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ADRIAN NEWEY SPEAKS OUT
Formula 1's trendsetter tells it like it is

LASERS IN THE WIND TUNNEL
How latest developments allow dynamic aero testing

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It's the April issue of *Racecar Engineering*, so it must be our annual investigation of the technical state of play prior to the start of the new Formula 1 season. Following tests in Valencia, Jerez and Barcelona, there are some good indications of the key areas on which the engineers, designers and aerodynamicists have been working in preparation for 2011. Our writers have been present for much of the pre-season testing, and they report there are a number of interesting detail developments being tried by individual teams. Not all of these will make their way through to the cars that line up on the grid for the first grand prix of the year, of course, but, as ever, Formula 1 remains an unrivalled and compelling hotbed of technical development in the world of motorsport.

Speaking of technology, we also have an exclusive interview with Red Bull Racing's design guru Adrian Newey this month, plus a feature on the use of PIV in wind tunnel testing, the latter allowing teams to measure transient aerodynamic effects as a model is moved in the course of a run.

This time of year also marks the start of the new hillclimb season, and we therefore decided it would be appropriate to have a look at some of the exciting new cars that will be taking to the UK's hills this year. Your guide is long time hillclimber, and our resident aerodynamics expert, Simon McBeath. Staying with the 'uphill' theme, we are also able to bring you an exclusive glimpse of a groundbreaking new single seater being developed by former F1 man, Willem Toet, which he intends should 'raise the bar' significantly in the world of hillclimbing.

Add to that a retrospective feature on Porsche's ultra-lightweight 909 Bergspyder, designed in 1968 to take on the might of Ferrari on the European hills, plus the thoughts of all our regular contributors, and you have another packed issue.

As ever, we enjoyed putting it together and we hope you enjoy reading it.

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Graham Jones

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FORMULA 1

New tyres could change the face of Formula 1 racing

The pre-season Formula 1 tests have suggested that tyres will play an even bigger part in the racing than usual this year, with reports that the new spec rubber not only has a quicker rate of wear and degradation than the previous covers, but also might be inconsistent.

Pirelli, which has taken over the F1 tyre supply deal from Bridgestone this year, has deliberately set out to make a tyre that wears quicker than its predecessor – with the aim of improving the show with extra pit stops, and of having cars on track at the same time with differing pace. But a number of drivers, Lewis Hamilton among them, have complained that they have had to nurse the tyres through the tests.

But perhaps more significantly, Team Lotus driver, Jarno Trulli, has gone on record to say that he believes the Pirelli rubber is inconsistent, telling *Autosprint*: 'I think something is missing in the development, because the tyres aren't balanced yet. I think this is the biggest problem to face at the moment.

'Pirelli said that this is what the FIA asked them to do, to have tyres that wear quickly... [but] in my opinion, tyre wear is secondary compared to the tyres' balance problems, because at the moment you get to the track with a new tyre that initially is understeering, and after three laps the behaviour is opposite, that is impossible oversteer.'

What is it they say? A bad workman blames his, er, tyres?

At this stage, it's impossible to say how representative Trulli's view is, as most other drivers have only commented on the degradation – as much as one second drop off after a flying lap – and the wear rate. But even with just the high wear rates experienced in testing so far – the fourth and final test is scheduled for Barcelona mid-March – it seems the tyres are going to be a major factor in this year's races.

Meanwhile, despite the lack of reliable data due to differing fuel loads, tyre compounds and other variables, a picture of which teams might have a long year ahead of them is at least beginning to emerge. Of the bigger teams, Mercedes GP seems to be the most concerned, with its head, Norbert Haug, admitting to *Auto Motor und Sport* after the third of the four tests that it's targeting podium finishes at best: 'We know that at the moment our car is not good enough for the top 10, but we had been hampered by having to cut holes because of temperature problems... Our plan is that with our new aerodynamics package we close much of the gap and have the car good enough for the podium.'

McLaren has also started the season slowly and, after bringing its 2010 car to the first test, has struggled to match rivals in terms of pace and mileage.

However, there is some respite for the struggling teams, with the news that the first race of the season, the Bahrain Grand Prix, which was scheduled for March 11, has been cancelled as a result of the ongoing political tensions in the region. The Australian Grand Prix, on March 27, will now open the season.

SUSPENDED ANIMATION

Ever wondered what a modern Mercedes Formula 1 car would like if it was broken down into 3200 components and then each part was dangled from the ceiling on a piece of wire? Well, if you have, you'll be delighted to hear that Dutch artist Paul Veroude has done just that at Mercedes-Benz World at Brooklands. Cool, eh?

RACECAR SAYS...

Hats off to Pirelli for what it has achieved so far. It was asked by the FIA to supply a tyre that wore quickly, and that's exactly what it has done. Let's just hope its reputation doesn't suffer when the drivers blame the tyres for races lost...

ENDURANCE

Green tech fails to show for Le Mans 24 Hours

The ACO's hopes of boosting the environmental credentials of the Le Mans 24 Hours have suffered a setback, with an experimental green car failing to materialise and the top works teams deciding not to opt for hybrid technology.

Le Mans organiser, Automobile Club de l'Ouest (ACO), had planned to allocate an extra pit garage this year for an experimental car that would have run outside the general classification but, on the announcement of this year's entry, it explained that its hopes to allow 'an innovative technological project' had come to nothing. The ACO said: 'Contacts were made with several manufacturers working on such vehicles but, as these projects were not sufficiently sorted out, nobody asked for an entry.'

Meanwhile, Peugeot has backtracked on its stated intention to run a diesel / electric hybrid challenger this year. At the launch of its second generation 908 HDi, Peugeot Sport boss, Olivier Quesnel, said the decision not to run the new technology had its roots in the French company's failure to win the race last year. He did, however, go on to say that the car will run with hybrid technology after Le Mans.

The new Peugeot is powered by a 3.7-litre V8 HDi FAP 550bhp diesel unit, in line with the new regulations, and Bruno Famin, Peugeot Sport's technical director, said: 'The only component which has been carried over at the end of the day [from the previous car] is the windscreen wiper.' The car features identical wheel sizes all round, in an effort to gain more mechanical grip at the front, and the now mandatory fin.

Audi had already said it would not be committing to the hybrid technology as yet, but there is some good news on the green tech front with Hope Racing running a mechanical hybrid system, which utilises energy collected under braking in its LMP1 ORECA.

This year's entry boasts 56 cars, with 17 LMP1 cars and 11 LMP2. The new GT category sees six manufacturers represented in the GTE Pro class, and five in the GTE A class. Of the LMP1 cars, joining Peugeot and Audi will be Aston Martin Racing, with its as yet unseen AMR-One, and Highcroft, with a HPD ARX-01e. Hope Racing's ORECA and the ASM Zytek complete the line-up.

Peugeot's second generation 908 may appear similar to its winning predecessor, but is said to share only the windcreen wiper

CAUGHT

Doug Howe, crew chief of the winning no 15 truck in the NASCAR Camping World Truck Series race at Daytona, has been fined because the rear spoiler on the Toyota pick-up did not meet the required spec, part of it having been displaced during the race.

FINE: $25,000 / PENALTY: 25 points

BRIEFLY...BRIEFLY...BR

RS KICKER

Ford's RS WRC might well have locked out the podium on the opening round of this year's World Rally Championship – the first event to the new rules – but, according to reports, Ford is still working hard on its engine before the homologation freeze comes into force in May. It's understood that the manufacturer is currently working on fuel injectors, combustion chamber shape and port shapes.

SIGNATURE TUNE

Nissan has signed an exclusive two-year official partnership with Signature Racing to compete in the new Intercontinental Le Mans Cup (ILMC), the Japanese car giant to provide Signature with its VK45 V8 engine for LMP2. The car will be entered as a Signatech Nissan and will make its debut at Sebring on March 19.

O ZONE

The FIA has released details on when the adjustable rear wing will be allowed to be used in F1. There is to be a 600m overtaking zone on a straight, but the driver will only be able to activate the wing – opening a slot to reduce drag – if he is within one second of the car in front at the preceding corner. There will be two lines painted on the track at the corner before the chosen straight to help assess the gap.

NASCAR

NASCAR signs McLaren

McLaren Electronic Systems is to supply teams with ECUs for fuel injection systems when NASCAR's Sprint Cup finally makes the switch from carburettors in 2012.

The deal is in conjunction with Freescale Semiconductors, which is to provide the processors for McLaren's ECUs, and to counter worries over tampering – a stumbling block in earlier talks to introduce ECUs – the units will be 'tamper proof', with a code and password system. Meanwhile, NASCAR will also have special electronic tools at its disposal to monitor the systems.

Robin Pemberton, NASCAR's vice president of competition, said: 'This move gives us an additional opportunity to incorporate the best technology in our racecars that will enhance the sport in a variety of ways. Selecting these two industry leaders reflects our commitment to this new technology, which our manufacturers and teams have embraced. This is a positive step that will provide greater fuel efficiency and a greener footprint while maintaining the same great competition we have seen on the race track.'

The system will be tested throughout this season, but it is looking unlikely that it will be used in all the races next year, and almost certainly not at Daytona and Talladega, where carburettor restrictor plates are used to keep the speeds in check. There are also no plans currently to extend the technology to the second tier Nationwide and Truck series.

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ELECTRIC RACING

Drayson Racing switches to electric

In what is perhaps the biggest endorsement for electric car racing yet, ALMS race-winning team, Drayson Racing, has pulled the plug on its mainstream Sportscar programme to race instead in the EVCUP – a new series for zero-emission racecars.

The team, which has raced at Le Mans and last year won the ALMS counter at Elkhart Lake with its LMP1 Lola, will enter a Westfield iRACER in the Sports EV (electric vehicle) series, which is a part of the EVCUP. The car boasts a peak power of 260bhp, and has 660Nm of torque per driven wheel.

In some ways the move is not so surprising for, while the team was a notable absentee from the recent Le Mans entry list, team boss Lord Drayson has been a huge proponent of green technology, in both his racing as a driver and team boss, and in his former role as minister for science and education in the previous UK Government.

Lord Drayson, who is also the honorary president of the MIA, said: 'Drayson Racing have paved the way in green racing over the past four years with second generation biofuels and we have been looking at electric vehicle technologies for a while, waiting for the technology to mature and for the right time to enter this exciting new field. The team at EVCUP have taken a bold step forward to create the world's first electric racing series, we want to be part of it and we want to win it!'

Former UK science and education minister, Lord Drayson, lends his considerable support to the new EVCUP series by entering a car in the Sports EV category

EVCUP is to feature two classes, one for City EV cars, whose drivers will compete in race-prepared THINK cars, and another for the Sports EV Class, which will use the Westfield. The seven-round series gets underway in August with four rounds in the UK, before going on to Spain, Portugal and the USA.

Grahame Butterworth, EVCUP race director, said: 'Lord Drayson has the foresight, experience and ability to help drive these cars forward in a realistic, but also very exciting way. He will be a great competitor and also a strong voice in developing the next era of high performance electric racecars.'

BRIEFLY...

SWEATY PITS

Top NASCAR outfit, Hendrick Motorsports, has shown it's getting serious about its pit stop performance. Firstly, it rented the Charlotte Motor Speedway to carry out pit stop training and evaluation – the first time a NASCAR team has done such a thing we're told – and secondly, because it plans to build its own pit crew training centre, complete with indoor and outdoor facilities, including a six-lane running track.

DYNO-MITE

There was an explosion at the Joe Gibbs Racing engine shop at the beginning of February, thought to be caused by a cracked carburettor on an engine being tested on a dyno starting a fire, which engulfed the dynamometer and spread to other parts of the shop. The explosion is said to have caused millions of dollars worth of damage, but thankfully no member of the Joe Gibbs Racing staff was hurt in the frightening incident.

TOURING CARS

Perfect 10 for new look BTCC

The British Touring Car Championship is to feature at least 10 different car makes this year, the first time such an eclectic grid has been seen in the UK's premier race series since 1997, when nine manufacturers lined up to do battle.

Manufacturers whose cars will start this year's championship, which kicks off at Brands Hatch on April 3, are: Audi, BMW, Chevrolet, Ford, Honda, SEAT, Toyota, Vauxhall and Volkswagen, while a Proton is set to join the grid later in the season.

The three new makes to join the grid are Audi – a pair of A4s to be run by Rob Austin Racing – Proton and Toyota, in the shape of the new NGTC (Next Generation Touring Car) -spec Avensis. All three have previously featured in the BTCC, Audi and Toyota as major works efforts in the '90s, while Proton was involved in 2002-2004.

Toyota GB has also announced it is funding an engine programme for the teams running its cars (Dynojet and Speedworks) and has appointed Northants-based engineering concern X CTech R to tune its stock 140bhp 3ZR engine into a turbocharged, 300bhp+ race engine.

Tests continue on finalising the aero package of the NGTC Toyota in MIRA's full-scale wind tunnel

Meanwhile, development of the NGTC Toyota continues, with the car visiting the MIRA wind tunnel. The Avensis racecar was joined in the wind tunnel by a road-going model, on to which TOCA tech staff had fixed a rear wing to help establish a baseline for the car's aerodynamics. 'We needed to fix a position for the rear wing, based on the aerodynamics of the road car, which gave the levels of downforce we were looking for,' said BTCC technical director Peter Riches, adding: 'I am pleased to say that this was quickly achieved, and we now have a baseline for all cars built to NGTC regulations and have saved a lot of development time and potential expense for the teams.'

The 10th make should join the grid mid-year, with the news that Welch Motorsport, run by former rallycross star John Welch, will campaign an NGTC-spec Proton. The car will be the booted version of the Gen 2 and will be powered by one of TOCA's unbranded NGTC turbocharged units.


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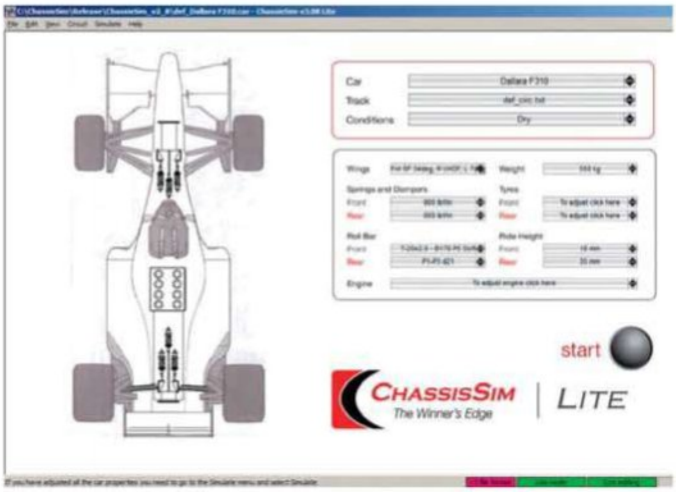
SOFTWARE

CHASSISSIM LITE



A new, cost effective simulation package has just been released by well known Australian-based firm, ChassisSim. Dubbed ChassisSim Lite, it is intended as an affordable simulation package for freelance crew chiefs / race engineers and team owners who want to be able to set up their cars scientifically, rather than just intuitively.

Priced from $2000 (£1240), ChassisSim Lite is claimed to provide a team with the sort of top quality racecar simulation currently in use by professional race organisations. As reflected in the lower price, ChassisSim Lite does not offer all the features of the Standard or Elite software, but will allow the user to export race data, explore the effects of spring, damper, anti-roll bar and bump rubber changes, adjust the car's suspension geometry and investigate many other useful set-up parameters.

ChassisSim Lite is suitable for use with any racecar and at any track, having already been successfully employed by teams in branches of motorsport as diverse as Formula Ford, V8 Supercars, NASCAR, the American Le Mans Series, Formula 3 and GP2.

ChassisSim also offers a service whereby its experts can measure individual cars and provide an accurate model from which to work.

For more information see www.chassissim.com/blog

SOFTWARE

WINDFORM XT 2.0

ITALIAN COMPANY CRP Technology, one of the market leaders in the rapid prototyping sector, has announced an evolution of its successful Windform XT additive, Windform XT 2.0. The new additive will replace XT, which was well known for its mechanical strength and was highly suitable for motorsport applications. The new Windform XT 2.0 material is eight per cent stronger in tensile strength, 22 per cent greater in tensile modulus and has a 46 per cent increase in elongation before breaking. The exceptional strength of the material makes it perfect for creating functional prototype parts that can withstand the forces of track or wind tunnel testing.

For more information see www.crptechnology.com

ELECTRONICS

DC LE MANS LOOM

DC ELECTRONICS HAS announced that it is now offering a wiring solution for teams affected by the new ACO rules regarding the now compulsory Cosworth Scrutineering System. For the 2011 race season, the ACO has made it mandatory the system be installed on all cars competing in the Le Mans 24 Hours, the Le Mans Series, the American Le Mans Series and the Inter-Continental Le Mans Cup.

As the Cosworth system does not come with the wiring harness needed, DC Electronics, and its US distributor, Kinetic Racing Technologies, is now offering a 'plug and play' wiring loom for the Porsche 997 GT3. For all other vehicles, the customer can supply their own dimensions on a template downloadable from the 'download' page on the DC Electronics' website.

For more information see www.wiringlooms.com

HARDWARE

BILLET BUTTON PISTONS

US-BASED SPECIALIST PISTON supplier, Diamond, is now offering a new inboard billet piston with buttons instead of gudgeon pin clips, designed specifically for racers who regularly replace pistons in a hurry and who want the benefits of a modern inboard piston design. Compared with the removal of the secure yet unwieldy spiral locks or round wire locks found on many pistons, changing buttons is remarkably rapid. In addition, on pistons where the pin bores intercept the oil control ring groove, the buttons prevent the expander in the oil control ring from distorting around the half-moon openings in the back of the groove. The use of billet pistons also allows for almost unlimited design iterations, permitting last minute changes to a multitude of design features. The new pistons are available in a range of finishes and can be specified with coatings on both the crown and skirt.

For more information see www.diamondracing.net

HARDWARE

CAMBRIDGE ALTERNATOR

UK-BASED CAMBRIDGE MOTORSPORT Parts recently announced the launch of its new Edge series of racing alternators. The high output 60amp alternator offers a weight saving over most OEM units, coming in at just 4.5kg. The company can also supply a number of different diameter pulleys to adapt the drive speed, and the universal mounting system makes it suitable for a wide range of applications.

For more information see www.cambridgemotorsport.com

It's all systems go for F1 2011

A new tyre supplier, adjustable rear wings and KERS are just some of the challenges facing teams this season

BY SAM COLLINS

It was all supposed to change in 2009 – Formula 1 was going back to basics. The aerodynamic appendages that littered the bodies of 2008 were gone and Kinetic Energy Recovery Systems (KERS) were introduced. It was all meant to spice up the show and improve the racing, but then the Brawn BGP001 turned up without KERS and a multi-layer diffuser, which exploited a loophole in the regulations. For the rest of the season, and well into the next, everyone else was playing catch up, at least they were until the FIA re-set things.

For 2011, the elaborate diffusers have been banned in favour of the smaller single layer rear floors of early 2009. 'With the diffuser, it means that in packaging and gearbox design terms, you need almost the opposite to what a double diffuser needed,' explains Sauber technical director, James Key. 'It's more about the architecture at the back of the car – where the suspension goes, what volumes you free up and what volumes you take.'

As a result, the teams have employed a wide range of approaches in this crucial area, but one of the most extreme solutions is to be found on the Williams FW33. It features the smallest gearbox in grand prix racing, possibly one of the smallest ever seen in open-wheel racing.


Circuito de Jerez

ROLL HOOPS

Both the Lotus T128 and the Force India VJM04 (shown) have re-visited the 'blade' concept for 2011

One of the most striking details of the Lotus T128 and Force India VJM04 is the lack of a roll hoop, in its place a 'blade'. The concept is essentially the same as that employed on the Mercedes MGP W01, removing the hoop and re-locating the engine intakes lower on the engine cover, while fulfilling the requirement for a roll-over structure with a solid central element. It is said this approach gives better flow to the rear wing.

When the MGP W01 was revealed at the Spanish GP, queries were raised about the safety of the concept – would the blade dig into the ground in a roll over? The rule makers took heed and the following appeared in the 2011 technical regulations: '15.2.4 The principal roll structure must have a minimum enclosed structural cross section of 10000mm², in vertical projection, across a horizontal plane 50mm below its highest point. The area thus established must not exceed 200mm in length or width and may not be less than 10000mm² below this point.'

Many took this as an outright ban on the blade concept, but Mike Gascoyne and his team thought differently, and the T128 meets the new regulation fully. 'Just on analysis, it is lighter than a hoop and a touch better aero-wise,' he explains. 'You had the Mercedes last year, people weighed it up but I think often these things that are visual get more weight put on them than they really deserve. They look very different but actually it's quite a fine line.'

> "it is lighter than a hoop and a touch better aero-wise"

Perhaps surprisingly then, Ross Brawn's Mercedes team dropped the concept for 2011, opting for a conventional hoop on the MGP/W02, explaining: 'There was no big gain to doing that this year, so we are doing different things.'

Roll blades are nothing new in F1. They first appeared in 1985, on the Arrows A8, Ligier JS25, RAM 03 and Brabham BT54, but had faded out by mid-'86.

'The main target was to clear all the area to the rear lower wing because it is a performance differentiator now,' explains Williams' technical director, Sam Michael. 'You've got to have the underside of the rear lower wing completely free, so we took the decision to lift the top wishbone and the track rod and go to a z-bone layout, which was commonly used in the early '90s to get that all above the underside. It means that all the weight is in line with the trailing edge of the legality box, so you are nowhere near the underside of the rear lower wing, and it's completely free airflow. The other thing was to clear the centre of it by lowering the gearbox. We dropped the top surface of the gearbox a massive amount and it is the smallest box we've ever made. That was quite a big step on driveshaft angle, definitely the most extreme I've seen, and Pankl – who we did the driveshaft design with – had never done anything that extreme before. The losses are pretty small with the joints we have got.'

PULL-ROD DAMPERS

The FW33 rear end also features pull rod-actuated dampers, pull rods having become something of a trend this season, with many cars on the grid choosing this solution. 'The pull rod was a no brainer,' explains Michael. 'It doesn't matter what you do with a push rod, even if it is swept forwards or backwards, you've got an interaction with the rear

The Williams FW33 features a unique rear end with the smallest gearbox in F1 (right), creating an extreme driveshaft angle and upper rear wishbone mounts in the wing support

When not arguing with Ford over model designations, Ferrari is developing a push rod rear end with a damper package reportedly linked front to rear

lower wing, whereas a pull rod is completely out of the rear lower wing. That was an easy decision to make.'

Not everyone agrees, though. Ferrari, for example, has adopted push rods on its F150th Italia, believing it has a better solution, carrying out substantial work on damper placement, moving them from above the transmission further forward and lower in the car. This allowed the Ferrari aerodynamicists to develop much lower rear bodywork, one of the key benefits of a pull-rod layout. However, sources suggest that one of the issues with this layout is that for the mechanics to adjust the dampers they now have to remove the floor of the car. 'We were working with different set ups for the suspension, such as Red Bull's pull rod,' explains Nikolas Tombazis. 'There are different options for the suspension regarding aerodynamics and the pull rod is an advantage. Our choice was to wrap the push rod up to improve the rear, and gain aerodynamics. We think we reached the same level as with the other suspension, and

> **“[suspension] pull rods have become something of a trend this season”**

THE CARS FOR 2011

Red Bull RB7
Engine: Renault RS27
KERS: Renault Sport

Ferrari F150th Italia
Engine: Ferrari 056
KERS: Ferrari

Renault R31
Engine: Renault RS27
KERS: Renault Sport

THERMAL MANAGEMENT

With almost every car featuring tightly packaged rear ends and innovative exhaust solutions, one of the critical factors on the 2011 cars is thermal management, as there are very few methods of shielding composite components. Gold sheet is effective in some applications, as are basic metallic components such as that found on the rear wing end plates of the Virgin MVR-02, but the most common approach this season is to use ceramic coatings applied directly to the composite parts.

High temperature, plasma-sprayed ceramic coatings provide light weight, durable thermal barriers suitable for a wide range of aggressive environments. Zirconia, for example, has a thermal efficiency of less than 1.7W/m K (compared with 4W/m K for alumina), creating a coating that is very effective at inhibiting heat radiation from a surface.

Believed to be the only product of its type available commercially, Zircotec's coating is so effective it allows composites to function in temperatures above their melting point. Testing for a typical application gave a reduction in composite surface temperature of more than 125degC.

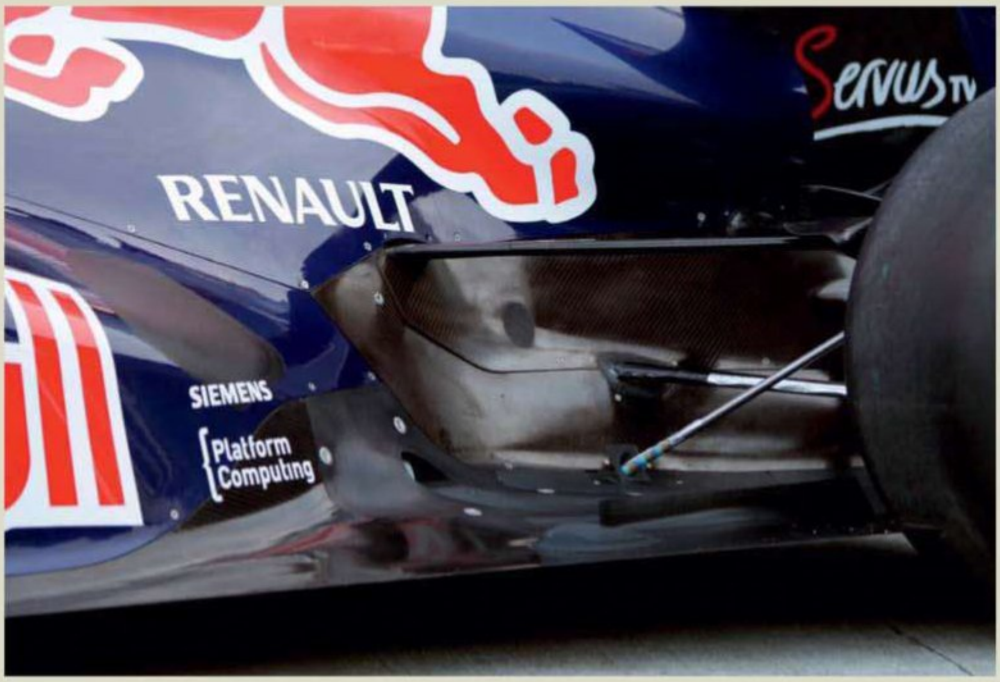
Adherence is vital to maintain heat protection and the heat treatment of the composite is crucial to determine the process parameters. 'Typically, glass fibre parts have had a very low heat treatment and may even have a range of unbound monomers in the resin,' says Zircotec's managing director, Terry Graham. 'Trying to bond to such a material would result in the out gassing of the monomer and our coating would not bond to it.'

'We also have the ability to build in a conductive sub-layer that will help dissipate heat away from any concentrated high temperature areas, and can also help deal with transient heating situations,' continues sales director, Peter Whyman. 'This means we apply just the right amount of coating to deliver the necessary protection while minimising the weight impact of the coating (as low as 0.03g/cm² for some applications). We are now able to vary and control parameters within our coating in all three dimensions - something that is vital for motorsport applications.'

> **"there are very few methods of shielding composite components"**

Increasingly in 2011, coatings are being engineered into the designs. In addition, the coatings are being tuned to improve other aspects of the car. One example is how Zircotec has modified its ThermoHold coating by giving it a smooth surface finish to minimise exhaust gas airflow disruption, enabling the teams to optimise their exhaust design and recover downforce lost with the banning of double diffusers.

'Our first coating applications in this area enabled teams to blow hot exhaust gases through the diffuser and floor safely,' explains Whyman. 'Engineers were able to introduce the feature to cars that hadn't been conceived to run blown exhausts. Teams are now seeking performance gains by maintaining high gas speeds. Our ability to finely adjust the surface finish means we can offer a smooth finish with no impact on thermal protection.'



Exhaust placement is a hot topic in the pit lane this year. With increased understanding of how the gasses can aid the car's aerodynamics, thermal barrier coatings are now commonplace, as seen here on the Red Bull RB6

we think we have a minimum in terms of space.'

Renault is using a pull-rod layout on its R31, but technical director, James Allison, makes it clear that the choice of layouts was not an easy one: 'There is a lot of discussion over the rear suspension,' he explains. 'It's not surprising as the fastest car of last year, the Red Bull RB6, had a pull rod, so I would imagine every team in the pit lane would have seriously evaluated it. Eventually, though, we came to the conclusion that in aero terms there wasn't a lot in it.'

EXHAUST DEVELOPMENT

Another area where teams are exploring different concepts and ways to re-capture some of the downforce lost with the diffuser rule change is exhaust layout, with some teams, such as McLaren, not even having finalised its design by the time it took to the track for the first time in Spain. 'It's all because people realised last year what could be done,' says Nick Wirth, technical director at Virgin Racing, 'and the engine manufacturers developed strategies that allowed more mass flow to come out of the exhaust with throttle off than had previously been thought possible. That means you can be more aggressive with your positioning, and with your use of the extra energy and momentum of that flow. People have been blowing exhausts into diffusers for a long time, but I don't think they understood it. Now I think a lot of people do understand it.'

The most aggressive approach so far is to be found on the Renault R31, the engineers of which were given a short, simple design brief: 'Be daring, try to innovate, take risks.' Clearly, they took this to heart with the exhaust system design, which has no obvious exhaust outlets. Instead, the rear bodywork is continuous, aside from the exit duct for the gearbox oil cooler, while the exhaust exits can be found at the front of the sidepods, just below the ducts. Renault technical director, James Allison, alluded to the benefits of the layout during the launch event: 'It represents our attempt to extract the absolute maximum aerodynamic performance from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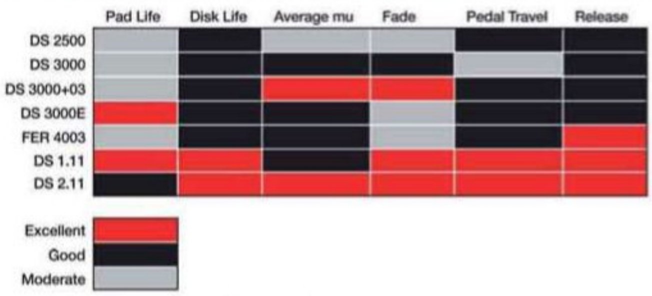

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the regulations, which have changed quite significantly for this year, and to further develop the concept of using the exhausts to blow the floor.'

