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July 2015 • Vol 25 No7 • www.racecar-engineering.com • UK £5.95 • US $14.50

Le Mans 2015

New aero approach for Audi's R18 contender

Porsche 1985

Reinhold Joest reveals the secrets of his Porsche 956B

Formula 1 analysis

We use OpenFOAM CFD to examine modern era cars

Formula E finale

Electric racing in the spotlight as new rules are analysed

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Je ne regrette rien

Three decades of life in the fast lane have left their mark – it's been one hell of a ride

Le Mans is a mistress that I have been visiting for 32 years or 11,684 days, which is a sizeable chunk of the 25,581 days, 15 hours, 0 minutes that I have been on this planet. During that period the gap that separates Europe and the Americas has widened by 80.23cm thanks to Tectonic plate movement and the earth has travelled 30 billion kilometres around the sun.

Coincidentally the Le Mans test day on May 30 will be the day I achieve my biblical three score and ten, hitting my sell-by date and voiding all manufacturers warranties. Hence this column.

During this period I must admit to spending far too much time in racing team garages workshops and pits, but quoting Oscar Fingal O'Flahertie Wills Wilde "One day your life will flash before your eyes. Make sure it's worth watching," and boy has it been so – I've loved being able to play with everything from karts to F1.

When I was 12 I began working on a fMaserati 250F, chassis #2322, which now resides in a private collection after being raced for a while in South America, part of the time as a 'Mecanica Continental', in which the thoroughbred Italian machinery had an American V8 transplanted in the interest of easier maintenance, what with Modena being a long way away.

A road well travelled

My first race with it was the Sao Paulo GP of 1957, where we finished fourth. One Juan Manuel Fangio won the race and he also collected several world championships, proving throughout his career that the old adage was true – form is temporary, but class is permanent.

It amuses me to think there are few people in a racing paddock nowadays that can true a Borrani wire wheel, one of my duties at the time. The Maserati also had a new-fangled Plexiglas windshield, and setting it up consisted of changing the tyre pressures and setting the float levels on the Weber Doppio Corpo carburetors, with any other handling foibles being corrected by the driver's steering and foot pedal artistry.

I have seen what was a nice game for budding enthusiasts and engineers turn into a mainstream occupation and entertainment for millions, and incidentally turn into a major revenue stream for those loathsome investment bankers.

The cars themselves evolved from the pre-war ladder-frame chassis to space frames to aluminium monocoques with aluminium honeycomb panels before mutating into today's carbon-composite honeycomb structures. Optical intuition aerodynamics morphed into using cutting edge ground-effect wind-tunnels and CFD to produce absurd levels of grunt. Engines that were at the pointy-edge of ICE technology have evolved from lumps that had a specific output, 108.26bhp per litre, into today's 375bhp per litre units, using 30 per cent less fuel.

It also gave me an opportunity to travel the world and visit a slew of racing tracks, 162 at the last count, meeting interesting people from all nationalities and walks of life along the way. There is a vast panoply of different characters attracted to fast machines, the people who build, maintain, sponsor and design fast cars. Plus, the drivers themselves are interesting creatures – the successful ones, the gifted but unlucky ones and even the run-of-the-mill ones, all individuals, and thus subject to all the foibles that define humanity.

It amuses me to think there are few people in a racing paddock nowadays that can true a Borrani wire wheel

Stonehenge and Divila – two ancient monuments that are still going strong in 2015

Drivers show an endearing lack of restraint with the spraying of champagne to mark their territory or spoils, or at a deeper level the ejaculate of orgasm. Incidentally, the first known example of it has the bottle preserved just by the coffee machine at AAR where I spent too much time this winter building another complex mechanical toy.

The other gift from the sport was the enduring friendships forged when thrust into difficult and challenging tasks done in exiguous time frames, where you learn to depend on your team-mates. I took to heart Sextus Propertius' exhortation "Let each man pass his days in that wherein his skill is greatest", thus probably depriving the world of another second-rate driver and drifted instead into racing car design and my real love, aviation.

Without really knowing how it happened, apart from enjoying every moment of the trip, I passed from being a promising young designer into a grizzled veteran. Tempus fugit…

The first intimations of mortality were when racing at Pau, quite a few years ago, and finding the grid of the historic sportscar race was almost entirely made up of cars of I had worked on, although, of course, there were a few exceptions.

The fact that presidents and prime ministers are also now routinely younger than me does not quench the idea that I am but a youngster – it's just a shame that the mirror contradicts this idea every time I shave.

Doing a rapid appraisal of the past decades just spurs me on to make use of the next decade to work on even more interesting projects, do more weekly races and find new mechanical, logistical and tactical problems to solve.

Continue to question everything, learn something and answer nothing, as Euripides once said.

Go motor racing? Yes young engineers, it will break your heart when you lose, but the satisfaction engendered when all the concepts work, all the parts fit and you bring your steed home at the top of the pile are priceless. It will accelerate your growth, give you a new measure of just what you are really capable of and will spur you on to new efforts. It will also give you a random walk through the thickets of chance, the kind of uncertainty that might interest a guy named Werner Heisenberg. Once you get an adrenaline addiction and start enjoying walking on the edge of the precipice, the rest of your life will seem boring.

Otto von Bismarck once said that fools learn from their own mistakes, whereas wise men learn from the mistakes of others.

No, je ne regrette rien….

Back to basics

Can motorsport trim back the excess and return to its racing roots?

It is not just Formula 1 that struggles with the costs of going racing. Budgets at virtually all levels have increased over the past few decades way beyond inflation. The reasons are obvious – technology leads to far more complex and expensive cars, engines and support equipment, increased professionalism, greater travel expenses, the introduction of costly government and motorsport authority legislation, less trade support, extortionate licence fees...the list is endless. Unfortunately, after the sponsorship boom years of the 1970s and 1980s such financial backing has diminished significantly, even if the global phenomenon of rapidly-accumulated personal wealth by many individuals has allowed some of these riches to trickle down into the sport.

Reducing the costs

As a result of this downturn, leading motorsport sanctioning bodies and promoters have constantly sought to introduce measures to reduce costs. One-make single-seater chassis series were among the first implementations of this, starting with the junior formulae, but in due course spreading through to just one step below F1, and even that is at risk now, in part at least. Formula 3 is an exception in regulation, but not in actuality. The real success of this policy could promote considerable debate, with more 'cons' than the 'pro' lobby would ever admit; those looking beyond the supposed benefits can see the harm that this has done to both the sport itself and the industry that supports it.

Nonetheless, the FIA and the ACO (who should be congratulated on working together closely in a way that would not have been envisaged just a few years ago) seem hell-bent on extending this arguably restrictive philosophy to the engines powering both of their sub-LMP1 two-seater prototype classes. The newly-introduced LMP3 has a mandated single-source, large-capacity normally-aspirated V8 that does not even give a nod in acknowledgement to the global trend towards more efficient, smaller displacement turbocharged power units. LMP2 is set to do a complete U-turn and reintroduce a pure racing engine, having found that adapting production engines to the demands of high-level racing can sometimes cost more than starting from scratch. Most experienced engine builders could have told them that, and if any did then nobody in charge was listening.

The intention is for a single-make engine based on a conventional V8 design. So detailed is the brief given to potential suppliers that beyond the fundamental architecture even the bearing, valve and piston dimensions, valve actuation, conrod and crankshaft design, general material specifications – and a whole lot more – are mandated. Some of this appears to be an attempt to revive the over-ambitious GRE 'one size fits all' idea promoted by the FIA some years back by suggesting that components from current F3 engine designs could be utilised, but creating one V8 out of two four-cylinder engines isn't simple and doesn't affect the most expensive items required to do this.

Mandating the external and internal engine specifications is stifling innovation with little benefit

Profits for independent engine suppliers are thin, and at breaking point for some

Beyond this argument lies a deeper subject. At this point I must declare an interest because I act as an adviser to a well-known racing engine company, but I am also a defender of our sport, and experience has taught me always to take a look at the broader effects of any change [as well as any stagnation to be fair]. Is it really the FIA's or the ACO's job to virtually design the engines to be used in their categories? Their technical competence is undoubtedly high, but it cannot be at the level of race engine specialists who have been at the sharp end of the business for many years.

Surely their part should be to dictate the parameters they are seeking – performance, cost, weight, durability, commonality of chassis installation– and then leave it to the former to propose their solutions? By tying down almost every last detail it risks demoting the independent engine companies to little more than subcontractors and assemblers. Not only does this have implications to the staffing levels and investment in facilities that they can bear, but it must also stifle and demotivate them.

Most of these firms are based on the desire of their founders to use their knowledge and ability to innovate and beat their rivals – racers with a capital R in fact. Restricting the market for them and removing the element of competition will lose this invaluable source of original thought and enthusiasm to continually improve. Looking back at major developments in motor racing, the bright ideas and their application come mostly from the independents and not from the major automotive concerns, although they may have sometimes funded them. So do of course, most importantly, the clever and experienced power unit designers of the future.

Less is more

I have no doubt that the FIA and the ACO are acting in what they believe is in the best interests of the category, the entrants and their desire for stable and well-populated grids. They have been successful in substantially reducing engine costs via price caps and insistence on extended life, and all credit to them for this. However, this means that the profits for independent engine suppliers have become very thin and are almost certainly at breaking point for some; any further restriction on their business may be a fatal stroke, whereas probably the largest real cost saving opportunity now is to avoid frequent changes and proliferation of different regulations.

With F2 on the horizon and requiring similar engine requirements to LMP2, it seems to me that having common engine regulations would make economic sense and while also permitting independent engine company participation by expanding the market over at least two categories.

As a free marketeer by instinct and observation, I hope that the governing bodies rethink this trend towards over-regulation and – within reasonable bounds – allow those doing the best job to earn their place at the top, rather than by dictat.

It's only skin deep

Audi's R18 boasts a significantly improved aero package, but beneath the new bodywork much of the technology is tried and tested

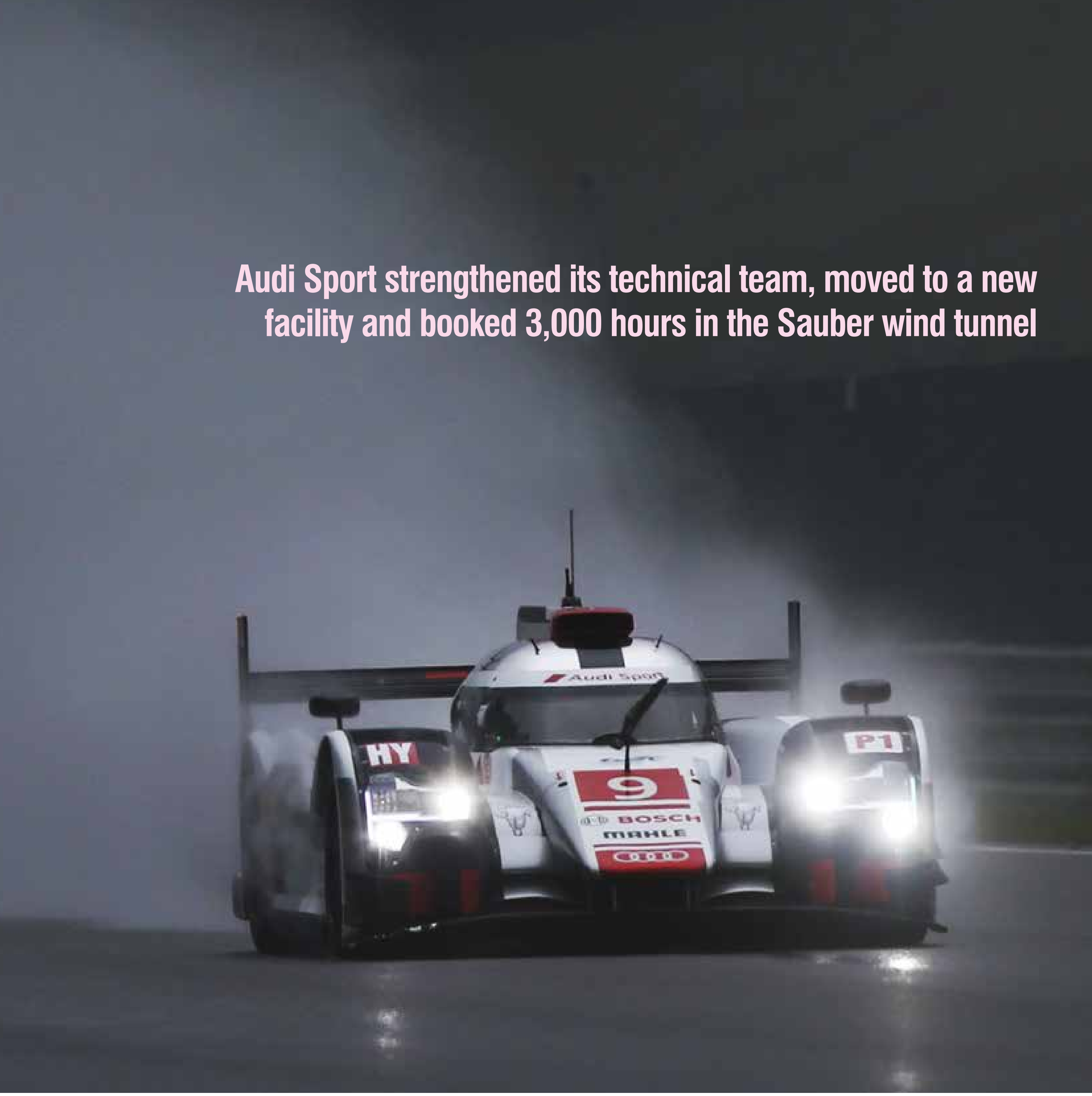
By SAM COLLINS

Audi has been the dominant force in sports prototype racing for almost the entire 21st century, having only been defeated once at Le Mans [by Peugeot in 2009] and by fellow VAG company Bentley in 2003. But in 2014, with the arrival of Porsche and a revitalised Toyota, the cars with the four rings on the nose looked the weaker than they had been in years – winning at Le Mans was an unexpected result and the World Championship was went to Toyota. Yet, in 2015, Audi Sport has fought back with a highly advanced and visually striking, but by no means pretty, LMP1 design which has already proven to be incredibly competitive in the opening rounds of the World Endurance Championship. However, looks can be deceiving and this car is perhaps not as 'new' as its appearance suggests.

'The car is based around the 2014 monocoque and concept,' explains Chris Reinke of Audi Sport. 'While we will be using three new monocoques at Le Mans, they are all the same design. The engine follows the same philosophy, although it has been optimised in some areas, and the transmission casing is the same. As well as a stable structural spine this also allowed us to start testing technologies early for the 2015 car.'

The philosophy of keeping the tried and tested core of the car offered an instant level of reliability, right from the car's first roll out shortly after New Year. 'We only had the definitive 2015 car on track in January, but we had tested all of the technologies on it extensively,' says Reinke. 'On the roll out we did 4000km straight out of the box, which is impressive, even to us. We then took the car to Sebring and did a full Le Mans race distance. That is not to say that there were no issues, but that's why we do it. We test the cars roughly, to break them and sort any issues out before the season starts.'

Indeed, the cars that Audi ran at the WEC Prologue, Silverstone and Spa had some race history from the 2014 World Championship season, so to say that the 2015 Audi R18 is a new design is not correct. However, it is a substantially updated design and that is immediately apparent looking at it. The aims of that update programme can be gathered



Audi Sport strengthened its technical team, moved to a new facility and booked 3,000 hours in the Sauber wind tunnel

not only by the car's striking visuals, but also by looking at the 2014 WEC season where it was apparent that, despite winning Le Mans, Audi seemed to be some way behind Toyota and Porsche in terms of outright pace.

Improved airflow

'We decided that we had to improve the car's efficiency,' says Audi techical director Joerg Zander. 'The 2014 contender had a lot of downforce already, which made it good for the WEC tracks, but for Le Mans, where you are looking at top speed, it was not so good. So the project focussed on the aerodynamics,'.

Ahead of the 2015 season Audi Sport strengthened its technical team with the appointment of Zander among others, and a move to vast purpose-built facility at Neuburg an der Donau, near Munich. It also booked a reported 3000 hours of time in the Sauber wind tunnel in Switzerland, although this time was shared with the 2017 DTM/GT500 car.

The result of this work was clear when the 2015 R18 was rolled out to the press at the new Audi Sport test track, which is also located at Neuburg. The whole front end of the car has followed a notably different route in terms of aerodynamic surfaces to its Le Mans winning predecessor. A noticeably smaller nose has been introduced, something that meant that the car had to undergo a new frontal crash test, but that was deemed to be worthwhile due to the gains it would bring. 'The upper panels of the front bodywork were all moved rearwards,' Zander explains. 'The idea was to get the front wing elements as clear as possible so that we can achieve a clean flow over it and under the chassis. We had to reshape some of the components so as to not create turbulent flows in sensitive areas and to maintain the energy in the airflow right under the car to the diffuser. So with that approach we have maintained a quite good level of downforce. We wanted to make the downforce with the diffuser and the underfloor rather than via the rear wing having a steep angle and lots of Gurneys, as that would let us reduce the drag co-efficient while maintaining the downforce level.'

Low drag specification R18

As if one major revision to the Audi R18's aerodynamic concept was not enough a second, very different, version of the R18 was revealed just before the Spa six hours race early in May. This low drag specification featured fundamentally different front end treatment with a minimal amount of front bodywork.

'The whole aero is completely different for Le Mans. It's almost a new philosophy,' says Audi Sport Team Joest Managing Director Ralf Jüttner. 'It's about the flow through the car again, but it's not quite as extreme as the R15 was. Here it's more about the front of the car. Almost everything is different between the two configurations in terms of bodywork. Everything has changed except for the the windscreen and the doors.'

From the side the changes to the car are as obvious as they are from the front – the rear wheel pod on the 2015 R18 is pulled slightly further forward than on the 2014 car, again something which was found to improve aerodynamic efficiency and reduce drag. However, in low drag configuration the pods are slightly shorter and notably higher

2015 standard configuration

'On the roll out we did 4000km straight out the box, which is impressive, even to us. We then took it to Sebring and did a full Le Mans race distance'

It seems the lessons of the blown diffuser R18 of 2013 have not been forgotten, even though the technique was outlawed and the value of sealing areas of the car floor off from the vorteces from the base of the rotating wheels is well understood. 'To achieve the under car flow we want there are a number of complex barge boards and turning vanes placed to manipulate the airflow, especially in the wake of the tyres, which is usually quite a dirty and turbulent region, so we want to keep that air away from the floor,' Zander continues. 'And that's gone quite well. As you can see on the front of the car, we have had to totally reshape the lights to accommodate some huge ducts on the front. You may think this is for brake cooling and you are partly right, but the majority of the flow through these ducts is simply to reduce the turbulent flow from the tyres.'

One external area of the car that does not look all that different to the 2014 concept are its flanks, but it seems that much detail work has gone on under the skin, again in order to improve overall car efficiency. 'The side panels are quite similar to last year in terms of aero functionality and cooling duct arrangement. But there has been a lot of detail adjustment and there has been a big step forward in efficiency here. That in turn has let us reduce the size of the coolers and reduce the pressure drop across the cooler core, and that in turn adds to the drag reduction,' Zander explains.

Following the flexible bodywork argument in 2014 with other cars, the FIA and ACO tightened up on the rules around the rear of the car, something that likely contributed to Audi's decision to focus on the floor of the car once more. 'We have to respect a 50mm distance between the top edge of the diffuser and the rear edge of the engine cover,' says Zander. 'In 2014 it was much closer, almost a single line. On the short tail 2014 car we could generate some upward flow there to influence the rear wing, but this year you can't have the interaction between the diffuser and rear wing so easily. But with this concept it is not a big issue as we are trying to feed more air to the diffuser and trying to get clean flow beneath the car.'

When direct exhaust driven blown diffusers and the related Coanda-style exhausts were outlawed in Formula 1 teams went in search with a more abrupt leading edge. The mandatory air extractors have been relocated from the top of the arch to the inner face, something seen on the 2014 low drag R18. The leading edge of the front wheel pods on the low drag bodywork are conversely longer than those on the higher downforce car, although they do feature a near vertical leading edge compared to the curved version used at Silverstone and on one car at Spa. Another difference is that the rear view mirrors on the 2015 Le mans car have been blended into the trailing edge of the front wheel pod In an attempt to reduce drag

'Because downforce at Le Mans is not as important as it is at other tracks, we developed other solutions and new body shapes,' says Jan Monchaux, the head of Audi's aero programme. 'All the turning vanes, wings and similar elements are no longer mounted so steeply in the airflow; the curvature of the wing profile is less. The cooling system's requirements are different at Le Mans. We were able to re-evaluate and adapt the flow across the cooler, because the track layout means that less air mass flow is necessary due to the higher average speeds,' he says.

2015 low drag configuration

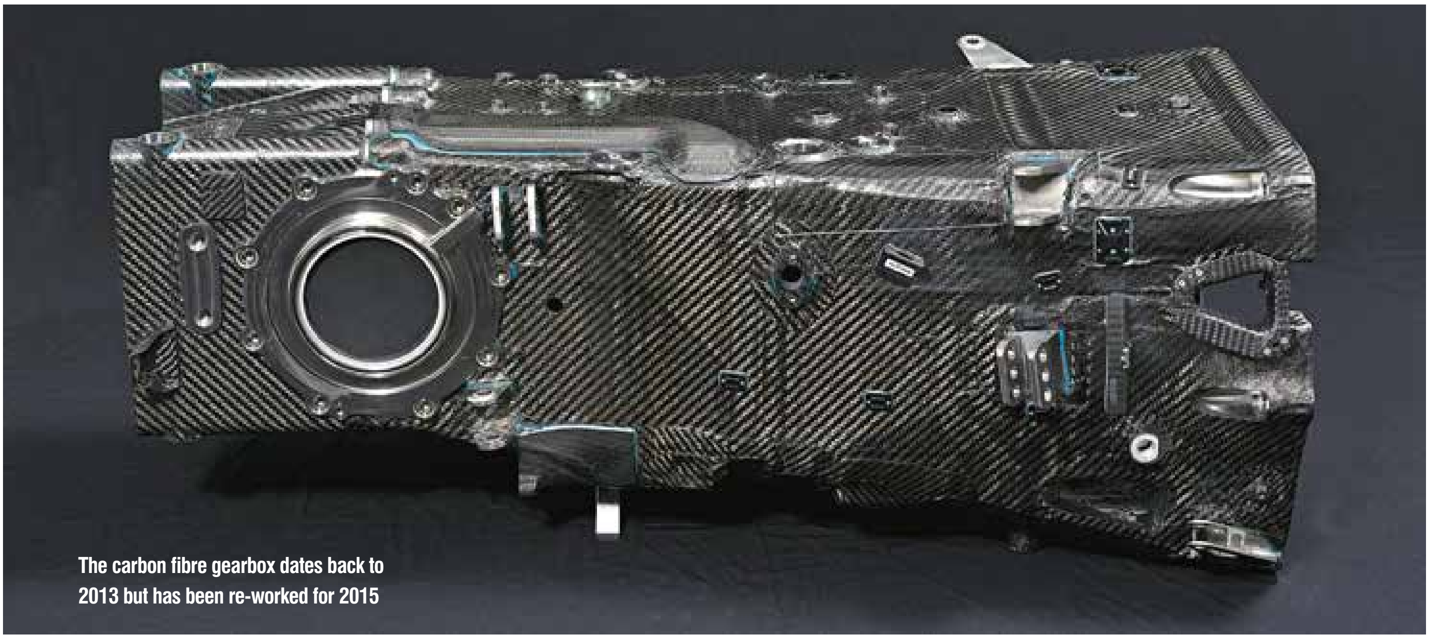
'Going to 4MJ means that the fuel flow is reduced, but we still increased power to more than 550bhp, and torque is more than 850Nm'

of finding new ways to regain some of the lost performance from the floor of the car. It is a process that Audi has also followed with the updated R18 and has resulted in the same technology being deployed, and this is fundamental to the whole car's aerodynamic approach. 'One of the options on the car is an interlinked suspension system, which is very similar to that used in F1 up to Monaco last year,' Zander reveals. 'The idea of these systems is to balance and stabilise the aerodynamic platform and stabilise the position of the underfloor, then we can play with the rake of the car. It's the wish of every aerodynamicist to maintain this, and the only way to achieve it is to stabilise the car floor. How to achieve that with so many vertical impacts and aero loads is not easy and that's why these systems are used. But it's a compromise from an aerodynamic perspective – you have to ensure that the car operates within a certain operating range of rake.'

