R and D and vehicle dynamics) in the technical department.

Bernie Ecclestone heads the motorsport money stakes in the 2011 *Sunday Times'* Rich List – the annual survey of who is worth what in the UK. Ecclestone comes in at number 23 in the list, with an estimated worth of £1.125bn. Other motorsport multi-millionaires include **Ron Dennis** (£177m), **Ross Brawn** and **Frank Williams**, both said to be worth £100m.

The pit crew for the no 18 Joe Gibbs Racing Toyota in the NASCAR Sprint Cup has been awarded with the Mechanix Wear Most Valuable Pit Crew Award for the first quarter of the 2011 season. The crew comprises **Nick O'Dell**, **Brad Donaghy**, **Jake Seminara**, **Kenny Barber**, **Jeff Fender**

Chris Saunders THE INTERVIEW

CONTINUED

1 teams, and also into wind tunnels in France and the UK for aerospace use.

The motion system moves the model through positional movements, which are generated directly from circuit data. It's all computer controlled, and you sequence it by feeding in a list of requirements, saying 'go from here to here', 'take data here and here', and it's completely automated. It's just a matter of sequencing a file and it will run a lap.

The road can be part of this sequence too, but you can either do this asynchronously, where you have the rolling road at a different angle to the model, or synchronously, where they're both at the same angle. One would be simulating a car with a bit of scrub in a corner, the other one would be the car in the corner with no scrub.

Q How important is the cooling system in the tunnel?

It is extremely important, and not all motorsport wind tunnels have this. The fan power for this tunnel is about three quarters of a megawatt. If you're running at high speed without a cooling system, the frictional forces will quickly heat the air up, and it will go up about five or six degrees in 10 minutes. If the testing schedule requires lots of back-to-back runs, it doesn't take very long for the tunnel air temperature to reach 40degC or more.

Model ride height can then change due to thermal expansion, as well as the tunnel itself moving a little, so the whole point is to try to keep the air at a known temperature so the testing environment is always the same. We have a very large heat exchanger sitting in the wind tunnel that actually performs a dual role, as it also aids flow quality, whilst keeping the air temperature to a constant 20degC.

Q What other facilities are available at the Technical Centre?

We can do chassis dynamics and we can do aerodynamics, and anything else anyone wants us to do if we've got the time and capacity. We have a good seven-post rig, along with a damper dyno, which means that before people use the rig they can run their dampers on the dyno. It's always good to check the dampers before you put them on the car, and before you put the car on the rig, because you might find you're trying to tune out a problem that is just a broken or badly set up shock.

Q You've worked with Adrian Newey at Williams and Red Bull. Just how good is he?

He's completely single minded, but he's extremely good at what he does, and he's a very nice guy, too. He has a lot of back up from a highly skilled aero department and he still draws at a drawing board, so these drawings do ultimately need to be turned into CAD models by others, so this allows Adrian to just scheme. His input, along with the rest of the department, can generate hundreds of parts to test, and if you test hundreds of parts a week in a good wind tunnel, it will eventually converge into a good solution. That, simplistically, is how it's done!

As well as a sophisticated motion system to control car attitude, the Lola wind tunnel has an highly controllable cooling system, so all tests are conducted under similar conditions

RACE MOVES

and **Tom Lampe**. The pit crew co-ordinator is **Paul Alepa.**

Tom German is no longer the technical director at Penske Racing's NASCAR operation. His departure came after a **Kurt Busch** outburst over the team-to-driver radio at Richmond, the driver questioning the performance of the cars since German joined the team. German has now left the organisation to take up a position at the Sloan School of Management at MIT.

Race engineer and historic racer, **Reg Hargrave**, has died at the age of 75 after suffering a stroke. Hargrave was best known for racing 500cc F3 cars, but he also competed in a Kieft Sportscar in the mid-1950s.

Keith Koldspaek has left the Red Bull Racing NASCAR Sprint Cup team where he was responsible for overseeing the car build. He is now at Hendrick Motorsports, where he manages new car final assembly and build, reporting to **Chad Knaus.**

Graham Pearce, team director of British race team Total Control Racing, has died after a short battle with cancer. Pearce was with the team for 13 years and helped it to successes in the Renault Clio Cup, the SEAT Cupra Championship and the Ginetta GT Supercup.

Red Bull Racing team boss, **Christian Horner**, made a one-off appearance behind the wheel of a racecar at Snetterton, sharing a car with Aston Martin chairman, **David Richards**, in the marque's GT4 challenge. Former F3000 racer Horner led the race briefly, before the pairing went on to finish sixth.


Christian Horner

LAT

Douglas Wilson-Spratt, an innovative designer who built a succession of distinctively-styled GT coupés based on BMC chassis in the 1960s, has died of heart failure at the age of 89. His cars are still regularly seen at the Goodwood Revival meeting in the UK.

Moving to a great new job in motorsport and want the world to know about it? Or has your motorsport company recently taken on an exciting new prospect? Then send an email with all the relevant information to Mike Breslin at bresmedia@hotmail.com

FILM REVIEW


SAM COLLINS

Brutal viewing

We locked Sam away in a darkened room, and put on some motorsport films to keep him happy

Two motorsport documentaries have hit the big screen recently, both focussing on individuals competing in incredibly dangerous eras of racing. The first is *Senna*, which details some aspects of the three-time world champion's career leading up to his death at Imola in 1994.