TYRES

Aside from the new aerodynamic regulations, the biggest single change for the 2011 season is the arrival of Pirelli as the single tyre supplier. To ease the Italian firm into its role, the weight distribution for all cars has been fixed - no less than 291kg on the front axle and 342kg on the rear. With the overall weight limit increased to 640kg, it gives teams a window of 7kg to play with. 'I think it would have been fine without the restriction,' admits Key, 'but I understand the concerns of others, because it's quite a neutral weight distribution and it doesn't really impact on the architecture of the car. It's more about packaging and aero. I think when it comes to the weight distribution, it's nice to have more freedom, but it's sensible because with new tyres it's good that you won't be doing something miles outside of the range.'

Allison echoes the Sauber engineer's comments: 'It removes one of the main degrees of freedom that the engineer has in his set-up arsenal, but it applies to everybody equally so it just means you have to fall back on the other tools available.

'It is not, however, the only thing that will impact the balance of the car. The challenge for us as teams will be aside from the one per cent of weight distribution we can move around in, and we will use all the other degrees of freedom on the car to get the most out of it.'

Team Lotus technical director, Mike Gascoyne, would like to be less restricted, especially as his T128 is not fitted with a weighty KERS. 'It's not an issue really, though, as it is the same for everyone. We'll just have to see where the tyres are. Certainly after Abu Dhabi, we would have wanted to play with it a lot more as we don't have KERS and thus have the ability to play a lot more, but it's not allowed.'

REAR WINGS

All cars will now be fitted with adjustable flaps on the rear wing. On a designated straight at each track, drivers will be able to use them in certain situations, though their use will be free outside race situations.

THE 2011 CARS

McLaren MP4-26
Engine: Mercedes-Benz FO108Y
KERS: Mercedes HPE

Mercedes W02
Engine: Mercedes-Benz FO108Y
KERS: Mercedes HPE

Williams FW33
Engine: Cosworth CA2010
KERS: Williams

Renault has fitted very unusual exhaust outlets on its R31, with the gasses exiting from the front of the sidepod

Teams will, however, be free on weight distribution in 2012, as the regulation is only in place for this season. The new tyres have also left the teams with some uncertainty, with extra flexibility designed in. 'One issue we had last year was that the car had very tightly linked aero and mechanical behaviours,' explains Key. 'Despite very good downforce figures, it was inconsistent. On the C30, I wanted a more benign aero characteristic, which gave more mechanical freedom. With the tyres in mind it was better to de-couple the aero and mechanical characteristics a bit to give more flexibility. That was one direction.'

> “you would be foolish not to have it”

KERS

In 2010, all the teams agreed not to use energy recovery systems, despite there being no ban on them. But this season almost all the cars on the grid are equipped with KERS, the exceptions being Lotus, Virgin and Hispania. 'The only real difficulty with KERS was that, although we ran it in 2009, we didn't have a great experience doing so,' explains Allison. 'You had to be mindful, though, that it is not 2009 now, it is 2011, and the rules are very different. Now there are a number of things that make it a more attractive proposition than it was in '09. So it was relatively easy to decide that we needed to have KERS as part of the car. We needed to make a better job of it than we did the first time round, make it have less impact on the car as a whole in packaging terms and make it much, much lighter.

'Without refuelling, there is less opportunity to overtake in the race with strategy. Qualifying and the start have always been important, but they are even more so without refuelling. KERS is at its best in qualifying, where it gives the most lap time, and it undeniably gives a decent advantage at the start. With that in mind, you would be foolish not to have it.'

One team that does not have KERS is Team Lotus. 'It's a time and resource limit, and it's a disadvantage where we are at the moment,' explains Gascoyne. 'The bottom line is that if you have to catch up 1.5 seconds, KERS is not the make or break. KERS was a step too far for us. In terms of ultimate lap time, people will struggle in the first half of the year, but the worry is the strategic one off the start. It would be galling if we got the speed but got held back by KERS runners staying ahead of us.'

The cost of buying the

THE 2011 CARS

Force India VJM04
Engine: Mercedes FO108Y
KERS: Mercedes HPE
Gearbox: McLaren

Scuderia Toro Rosso
Engine: Ferrari 056
KERS: Ferrari

Hispania F111 (Dallara F110)
Engine: Cosworth CA2010
KERS: none
Gearbox: Williams
(NB: the HRT F111 had not been revealed as *Racecar Engineering* closed for press, though it is expected to be an evolution of the Dallara F110)

THE 2011 CARS

Sauber C30
Engine: Ferrari 056
KERS: Ferrari
Gearbox: Ferrari

Lotus T128
Engine: Renault RS27
KERS: none
Gearbox: Red Bull

Virgin MVR-02
Engine: Cosworth CA2010
KERS: none
Gearbox: Wirth Research / Xtrac

systems is siginificant, with only Williams, Ferrari (with Magneti Marelli) and Mercedes (with Zytek) offering F1-spec units.

'We buy the battery cells from the Far East and assemble them ourselves at Williams,' explains Michael. 'Doing that, there is an amazing difference in cost. If we were to get someone to assemble the battery packs for us, there was no way we could do KERS on that basis. So we employed two people who were trained to build the li-ion battery packs, while the MGU was developed in-house with help of a University. The ECU is fairly standard and made inside Williams, with all of the electronics in house.'

Even once the systems are purchased, teams have to package them into an already crowded space. 'It is a significant thing - there are various approaches to where you can put it,' explains Key. 'Depending on how you do it, it makes a bigger difference to your wheelbase and powertrain or a bigger difference to your aerodynamics. Without KERS you would have more freedom to play with wheelbase, sidepod shapes and the way the chassis looks, but installing it hasn't been a great drama. The big risk if you decide to use the wheelbase to accommodate it is that with last year's cars you had a big diffuser, so going longer was okay as there was a lot of floor to suck on. But now, with the small diffusers, there is a lot less power, so maybe you want to go shorter.'

Of course, all this is just the start of the development race. The first grand prix of the year, in Melbourne in March, will undoubtedly bring many updates and innovative new solutions. Keep up to date with them at www.racecar-engineering.com

NOSE JOBS

A number of cars this season have adopted the wide 'platypus' nose first introduced by Red Bull. The very high, wide and thin structures may not be aesthetically pleasing, but apparently they work in the wind tunnel, as James Key explains: 'It's a tricky aerodynamic thing. The Sauber C29 had a high nose last year, but a different concept and a different shape. Ever since the 2009 regulations came in, you had this FIA-prescribed centre section of the front wing. It left that area difficult to do much with, as everything there was taking place outwards where the rules allowed it - intricate flaps and bits and pieces on top of the wing to make the air do complex things. These tended to be outwash devices rather than inwash, so the middle of the car ended up with little to interact with but, if you lift the nose up, then at least you are feeding a fresh flow to the middle of the car. It's driven by the centre of the front wing being what it is. In fact, the front wings now tend to out rather than in, which is what they did in 2008.'


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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

Low-speed aerodynamics

UK hillclimb single seaters generate Formula 1-beating downforce and efficiency, but what is the drag cost?

With wide span wings and fully profiled underbodies allowed, downforce potential in UK hillclimb racecars is high. But from what speeds can useful downforce really be generated? Continuing with insights into the aerodynamics of the DJ Firestorm hillclimber, we'll look later at the absorption of power by aerodynamic drag, but kick off this month with a topic of special interest in all disciplines where low-speed aerodynamics is important. An oft-asked question is 'At what speed do aerodynamics start to play a role?' There are two main influences on the answer. First, the flows on downforce-generating (and drag-inducing) surfaces do not fully develop and 'attach' until speed is high enough, which in practical terms means that vehicle speed needs to exceed the stall speed of downforce-generating devices. Secondly, the speed also needs to be sufficiently high for the aerodynamic forces generated to be tangible, meaning that useful additional grip is generated. Drag is also governed by these same factors, but at low speeds it has very little relevance. Two separate trials were performed on the Firestorm at different speeds.

"vehicle speed needs to exceed the stall speed of downforce-generating devices"

The first trial was carried out, as usual, at the start of the session to see at what speed the remainder of the session would need to be run. Generally this involves running in the configuration as delivered to the wind tunnel at 60mph (26.8m/s) and then at 80mph (35.7m/s). Sometimes the lift coefficients on racecars can be significantly smaller at 60mph than at 80mph, which is an indication that flows are not fully attached at the lower speed, so subsequent tests are performed at the MIRA tunnel's maximum of 80mph. In this case, the DJ Engineering team who constructed the Firestorm

TABLE 1

	CD	-CL	-CLfront	-CLrear	%front	-L/D
21.7m/s (~50mph)	0.767	1.466	0.583	0.883	39.8	1.911
26.4m/s (~60mph)	0.768	1.481	0.589	0.892	39.8	1.928
35.1m/s (~80mph)	0.759	1.456	0.583	0.873	40.0	1.918

also wanted to see how the aerodynamics worked at lower speeds, so another run was done at 50mph. The results are shown on the previous page in table 1.

Although there was a wider spread of results than might ordinarily be expected between runs in the same configuration, the lowest lift coefficients actually occurred at the highest test speed. Had there been flow separations occurring at lower speeds then the lowest lift coefficients would be expected to have been at the lowest test speed. And the differences in the coefficients at 50mph and 60mph were very small, too. So it appears the flows were fully attached at 50mph, and that the aerodynamic devices were working efficiently at this speed.

A second trial was carried out with a four-element rear wing installed, and runs were done at 40mph and 60mph to see whether the flow was attached to this aggressive device. The results are in table 2. Interestingly, the rear wing performed well at 40mph, but the front wing showed a reduced coefficient at the lower speed and, combining this with the results of the first trial, we can say that the front wing started to work fully between 40mph and 50mph.

So what levels of downforce are being generated at 50mph? Using the downforce equation $F = \frac{1}{2} \rho A v^2 CL$, where ρ is air density and A is frontal area, the overall downforce at 50mph was approximately 570N. With an estimated weight, including driver, of around 560kg (5494N), this represents just over 10 per cent of car weight, and corresponds approximately to 10 per cent additional grip. So even at 50mph, the level of downforce here is pretty significant in relation to performance in acceleration, braking and cornering.

POWER ABSORPTION

A variation of the aerodynamic force equation enables the calculation of drag as power absorbed. With a frankly shocking but familiar mix of imperial and metric units, where power is in bhp but frontal area is in m² and speed in m/sec, this is:

$BHP\ absorbed = (CD.A.V^3)/1225.$

Re-arranging this it is also possible to calculate a theoretical maximum speed if power is adjusted to a figure at the wheels, so the equation becomes:

$V_{max} = \sqrt[3]{[(BHPwheels \times 1225) / CD \times A)]}$

The quoted peak power of the Firestorm's 2.65-litre Cosworth XD was 528bhp (so approx 475bhp at the wheels) and the CD value in late 2010-spec was 0.793. From these numbers we can calculate the theoretical top speed of the Firestorm to be 81.8m/s, or 183.1mph. The maximum the car *actually* saw was 137mph (61.2m/s) over the finish line at Gurston Down hillclimb, so the car had power to spare.

The other way to look at this is to calculate the power absorbed at the maximum speed achieved. With this CD, it comes to 198.8bhp, or just over 40 per cent of the available power at the wheels, so the car had over 275bhp still available for acceleration at this speed. This, together with the fact that the cars spend a very short part of their runs at the highest speeds, is why drag was not considered the primary aerodynamic concern.

One last comparison can be made on this subject. As described last month, one of the 'best' configurations tested during this session produced the data in table 3. Another 17 per cent downforce was found during the session relative to the end-of-2010 configuration. But drag went up by over 20 per cent. How much extra power would be absorbed at the 2010 peak speed with this higher drag coefficient? As power absorbed is linearly related to drag coefficient, it too would increase by 20.4 per cent to 239.4bhp at 137mph, or by an additional 40.6bhp. This would still leave over 235bhp available for acceleration at this speed. Better still, engine developments over the winter are expected to release a further 75+bhp, which will more than compensate for the additional drag. More next month...

Racecar Engineering's thanks to Wallace Menzies and all at DJ Engineering Services Ltd

TABLE 2

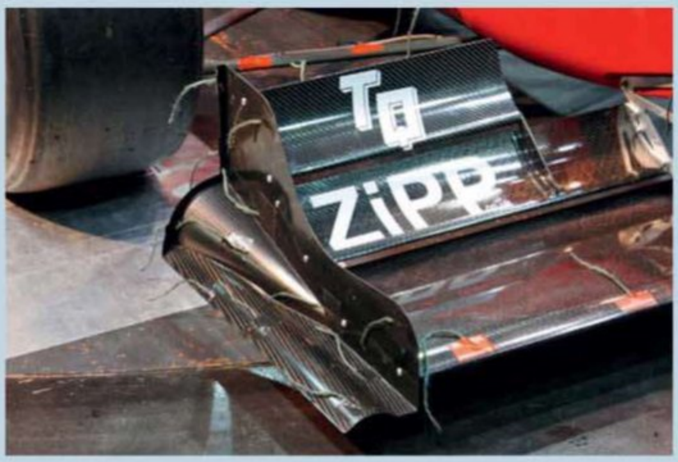
	CD	-CL	-CLfront	-CLrear
18.3m/s (~40mph)	0.919	1.805	0.772	1.033
26.4m/s (~60mph)	0.932	1.904	0.881	1.024

TABLE 3

	CD	-CL
2010 end	0.793	1.806
Session best	0.955	2.117
Change, (counts)	+162	+311
Change, %	+20.4%	+17.2%

Smoke and wool tufts seem to show attached flow on this rear wing even at the 25mph speed used for the flow visualisation session

This four-element rear wing showed attached flow at 40mph...



...while this front wing did not develop its full performance until somewhere between 40mph and 50mph

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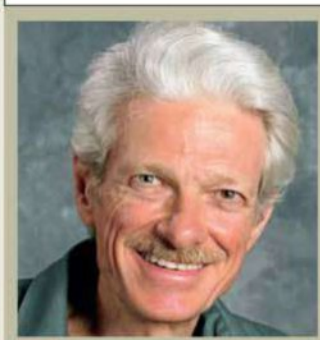

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THIS MONTH:
Q Can you relate the relationship between anti-roll bars and springs?

A Yes, but in in measuring and expressing anti-roll bar rate and evaluating its roll resistance equivalency to ride springs, it is imperative you understand which method of measurement you are using

Anti-roll bar / spring rate equivalency

Q Do anti-roll bars reduce mechanical grip? From what I understand, theoretically an anti-roll bar is supposed to act like a spring, but only reduce body roll when a car experiences lateral forces. I also believe most anti-roll bars are linear in rate. Is this true? If so, what happens if we compare two identical cars in all aspects except car A has 200lb/in front springs and a 200lb/in anti-roll bar rate, with 300lb/in rear springs and a 300lb/in anti-roll bar rate. Car B, on the other hand, has 400lb/in front springs and no anti-roll bar, but 600lb/in rear springs and no anti-roll bar.

Since both car A and B have the same amount of roll resistance and the same ratio of front / rear roll stiffness, both cars should handle identically and achieve the same lateral acceleration on a smooth surface. Correct? I ask this because I've come across a post made by the 2010 SCCA DP champion who states that anti-roll bars reduce mechanical grip. If this is true, how would they do this and where would the static load go under cornering? Here's a precis of his post, and a link to the message board: http://www.mr2oc.com/showthread.php?t=298272&page=2&pp=30

'...with 550lb/in front and 400lb/in rear spring rates, it's easy to now choose a front spring rate that will produce a more comfortable ride. 300lb/in front springs would give us a positive favoured speed and move the centre of suspension closer to the c of g of the car, just aft of the centre point between the two axles. We can then add back the spring rate by installing a anti-roll bar with a rate of 250lb/in.

250lb/in front bar + 300lb/in spring = total rate of 550lb/in

'...but it's hard to find an off-the-shelf anti-roll bar that has exactly the rate you want. In reality, unless you want to fabricate a custom bar every time you want to test a different set up, you need to calculate the rates of the available bars and then determine how much spring rate you need to achieve the desired

total rate. If you measure your existing anti-roll bar and find it has a rate of 200lb/in, the spring rate you would want is determined by subtracting the existing bar rate from the target spring rate eg 550lb/in target rate - 200lb/in bar = 350lb/in springs.

'But anti-roll bars are not the dynamic equivalent of springs. An anti-roll bar transfers load from the inside tyre to the outside tyre and so reduces mechanical grip as they add spring rate. And the effect is not linear. The stiffer the bar in comparison to the springs, the greater the loss of mechanical grip. To give an example, if we set our proposed racecar up using the target data we have assumed above using the target spring rates without any anti-roll bar, the car should have good balance. But if we achieved that same target spring rate using a front anti-roll bar, the car would tend to understeer more than if we used only springs and no anti-roll bar. The greater percentage of the total front spring rate the bar accounted for, the more the car would understeer.

'With this simple method, it is easy to compare the effect of the front bar by comparing the same total spring rate using just springs and no front bar to the same total spring rate incorporating a front bar.

'The same total front spring rate achieved using a front anti-roll bar will produce more understeer than the same total front spring rate achieved using springs only. In addition, the effect of the front bar changes based on the level of grip the surface offers. As a result, the car does not have consistent balance from surface to surface, or even from run to run, as the tyres heat up and the surface cleans and heats up through the day.

'If one chooses to use a front anti-roll bar, the effect resulting from the loss of mechanical grip will have to be accounted for by softening the front springs enough to bring the balance back to neutral.

'Choosing the amount of anti-roll bar to use is now easy. If the driver prefers a smoother / softer ride, use a very stiff front anti-roll bar and subtract the front bar rate from the total spring rate to determine the required front spring rate. Testing can then determine how much less spring rate is necessary to bring the handling balance back to neutral. One could also compromise and use a very soft front bar, in doing so minimising the loss of mechanical grip.'

"The stiffer the bar in comparison to the springs, the greater the loss of mechanical grip"

A In fact, anti-roll bars (sway bars) *are* dynamically equivalent in roll to springs. They are generally linear and do not transfer weight or wheel load any differently than ride springs. However, many people get confused about this because of a subtlety in measuring and expressing anti-roll bar rate, and evaluating its roll resistance equivalency to ride springs. This causes people to think they are adding one amount of roll resistance with the bar, when in fact they are adding twice as much as they think. Of course, the effect on the car reflects the difference, and they then erroneously conclude that the bar must work in some fundamentally different manner in roll than the ride springs do.

"Many people get confused about this..."

Ordinarily, a ride spring has one end fixed with respect to the frame, and one end that moves with respect to the frame. An inch of movement or displacement of the spring is simply an inch of movement at the end that moves. Simple. No way to get confused about that.

But an anti-roll bar has a middle portion that is fixed with respect to the frame, and *two* ends that move. In roll, the ends move oppositionally. So, what then is an inch of movement for the device as a whole? Is it an inch of movement at each end relative to the frame, which is two inches of relative movement between the ends? Or is it one inch of relative movement between the ends, which is half an inch of movement at each end relative to the frame? Both definitions make semantic sense, and neither is right or wrong, but the two methods produce rate numbers that differ by a factor of two.

A typical sway bar rate testing fixture measures the force produced at the moving end of one bar arm when that arm is moved an inch. That is the bar's rate in pounds per inch per end pair. The bar's rate in pounds per inch per end is twice that value.

When we multiply the bar rate in lb/in/end pair by the square of the bar-end-to-contact-patch motion ratio, we have the bar's contribution to wheel rate in roll in terms of lb/in/wheel pair. An inch per wheel pair is therefore half an inch per wheel.

When we multiply the bar rate in lb/in/end by the square of the bar-end-to-contact-patch motion ratio, we have the bar's contribution to wheel rate in roll in terms of lb/in/wheel. An inch per wheel then is two inches per wheel pair, and that displacement results in twice as much force change as an inch per wheel pair.

We evaluate wheel rate in ride, and roll resistance contribution from the ride springs, in lb/in/wheel. Therefore, to have an equivalent value for the bar's contribution we need to also use lb/in/wheel, which is double the number we get if we simply multiply the number from the bar rate by the square of the motion ratio.

So, if we take a front bar that contributes 200lb/in/wheel pair and add it to ride springs that give a wheel rate of 350lb/in, we don't have a wheel rate in roll of 550lb/in, we have 750lb/in in roll. So of course the car has more understeer than it has with 550lb/in wheel rate in both ride and roll. If we used a bar that contributed 100lb/in/wheel pair, we'd have an equivalent set up, and similar car behaviour.

The anti-roll bar set up on a Formula Ford, running through the top of the gearbox casing and with angled links back to the rear suspension


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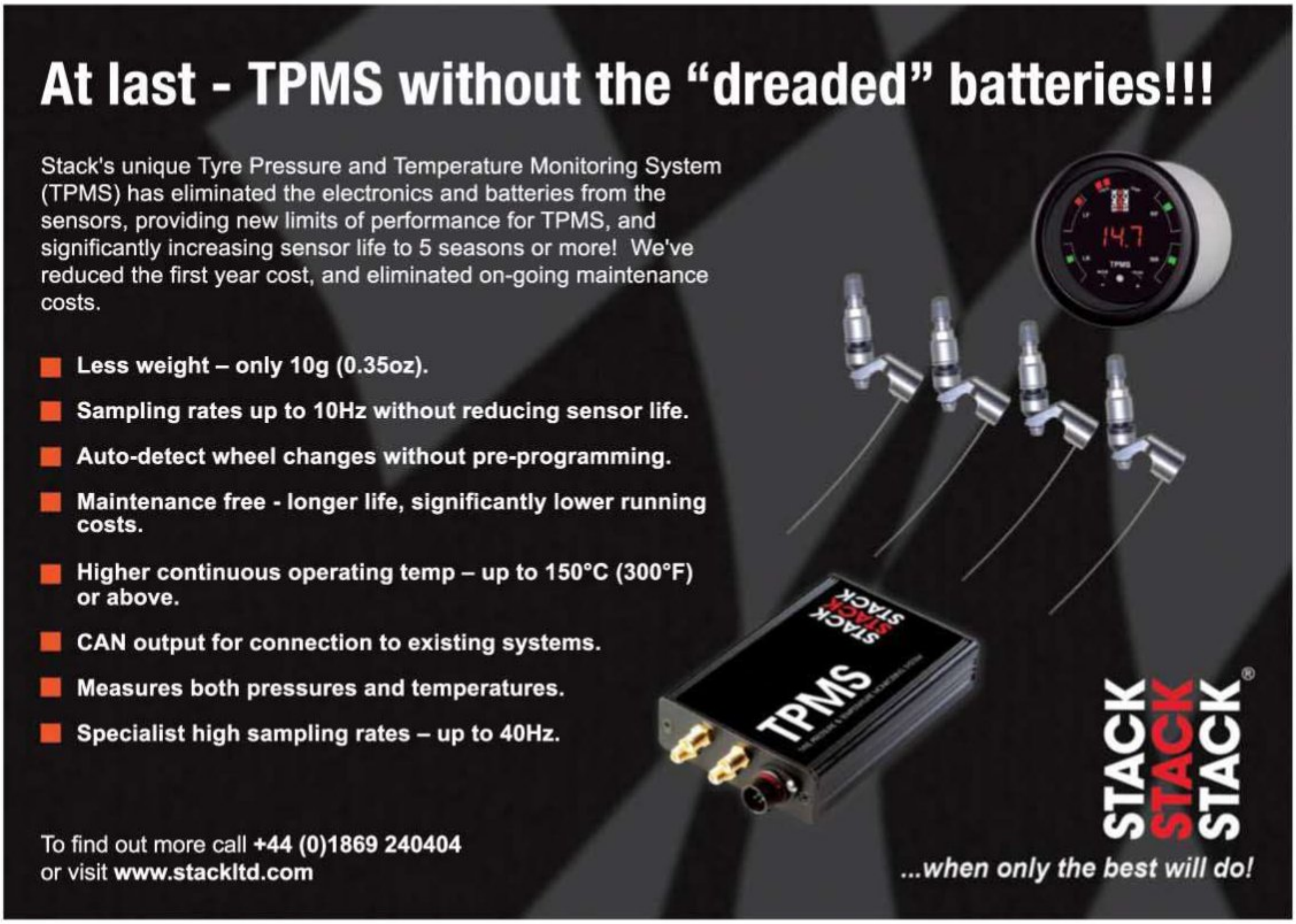

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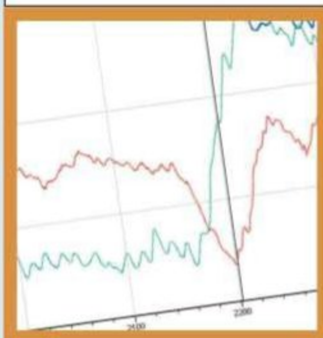


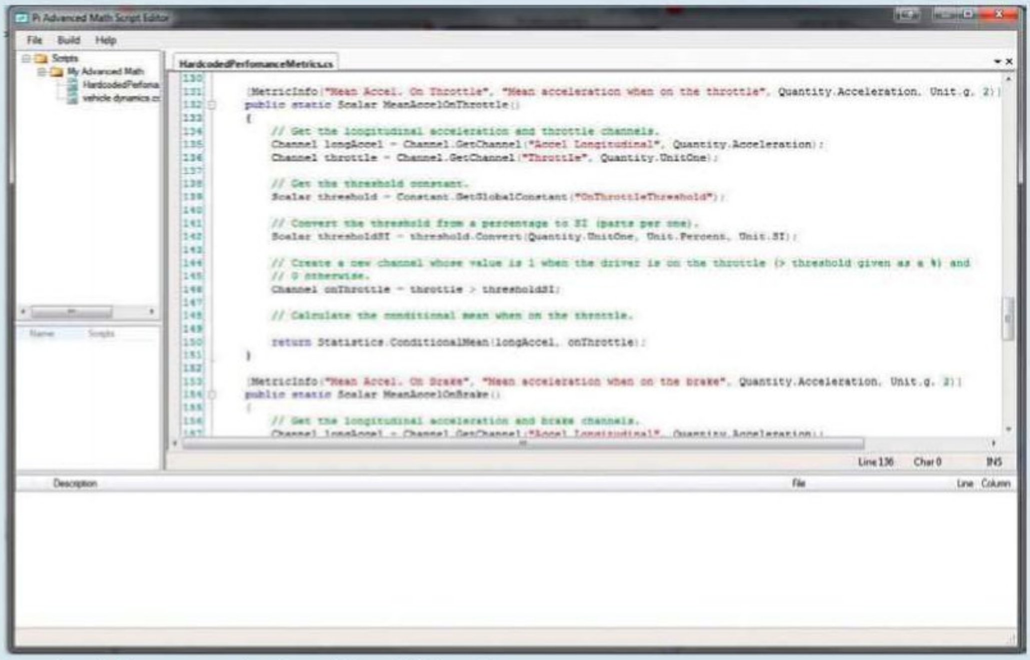
FIRST PRINCIPLES

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

Advanced mathematics

Improving your race engineering by numbers



Sample code for mean acceleration while on full throttle

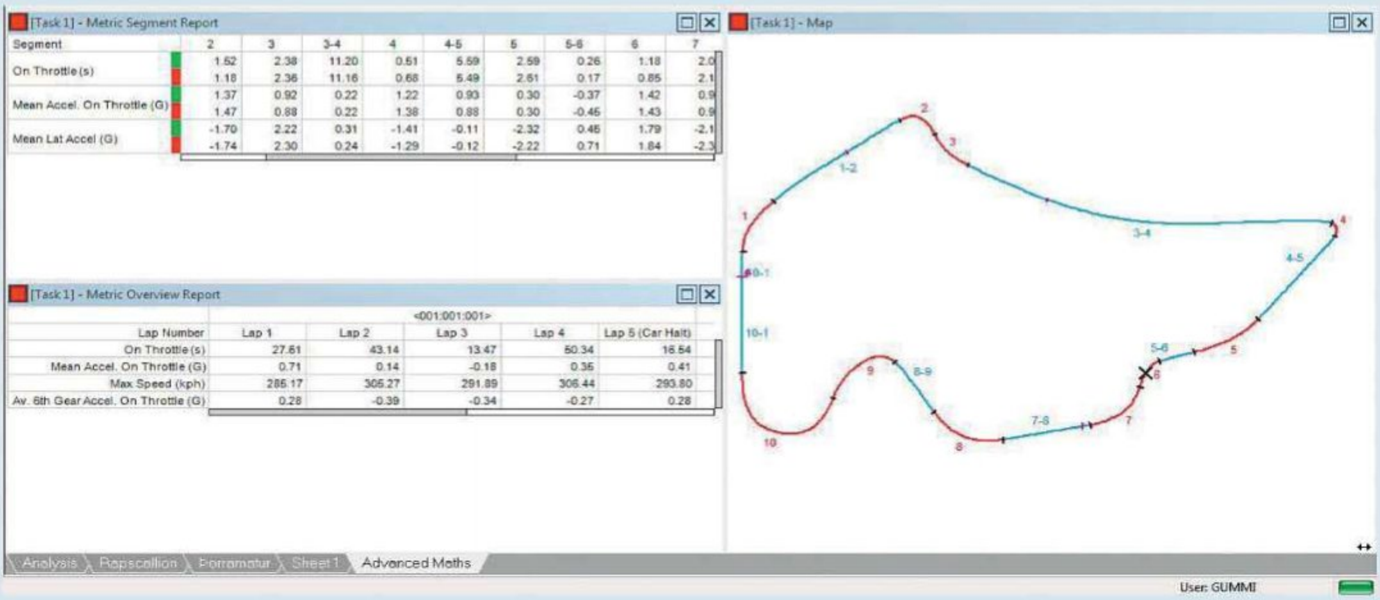
Anyone with a serious interest in racecars will very soon realise that not a lot is left to chance when it comes to deciding what changes are made to make the car go faster. In many instances, it may seem like it just comes from experience and gut feeling, which in some part is true because good engineering instincts are second nature in the motorsport world. But these instincts are rarely borne out of experience alone, as when decisions are analysed, they always boil down to one thing – mathematics. Engineers spend vast amounts of time calculating even the most minute things and simulations are nothing more than giant sets of mathematical equations describing the behaviour of racecars given certain inputs and parameters.

Once you put a few sensors together on a racecar you can start calculating and visualising what the racecar is doing in the hands of our tame racing driver.

Most data analysis packages allow simple maths channels to be made up so we can calculate basic things like instantaneous brake balance, loads on suspension components and aerodynamic forces among others. However, as we get more and more into the mathematical analysis of racecars we find that basic maths channels or equations simply won't cut it. For example, how can we travel through time in our data and use values from any point in time (or distance) in our calculations?