Suspension issues?

As was the case with most F1 cars before the so-called front to rear interconnection systems (FRICS) were outlawed, many of the suspension functions are combined into a single component mounted in the centre of the car. One is at the front of the car on the bulkhead, while the other is at the rear and is positioned on the transmission. 'The interconnection is achieved hydraulically and its use is optional,' says Zander. 'The action of the rear suspension moves a hydraulic cylinder on the front and then the operating window of the front ride height of the car is getting smaller, but the platform is stabilised. At the moment the system only operates front to rear and rear to front, not side to side or diagonally. The system has a centrally-mounted heave element which comprises a Cambridge inerter and heave elements with some Belleville stacks aimed at getting the right characteristics in terms of the vertical dynamics. The whole idea for these combined units are that you have a certain space available, so you put it all in one. They are still operated from the rockers and putting them all in one unit is just packaging. We do have a bit more freedom than in F1 as our chassis is a lot wider.'

At Silverstone the R18s displayed some unusual suspension oscillations at times during



The carbon fibre gearbox dates back to 2013 but has been re-worked for 2015

This year's four litre V6 turbo diesel is now more powerful despite the lower fuel limit mandated by regulation

the race, although it is not clear if this was down to something related to the interlinked suspension or something else, and it did not appear to slow the car down at all. 'We put a lot of effort into that and in the run up to Le Mans we have been trying to get the optimum setup in terms of the vertical damping and springing because there is a lot of interaction between the vertical inputs on the car and the aerodynamic forces on the car,' says Zander. 'We need to get it all balanced. It varies from track to track too, so it has taken some time to understand the whole arrangement.'

Overall, the suspension is a carry over from 2014 – a result of retaining the same monocoque and transmission casing. It is double wishbone all-round with pushrod actuated Öhlins dampers at the front and pull rod units at the rear. Springing is via torsion bars on the front with coil springs at the rear, something Zander says is for packaging reasons around the transmission casing. The transmission once again features the carbon fibre casing concept first introduced on the 2013 R18, but there has been substantial work on the internals. 'We have changed things in order to improve efficiency by reducing friction. It sounds simple, but there has been a lot of work there that has taken a lot of time and while the result is a reduction of losses in a decimal point of a percentage, at the end of the day it means the car will go faster,' Zander adds.

Those changes are thought to be related to the use of new coatings technologies as well as revised lubricants from Castrol. 'We also have the challenge of thermal management back there and we have to get the hot air from the transmission and hot air from the engine evacuated well. It is especially important with the transmission casing where temperatures should not exceed a certain level. It is probably similar with aluminium casings where temperatures above 130degC will result in some drop in mechanical properties.'

The revised transmission internals also featured some changes aimed at improving the overall handling of the R18. 'The differential is a step forwards – the 2014 car had a problem with mid-corner understeer and understeer on traction in corner exit. We have improved that area substantially,' Zander admits. 'We have intensified the collaboration with Michelin to improve things. We have already made some big steps because the new aero package means new tyre configurations in terms of how it loads the tyres, how it operates, the slip angles and temperature management. We already know we have made a good step forward compared to the old car from back-to-back testing.'

More power and torque

One big influence on the way the car handles and operates in race trim is one of the headline changes to the car's specification, but it is a change that is impossible to see externally – the step up to a 4MJ hybrid system, although the R18 remains the only works LMP1 to only feature a single recuperation, deployment device [motor generator unit], Toyota, Porsche and, in theory, Nissan all use the regulatory maximum of two systems. 'For us this is a good compromise at 4MJ. The diesel concept

'It has taken time to understand the whole suspension arrangement'

The rear of the R18 shows the impact of the rule change that stipulates that the engine cover and and diffuser gap covers the crash structure

The front end of the R18 has been re-done this year, requiring a new crash test for the car. Front suspension is pushrod, also pictured here are the ERS driveshafts

The new aero programme has seen Audi use smaller, more efficient heat exchangers

is heavier than the competition, so there is a limitation there,' continues Zander. 'Our V6 4.0-litre turbo diesel engine is similar to what we had before. But there has been a lot of work by Ulrich Baretzky and his crew. They had to change things because going to the 4MJ means that the fuel flow is reduced, but we still increased power to more than 550bhp and torque is more than 850Nm, so that's a massive step in efficiency.'

The Audi 'e-tron' hybrid layout is essentially the same as it has been since it was introduced – a single large MGU-K is mounted at the front of the car between the front wheels, to which it is linked by small driveshafts. The MGU is linked by a high voltage circuit to a GKN electro magnetic flywheel energy storage medium mounted in the passenger compartment of the car. Retaining the same chassis as 2014's 2MJ car meant that doubling the potency of the cars hybrid system had to be done within essentially the same available space.

Flywheel here to stay

'People ask all the time why we use a flywheel system, but I look back to my Formula 1 times and I still find that the very thorough examinations and explorations done at the time prove that the flywheel concept is the best solution in terms of energy density at those levels [around 400KJ],' says Zander. 'That is why we still use the flywheel concept. For use up to 4MJ it is quite efficient and has good energy density with the volume that it occupies. The flywheel sits alongside the driver as it did in 2014 and spins to around 46,000rpm in 2015 specification with around a 700KJ charge capacity. The rotor is of carbon fibre construction and has about 8kg of weight. We are still trying to get a bit more out of it, but you can get close to the structural limits. I know it can do more on a short cycle, but for it to last 24 hours we have to be sure. We have test cycles where we have seen it do much more than

Audi's 'no' to Grand Prix racing return

Audi's appointments of well known F1 figures Joerg Zander and Stefano Domenicali, allied to changes in senior management at the firm's parent company, have fuelled ongoing rumours that the brand will return to Grand Prix racing in the near future. Sources inside Audi AG have admitted that it is looking at Formula 1 'but we would be remiss if we did not. Right now there are no longer plans, perhaps you don't want to catch a falling knife as we say in Germany.' It is important to understand what Audi's motivations for racing are and, according to Chris Reinke, Formula 1 does not seem to meet them at the moment. 'When we go to Le Mans the idea is simply to test road relevant technologies, to market those technologies and to feed into the Audi R&D department,' he explains. 'This is part of our DNA. Our road cars have race tested technologies on them. We are part of the technical department of Audi. Our seven post rig is not located at Audi Sport here in Donau, instead it is at the technical department. When we take the R18 off the RS6 goes on immediately afterwards. It's the same staff running it and that allows for the transfer of ideas and knowledge. That is why Le Mans is the perfect environment.'

So while Audi and the wider Volkswagen group refuses to rule out a Formula 1 entry entirely, it does seem that there are no firm plans at the moment, despite the paddock rumours.

Changes to the 2014 R18 (pictured) have been extensive and in the opening races of the World Endurance Championship have proven to be successful, with wins at Silverstone and Spa

46,000rpm. But that has shown that there are some limits there that we don't want to exceed.'

Obviously by increasing the potency of the system, the MGU would have to both recover and deploy more energy over the course of a lap, yet it retains the exact same housing. 'It is the same size but the internal electronic elements have to be changed like the IGBTs for motor control and things like that,' Zander explains. 'Last year the hybrid system had 170kW [228bhp] and now this is in excess of 200kW [268bhp], but we are still trying to get the system optimised there. It's not as simple as recuperation and boost as it has to fit within the whole strategy of how we use the energy, when to recuperate and when to boost.' Overall this gives the 2015 R18 a total power output in excess of 820bhp, a figure which is notably down on the competition, although its deliverable torque is thought to be higher than all of its rivals, aside from perhaps a fully functional Nissan GT-R LM.

The change to the car's hybrid system and its aerodynamic revisions have already delivered in ways that the team did not foresee and at Silverstone that resulted in great racing on track.

'It is a big change to go up to 4MJ, we are doubling our capacity while the others only went up by a maximum of a third,' explains Ralf Jüttner, Managing Director at Audi Sport Team Joest. 'The changes to the car make it a little better in traffic, and this is something we did not expect. By moving up to 4 MJ we have a bit of boost out of every corner, not just out of some like last year where we did not have the capacity to do that. In the past that meant there were some places on a lap where we had a four-wheel-drive car and in other places a two-wheel drive car, and that made things difficult with setup and handling. Now the car is more consistent around a lap. Thats' a big benefit, but it's hard to judge if that is aero or suspension.'

Audi's overall approach to the 2015 car is far more intricate than that of previous years and, with no major rule changes expected in LMP1 until 2017, it seems likely that going forward the R18 concept will be continuously refined, with a mildly updated chassis expected in 2016 to possibly accommodate a revised hybrid system and twin ERS (see Bump Stop P98). It remains to be seen whether Audi's rivals in the class can match the level of refinement displayed on the updated racecar.

TECH SPEC

Le Mans prototype (LMP1)

Monocoque: Carbon fibre composite (CFC) with aluminium honeycomb and Zylon side panels, tested according to the strict FIA crash and safety standards, rear CFC attenuator

Battery: Lithium-ion battery

Engine: Audi TDI, turbocharged 120° V6, 4 valves per cylinder, 1 Garrett VTG turbocharger, diesel direct injection TDI, fully stressed aluminium crankcase
Cubic capacity: 4000cc
Power output: Over 410kW (558 PS)
Torque: Over 850Nm
Hybrid system: Type of accumulator
Electric flywheel accumulator, WHP/GKN, usable storage capacity over 700KJ
Motor Generator Unit (MGU):
One MGU on front axle, water cooled with integrated power electronics, over 200kW

Drivetrain / transmission:
Drive system: Rear wheel drive, traction control (ASR), four-wheel-drive e-tron quattro in hybrid mode
Clutch: Carbon clutch
Gearbox: Sequential, electrically activated seven-speed racing gearbox
Differential: Limited-slip rear differential
Gearbox housing: CFC with titanium inserts
Driveshafts: Constant velocity sliding tripod universal joints

Suspension / steering / brakes:
Steering: Electrically assisted rack and pinion steering
Suspension: Front and rear double wishbone independent suspension, front pushrod system and rear pullrod system with adjustable dampers, twin wheel tethers per wheel
Brakes: Hydraulic dual circuit brake system, monobloc light alloy brake calipers, ventilated carbon fiber disc brakes front and rear
Wheels: OZ forged magnesium wheels
Tires: Michelin Radial, Front: 31/71-18, rear: 31/71-18

Weight / dimensions:
Length: 4.650mm **Width:** 1.900mm
Height: 1.050mm **Minimum weight:** 870kg
Fuel tank capacity: 54.2 liters

'Before, we had some places with four wheel drive and some with two, and that made set-up difficult'

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Case closed?

Le Mans 1985 saw Reinhold Joest's 956 beat the Porsche factory team at Le Mans. For almost thirty years conspiracy theorists have been saying he cheated with the fuel allocation. Thirty years later, Racecar Engineering can exclusively reveal the truth

By SERGE VANBOCKRYCK

For Reinhold Joest, 1985 was the second consecutive win for his team and indeed the very same car, Porsche chassis 956 117. It was only the second time in history the same car had won Le Mans twice, and in consecutive years; the first time being the Ford GT40 winning the 1968 and 1969 editions (chassis P/1075).

Joest's win was the first, and to date the only, time that a Porsche customer had beaten the factory team when both raced in the same category. It was a perfect race for the No7 New Man Porsche 956B, with no reliability issues, a perfect call on strategy and with high top speed and impressive fuel economy. By contrast, none of the other Porsche teams – which claimed eight of the top ten places – had a perfect race; all ran into mechanical issues eventually, including the factory 962Cs.

The factory team started as the clear favourites to win the race with their Rothmans 962Cs, having won two of the three opening rounds of the 1985 WEC season. For this season, the fuel allocation had been reduced by 15 per cent compared to the previous three seasons and the works Porsches had mastered the maximum fuel consumption of 51 litres/100kms for 1000-kilometre races best. But for the fourth year running, the technical regulations maintained the bizarre discrepancy which stipulated that in Le Mans the teams would have to make do with just 44 litres/100kms, thus increasing the challenges for the engineers.

To this day, certain media and observers alleged that Joest had not played a fair game in 1985

Le Mans 1985 slipped away from the works 962Cs after a number of issues on all three cars, but there was always a niggling doubt that Joest had not played fair and, as is common with such a result, the conspiracy theorists went wild. For three decades there have been rumours galore about how Joest's 956B managed to stretch its fuel for stint after stint, allegedly by using the fuel bottles from the sister car or even by running a secondary hidden fuel bladder, but these proved false. But since the Joest 956 used less fuel than anyone else in the race, despite spending less time in the pits, the real question is: if he didn't do either of these things, what did Joest do? The answer is simple – he developed his car to great lengths, had a perfect race, and produced an extraordinary result.

Theories debunked

Soon after the race – and to this day – certain media and observers alleged that Joest had not played a fair game. He had, some claimed, used fuel from his team's second car on the No7 lead car, thus accessing more than the allocated maximum 2210 litres for the winning 956B. This he allegedly would have done by swapping the overflow bottles between both cars. But, contrary to popular belief a quarter of a century later, the overflow bottles didn't have opaque fireproof covers, which could hide extra fuel from view, but were translucent, so the pit marshals could easily see any amount of fuel in them. And, they also had the number of the corresponding car in huge, black digits stickered on them, so the marshals could also verify the excess fuel in the bottle was indeed put back in the corresponding fuel rig.

Working with the data released by the ACO after the event, one can learn that the winning Joest 956B had used just 1988 litres of fuel (out of the 2210 available) to cover the distance of 5,088.507 kilometres, a distance which made 1985 the third fastest Le Mans in history. This translated to an average fuel consumption of

Main picture: The No7 Joest Racing Porsche 956B surprised many by taking the overall win with drivers Klaus Ludwig, Paolo Barilla and 'John Winter'. According to Reinhold Joest, Porsche was constantly monitoring its fuel meter gauge, so the team covered it up. The garage was searched and marshals were careful, checking the overflow bottles, but no extra deposits were found. Unbeknownst to Joest, the ACO sent the gauge of the winning car to check the calibration and found it to be correct.

39.068 litres per 100 kilometres, at an average speed of 219.310kph, pitstops not included. Ludwig, Barilla and Winter actually spent 23 hours and 12 minutes on the track and just 48 minutes in the pits. With more than two tanks of fuel still available, there was never any need for Joest to 'borrow' fuel from the team's sister car, something which he in any case could only have done until the No8 car retired at 9.41am on Sunday. Thus, any deliberate and predetermined plan based on taking a few litres from next door at every pitstop would not only have carried the risk of being discovered, but also of backfiring once the second car retired and its fuel allocation could no longer be accessed, something which could have happened at any given time in the race, even right at the start.

The second-placed RLR 956 had needed more than a full tank of fuel more than the Joest 956B – 2097 litres – but at 220.479kph its average speed when on track was also higher. With an additional quarter of an hour lost in the pits, the RLR drivers had the luxury of being able to burn some extra fuel to make up some of the time lost, resulting in an average consumption of 41.596 litres/100kms, still well below the theoretical maximum of 44 litres/100kms. But, more importantly, the competitiveness of the Canon 956 clears the Joest team of all doubts as to their alleged fuel trick, because the RLR

Joest and his engine builder, Michel Demont, worked their magic on the block, cylinder heads, pistons and camshafts

team had only one car in the race and therefore could not have 'borrowed' fuel. Still, the No14 honeycomb 956 was just as competitive as the New Man 956B. The Rothmans 962C had needed barely more fuel than the RLR 956 – 2102 litres – but its average fuel consumption was markedly higher than that of the Canon car: 42.034 litres/100kms for an average speed which, at 217.581kph, was considerably lower.

The No7 Porsche's exceptional fuel economy had been a thorn in many people's sides already during the race, but although Joest played games, he did not cheat. The fuel meter had a cover and the wily team manager flipped it shut just after the first pit stop. He didn't want to alert anyone as to what he had done just yet, but was ordered by the ACO to keep the flap open. The game was up – his engine was using less fuel than expected. 'One hour later, ten officials came to our pits to look for extra [hidden stashes of] gasoline,' remembers Joest. 'I couldn't do anything [wrong] and didn't want to do anything [wrong], because the whole team was under [surveillance] for 24 hours long.' The ACO even confiscated the fuel meter immediately after the race only to find it completely legal, months later. Says Joest: 'The funny thing was, in Spa, at the last [European] race of the season, Monsieur Bertaut [of the ACO] came over and said: 'Congratulations for Le Mans'. I said: 'You know, this is Spa'. It appeared some people thought we had changed the fuel meter at Le Mans. And he had sent the whole thing back to the manufacturer and the manufacturer made all the checks and said: 'Everything is fine'. Which was why Bertaut came over [at Spa] and said: 'Now you've really won Le Mans'.

Development programme

The reason Joest had won was that in 1985 the works team, uniquely, was never in a position to win this race, as was demonstrated by the fact that none of the works cars led the race for a single lap. The Bell-Stuck 962C had had some minor issues resulting in an extra nine-minute pitstop and another, regular, pitstop taking three minutes extra, thus totalling 12 minutes lost over the regular time spent in the pits. The RLR 956 lost an extra 15 minutes over its regular pitstops, while the Brun 956B had already lost 17 minutes before its Sunday noon retirement at which point it was still running ahead of the No2 962C.

One of the reasons the works cars were never in a position to challenge the privateers was that their fuel consumption was noticeably higher than that of Joest and RLR. At 8.00pm on Saturday, five hours into the race, the ACO published a first list of average fuel consumption figures per car, based on the amount of fuel used and the actual time they had spent on the track. The No7 Joest 956B, while slowly disappearing in the distance, was not using more than 40.95 litres of fuel per 100 kilometres at an average speed of 224.290kph. Indeed, at that point, Ludwig, Barilla and Winter drove the most economical car in the race. The works Porsches were averaging near the 44 litres/100kms mark, which meant they would have no margin left to speed up in the second half of the race and in fact would even have to slow down, or hope for rain or safety car periods. Twelve hours later, the Joest 956B's fuel consumption had slightly increased to 41.07 litres/100kms, while that of the No3 Rothmans 962C running in second place was stable at 44.10 litres/100kms. At that time in the race, Holbert, Schuppan and Watson had not missed a beat, only visiting the pits for fuel tyres and occasional brake pads, but had still lost two laps on the leaders.

So where did his advantage come from? For 30 years, Joest kindly refused to disclose the specifics of his 1985 advantage, but there had always been enough elements to piece the puzzle together. First of all, Joest was an

Joest had spent months developing his own electronics and had raised the engine's compression ratio to 8.9:1

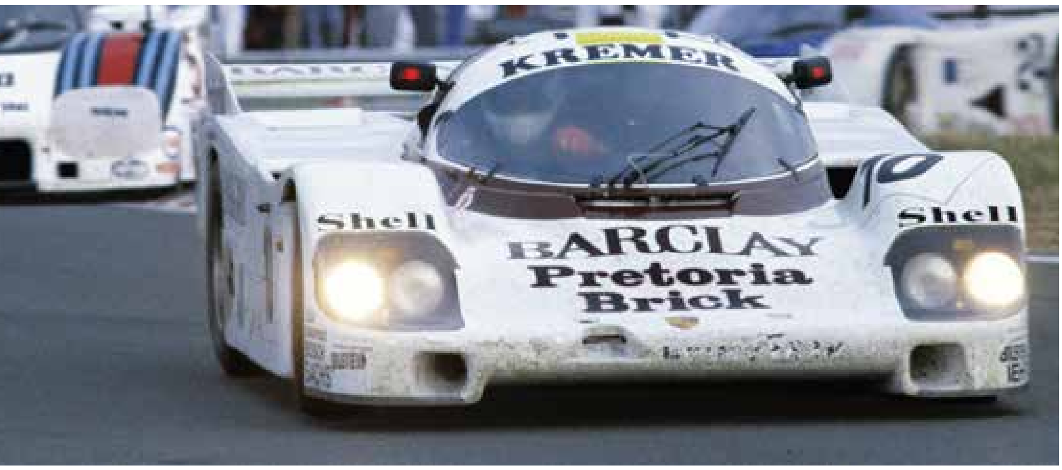
Had Joest done something with the engine, gearing or aerodynamics?

engine wizard in his own right, as he had amply demonstrated in the past, when before even his team's very first WEC race with the 956, in Monza in 1983, he had already changed some of the internals of the engine, such as custom-made Mahle pistons, a move that itself led to a major engine development programme. Sources suggested Joest ran a 3.0-litre engine with different turbochargers, whereas all the other Porsches ran the standard 2.6-litre engine with KKK blowers, but this was not true, certainly at Le Mans in 1985. Privileged contacts with the people from Bosch, who built the Motronic ECU, were also rumoured to have been key. Or an exclusive deal with BP to supply the engine oil, whereas the Porsches always used Shell? 'No, the sticker said BP but in the engine we had Shell,' Joest says. 'I told [BP] the truth. We have all this experience with Shell and I don't want to risk the engine. You can have the sponsorship on the car and we will not have a single Shell oil can in our pits. That was the guarantee from our side.' There was no advantage in the tyres either, since the New Man 956s ran the same Dunlop Denlocs the works team. The deal with Goodyear, cited so often, didn't happen until 1986.

But even without Joest putting his cards on the table just yet, some figures always spoke for themselves, and those were the speeds at which the No7 956B was clocked both in practice and in the race. While the difference in race lap times between the Joest 956B and the works 962Cs was minimal and showed a small advantage for the works car, it was on the long Hunaudières Straight (in those days still without chicanes) and the stretch back from Mulsanne to Indianapolis that Ludwig and co did business. Top speeds were considerably higher for the Joest car compared to everyone else, including the other customer 956s, and the fuel consumption was lower. Had Joest done something with the engine, the gearing, or the aerodynamics? The answer was that he had done all three.

The Fitzpatrick 956 briefly led the race and eventually finished fourth

The one-car Richard Lloyd Racing team's 956 was also competitive with the works Porsche 962s, further proving that the assumed factory advantage was not actually apparent on the track



Without any issues, the Kremer 956s (pictured) could also have had a shot at the podium

Shift up a gear

Joest's notes show that the No7 Porsche ran a fourth gear ratio of 29:23 and a fifth gear ratio of 32:20; ratios almost identical to those the works team ran on their 956s in 1982, and probably in 1983, the only difference being a fourth gear ratio of 30:23, although two of the Rothmans 956s that year tested a 29:23 ratio in practice.

The real reason for the works cars' lack of punch, however, was only discovered a long time later, but had since been buried in corporate secrecy, as Porsche's engineer Norbert Singer told the author a few years after his '24:16' biography had been published: 'Not right after the race, but some months or even a year later [we found the reason]. It was not a new aerodynamic floor used by Joest. We had a debriefing with [Porsche's Head of R&D] Mr Bott and he said "I heard Joest had a new undertray" and so on, but that was definitely not what had made the difference. In some publications it was written that Joest had used a new floor. It was a new floor, but made from a mould made from a Porsche part. So it was newly made, but not new in design. At the end [Joest] had a perfect race and we struggled with technical problems, but doing some rough estimations, we were at the end of the race about three laps shorter on fuel. The reason is Joest's and our secret.'

That secret was a combination of things, Joest now reveals to *Racecar Engineering*. He had made Le Mans his main goal for the season and as such had been looking at more ways than one to make a difference in France. Firstly, the engine had received some additional attention from himself and his Swiss engine man, Michel Demont. Joest admits that the block, cylinder heads, pistons and camshafts had received particular attention, and, more importantly, that the compression ratio of the Typ 935/79, 2649cc engine had been increased to 8.9:1, whereas the norm for Le Mans, for the sake of longevity, was 8.5:1 or less, which was what the other Porsches ran. 'It was a risk, you know, a very big risk,' Joest says now, 'but I said: 'we do it.' Less gasoline, more power, you know, but a big risk for 24 hours.' However, it should be noted that while the factory team had already successfully used its own 9.0:1 engine in the opening races of the season, it did not run it at Le Mans in 1985.