Some of the footage is stunning and previously unseen, whilst other parts of it have been on YouTube and viewed hundreds of times. What the film does make you realise though is just how raw and unhinged Formula 1 was during Senna's time. The cars were beautiful, simple creations, with cigarette branding and big fat sticky slicks, and a real sense of just how brutal these machines were compared to today's digital missiles can be gleaned from this film.

Where the new film also scores is in its use of footage from the drivers' briefing room, which sees FIA president, Jean Marie Balestre, at his most monstrous. Finally, seeing the Imola crash from new angles puts it all into sickening context, and reveals just how dangerous racing was in the mid-1990's. The film makers do not flinch from showing the fatal accidents, but the crash that really hits home is that of Rubens Barrichello in his Jordan, the impact of which will make your heart skip a beat.

I find it hard to see *Senna* being a huge commercial success, but one film that will be is *TT3D: Closer To The Edge*. This follows motorcycle road racer, Guy Martin, through his attempt to win last year's Isle of Man TT, and is simply breathtaking. In my opinion, it is by far and away the best motorsport documentary ever made. That's a bold statement, but go and see it and you will see what I mean.

One super slow motion sequence in *TT3D* is as beautiful as it is fascinating. It shows Martin's bike landing after flying off the famous Ballaugh Bridge on the Isle of Man TT course, and you can see perfectly the extreme deformation of his tyres, the bike's chain whipping around and the chassis ultimately bottoming out. This sequence is typical of this incredibly well-shot film, which really puts all others in the same vein to shame.

Motorcycle road racing is fairly unique in world motorsport in that its biggest event is still an incredibly amateur affair. There is little corporate sponsorship, the scoreboard is still operated by Scouts (as it has been for a century) and the competitors arrive in Ford Transit vans. Yet the Manx TT is right up there with the Le Mans 24 Hours, Daytona 500, Indianapolis 500, Monaco Grand Prix and

> **"by far and away the best motorsport documentary ever made"**

Dakar Rally. This unique aspect gives the event a real salt-of-the-earth feel.

In a similar vein to *Senna*, one thing that comes across at the end of the film is the horrific injuries many of the riders sustain, and the matter-of-fact approach they have to their own mortality.

The real interest for me, however, is how this form of racing has captivated audiences up and down the country. The first two times I tried to go and watch the film it was sold out, and almost a fortnight after its release it is still going strong in the UK.

The raw, unhinged and sadly dangerous nature of motorsport iswhat is switching on fans these days as everyday life gets more and more bound up in cotton wool safety regulations. It now falls to motorsport's rule makers to realise this and act appropriately. Should racing be made less santitised and more extreme? Almost certainly but, as the fatalities in both these films remind you, it still must have some degree of safety.

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Publisher Luke Bilton
Senior Publisher Sarah Arthur
Managing Director Paul Dobson
Editorial
Racecar Engineering, Chelsea Magazine Company, Suite 19 Chelsea Wharf, 15 Lots Road, London SW10 0QJ UK
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Advertising
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As a 10-year-old boy, at a windswept but sunny Silverstone, I was strapped into the cockpit of a Porsche 956 alongside British driver Richard Lloyd. I say strapped. In fact, I was balanced on the fire extinguisher, clung to the dashboard, and was taken on a lap of Silverstone's Grand Prix circuit.

A love of racing, forged by watching Keke Rosberg and Ricardo Patrese in the early 1980s, was cemented there and then and, as I scrambled out of the cockpit, my path in life had been pretty much defined. I loved Formula 1 in the mid-'80s but, since I started my writing career, it has rarely lit my fire in the same way as a good Sportscar or Touring Car race.

In my opinion, Formula One still sucks up too much money, column inches are wasted on inane topics, and so many drivers waste their lives and cash trying to get there.

All the while, other valuable race series are going unnoticed, and that, as a Sportscar fan in particular, breaks my heart.

Granted, sports car racing has to get its own house in order before it can hope to move up the pecking order, but Formula 1 has not, in the past 20 years, justified the exposure it was getting. It wasn't a sport, it was an exercise in making money for the teams, and the fans were duped in to spending hard-earned cash attending events. Le Mans was always better value for money, and still is, as more of a genuine motorsport festival. But Formula 1 is starting to fight back.

Since Michael Schumacher began his temporary retirement in 2006, young drivers have come into their own, and the racing has become unpredictable once again. Hamilton, Button, Massa, Rosberg and Vettel are exciting to watch, while Alonso and Webber are sticking two fingers up at the young chargers. This year, things are even better, and it has nothing to do with that stupid DRS system.

Thanks to Pirelli's fast-wearing tyre, for the first time, the important stage of the race is after the final pit stops. No longer do we have a procession from start to finish, and no longer do we have to pray for rain to see a decent race. The start is exciting, as it always was, and finding out who is on what strategy mixes up the order, so then the final run to the flag can be the making of a great race. Now, a spectator is as uncertain of the final result as watching a football match. Tyre management has put tactics at the forefront of Formula One racing, and not before time.

> **"Formula 1 is starting to fight back"**

As for DRS, it clearly doesn't work. Up against a KERS system it produces nothing other than a topic for commentators, and more column inches discussing whether or not it can be used in a tunnel, and if a track is a double DRS zone or not. Yawn.

To make it really work, DRS needs to be available everywhere, at all times during the Grand Prix. The brave drivers would use it more than the faint of heart and we could see some experimentation.

KERS can be used all around the track according to the drivers' needs, so why not let the drivers decide when to use DRS? Modifying the DRS rules gives the drivers a chance to take risks for the ultimate gain. And that is what Formula One should be about.

EDITOR
Andrew Cotton

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