This is where advanced mathematics comes into play, or the ability to program the calculations as if they were a computer program. Advanced mathematics sets the engineer free from the constraints of basic mathematical functions and opens up the ability to calculate just about anything, with as many variables or constants imaginable. As long as the relevant data is available, the engineer can create short (or long) programs that make use of constants and logged data to visualise, for example, the percentage of brake balance based on the maximum value found in the data, or dynamic camber changes for each individual wheel. Another

> **"Advanced mathematics sets the engineer free..."**



Visualising the scripts based on segments of a circuit and an overview report for each lap

significant advantage of advanced mathematics is the possibility to calculate statistical values eg a mean or an average over a set distance or part of a circuit. For example, it is possible to calculate the time spent on full throttle for each segment of a circuit.

Program script in text format:

```
        [MetricInfo("Mean Accel. On Throttle", "Mean acceleration when on the
throttle", Quantity.Acceleration, Unit.g, 2)]
        public static Scalar MeanAccelOnThrottle()

                // Get the longitudinal acceleration and throttle channels.
                Channel longAccel = Channel.GetChannel("Accel Longitudinal",
 Quantity.Acceleration);
                Channel throttle = Channel.GetChannel("Throttle",
Quantity.UnitOne);

                // Get the threshold constant.
                Scalar threshold =
Constant.GetGlobalConstant("OnThrottleThreshold");

                // Convert the threshold from a percentage to SI (parts per one).
                Scalar thresholdSI = threshold.Convert(Quantity.UnitOne,
Unit.Percent, Unit.SI);

                // Create a new channel whose value is 1 when the driver is on the throttle
(> threshold given as a %) and
                // 0 otherwise.
                Channel onThrottle = throttle > thresholdSI;

                // Calculate the conditional mean when on the throttle.

                return Statistics.ConditionalMean(longAccel, onThrottle);
```

DECLARING THE VARIABLES

If we look a bit closer at how a typical advanced mathematics channel or program would be built up, it is very similar to popular programming languages.

We start by declaring the variable we will be calculating, followed by a list of data channels we wish to use in the calculation. This could be anything the data system is currently logging. Next we need to declare all the constants we wish to use. Normally, these are handled separately and, in this example, the advanced mathematics package in the data analysis software automatically knows the location of the constants. Then any intermediary values that will be needed are calculated, then the calculation of our desired value. If the advanced mathematics are a part of the data analysis software, the calculated channels are available as soon as the advanced maths script has been compiled and can be used like any other channel in the data.

Above is an example of an advanced mathematics channel that shows mean longitudinal acceleration while on full throttle. This can then be displayed as a segment report based on a track map, as an overview report showing values per lap, or alternatively, custom events can be created to highlight an area of specific interest.

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Most of the fuels and gas flows used in motorsport fall within the wavelength of the green laser, seen in the pictures here

Changing the oil

How lasers and a substance not dissimilar to vegetable oil are quietly re-shaping motorsport

BY SAM COLLINS

Quit smoking, throw away your balls of wool and send the day glo liquid back to the paint shop because Particle Image Velocimetry (PIV) is rapidly becoming the state-of-the-art in car development.

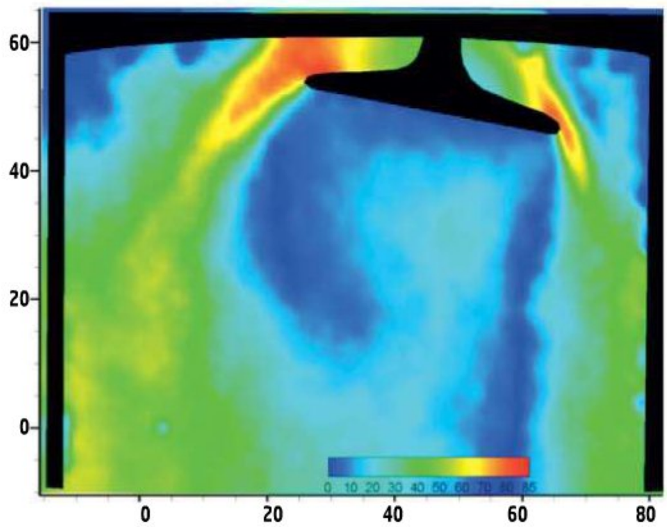
At its most basic, PIV is simply another form of flow visualisation, using particles of a vegetable oil-type liquid spayed into the air and then tracked as they flow over the subject of interest. In reality, though, it's far more complex than that.

The technique has been used by Toyota Motorsport in Cologne, Germany for some time now in its highly advanced engine development facility. 'There are various techniques for visualising fuel spray,' explains Marcus Send, Senior Engineer Engine Research at Toyota Motorsport. 'We use a bench where we study the spray and gas flow of a single injector. We illuminate the particles so we can see the movement and create the vector field from that.'

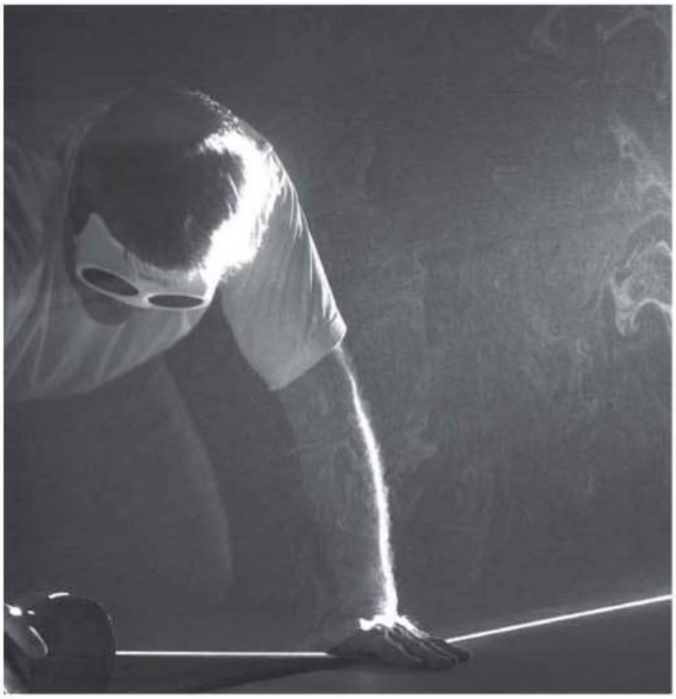
'PIV is a very nice visualisation tool,' adds Send. 'For in-cylinder work it's harder than on the bench as you don't have that level of access in the engine. Instead, we make a window in the [cylinder] head and shoot the laser in while a camera is placed at 90 degrees to the light. The technique then is very sophisticated from both a hardware and software standpoint. It involves illuminating the flow after it has been seeded, then illuminating it again with a laser sheet. The two pictures are taken a fraction of a second apart, then a complex algorithm processes the images and produces a vector field. Its use is becoming more common, but we don't know if other F1 teams do it.
It looks like CFD, and is a great way to validate the CFD and tune its accuracy.'

Because the only light source is the laser, the only particles visible are the ones passing through the area of interest. It goes without saying then that is a very fast process indeed, with just two or three thousandths of a second between images.

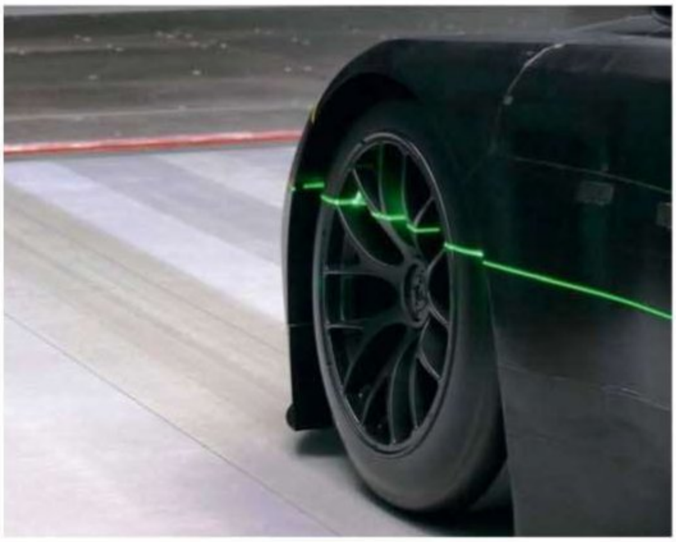
Toyota developed its PIV methodology in house, albeit



Toyota initially used PIV for in-cylinder flow visualisation, as shown here. The technique gives results similar in appearance to CFD



The DEHS particle mist can clearly be seen in this image. The powerful lasers make protective eyewear essential for those working when the system is on



A green laser is projected into the test section to illuminate the particle cloud and allow the cameras to 'see' the flow patterns. In this image the house lights are switched on, but a real run is done in total darkness

with external suppliers providing equipment and advice. The results do indeed look a lot like CFD, but the crucial difference is they are real, experimental results, not simulation.

It's a technique that has applications outside of F1, too. NASCAR, for example, places great importance on the flow in the inlet manifolds. 'We have done some work on internal projects like that,' adds Send. 'It requires some design work on top, to allow optical access to the engine, and this is something we have done, but more to look at the airflow than the fuel specifically.'

tunnels anywhere equipped with this technology, but also are the only ones in the world available for customer use.

'By looking at the smoke, we could visualise the flow, but we were unable to quantify it,' explained Frank Michaux, a CFD/PIV researcher at Toyota Motorsport. 'You could therefore only make assumptions about speeds based on the visual aspects of the flow.

'The whole problem in this industry is how to visualise airflow without introducing something new into that flow that could potentially compromise the end results. With the PIV

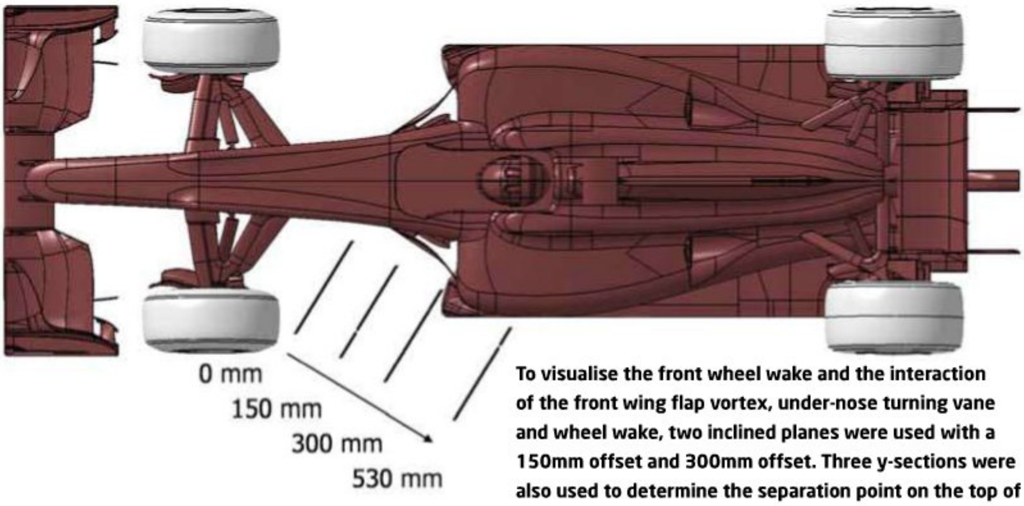
"With the PIV method, you can really attach numbers to airflow"

Although the technique is already widely used in the development of missiles and sub and supersonic aircraft, it is less common in land vehicle development. But Toyota's aerodynamics team decided to employ it in the firm's two already highly advanced windtunnels capable of running 60 per cent scale wind tunnels (full scale in one of them). More powerful lasers were required, as well as more cameras, but the system was soon up and running in both working sections, the first coming on stream in 2007. What's of particular note about this is that not only are Toyota's tunnels the most advanced dedicated land vehicle test

method, you can really attach numbers to airflow.'

Toyota's PIV system involves introducing particles into the airstream, in essence, the tunnel is filled with a fog, or mist, made up of a substance called Di-Ethyl-Hexyl-Sebacat (DEHS), which has a very similar density to air and so 'floats' in the tunnel. It is also liquid at room temperature, which makes for ease of handling. 'In the beginning of this technique people just used oil similar to that you might put on your salad,' admits Michaux, but the technique has since been refined. 'Theoretically, by putting particles inside the flow you *are* disturbing it slightly, but the particles are micron size so the disturbance is minimal. At high pressure, the oil is vaporised, creating the mist you need. We inject the particles behind the working section so that they are evenly distributed. Once it's up and running, you have to wait a bit and run at low speed before you start measurement to ensure the distribution of the flow.'

Particle size was heavily studied, not only by Toyota, but by many universities and technology firms, especially in the aviation industry, but TMG settled on the non-toxic DEHS as the best solution. 'We have a size that works for us with this type of flow,' explains Michaux. 'But if



To visualise the front wheel wake and the interaction of the front wing flap vortex, under-nose turning vane and wheel wake, two inclined planes were used with a 150mm offset and 300mm offset. Three y-sections were also used to determine the separation point on the top of the wheel and the scan was done in eight z-sections you were looking at supersonic flow, or really detailed flow inside the boundary layer, then you may need a different particle generator as DHES is not suitable.

Another advantage of the system is that after time, the particles dissolve in air, so there is no clear up work to do, which makes it more efficient in wind tunnel time, too. 'After a PIV session we just vent the tunnel. Some particles do get stuck on the model or on a camera lens, but only a tiny amount in a full day's running so you may have to clean a lens once.'

For most of the measurements (eg x-sections, y-sections, z-sections, under-floor measurements) specific optics are permanently installed in the wind tunnel to ensure the laser sheet is in the correct position, while all the laser optics are mounted on traversing units, to be able to move the laser sheet to the desired measurement positions. This makes the set up of the measurements quick and repeatable. 'With PIV, the only set up work we need to do relates to what plane the customer wants to measure,' explains Michaux.

> **"the ultimate step on from the smoke wand!"**

'Using the system does not stop you doing other testing because, as the particles are not intrusive. It's really flexible, we can even put cameras behind the rolling road if we want.'

Of course, playing with light in a clear-walled wind tunnel does create some issues with reflections, and TMG faced just this problem with one of its working sections, as Michaux explains: 'In one tunnel there are glass walls, so it's no problem, but in the other tunnel there is a small difference in that the walls are made of Plexiglas in the area where we use PIV. So we have had to replace this in some areas with a special anti-reflection glass instead.'

CASE STUDY

In 2009, Toyota engineers wanted to study the wake behind the front wheels of the TF109 (and, later, the still born TF110), but the issue with visualising the flow in that area of the car is that you basically cannot see it. Therefore, to allow the PIV to 'see' the wake of the front wheels, an extra camera had to be installed in the roof of the working section of one of the twin tunnels.

To change the wake, the Toyota engineers needed to look at options for adding or modifying various front end parts, for example, adding a turning vane under the nose or changing the design of the front wing end plate.

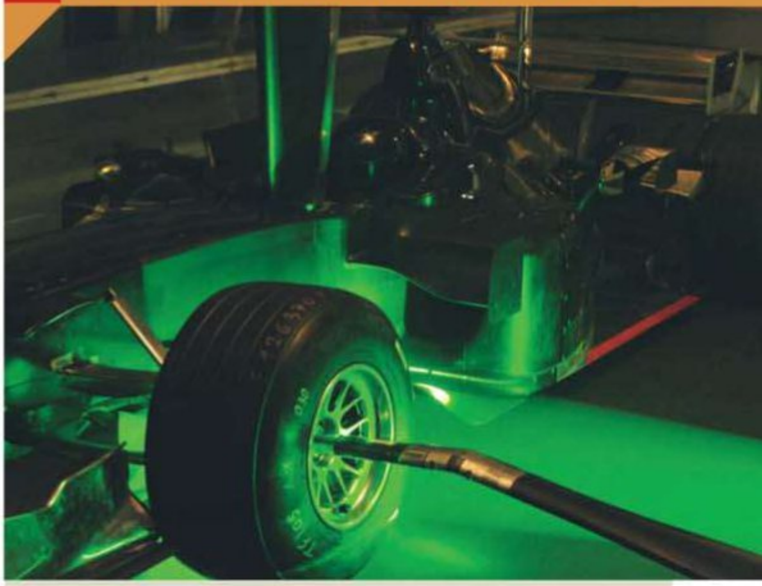
So after gathering the raw data from the PIV measurements of the separation point on the front tyres, the engineers post-processed the data using Tecplot software, which allowed them to see and measure the *exact* position of separation. Each of Toyota's PIV measurements consisted of 300 data sets, with each dataset containing the two photographs. The end result of the PIV process is a complete 2D field of vectors. From this, the velocity magnitude, or vorticity, could be plotted, with vectors based on the average of all 300 data sets. The corresponding CFD result was then also imported into the same software so Toyota engineers could compare the two data sets and determine how accurate their CFD methods were. Whenever necessary, the engineers tweaked the CFD process to get it closer to the PIV wind tunnel results.

In the case of the separation point on the front tyres, initial tests showed the separation point to be too far back from the tyres, so various design iterations were carried out until the problem was resolved.

THREE-DIMENSIONAL TESTING

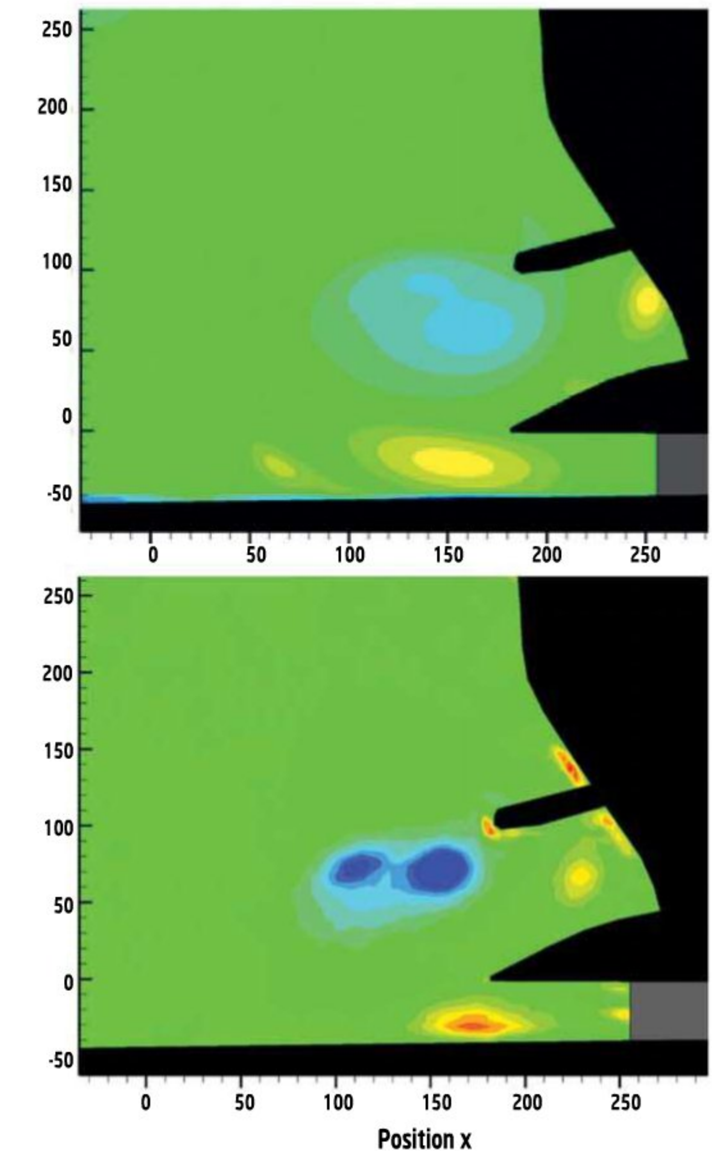
More recently, Toyota has been experimenting with a new technique using a pair of cameras to give a three dimensional or stereoscopic result. 'When you look at the wheel wake you can

A COMPLETE PIV TEST



A complete PIV test is a procedure that is easy for the engineers and quick to complete:

- Before a PIV test can run, special attention is paid to the model as parts hit by the laser must be specially prepared to reduce reflections.
- The camera position is calibrated first, then the laser can be correctly positioned based on this, with reference measurements taken. During the time the laser is active, lights are out inside the tunnel while an infra-red camera allows for the engineers to keep an eye on the model during testing. At the same time, a 'laser curtain' closes off the windows between the control room and the test section.
- The seeding generator is turned on while the tunnel starts running at low speeds. During this time, final checks are performed to ensure an accurate measurement. One of the most important aspects here is to check whether the DEHS particles are evenly spread in the air.
- When everything is deemed ready for the test, the wind tunnel speeds up to the required testing speed and images are recorded with one of the cameras.
- At this time, it also easy to measure flow characteristics when the car is in a different state. Without having to go through all the previous steps, the engineers can adjust the ride height of the car, change wind tunnel speed or change the front wing flap angle from within the control room, thanks to the model being rigidly attached to the movable wind tunnel pylon. At TMG, the data system supports up to 512 measurement points within the tunnel model.
- All data collection results in 300 data sets, with each data set containing two images taken 10-20 microseconds apart. After post-processing, this results in a complete 2D field of vectors.



These images are a comparision between CFD (top) and PIV (bottom), detailing the front wheel wake of the Toyota TF109. While the CFD results clearly show the vorticity diffusing too soon and the turning vane vortex being too far outboard, the PIV allows for much clearer definition of the three relevant vortices (front wing flap, turning vane and wheel wake)

The scale is vorticity, with red positive rotation and blue negative. Green is zero

really see the vortex. You can see the direction of every individual particle. It's the ultimate step on from the smoke wand!' enthuses Michaux of the technique.

'One challenge with PIV is that you need enough light to see the particles, and that's why you need strong lasers,' adds Michaux. 'When you do normal PIV you have to put the camera perpendicular to the light otherwise you cannot measure the velocity. But when you do stereoscopic PIV, for the three dimensions you use two cameras, which you can position differently. If you put them in the wrong positions, though, you won't see anything as you have no reflection of the light.'

Toyota's permanently installed PIV system is rare, possibly even unique, in a commercially available facility, and many different customers have already utilised it, though TMG is not at liberty to discuss them for confidentiality reasons (all the images in this feature are in-house projects). However, McLaren, Williams and Ferrari have all openly revealed that they have carried out work in the Toyota tunnels in Cologne, so it seems fair to assume that at least some of them have utilised this cutting-edge technology in search of that elusive competitive advantage.

CONTINUOUS MOTION

The Toyota wind tunnels are capable of up to 60 per cent model testing, while WT1 is also equipped for full-size cars. Both tunnels have a continuous steel belt rolling road with a maximum speed of 70m/s.

As well as permanently installed Particle Image Velocimetry, the wind tunnels both feature what is known as a continuous motion system (CMS). This means that instead of taking a reading, then adjusting the model's yaw or pitch in the working section, then taking another reading, the system constantly logs. Essentially, it means it gives the results as a line rather than points on a graph. 'Once the model is installed,

everything is run from the control room,' explains Frank Michaux, CFD/PIV researcher at Toyota Motorsport, 'and you can change everything from here. Say you are testing a new wing and it stalls at seven degrees yaw, if you run a test at five degrees and another at 10 degrees you would miss that. But with constant motion you see it.'

In CMS mode, a user-defined program of ride height, yaw, roll, steer and individual pre-load changes provides continuous motion on a pre-defined trajectory, while the high speed logging system is continuously acquiring data at high frequency. This allows realistic road or track analysis, reduces tunnel time by as much as 70 per cent and increases the amount of useful data generated from each individual test, compared with standard motion and acquisition systems.

Crucially, this allows Formula 1 teams constrained by the FOTA Resource Restriction Agreement to maximise the limited hours they are allowed to spend in the wind tunnel. All of this technology apparently makes the twin tunnels in Cologne 'avant garde'. Not our words, but those of Ferrari's Aldo Costa.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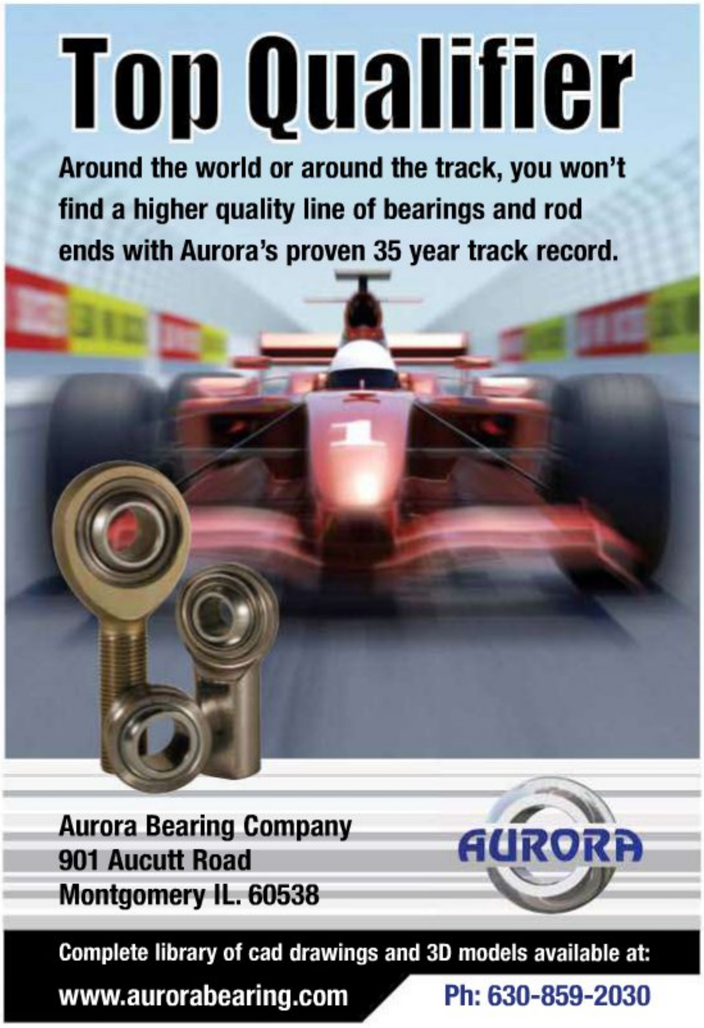
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A walk on the wild side

A glimpse into the life of one of the most talented racecar designers working in grand prix racing today

BY ROB WIDDOWS

> "The ground-effect aerodynamics thesis proved to be a very useful choice"

Genius. The most creative man in grand prix racing. The outstanding talent of his generation. Just some of the many phrases that have been used to describe racecar designer Adrian Newey. And few would argue with any of them. Like many of his ilk, Newey is a very competitive man, in it to win. But in conversation he is reserved, thoughtful, modest about his achievements and slightly impatient – as if something more interesting is occupying his mind. In fact, you can almost hear his mind working, undoubtedly fidgeting with solutions to a problem. Talking to journalists is not Newey's favourite way to spend his time.

There is another side to the man, however, a wilder side. This is the man who races historic cars, and here too he is hugely competitive, not a gentleman racer. The truth is, not only is Newey an exceptional designer of grand prix cars, he has a real passion for cars and for the sport

Newey's break in Formual 1 came with his first job out of university with March where, after a stint away with Force F1, he returned to the position of chief designer on the March 881 grand prix car

that has made him a wealthy man, with an enviable collection of cars, including a Ford GT40, a lightweight E-Type, a Ferrari California and an Aston Martin V12 Vantage.

Adrian Newey left school without any 'A' levels, choosing instead to take an Ordinary National Diploma, gaining a place at Southampton University where he achieved a first class degree in aeronautics and astronautics, with a thesis on ground-effect aerodynamics as applied to a Sportscar. From there, in 1980, he went to work for Fittipaldi, but swiftly moved on to March Engineering, where he re-designed its GTP car and a series of March Indy cars, which took both Al Unser and Bobby Rahal to their IndyCar championships.

'The ground-effect aerodynamics thesis proved to be a very useful choice,' remembers Newey, 'because I was able to use it on my CV to get that elusive first job in motor racing and subsequently, when I went to March, they had a GTP car that was aerodynamically a fair way off the pace. There was no budget to do any wind tunnel testing, so I was able to use the results from my third-year project at Southampton to effectively re-design the car by eye to decent effect.'

To decent effect indeed. The car won two successive IMSA titles.

Newey's not just a superlative designer, but a committed racer too, both in historics and, as here, at Le Mans in 2009 in a Ferrari F430GT

From March, he went briefly to the American Force F1 team, and then back to March as chief designer on the 881 F1 car. A lean period at Leyton House found him out of work, but he was quickly snapped up by Patrick Head at Williams who had seen his potential. This was the breakthrough, the Renault-powered FW14 continuing a theme he had tried to develop at Leyton House.

Newey's cars went on to win five Constructors' Championships and four drivers' titles for Williams, who dominated grand prix racing throughout the '90s.

As soon as he joined McLaren, they too began to win, with two successive titles for Mika Hakkinen. 'My philosophy has always been to spend as much time as possible in research and design before anything is manufactured, or a car is built,' the designer says. 'There is always this annual cycle where we try to develop the existing car and design a new car. If you are striving for reasonable results, it becomes a balancing act between development and drawing up a new car. And it is increasingly difficult to assess a new car's potential until you start doing race simulations. You may have a reasonable idea, from day one, of whether or not the car is performing as expected, but you don't know what the competition are doing with their fuel loads.