The biggest single contributing factor to Joest's success was that he also had his own software developed so he could change the mapping of the ECU himself. It was a costly effort, which took many transatlantic flights and months of trying and testing at Paul Ricard but it crucially allowed the team to alter the engine characteristics, rather than having to rely on just the standard qualifying and race chips Porsche and Bosch gave their clients.

The undertray, too, had received attention and had slightly wider venturi than the standard part. And, instead of being made of three parts (one metal part covering the engine and two glass-fibre reinforced plastic parts covering the gearbox and transmission) it was now made of a single GRP part with metal inlays, with the hot engine air expelled through the rear of the tail section rather than through louvres in the floor. The idea to reshape the undertray had come from Lothar Beier, one of Joest's senior team members. Another such advantage was the decision to use Sachs shock absorbers rather than the standard specification Bilsteins. 'Together with Sachs we did all the development of the shock absorbers,' Joest explains. 'In the end we were maybe a little bit better than Bilstein. This was a very expensive endeavour for Sachs, but I had a very good sponsor contract with them, so it was fine.'

The new works Porsche 962Cs were expected to be dominant, but the shrewd team tactics of the Joest team made it possible to beat the factory without resorting to underhand tricks. The three 'works' cars never led a lap in the race

The Porsche engineers calculated that they did use between nine to ten per cent more fuel compared to the Joest winning car – that is not a fact that has been argued. According to their calculations, the higher compression ratio helped for about two to three per cent. The aero improvement from the underbody gave an improvement of more than five per cent, which is a lot without a wind tunnel and only with on-track testing, while other modifications to the car probably contributed one to two per cent. However, in the race, the No7 Porsche was around a second faster than the factory car, which would have led to an increased consumption of around two litres per stint, an additional two per cent.

This still leaves a significant gap in performance that is not accounted for. Of course, there can be explanations including the revised electronics, the use of different tyre pressures, different grease, different wheel bearings, better oil pumps in the gearbox. And let's not forget the well-publicised fact that the RLR and Joest drivers spent hours elegantly taking turns at slipstreaming each other down the Hunaudières Straight; another fuel-saving factor for both cars.

One thing that is certainly not disputed by anyone is that Joest had a perfect race in 1985. The car was perfect, reliability was perfect and his drivers never missed a beat. Between the altered engine, the optimised electronics, different shocks and some aerodynamic fine-tuning, Joest had built a supremely capable, Le Mans-winning car. The opposition suffered from reliability problems which contributed to the size of the victory. So, after 30 years, can we now put the matter to bed?

BP stickers may have been prominent on the bodywork, but it was nothing more than a sponsorship exercise – the reality is that the Joest 956B used Shell oil

Can't get no satisfaction

Final preparations are complete ahead of Nissan's GT-R LM NISMO competition debut, but no one is expecting miracles

By ANDREW COTTON

The eagerly-anticipated competition debut of the Nissan GT-R LM NISMO is unlikely to set the world alight as it will not take part in the anticipated 8MJ hybrid category as originally intended, and will instead run in the 2MJ category. That's the assessment of the car's designer, Ben Bowlby, who says that he would be 'pretty chipper' about the entire programme but for the challenge of hooking up the potential of the 8MJ mechanical flywheel system, and the associated problems that has had on the rest of the car. The reduction in hybrid power, caused by a need to lose weight and a change to the physical access to the unit mid-build, will by regulation cost at least three seconds per lap at Le Mans compared to the opposition. However, an overall lack of development, and the failure of a crash test early in 2015 set the team back early in the year before final sign off of specification.

The GT-R LM NISMO programme has been conducted largely in the public eye. Its crash test failure is widely documented, as is the change in wheel size and subsequent brake issues caused by switching hybrid class so late in the programme.

'Necessity is the mother of invention, and failing the crash test for the first time was a real headache,' confirms Bowlby. 'The front roll hoop failed at 73.5kN out of 75kN. We had to do a big update to the chassis because of the way that we accessed the energy recovery system, which was by taking the front of the chassis off. The FIA decided that was a survival cell, and that the survival cell should be continuous like it is in the F1 regs, whereas I understood that it was a survival cell assembly that is part of the crash test. We had to then bond that on, which meant that we had to access the ERS through the

windscreen, and taking a piece like that through the windscreen was a very difficult challenge for us and set us back.'

Crash testing has been particularly onerous for the team due to the car's unusual layout and Bowlby reckons this is the only car to be tested from stem to stern. As reported in *Racecar Engineering V25N3,* the Xtrac gearbox had to be a bespoke design, which also led to delays. 'It ended up being the heaviest gearbox in LMP1,' says Bowlby. 'It is working fine, it passed the crash test with flying colours and that was something we were all stressed about. Our frontal energy absorption structure was mounted to the gearbox, which was mounted to the engine, which was mounted to chassis. No one else puts their engine in the middle of the test and crash tests its whole assembly. That was a big burden, a huge cost and complexity, to prepare the engine and gearbox for the impact test, and push off tests. We had to do our own tests where we tested the engine to chassis push off, as well the gearbox to engine to chassis push off, as well as the front energy absorbing structure to gearbox, to engine to chassis!'

Mechanical solution

Integrating the ERS has proven to be one of the biggest headaches for the team, and the best solution was considered to be disengaging the rear drive and developing the rest of the car in the time remaining before Le Mans.

'Our Achilles heel, right now is our energy recovery system,' says Bowlby. 'The ERS is in the car, but we started at 8MJ and we will use only a bit, probably 2MJ, and only do front recovery and deploy. The flywheel is nature's greatest energy storage device. It is definitely a strong

Lifting the inside rear has meant that the team has to watch out for flat-spotting the tyres. It's an unusual phenomenon in an unusual design concept

Being front wheel drive, the GT-R LM NISMO runs bigger tyres up front – 14 inch wide Michelins versus nine inch rears

technology, but it is how you harness it and the devil is in the detail. The problems included the scavenging pumping and shifting – the Swiss watch element that needed more development time than was available.'

This failure to compete in the 8MJ class should not be classed as a catastrophe – both Porsche and Toyota campaigned in the 6MJ category during their debut years, but the Nissan was designed around the flywheel reaching its full capacity. So critical was the ERS to the design of the car that, prior to Christmas, the team even looked at switching to super capacitors, similar to those run in the Toyota, although that would have led to more problems.

'Nothing takes no time, and to decide before Christmas to change would again be a curve that would be very steep and you do not want to mess around with high voltages at the last minute,' confirms Bowlby. 'We have seen and had a big dose of that with the ZEOD, and yes you can manage it, but as a weapon to take into a battlefield, it is burdensome. You want a system that is mechanic friendly and simple and quick to use, and you can attack the car with accident repair quickly. The whole burden of high voltages is onerous. It can be done, but the mechanical solution had a lot of attractive properties from a racing weapon standpoint.'

Rear wheel system

The system will only recuperate and power the front wheels despite originally being designed to power all four wheels through a series of drop gears. Powering the rear was, according to Bowlby, a relatively simple exercise. 'There is a prop tunnel that takes the drive from the energy recovery unit in the front of the car to a diff, which is a dead simple tiny pumpkin that has driveshafts out with no joints in it, just straight driveshafts out to two drop gears that mount on the outside between the wishbones. Then there is a driveshaft that is about nine inches long with tripods in the uprights. The diff doesn't do any reduction; we have a 3:1 reduction at the driveshafts. It is very heavily biased towards aero efficiency, so mechanical design weighs probably 10kg more than it could have done, but we gained the possibility to have a completely uncluttered duct. By the rules, you cannot see mechanical components [in the aero tunnels that run from the front of the car to the rear], so if we had driveshafts, we would have to have bodywork and louvres. We made a completely clean shape, and it all ran well but we can't run it this year. We will definitely have it next year!'

With so little going on in the rear of the car, and with the regulations allowing for a second ERS to be housed there removing the need for the propshaft, why was a second ERS not installed behind the driver? 'In hindsight it might have been a good idea,' admits Bowlby. 'We maximised the aero space at the back of the car, and we wanted to make sure that we could achieve a forward weight distribution so the back of the car is super light, there is very little in it, and that is to make sure that we have a heavy bias forwards so that we could bias our aero forwards.'

The car's braking system has also had to change from the switch in ERS categories. As with the Toyota TS040, the rear brakes are much smaller than the fronts, and the whole system relies on ERS to help slow the car. The reduction in flywheel braking effect has meant more burden on the front pads and discs, which are particularly vulnerable and that has led to significant braking issues in testing.

At the rear, the car behaves very much like a front wheel drive touring car. Although the team says that the rear is planted, at Le Mans the car will be seen to be lifting the inside rear in the last stage of heavy braking. This has led to an unexpected headache for the team - drivers have the very real possibility of flat-spotting the rears under heavy braking.

'We will probably run 2MJ, and only do front recovery and deploy'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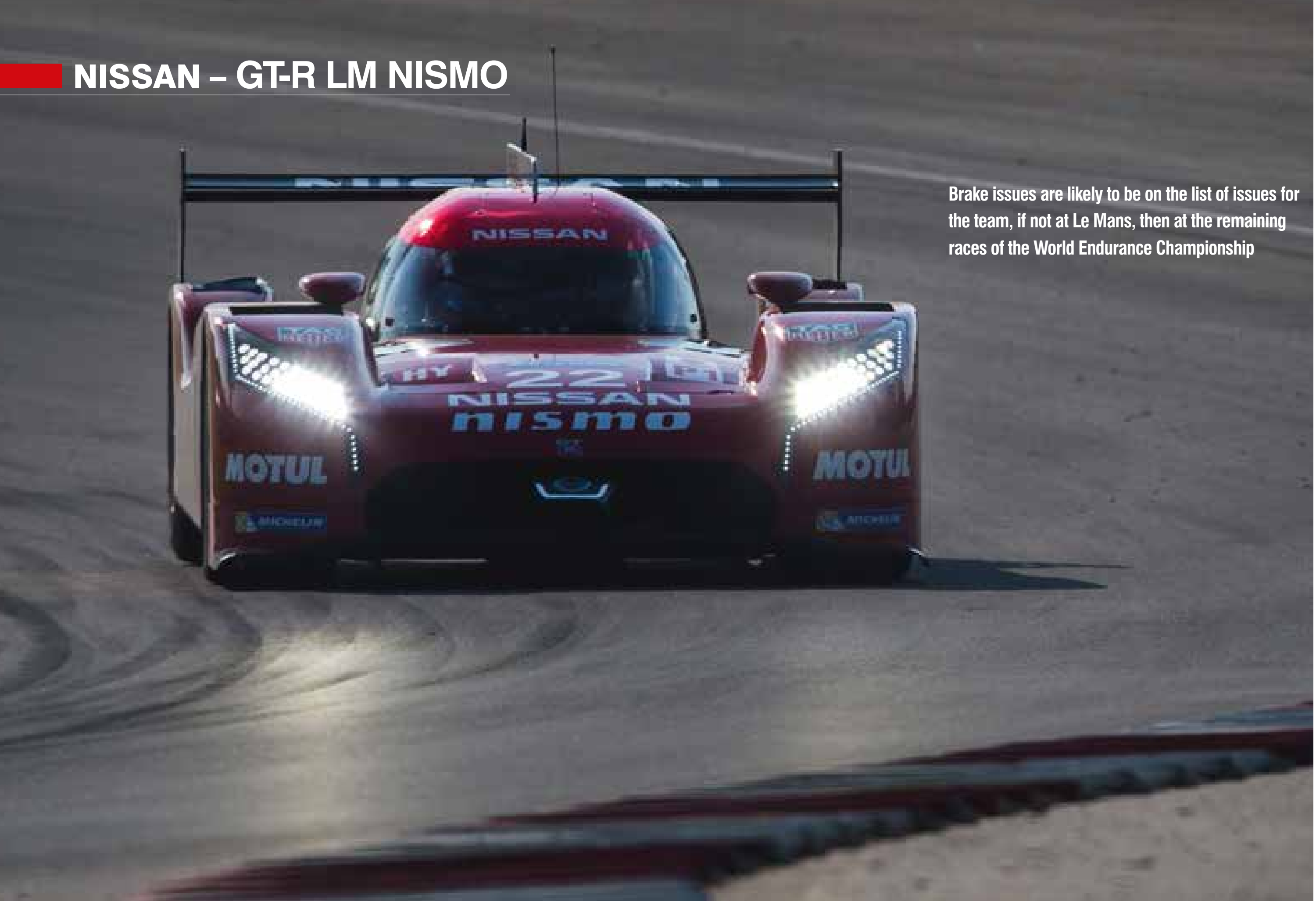

Brake issues are likely to be on the list of issues for the team, if not at Le Mans, then at the remaining races of the World Endurance Championship

Pace Potential

A burning question is one of lap time at Le Mans compared to the other cars, but here the team is not concerned. It believes that the GT-R LM NISMO will be faster than the LMP1 cars of 2014, but until we see the true pace of the cars on track, it cannot judge how far off this year's pace it will be. Certainly, the team expects to run in the 3m20s while its rivals are expected to dip into the teens, but at this stage Nissan will be collecting data in preparation for a full attack in 2016. 'Everyone has clearly made huge steps forward, and where we will be next year compared to this year is a handful of seconds,' says Bowlby. 'They are doing a great job, and I think the good thing about the rules being as free as they are, there is a lot of innovation particularly aero wise on some cars, but it is an arms race. It is an engine race, and we are starting to see what the manufacturers really have rather than what they pretend to have.

'It is going to be a building year, and we cannot say it will be anything else. It is a new car, new team, new engine, new ERS system, so it is a steep curve'

We are seeing a genuine race in that respect, and high power ERS coming to the fore, and the benefits of big aero programmes, extracting a lot from the basic rules package. It is not unexpected. We looked at where people were last year and hoped to be faster than that, so I don't think that our original targets were wrong at all. What is sad is that we are going to suffer from our current ERS class. Our goal in 2015 is the race in 2016, to collect data and get our act together. A lot of the car is what we envisioned and it is working well.'

One other point to raise was the accusation that Nissan placed priority of marketing over engineering, and that the base in the US may have been a hindrance. On both points, Bowbly defends the decisions. 'We have benefited from being the biggest fish in our pond, able to attract good people, and have great facilities, and test in many places,' he says. 'We have had good weather testing all year round. We have heard of teams going to Bahrain to get decent weather. We have been to Circuit of the Americas, Sebring, now the Kentucky Bowling Green national Corvette museum track which is modelled on Le Mans, and that has been super useful for us.

'I defend the decision to be an American based team. It could have been a Japanese based team or an English based team, all the others are German based. Don't forget that in our strategic planning, there was talk of the Circuit of the Americas being the first race, the prelude was to be at Sebring, and we thought that we had made a smart choice.

'Our dirty laundry is being washed in public, which is painful as a designer because you would like to be like a swan and all the paddling under the surface no one sees, but everyone has seen our struggles and that makes it interesting. Some other manufacturers might like to take note as they put up barriers and, I think, lack the appreciation of how important fans and consumers are to the racing activities.'

Post Le Mans the team will regroup, ready for the Nürburgring at the end of August and the fly away races at the end of the season. There, by its own admission, the car will not be able to play to its strengths of high top speeds. It will also need to find a solution for the brakes as no other track has consistently long straights on which to cool the brakes. 'It will be fascinating to see how we get on,' says Bowlby. 'It is going to be a building year, and we cannot say it will be anything else. It is a new car, new team, new engine, new ERS system, so it is a steep curve.

'The second half [of the year] will be rough. We have to be realistic. We are building. We haven't run the high downforce kit yet, but we will. I would be feeling pretty bullish if we had what we had hoped for from our ERS but we don't have that, so I can't be bullish about the car at all. We don't know about the tyres, we haven't raced on a track that has rubbered in, for example, but where we think we are is pretty reasonable. We have some encouraging signs. We may be quicker than the LMP1 cars were last year, but we won't be on their pace this year, which would be terrible, but you can't hide anything. You have what you have.'


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GT3 tyre war

In a category that is largely one-brand, manufacturers have targeted the Nürburgring 24 hours as a place to develop GT3 tyres in open competition

GT3 racing is pretty much the preserve of one brand tyre manufacture as it is a cost-control formula that was originally aimed at the gentleman driver. No gentleman driver wants to be involved in a tyre war, and balance of performance is much easier with the same regulations and tyre supply around the world. Also, for Pirelli, supplying the same specification tyre around the world is a cost control measure. However, in the German VLN series that incorporates GT3 cars as its top category, a tyre war has nevertheless broken out. While Pirelli continues to hold the cards in most of the GT3 series around the world, in the German national VLN series, which incorporates the Nürburgring 24 hours held this year in May, Falken, Dunlop, Pirelli, Michelin, Kumho and Hankook have produced tyres for the category and the race has been targeted next year.

There is no danger of the tyre manufacturers challenging Pirelli's supremacy in global tyre supply in the short term, as the tyres developed are unique to the series, and the unusual circuit. 'We do not do a standard GT3 tyre, we only develop tyres especially for the Nürburgring,' says Falken tyre technician Takeshi Imakita. 'There will be a difference as you have different conditions at the Nordschleife, and if we did a GT3 spec tyre it would be a different construction and compound. This tyre is just conceived for this track and for this 997 GT3R.'

Clearly there is a desire to use GT3 racing to promote tyre building capability, but the question is, why choose a formula that around the world is locked out by a single tyre brand?

'We, as all the other tyre manufacturers, regard the Nürburgring Nordschleife as the ultimate challenge,' says Imakita. 'If you can make a tyre for this track, it will be competitive anywhere. This is the same reason why all the car manufacturers also compete here. We chose the Porsche as it is a harder car to develop tyres for, so if we can make this work, we can show what we can do. As Falken is not selling the tyres at the moment, we are not so much into this competition right now, but that may change for the future.'

Tyre development for the VLN is a particular skill. Vast temperature changes around the Nürburgring Nordschleife circuit can occur in a single lap with changes in elevation, plus during the 24 hours accommodating day time and night time temperatures. The track surface changes from the high-grip Grand Prix loop to the older tarmac around most of the circuit. Producing a tyre that has a wide temperature operating window is critical. 'It is quite a different technical requirement in that the temperatures are quite cool, so it is the only time that we can test in England in February and it is worthwhile,' says Hembery.

Pushing performance

The tyre development programme has to lead to overall race victory, although a podium this year for the Falken team was its best finish at the 24 hours to date. 'Falken picked the Porsche so they have one of the top cars,' says Schnabl. 'They could have gone for a BMW or an Audi, but they were not up to the pace. The competition is there and they eventually Falken wants to sell road tyres and race tyres. Now they have picked one car to develop a tyre, as business-wise we are not as big as others.' However, the link with Porsche has thrown up a new challenge as the new GT3 model had its public debut at the Nürburgring in a static display, and the car will be delivered to customers in December. For a tyre company that is developing solely for the Nürburgring, that delivery date is too late and it has had to negotiate that some of the pre-delivery tyre testing will take place with Falken tyres.

'The new car will only become available in December,' says Schnabl. 'For further development it doesn't make sense to go to Estoril, Portimao or whatever because there are different track conditions than out here. We can only start in March, cross our fingers that the car is good, and so we have spoken with Porsche already to test in the near future in order to get developments into progress for 2016, or we have to run in 2016 with the old car.'

'The speed increase only comes from the tyres. Development of the car has stopped and engine power has been decreased'

Pirelli admits that it was set to introduce development tyres for the series this year, but its now stillborn LMP2 programme distracted the Italian manufacturer from developing a tyre that would have raised its level in the VLN. 'If there is an area that we are interested in expanding our involvement it is in the VLN,' said Pirelli's Motorsport Director, Paul Hembery. 'We have been developing tyres there but we are just not saying much about it.'

Dunlop has long had a development programme in the VLN, and with so many tyre and car manufacturers involved, it is only a matter of time before all-out competition begins in the VLN.

Japanese tyre brand Falken says that it wants to develop a customer base in Germany, not only in GT3 but also for other cars competing in the VLN. However, it has chosen that this market, and with a Porsche GT3, to showcase its technology. 'If you want to run a Falken car, in Germany you can only run it here,' says team manager Sven Schnabl. 'You cannot compete in the 24 hours of Dubai, for example. Falken wants to develop tyres, and there is no other option for us.'

Tyre development has been a contributory factor in the overall lap speeds, even with the speed limits imposed at points around the circuit following Nissan's accident in March. In qualifying, the Falken Porsche lapped only three seconds slower than in 2014 despite the speed limits that were widely estimated to be worth around 12 seconds per lap.

'The speed increase only comes from the tyres,' confirms Imakita. 'Development of the cars has been stopped, engine power has been decreased from 525bhp to 500bhp after the accident at VLN1 and now we have the speed zones. But lap times are nearly the same lap as in the 2014 24h race. There is a "tyre war" at VLN and the 24 hours. Everybody is pushing like mad. We have shown this weekend what can be done with tyres when the car is frozen.'

A tyre war with unlikely protagonists could be about to break out in GT3 racing, as the VLN does not have a one-brand deal with any manufacturer

Righting the wrongs

After a disappointing 2014 campaign, Lotus went back to the drawing board in a bid to create a stronger package for 2015

By SAM COLLINS

When the Lotus E23 Hybrid made its first ever runs on track, its looks suggested that the car was, in essence, a gentle evolution of the concept that began the previous season with the E22. In 2014 the E22 did not perform well – it had reliability issues and only managed to score points twice, at Spa and in Monaco. The media laid much of the much of the blame on the troubled Renault RS34 power unit, although those articles tended to overlook the fact that the RS34 had powered other cars to race wins.

Lotus technical director Nick Chester does not try to hide from the fact that the team did not have a good year in 2014 and readily admits that the problems of the E22 were the starting point of the E23.

'It's no secret that we struggled with last year's car, so we've targeted every area that caused us an issue,' he said at the car's roll-out. 'We've made strong progress in the wind tunnel, as well as in areas such as packaging and cooling. We expect the E23 to perform far, far better than its predecessor.' It is clear that some of the stronger concepts of the E22 have carried over to the 2015 and this includes much of the overall chassis design. This makes the two versions of the cars almost impossible to tell apart in some areas of the monocoque, although in others the differences are strikingly clear. 'Our chassis is indeed fairly similar,' Chester continues. 'Some areas, like the roll hoop, have very few changes structurally but there have been alterations for the regulations such as the front bulkhead heights. That meant we had to change the front suspension, but it's not enormously different to the previous car.'

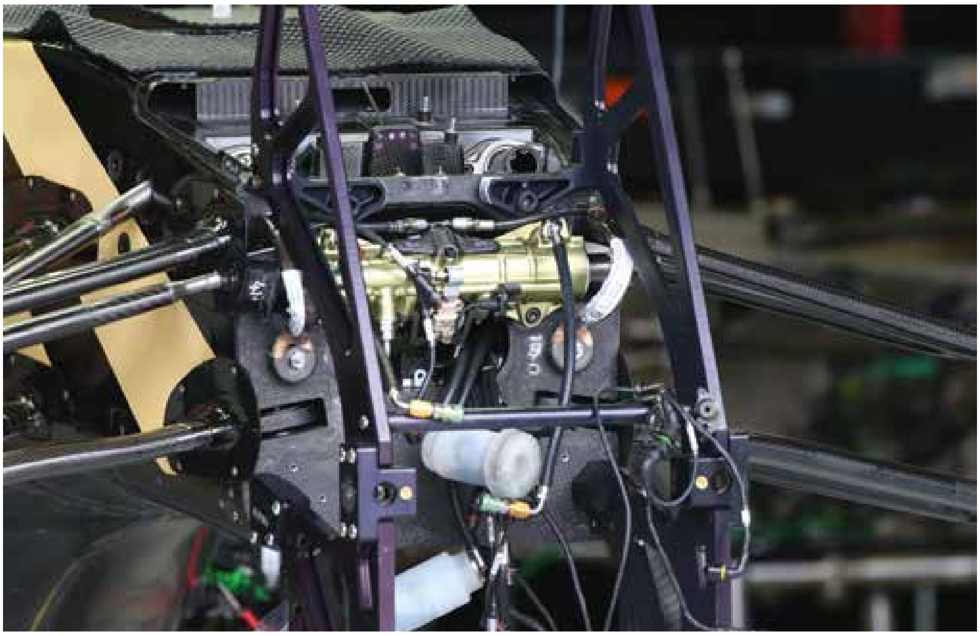
‘It’s no secret that we struggled with last year’s car, so we’ve targeted every area that caused us an issue. We’ve made strong progress in the wind tunnel as well as in areas such as cooling’

Visually the two cars are impossible to confuse – the E22 featured a distinctive nose with twin front impact structures, while the E23 does not. The E23’s nose tip is located quite far back relative to the leading edge of the front wing, much further back than the solutions seen on some rival cars such as the Ferrari and Sauber.

‘In 2015, a new regulation made it clear that the twin tusk approach would not really work,’ Chester explains, ‘so we played around a bit and found what we thought was the best nose in terms of data from the tunnel. It was a bit tough to get through a crash test but we started it early, worked through a number of iterations and got through. It works well now.’

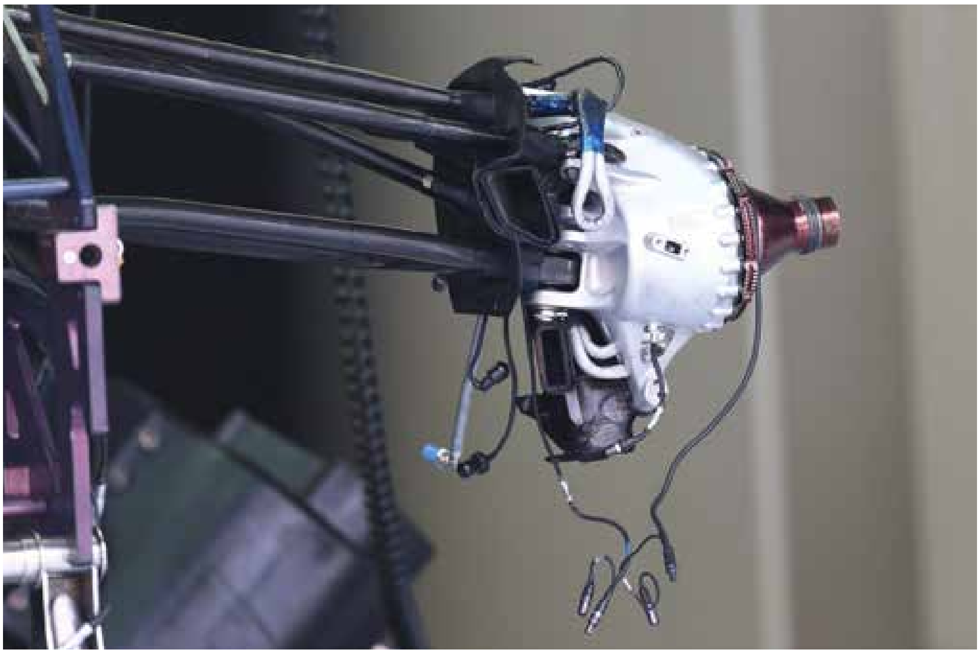
Despite working well Lotus was reportedly developing an even shorter nose as *Racecar Engineering* went to press, a design that had proven something of a challenge in terms of passing the frontal crash test. The team, which is based in Enstone, England, uses the Cranfield Impact Centre to do its crash testing and has made quite a number of trips this year.

‘Getting the noses done is a bit of a mix of techniques, you can do some things computationally and some things physically,’ Chester explains. ‘If you fail a test you come back and look at the laminate and you re-work that. You can simulate that performance to some extent, but there is still quite a lot of scatter and you can get some odd failure modes so it’s never perfect. Then you have to go back and retest. Our initial tests are usually just with a nose on a plate, but when you have passed that you have to get the FIA to come along and observe, and to do that you first have to get hold of an FIA observer and then you have to do the test with the chassis rather



Monocoque features a stepped design to accommodate the torsion bars above and rearwards of the main bulkhead

The E23's distinctive roll hoop inlets certainly catch the eye – the usual airbox intake is flanked by two additional inlets



Different bulkhead design has led to lower pushrod angles which are therefore subject to higher loads

than just the plate as that is the way the rules are written. Cranfield is a very good test house, but at some times of year it gets quite busy.'

The nose changes are a part of a major trend in 2015 F1 car development as the teams strive to recapture some of the downforce lost due to rules relating to the front chassis height. These rules also reduced the available volume at the front of the chassis to package components. In order to accommodate the inboard front suspension, brake components, steering and some electronic boxes, Lotus has opted for a stepped design at the front of its tub with the torsion bars mounted above and rearward of the main bulkhead.

'The layout we have there works well with how we wanted to install the rockers. You need some access in there and this was a good solution. When the bulkhead came down it made things a bit tighter and we have to have shallower pushrod angles which makes their loads go up,' Chester continues. The E23 features a steering rack that appears to be larger in size than those seen on some other cars, and while Chester agrees with this he claims that the additional size may not be quite as much as it seems. 'The rack may be a bit larger than some, but there is lot of variety out there. I'm not sure if some racks mount the hydraulics behind them so you can't see them from the front. Steering racks are tricky things. In the past we have tried to take weight out of them and that has led to them becoming too flexible or binding. So when you get a rack that works well you are a little loathe to change them because you end up introducing lots of problems for the driver.'

Aero changes hit hard

Beyond the nose the overall shape of the E23 is quite similar to that of the E22, but there are many detail changes impacting on almost every area of the design. However, despite all these changes the aero concept has continued in the direction started with the troubled 2014 car.

'The E22 delivered good figures in the wind tunnel, even if it was difficult to unlock its potential, so we've paid more attention to making the characteristics of the car more adaptable,' Chester reveals.

Lotus was hit harder than many other teams by a small rewording of a rule relating to moveable aerodynamic devices which essentially outlawed front-to-rear interconnected suspension systems.

'It was painful because we had run the systems for six or seven years and we had optimised our suspension settings and the aero packages around it,' says Chester. 'Going back to something without a link is not a huge challenge mechanically speaking, but in aerodynamic terms, especially the ride heights, it's a massive challenge. It took some time to get right. When the systems were banned the aero guys were already testing the 2015 model and it had some influence on the front wing design.'

'I think that the car has no nasty vices and it has no real elements that are weak – we would just like to get a bit more grip'

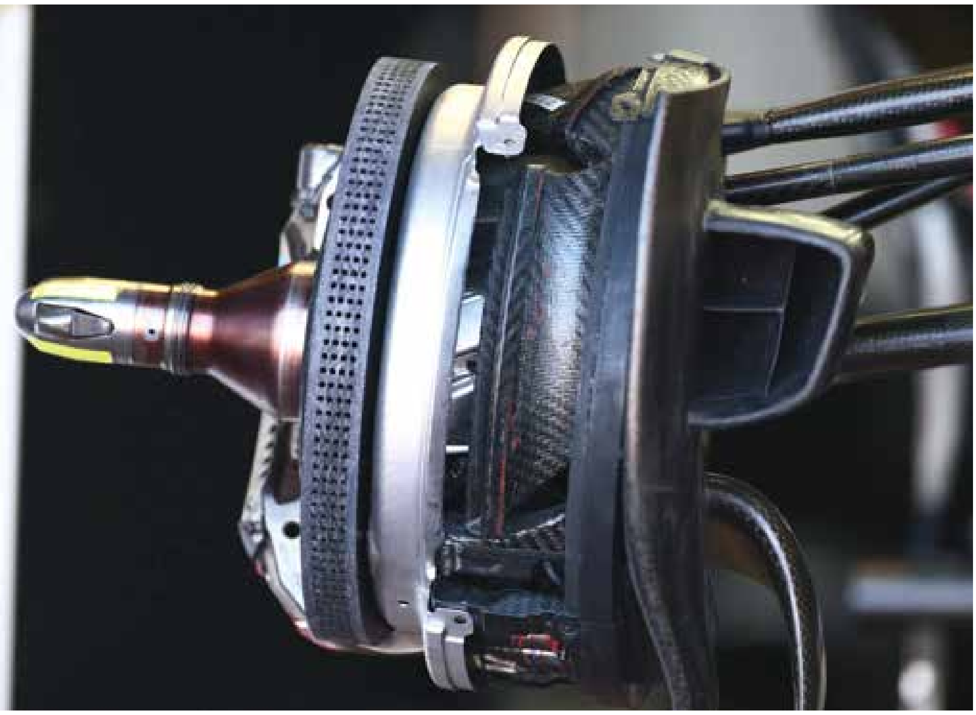
But the nose rules and the change to the suspension systems were not to be the things that had the biggest effect on the overall concept of the E23 – the switch from Renault to the all-conquering Mercedes power unit has clearly had the biggest difference. It was not just a major change for the engineers but also the whole culture of the team, as the last time it had switched supplier was in 1995 when it changed from Ford to Renault.

The Mercedes is a significantly different design than that of the Renault RS34 but Chester is not keen to divulge specifics for obvious reasons. 'The Mercedes is a very nicely packaged power unit. It's very powerful and drivable – it's just a good power unit. It looks to be the one area of the car which could bring us the greatest performance gain. It's not just performance, but reliability and driveability, as well as packaging and cooling too,' he states.

Mercedes HPP has updated its power unit substantially over the winter months (see RCE V25N4) and has changed its exhaust layout as well as adopting variable inlets, resulting in a larger plenum. Lotus was designing the E23 at the same time as Mercedes developed the PU106B. 'The data for its installation came in stages, so Mercedes HPP would regularly update the PU design and we would regularly update the chassis and it had to feed both ways. There are different cut-off dates for different things and Mercedes HPP made it really easy to install, even though we switched quite late. Normally you would want to change in, say, April for a new supplier, and on this we did not switch until late June,' Chester reveals.

The operating and installation demands of the Mercedes differed in a number of areas to that of the Renault, as can be expected, but in one area in particular it had a profound impact. 'It has some packaging advantages and it works well with our chassis layout,' Chester admits. 'We have taken the opportunity to change our cooling system significantly to be much simpler and more elegant than last year.'

Lotus has ditched Renault power in favour of Mercedes units in an attempt to return to the podium once again



Simplified cooling

Indeed the cooler packaging is fundamentally different to that of the E22, something hinted at by the addition of a pair of ducts mounted on the roll hoop of the car, giving this area a look not dissimilar to that of a Dassault Rafale jet. 'Those ducts are largely for gearbox cooling,' Chester explains. 'It's quite a nice solution and it means that the left and right-hand side pods are neatly laid out for the charge air cooling on one side and oil and water on the other. The hoop ducts look quite draggy but they are actually quite efficient and work well. The architecture of the power unit meant that we couldn't really do what we did before. But we also wanted to have a simpler cooling layout than on the E22. The E22 was quite problematic to cool, but with this layout the E23 is sometimes even a little over-cooled, so we end up closing up the bodywork. It's nice. We are not losing aero performance by having to open up the bodywork a lot. The E22 was a bit different – our charge air cooling was quite complex, so that level of complexity was not needed with the Mercedes, and it would be a big job to optimise and integrate.'

Chester goes on to explain that while he still believes that the E22's cooling concept was good, the execution was not and that influenced other areas downstream. 'In 2014 we had a lot of problems related to exhausts or to the charge air system coming into the engine; either the cooling of the charge air or the associated pipework. The 2015 exhausts follow a different concept. We did get on top of last year's concept, but it was certainly an area where we suffered at the beginning of the year. On the charge air side, the cooling is far simpler than last year's and we've paid a lot of attention to the pipework to get away from some of the sealing issues we had on the E22,' he admits.

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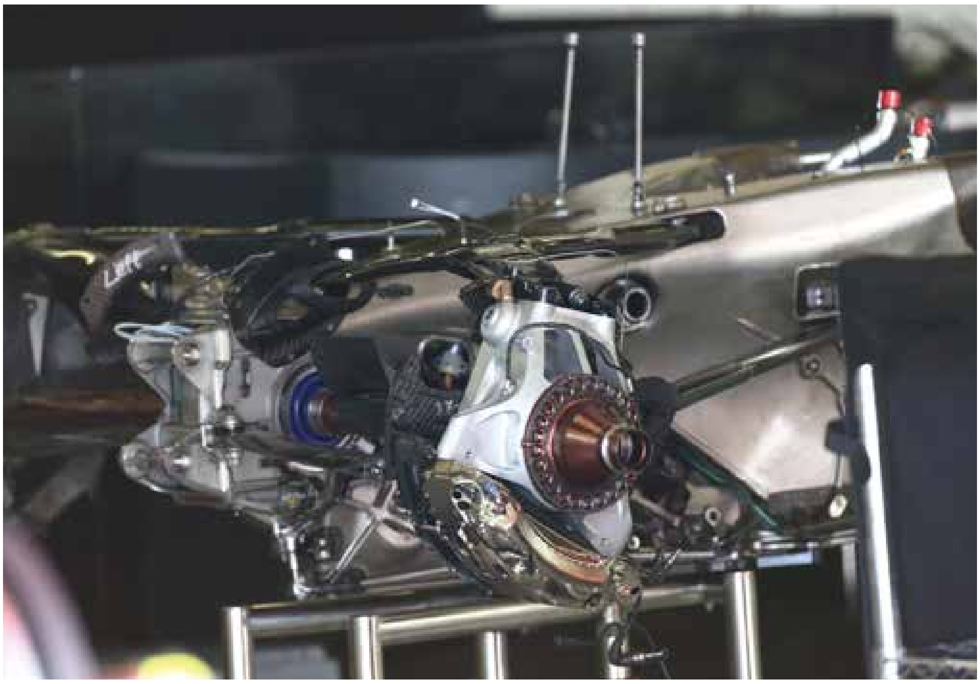
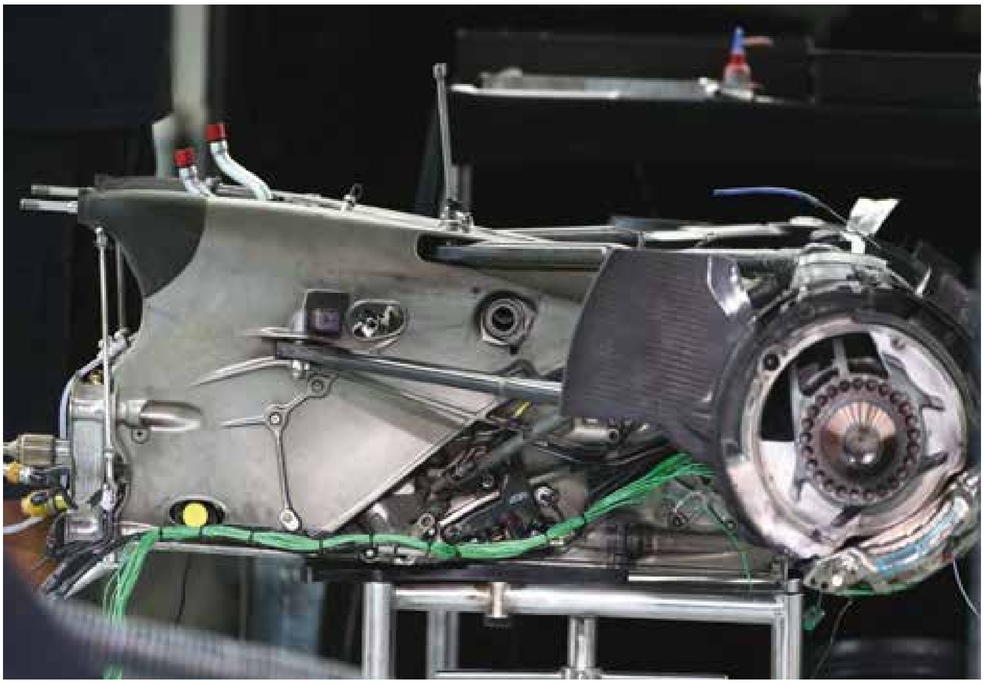
'The E23 is in many ways a far simpler car than the E22 and we think this will give us some advantages relating to our ability to evolve'

At the rear of the car the power unit has had an impact too, but not a great one in terms of the transmission. Lotus continues with its well proven gearbox concept, retaining a titanium casing and most of the internals. However, at the forwardmost points at the top of the bell housing where the casing picks up on the engine block, a pair of small composite sections are now present. It has been suggested by insiders that these were necessary due to the late adoption of the Mercedes V6, and that they could be signed off later than the main case – a long lead time item.

'We are happy with our concept, it's easy to adapt the main case,' Chester explains. 'The composite leading edge is a way to get the gearbox the correct length and it's also the lightest and stiffest solution. The change of PU has meant we have a slightly different wheelbase, and part of that gearbox design is based in the weight distribution targets. Overall the transmission is generally of the E22 design, but the rear suspension layout is somewhat different. Like most years we have changed the pickup points, so that changes the casing too.'





The rear suspension is new for 2015, and that has led to an evolution of the titanium casing of the gearbox

Overall, the Lotus technical team seems satisfied with the E23 Hybrid, although as always they know that there is room for improvement, especially considering that one of the drivers has failed to score a single point since he joined the team in 2014. 'The E23 is in many ways a far simpler car than the E22 and we think this will give us some advantages relating to our ability to evolve,' says Chester. 'The packaging is more compact, partly though the power unit installation as I mentioned previously, and partly through what we've learnt with the associated ancillaries. All of this should reap benefits in the coming races. We have had scrappy races, not poor car performance. So compared with the E22 I think this is a good step – the season so far has not been where we wanted because we have not had both drivers in the points so far. If we had then I think we would be up with Red Bull,' he says.

More downforce needed

Importantly it seems that the Lotus drivers agree. 'The car has consistency and balance, they can push the car, they can slide it and generally they have more confidence as they feel that the car has more traction,' Chester explains. 'The drivers say that this one is fun to drive but they hated driving the E22. The improvement is a mix of mechanical and aerodynamic gains.'

But even with this new found confidence Chester and his team of engineers are not satisfied enough to sit still as they know they need to push hard to be able to match Williams, Ferrari and the Mercedes works team. 'Of course we would like more downforce, but everyone says that,' he jokes. 'I think that the car has no nasty vices and it has no real elements that are weak – we would just like to get a bit more grip. Sometimes the E23 has a bit of mid-corner understeer in the low speed corners, but compared to last year, where we had such an inconsistent car, it's big improvement and the drivers can push it to the limit. So with a bit more downforce we can be right up there.'

Lotus last won a race in 2013 at the season's opening round, and while Chester did not want to stick his neck out and say that the feat would be repeated in 2015, just by listening to him you suspect it might be possible in the right conditions, providing they can find a way to get closer to those two silver arrows.

'It's pretty competitive in the midfield and we're fighting to be at the head of the chasing pack,' Chester concludes. 'Mercedes is still the team to beat, although Ferrari is pushing them. There is then a fairly big gap to Willliams who are followed by Red Bull and us – there is a smaller gap there and we can race them.'

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Five-year plan

How Formula E hopes greater technical freedom will lead to improved electric powertrains

By GEMMA HATTON and SAM COLLINS

Formula E set out to be different from the outset and, by having two cars per driver and even playing music during the race, it was clear that this was a series that wanted to re-invent motor racing. However, from a technical standpoint things remain deeply conventional with a single spec Dallara chassis, and while the cars are electric the power trains have not exactly pushed the technological boundaries. This has led some to criticise the cars and their relatively low speed.

However, TV audiences and healthy spectator figures have proved the championship's entertainment value and its organisers are slowly starting to open the doors to real technical freedom. A group of eight 'manufacturers' have entered the sport this season and each will be able to develop their cars within a set of technical regulations, although the scope for development will be restricted and all teams will still have to use the Spark-Renault SRT_01E and its Williams battery.

'The FIA are opening up the Formula E regulations to encourage manufacturers to innovate and develop more powerful and efficient electric powertrains,' highlights Sylvain Filipi, chief technical officer of the Virgin Racing Formula E team. 'The scope of development is limited to the powertrain as the idea is to focus R&D budgets and resources on technologies that are directly relevant to electric road cars. This means that no development is allowed on the chassis and bodywork to avoid expensive aerodynamic developments. As a result the manufacturers will instead focus their development work on electric motors, inverters, power electronics, gearbox and differential.'

New motor, old battery

It seems that most teams which are backed by the 'manufacturers' are planning to drop the electric motor used in the first season – the 200kW, 26kg synchronous permanent magnet MGU, which is in essence a lightly modified version of the unit used on the McLaren P1 production car rather than a bespoke racing unit. While opening up the motor (and inverter) technology there are still some restrictions on what can be done. For the second season, the MGUs will only be able to transfer torque to the driven wheels through a single mechanical differential with no torque vectoring in an attempt to prevent teams developing complex electronic differentials and other technologies.

The performance bracket of the MGU is still partly governed by the energy store and the regulations surrounding that. Officially dubbed the Rechargeable Energy Storage System (RESS), the battery will remain the same as in season one. It can only supply a maximum of 28kWh to the MGU with the total power out of the battery capped at 200W. Indeed, while it had been planned to open up the battery chemistry, layout and overall technology in the third season, Formula E is now reconsidering this move. 'The costs of developing one battery each are very high, so we are suggesting that the teams pool together and develop a battery, that means there are more resources to develop it and they can make a significant jump' Formula E CEO Alejandro Agag told the press at the race held in Berlin, Germany.

'We still want to make an evolution on the battery for season three and sticking with the current battery would not allow for that big a jump. So we want to develop a new one. It might be Williams or it might be someone else, but we think it should be one spec design.'

While this move may disappoint many, Formula E always planned to restrict technical freedom in the energy store. This prevents the teams' resources being spent on alternative technologies such as capacitors and flywheel storage systems in the initial seasons, as well as keeping out the experimental cells at the prototype and research stage. The series eventually hopes to be able to have cars and energy stores that will last the full race distance without the need to stop for a car change, but it does not expect this to happen until season five.

'The cost of developing one battery is very high, so we are suggesting that the teams pool together'

CAUGHT

The race winning car of the Berlin e-Prix, run by Audi Sport Team Abt, was excluded as the front wing fairings had been modified to include internal metal reinforcing rods. The stewards also discovered that six of the eight holes in the front wing had been sealed. The remaining two holes were found to have had helicoil inserts and chamfers made and that the front flap and gurney had a filler layer added and a chamfer made.

Abt argued that these changes were the result of repairs and gave no performance advantage, although others say that it reduced drag. 'After making necessary repairs, some of the parts were no longer in their original form as specified by the regulations in Formula E,' said Hans-Jürgen Abt. 'The cars and all spare parts are transported around the world in boxes and the team doesn't have the time or opportunity at the various tracks to carry out repairs with the same precision as at home in our workshop. This is a situation that affects all the teams and we must find a solution in the future.'

RESULT: EXCLUSION

Despite this, a good range of motor technologies are expected to be used, with at least one team opting for a twin motor layout; Team China Racing has announced that it has partnered with a local producer of EV technology called NextEV and that together they will develop a twin motor layout with dual controllers and a gearbox configuration that maximises efficiency in both drive and regeneration modes.

Although the cars will remain rear wheel drive for the near future, all-wheel drive systems will be looked into as this will enable a higher amount of recoverable energy, generating more power which will also help towards achieving a single car per driver.

The second season changes will also see some alterations made to the Spark-Renault / Dallara 01E chassis itself. Although the Spark-Renault chassis will remain the same throughout the grid, the first season highlighted concerns with braking stability and the durability of the suspension on the very bumpy street circuits used in Formula E. 'We're constantly improving the car's mechanical components in order to meet street circuit requirements,' explains Theophile Gouzin, technical director of Spark Technologies. 'We have been developing upgrades for the cars suspension and braking system. We are also looking into brake temperature management to improve the initial bite and controllability during braking.' Tests have been run on various carbon disc designs as well as revised ducting, and significant improvements in the systems were reportedly found after runs at Magny Cours.