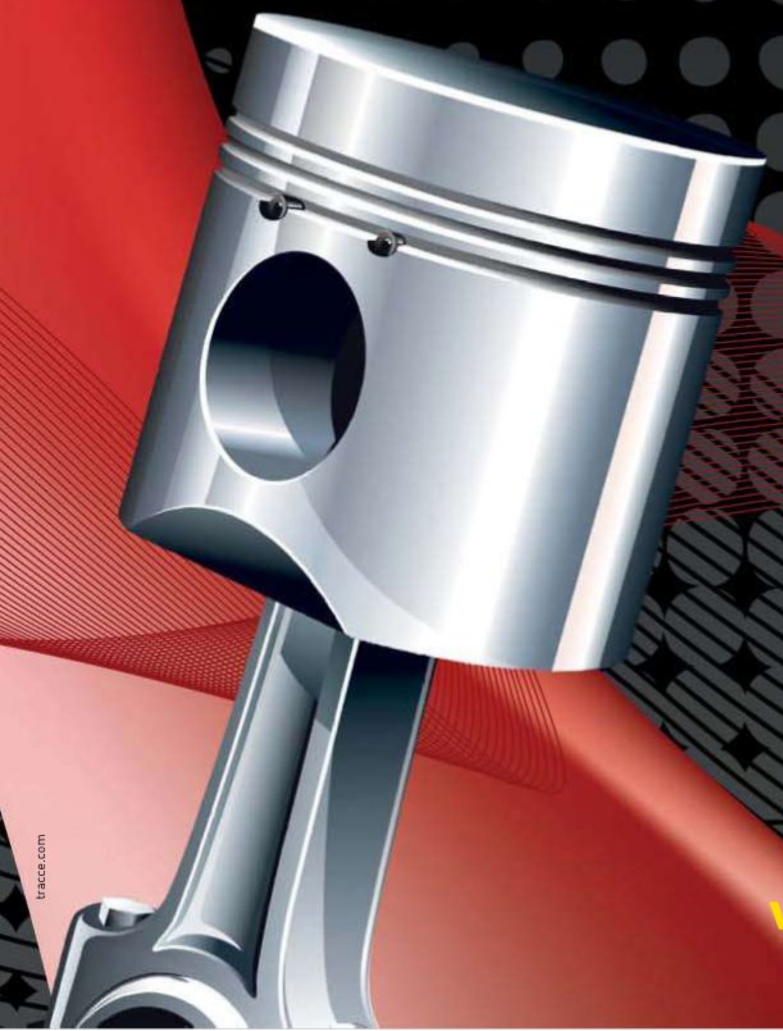
"Having a great idea in itself is no use if it doesn't stand up to the harsh test of the physics"

ART VS PHYSICS

'What has always fascinated me more than anything else about racecar engineering, in its broadest concepts, is the combination of art – in terms of the ideas – and the test of those ideas, against well established physical principles. Having a great idea in itself is no use if it doesn't stand up to the harsh test of the physics. And, of course, we have to adapt ideas to any changes in regulations and sometimes, as in the case of a new tyre manufacturer, we don't always know quite what we've got to work with. It can be that a new tyre demands a fundamental change in the design of a racecar, and tied in to that is the weight distribution range because that's an important tyre-tuning device. Getting a racecar to be underweight, with a bit of ballast to spare so we can tune the weight distribution, is quite a challenge.'

You might expect a man with this degree of talent, and little else to prove, to be tempted away from the relentless rollercoaster that is modern grand prix racing, but there is always a title to win, or defend.

'What is great, and unusual, about motorsport is the blend of artistic design and hard engineering principles, which are then out on display, during the season, every two weeks,' says Newey, 'so there is pretty direct feedback, which is great if you're doing well, and not so nice if you're doing badly. Then there's working with sportsmen, the man and machine side of it. Elsewhere in industry, in aerospace for example, the timescales are so much slower and it's that



For much of the 1990s, Newey worked at Williams, on such as the World Championship-winning FW14 (above). In his time with the team, its cars won five Constructors' Championships and four Drivers' titles

In the foreground, the 2010 Red Bull RB6, behind it the Toro Roso STR5, which took clear inspiration from the former, leading to the unusual situation of two Newey-designed cars racing against each other in the same season

pace of development that is particularly exciting. Having the fastest car at the beginning of a season does not guarantee you a championship by any means. If you get out-developed by your competitors, then you will be well down the grid by the end of the year. There are very few other areas where you find this blend of competition between man and machine, and at such a high pace of development.

I did look at yacht racing as a possible career change – it's a parallel universe in that we face the same technological challenges in terms of aerodynamics, hydrodynamics, lightweight structures, control strategies and simulations – but applied in a very different way. I'm still enjoying the design aspects of working in Formula 1, though, and will keep doing it as long as I'm enjoying it.' Bad news for his rivals in the pit lane.

> **"Luckily there's no such thing as intent of regulation in the rulebook"**

It's no secret that many of the leading grand prix teams looked closely at the Red Bull RB6 before completing their designs for the 2011 season, in particular the front wing and the ride heights of the chassis. Indeed, Patrick Head of Williams declared that the RB6 would be a source of inspiration to other teams, and there remains a mutual admiration between Head and Newey, sustained from the latter's years with Williams.

'I am certainly flattered if Patrick was impressed by the car,' says Newey, 'and the cliché remains true that copying is the sincerest form of flattery. But all the teams introduce new concepts and new parts every year. The real test is if these are in fact adopted along the pit lane and indeed, if you stay with those ideas on your own car. Remember, there are very few absolutely new ideas.

'It is true to say that the double diffuser and the f-duct kind of came out of nowhere, if you like, but the double diffuser was a loophole in the regulations that had not previously been considered legal. The f-duct was a very clever application of fluidic logic, which in itself came out of the Cold War in the 1950s. So the basic technology was well known already and then it was cleverly applied to the rear wing of a racecar to get round the moveable aerodynamic device regulations. What the next idea will be, who knows? But luckily there's no such thing as 'intent of regulation' in the rulebook. Although a regulation might have a clearly stipulated intent, if I can find a way around that intent – in a legal manner – then that's fine,

Of recent developments, the f-duct is one Newey particularly admires - not so much the technology itself, which he says is old hat, but its application to a racecar. Here, Mark Webber checks the system out on the 2009 McLaren

and that's all part of the game and the challenge.'

Looking at the season ahead, Newey is frustrated by some of the changes in technical regulations, presented as further ways in which to cut costs, improve safety and encourage overtaking. He believes, for example, that the moveable rear wing will make overtaking far too easy and thereby change the shape of races.

'The unfortunate aspect of the new rules for 2011 is that they are all restrictions. Banning the double diffuser, once we all had them, removes an area of freedom. And designing a car around the new Pirelli tyres was a challenge as we knew so little about the nature of the tyre, the way in which it might affect the performance of the car, or what it would demand in terms of the weight distribution which, again, is restricted this year. In terms of the fundamental architecture of the new car, that was already done, and lead times dictate that basic layouts cannot be changed. Regulation changes do, however, allow me to start with a clean sheet of paper and look at solutions from first principles. In motor racing you simply cannot predict the outcome, the sport moves so fast, you are constantly developing new parts in the race to stay ahead of the competition.'

Like the Toro Roso on the preceding page, the 2011 Mercedes F1 car, designed under the guidance of Newey's arch rival, Ross Brawn, also takes clear design cues from Newey's RB6, something he sees as a compliment

Newey, one of that rare breed of designers who instinctively knows how to get a racecar to work

When he talks about a clean sheet of paper, that is quite literally what he means. Most unusually for a 21st century grand prix car designer, Newey still uses a drawing board and still draws shapes on pieces of paper as ideas form in his fertile mind. Not for him, the total dependence on computers and simulations. 'The human mind is an amazing piece of kit,' he says, 'and sometimes I will quite suddenly see a solution to a problem that has been churning around in the back of my mind for a couple of months. I might be driving, I might be in the shower, and an idea just pops up into my mind.'

Red Bull Racing team leader, Christian Horner, has described Newey as 'an inspirational leader', a man who has galvanised his engineers and aerodynamicists into a highly motivated and competitive group of people.

'When I went to Williams, and then to McLaren, they were already front-running teams,' says Newey, 'and part of the appeal of joining Red Bull was that I could start from scratch. Of course I also had concepts or themes that I'd already been considering, but this was an opportunity to work with a new set of people, some very good and capable people in their own right. A good racecar is never down to just one man and the entire team in Milton Keynes worked incredibly hard throughout the championship battle in 2010.'

A TERRIFIC MIND

IndyCar champion Bobby Rahal, with whom Newey races his lightweight E-Type Jaguar in historics, speaks highly of the young man who engineered the car that took him to an Indy 500 victory and the championship in 1986: 'We had a really good rapport, very good communication, we still do. We never used to talk that much, but there'd be times when he just knew what to do with the car. I didn't need to go into long explanations. Adrian has a terrific mind, he knows how to get a racecar to go where he wants it to go, do what he wants it to do, and he understands racing drivers. An exceptional engineer, and he proved that time and again in the States, and more recently in F1.'

It would be nice to think, fanciful as it may be, that a mind like Newey's could be applied to some of the enormous challenges that face the real world outside the grand prix paddock. A majority of scientists believe that new technologies, applied cleverly, can be used to solve the problems thrown up by a rising population, a scarcity of food and water and diminishing resources. Right now, however, Adrian Newey may be at the peak of his motor racing career and, just as importantly, he simply loves the bare-knuckle competition that is grand prix racing in the 21st century.

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High-speed solution

The IBM 704, an early example of a 'super computer', as used to design the suspension of the Ford GT40

The switch to GPUs for high-performance computing offers a competitive advantage for those willing to invest in the technology

BY DR CHARLES CLARKE

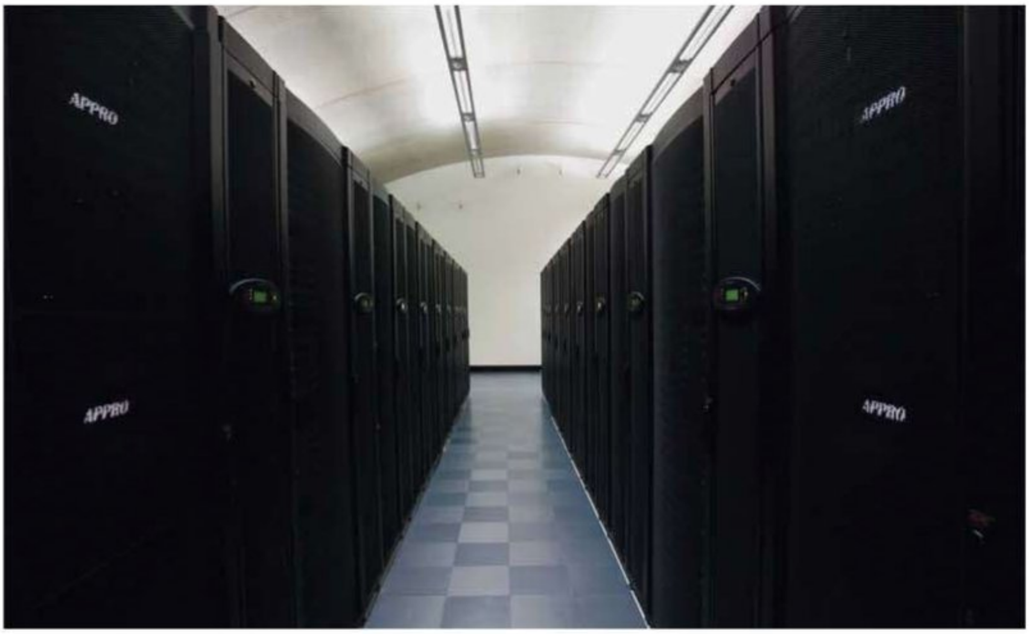
There is a quiet revolution taking place in the world of computer-aided engineering (CAE). With the introduction of new graphics processors from Nvidia and AMD/ATI, CAE developers can now offload some of the more compute-intensive parts of the CAE simulation calculations to massive parallel graphics accelerators, slashing CAE solution times by up to 80 per cent compared with conventional multi-core CPUs.

Central processing units (CPUs) are highly versatile processors with large, complex cores capable of executing all routines in an application. They are used in the majority of servers and desktop systems. Compared with CPUs, graphics processing units (GPUs) are more focused processors with smaller, simpler cores and limited support for input/output (I/O) devices. Recent generations of GPUs have specialised in the execution of the compute-intensive portions of applications as they are particularly well suited for applications with large data sets. Application development environments for GPUs use techniques that allow the GPU to handle compute-intensive portions of applications that usually run on CPUs.

The solution of the simulation equations is relatively trivial, at least in comparison with the complexities of their formulation, yet complex analyses have been constrained by hardware capability for decades. And as faster hardware became available, with corresponding increases in memory capacity and speed, so analyses got ever more complex. Today, multi-physics simulations are commonplace and automotive designers can do reliable CFD simulations of whole cars instead of just the discrete components they were analysing a few years ago. However, these complex analyses still take significant time to solve, with solution times measured in hours, days or even weeks.

Obviously, reducing this solution time is the Holy Grail, not just to lessen overall project development times but because the shorter the solution time, the sooner you find out if you've made a mistake and can start on the next iteration.

There was a time when any kind of computationally intensive activity involved large, air-conditioned rooms full of very expensive, super-cooled equipment – the stuff of science fiction movies. The problems these high-powered computers were directed at were commonly of the geo-physical kind, such as climate modelling or seismic analysis, or any kind of 'domain' problem that required the solution of millions of simultaneous equations. It's not that the mathematics of such problems itself is complicated, it's just they're enormous and highly iterative, hence the use of these number crunchers in the first place. Complex multi-physics finite element modelling and CFD simulation also fall into this category.



Renault F1's 38 Teraflop Appro Xtreme-X2 super computer is based on quad core AMD Opteron processors

FASTER PROCESSING

Fundamentally, there are only two ways to speed up a computer. You can increase the system clock frequency by improvements in silicon technology, thereby processing information faster, or you can attempt to do more processing in each cycle, effectively doing work in parallel. Throughout the late 1970s and up to around 1985, there was about a 30 per cent performance gain every year through improvements in semi-conductor technology alone. But from 1985 to the turn of the century, the computer industry has recorded a 700 per cent performance gain from improvements in semi-conductor logic and the exploitation of all available forms of parallelism. Of the latter, there are basically three different levels: uni-processor parallelism, multi-processor parallelism and multi-computer parallelism.

In the quest for ever-increasing performance there is no substitute for very fast single processors. The better the performance of the processor, the greater the overall system throughput. Similarly, parallel systems made from fast processors, whether singly or in clusters, benefit from these higher levels of performance.

However, the ultimate in processor performance is very expensive. It needs very fast memory, water-cooled, gallium arsenide chip technology, together with highly specialised operating systems and system administration software. These are characteristics found in the 'old' multi-million dollar Cray computers.

"capable of cutting solution times by up to 80 per cent"

To achieve a more affordable alternative to Cray, the performance gains arising from parallel chip architecture can be extended to using multiple processors or multiple computers, which are then capable of executing parallelised applications.

PARALLELISM UNIVERSE

Uni-processor parallelism is the simplest form of parallel computing and is combined with the benefits of RISC (Reduced Instruction Set Computing) processor architecture developed during the late 1980s to produce increased performance. As all the parallelism is achieved within the chip, the system design is relatively simple, and the parallelism is achieved by the application software compilers. Modern, high performance, desktop workstations utilise uniprocessor parallelism.

Multi-processor parallelism was the next logical step for uni-processor systems, where a single computer contains more than one processor. Again, compilers take care of the parallelism in a semi-automatic fashion and, because more that one processor is being accommodated, the operating system software is more complex. Multi-processor systems have 'shared memory' and a single copy of the operating system. The most common form of multi-processing is Symmetric Multi-Processing (SMP), where all the processors have equal rank and there is no master processor. With this arrangement you can have up to 128 processors in a single box running under a single operating system.

The benefit of such a system is the programming model is relatively easy and the system administration is straightforward because individual machines are concerned. From the user's point of view, multi-processor systems offer the most cost effective form of parallel computing. SMP systems are also general purpose compute servers covering a large range of application areas.

However, multi-processor systems have limited 'scaleability' because the processors share system resources within the machine. This means the increase in performance reduces incrementally as more processors are added, and this effect is compounded with faster processors.

The next step then is multi-computer parallelism, where the parallel computing environment is provided by two or more self-contained computers linked by a network. This type of environment is often referred to as 'clustering'. The characteristic of this environment is that nothing is shared, each machine has its own processor(s), memory, input/output architecture and operating system. The memory is then dedicated to the processor(s) within the machine.

The main advantage of this environment is its flexibility. Individual machines can be switched from parallel tasks to specific dedicated tasks, and the individual machines can be either uni-processor or SMP machines. In the latter case, as there is double parallelism, there is a double performance benefit and SMP machines increase the throughput per node within the cluster. However, application software must be parallelised manually because of the

BMW's Albert 3 super computer is capable of 50.7 Teraflops and is based on quad core Intel Xeon processors

complexity of this environment.

The price per performance of these systems is excellent as they offer 'super computing' processing power at multiple workstation prices. They are also highly scaleable as nothing is shared and each time a machine is added, the performance of the cluster increases almost linearly (although this clearly will depend on the software being executed in a cluster environment). A cluster cannot, however, yet be treated as a single system with global shared memory so that it performs like a 'virtual' super computer.

Parallel hardware produces performance gains, which can be maximised by appropriately parallelising the application software, either to utilise the parallel architectures, or to use the system resources in clusters more effectively.

AMDAHL'S LAW

Gene Amdahl (one of the great visionaries of the computing industry) recognised that the execution of a software application had two distinct stages. At the start of execution there is a set-up stage where all the connections are made and all the 'house keeping' is done, like checking the password etc. Then there is the actual calculation stage. In each individual application, every set-up activity is always the same and there is no way to accelerate this process, other than to use a faster machine. The set-up stage is referred to as the sequential phase of an application, as operations are constrained to occur in a particular fashion, and in a particular order. By this definition, the set-up phase can only occur on a single processor.

In contrast, the calculation stage can be speeded up by breaking it up into smaller sections and executing these sections in parallel on separate processors. Therefore, if an application takes 10 hours to complete and it is almost ideally paralleliseable, say up to 90 per cent, then there will be a one hour sequential portion and a nine hour potentially parallel portion. With two processors, this application would take one hour for the sequential part and four and a half hours for the parallel, computation part. Similarly, if there are four processors, the execution time is one hour for set up and two and a quarter hours for computation.

What's important to understand is that if the number of processors is increased to, say, 40 there will still be a one hour sequential part, while the time necessary for the calculation part will be down to 0.225 hours. A factor of 10 increase in the number of processors only saves approximately half the execution time – a phenomenon known as Amdahl's law.

For decades, large complex analyses have been broken into bite-sized chunks and solved this way on parallel, multi-processor machines, generally dubbed 'super computers' or HPCs (High Performance Computers). These gave way to specialist parallel processors, resulting from workstation research, and eventually to 64-bit cluster computing using the UNIX and Linux operating systems. All this in a quest to reduce solution times further.

So with the kit available today, you would think the number crunchers had never had it so good. The general availability of 64-bit computing means vast amounts of cheap, fast memory and multi-core chipset technology is available at PC World. And, as generally speaking, the solution time is directly proportional to the number of processors involved, surely it's just a case of buying more computing power? Not exactly, as for CAE engineers the perfect machine will never be built.

> **"for CAE engineers the perfect machine will never be built"**

Ever since CAD started to get complicated, GPUs and graphics cards were developed to offload the more mundane graphics manipulation algorithms from the CPU and let it get on with the hard stuff. These graphics cards had lots of simple processors (sometimes as many as 1000/GPU) for handling the relatively simple graphics instructions, so why haven't GPUs been used for CAE calculation before?

Graphics Processing Units (GPUs) designed to accelerate graphics applications are highly parallel processors capable of hundreds of Gflops/second (Billion FLoating point Operations Per Second). Competition among the GPU vendors for market share in the PC gaming market has driven technological advancements in graphics cards, and the volume in this market has driven prices down. These processors can now be applied to non-graphical, high-performance computing applications. In fact, researchers have been investigating this usage for several years now, with success in a number of areas. So much so that this new market for their technology has been recognised by the main graphics card vendors, Nvidia and AMD/ATI. Both have introduced product lines specifically targeting high-performance computing, sometimes called the GPGPU market, for General-Purpose computing on Graphics Processing Units.

But until fairly recently, GPUs were not generally accessible by any software other than graphics software. However, with the arrival of the NVIDIA Tesla GPU, all that changed. Tesla GPUs are based on CUDA, NVIDIA's computing architecture that enables its GPUs to be programmed using industry-standard programming languages like C++ and C#, opening up massively parallel processing power to a broad range of computing applications beyond traditional graphics. With power-efficient cores and increasingly fast access to memory, GPUs are well suited to accelerate many

LOTUS AND DELL

In 2006 BMW really opened the Formula 1 market up to high-powered computing with the installation of Albert 2, at the time one of the fastest computers in the world. Today every Formula 1 team, and many other professional motorsport operations, now use a reasonably powerful system, many of which exceed the performance of Albert 2.

One of grand prix racing's smallest operations, Team Lotus, has partnered with Dell for its computing needs from a CFD cluster to track side laptops.

Team Lotus uses a Dell high-performance computing (HPC) solution in its factory consisting of Dell Power Edge M1000e blade enclosures fitted with R610 and R710 rack servers. The system greatly increases the new team's CFD capability, and is partly responsible for the more complex design of the 2011 T128, in comparison with last year's T127.

Perhaps unsurprisingly, Formula 1's resource restriction agreement covers high-powered computing, so a small team like Lotus is allowed between 40 teraflops of CFD / zero wind tunnel hours and zero teraflops / 60 wind tunnel hours. 'We have to find the right balance between the wind tunnel in Italy, which gives us about 14-16 hours per week, and our CFD cluster,' explains Lesmana Djayapertapa, CFD manager at Team Lotus. 'At the moment it doesn't really present a big problem for us because the sum of our wind tunnel hours and CFD teraflops is still below the FOTA restriction. I think it's going to become a problem when we get closer to the line, though. Also, there's a discussion that they're going to reduce it next year to 40 teraflops or 40 hours.'

There are those who believe that the rise of high-powered computers is about to make wind tunnels irrelevant, but Djayapertapa doesn't agree: 'CFD is not ready to replace wind tunnels. When you are dealing with unsteady flow, it is difficult to fully trust [it]. If you look at a rear brake duct, for example, the flow is so disturbed it is difficult to trust CFD exclusively. But it does have many advantages, as we do not have to run the entire car model. We tend to use CFD to look at design ideas, so instead of analysing the full car you can look at the front end model. That's just from the front wing to the cockpit. So we can play with the camera positions. Then draw a conclusion from that on which parts to take to the wind tunnel.'

All laptops used near Formula 1 cars have to be solid state as the vibrations created by the engines can crash spinning disc hard drives

CAE simulations. Benchmarking of the new ANSYS Mechanical implementation has shown that double precision computations of a typical workload can be performed on a GPU up to twice as fast as a traditional CPU. This technology milestone was demonstrated on the NVIDIA Tesla platform with a variety of customer-relevant models.

'This initial development for GPU computing demonstrates our focus on evolving ANSYS software to take advantage of important technology trends in high-performance computing,' said Dipankar Choudhury, vice president of corporate product strategy and planning at ANSYS. 'HPC is a rapidly changing technology arena and also a key enabler of simulation-driven product development. We work to achieve optimised software performance across the full spectrum of HPC technologies, so that our customers get maximum value from their investment in HPC. Here, our technical collaboration with NVIDIA has resulted in a significant benefit for our mutual customers.'

As an example, MSC. Software's Marc finite element analysis software has demonstrated performance gains with Tesla GPUs of up to five times that for typical complex models, compared with the latest dual-core CPUs.

'Our customers will achieve new levels of simulation fidelity and product innovation using this breakthrough technology,' said Ash Munshi, CEO of MSC. Software. 'This successful collaboration with NVIDIA is the beginning of an alliance that will ultimately add value across a broad range of simulation products from MSC.Software.' The GPU solver work at MSC.Software is being carried out on the advanced non-linear solver MSC. Marc and will be available soon.

'NVIDIA Tesla GPUs have quickly gained a reputation in the HPC industry for delivering dramatic changes to workflow, resulting in significantly reduced computational time across complex problems,' said Andrew Cresci, general manager of vertical solutions at NVIDIA. 'The combined processing power of Tesla GPUs and ANSYS tools accelerates time to insight and helps ANSYS customers deliver innovative products that can consistently exceed market expectations.'

HOUSEKEEPING HEADACHE

The use of GPUs for CAE simulation also causes the software vendors a housekeeping headache. Generally speaking, software licensing is tied to the number of processors in use in the traditional CPU sense ie dual-core or quad-core. So a new and different pricing model will need to be developed for GPUs that can house hundreds or even thousands of simple processors.

> **"The use of GPUs for CAE simulation also causes the software vendors a housekeeping headache"**

The GPU accelerator capability accelerates only the shared memory equation solvers that support the usage of a GPU. In the case of ANSYS, these are the sparse direct and pre-conditioned conjugate gradient (PCG)/Jacobi conjugate gradient (JCG) iterative solvers. This includes the use of block Lanczos and PCG Lanczos solvers in an eigenvalue buckling or mode frequency analysis. Other equation solvers will continue to run on only the CPU and will not see any performance benefit when using the GPU accelerator capability.

As yet, much of the simulation using GPUs is limited to linear and static stress, but there is a lot of work being done especially in specialist areas such as F1 CFD. Such is the competitive advantage gained by this technology that the practitioners and protagonists are still very reluctant to talk about the details. But, as more work is done, even more complex analyses will undoubtedly be able to be accommodated.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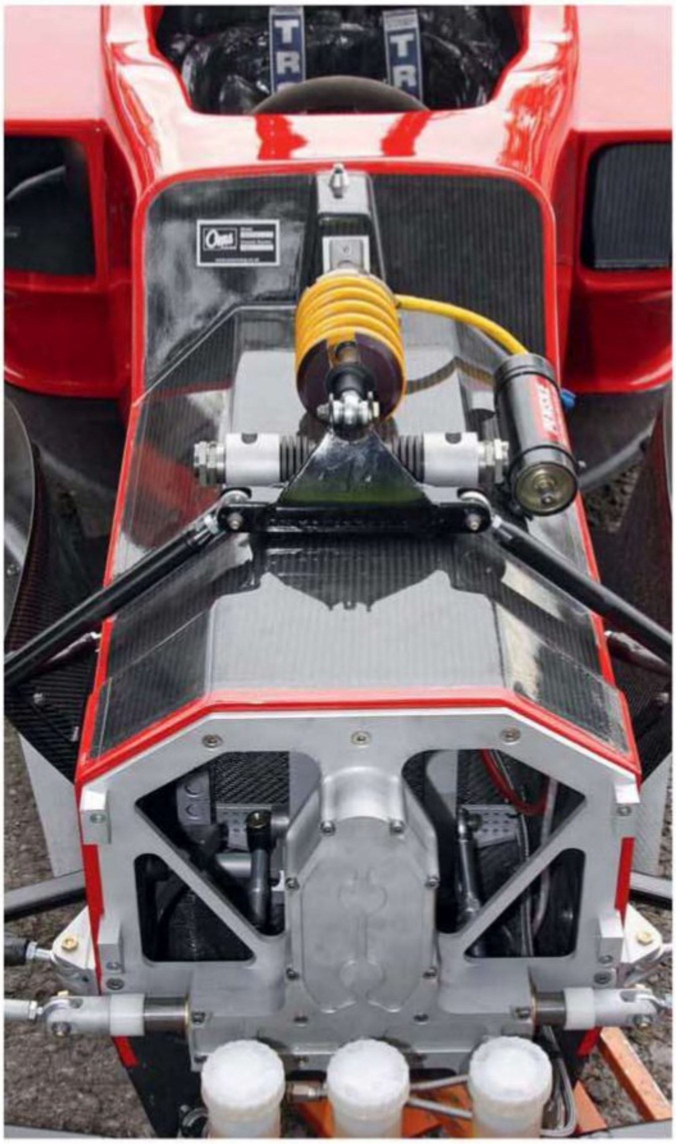
Recent arrivals on the hills

At a time of world economic recession it's heartening to see the vibrant UK hillclimb scene is still producing new racecar designs

BY SIMON MCBEATH

The technical freedoms offered by UK hillclimbing and sprinting regulations is a point invariably highlighted in our occasional articles about this category, and this sees it as a favourite proving ground for the ingenuity of the special builder, a species that, unsurprisingly, has long flourished here. But it is perhaps remarkable that this entirely amateur category also supports quite a number of commercial constructors whose products are principally, if not wholly, destined to compete within this fascinating, yet sportingly friendly branch of motorsport. A quick count reveals that eight were active in 2010. And even in the current economic situation, when disposable income is generally tight and many competitors have retained their existing cars, a number of these small constructors have recently produced new designs. In this feature we look at three of them – two entrants in the Up To 1600cc Racing Car class, the OMS 25 and the GWR Raptor, and the Force LM001 Sports Libre machine.



For an entirely amateur category, the top-level hillclimb cars show immense engineering skill and know how. The front end of the OMS25, for example, illustrates the range of composite and CNC capabilities OMS offers

OMS 25

OMS takes its name from the initials of its principal, Steve Owen, spelled backwards. But since he started constructing hillclimb cars in 1985, Owen hasn't exactly looked backwards, as just he and wife Lynn have toiled long hours to produce 21 different models and some 200 racecars in that period! Now his products can be found on the hills and circuits of the UK, Europe, North America and Australia.

It was partly in celebration of the company's 25th anniversary that the OMS 25 was conceived, Owen as usual building the first for him and his wife to run, test and develop, prior to supplying the eager half dozen others who had already paid deposits before the first car appeared. But, typifying Owen's business-like approach, the main reason for producing the new design was that the previous model, the OMS CF04 and its later derivatives (which had featured in the top three of the British Hillclimb Championship from 2008-'10), was that he had 'more new ideas than a CF04-type chassis was able to accommodate, or that I would have been able to accept from an engineering point of view. So we decided to start afresh with a new design to include the new ideas. It is always simpler to start afresh than to try to adapt a product that was never meant to take new design concepts,' Owen commented.

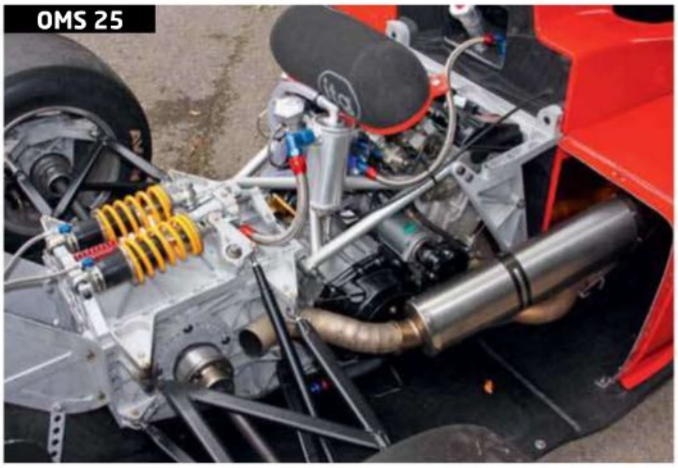
The decision to create yet another model was made in late August 2009, and the first OMS 25 debuted the following July, 'which was a bit slow compared to previous designs,' quipped

The OMS 25 celebrates a quarter of a century of industrious racecar creation by Steve and Lynn Owen

The GWR Raptor is more compact than the OMS and, although the front wing is suspended under the nose, the chassis has a much lower line overall

LAT

The Force LM001 is unusual in running front wheel pontoons and sidepods that blend into the rear wheelarches



The rear end, though conventional in layout, features the OMS CNC machined final drive and suspension case. Engine mounting is partly by steel tubes, partly by machined alloy components

The radically high nose sees the upper front wishbones mounted near the bottom of the chassis sides, with the lower wishbones mounted on twin keels suspended below the chassis

Built to facilitate OMS' latest aerodynamic thinking, the OMS 25 also features bargeboards that were first used on the company's 2009 CF06

The OMS CF04 and its derivates represented the previous generation of composite tub hillclimber from the marque

Owen. But a determination to set new standards with the latest model slowed Owen's generally phenomenal output somewhat.