Suspension and cooling

The new season's suspension design will still be an independent double wishbone layout, using a coil spring over a damper which is actuated via rockers and pushrods. A rear anti-roll bar can be used and the regulations permit a maximum of five links on each side, all constructed from steel. Any dampers can be used as long as they are attached to the rocker at one end and mounted to the chassis on the other, and they act independently on each corner of the rear.

Another area of development will be the cooling system. The main limiting factor on achieving high efficiencies with the battery is temperature, so the heat of the battery needs to be managed effectively. However, to last the full race distance, recoverable energy is required and as this is stored in the battery, the temperature increases. Therefore, it is a vicious trade-off between balancing the battery temperature to avoid thermal runaway, yet still generating enough energy to finish the race. 'Dry ice lowers the battery temperature by about 25°C and we need to decrease that temperature to increase power,' explains Hans-Jurgen Abt, team owner of Audi Sport Team Abt. 'In the race you only have the cooling from the air, and the RESS liquid cooling system.'

Formula E continues on its much debated path both in terms of promotion and its philosophy of limiting and mapping out its development and technical freedoms. For the time being this approach is certainly beginning to show some success, although whether it continues to do so by the start of season five will only become clear with time.

Roaring to success

We look under the skin of team Lion GP's racer, one of the Cranfield University 2015 Formula Electric Series designs

By SAM COLLINS

Above: The Lion GP entry used two separate cooling systems – a glycol circuit for the batteries and a water circuit for the electric motors
Right: *Racecar Engineering* deputy editor Samuel Collins with Cranfield Formula Electric Series team Lion GP

With the ongoing electrification of motor racing a shortage of key skills has been identified by many in the industry. It is becoming increasingly difficult for teams and suppliers to recruit people with serious levels of high performance electric vehicle and hybrid knowhow. However, there are some out there taking a proactive approach to addressing this skills gap and most notable among them is Cranfield University. Each year it sets its Motorsport Engineering and Management MSc students a tough problem to solve in small competitive teams.

This year the task was perhaps the toughest ever. Dubbed the 'Cranfield Formula Electric Series' (CFES), the challenge was to create a national level electric racing series. The 'races' would consist of 20-minute races with no pit stops and qualifying sessions run on the same day. Cars would have to be fully recharged between qualifying and the race in no more than 90 minutes. Donington Park in England was used as the sample circuit.

To prevent it from becoming a full car optimisation project the student groups would utilise a number of single specification components – a Mygale FB02 Formula BMW monocoque was to be used and, aside from the power train cooling, the car's aerodynamic package was not in the scope of the project, nor was suspension design. A spec tyre model had to be used too, although one group managed to use an illicit higher performance model during the final presentation to industry.

Limited cell choice

Another crucial restriction was a mandated battery cell, with its size, requirements and performance based on a cell currently used in motor racing. These 'Cranfield cells' could be arranged however the students desired, but they could not be adapted or changed. Again this prevented complex investigations into the vast world of cell chemistry and supplier claims. Additionally the power electronics were out of the scope of the project and the teams were instructed to 'use what already exists'.
Within the scope of the project was a free selection of commercially available electric motors. The battery pack size, location and layout were also free as long as the Cranfield Cells were used. The car's cooling layout was also in the scope of the project, but the coolant had to be distilled water, a water/glycol mix and transformer oil. Anything else would have to be approved through phase change systems and heat pipes were deemed illegal. No more than two heat exchangers could be used, both using commercially available cores, with the focus being on the sizing and placement of the coolers to both provide minimal drag and adequate heat exchange.

The battery packs had to be designed so that they could withstand a lateral impact into a EuroNCAP deformable barrier structure at 50kph using an LS-Dyna model.

The resulting projects proposed a wide range of solutions, and there was no real consensus on any element of the layout. Single motors, twin motors, transmissions and a range of battery pack layouts were all proposed, including one air cooler layout that saved a notable amount weight but raised questions about legality and debris build up.

The groups had to create a detailed technical report explaining their findings and how they arrived at them before facing a grilling from the Cranfield academics. The groups then had to present their projects to some of Britain's leading motorsport engineers, and all of these elements counted towards the final MSc marks.

The 'Cranfield cells' could be arranged however desired, but they could not be adapted or changed, preventing complex investigations

Of the five groups that took part the one that really caught the eye of the *Racecar Engineering* staff was made up of Marc-Andre Côté, Stephen Glass, Colton Harrison-Steel, Paul Henry, Maxime Menneglier, Niamh Ryan and Shriram Thirumalai. They called themselves collectively 'Lion GP'. Some of the highlights from their collaboration are as follows:

The team evaluated the packaging constraints of the existing FB02 car to determine possible layouts for the electric powertrain. Different battery pack layouts were examined, from a single stressed battery box taking loads from the chassis to four separate boxes incorporated inside a space frame. The team's final choice was the latter, with ease of maintenance being the determining factor.

Preliminary lap time simulations were conducted using a simple point-mass software and evaluating different motor and battery configurations. Twin motors, each driving a rear wheel, offered the advantage of having endless differential configurations. Alternatively, a single motor has the advantage of reducing the complexity of the car, making it easier to maintain for club level racers. The final configuration decided upon by the team was two Emrax 228 motors, each driving a wheel with an electronic differential programmed to mimic the behaviour of a mechanical one.

Dual cooling system

The car's cooling system consists of two separate circuits, one containing glycol and one containing water. The glycol circuit is used to cool the batteries as it doesn't react with the lithium in the batteries in the event of a spill and this cooling circuit has been purposefully sized to ensure the temperature of the battery pack is always within an acceptable tolerance. The water circuit, on the other hand, is used to cool both the electric motors.

The team then carried out energy harvesting calculations and analysed how these could be integrated into the rear braking system to make the most of the available grip from the rear tyres. New wheel and roll rates were calculated and motion ratios were changed on the rear suspension to take the extra weight of the electric powertrain into account.

Conversion costs

The last part of the project focused on costing the parts that would be used in the electric conversion for the FB02 race car. Labour costs and manufacturing costs were not included as this would vary by from company to company, but an estimate of the raw costs of converting an existing secondhand Formula BMW car into a CFES racer came in at a little under £57,000.

The groups have now separated and the students are working on their own theses, which will be revealed in September.

Introduction

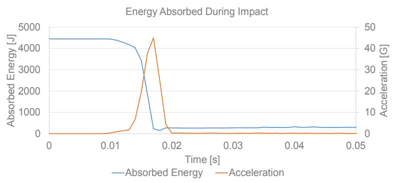
With the increasing awareness of the need for alternative fuels and the growing prevalence of electric cars it makes sense that motorsport would branch out in that direction. With only a handful of series permitting the use of electric only vehicles, LiON GP set out with the goal to build a powertrain and cooling system for a new, club level electric racing vehicle the LGP-01.

Objectives

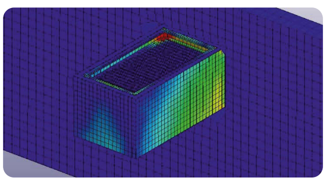
- To design a structure capable of protecting the battery packs in a side impact collision
- To design and model a cooling system capable of keeping the batteries and motors within safe operating conditions throughout a 20 minute race
- To complete a performance statement of the system via Donington GP lap simulation

Battery Design and Safety

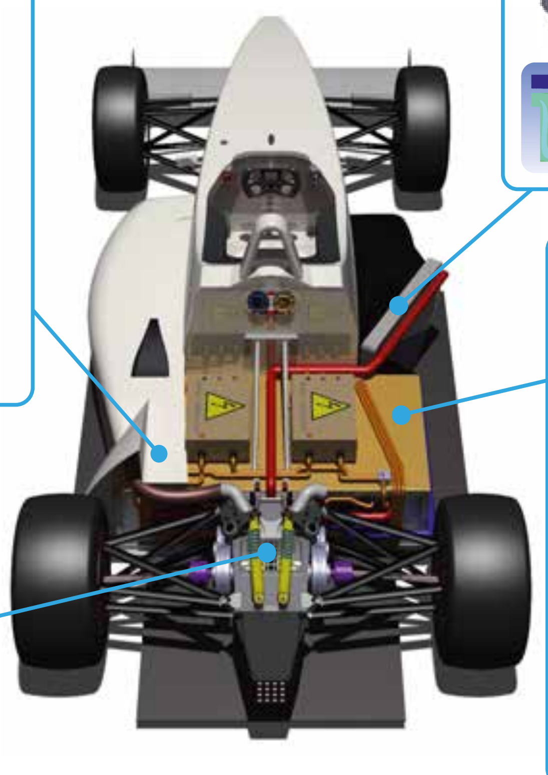
- Simulate a crash at 50kph in to a Euro NCAP deformable barrier
- Battery pack was capable of absorbing 4500J without structural failure



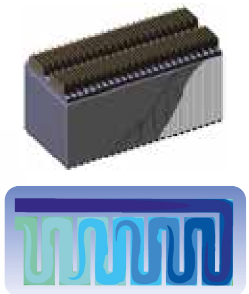
- 6061 aluminium sheet + Rohacell 110 IG structural foam crash structure
- 200 cells for a total of 740V, 29.6 kWh battery pack.



Vehicle Mass	735kg
Peak Power	200kW (270bhp)
Qualifying Pace	1:30.15
Race Pace	1:35.16

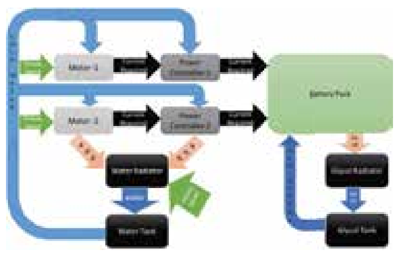


Battery Cooling

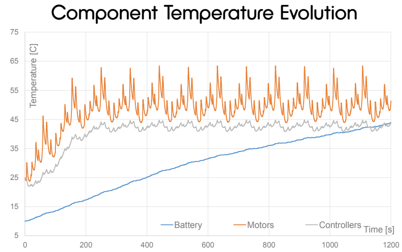


- 100% ethylene-glycol
- Chiller plates alongside the battery packs within the structure
- Battery cells separated with flanged aluminium plates within battery box
- External cooler during charging and between sessions

Thermal simulation

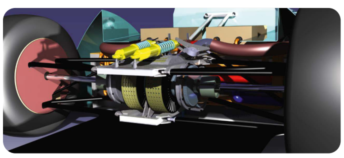


Component Temperature Evolution



Motors & ReGen

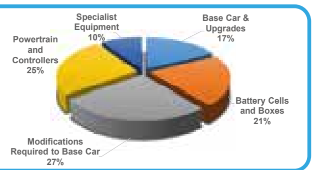
- Two EMRAX 228 water-cooled electric motors
- Single speed gearbox 2.4:1 ratio



- 35% of braking energy harvested
- Up to 480Nm of braking torque
- Both high grip and low grip setups
- Braking force electronically controlled for good brake distribution.

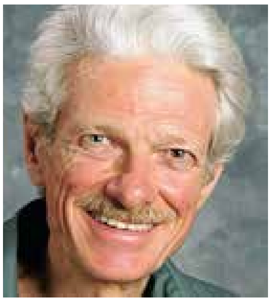
Costing

- Second-hand FB02 retrofitted for use in CFES
- Materials sourced locally when possible
- All components last for a minimum of 1 season
- Total cost of £57000



Conclusion

- Using two Emrax 228 electric motors it has been shown that it is possible to achieve a similar performance level to BRDC Formula 4 with a fully electric powertrain.
- An aluminium battery crash structure can meet necessary safety requirements while still being relatively inexpensive and simple to build.
- It is possible to effectively manage the thermal characteristics of the systems with a traditional cooling system



Can front wheel drive compete at Le Mans?

Our man considers Nissan designer Ben Bowlby's calculations

Question

It would be interesting to hear your thoughts on the Nissan front-wheel-drive LMP1 car. Is this mainly for marketing reasons? Or is it to take advantage of the aero rules?

The consultant says

Peter Wright has a very good article about the car in the May issue of *Racecar Engineering* based on his discussions with the car's designer, Ben Bowlby.

Evidently, the idea is indeed to take advantage of the aero rules. I don't think Nissan intends to promote front wheel drive, as they are not really more associated with that than any other manufacturer. However, the car does stand to have a marketing advantage of sorts, simply because its unusual design will always attract attention.

Of course, it does no good to attract attention and then fall flat on your face. This isn't a show car– it's a car that has to work, and making it novel doesn't get the job done.

So what is the functional logic of the design? And does it make sense?

This car is about the aero rules. The existing rules strictly control the design of rear wings and diffusers, and are more lenient on front diffusers. The thinking, presumably, is that the rear downforce automatically limits the front downforce, because if the designer creates too much front downforce with respect to the rear, the car will be aero-loose: it will have high-speed oversteer unless its suspension is set up for understeer, in which case it will understeer excessively at low speed. So any attempt to increase total downforce by increasing only front downforce will be self-defeating.

To get an acceptable understeer gradient at all speeds, the drag and lift forces on the car must add rear tyre load at a greater percentile rate than they add front tyre load. With rear wheel drive, we need an extra dose of this because in constant-speed cornering at high speeds the rear wheels are using a large portion of their traction circle or performance envelope for propulsion, and they have less grip available for lateral acceleration. With front drive, we have a similar effect for the drive wheels, but they're at the front.

In simple terms, the centre of lift/downforce needs to be behind the centre of gravity – more so with rear drive than with front drive. If the centre of gravity is further forward, the centre of lift/downforce can also be further forward. If the rules limit rear downforce but not front downforce, then a nose-heavy front-drive car can have more total downforce without being aero-loose. More downforce; more grip; faster corner speeds; all the requirements for a car to win races.The kicker is that this advantage has to be big enough to trump the considerable disadvantages of front drive for a racecar.

The fundamental problem is that rearward load transfer under power works against us with front wheel drive. The car is therefore at a disadvantage for forward acceleration, up to the speed where it becomes power-limited rather than traction-limited.

To minimise this disadvantage, front-drive cars are always made nose-heavy – typically from 58 to 62 per cent front. They also have equal size tyres front and rear. The result is that they invariably understeer, even when set up to corner on three wheels.

I read in the article that the NISMO is even more nose-heavy than that: around 65 per cent front. However, the front tyres are much wider than the rears. The car reportedly does still corner on three wheels at times, at least in the lower speed ranges where downforce is moderate. That's as it should be and it helps the inside front tyre put power down. So Bowlby has got the tyre sizes and roll resistance distribution right. That will definitely help.

He has also got the wheelbase right: he's made it unusually long. That reduces the rearward dynamic load transfer under forward acceleration. The car therefore has the two main characteristics needed to minimise the disadvantages of front wheel drive. Despite this, the car will still have less of its weight on the drive wheels dynamically than a rear-engined car when powering out of low-speed turns.

Bowlby has got the tyre sizes, roll resistance distribution and wheelbase right

The other big drawback of front wheel drive is that the necessary nose-heaviness is a disadvantage in braking. The front wheels have to do most of the work. Due to load sensitivity of the coefficient of friction, the tyres tend to deliver less rearward acceleration when they are worked less equally. However, when the front tyres are bigger than the rears, the situation is not so bad.

Nissan's GT-R LM NISMO features a weight distribution of at least 65 per cent front, and 35 per cent rear

The tyres are only one limiting factor in braking, with the other main factor being the brakes themselves. It is easier to keep the brakes alive if they share the work fairly equally. If the front brakes have to do most of the work, they have to be awfully good to survive an endurance race.

Now, all of the foregoing assumes that the front-wheel-drive car has similar aero properties to its rear-drive counterpart. But what if the front-drive car has a lot more total downforce? Won't it then be capable of outbraking the rear drive alternative?

Answer: yes, at least in the upper speed ranges – provided the front brakes hold out.

Nissan's design team has run simulations that it says support the team's decisions. I can't say whether that's true or not, but I can do simple maths. Let's run some quick numbers. These won't necessarily exactly represent reality, but they will be close enough to illustrate basic principles and relationships.

The front-wheel-drive approach does make sense if it buys us a big total downforce increase

Case #1

Rear-engined car of weight W, at low speed, disregarding any aero effects; 60 per cent rear statically; longitudinal coefficient of friction μ_x = 1.4; c.g. height 1/6 of wheelbase

Forward load transfer = (1.4/6)W = 23.3 per cent W
Dynamic normal force distribution 63.3/36.7
Front brakes need to do about 65 per cent of the work, since the car should be set up so the fronts always lock before the rears.

Case #2

Similar to #1, but for a front-drive-wheel car with long wheelbase; 65 per cent front statically, c.g. height 1/8 of wheelbase

Forward load transfer = (1.4/8)W = 17.5 per cent W
Dynamic normal force distribution 82.5/17.5
Front brakes need to do about 85 per cent of the work

Case #3

Similar to #1, but at high speed, with serious aero: 1.5W in downforce, distributed 30/70, and .5W drag force acting at c.g. height; μ_x = 1.3

.5W/6 = 8.3 per cent W rearward load transfer due to drag
1.5(.30)W = .45W added to front
1.5(.70)W = 1.05W added to rear
Rearward force at contact patches = 2.5(1.3)W = 3.25W
Forward load transfer = (3.25/6)W = 54.0 per cent W
Front normal force = .400W – .083W + .450W + .540W = 1.31W
Rear normal force = .600W + .083W + 1.050W – .540W = 1.19W
1.31/2.50 = 52.4 per cent dynamic front
1.19/2.50 = 47.6 per cent dynamic rear

Front brakes need to do only about 55 per cent of the work, but it's a lot more work. Also, if the car has constant brake bias, this will need to be close to 65/35 to avoid rear lockup in lower speed ranges.
Car is decelerating at 3.75g.

Case #4

Front-drive car as in #2, but with same downforce and drag as #3, except downforce distributed 60/40

.5W/8 = 6.3 per cent W rearward load transfer due to drag
1.5(.60)W = .90W added to front
1.5(.40)W = .60W added to rear
Rearward force at contact patches = 2.5(1.3)W = 3.25W
Forward load transfer = (3.25/8)W = 40.6 per cent W
Front normal force = .650W – .063W + .900W + .406W = 1.89W
Rear normal force = .350W + .063W + .600W – .406W = 1.19W
1.89/2.50 = 75.6 per cent dynamic front
1.19/2.50 = 47.6 per cent dynamic rear
Front brakes need to do about 77 per cent of the work if the car has active brake bias control. If not, they still need to do about 85 per cent to avoid low-speed rear lockup.
As in #3, car is decelerating at 3.75g.

Case #5

Front-drive car as in #2 and #4, but now let's suppose that we have the same rear wing and diffuser as in #3, and we get 60/40 downforce distribution by adding front downforce. Let's suppose that the added front downforce acts slightly forward of the front axle, so that net rear downforce is slightly diminished, even though the rear wing and diffuser are making the same forces. Let's also suppose that both have a similar lift/drag ratio. We now have 2.5W downforce total, 1.50W front/1.00W rear, and .8W drag. That's a lot more tyre loading, so let's suppose that μ_x = 1.25.

.8W/8 = 10.0 per cent W rearward load transfer due to drag
2.5(.60)W = 1.50W added to front
2.5(.40)W = 1.00W added to rear
Rearward force at contact patches = 3.5(1.25)W = 4.38W
Forward load transfer = (4.38/8)W = 54.7 per cent W
Front normal force = .650W – .100W + 1.50W + .547W = 2.60W
Rear normal force = .350W + .100W + 1.00W – .547W = .90W
2.60/3.50 = 74.3 per cent dynamic front
.90/3.50 = 25.7 per cent dynamic rear

This hypothetical car is decelerating at 5.18g! It will clearly outbrake the rear-engined car with the same rear wing and diffuser – provided we can keep brakes and tyres under the thing, and provided the driver's eyeballs stay in his skull. It will also outcorner the rear-engined car, except perhaps at low speeds

Again, these are hypothetical examples, presented to illustrate general principles. But it should be apparent that, at least in theory, the front-wheel-drive approach does make sense if it buys us a big total downforce increase.

I am reminded of another great exercise in outside-the-box thinking; the Chaparral 2J 'sucker car' of 1970. It achieved more downforce than its competitors, by using powered evacuation of the underside of the car. It was wickedly fast as a result – but only for a few laps. Then the brakes would quit.

Now we have carbon brakes, which didn't exist in 1970. Will this technology make it irrelevant whether the rear brakes do a substantial amount of the work? Will it mean that tyre grip is now the only thing limiting braking? I guess we'll find out.

Is the NISMO uniquely suited to Le Mans, and will it be uncompetitive elsewhere? Actually, I would expect that in its current state, the Le Mans circuit is less suited to this car than it would have been years ago as lots of chicanes and wiggles have been added to keep speeds down. There is now much more low speed braking and forward acceleration in a lap than there used to be.

The sort of track that would really favour the NISMO would be one where a large portion of the lap is spent in high-speed cornering, and there is relatively little need for low-speed braking or digging out of slow turns – a track with a lot of sweepers, like Spa in the old days, or Goodwood. Or Indianapolis – the rectoval part, not the infield part.

One other thing is important to note about the GTR-LM: it was not originally conceived as a pure front-wheel-drive car. The idea is to have a kinetic energy recovery system (KERS) braking and powering the rear wheels. The car will run without that this year because it isn't ready yet. So the car will be an interesting case study in the possibilities and limitations of pure front wheel drive, but actually that was not the original design intent.

CONTACT
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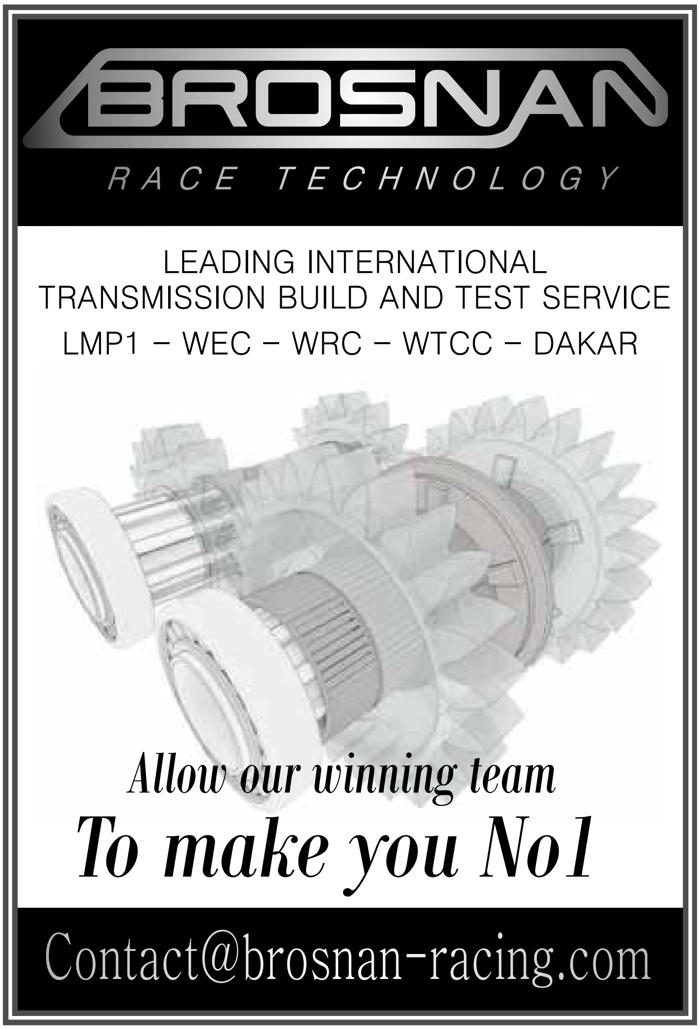
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Speed control

The Nürburgring 24 hour race in May was probably the first to have permanent speed limits on the circuit, implemented for safety reasons. We look at what needs to be done to achieve it

Databytes gives you essential insights to help you to improve your data analysis skills each month, as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems

Figure 1: Dash reminds driver to push pit lane speed limit button

Last month we looked at some methods for limiting the speed of a car based on driver input, such as the pit lane speed limit. Recently some series have been experimenting with limiting the speeds of cars based on track conditions and/or the location of the car on the track. The latest in this is the mandatory speed restrictions at certain parts of the Nürburgring for the 24 hour race and VLN series.