The design features a significantly higher nose than the previous CF04-based models, and Owen pays tribute here to the assistance of Rob Thomson, the pattern maker for the project, who had worked on various Formula 1 cars when at Activa. 'Rob contributed to the appearance and aerodynamic thinking,' explained Owen, 'and we worked out the shapes in outline drawings and sketches on paper. No CAD was involved. Rob then made wooden patterns and I applied the finish and made the moulds and components. My wife Lynn did the engine cover design.'

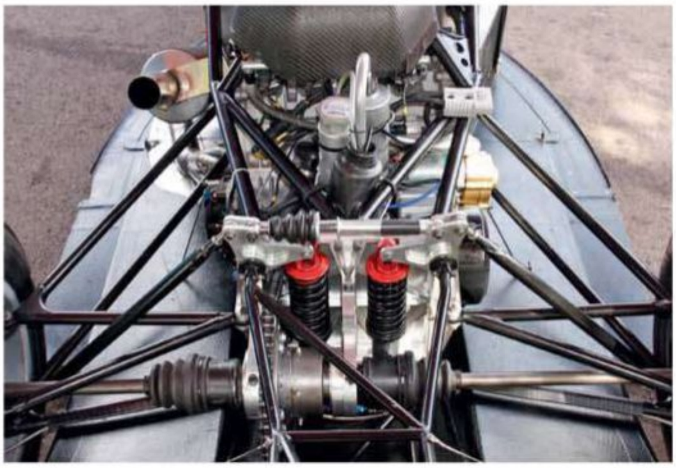
Historically, OMS racecars have looked visibly more softly suspended than most of the competitor marques, so it was no surprise to find 'good mechanical grip' at the top of Owen's list of key design parameters. Second on his list, though, was good low-speed downforce, and this highlights compromises that hillclimbers have to strike between the oft-conflicting requirements of good turn in to 25mph hairpins and slow corners, plus good exit traction, coupled with a good mechanical and aerodynamic balance in corners in the 60-120mph range. The emphasis on the OMS 25 seems to be more on the aerodynamic requirements than previous cars and, in late 2010, the car looked to be stiffer than its predecessor. Owen also places emphasis on the ability to accept a range of engines so that the cars can run in as many classes as possible. There are five single-seater classes under UK regulations, with splits at 600cc, 1100cc, 1600cc, 2000cc and over 2000cc, and OMS models are present in all of them. This is simply to make the design more commercially viable. Interestingly, when asked if low weight was on his list of key parameters in a sport with no minimum weight limits, commercial reality again coloured the response: 'Yes, weight is up there with the important things, but I'm more business-minded about this. We won the Monoposto championship two years running with the heaviest car there. There's more happening than just low weight. So you need to be in the ballpark, but I'm not known for making the lowest weight cars.

> **"I'm not known for making the lowest weight cars"**
>
> **STEVE OWEN, OMS**

The first two OMS 25s running by the end of 2010 featured the almost ubiquitous 1.6-litre Suzuki Hayabusa variant, this currently the engine dominating the Up To 1600cc Racing Car class. But also on order are cars featuring the SB Developments supercharged version of the Hayabusa in its standard 1.3-litre capacity, which will run in the Up To 2000cc class when the regulation equivalency factor of 1.4 is applied. Ford Duratec and Powertec V8 options will also be possible, Owen adding, 'We'll be able to run anything, to be honest, we're just currently tooled up for those engine options.'

Like all the cars featured here, the OMS 25 has a carbon composite chassis. Is this now a virtual necessity? Owen: 'The market is a bit different in the recession and it's more that the customers [who are buying at the moment] are after higher tech cars. It's also about being able to get the shape you want, which

The Martin Ogilvie-designed pull rod monoshock front suspension layout has been carried over from the previous Predator. The steering rack is mounted inside the chassis



Martin Ogilvie's tight rear end packaging sees the spring / damper units straddle the right hand differential support, and the layout of the bell cranks enables a neat 'third spring' arrangement

Rear end of the GWR Raptor could be described as minimalist

The resemblance of the Raptor to the earlier Predator is clear

requires the tub to be moulded. But,' he added, 'the idea I've had for the next model will not feature a composite tub...'

Owen considers his most successful design to date to have been the spaceframe 2000M model, of which he says they made 35. 'They're still going strong in lots of categories on the hills and the circuits, and it was nice to make. Hopefully, the new design will supplant it, but the 2000M will take some beating.'

GWR RAPTOR

Former double British hillclimb champion, turned constructor, Graeme Wight jr, always had in mind a smaller engined version of the stunning 3.0-litre Arrows Hart V10-powered GWR Predator (featured in V15N11) when he was working on that first project. So, after a troubled but ultimately successful few years with the currently mothballed Predator, which gave Wight jr an outright win and a second place in the Doune hillclimb in his native Scotland at the end of 2008, attention was focussed on its smaller sibling, the Raptor.

Wight jr's take on the key design parameters put them in a more expected order than Steve Owen's, with chassis strength (for safety and handling benefits) at the top, followed by low weight, good handling, a strong engine and good aerodynamics.

> **"hard points to cater for any engine that customers would like to fit"**

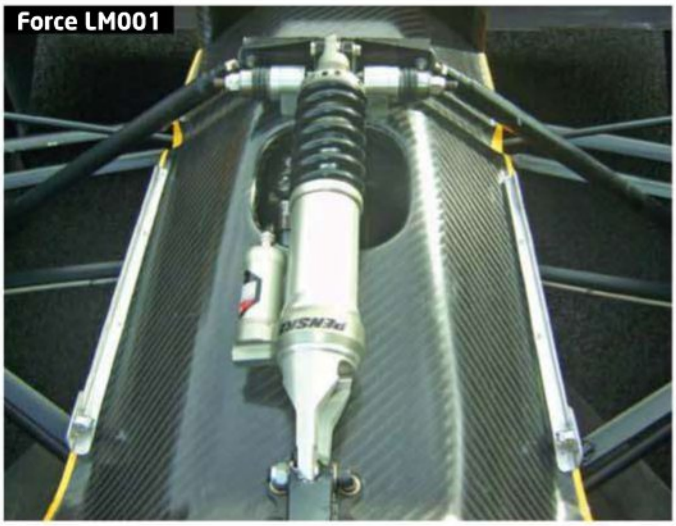
'Each area received a great deal of thought and attention,' commented Wight jr.

As with the Predator project, the help of former Team Lotus F1 chief designer and now Prototype Car Designs principal, Martin Ogilvie, was enlisted on the design side. Wight jr explained: 'A lot of features were carried over from the Predator, on which Martin had controlled the design. But specifically on the Raptor, Martin laid out the rear-end packaging, including the suspension. We also had assistance from SM AeRo Techniques on wing design and other aspects of the aerodynamics. And we had developed lots more understanding on set up and handling by running the Predator, all of which was brought to bear.'

Superficially, the Raptor's chassis looks similar to that of the Predator but, surprisingly, it is actually 50mm longer and 50mm higher at the 'shoulders'. Wight jr: 'The Predator chassis was a bit small. It fitted me perfectly but it was too tight for larger customers.' As with its forebear, the tub pattern was made using low cost materials, comprising transverse MDF sections CNC cut to shape, bonded together to build the pattern, then blocked down and surface finished prior to taking moulds. But this time Wight jr did all the composite work himself, having constructed his own curing oven for the purpose. 'Not everybody's first composite project is a racecar chassis,' he observed.

The rear bulkhead of the chassis incorporates a number of hard points to cater for 'any engine that customers would like to fit,' said Wight jr, and this would include other motorbike engines of different capacities, as well as car engines. Wight jr has also pondered the use of the ex-DTM, 2.5-litre Cosworth V6 engine that took him to his 2001 and '02 BHC titles, the supporting notion being that small and nimble can still score very well on many of the UK hills, as demonstrated for the past two seasons in which 1600cc racecars have finished in the

Force LM001



The Force's front suspension is push rod monoshock with a Penske through-shaft damper (photo courtesy: Graham Wynn)

Front wheel pontoons and separate side pods are part of the LM001's trendy body styling package

The side pods blend into the rear wheelarches

The rear suspension sees twin springs and Penske dampers supplemented by a third bump stop arrangement. An optional carbon rear end replaces the tubes and bulkheads

The predecessor

The LM001 uses running gear and many other components from the successful Force PC single seater

championship top ten. But that's possibly for the future.

Meanwhile, the Suzuki Hayabusa engine is again the initial engine of choice, around which there is now a substantial tuning industry. Renowned Essex-based tuner, Mistral, supplied the engine for this first customer Raptor.

Although Martin Ogilvie was unsure if his front pull-rod monoshock layout, first seen on the Predator, was novel, it is certainly highly unusual and has been retained by Wight jr on the Raptor. The main aim is to keep the c of g down and enable a low-line chassis. Ogilvie said of its use on the Predator: 'It's not ideal because [the pull rod] angles forwards, so all the loads are angled. But with the relatively low spring rates on hillclimb cars I thought we could get away with it.' In practical terms, the installation of such a layout requires compromises with the location of the hydraulic master cylinders and the steering rack, which uses Formula Renault internals, featuring a drop gear in GWR-manufactured casings, while the rack is mounted inside the chassis. Pretty solid damping makes the car feel stiff in compression, and Wight jr allows that the car is 'very stiff in roll too. In fact, the front controls the roll of the whole car. But out on track the front end just does not move and it's got unbelievably good turn in.' The relatively wide front track (for its wheelbase and compared to the rear track) may also play a role here of course.

The first season with former kart racer Lee Adams at the wheel yielded the Scottish Hillclimb Championship and a number of class records in that series, and BHC results and times at the aforementioned Doune hillclimb in particular that demonstrated the Raptor's giant-killing potential.

FORCE LM001

The Force has been among the most competitive cars in the Up To 1100cc and Up To 1600cc single-seater classes in the UK for some years, most recently winning the 2010 Hillclimb Leaders' Championship in 1600cc form. And in the British Hillclimb Championship, 1.6-litre Forces took eighth and 10th overall in 2009, and 10th again in 2010.

The model that achieved these results was the Force PC – another radical, high-nose design originated by the marque's founder, Bill Chaplin. In October 2006, former Westfield engineer Ian Dayson, who had been preparing top-level hillclimb cars for a number of years in his spare

> "another radical, high-nose design"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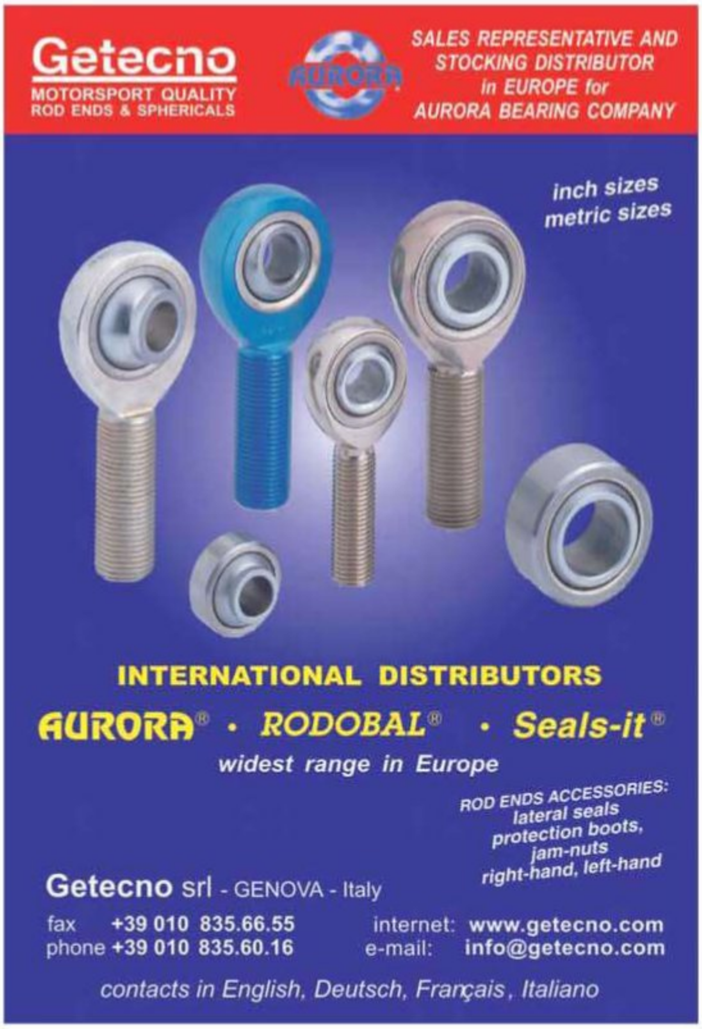
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time, bought the Force name and all its assets and started making single seaters to the original designs himself, as well as developing, preparing and maintaining cars for existing Force customers.

The idea of creating a Sports Libre car based on the Force PC single-seater design occurred to Dayson because, 'I felt there was a market there. There hadn't been much development in the class for a number of years.' Specifically, the target was the Up To 2000cc Sports Libre class, and indeed recent seasons had seen some nicely produced but very traditional designs win the class in the Leaders' Hillclimb Championship. And given the aforementioned giant-killing abilities of the smaller single seaters, in principle a lightweight, motorcycle-engined Sports Libre car ought to be competitive in a class where the quickest cars recently have been relatively heavy, automotive-engined devices. And the 'lightweight' principle had in one sense been proven in 2007 when the class and the overall Leaders' Hillclimb Championship went to a 1.6-litre Hayabusa-powered OMS SC1, despite the fact this design was originally laid out in 1991!

So sketches began in August 2009, with the basic aim of using the running gear from the proven Force PC, partly to keep the parts count down but also, as Dayson observed, 'Why change something that worked so well?' Dayson's list of key design criteria mirrors Graeme Wight jr's very closely, with a composite tub topping the list primarily for safety reasons. Low weight again features next on the list, with a good power-to-weight ratio following on from there, which essentially reflects Dayson's ethos in tackling this class. Good aerodynamics again comes after these other factors on Dayson's critical path.

The tub patterns were created with help from Dayson's former Westfield colleague, Terry Gardner of Herbee Engineering, who also assisted with the body patterns, and the basic layout was based on the central driving position of the single-seater PC, but with the minimum cockpit opening width of 810mm prescribed by the technical regulations.

TECHNICAL SPECIFICATIONS

Car	OMS 25	GWR Raptor	Force LM001
Engine	Suzuki Hayabusa, 1598cc	Suzuki Hayabusa, 1598cc	Suzuki Hayabusa, 1398cc
Transmission	DID chain, Quaife ATB differential	DID 530 chain, Quaife ATB differential	EK chain, Quaife ATB differential, Geartronics paddle shift
Suspension	Front pushrod monoshock, rear pushrods, three springs, Penske dampers	Front pullrod monoshock, rear pushrod, two springs, third element by bump stops, Koni 2612 dampers	Front pushrod monoshock, rear pushrod, twin springs, third element by bump stops, Penske dampers
Brakes	Wilwood four-piston calipers front, two-piston rear, OMS 260mm x 6mm discs	AP Racing two-piston calipers front and rear, 274mm x 7mm discs	Force billet four-piston calipers, 280mm x 6mm front discs, 240mm x 4mm rear discs
Wheels	OMS 8in front, 10in rear	Speedline 8.5in front, 10.5in rear	BBS 8.5in front, 10.5in rear
Tyres	Avon, 195/530-13 front, 250/570-13 rear	Avon 195/530-13 front, 245/600-13 rear	Avon, 195/530-13 front, 250/570-13 rear
Chassis	Carbon skins over mostly 19mm aluminium honeycomb	2mm carbon skins generally over 17mm Nomex honeycomb	Autoclaved carbon and Kevlar skins over minimum 13mm aluminium honeycomb
Electronics	SBD/MBE incorporating full throttle shift system	SBD/MBE incorporating full throttle shift system	Standard ECU plus Power Commander
Fuel tank	OMS, 4.0-litre	GWR, 4.0-litre	Force, 4.5-litre
Dimensions	Width: 1778mm; length: 4267mm; wheelbase: 2489mm; front track: 1575mm; rear track:1524mm; weight 340kg	Width: 1740mm; length: 3900mm; wheelbase: 2270mm; front track:1524mm; rear track: 1402mm; weight 291kg	Width: 1676mm; length: 4040mm; wheelbase: 2260mm; front track: 1460mm; rear track: 1408mm; weight: 350-355kg

This central driving position sometimes offends traditionalists, who prefer their sports racers to at least have room for two seats, but it maintains an even side-to-side weight distribution, so it's a loophole not to be ignored. Panther Composites made the composite moulds and the chassis, while Ace Fibreglass made the body moulds and patterns. A carbon rear structure is available to replace the standard aluminium bulkheads linked by steel tubes, offering both reduced weight and increased stiffness.

"the hope is that the power-to-weight ratio and nimbleness of the LM001 will see it succeed"

The engine fitted for its debut season to the LM001 was a 1.4-litre Suzuki Hayabusa unit, again prepared by Mistral Performance. This an interim choice as there are plans to increase power for 2011, most likely by stretching to the same 1.6-litre unit fitted to the single-seater PCs. Although this leaves the engine well short of the 2000cc class limit, and possibly 30-50bhp down on a reasonable, automotive-based, 2.0-litre engine, the hope is that the power-to-weight ratio and nimbleness of the LM001 will see it succeed. Supercharging or turbocharging an engine up to 1428cc would keep the car in the same class and, although there are no reasons why this could not be done, there are currently no plans to follow that route.

The aerodynamics may have come a little way down the list of key parameters, but the LM001 features some up-to-the-minute ideas, such as the front wheel pontoons and slender, raised forward chassis, and it is claimed to generate more downforce than traditional Sports Libre cars.

Certainly the front and rear wing set ups are relatively potent, and the car featured a large plan area flat floor and diffuser, so the potential for generating substantial downforce is there.

Despite limited running in 2010, two cars were on order for 2011 at the time of writing, so the lightweight and nimble recipe appears to be finding an increasing number of followers in the hillclimb fraternity.


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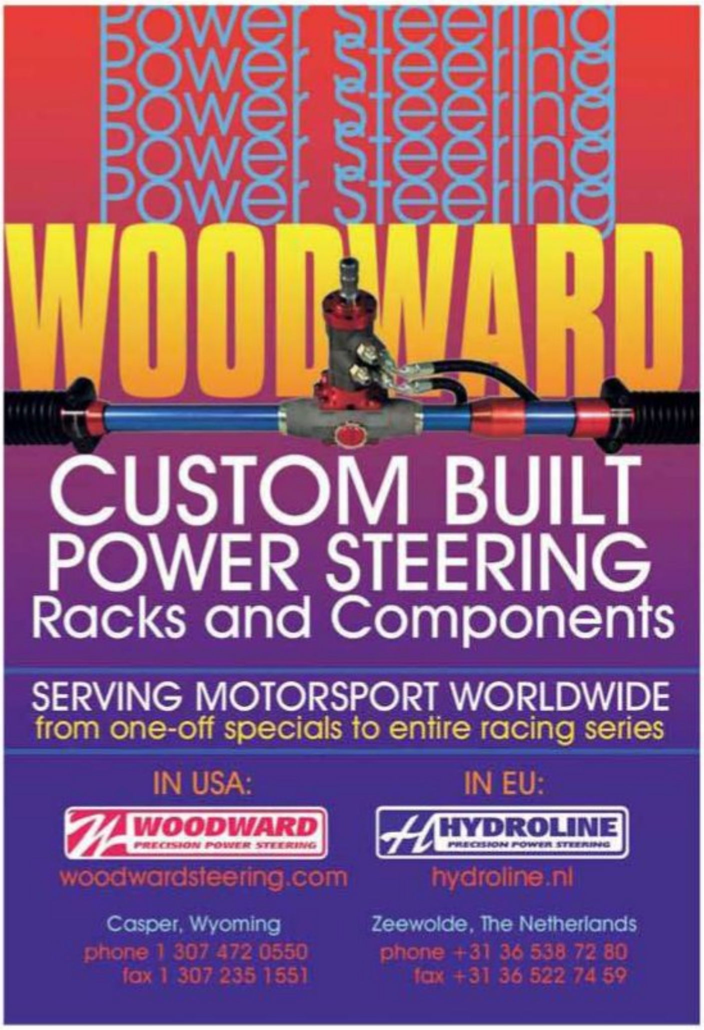
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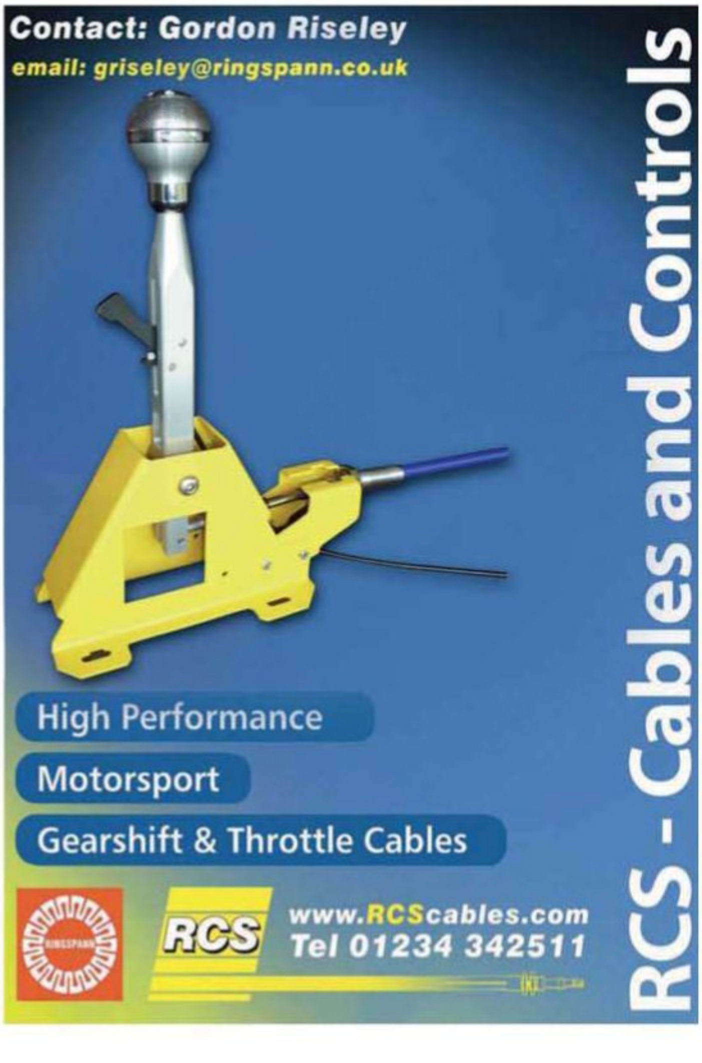
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Fresh wind on the hills

When an ardent hillclimber and former F1 aerodynamicist decides to develop a new car for the hills, it's a good chance something special is in the works

This was John Keogh's eighth concept sketch for the project and one the team involved really liked

BY GRAHAM JONES

The word 'ultimate' is always one to be used with great care, particularly when applied to motorsport projects, such is the speed with which technological development moves on. That said, we couldn't let the start of the 2011 hillclimb season pass without mention of Willem Toet's plan to build 'the ultimate hillclimber'.

Unfortunately, we can't divulge the full story at this point because (a) the car isn't finished, and (b) we've been sworn to secrecy on the details for the time being. However, we are able to bring you a glimpse of some of the thinking behind the new car that Toet intends should re-define the performance envelope for the top level of British hillclimbing – and maybe further than that.

Willem Toet is, of course, no stranger to regular readers of *Racecar Engineering*, or to technically aware followers of Formula 1, having held senior technical positions at Toleman, Benetton, Ferrari, BAR/Honda F1 and BMW Sauber during a busy 25-year career at the sport's top level. Making it even busier, however, was the fact Toet acquired the hillclimbing 'bug' during this time, initially competing in a self-developed Peugeot 205, which he shared with F1 electronics guru, Richard Marshall, before moving on to a succession of ever more powerful Pilbeam single seaters, culminating in a twin turbo, 1000bhp, Cosworth XD-powered MP88 chassis. Toet then stepped away from the cockpit for several years during his time with BMW Sauber in Switzerland.

Willem Toet originally competed in a self-developed Peugeot 205

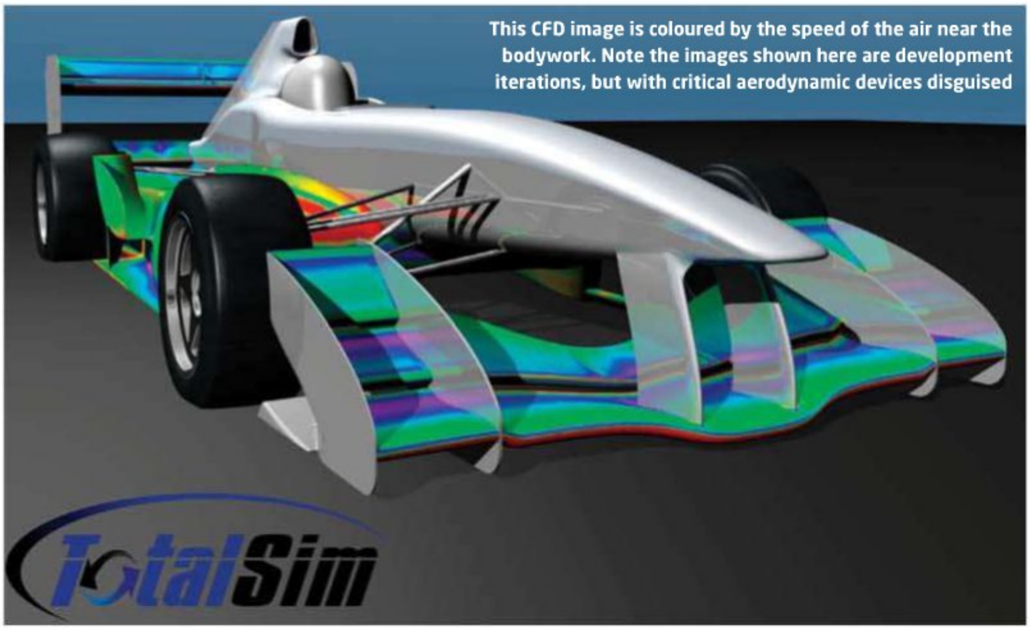
Now back in the UK, and managing director of RML, Toet's out-of-hours thoughts have returned to the hillclimb scene, but this time with a specific aim – to create a single seater that will incorporate his many years of aerodynamic experience and set a new standard for hillclimbing for at least the next few years.

'I've been hillclimbing for a long time and given a lot of people advice during that time,' he says. 'Now I quite fancy the idea of using the knowledge I've acquired over 25 years to try and produce a car that, ultimately, is more efficient and, if possible, faster than an F1 car. Although that is pretty difficult – with the money F1 can spend, mechanically they will always be superior. For the comparatively low speeds and the sort of courses you have in British hillclimbing, however, I think you can produce something that is very, very special.'

> **"I quite fancy the idea of using the knowledge I've acquired over 25 years"**

Toet and some carefully chosen cohorts launched into the project by starting with the CFD of a known single seater hillclimb car as a baseline. 'We scanned this existing car, which has an aero efficiency of 2.3:1,' he explains. 'With the first series of iterations, we got the aerodynamic efficiency up to about 3.5:1, which is similar to the present top hillclimb cars. Now, if you compare the efficiency of that with a Formula 1 car, the latter has hovered, at least in the teams I've been with, between 2.3 and 3.7:1 lift-to-drag ratio over the last 25 years, depending on the usual battle of rule changes vs developments. In 2010, with

another year of development, with double diffusers and the f-duct allowed in, I would picture the Formula 1 cars now to have an effective aero efficiency of, say, 4:1 – probably the highest it's ever been.'



This CFD image is coloured by the speed of the air near the bodywork. Note the images shown here are development iterations, but with critical aerodynamic devices disguised

FREEDOM OF EXPRESSION

Critically, Toet is not aiming to build a Formula 1 car for the hills, but something very different. 'I know the regulations for hillclimbing and Formula 1,' he says. 'I know why all the Formula 1 cars look the way they do, and that is 90 per cent down to the regulations and 10 per cent freedom of expression, so where most people might just copy a Formula 1 car, I'm not going to do that. I want to do what I know is right – for example, the front wing on an F1 car is not what you'd want for pure performance. It is significantly limited by rules that don't apply in many other categories. I can therefore use the greater freedom of hillclimbing to develop completely different devices, which would be illegal in Formula 1. I'm talking of things that most people wouldn't even think of as they wouldn't know to go there. Initially, though, we have concentrated on drag [reduction] to make the car suitable for small engines as well.

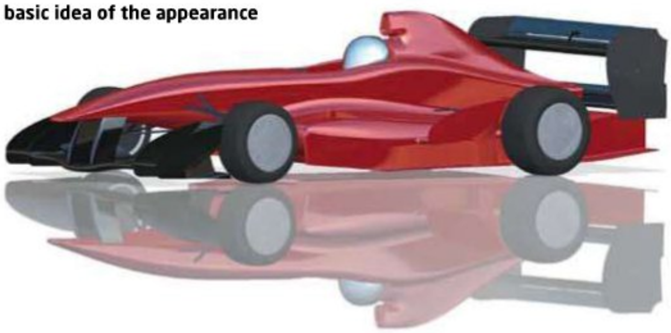
'We're looking at this from a commercial perspective, as well as from an engineering perspective. In F1 you sell the success of the car, but with this project you need to convince people on many levels, including the look of the car and its performance. Throughout my time in F1 I've only been interested in performance, and often wondered why people like Ross Brawn would be interested in looks, but now for the first time we're interested in style as well, which is why we've engaged the services of John Keogh.'