There are a number of ways to implement a speed restriction as described above. It all depends on the team/manufacturer and what philosophy they employ. The simplest is to rely completely on the driver to notice the zones and reduce the speed – this is the least invasive way, but consistency can be a challenge. Speed limits aren't always one of the values presented to drivers and, if it is, it tends to be a small number. To aid the driver in this it is fairly easy to set the display to bring up an overlay based on a button press. This can then be tailored to show different overlay depending on gears, so the speed is displayed in a larger area and other graphics can also be used to help maintain the speed, as shown in **Figure 1.** This was implemented for some competitors using Cosworth ICDs in VLN as a fast way to achieve what the organisers proposed. The ECUs were also modified in the same way and these then limited the speed when the pit lane speed limit button was pressed. However, this time the driver can use full throttle and the ECU takes care of the speed control.

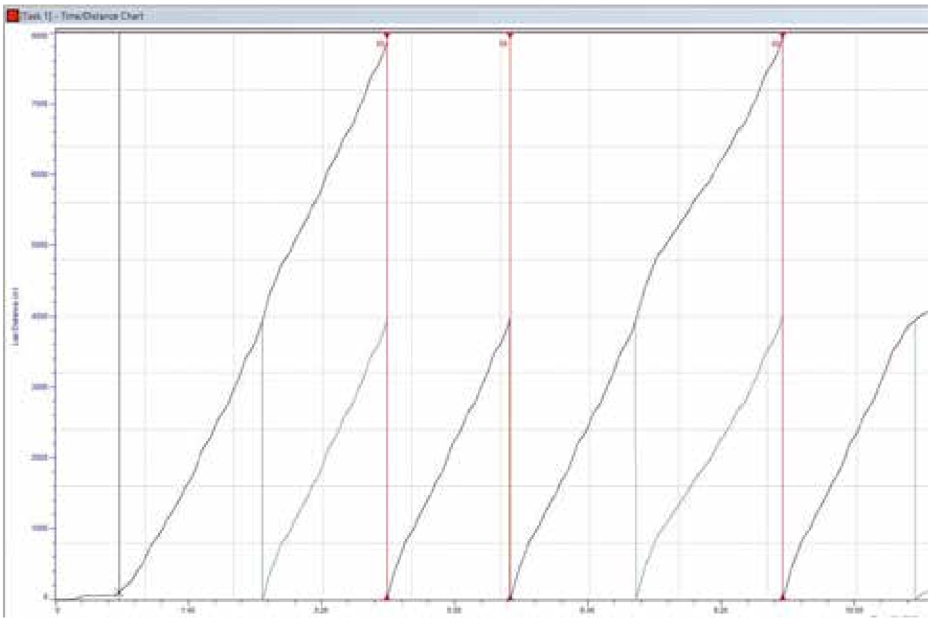

Figure 2: If a lap beacon suffers a complete failure the ECU will be unable to work out where the car is on track

Full automation

The third method is to take the driver out of the equation and to let the car's control system take over completely. For this to work it is necessary to get a reasonably accurate distance measurement into the ECU and then map an engine speed limiter based on how far along the lap the car has gone. There are some implications for full automation that need to be taken into account. Normally lap distance is reset with a lap beacon and this is usually an infrared beam sent across the track at the pit wall. If for some reason the beacon is missed the lap distance will not reset. There are a number of ways around this, although the easiest method (if possible) is to automatically reset the distance if it goes above certain number. Another way is to map two laps into the distance tables.

choose([Lap Distance] > 3945, [Lap Distance]-3945, [Lap Distance]);

This maths channel resets the lap distance automatically if it goes above 3945 and recalculates the distance for one lap after a missed beacon.

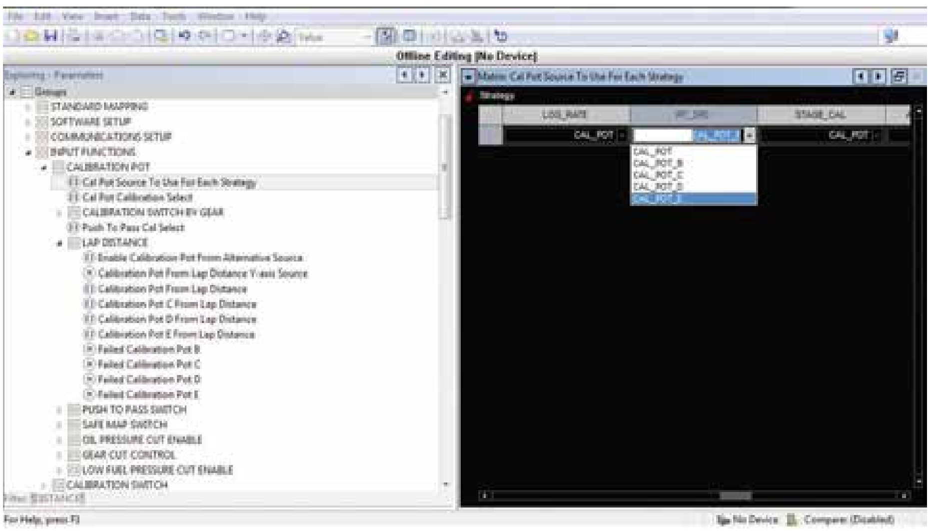

Figure 3: Pit lane speed limiter is programmed to automatically change the ECU map

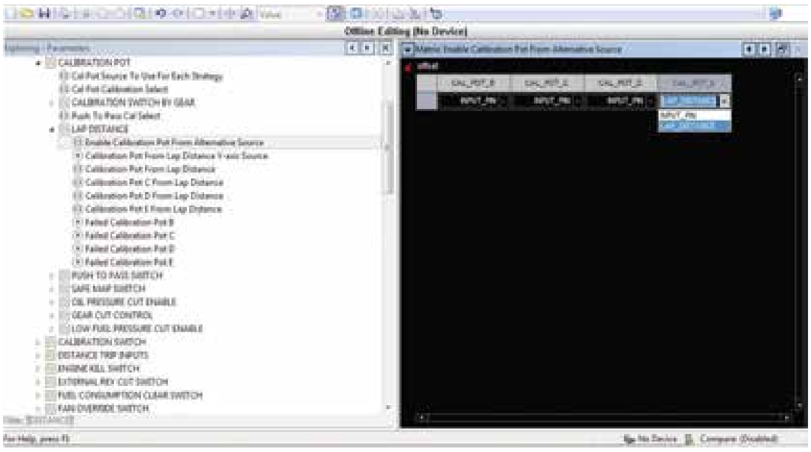

Figure 4: Calibration based on lap distance

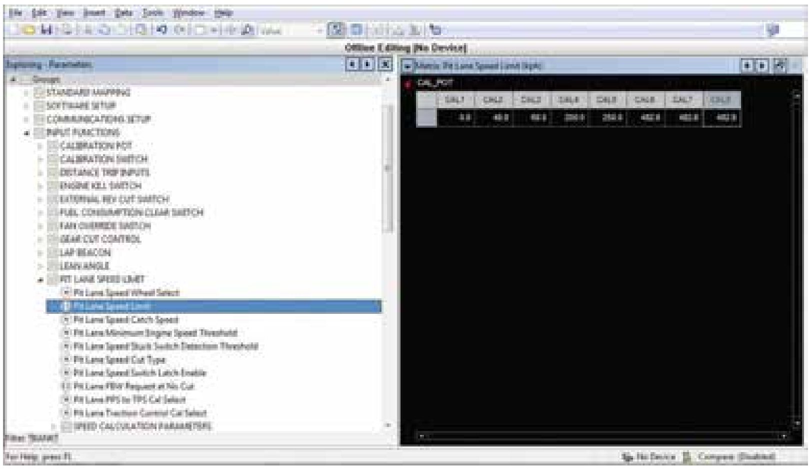

Figure 5: Configuring the distance for eight different speed limit values

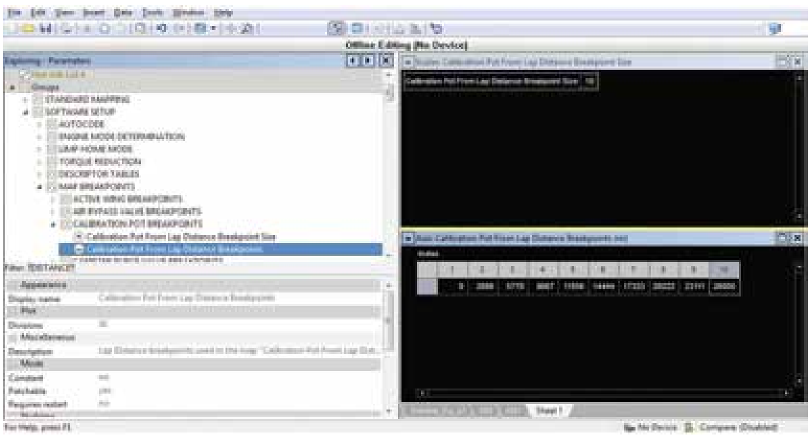

Figure 6: Configuring the distance for each sector

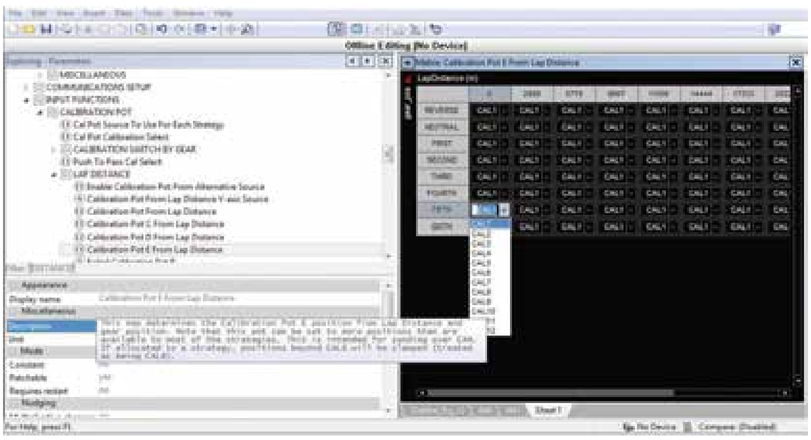

Figure 7: Assigning the distance values to the calibration pot

However, this channel does not cover the scenario of a completely failed beacon system, as illustrated in **Figure 2.**

In order to implement a distance based speed restriction in the ECU, first we need to choose the source which determines the map to use in the ECU. In this case the pit lane speed limiter should be used to change the ECU map, as shown in **Figure 3.**

The next step is to make this calibration pot work from an alternative input or virtual function, in our case lap distance. This is demonstrated in **Figure 4.**

The different speed limits must be programmed into each calibration available for the calibration pot. In this case there are eight different values possible. The order does not matter strictly speaking, but using the order at which the speed restrictions occur at the track makes the configuration a bit easier – see **Figure 5.**

The distance for each sector then needs to be configured. In this case a lap of the Nürburgring has been programmed at 26km in distance with 10 breakpoints. These values do not represent any series regulations. The number of breakpoints can be configured if need be, as per **Figure 6.**

The last piece of the puzzle is then to assign the distance to the calibration pot. The dropdown menu relates to the speed limits selected earlier. Note that up to 12 positions are possible, but in this case we only use eight and in real world terms only three have any effect, Cal2, Cal3, Cal4 and Cal5 – see **Figure 7.**

It is possible to take the automation process to a further level with the driver only selecting a gear and the distance controlling the speed limit at each point on the track

In this strategy there are two elements to the control strategy. Firstly the driver needs to select the appropriate gear and initiate the pit lane speed limit. The second part is automatic and selects the speed limit based on distance. It is possible to take the automation process to a further level with the driver only selecting a gear and the distance controlling the speed limit at each point on the track. This means that the pit limiter strategy is effectively always on and track position dictates how fast the car can go. This also means that for most parts of the track the speed limit would be far beyond the capabilities of the car, but in the speed restricted zones there would be a limit. If such an approach is taken, it would be wise to have the option of turning the strategy off.

In this case the speed signal is taken from the wheel speed sensors, but it is also possible to develop a strategy that used GPS. There are pros and cons for each and ideally there would be an algorithm that selects each strategy based on which one is more accurate at that point in time.

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Front end drag and aero balance

Our last look at VUHL's 05; front end and surface pressure mapping

The VUHL 05 concept from the Echeverria brothers Iker and Guillermo fits the same 'lightweight sportscar for road and track' genre as the Lotus 2-11, the Ariel Atom, the BAC Mono and the Caterham AeroSeven concept. UK-based Collins Advanced Engineering, run by brothers Jenner and Jilbruke Collins, were carrying out development work for VUHL, enabling *Racecar Engineering* to host the 05 in a MIRA wind tunnel session, as per **Picture 1.**

Briefly recapping, the 05's baseline configuration at this early stage of the car's aero development produced the data shown in **Table 1** at the wind tunnel's maximum speed of roughly 35m/s (80mph or 126km/h).

So, moderate drag (it is an open sports car) was accompanied by modest but genuine downforce with a forward bias relative to the static weight distribution of 37-39 per cent front. Rear wing re-location, reported in the last issue, enabled improved aerodynamic balance and higher overall downforce to be attained, albeit at a drag level a few per cent higher.

Front end modifications

Some covers were then applied in succession to the front end of the car to examine the responses – see **Picture 2.** First, the front light clusters were covered, and the changes (deltas or Δ values) are shown in **Table 2** as 'counts', where 1 count = a coefficient change of 0.001. The effect then of smoothing over these areas was really quite small, the most significant aspect being that balance was shifted slightly further forwards. A very small drag improvement was also achieved.

Second, the cutouts in the airdam ahead of the front wheels were covered over, and the changes relative to the configuration above are shown in **Table 3.**

Perhaps surprisingly, drag increased slightly with this modification but, most significantly, front downforce increased by 84 counts, or 77 per cent in this instance. Rear downforce declined by 25 counts, which together with the front gains meant that almost 100 per cent of the downforce was now on the front. Whether this modification would be deemed beneficial would depend on development aims, because obtaining an aerodynamic balance with this front end would require a stronger rear end package than was available for this session, which in turn would most likely add more drag.

Third, the upper surfaces of the outer sections of the front splitter were covered over, with the results in **Table 4.** This time some front downforce was lost, the 50 count reduction representing 25.9 per cent, meaning the splitter was still generating nearly three quarters of its original downforce from the centre section and the unmodified underside (where most of a splitter's downforce comes from). What was interesting though was the 18 count drag reduction, which put the other way around means that these sections of the splitter and airdam were creating 50 counts of downforce for 18 counts of drag. By way of comparison, various splitter extensions we have examined in the past have yielded front downforce gains for minimal if any drag change.

Obtaining balance with this front end would require a stronger rear end

Table 1 – baseline data on the VUHL 05

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.533	0.135	0.102	0.032	75.6	0.253

Table 2 – the effects of covering the light clusters

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Lights covered	-2	+1	+7	-6	+4.6%	+4

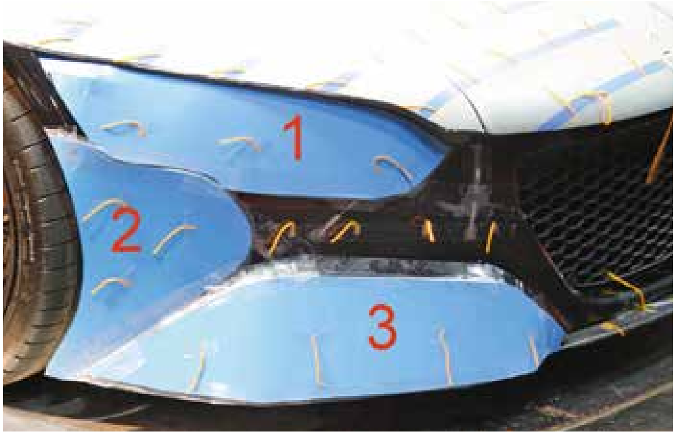
Picture 1: This month the VUHL 05 front end is modified, and surface pressures are measured via the loom of capillary tubing seen emerging from under the car

Table 3: the effects of covering the cutouts in the front airdam

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Cutouts covered	+7	+58	+84	-25	+19.5	+104

Table 4 – the effects of covering over the outer sections of the front splitter

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Outer splitter covered	-18	-43	-50	+7	-5.3%	-70



Picture 2: These three cover panels were applied in the order shown, with very interesting results

Picture 3: Two of the 46 pressure tappings attached to the VUHL; each features a pinhole open to atmosphere which is connected by capillary tubing to the pressure scanner

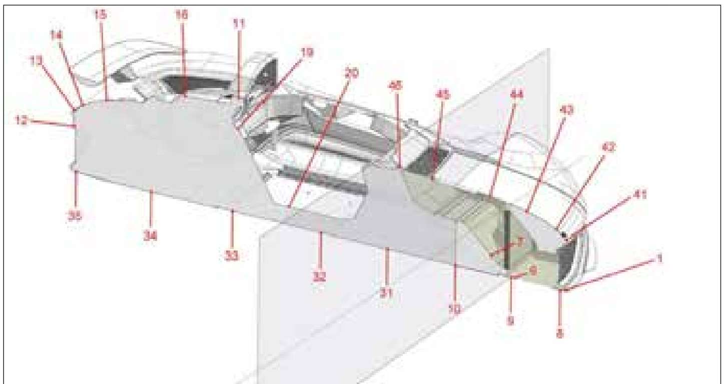


Figure 1: Pressure tapping locations on the VUHL's centreline

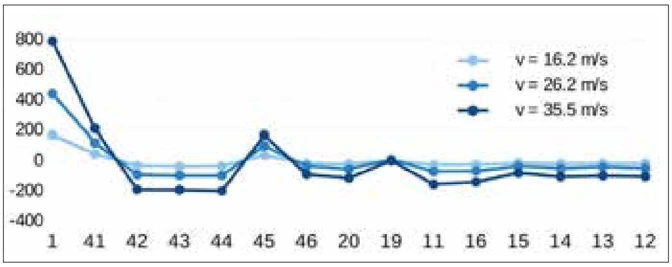


Figure 2: Pressures (pascals, Pa) on the VUHL's upper centreline profile at three different speeds

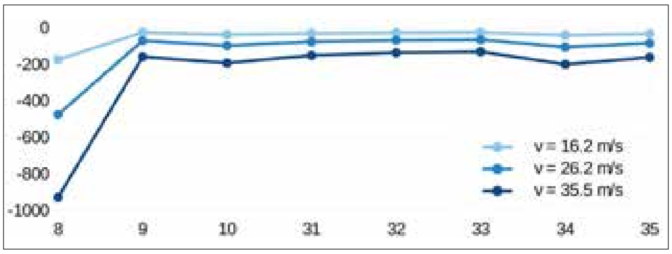


Figure 3: Pressures on the lower surface at three different speeds

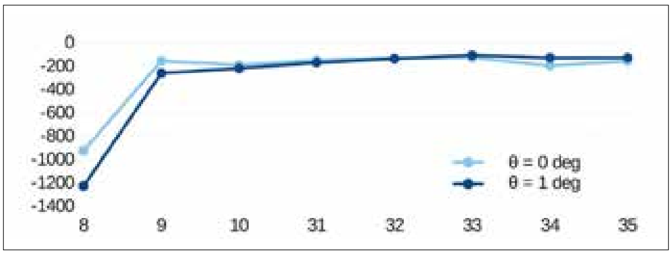


Figure 4: Pressures on the lower surface at 35m/s in zero rake and 1 degree rake configuration

Feeling the pressure

Although not something we normally have time for in our half day sessions, diligent preparation by Collins Advanced Engineering and exceptional cooperation from the wind tunnel crew saw, for this occasion only, a 46-port static pressure monitoring loom applied to points of interest on the car and logged by MIRA's pressure scanner and data acquisition system, as shown in **Picture 3**. The primary objective was to correlate with Collins' CFD analysis, and *Racecar Engineering* hopes to delve into these correlations, together with the track test data, in a future issue. Meanwhile, space allows us to cast a few glimpses at the data from these pressure tappings.

Figure 1 shows the locations of the pressure taps on the car's centreline, and **Figures 2 and 3** show the measured pressures (in pascals) on the upper and lower surfaces along the centreline at three wind speeds. In **Figure 2** the most obvious aspect is the increase in the magnitude of the pressures with increasing speed, be they positive (increases) or negative (decreases) relative to ambient pressure. Next, we can see how the positive pressure on the front of the car reversed to suction over the forward, convex part of the bonnet and then reversed again to positive ahead of the Gurney located in front of the grill that sits in front of the front screen. Then, as intended, the pressure behind the Gurney at the base of the screen was in fact slightly negative to enable the aforementioned grill to function as a cooling exit, an unusual choice at this location; the presence of the Gurney appeared to assist this function.

Moving on to **Figure 3** and the lower surface, again the change in pressure magnitude with speed is clear, as is the negative pressure under the forward part of the splitter. Notice, too, that even at the relatively high ground clearance the VUHL was running (110mm front and rear in this configuration) the suction under the forward part of the splitter (**Location #8**) was actually somewhat greater than the positive pressure on its forward upper surface (**Location #1**). The pressure remained negative through the entire underbody, demonstrating the benefit of a tidy, smooth underbody even at relatively high ground clearance and with zero rake. And although the centreline did not include the rear diffuser profile, **Location #34**, just ahead of and laterally offset slightly from the diffuser transition, showed an additional modest 'suction peak'.

Finally a quick glimpse at the change in underbody pressures with 1 degree of rake, (simulating heavy braking) is instructive, as **Figure 4** shows. Here we see how the suction under the front of the car was increased as far aft as **Location #31** by the reduced front ground clearance, but also that the magnitude of the suction in the diffuser region (**Locations #33 to 35**) was reduced in the raked case, presumably as the result of the increased ground clearance at the rear in this configuration.

Next month we'll move onto another new project.

Racecar Engineering's thanks to Iker Echeverria at VUHL, and Jenner and Jilbruke Collins at Collins Advanced Engineering. And special thanks to the MIRA wind tunnel crew for their extra assistance prior to this session.