Tantalisingly, we are told the figures coming out of the latest CFD iterations are impressive. 'We now have the aero efficiency of a perfectly legal, low drag, open-wheel racecar of well beyond where I believe F1 cars are currently, and we haven't finished by any means,' says Toet. 'I'm not spending big bucks on this at all, in F1 terms, just capitalising on my specialist knowledge. I'm going to keep developing the car, though, as the aero balance isn't where I want it, it's not as stable as I would like it to be, and there are still areas of detached flow. There remains a lot to do, but we'll probably freeze the chassis design at some point and start making it. Then I'll select the front wing and, with an existing rear wing, I'll put a motorbike engine in the back and we'll start doing some testing. Later, we'll fit the remainder of the bodywork, which is when people will see the trick bits. At that point, the shape, and the whole overall concept, will make sense.'

ENGINE CHOICE

On the matter of engine choice, the plan has to be to go for more power as the car is developed, in order to achieve the sort of performance levels Toet has targeted. 'We're looking for a longer term engine partner and it's likely this could be John Judd, as I was so impressed with the torque and drivability of the ex-F1 Judd EV I ran in my Pilbeam in 2003-2005, but a version of my present Cosworth is also an option. With clever design, however, the moulds for the car and the chassis shape are being developed to take almost any engine, from a motorbike power unit to big, F1-beating engines.'

CAD image shows a pre-production version of the car, but provides a basic idea of the appearance



The problem for innovators, of course, is that the moment their groundbreaking ideas move into the public arena, they become fair game for others to copy, and perhaps even improve on. And Toet is under no illusions on this score. 'Yes, others will catch up when they see it. Aerodynamics is visible, but in hillclimbing, you can also crawl all over and under people's cars, and I'm not going to hide what we're doing once we're there. People will use their brains and copy what's there. But it will take time for them to catch up.'

Bearing in mind the apparent potential in the new design, it seems likely there could be interest from other hillclimbers. Would Toet consider selling examples of his new car?

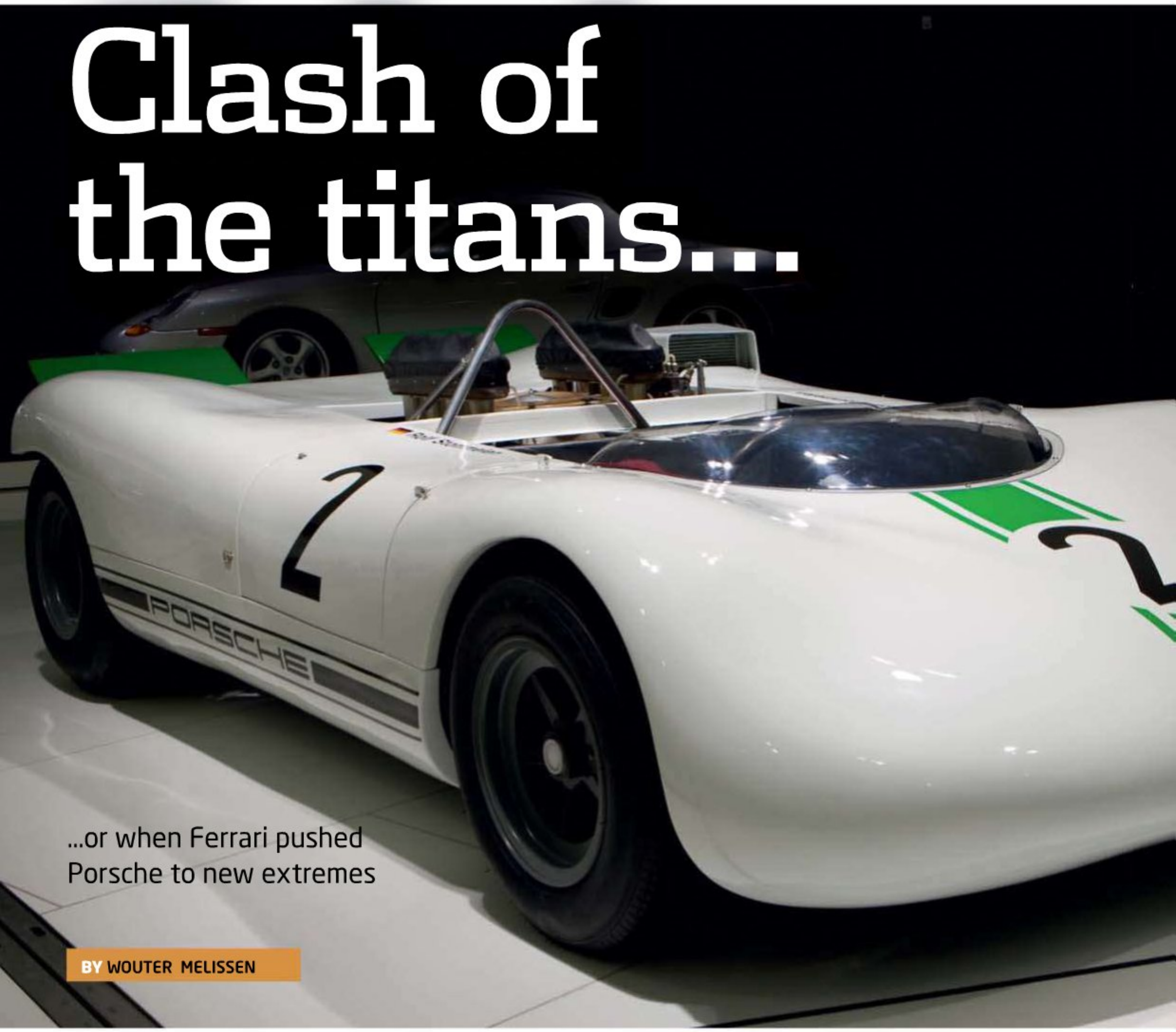
'When we build this,' he says, 'the first one will go up for sale, at a price that will allow us to invest a small amount more to do the next part of the research. If more people are interested, then we'll build more at that level, which will allow me to do the next level of research. Of course, it need not be limited only to hillclimbing. Imagine how incredible it would be as a track day car – 500kg, 850bhp and F1 aero plus.'

Although the project remains under wraps at this stage, we asked Toet if he could provide some indication of the likely size of the new car. Will it be closer dimensionally to a Force chassis than a Gould, for example? 'It's going to start smaller,' he says with a smile, 'and that's as much as I can say at the moment…'

Details may be sketchy, but one thing seems certain – the British hillclimb scene is soon to witness the arrival of a groundbreaking new car.

"Toet is not aiming to build a Formula 1 car for the hills, but something very different"

Clash of the titans...



...or when Ferrari pushed Porsche to new extremes

BY WOUTER MELISSEN

The fierce rivalry between Porsche and Ferrari has its roots in the 1960s. Even though the two companies were founded at about the same time and competed in many of the same races during the 1950s, up uintil then they rarely crossed swords. But when Porsches started to vie for outright victories, the two legendary manufacturers became direct competitors.

The epic fight between the Ferrari 512s and Porsche 917s in the 1970 and '71 editions of the 24 Hours of Le Mans is well documented. These firmly established Porsche as the new dominant force in endurance racing, a position Ferrari had previously held for nearly two decades.

> **a brief and hardly convincing racing career**

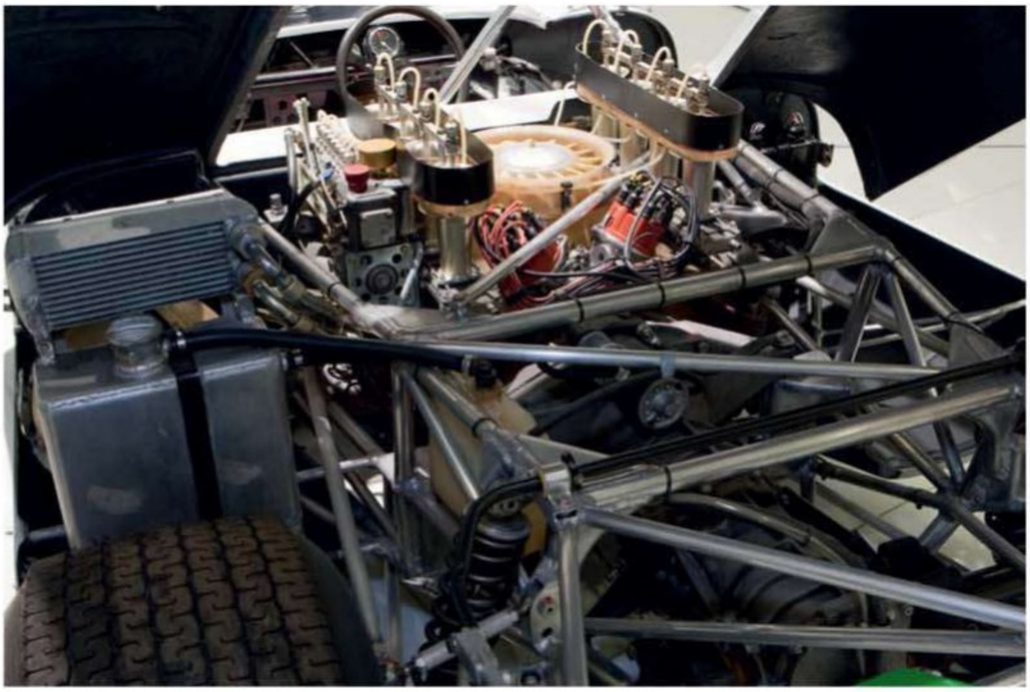
Ironically, though, it was a fight between the two that *didn't* take place that resulted in one of the most extreme competition Porsches ever built. Known as the 909 Bergspyder ('berg' is German for mountain), it was constructed specifically for the 1968 running of the coveted European Hillclimb Championship.

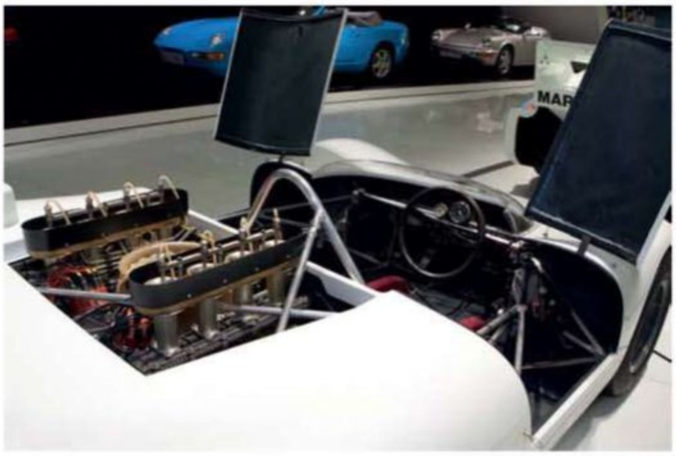
Late in 1967, Ferrari announced and even tested a purpose-built hillclimb racer. Powered by a Formula 1-derived flat 12 engine, it looked to be a serious challenger for Porsche in the prestigious championship.

In previous years Porsche used adapted versions of its latest Sports Prototypes, but the company's development chief, Ferdinand Piech, feared that this approach would not suffice against the new Ferrari. Consequently, the grandson of Ferdinand Porsche commissioned the construction of a no-compromise racecar instead.

From the start of the 1967 season, the European Championship was disputed under Group 7 regulations. These stipulated mandatory road car equipment and two seats, but no minimum weight. The ferocious Can-Am cars of the same period were built following the exact same rulebook, but the one

Right: the immensely complex, 2.0-litre, flat eight, Type 771 engine had four shaft-driven overhead cams and, with mechanical injection, produced 275bhp at 9200rpm





major difference was a 2.0-litre engine displacement limit for the hillclimb cars.

Due to the nature of the sport, this placed the emphasis on keeping the weight down. Based on the 910/8 sports racer, the first Porsche Group 7 hillclimb car weighed in at 420kg (926lb), but Piech believed he required an even lighter car to fend off the new Ferrari.

ADD MORE LIGHTNESS

It was Lotus' Colin Chapman who famously coined this phrase, but Porsche's engineers turned the concept into a science and, during the 1960s, few manufacturers could rival Porsche's knowledge of lightweight metals, alloys and glass-reinforced plastics.

Like its predecessors, the 909 Bergspyder used an aluminium spaceframe chassis and exotic titanium was then used for various suspension components, including the four coil springs. The engineers even experimented with alloy steering arms, but these proved too fragile for competition use. It was the disc brakes, however, that underlined the extremes to which Porsche was ready to go to get the desired results. First used on the 910/8 Spyder, they were cast in the rare earth metal, beryllium. A quarter of the weight of conventional cast iron discs, they resulted in a massive 14kg (31lb) cut. The drawbacks were the steep price – $1000 per disc in 1967 – and the toxicity of the inevitable beryllium dust. As a result, only five examples were available, usually fitted on the car of the fastest driver. In a previously unheard-of move, to contain the poisonous dust the discs were chrome plated.

> “few manufacturers could rival Porsche's knowledge of lightweight metals, alloys and GRPs”

A further unique feature of the 909 was its fuel tank. At 16 litres, it could hold just enough fuel for one run up and back down the mountain. All 1.7kg (3.8lb) of the fuel pump were saved by using a nitrogen-pressurised sphere, while the so-called 'kugeltank' consisted of a titanium exterior shell with a rubber bladder inside, which contained the fuel. Before the start, nitrogen was fed into the space between the shell and the bladder to build up the necessary pressure required to send the fuel to the engine.

THE FINAL EVOLUTION

The one constant in the Porsche hillclimb programme was the Type 771 engine. Developed in conjunction with the Type 753 Formula 1 engine in the early 1960s, the horizontally opposed eight-cylinder engine gave Porsche the final push up the ranks it was looking for.

Although it had twice as many cylinders as the four cylinder engines used before it, the Type 771 incorporated many of the same design ideas. Needless to say, the engine was air cooled, with forced cooling provided by a fan mounted on top of the magnesium alloy crankcase. To further aid cooling, each bank featured four separate finned cylinders and heads.

Also typically Porsche were the shaft-driven overhead camshafts, originally developed by Ernst Fuhrmann for the four cylinder engines. The shafts were driven from the middle

The Bergspyder used a purpose-built chassis designed specifically for the class it was destined to compete in . The wheelbase was therefore unusually short and balance was the key concern – to the point that the gearbox was mounted between the engine and the differential and the driver's feet were ahead of the front axle line...

> **the entire wiring loom was made in silver**

of the crankshaft at half speed through bevel gears. Fuhrmann's original design used a single shaft per bank but, for the new eight-cylinder engine, two were used, one for each of the four camshafts. By placing the valves at a 90-degree angle, the largest valves possible could be fitted.

Using four Weber downdraft carburettors, the Type 771 produced 210bhp at its 1962 debut. By 1968, the Webers had been replaced by fuel injection, which saw the power rise to its ultimate figure of 275bhp at 9200rpm. Each of these complex engines took a staggering 220 hours to build.

In 2.0 and 2.2-litre trim, the Type 771 propelled the Porsche works cars to many victories, including the manufacturer's maiden victory in the Daytona 24 Hours in 1968.

VERY TIGHT PACKAGING

In addition to the extreme weight saving measures, the 909 Bergspyder's packaging also broke new ground. It was the first time the Porsche engineers could design a chassis to suit the particular needs of a hillclimb course, and this resulted in a significantly shorter wheelbase and wider tracks compared with its predecessors. The wheels were literally mounted on each of the four corners of the car.

Although there was very little of it, the balance of the weight was also considered a critical factor, and led to the engine being pushed as far forward in the chassis as possible. The specifically developed five-speed gearbox was mounted between the engine and the differential. This novel approach ensured that all the mass was held within the wheelbase – a configuration that would become common practice over the years that followed.

With the engine mounted so far forward in the chassis, the space for the driver was heavily compromised. He was forced to sit virtually between the front wheels, with his feet well ahead of the axle. In fact, there was so little room up front that the anti-roll bar had to be mounted in front of the dashboard, between the steering wheel and the instruments.

The fuel tank, dry-sump oil tank and oil cooler were all mounted on the left hand side of the engine, while the space on the right was reserved for the electric systems and the battery. And this didn't escape the engineers' eyes either – with copper considered too heavy, the entire wiring loom was made in silver instead, while balsa wood was used for the mounting plinth for the ignition system's two ballast resistors.

The rolling chassis was tightly wrapped in a glass fibre body, whose round nose sported two circular holes to cool the front brakes, with small dive planes mounted on the edge of the nose and two small, adjustable rear wings.

The result of all this laborious work was a car that weighed just 375kg before adding fuel and driver, an improvement of 45kg (99lb) over the previous year's car. Illustrative of his obsessive approach to the whole project, legend says Piech then went over the finished car with a magnet to make sure the mechanics had not used a single steel screw or nut.

NO UPHILL BATTLE

Two cars were completed but they were not ready in time for the start of the '68 season. In the end, this proved inconsequential as Gerhard Mitter more than held his own in the rebuilt 910/8s, and the Ferrari threat proved hollow as nothing was seen or heard of the flat 12-engined special, at least not in 1968.

Although Mitter dominated the opening rounds of the championship, it was far from a happy campaign for Porsche, as Mitter's team mate, Rolf Stommelen, broke his arm when his 910/8 left the road, and new signing, Lodovico Scarfiotti, fatally crashed at the same event. Remarkably, this earned the popular Italian the dubious title of being the first driver to die at the wheel of a works Porsche. His death cast a deep shadow over the rest of the year.

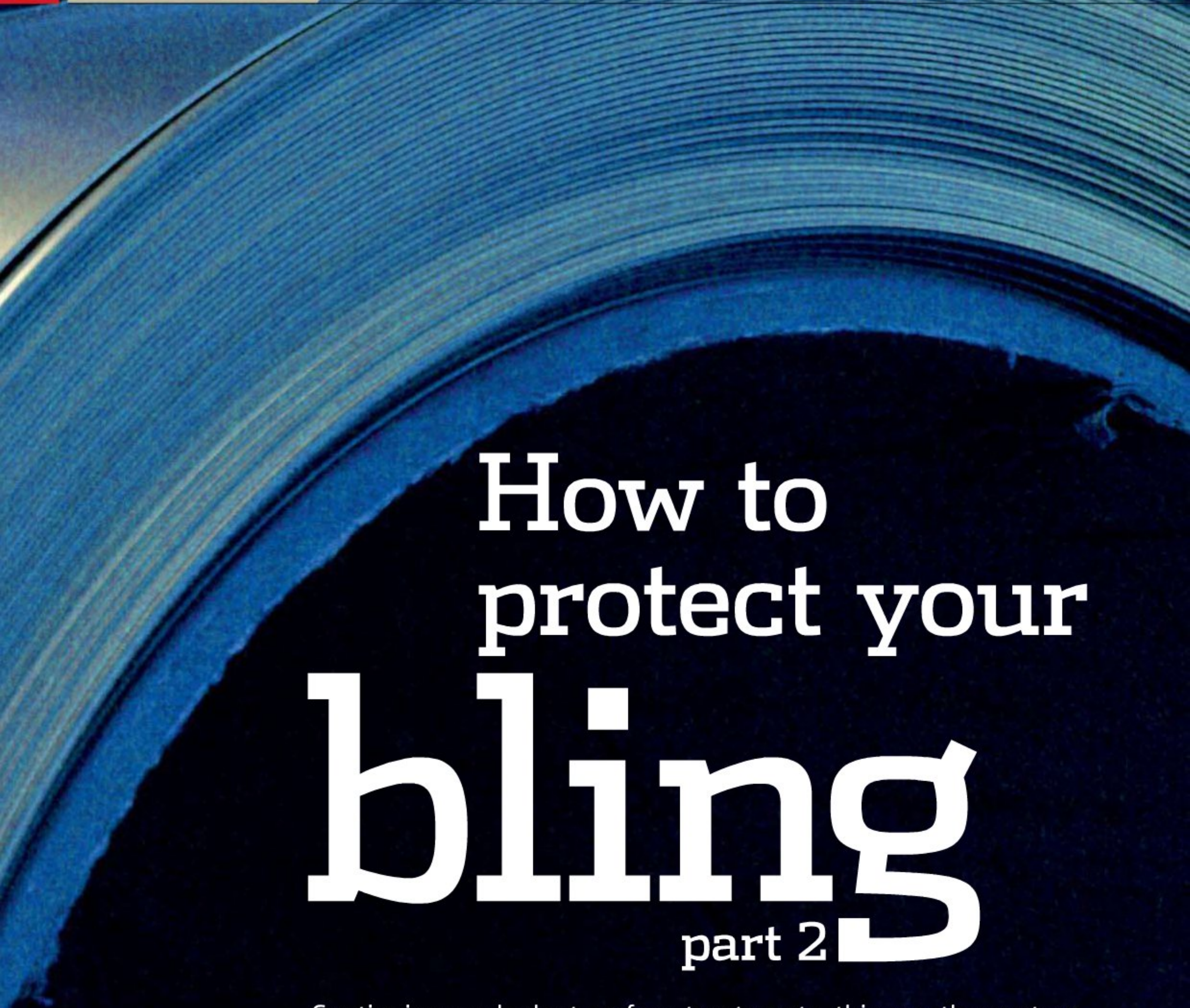
With just two of the seven championship rounds to go, the 909 Bergspyder finally made its debut at the Gaisberg climb, but Mitter decided to carry on with the 910/8 and won both rounds. Stommelen used the much-anticipated new car and finished third at its debut, despite suffering fuel feed problems. A more conventional electric pump was fitted for the final climb at Mont Ventoux, which helped him secure second place behind his team mate.

With six wins out of seven attempts, Mitter won his third championship in a row, while Stommelen secured enough points for second in the standings. With little more to prove, Porsche ended its hillclimb programme and the 909 Bergspyder was not used again.

In Porsche's absence, the Ferrari 212E Montagna made its belated appearance at the start of the 1969 season. Whether it would have been enough to take on the Porsche will never be known, but what is irrefutable is Ferrari's unbeaten winning record that season, which showed Piech's fears were certainly not unfounded.

ALL FOR NOTHING?

With a third and second place finish, the 909 Bergspyder had a brief and hardly convincing racing career, but many of the lessons learned during the car's development were applied to later and very successful Porsche racecars, in particular the 908/3, which owes much to the innovations made on the 909. Though there have been many more powerful, faster and more successful racecars to emerge from Weissach since, to this day, the 909 Bergspyder remains one of the most extreme and obsessive Porsches ever constructed.



How to protect your bling part 2

Continuing our look at surface treatments, this month we stray into the wonderful world of aluminium and magnesium

BY FORBES AIRD

Whether you spell it aluminium or aluminum (you can call me Al!), it is surely the second most commonly used metal in high-performance machinery. Part of this is undoubtedly due to the fact that pure aluminium is highly corrosion resistant, thanks to the continuous oxide film on its surface. That film is, moreover, 'self-healing' – if scratched through, fresh oxide instantly forms. And polished, it shines up a treat! Sadly, though, pure aluminium is hopelessly weak stuff.

Aluminium alloys, on the other hand, can be as strong, per pound, as high-strength steel, but those same microscopic grains of alloying elements that increase strength can also serve as the seeds of destruction. These grains, distributed throughout the metal, include some at the surface, so whenever the surface is wetted by an electrolyte – say, moist air with the usual load of atmospheric pollutants – galvanic corrosion will occur. Steps must therefore be taken to preserve both structural properties and cosmetic appeal.

ALCLAD

Pure aluminium's corrosion resistance is exploited by the 'Alclad' process, in which a thin layer – essentially a foil – of chemically pure aluminium is metallurgically bonded to the surface of a sheet or plate of aluminium alloy. The cladding, applied by hot rolling, is very thin, typically no more than five per cent of the sheet thickness. Nevertheless, the ability of the surface to form a tenacious protective oxide film makes cladding convincingly effective at corrosion resistance, and it too can be buffed to a reflective brilliance. That's fine for sheets, and parts formed from them, but

Aluminium forms its own natural oxide coating, but electrolytic anodising develops a thicker, more robust layer, making it ideally suited to components that are frequently fiddled with, such as fluid line fittings. The downside is anodising reduces fatigue resistance, so such parts only have a finite lifespan

cladding cannot be applied to castings, forgings or extrusions – in other words, many of the things aluminium alloys are used for in racecar engineering.

Magnesium cannot be 'clad' either, but other surface treatments are applicable to both aluminium and magnesium, and so can be discussed together.

MAGNESIUM

Long beloved of racecar component manufacturers, magnesium is the least dense of accessible structural metals (assuming you do not have access to beryllium!). It has comparable weight-specific strength and stiffness to aluminium and steel, which particularly recommends it for any structural application that may involve compressive or bending loads, yet it is most commonly used in wheels and other parts that are sized according to externally imposed dimensions (eg a wheel has to span the tyre, a bellhousing has to enclose a clutch assembly), rather than according to the loads it has to sustain.

There are several reasons why magnesium (mag for short) is not more widely utilised. Partly this reluctance is because of concerns about corrosion. Magnesium is the most anodic of structural metals, which not only encourages galvanic corrosion when it is used in combination with other metals, but also ensures that it is the magnesium that will get 'eaten' by the reaction. Like aluminium, mag forms a continuous oxide film on its surface immediately on exposure to the atmosphere, but that film is less robust and more chemically vulnerable than aluminium's natural shield.

In response to these concerns, the magnesium industry has done considerable work over the last couple of decades to demonstrate in practice what was known in theory in the 1940s – that magnesium's problems mostly stem from traces of heavier metals, especially copper, iron and nickel, which had not been removed during refining. New high purity versions of familiar alloys (often identified by the letters 'HP' or 'UX' added after the basic spec number) show dramatic improvement in corrosion resistance. Nevertheless, for even moderately aggressive environments (eg severe weathering, exposure to engine exhaust gasses) it requires surface properties beyond those conferred by the natural oxide film.

> **"Straight out of the tank, an anodised coating is porous"**

ANODISING ALUMINIUM

The film of oxide (Al2O3) that forms naturally on aluminium is almost unimaginably thin – a mere two ten-millionths of an inch. Anodising is an electrolytic process that develops a thicker, more robust oxide layer. When used for resistance to weathering and general corrosion, a film typically about 0.001in thick is developed. The pertinent mil-spec (see references on p76) calls for 0.002in, minimum.

Straight out of the tank, an anodised coating is porous, so must be sealed. Prior to sealing, however, the surface can be dyed – that's how plumbing and hydraulic fittings become red, blue, black, gold etc. Whether dyed or not, a flooding with boiling water seals the surface. The appearance of the anodised surface depends partly on the alloy involved. Generally, a silvery shine, or some shade of grey, can be expected, the shininess depending considerably on the level of polish on the substrate prior to processing. Anodised castings are likely to look patchy.

The tank chemistry, too, affects both the performance and the appearance. The most common process – and the one that most readily builds a thick oxide layer – involves sulphuric acid. While this is perfectly satisfactory for monolithic pieces, anodising an assembly this way is a bad idea as any residual acid trapped in crevices may lead to severe but invisible corrosion. When an assembly must be anodised, a solution based on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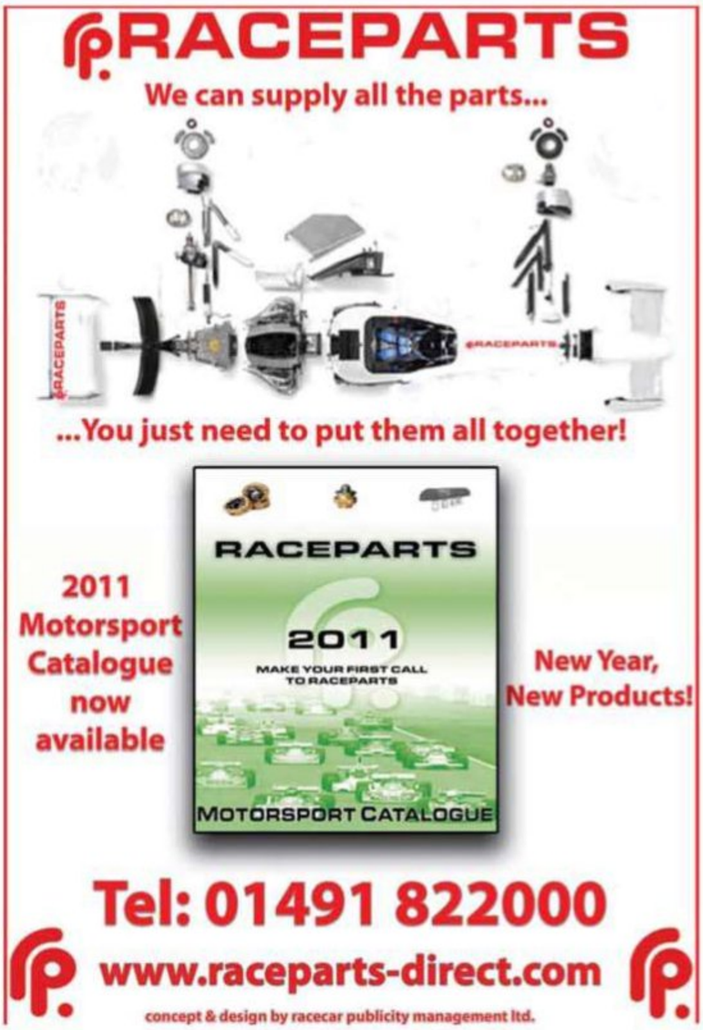
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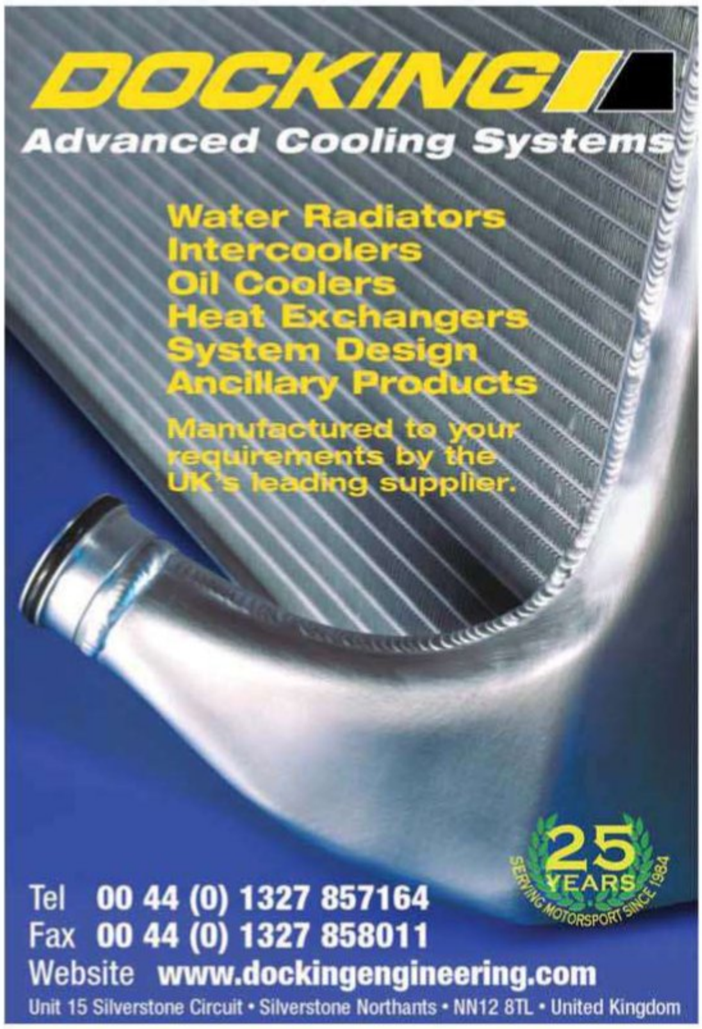
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Magnesium has long been prized for its light weight, but it is also the most anodic of structural metals, so has to be carefully treated to prevent corrosion. Even modern high purity versions require specialised surface treatment

In high usage areas, such as foot pedals, anodising will wear off rapidly, but this is accepted as the aluminium underneath has good anti-corrosion properties in its own right. In other words, much anodising is cosmetic

chromic acid is called for as any residual chromic acid confers additional corrosion protection.