CONTACT

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

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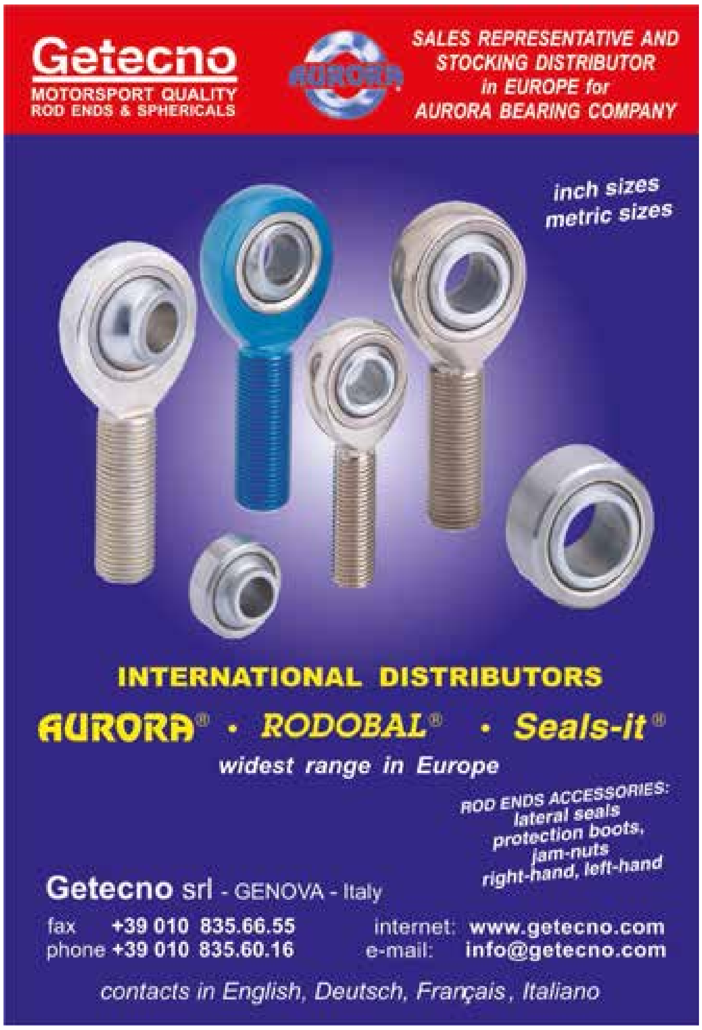

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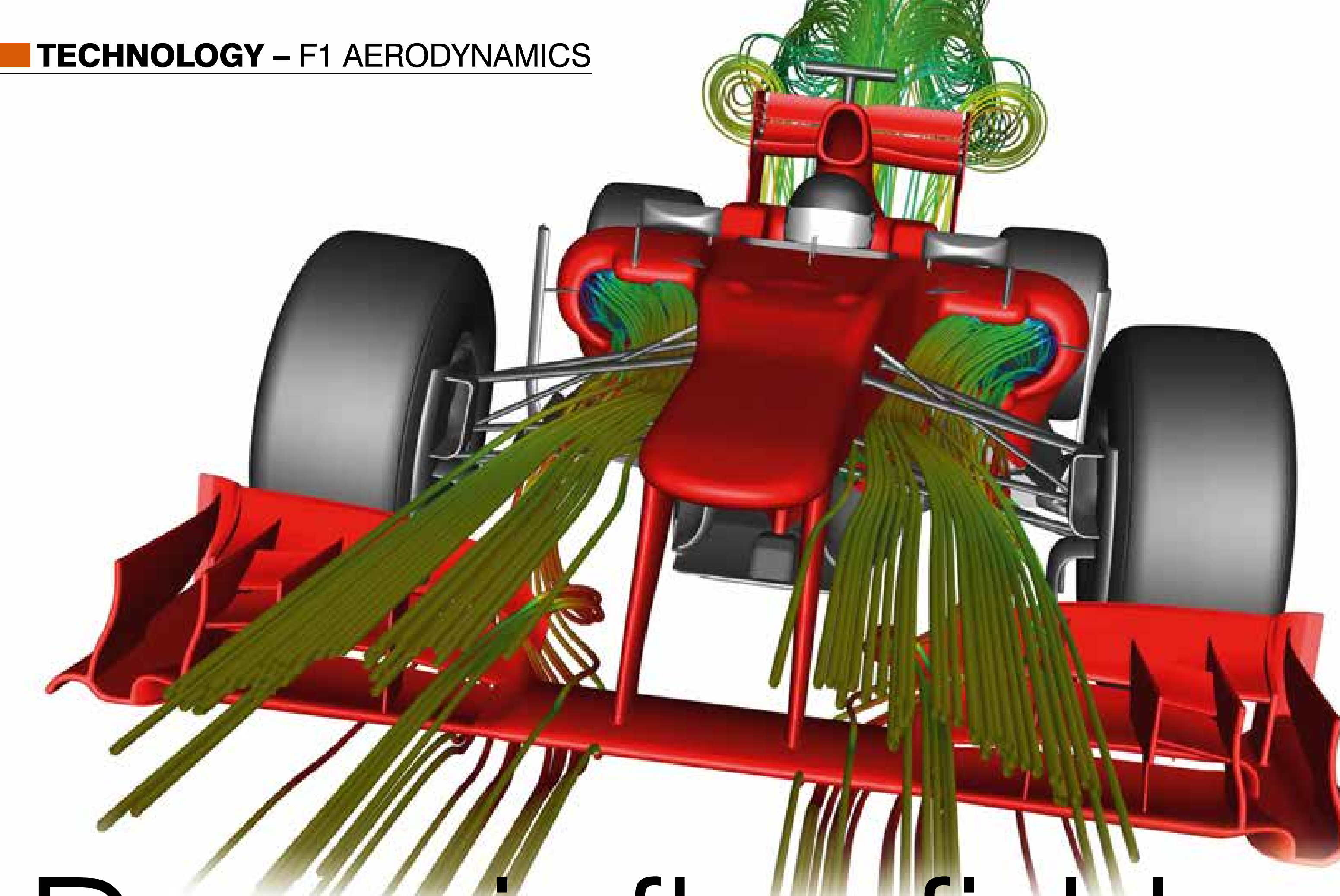


Dynamic flow fields

In the first of an exciting new, occasional series we delve into the real secrets of Formula 1 aerodynamics

By SIMON McBEATH

More often than not, discussion on the aerodynamics of top level racecars, especially Formula 1, is restricted to speculating about the function of particular devices or details. Occasionally a team will issue a generic CFD image that tells you little more than that the team does indeed use CFD to help develop its cars. And it's perfectly understandable that this is – normally – the limit of what we get to read and see because it's not in any of the teams' competitive interests to spill the beans openly and publicly. So it's all the more exciting that *Racecar Engineering* can now bring you exclusive insights into the aerodynamics of Formula 1 cars, courtesy of Dynamic Flow Solutions Ltd. The director of this aerodynamics consultancy, Miqdad Ali, has been creating 3D CAD models of F1 cars to the pre-2009, pre-2014 and post-2014 technical regulations to run in CFD using OpenFOAM in order to share some illuminating aerodynamic insights with *Racecar Engineering*.

It should be understood that the models are necessarily generic and somewhat simplified. As Miqdad Ali says: 'We chose to create a model that is simplified in some regions and detailed in regions where it matters most for what we were trying to achieve. Brake ducts, for instance, are simplified; front and rear wings are detailed to a point. Other details that matter such as vortex generators have been incorporated so that a realistic representation of the flow can be produced.' So our simulations may not be directly comparable to the models that F1 teams create with large departments of aerodynamic engineers pounding away at their keyboards developing at an almost microscopic level of detail. But a glimpse at the illustrations throughout this introductory article will tell you that they are very realistic-looking representations and that we will be able to learn a lot about the complexity of the flow fields and the management thereof that goes into generating aerodynamic performance on these cars. We will also, in future issues, be able to compare data on models to different rule sets, and investigate specific areas of interest to gain an improved understanding of what the teams are up against. In this first instalment we will start exploring what the first few runs of a 2013 F1 model revealed and derive further insight with comments from Miqdad Ali (MA) himself.

Table 1: basic CFD info
OpenFOAM, steady state RANS solver
Hex and split-hex mesh, 38 million cells (half car)
Inlet speed 67m/s (150mph)
Moving ground and rotating wheels
SST k-omega turbulence model
Engine inlet and exhaust flows modelled at 17,000rpm equivalent

Table 2: baseline coefficients at representative ground clearance

Configuration	CD	CL	L/D
15f 72r	1.174	-3.476	-2.961

Figure 1

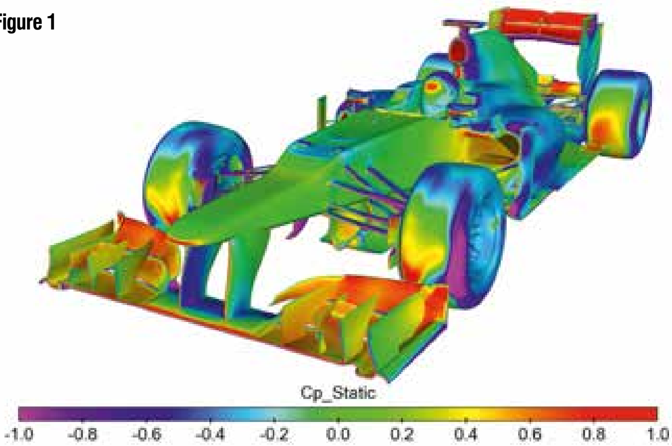


Figure 2

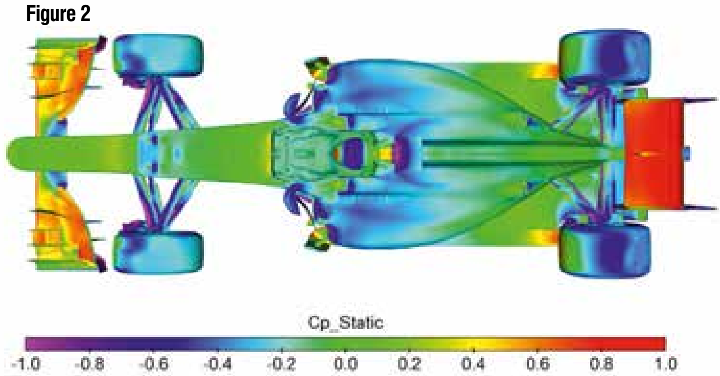


Figure 3

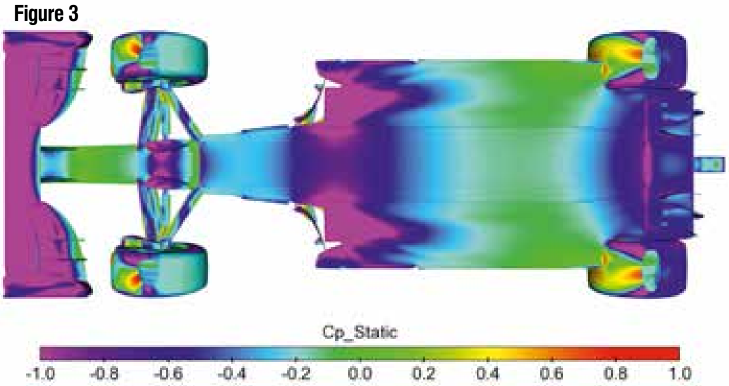
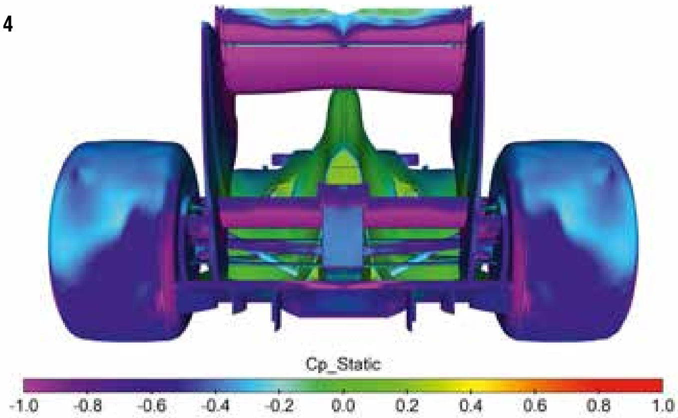


Figure 4



Figures 1 to 4: Static pressure coefficients on the surfaces of the 2013 phase 1 model reveal the sources of lift, downforce and drag

Initial runs

Having ascertained that the CAD model meshed and solved satisfactorily (see **Table 1** for the basic CFD parameters), one of the first comments arising from examination of the front to rear aerodynamic balance on the model was the importance of chassis rake in allowing the restricted diffuser to work effectively, something echoed in side views of pre-2014 and current cars. The initial target was to try to achieve between 45 per cent and 48 per cent of the total downforce at the front of the car in order to be representative of pre-2014 F1 car static weight balance, and although the first few runs illustrated here were still a little short of that in spite of significant rake being applied to the car, MA was confident that further attention to the diffuser in particular and modification of the wheelbase would generate more underbody downforce and enable balance, total downforce and efficiency improvements.

Table 2 shows the first set of data on the car at a representative ground clearance, indicated here as 15f72r – these being measurements in millimetres at the intersection of the reference plane (chassis bottom minus the 'plank') and the front and rear axle lines. We will revisit the effects of reductions in ground clearance later in this article but for now, let's just study the first set of data and ponder the sources of the forces.

The initial percentage front value was fairly close to 50 per cent, a little on the high side, but considering this was just a handful of runs into the model's development it was in the right ballpark. Can we know if the coefficients and L/D were also of the right order? Well, we have evaluated two F1 cars (the Benetton B199 and Honda RA107, both built to earlier rule sets) in the MIRA full-scale wind tunnel for our Aerobytes column and they had drag coefficient (CD) values of 1.000 and 1.046 respectively in the baseline configurations they were tested in, but with a reference frontal area of 1.2m^2 (producing CD.A values of about 1.2) compared to the reference value in our CFD simulations of 1.0m^2. So a CD. A value of 1.164 on our 2013 model's first runs was very similar to those earlier cars.

Determining whether the CL value on our 2013 model was of the right order cannot be done by comparison with the MIRA data because of that wind tunnel's fixed floor and stationary wheels, which are known to significantly underestimate the lift coefficients of ground effect cars. In the absence of recent and complete data, MA added (from his own knowledge base) that L/D for 2012 front running cars for instance ranged from 3.5 to 4.0. Smaller teams were anywhere between 3.1 and 3.5. So there was good cause to think our coefficients were pretty realistic, a really good result considering that no development had as yet been done.

Feeling the pressure

Accepting then that even at this early stage we were seeing some pretty representative data, let's look at some visualisations to get a better idea of the overall picture and of the complexity in the details.

Figures 1 to **4** show the surface pressure distributions and allows us to see where drag and lift were being generated. Colours from red through to yellow are regions where the surface pressures were high, and from green through to pink are regions where surface pressures were low.

Starting with **Figure 1**, at the front of the car the front wing's upper surfaces showed generally increased pressure coefficients, with the steepest surfaces showing the highest pressures. Clearly there are vertical and horizontal force components from pressure differentials on such forward facing inclined surfaces, contributing to both downforce and drag. The central 'neutral' section (which is defined in the rules) between the wing supports shows reduced pressure, but, as **Figure 3** shows, the pressure coefficient on the underside was generally lower still, thanks to ground effect, so this section would still have been contributing net downforce.

Moving aft to the front tyres, and we see a pretty complex pattern of

Due to the restrictions on underbodies in modern F1 rules, downforce generation has to be done by generating and managing vortices

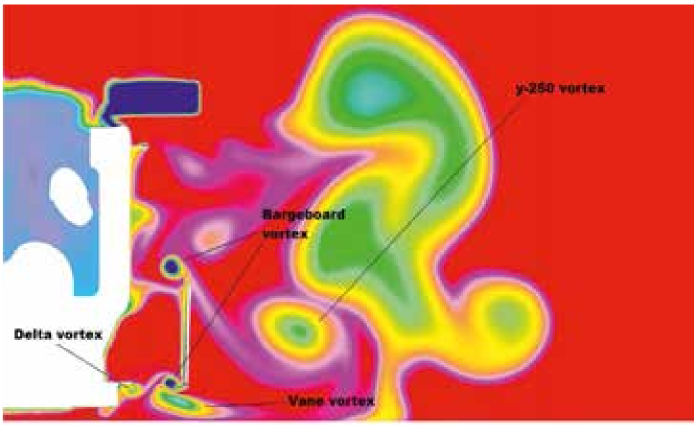


Figure 5: Transverse total pressure slice showing various vortices initiated by the front wing, the under-chassis vane and the bargeboard

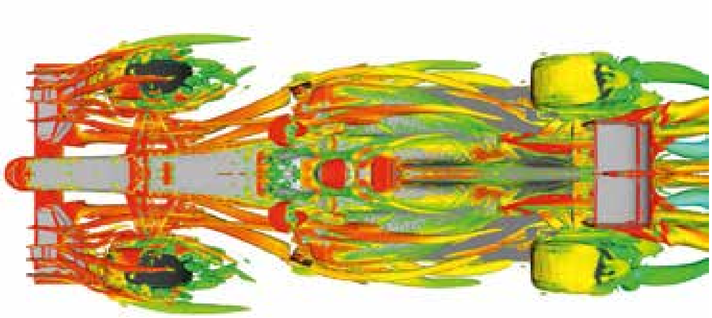


Figure 6: 'Lamda-2 iso-surface' plot shows the mass of vortices generated from the top

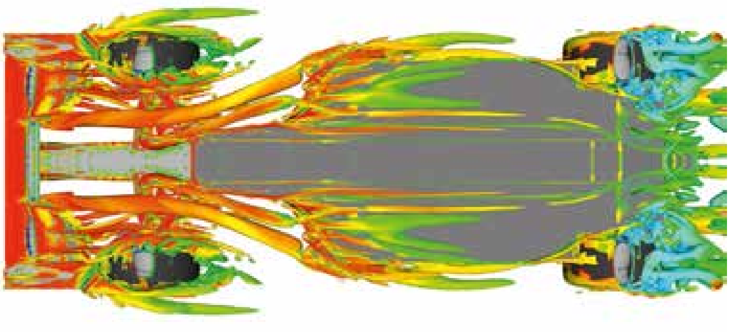


Figure 7: Bottom view of vortices reveals yet more flow complexity

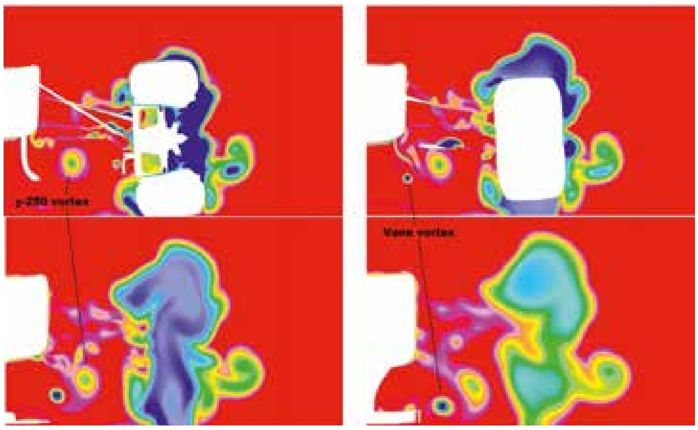


Figure 8: Transverse slices plotting total pressure at the front wheel centre (top left) and three successive steps to the rear show the 'y-250' and 'vane' vortices moving towards the ground

pressure distributions. The red region highlights where air was essentially running directly into the tyre, but the shape and size of this area is smaller than it would be if there were no wing in front of it because, as MA put it 'a combination of [end plate] footplate vortex, gutter vortex and the separation vortex from the rear of the endplate is managing the flow efficiently around the front tyre.' The top of the front tyres showed reduced pressure, no surprise over a convex surface, and this in part explains why the front tyres generated lift, along with the slight upward component from the raised pressure region on the lower front part of the front tyres. The blue and pink region on the outer, forward part of the front tyre wall shows much reduced pressures and in part this was due to the above mentioned wing tip vortices, with their low pressure cores, encountering the tyres here, as well as the general acceleration of the flow field around the tyre's outer edge. Inboard of the tyres, the front suspension links all showed reduced pressure on their upper surfaces, which is indicative of increments of lift too.

Moving to the top of the chassis, the pressure along the majority of the forward chassis was essentially 'neutral' (green), with minor changes on the step from the nose to the chassis itself. The turning vanes under the forward chassis look like areas of interest and we will return to those later as well.

Continuing further aft on the car's upper surfaces we can see reduced pressure over the sidepods, indicating an increment of lift here before we get to the rear 'tyre shelf' region, where there are also Gurneys on the trailing edge, which saw a region of raised pressure, and hence downforce, ahead of the rear tyres. The forward faces of the rear tyres clearly show large areas at raised pressure, and it is well known that they are a major drag contributor; again there was raised pressure on top of the rear tyres, indicating probable lift generation. Finally the rear wing obviously saw increased pressure on its upper surface, generating some of its downforce and drag.

Figure 2 makes it more obvious where the sources of downforce and lift are on the upper surfaces. More striking perhaps is **Figure 3**, showing the bottom view of the static pressure coefficients, and here we see where the majority of the car's downforce was generated, excepting that we cannot see the rear wing's underside at all in this view. Starting at the front again it is clear that the whole of the front wing's underside was at much reduced pressure (the pressure coefficients will be a lot less than -1, the restricted pressure range is used in these images for greater clarity). Again we can see a local area of interest in between the turning vanes in line with the inboard front suspension mounts, and clearly some downforce was generated here, although this was probably not the primary reason for these vanes. The region under the front splitter was at reduced pressure but the front section of the main underbody was at even lower pressure, as was the area from just ahead of the diffuser transition to the trailing edge of the diffuser itself.

Finally on this static pressure tour, **Figure 4** shows that the rear wing's underside did indeed develop much reduced pressures, as did the lower beam wing (absent on 2015 cars) and clearly the drag of the rear tyres was also about the reduced pressure on their rearward facing surfaces too.

Vortex generation

Due to the restrictions on underbodies in the modern F1 rules, downforce generation has to be done in large part by generating and managing vortices. This not only directly utilises the low static pressures created in the cores of vortices but also involves the use of vortex generators (and other devices) to manage and steer the flows in other beneficial ways. An example of the former is the use of bargeboards, which generate vortices from their top and bottom edges, and those generated by the bottom edges are used to enhance the low pressure in the forward underbody. And a much discussed example of the latter is the use of the 'y-250' vortex, generated

The forward faces of the rear tyres clearly show large areas at raised pressures, and they are a major drag contributor


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Table 3 – the distribution of downforce on our 2013 model and on the 2009 Sauber

	2013 model downforce, %	2009 Sauber downforce, %
Front wing assembly	39.0	29.0
Front wheels, suspension, brake ducts	-2.4	-1.0
Chassis, bodywork	-9.9	-8.0
Floor and diffuser	46.3	52.0
Rear wheels, suspension, brake ducts	0.1	3.0
Rear wing assembly	27.0	25.0

Table 4 – the distribution of drag on our 2013 model and on the 2009 Sauber

	2013 model drag, %	2009 Sauber drag, %
Front wing assembly	24.3	20.0
Front wheels, suspension, brake ducts	5.7	10.0
Chassis, bodywork	12.6	10.0
Floor and diffuser	3.9	13.0
Rear wheels, suspension, brake ducts	24.1	17.0
Rear wing assembly	29.4	30.0

Table 5 – the effects of ride height reductions

Configuration	CD	CL	L/D
25f 82r	1.164	-3.188	-2.738
20f 77r	1.155	-3.356	2.905
15f 72r	1.174	-3.476	2.961
10f 67r	1.154	-3.524	3.053

Table 6 – downforce distribution values at four ride heights, as percentages of the total

	Static	Down 5mm	Down 10mm	Down 15mm
Front wing assembly	39.6	38.7	38.4	39.0
Front wheels, suspension, brake ducts	-3.7	-3.4	-3.0	-2.4
Chassis, bodywork	-10.7	-10.1	-9.7	-9.9
Floor and diffuser	45.0	46.5	45.8	46.3
Rear wheels, suspension, brake ducts	-0.8	-0.5	0.9	0.1
Rear wing assembly	30.5	28.7	27.7	27.0

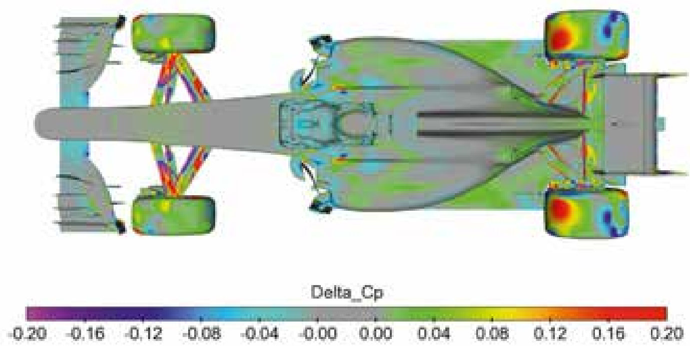


Figure 9: Upper surface static pressure changes are shown as the result of the lowering the ride height by 15mm

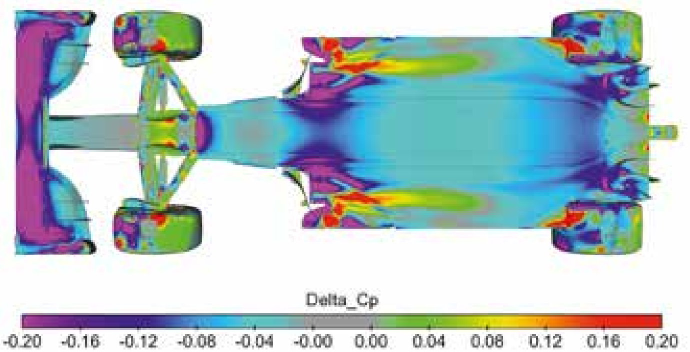


Figure 10: Lower surface static pressure changes are shown as the result of lowering the ride height by 15mm

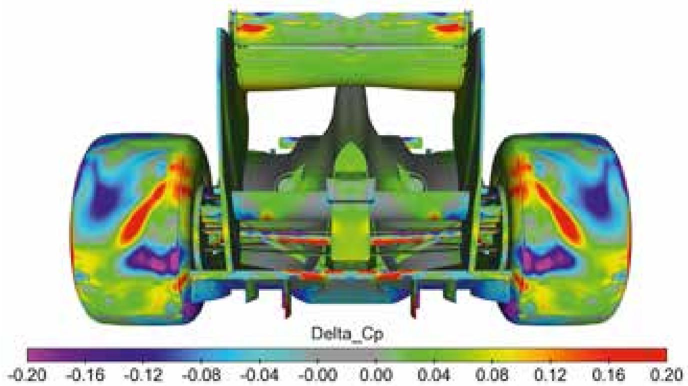


Figure 11: Rear surface static pressure changes are shown as the result of lowering the ride height by 15mm

at the intersection of the mandatory 500mm wide neutral central section of the front wing's main element and the potent multi-element sections outboard of that (this intersection, in the global coordinate scheme, is on the xz plane at y = 250mm, hence the name). This potent vortex can be used to turn the front wheel wake outboard so it does not impinge on, and adversely affect, the airflow entering the underbody – see **Figure 5**.