Whichever process is used, anodising substantially reduces the fatigue resistance of aluminium alloys. This makes intuitive sense: micro cracks can be expected to occur in a hard, brittle 'shell' that is intimately joined to a more ductile base metal and, when the whole lot is flexed by working loads, eventual progression of a crack into the substrate is inevitable.

ANODISING MAGNESIUM

Magnesium, too, can be anodised. The chemistry is entirely different from that used for aluminium (mag is rapidly gobbled up by acids, so the various processes are, with few exceptions, based on alkaline solutions), but the upshot is the same: a thicker, more durable version of the natural oxide film.

Use of a caustic soda electrolyte will produce a grey or tan surface film, depending on the alloy, about 0.0003in thick. As with aluminium, the surface can be dyed before sealing. Another process (Dow #14) yields a white-to-grey appearance, again depending on the alloy, while Dow #17A produces a green shade, varying from light to dark depending on the thickness of the film (0.0004-0.0008in), which is a function of immersion time. A really stout coating, as much as 0.001in thick is produced by the 'H.A.E.' process, but the appearance leaves something to be desired – somewhere between olive drab and a muddy brown.

Renewed interest in mag for production vehicles has seen the recent emergence of various proprietary magnesium anodising processes – 'Anomag', 'Tagnite' and 'Magoxid' among them – all of which promise effective corrosion resistance in films as thin as 0.0003in. Such ultra-thin coatings aren't much for abrasion resistance, but their very thinness makes them virtually transparently clear and, since they make an excellent base for organic coatings, a common treatment for mag castings is one of these anodising steps, followed by a clear synthetic (usually urethane or epoxy-based) sprayed enamel / varnish.

CHROMATE CONVERSION

In part one last month, brief reference was made to this process in the context of cadmium and zinc plating. Substantially the same technique that improves the corrosion resistance and surface appearance of parts plated with these metals can also be applied to aluminium and magnesium alloys. Although a chromated surface has little resistance to abrasion, it has corrosion resistance comparable with anodising.

In the case of aluminium, in simplest terms, the surface gets converted from aluminium oxide to aluminium chromate, but the chemistry is exceedingly complex, and both the degree of protection afforded and the appearance vary considerably according to the alloy involved and details of the treatment.

The protection provided seems to be inversely proportional to the amount of copper, nickel and iron in the alloy, which is unfortunate, since one of the most common and versatile structural aluminium alloys (SAE/AMS 2024) has copper as its principal alloying constituent. Generally, thicker coatings (again, it's just a matter of immersion time) provide superior protection – although when we say thicker, we're talking about the difference between 20 millionths of an inch and 50 millionths. As coating thickness rises, the surface colour shifts darker, from yellow to golden to olive to brown.

The same materials and processes are also applicable to magnesium and, in the case of both metals, this is potentially a DIY procedure. The requisite materials are available under various proprietary names such as 'Iridite' and 'Alodine', which can be swabbed or brushed onto

The diversity of anodising effects available on aluminium is shown to great effect on these two sample pieces created by UK-based Langstone Engineering

large areas, although the results are likely to be streaky. Small parts can just be dropped into a bucket of the stuff. Alodining is often used to touch-up anodised areas that have been eroded bare, and is widely used by aircraft mechanics for field first aid for degraded anodised aluminium or magnesium parts.

The most rigorous aerospace specifications suggest that chromating of magnesium is suitable only for protection in storage and shipment, or as a base for paint. For those without aerospace budgets, it is reassuring to know that a careful chromating job, followed by wax, is generally adequate protection – just keep an eye on it and re-wax it frequently.

PLATING

Aluminium and magnesium can be plated with chromium, nickel and numerous other metals. Chroming aluminium involves even more steps than the same operation on steel – first a non-electrolytic zincate treatment, then a brief copper 'strike', followed by nickel and chromium. There hardly seems any point, unless the purpose is to develop a hard surface, as a marginal chrome plate is more likely to lead to corrosion than none at all.

Likewise, while magnesium can also be chrome plated, the resulting surface is likely to be porous, so the 'corrosion resisting' coating isn't. This is surely the preserve of show cars only.

ORGANIC COATINGS

If you have a shiny, silvery-grey anodised surface, or something with the attractive golden hue of many chromating procedures, why would you want to paint it? About the only case that might justify itself is when a magnesium casting or forging that needs a high level of corrosion protection winds up – because of the alloy and anodising process involved – some intolerably nasty colour, like ghastly green, and you just can't tolerate it, aesthetically.

CONCLUSION

There are, of course, innumerable alternative procedures available for coating, plating, colourising, plasma spraying of ceramics and cerametallics onto metal parts. Some of these are highly valuable, some are pure 'Pixie Dust'. In these two articles we have covered the traditional methods used to increase the corrosion resistance – and in many cases improve the surface appearance – of the most common structural metals used in racecars, based largely on long-established military and aviation practices. These folks don't do 'bling' – their concern is purely corrosion protection and minimal risk of diminishing the structural properties of the treated metals – so you can have decent confidence in the results.

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More Dynamics of the Race Car

Further excerpts from Danny Nowlan's new book, this month a dynamic racecar stability index and a classification for differential performance

This month, I'm presenting two further extracts from my book, *The Dynamics of the Race Car*. The first is determining the dynamic racecar stability index using race data, the second using metrics to classify differential performance. As with last month's extract, this material comes directly from the manuscript so the equation and figure numbers have been changed so they make sense.

Hopefully, you will find a few nuggets of gold among this that you can use in your day-to-day racecar engineering.

As intimidating as this may sound, we can actually use race data to approximate it. If you have a yaw rate sensor (or lateral accelerometers on both ends of the car), if you know what the maths is telling you and what to look for in the data, the stability index can be approximated.

The first trick then is inferring the side slip angle. If you have a good accelerometer and a yaw rate sensor, this is straightforward. Looking again at the equation, we have:

$$\dot{V}_y = a_{ymeas} - V_x \cdot r \quad (5.39)$$

Any data analysis package worth its salt can take this, integrate it and produce lateral velocity. It also helps that the vast majority of circuits have the beacon placed on the start / finish line. This means that we can assume a zero side slip velocity at the start of the lap. Once we have this, the side slip angle can be estimated by,

$$\beta = \frac{V_y}{V_x} \quad (5.40)$$

where Vx is recorded by any decent data logging system.

The second trick comes in looking at the differential equation for yaw rate. Re-capping for the purposes of this article, we have,

$$I_Z\dot{r}=N=C_f\cdot\alpha_f\cdot a-b\alpha_r(C_r+F_{xr})$$

(5.41)

Equation (5.41) tells us that the current lateral moment acting on the car is directly proportional to the time derivative of yaw rate. Good quality data analysis programs should readily give reliable readings on the derivative of any logged variables. If you are doing it from first principles, it's best to take a curve fit of, say, three points either side of the point of interest, then take the derivative of the curve fit.

Another way of constructing yaw moment is to have accelerometers fitted to both axles. This is actually a much better measurement of moment because acceleration is effectively measuring the forces. Presuming that we are measuring in m/s^2 and we are measuring ayf for the front lateral acceleration, and ayr for the rear lateral acceleration, the yaw moment N is given by,

$$N=\left(a\cdot wdf\cdot a_{yf}-b\cdot(1-wdf)\cdot a_{yr}\right)\cdot m_t$$

(5.41b)

Here, wdf is the weight distribution at the front and m_t is the total mass, measured in kg.

The final trick comes in looking at the definition of the stability index in a slightly different manner. Recall our definition of the stability index,

$$stbi=\frac{\partial N}{\partial a_y}\cdot\frac{1}{m_t\cdot wb}$$

What this means is that the stability index is actually contained in an xy plot of the

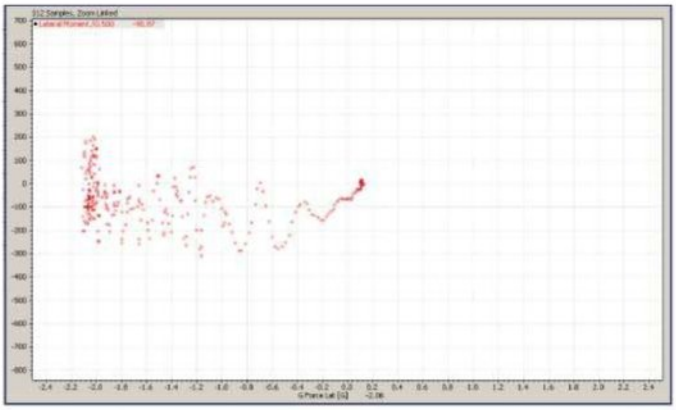


Fig 5.8: plot of lateral moment vs lateral acceleration

acceleration. It really is that simple. To illustrate, consider figure 5.7 below, a plot of actual steer vs neutral steer for a Formula 3 car.

Just so we are clear, this is a simulation of an F3 car produced by ChassisSim. Consequently, we know it is being driven on the edge of its performance envelope.

We have focused on the mid-corner to turn exit section and, in the main, the car is stable. The only exception we have is at the mid-corner position. An xy plot of lateral moment vs lateral acceleration for this data confirms this, and is illustrated above in fig 5.8.

As we can see, this plot in the main is below the 0 axis. This indicates we have stable behaviour because the bulk of the slopes are negative (the logger has a right-hand turn being recorded in negative *g* so, when we do the corrections, the slope is less than zero). This means in the main you are dealing with a car that is stable. The only exceptions to this are when we get to high lateral *g* numbers and when the steered angle crosses back to the neutral steer line. This occurs at values between 0.15 and 0.6*g*, which correlates very well with

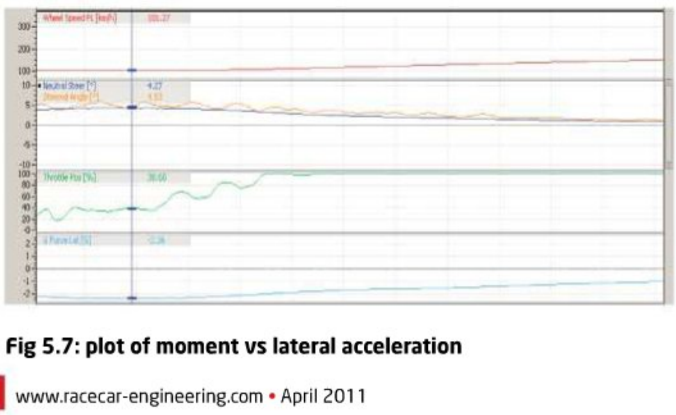


Fig 5.7: plot of moment vs lateral acceleration

trace. If anything, the slopes in fig 5.8 pre-empt the reduction in steered angle back towards the neutral steer line and below it. This can be seen in reviewing the plots of lateral acceleration and steer and neutral steer in fig 5.7. Another thing to be watching for is that for right-hand turns you want the moments below zero, while for left-hand turns you want them above the line.

While this example looks slightly trivial, it nonetheless underscores a powerful way of looking at racecar stability. Yes, fig 5.8 does confirm what we say in fig 5.7, but we know for a fact the car is being driven on the performance envelope, so fig 5.7 will give us a good indication of racecar stability. Fig 5.8 takes this to the next step, because it will give you a true indication of what the car is up to, regardless of what the driver is doing. This is the power of fig 5.8 - it is the ultimate driver lie detector!

I should also add that the reason the stability index is moving around so much is that the car is on a notoriously bumpy circuit. This shows you how dependent car stability is on the inputs it's being subjected to, both by the driver and its operating environment.

We can extend the approach we have just taken here to deal with breaking down the various elements of the stability index. This is why we went to so much trouble to estimate the side slip angle. Recalling equation (5.40) we have,

$$stbi=\left(\frac{\partial N}{\partial\beta}\cdot\frac{\partial\beta}{\partial a_y}+\frac{\partial N}{\partial r}\cdot\frac{\partial r}{\partial a_y}+\frac{\partial N}{\partial\phi}\cdot\frac{\partial\phi}{\partial a_y}+\frac{\partial N}{\partial p}\cdot\frac{\partial p}{\partial a_y}\right)\cdot\frac{1}{m_t\cdot wb}$$

Given the analysis we have already done, we can use the slope of a number of xy plots to break down the various components of the stability index. In practice, this can be tricky because, as we saw in the F3 example, the stability index is affected by a number of different factors.

DIFFERENTIAL PERFORMANCE

While there is no magic bullet for divining the perfect differential set up, there are a number of metrics we can use to light our way and get into the ballpark. Given the nature of what we are dealing with here, this is better than nothing.

The first metric we'll discuss is the concept of the maximum slip ratio. Assuming no tyre stagger (ie equal rolling tyre radius right to left) and that we are accelerating, we have,

$$V_{Diff}=t\cdot r\approx\frac{t\cdot a_y}{V}$$

$$SR_{MAX}=\frac{V+t\cdot r/2}{V-t\cdot r/2}-1$$

(7.3)

Here we have

V_{Diff} = the differential speed between the wheels
SR_{MAX} = the maximum slip ratio
V = current forward speed of the car (m/s)
r = current yaw rate (rad/s)
t = relevant track width
a_y = lateral acceleration (m/s2)

It is absolutely critical to have a handle on the differential wheel speed and the critical locking ratio. Firstly, the differential wheel speed will tell you the envelope of the differential characteristic you are working with. To make the numbers easier, we have presented the static case as an approximation in equation (7.3).

Now let's consider a worked example,

$$V = 100 km/h = 27.8 m/s$$
$$a_y = 1.5g = 14.7 m/s^2$$
$$t = 1.5m$$
$$\therefore V_{diff} = \frac{1.5 * 14.7}{27.8} = 0.8 m/s$$
$$r = \frac{a_y}{V} = \frac{14.7}{27.8} = 0.528 rad/s$$
$$SR_{MAX} = \frac{27.8 + 1.5 * 0.528/2}{27.8 - 1.5 * 0.528/2} - 1 = 0.03$$

It's a simple example but it serves to give you an idea of the scale of numbers to expect. The astute reader will realise that there will be some leeway in these calculations due to the outside tyre slipping, but these numbers will at least put you in the ballpark.

ratio if we have the following:

- **A good indication of tyre load**
- **A good tyre model with good traction circle properties**

If we have these, we are in business. It's also one of the many reasons we went to great trouble to construct a useable tyre model. To start the discussion let's consider figure 7.6, below.

To keep the maths simple, I'm going to assume the traction ellipse is a circle. This has the effect of making the algebra

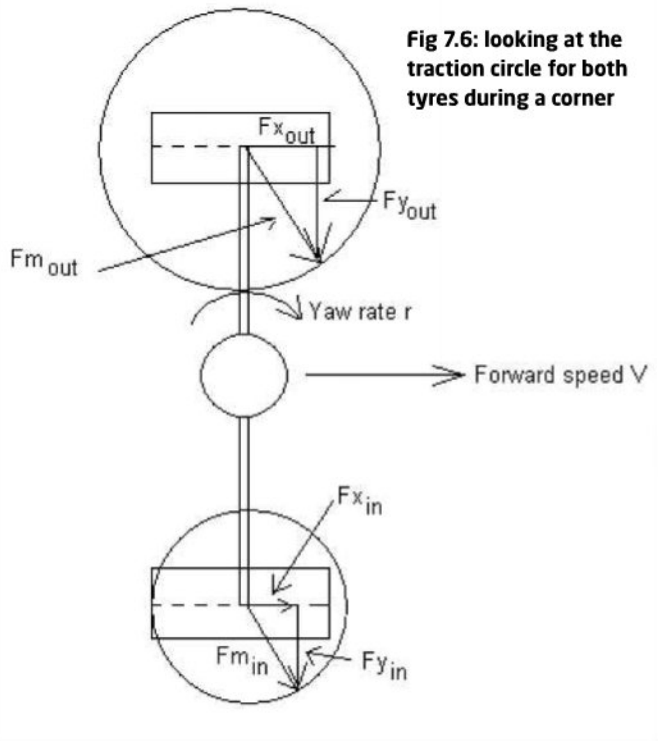


Fig 7.6: looking at the traction circle for both tyres during a corner

Also remember that the differential is a device that works on differential wheel speed. That is, it is driving force away from the wheel that is spinning the most to the wheel that is spinning the least. Consequently, the maximum slip ratio is a very good approximation of just how hard we can drive the inside tyre. It will be a conservative measure, but it's that line in the sand that you know if you cross you are in trouble.

The next metric we'll discuss is the critical locking ratio, CR. The critical ratio represents the locking ratio when the forces are distributed per the traction limits of the tyres. Fortunately, we can approximate the critical locking

simpler. As we walk through the formulation, the terms to modify in order to model the situation more accurately should be fairly obvious. For the formulation of the critical locking ratio, let's assume we know the following:

a_y	**= lateral acceleration (m/s^2)**
wd	**= relevant weight distribution**
m_t	**= total mass of the vehicle**
r	**= yaw rate (rad/s)**
Fm_{in}	**= max possible tyre force for the inside tyre**
Fy_{in}	**= inside lateral tyre force**
Fx_{in}	**= longitudinal tyre force for the inside tyre**
Fm_{out}	**= maximum possible tyre force for the outside tyre**
F_{yout}	**= outside lateral tyre force**
F_{xout}	**= longitudinal tyre force for the inside tyre**
V	**= forward car speed (m/s)**

Remembering back, and using the ChassisSim v3 tyre model, lateral tyre force can be approximated, and we are now going to put this to good use. Assuming the slip angles are relatively equal (not perfect I know, but an okay approximation to kick off with), we can assume the following:

$$F_{y_{OUT}} = wd \cdot m_t \cdot a_y \cdot \frac{Fm_{OUT}}{Fm_{IN} + Fm_{OUT}}$$
$$F_{y_{IN}} = wd \cdot m_t \cdot a_y \cdot \frac{Fm_{IN}}{Fm_{IN} + Fm_{OUT}}$$
$$F_{x_{OUT}} = \sqrt{Fm_{OUT}^2 - F_{y_{OUT}}^2}$$
$$F_{x_{IN}} = \sqrt{Fm_{IN}^2 - F_{y_{IN}}^2}$$
$$CR = \frac{F_{x_{OUT}}}{F_{x_{OUT}} + F_{x_{IN}}} - 0.5$$

(7.4)

As before, let's do a sample calculation of what to expect. We'll take up where we left off with our calculation of critical slip, using the numbers in table 7.1.

The reason I have stated the loads, as well as the traction circle radius, is to highlight to the reader the importance of using the plot of load vs traction circle radius to relate these two parameters. Doing the calculations, we see:

$$F_{y_{IN}} = 0.6 \times 550 \times 1.5 \times 9.8 \times \frac{3395}{3395 + 6000} = 1753N$$
$$F_{y_{out}} = 0.6 \times 550 \times 1.5 \times 9.8 \times \frac{6000}{3395 + 6000} = 3098N$$
$$F_{x_{IN}} = \sqrt{3395^2 - 1753^2} = 2907.4N$$
$$F_{x_{out}} = \sqrt{6000^2 - 3098^2} = 5138.3N$$
$$CR = \frac{5138.3}{5138.3 + 2907.4} - 0.5 = 0.14$$

What this hand calculation is telling you is that the critical locking ratio for this particular case is 14 per cent. The critical ratio number gives us the ideal value for the slope. Naturally, this will vary, but it represents a pretty good starting point.

The question then has to be asked how this relates to the LR numbers the diff manufacturers give us. This relationship is outlined in equation (7.5), below.

$$LR = \frac{F_{OUT} - F_{IN}}{F_{TOT}}$$
$$\therefore F_{OUT} = F_{TOT} \cdot (1 + LR)/2$$
$$\therefore F_{IN} = F_{TOT} \cdot (1 - LR)/2$$
$$CR = \frac{F_{OUT}}{F_{TOT}} - 0.5$$
$$= \frac{F_{TOT} \cdot (1 + LR)/2}{F_{TOT}} - 0.5$$
$$\therefore LR = 2 \cdot CR$$

(7.5)

And this bit of mathematical fancy footwork tells us that if the critical locking ratio we have calculated is 0.14, then we require a locking ratio of 28 per cent.

This is not perfect because we've had to use a static assumption and fudge the slip angles a bit, but forget perfection when it comes to calculations and differentials. What makes the diff so uncertain is that we have a combined slip condition marrying with a messy mechanical device. Consequently, what we have here is an approximation that we can marry up to what we see in a diff manual.

I should also add that if you are in any doubt, treat the critical ratio as the line you do not cross. You are better off being conservative, particularly on a tight street course, because the last thing you want is to be pulling out a diff between sessions because the car is wildly varying between understeer and oversteer.

Table 7.1: typical F3 values for an LSD calculation

Parameter	Value
Total lateral acceleration, ay	1.5g
Total car mass, mt	550kg
Weight distribution ,wd	0.6
LIN (load on inside tyre)	135.5kg
LOUT (load on outside tyre)	290kg
FmIN (traction circle radius inside tyre)	3395N
FmOUT (traction circle radius outside tyre)	6000N

TECHNICAL INNOVATION

Anglo-Austrian partnership a winner

The Best Technical Innovation Award at Autosport Engineering 2011 went to Arrow Precision's new M2000 connecting rod. **Alan Lis** uncovers the story behind its development

The markets being targeted range from Touring Cars to F1, or any race series where there are high-revving engines

A new generation of connecting rod is the product of a technical partnership between the Anglo-Austrian engineering consultancy, Zzuhl, and UK-based engine component manufacturer, Arrow Precision.

Zzuhl was founded two years ago by ex-Pankl employees, James Oakenfull and Bernhard Matzinger, with the aim of bringing high-level technology to a wider motorsport market. 'The only customers who can afford to buy high-end products from other connecting rod manufacturers, whether titanium or steel, are those in F1, MotoGP or NASCAR,' says Oakenfull. 'Outside of those categories, the products manufactured by those companies are beyond the means of other customers, especially the way motorsport is nowadays with budget constraints.

'The USP of Zzuhl is that we can provide the same level of service and technology, but instead of paying 1000-1500 euros ($1400-2000) for a connecting rod, the customer can pay £400-600 ($650-975). That's a significant reduction in cost, but with the same material strength as the best products from the leading manufacturers.'

Oakenfull worked at Cosworth for 11 years before joining Pankl in 2008, where he met Matzinger, who was a Pankl project leader on its Formula 1, Moto GP and NASCAR connecting rod development programmes. Zzuhl's in-house design and engineering capability is enhanced by the company's use of Oliver Allen Design, whose owner worked on piston and connecting rod design for Mercedes Benz when its engines won the F1 world championship in 1998-'99, and also has experience in Sportscar racing.

Prior to developing its own connecting rod design, Zzuhl began by re-designing other manufacturers' parts for new applications. 'For example, we would take a commercially available piston, add our own twist to the design and optimise it for certain markets,' explains Oakenfull. We were taking very cost-efficient parts and making them suitable for higher level motorsport.

'We never wanted to be a manufacturing operation ourselves, mainly because we didn't have the £3-5million we would have needed to buy the facility, equip it and employ the staff. That would have defeated the object of the exercise,' says Oakenfull.

> **Using FEA, we did a lot of work on material testing and design**

The search for a manufacturer capable of working to the required standards led Zzuhl to Arrow Precision. 'Depending on the application you are talking about, a market norm of 5-20 microns tolerance on bore sizes [is normal],' says Matzinger. 'Obviously we aim for the lower limit. This was the basis on which we approached Arrow, and they were able to meet our requirements, so we formed a technical partnership.'

Soon after the companies began working together, it became clear that a new connecting rod material specification was required. This turned out to be what Arrow internally calls M2000, but is known by Zzuhl as AZZ-2.1.

Developed over a 10-month period in 2010, the new material has a number of advantages compared with more conventional steel alloys such as EN24V and 4340. 'The obvious difference is that a conventional steel connecting rod material has a tensile strength in the order of 1100mPa, while M2000 is rated at 2100,' explains Oakenfull. 'Also, M2000's hardness rating is 59 against around 36 for a more conventional alloy. Typically, high-strength alloy steels at this level suffer from increased notch sensitivity but, with very careful chemistry and attention to the heat treatment process, we have managed to eliminate that fatigue issue in this material spec.'

'Using FEA, we did a lot of work on material testing and design,' explains Matzinger. 'Arrow carries out the production work, but we work together on any problems that arise in manufacture. It's a team effort.'

At the time of writing, the Zzuhl / Arrow rod had yet to be raced for the first time, but had already successfully tested in a V8 engine and a turbocharged power unit.

BRIEFLY...

Record year for Renault Sport Technologies

The French car manufacturer's sporting arm, Renault Sport Technologies, has recorded record sales this year for both its racing and road vehicle range. Sales of the company's new Formula Renault 2.0 single seater have already reached over 100, while its range of rally cars continues to grow, with the addition of the Twingo R2/1 packages and the Megane RS N4.

Michelin increases support in ALMS race

Tyre supplier Michelin has announced that it will partner two new teams in the 2011 ALMS series. The company will now support the Ford GTs of Roberston Racing and the new Panoz Abruzzi effort. The company will also continue to support the Flying Lizard Motorsports, Risi Competizione and Corvette Racing teams.

Dallara and Ferrari go virtual racing

Italian racecar constructor, Dallara, has developed a new driver training simulator, in collaboration with Ferrari. The rig has been developed to cover a variety of disciplines, allowing access for the maximum number of potential customers. The company views simulators as a vital tool to aid drivers and engineers who want to take advantage of the cost savings made by avoiding track testing.

Oreca drops LMPC parts prices

French LMP manufacturer, Oreca, has announced a 10 per cent price drop on all spare parts for LMPC (Le Mans Prototype Challenge) cars running in the ALMS. The company stated that the drop, agreed in conjunction with its US distributor Carl Haas, is recognition that teams need as much support as possible in the challenging economic climate.

STRAIGHT TALK

Floating a concrete boat

PAUL J WEIGHELL

Some years ago, Patrick Head explained to me how to make boats from concrete, but I never envisaged he and Williams would ever embark on a similarly curious public flotation exercise for the entire team.

Although growing companies tend to float their shares in order to glean money for expansion, it is hard to see why, having made a net loss over the last five years, Williams are anywhere but at their own sunset, yet they really are seeking to sell some of the company to the public to raise money.

What is that money for? Disturbingly, chief executive, Adam Parr, has admitted that none of the cash raised will go to the company. In other words, the flotation cash will go into the pockets of current owners, Williams, Head and Toto Wolff.

If the cash is not to re-capitalise the company, then has Williams already secured good contracts for the future? Unfortunately, Williams has chosen to list in the less regulated Frankfurt exchange precisely to avoid answering that question. In London, they would have to make lots more information available to prospective investors but, for whatever reasons, Williams may opt for secrecy with regard to income via the Concorde Agreement. Investors will no doubt draw their own conclusions from the fog, including the reported loss of more than 40 per cent of sponsors' cash since last season.

> "a vanity flotation aimed at well-heeled fans"

So without new business investment or current income data, are the assets worth buying a share of? The land and building assets included in the flotation vehicle are thought to be worth about 25m euros, but pointedly the list excludes the 100-plus historic racecar collection, arguably of solid, long-term, appreciating value.

The flotation price is around 250m euros, or 10 times the known asset value, and that is an awful lot of 'intangible goodwill' or 'possible future prospects' for potential investors to swallow.

Indeed, history may be repeating itself, for in 1986 March Group plc was floated via the London Unlisted Securities Market. March was a more diverse business than Williams and had several different cash streams, yet still struggled to meet public company expectations. By 1988, merchant banker John Cowen was chairman and spoke about the flotation: 'A grand prix team, in my judgment, is not a proper constituent for a public company. It is not a profit centre. That's not saying it isn't possible for a GP team to make a profit, but racing people believe sponsors are there to finance the teams, not put money in shareholders' pockets. There is no real concept of cost control. The important thing is winning the race... [and] in a commercial environment it just doesn't work.'

Perhaps unsurprisingly, March Group plc went into receivership a couple of years later.

Williams seem to be involved in a vanity flotation aimed at well-heeled fans who do not need a return on their investment and will be pleased to accept what amounts to corporate hospitality in return for buying a minimum of one per cent of the stock. Its only practical use seems clearly as a belated exit strategy for its current shareholders – so much so that one of my City colleagues already places the entire idea into the 'they must be havin' a laugh' bin.

Williams F1 is being floated on the Frankfurt stock exchange. But, if you're thinking of investing, you might want to look at what you're investing in...

DJ wings now available down under

Racers, hillclimbers and autotesters in the southern hemisphere will now have access to DJ Engineering's range of wings, the Tuners Group having recently been appointed Australian and New Zealand representative for the British company's range of high downforce and high-efficiency aerofoils. The wind tunnel tested, pre-preg carbon fibre units are manufactured by DJ and designed by *Racecar Engineering*'s very own aerodynamics expert, Simon McBeath. For more information, visit www.tunersgroup.com/Products/wings.html

VI-grade support Formula SAE

Germany-based simulation specialist, VI-grade GmbH, has announced it will be providing the Squadra Corse Politecnico di Torino with its VI-Drivesim static simulator to train its racing drivers, in preparation for the 2011 Formula SAE competition. Squadra Corse Politecnico di Torino has been granted free access to VI-Drivesim due to its victory in the 2010 edition of the Virtual Formula, a competition (organised by VI-grade and partners) based upon the rules and regulations of the popular Formula SAE and Formula Student competitions. 'We are extremely grateful to VI-grade and partners for granting us access to the VI-Drivesim technology,' declared Professor Andrea Tonoli, faculty advisor of Squadra Corse Politecnico di Torino. 'This breakthrough driving simulator technology will enable our driver to gain confidence on the Formula SAE circuit, providing us with a competitive edge that will be of crucial importance for our success at the 2011 edition of this competition.'

Driver simulators have now reached Formula SAE. Once one has it, the others are sure to follow

BRIEFLY...

TMD Friction expands with new acquisition

Brake manufacturer, TMD Friction Group, has strengthened its ties to the motorsport industry with the acquisition of bt Bremsen Technik GmbH. TMD Friction has been a minority shareholder of bt Bremsen since 2001 and Derek Whitworth, president and CEO of TMD Friction Group, Luxembourg, and Dieter Goldbach, managing director of bt Bremsen Technik GmbH, jointly announced TMD Friction's acquisition of the remaining 51 per cent of the company. The acquisition of the company also included bt Brake Technology of America.

Qatar's the star

A delegation of senior executives from some of the UK's leading companies led by UK minister of state for trade and investment, Lord Green, visited the Williams Technology Centre (WTC) in Qatar as part of an official tour of the Qatar Science and Technology Park. The delegation were shown the advanced vehicle simulator development platform from which WTC engineers are developing solutions for motorsport, road cars, emergency services and commercial fleet driver training. The delegation were also briefed on the Centre's high-powered flywheel energy storage development programme, which it is hoping will make Qatar's ambitious transport and electricity infrastructure more efficient and reliable.

Join the Draft

Dassault Systems, provider of 3D CAD and PLM solutions, has announced the general availability of DraftSight for Windows, a free to download 2D CAD product for CAD professionals, students and educators. Originally launched in Beta version in June 2010, the general release for Windows includes many updates based on user feedback. DraftSight is available for download at www.draftsight.com.

UNDER DISCUSSION: BLOODHOUND SSC

Less drag, more speed

Bloodhound SSC's favourite dissenter offers up a few more points for consideration

In response to Ron Ayers' piece in last month's *Racecar Engineering* I would like to raise the following points: even J85 jet dragsters, with airflow to the engine blocked by the cockpit and no inlet ducts, can still run a standing quarter mile in under six seconds at over 280mph.

In 1965, in exactly the same configuration with which he set his 576mph record, Art Arfons drove his J-79 Green Monster land speed car to a standing start quarter-mile record of 258.62 mph in 6.91 seconds, using all four afterburner stages. That's an average acceleration of 1.7*g*. This was with the big pitot body in the inlet partially starving the engine for air at low speeds. So simply because an inlet is designed for high speeds is no reason to assume it can't support at low speeds what is still hard acceleration. The Super Cyclops, the dragster version of Arfons' J-79 cars, with its lighter weight and unrestricted air inlet, boosted average acceleration to about 2*g*, gaining Arfons about one second and another 40mph in the quarter mile.

The graphs published with the piece show Bloodhound's acceleration remaining at under 1*g* for over 20 seconds and a distance of close to a mile, taking 20 seconds to exceed 200mph and about another five seconds to reach 400mph, eventually hitting 600mph after 30 seconds of acceleration. The Budweiser Rocket, clocked through an electric eye timing trap on Barrett's next to last run, reached 692mph in 17 seconds in 1.7 miles. That's 13 seconds quicker and 92mph faster than Bloodhound in approximately the same distance. No wonder it takes Bloodhound 44 seconds and 4.5 miles to reach 1000mph.

An optimised dragster version of an EJ200 jet car, assuming a car weight of 4000lb, would be able to launch at close to 5*g* with the engine in full burner. Even if the restricted air intake inherent in a land speed car cost a full 1*g*, a land speed version could still be able to launch at close to 4*g*. It would come out of the first quarter mile at over 300mph and out of the first mile at well over 500mph. On a 10-mile course, that would leave it another 3.5miles to reach 1000mph before entering the measured mile. Acceleration in full burner on a pure jet EJ200 car weighing 4000lb would not drop below 2*g* until combined rolling resistance and aerodynamic drag reached 12,000lb.

It takes a rocket car about as much energy to accelerate from 750mph to 1000mph as it needs to accelerate from 0-750mph. For the Silver Bullet RV-1 rocket land speed car, we are looking at a length of 30ft, so that we can keep empty weight down to no more than 6000lb. This will still allow a propellant volume of over 500 gallons (about 4200lb), enough to support a thrust of 35,000lb for 30 seconds. We believe this design will be capable of accelerating to 1000mph in under four miles, allowing the record attempt to be made on a nine-mile course on Lake Gairdner.

Sincerely,
Franklin Ratliff

Is this enough?

Going by the text on the Bloodhound SSC website, with just two 7ft 6in drag 'chutes on the car it will have less drag 'chute capacity than the Reaction Dynamics X-1, the original hydrogen peroxide rocket dragster. The X-1 had two 8ft chutes for normal operation and a single 16ft chute for emergencies. The X-1 weighed 750lb empty. The Bloodhound SSC, on the other hand, has a projected empty weight of 12,000lb, so is this enough 'chute?

In my role as an advisor to the Silver Bullet team, I have suggested to the other team members that they consider using a ballute parachute as the primary aerodynamic decelerator.

Franklin Ratliff

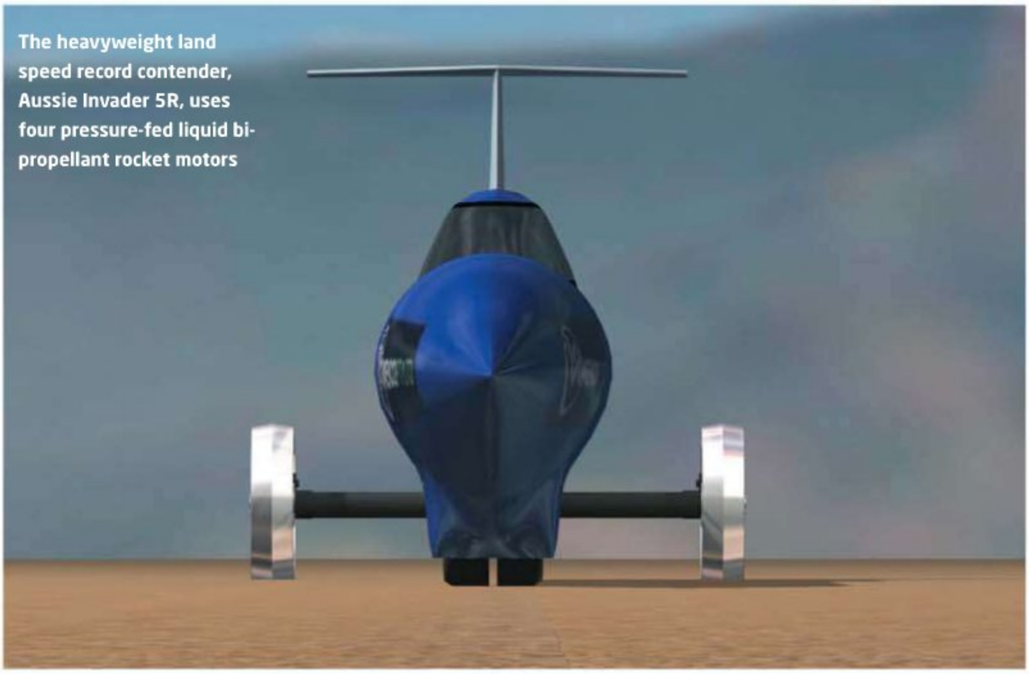
RIGHT TO REPLY

No need for concern

A response by wing commander Andy Green OBE, British Royal Air Force fast-jet pilot and World Land Speed Record holder

'Please do not be concerned by Franklin's comparisons – I'm fairly confident Bloodhound SSC will be fine. A single 7ft6in ring slot 'chute at Mach 0.9 will provide over 20,000lb of drag – ample to stop Bloodhound SSC within the 4.5 miles available (the other 'chute is a reserve / emergency – Franklin, you might want to read the article again). If the X1 was stopping from Mach 0.9 over 4.5 miles, I would suggest that it was over catered for in 'chutes. On the other hand, if it was actually going slower and stopping more quickly… then there is no point in comparing the two.

Any sensible data on ring slot 'chute opening transition loads would be most welcome. The manufacturers' data is a little thin in our environment, while our Thrust SSC data (same 'chutes) was collected at too low a data rate to be definitive. There must be a 'book' answer out there somewhere?



The heavyweight land speed record contender, Aussie Invader 5R, uses four pressure-fed liquid bi-propellant rocket motors

IN RESPONSE TO FRANKLIN'S COMMENTS:

- **Detailed EJ200 performance data is restricted, so the graphs in *Racecar Engineering* (and all of our other public sources) are indicative, not exact. You cannot extrapolate performance data from these generic sources.**

- **The Budweiser Rocket was unable to sustain its speed for even one mile, so is clearly not an LSR contender, then or now. Worse still, the rear wheels left the ground at peak speed, so this was self-evidently not a safe car, and did not even manage to beat the record in 1980, so it is not a good point of comparison against a target of 1000mph. It was remarkable, but not relevant in this context.**

The Reaction Dynamics X-1, the original hydrogen peroxide rocket dragster

- **An EJ200 car with 1000mph capability would be carrying an EJ200 weighing over 2500lb (this is the true installed mass of engine plus essential ancillaries), plus wheels stressed to take 50,000*g* at the rim, which will total nearly 1000lb for a set of four (that's the lightest Lockheed Martin (UK)'s considerable expertise can get it down to). Add about 200lb for a driver, at least the same again for a cockpit structure and protection, and the rest of your chassis mass is about zero, so you might want to look at your figures again.**

I know you're an advocate of the light weight LSR car Franklin (as am I) but, once you look at the real-world issues, the Aussie Invader 5R (at well over 20,000lb) is a practical solution, and Bloodhound SSC's 12,000lb or so starts to look like the 'lightweight' answer to the problem. The last 4000lb (empty mass) LSR car was The Blue Flame, which went 622mph. We need to go a lot faster than that!

If you have an issue you want to discuss here, please email the editor at: **graham.jones@chelseamagazines.com** or write to: the editor, *Racecar Engineering*, Suite 19, 15 Lots Road, Chelsea, London SW10 0QJ, UK. Visit **www.racecar-engineering.com**

RIGHT TO REPLY

Please, be very careful...

Ron Ayers, chief aerodynamicist to the Bloodhound SSC project, adds his thoughts to the debate

Franklin makes many points in his latest letter, and I will try to answer most of them.

1. Scaling laws. These are very useful if used with caution and with strict regard to practical limitations. The standing quarter mile time achieved by Arfons (and by Richard Noble in Thrust 2) give absolutely no indication of what is achievable when aiming at 1000mph. Quite simply, Bloodhound is not in the drag racing business, so such comparisons are not helpful.

2. In my earlier designs for Bloodhound, the first thing I tried – and rejected – was the pure jet solution. It was quite impossible to get the average thrust / weight ratio high enough over the whole speed range, and other configuration / intake problems combined to make this option a clear non-starter.

3. The next option considered – and again rapidly discarded – was that of liquid propellant rockets. Having worked as a guided weapons engineer, I have witnessed some truly horrific explosions with these engines, even when handled in ideal conditions and by experts. I am firmly of the opinion that they should be used purely in a military environment, and only as a last resort. I readily agree that they will provide greater thrust / weight ratio than any other solution, but they are not for me. I genuinely wish you well with the Silver Bullet (the competition is clearly good for all of us) but please, be very careful.

4. I also rejected solid propellant rockets, and batteries of such rockets, because of the problems of vehicle speed control.

5. Bloodhound can also get to 1000mph in four miles, but it does not need to do so. We have 4.5 miles available for acceleration, so we will use it. Our target is 1000mph through the measured mile, so we are not in a supersonic drag race. Our combination of jet engine and hybrid rocket gives us a combination of safety and precise speed control, and an average thrust / weight ratio up to 1000mph. This operational flexibility also makes the test programme, including the low-speed runs on runways, easy to design and manage.

The fact that our two projects use such different technologies will be very attractive to the press. They love such comparisons. However, as a professional engineer with 61 years' experience, I am much happier with the Bloodhound concept, whatever its weight. May the best team win!

Of course weight is a consideration in any form of racing, and The Blue Flame was very light, but safety is also a critical factor that must not be overlooked

What is a ballute?

The Goodyear Company designed the ballute parachute in the early 1970s. It looks very much like a boxer's punch bag and was designed for operation at high altitude with an upper speed limit of Mach 4 at 80,000ft, finding applications on ejector seats and as a bomb retarder. It is inflated by ram air and has been tested decelerating between Mach 1.4 and 0.5, exactly the region where the five current land speed record contenders will be running.

Interestingly, ballute parachute testing was carried out in 1973 using a Lockheed F104 Starfighter, the same design that forms the basis of Ed Shadle's North American Eagle, which, incidentally, is using conventional parachutes.

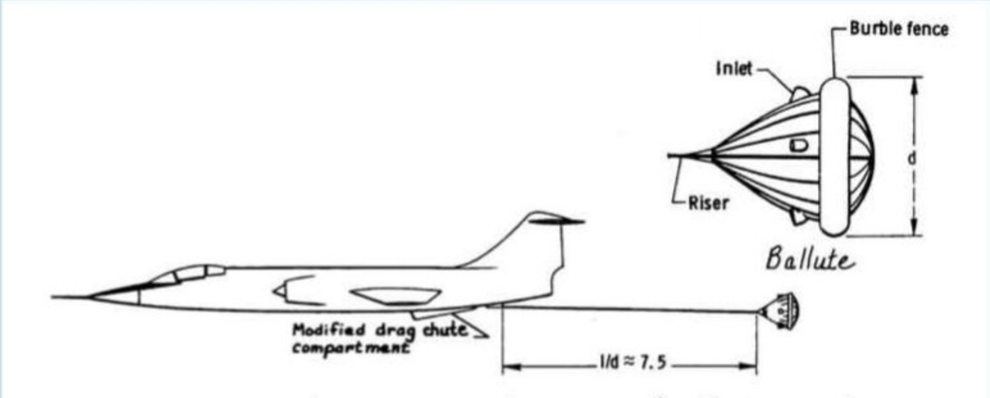


Figure 1. F-104B airplane towing a ballute decelerator.

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William Hewland

THE INTERVIEW

Q You were just 24 when you took over the company following your father's retirement in 1990. How much of a challenge was that?

Well, it was a challenge. I was very young. I'd been in the design office a few years, but I knew there was a whole side of the business I didn't understand. But my father had an almost irresponsible amount of faith in me! It was okay though because I didn't have an ego and I went out and employed a 50-year old guy who knew loads about engineering and machine tools and gear cutting and we moved on from there.

Q What would you say have been the major changes since you've been involved in the business?

Technologically, to a great degree much of it has been refinement rather than sea change, but the obvious one that the customers will see is the semi-automatic [gearbox]. Some of the technological direction it was heading in a few years ago got stymied by financial constraints and everyone started to go one-make racing, while every series started cutting back. In many ways we had technology 10 years ago that was almost more interesting than now.

You've got different problems now too, in as much as you've got a grid of 25 to supply, and they've all got to work at once. In my Dad's day, you would have never have sold 25 gearboxes to a customer in one hit. So the market has changed massively.

Q So there's a lot riding on clinching those contracts then?

Yes, you're playing roulette with very big chips. If it doesn't land on black you've got nothing. Equally, if you've gone a bit too cheap to get the contract, then you've got years of something that's going to lose you money. In my Dad's day the business ran purely on his technical expertise, whereas nowadays so many conversations start with what budget they can afford. You almost have to feed in the technology, to look as good as you can, within that budget.

William Hewland, president, Hewland Engineering

- **1982:** joined family firm to work in design office (Hewland Engineering was set up by William's father, Mike, in 1957)
- **1990:** took control of company after Mike Hewland's retirement. Also started own race driving career, going on to compete in F3 and GTs, amongst others
- **1997:** Hewland Engineering moves from Maidenhead to new factory in nearby White Waltham

Q Once Hewland was synonymous with Formula 1, is there any link today?

We're back in Formula 1 these days, making components, and that's still amazingly testing and fun. The F1 teams all do their own gearboxes now as they're just such an integral part of the car, but they seek manufacturing help from outside. And some of them are actually doing this more than they used to, because they are now trying to control the costs. We've upped our game and met them where they've an interest in listening to a gearbox manufacturer again. More so than in the past, where they just used to design stuff and get it made whatever the cost.

Q Which race series do you supply gearboxes for now?

We do the entire transmission for the new GP2 cars. We do GP3, we do Formula 2, we do Superleague transmissions and we do the transmission for the DTM cars, too. Then there are 13 gearbox types available off the shelf, while we also

RACE MOVES

Former Renault F1 team principal, **Bob Bell**, has taken up the post of technical director at Mercedes GP. He now reports to team principal **Ross**

LAT

Bob Bell

Brawn and heads up the chassis team at the F1 outfit's Brackley base. Bell was team principal at Renault following the race fixing scandal and the subsequent departure of **Flavio Briatore** and **Pat Symonds**. He has also worked at Jordan and McLaren during a long F1 career.

Tony George, the founder of the Indy Racing League, has returned to the board of Hulman and Company, the

LAT

Tom George

George family firm that's responsible for IndyCar and the Indianapolis Motor Speedway. George lost his position as president of IndyCar two years ago, when he was replaced by **Randy Bernard**.

Brett Jewkes is the new head of NASCAR's Integrated Marketing Communications department. Jewkes, whose job title is vice president and chief communications officer, joins NASCAR from marketing company Taylor, where he oversaw the firm's motorsport projects.

TRG Motorsports has signed veteran crew chief **Jay Guy** to look after its no 71 NASCAR Sprint Cup Chevrolet this season. Guy was at Penske Racing in 2010, and

LAT

Jay Guy

has some 30 years' experience of the sport, having started his career in the 1980s – ironically on the no 71 Chevrolet, at the time driven by **Dave Marcis**.

Former Sauber and Arrows designer, **Sergio Rinland**, is no longer working full time at Epsilon Euskadi. He is still, however, involved with the Spanish company as a consultant, via his re-launched consultancy firm Astauto.

Tom Carnegie, the

LAT

Tom Carnegie

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RACE MOVES

legendary Indianapolis Motor Speedway commentator, has died at the age of 91. Carnegie's voice was a feature at the Indy 500 for 60 years, from his debut at the mic in 1946, until he retired after the 2006 race.

Former Renault technical director, **Pat Symonds**, has returned to Formula 1 as a consultant to the Virgin Racing team. Symonds is banned from taking any operational role

Pat Symonds

in F1 until 2013 for his part in the race fixing scandal at Singapore in 2008, but he is allowed to work for a team on a part-time consultancy basis.

Team Lotus boss, **Tony Fernandes**, has been awarded a CBE – Commander of the Order of the British Empire – by the Queen. The award is for promoting educational and

Tony Fernandes

LAT

business links between the UK and Malaysia, and is for work he's carried out in his role as head of Air Asia.

Former Jordan, Midland and Force India commercial boss, **Ian Phillips,** has taken on the role of chief operating officer at the Virgin Racing F1 team. The appointment is part of a management

Ian Phillips

LAT

re-shuffle at Virgin, which also sees **Graeme Lowdon**, who was previously the team's chief executive officer, move to a new role as team president. Replacing him as CEO will be **Andy Webb**, who is the UK managing director of Virgin's title sponsor Marussia Motors. Meanwhile, **Nikolay Fomenko,** president of Marussia Motors, has been appointed as engineering director.

Paddy Lowe has been promoted to technical director at McLaren, with **Tim Goss** – who was chief engineer on the 2010 MP4-25 – stepping into Lowe's former position of engineering director. Both will continue to work alongside **Neil Oatley**, who stays in his post as director of design and development programmes.

William Hewland THE INTERVIEW

CONTINUED

have a range of our classics gearboxes, and also build bespoke units for customers.

Q What staff and facilities do you have there?

There are about 110 people working here now, about 15 of whom are in the design office. It's all on CAD now, we haven't had a drawing board for 15 years. In fact we didn't even bring a drawing board to this factory when we moved here in 1997!

On the manufacturing side it's nearly all in house, and of a very high standard. We've also invested a great deal recently – for instance, we have a Kapp gear grinder, which is a rather unusual piece of kit. You won't find many of those in the country. It's for grinding gear teeth and gear profiles and is very useful for prototyping, as you can generate the shape of something very fast. You can grind from solid, and it is the only way of producing the incredibly high tolerances that certain applications demand.

Q What's the future for motorsport gearboxes in general, and for Hewland Engineering in particular?

I think you're going to get more and more semi-auto. I also think the energy recovery thing hasn't happened quite as quickly as I believed it would. I thought there would be more take up on it, but it's coming, and most of our gearboxes are being future proofed with designs so that it can be added – as a lot of it works through the gearbox.

But whatever we do, it's always important to look at what the regulations are likely to allow. For instance, we had some very clever Touring Car differentials in the late '90s, but they got banned. One team actually tested one and found it was so good they lobbied to get it banned so they didn't have to buy it.

To be honest, the future very much depends on racing itself. And we will always respond to any changes.

RACE MOVES

Alex Somerset has left Mofaz Racing and moved back to Europe. Somerset was technical director at Mofaz, overseeing its World Series by Renault 3.5 programme and setting up its Asia Pacific FBMW squad. He also ran the team's Aston Martin GT4 in the MME 12 Hours at Sepang.

David Ingram has been taken on by Faith Motorsport to look after **Morgan Shepherd**'s NASCAR Nationwide campaign for this year. The veteran crew chief worked on the K-Automotive no 26 car in 2010.

Mark Slade has been confirmed as **Michael Schumacher**'s race engineer at Mercedes

LAT

Mark Slade

for the 2011 season. Slade has previously engineered **Kimi Raikkonen** at McLaren and **Vitaly Petrov** at Renault.

Michele Mouton has taken up the position of World Rally Championship manager for the FIA.

LAT

Michele Mouton

The four-time world rally winner, the only woman ever to win a round of the WRC, will oversee the governing body's input into the safety, regulations and the calendar of the championship.

James Robinson, the former Williams F1 senior operations engineer, has joined Rebellion Racing for its LMP1 campaign this season. He will engineer the Lola-Toyota that's to be driven by **Neel Jani** and **Nicolas Prost** in this year's Intercontinental Le Mans Cup and LMS.

Chris Norman is the new competitions secretary for the 750 Motor Club, the champions of low cost club motorsport in the UK. Norman, who has previous experience at the MSA, BRDC, Goodwood and Rockingham, takes over the position from **Robin Knight**, who is retiring.

■ 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

AWARDS

Strong, reliable horsepower gave 20-year old sensation, Trevor Bayne, the momentum he needed to capture his historic Daytona 500 victory, picking up a victory for the fabled Wood Brothers along the way in the 53rd running of the legendary race.

The engine in the no 21 Ford also earned Roush Yates Engines the MAHLE Clevite Engine Builder of the Race Award, based on qualifying, laps led and finishing position.

LAT

The Wood Brothers rack up yet another victory at Indy, this time for 20-year old Trevor Bayne

The award is part of the NASCAR Prize Money and Decal Programme, also referred to as the contingency programme, which provide teams prize money and weekly awards based on performance in several categories.

Other notable contingency award winners include David Gilliland, whose Front Row Motorsports team captured three awards: Mobil 1 Oil Driver of the Race, MOOG Chassis Parts Problem Solver of the Race Award and O'Reilly Auto Parts Position Improvement Award, as a result of gaining 36 total positions during the race.

In a race that witnessed multiple engine failures, three different NASCAR Sprint Cup Series race teams carrying the FR9 engine swept the top three finishing positions in the race, including Roush Fenway Racing's Carl Edwards who finished second and Gilliland who crossed the stripe in third.

'I'm really proud of the Ford FR9 by Roush Yates,' said Doug Yates, CEO of Roush Yates Engines. 'We've done a lot of work on this engine and I think we all saw how the performance was at the end of the year last year by winning a couple of races. To come to Speedweeks and be fast says we've done our homework, not only on power but also on the cooling system. And to have three different teams finish 1-2-3 says a lot for our company and personnel.'

'Doug Yates and those guys build great engines,' said race runner-up Carl Edwards. 'Now that we have this new engine, we may have a lot to look forward to. I don't want to jinx it or anything, but I'm really excited to run that engine for the whole year.'

LAT

Ford's FR9 is proving to be the engine to beat this season, as others blow up by the wayside

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LATE APEX

Bring on the new season

If the opening round of this year's World Rally Championship was anything to go by, you would have to say this important branch of the sport is finally on its way back from a spell in the doldrums. Granted, there were still only two manufacturers – Ford and Citroën – battling for top honours but, in both cases, the factory teams were seriously pressed by entries from satellite teams and, at the finish, there was less than 50 seconds covering the top four finishers.

In the end, the win went to Ford, and although the specialist nature of the Swedish event means it is difficult to draw any meaningful conclusions regarding likely form for the rest of the season, what was significant was the closely run nature of the rally, given that it marked the competition debut of the new generation World Rally Cars – the DS3, in the case of Citroën, and the Fiesta, in the case of Ford. Physically smaller than their predecessors and powered by 1.6-litre, direct injection, turbocharged engines, compared with the previous 2.0-litre units, it became clear watching the in-car television footage that they require a very different driving style from the previous specification WRC machines.

Add to this the fact that Mini will shortly arrive with its new car for a limited 2011 WRC programme in preparation for a full-on assault in 2012, and talk of possible interest from Volkswagen and Saab, and there is no doubt the situation is looking considerably brighter than it has for a number of years.

By comparison, the run-up to the start of the 2011 Formula 1 season seems to have been dominated by legal wrangles rather than news of the technical developments at the heart of the new cars, which will likely determine if we have another exciting year of racing to match that of 2010. The ongoing fight between the 1Malaysia Racing Team and Proton / Group Lotus regarding the right to use the Lotus name, the Formula One Group losing a European Court case over its claim to the exclusive rights to 'F1' as a trademark and the case of Dr Gerhard Gribkowsky, former risk management boss of Germany's Bayerische Landesbank and former chairman of F1 commercial rights holder, SLEC, who is currently on remand in a Munich prison on suspicion of receiving a $50 million bribe for undervaluing shares in SLEC are the stories that dominated the pre-season headlines.

Then we had the almost comedic situation of Ford threatening to sue Ferrari over alleged infringement of the former's trademarked F150 brand (attached to its top-selling pick-up truck), the Scuderia having used the same designation for its 2011 Formula 1 car by way of recognising 150 years of Italian unification. Fortunately, sane heads prevailed quickly on this one, and Ferrari altered the name of its new challenger to F150th Italia. How anyone could confuse a pick-up truck with a Formula 1 car is difficult to grasp but, as we all know, the brand is king in this day and age, and companies will not hesitate to 'go legal' to protect their investments.

In any event, it is fervently hoped that all the legal battles will have been fought out before the beginning of the new F1 season and we can focus on the important part of motorsport – the competition.

EDITOR
Graham Jones


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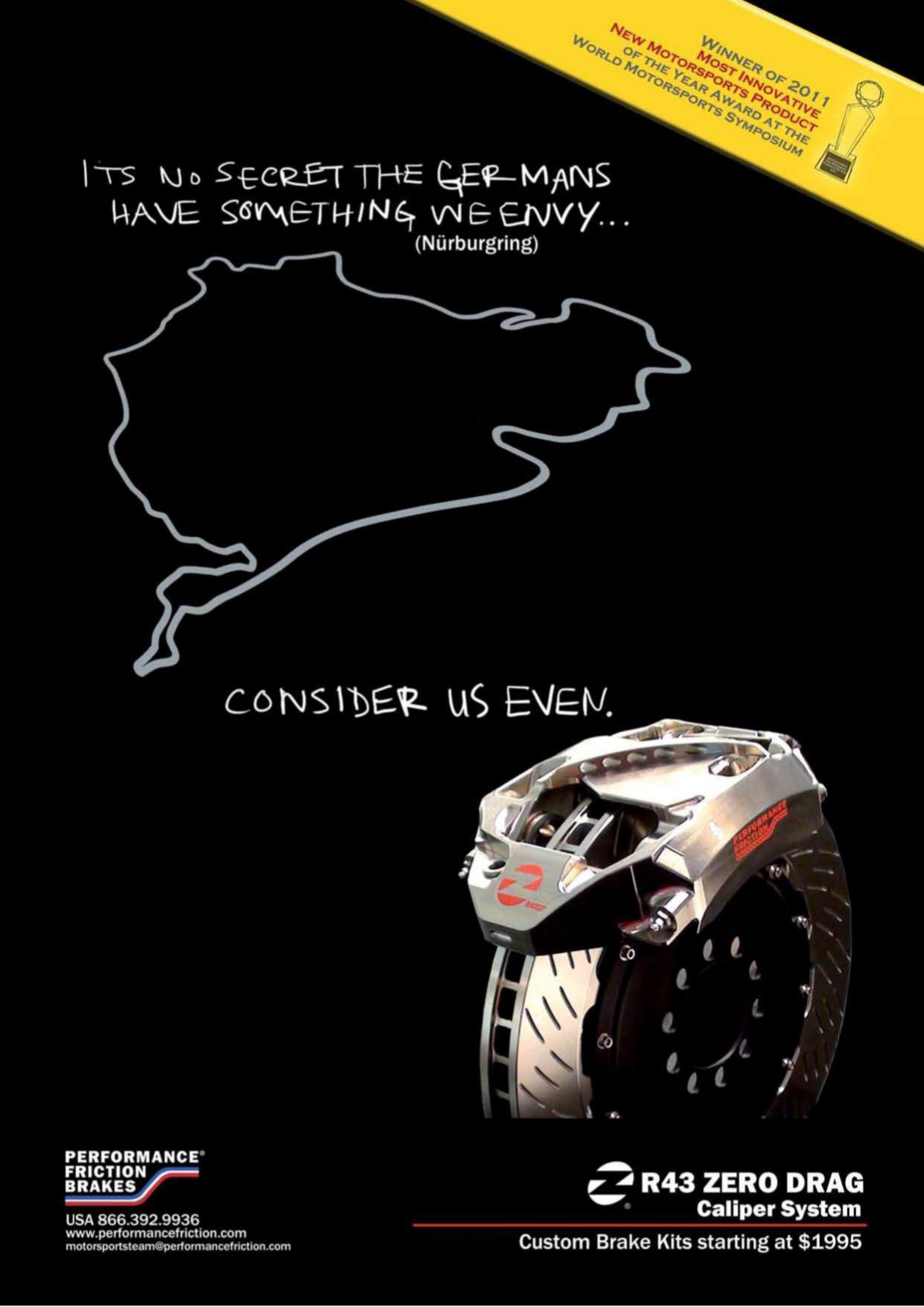

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