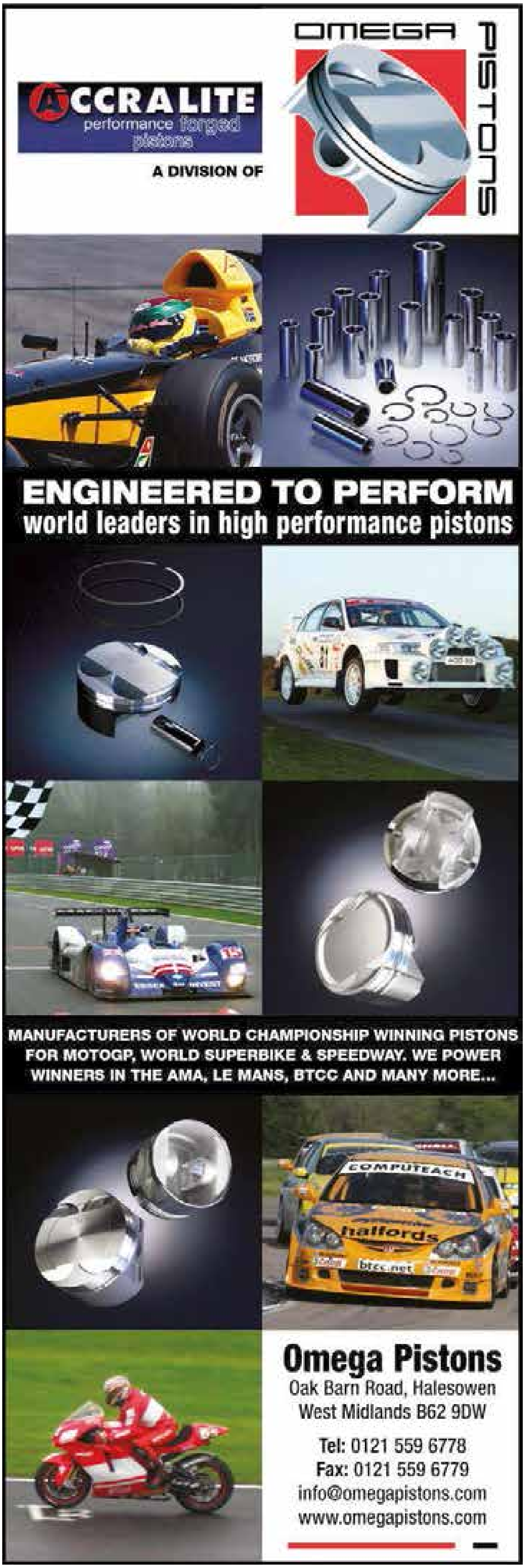
Figures 6 and **7** are 'lambda 2 iso-surface' plots coloured by total pressure (equivalent to total energy, so red is high energy, blue is low energy) and are a means of visualising coherent vortex structures in the flow. The first thing to leap out of such plots is the amazing complexity in the overall flow field. Looking more closely, the y-250 vortex is the single biggest vortex generated by the front wing, and although it was initially perceived as a nuisance when wings with the central neutral section were introduced for 2009, the teams soon learned how to manage and exploit it.

Another potent vortex was generated by the vanes on the chassis underside, between the front suspension connections. This area was mentioned earlier as one where some downforce was generated between the vanes. But in **Figures 5** and **6** it can clearly be seen that a potent vortex formed on either side and headed towards the bargeboard and underbody. What is less clear in these images, but which becomes apparent in **Figure 8**, showing, from the front, transverse total pressure slices through the front wheel and at two further steps downstream, is that the vortices from these vanes induced some downwash ahead of the underbody entrance. The vane vortex and the y-250 vortex can be seen getting closer to the ground in each of the three downstream steps from left to right in **Figure 7**. This downwash helps to increase the mass flow into the underbody to increase downforce. Vortex management thus plays a large role in F1 aerodynamics, and we shall revisit this principal in future issues.

Force distributions

One of the incredibly useful facilities of CFD is the ability to calculate separately the forces on individual components. **Tables 3** and **4** show the distribution of the forces on the major groups of components of our 2013 model (at 10f67r) compared with a published set of data on the 2009 Sauber (in a paper referenced at the end of this article). The latter were derived from a bar chart and are thus approximate, but in any case would

CFD provides the ability to calculate separately the forces on components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Another trend was the reduction in lift generated by the front wheels/suspension/brake duct sub-assembly with decreasing ride-height

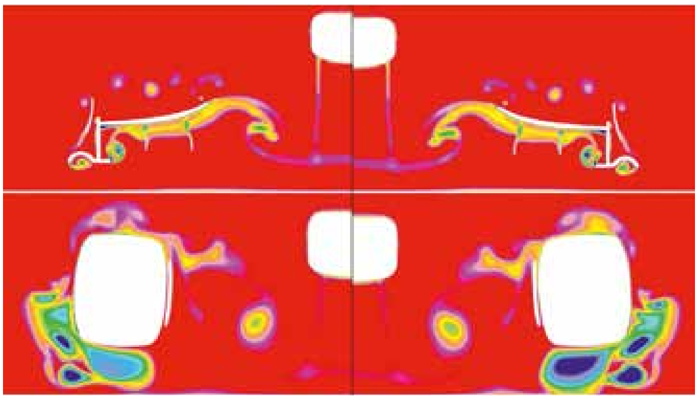

Figure 12: Transverse total pressure slices at the front wing and just downstream of it, at two ride heights (lower on the right). Note the differences in total pressure in front of the front wheel

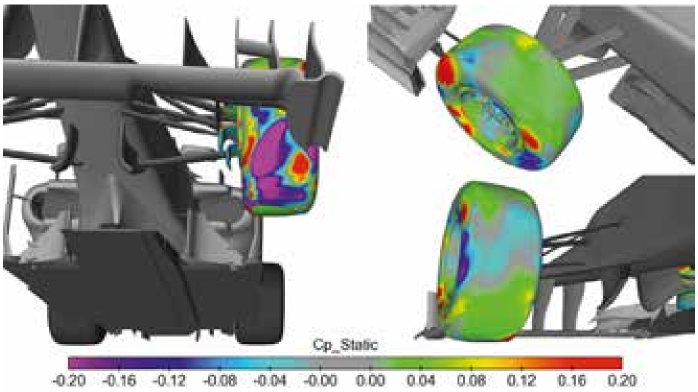

Figure 13: Three views of the changes in static pressure on the front wheel as the result of lowering ride height by 15mm. Compare the reduced static pressure on the front of the front wheel with the reduced total pressure encountering the wheel at the lower ride height in Figure 11

clearly depend on the car's exact configuration so are only indicative. There are some obvious differences but also some broad similarities between the force distributions on these two cars. Assuming exactly the same component surfaces were grouped together, one of the main differences in the applicable rule sets was that the 2009 cars were permitted to use more potent diffusers. Thus it would be expected that the 2009 car would generate a greater proportion of its total downforce with its floor and diffuser, which it did. MA added 'what should also be noted is that in 2009 the cars still had the wider front tyres, which produced a bigger proportion of the drag compared to 2013 tyres, which were narrower'.

Changing ride heights

We'll round off this introduction to our F1 CFD insight with a look at the changes arising from ride height reductions on the phase one 2013 model. Front and rear ride heights were reduced in three increments of 5mm, and these coefficients are shown in **Table 5**.

Broadly, the changes to drag were quite small and variable with decreasing ground clearance. Total downforce increased with each ground clearance reduction, with the gains tailing off. The front downforce gains were more or less linear, but the gains at the rear tailed off over the first two height reductions and then reversed at the last height reduction, suggesting perhaps that diffuser performance was beginning to decline, although as we shall see shortly this was not the only reason. This also saw the balance shift forwards at the lowest ride height, but as MA remarked 'we will investigate this properly once the car is developed to produce the right numbers both in terms of L/D and balance – but the initial observations here are indicative of what to expect'.

By looking at the changes in the force distributions at the four ride heights we get **Table 6,** which shows the downforce distribution values on the major component groups.

As well as some of the more obvious and expected changes, which **Figures 9 to 11** help visualise, there were two detail changes that are worth looking at in **Table 5**. First, and initially the most perplexing, was the decline in rear wing downforce (in absolute as well as relative terms) with decreasing ride height, which we can also see in **Figure 11** as an increase in the static pressure on the wing's underside from the highest to the lowest ride heights. It wasn't immediately clear why rear wing downforce should reduce with reducing ride height. However, the front wing has a profound effect on the performance of every item downstream, and in this case it was thought that the increase in the front wing's ground effect-aided downforce may have either modified the effective angle of attack of the rear wing and/or reduced the total pressure in the flow to the rear wing.

Another interesting trend was the reduction in lift generated by the front wheels/suspension/brake duct sub-assembly with decreasing ride height. First, it's worth noting that the suspension links themselves, which we mentioned earlier could be seen to generate lift in the static pressure plots in **Figures 1** and **2**, create some downwash to parts further downstream, mitigating to an extent the upwash that is generated by the front wing. And the changes we saw in the lift created by the wheels and suspension as ride height is reduced also arise from changes to the flow emerging from the front wing. See **Figures 12** and **13**.

Summary

This first model iteration has already enabled unprecedented insights into F1 aerodynamics for those of us who have not previously been intimately involved in this subject matter. Further developments and configuration changes will yield more fascinating features in future issues.

Reference: *Aerodynamics and aerodynamic research in Formula 1, Toet, W., The Aeronautical Journal, January 2013, Vol. 117, No. 1187*

Dynamic Flow Solutions

Dynamic Flow Solutions Ltd is an aerodynamics consultancy headed up by director Miqdad Ali, ex-MIRA aerodynamicist, who carried out the CFD simulations showcased in this article.

Miqdad Ali has performed design, development, simulation and test work at the highest levels of professional motorsport, from junior formula cars to World and British touring cars, Le Mans prototypes, up through to Formula 1 and Land Speed Records. *Racecar Engineering* readers may recall his contribution to the 'CDG wing' discussions in our June 2007 (V17N6) issue.

With significant experience within the automotive sector too he has also provided aerodynamic solutions to a number of major auto manufacturers, and has been involved in various research activities involving transient aerodynamics, fluid structure interaction, vortex flows and flow visualisation. He has also worked in the hydrodynamic design of ship hull forms, warship aerodynamics, HVAC and thermal management, gas dispersion and multiphase flows.

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Miqdad Ali, director of Dynamic Flow Solutions Ltd

DYNAMIC FLOW SOLUTIONS

Printing potential

With printed parts now a regular occurrence on our racecars, the capabilities of 3D printing have been significantly developed

By GEMMA HATTON

Since the first 3D printer was developed in 1983, the concept of additive manufacturing has become an increasingly important part of building components. The fundamental difference between additive processes and standard machining is the addition of material. 'With additive manufacturing you are building a product up from raw materials using additive layers, whereas with machining material is subtracted from the initial material block,' explains Andy Storm, General Manager for Automotive, Defence and Aerospace at Stratasys – the world leader in 3D printing. 'The benefit of additive over subtractive processes is the utilisation of the machines and the ability to optimise the design within each layer to minimise weight, cost and waste.'

The reason 3D printing has been in the limelight for the past five years is due to the advances in material technology that has enabled the manufacture of titanium and carbon fibre parts, some of which can now be integrated onto a racing car as a functional end use component. However, the current value of 3D printing still remains in prototyping and tooling. 'People assume that additive manufacturing allows you to make parts that go directly on the car when actually it's often used for jigs, test parts and fixtures which allow parts to be made quickly and cost effectively. We are always finding new methods to exploit additive technology,' explains Kieron Salter, managing director of KW Motorsport who, together with its sister company KW Special Projects, are the market leaders in additive manufacturing. For example, a metal spring assembly designed for Le Mans would have taken up to six weeks to cast due to manufacturing the pattern, the mould, the investment cast and then the post-machining processes. With 3D printing the same process takes less than 48 hours.

'3D printing is not yet a replacement for CNC machining, it is just another process that on its own is limited. However, when you combine it with other processes and design skills it provides an excellent opportunity to optimise design,' says Salter. 'It is still a relatively new technology, so the design chain still needs to be educated both upstream and downstream. You cannot exploit additive manufacturing if you have already designed the part, you need to design the part to exploit additive manufacturing. This is why we bought our own Stratasys machines so that we could develop the IP surrounding 3D printing and design higher quality products.'

The process

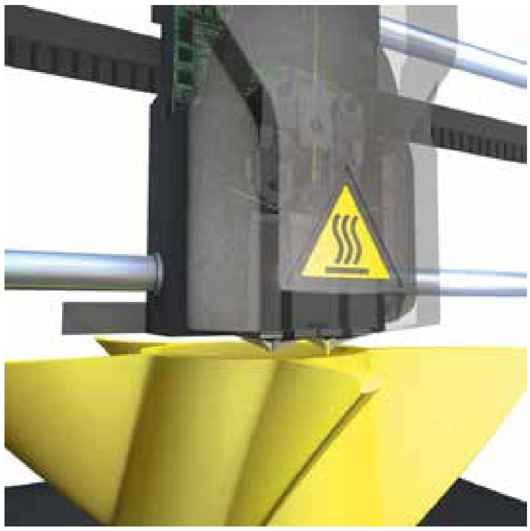
There are five main additive manufacturing processes used today:

Selective Laser Sintering (SLS) – a laser beam is used to melt a powder which is usually metal or nylon. The laser scans the desired cross-sectional area onto the bed of powder, selectively fusing the required powder particles. Once that layer is complete, the powder bed is lowered by the thickness of one layer, new powder is applied on top and the laser begins sintering the cross section of the next layer, which is repeated until the 3D part is complete. This method generates high resolution and relatively stiff parts which are not suitable for end use applications on racecars, so they are mostly used on wind tunnel models.

An example part showing the support material

Stereolithography (SLA) – similar to SLS, but an ultraviolet curable photopolymer resin is used instead of a bed of powder. The laser is ultraviolet and so cures and solidifies the desired areas of the resin and fuses it to the layer below. Again, this offers parts with high resolution and therefore a decorative finish, but being resin based it is also brittle.

Direct Metal Laser Sintering (DMLS) – the same process as SLS but the bed of powder is usually aluminium, steel or titanium. The main advantage of this method is it allows design freedom, meaning hollow parts can be made using honeycomb structures. This means the design can be optimised much more than can



The Stratasys 3D printers that use FDM technology have two print heads, one for the actual part and one its support. The ribbons of extruded thermoplastic are as thick as a human hair

A range of 3D printers from Stratasys – the company specialises in using a range of additive manufacturing technology, but primarily FDM for motorsport

Case Study: DOME S103 door

The difficulties Strakka Racing faced last season are no secret to the motorsport paddock. However, they overcame the design challenges and re-engineered a racecar which has now successfully raced in the opening rounds of the WEC – and 3D printing was key to this redevelopment.

One issue in 2014 was the homologation of the driver's headrest and the design of the doors. 'The DOME S103 was designed to be as compact as possible to minimise the frontal area for aerodynamics, so the cockpit was the smallest you could make it within the regulations,' explains Kieron Salter, managing director of KW Motorsport and sister company KW Special Projects which specialises in 3D printing. 'The FIA requested modifications to be made so that the headrest could be mounted more securely on the door. They also requested the door be made stiffer and have two hinges rather than the original one hinge system.

'In partnership with Strakka Racing we designed new hinges, latch mechanisms, safety release mechanisms, the entire door and headrest mounting, all with the aim of retro-fitting to the current monocoque. There was simply not enough time to design, make and test a carbon fibre door and then potentially redesign it. We decided to 3D print a replica of the door, including all the hinges and latches, to actually fit and test this prototype part. This was not only quicker, but also ensured that once we began manufacturing we had complete confidence that the design of the door would be right.' The fully functional prototype door was 3D printed using a Stratasys FDM 3D printer in ABS in under two days. The tooling block patterns, moulds and the carbon fibre doors took four weeks.

'The second problem was that we couldn't make the door hinges we wanted, mainly because we were retro-fitting them to the already homologated cockpit. Therefore, we had to locate the hinges on the exterior, but make them aerodynamic.' This resulted in an intricate and complex ball socket mechanism that could not be CNC machined due to expense and time constraints. 3D printing was once again the hero and was used to make end use components that were then fitted to the final car. '3D printing may be more expensive than CNC machining on a single part basis,' says Salter. 'However, due to the complexity of this mechanism, we were able to make it cheaper in titanium through 3D printing. So not only was it cheaper and quicker, it also gave us the design freedom to make a very intricate part – 3D printing was the only way to solve that particular issue.'

Above: The fully functional door constructed from the 3D printing processes
Right: The final intricate hinge mechanism which was 3D printed as an end use part and is featured on the final car

be achieved with CNC machining. 'It produces an homogenous metal component, achieving similar properties to that of a normal titanium part,' explains Salter. 'The reason parts like these are not appearing on aircraft is because there are still a lot of quality control issues that are not yet fully understood. By melting the material each time there is the potential for impurities, which could result in defects that could never be located within the part. However, for racecar purposes this process is perfect.'

Fused Deposition Modelling (FDM) – this is where molten thermoplastic is extruded and deposited layer by layer to build up a 3D part. This is the most utilised 3D printing technique and will be further detailed in the next section.

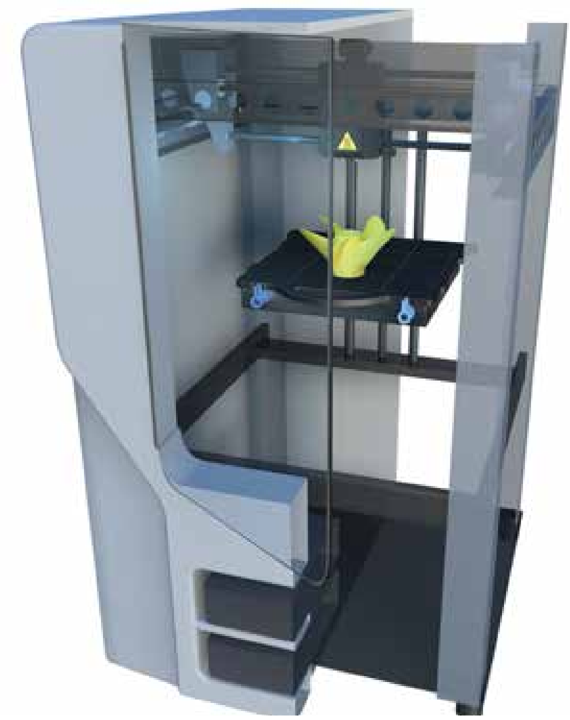
Inkjet – a process not commonly thought of as additive, is similar to inkjet printing, but instead of drops of ink onto paper, PolyJet 3D printers jet layers of curable liquid photopolymer onto a build tray. This is a much more accurate way of material deposition and also enables a number of materials to be printed at any one time. For example, Stratasys' unique triple-jetting Connex3 technology combines droplets of three base materials to produce parts with virtually unlimited combinations of rigid, flexible and transparent colour materials as well as colour digital materials, all in a single print run. This helps product manufacturers validate designs and make decisions before committing to manufacturing and bring products to market faster.

Fused Deposition Modelling

FDM is utilised throughout motorsport due to its feasibility for so many applications, and it can seen in rally, NASCAR and LMP racing. These can be divided into four main categories: concept models, functional prototypes, manufacturing tools and end use parts.

Once the CAD file of the desired part has been 'sliced' into 2D cross sectional layers, each around 0.18mm (0.005inch) thick, and the tool path has been designed, a build file is created and sent to the printer. The platform then rises to the starting position, which is only tenths of a millimetre below the extrusion tips. Stratasys' FDM uses two materials in its manufacture; one to make the part and one to support it, and the extrusion head alternates between the two throughout manufacture. The latter is the first to be extruded to provide a foundation and is used to support features of the part such as overhangs. The extrusion head then moves in a 2D plane, laying down ribbons of thermoplastic (usually ABS or polycarbonate). Once the layer is complete, the platform moves down and the extrusion head begins depositing the next layer while simultaneously flattening the previous layer for a homogenous fusing of the particles.

FDM can generate parts with astonishing 0.08mm (0.003inch) tolerances. The secret behind this lies in the material feed rates and the extrusion head motion which constantly



An example of a 3D part being printed using FDM technology

Carbon fibre printing

Last year, MarkForged developed the world's first continuous strand carbon fibre 3D printer, the Mark One, with patent pending Continuous Filament Fabrication (CFF). The machine essentially uses two print heads – one that builds nylon parts, and the other which reinforces those parts with continuous carbon fibre. The consequent parts are 20 times stiffer and five times stronger than ABS plastic, as seen in **Figure 1,** and each layer has a resolution of 200 microns.

'We removed the strength limitations of 3D printed plastic parts,' said Greg Mark, founder and CEO of MarkForged. 'The magic is in the print head of the Mark One, which uses a dual extruder system that combines traditional 3D printing and CFF printing within a single part. Designers can choose between lightweight carbon fibre, low cost fiberglass or Kevlar for puncture and abrasion resistance. The printer also supports traditional 3D printing (FFF) with nylon and PLA plastic.'

Time will test the suitability of this technology for motorsport applications, but it is certainly a revolutionary step into achieving printed carbon fibre wings.

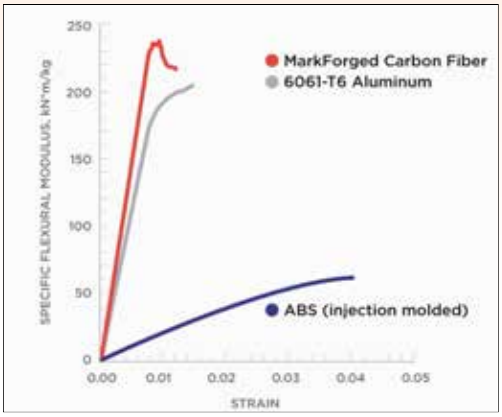


Figure 1

change to produce the consistently fine ribbons of material. This is achieved with drive wheels forcing the plastic filament into the hot liquefier section of the tip assembly, where the pressure pushes the plastic through a tiny orifice in the tip, flattening the bead of plastic. While the head accelerates and decelerates across the platform, the drive wheels adjust the material flow rate and therefore the ribbon width can adjust as required by the part.

Once completed, the supports need to be removed and this varies depending on their type; soluble supports are simply washed away with an agitated water based detergent solution or broken away.

It appears that this process ticks all the boxes, so surely the only thing needed to change to advance this process further are the input materials. However, this comes with its own complications. 'I doubt metals will be able to be used with FDM because the high temperatures required at the nozzle will result in molten metal which has a lower viscosity when compared to molten plastic, and therefore cannot be extruded in a controlled manner,' explains Salter. 'It's more likely that metals will be used in inkjet type processes, where it is heated and then ejected from a print head in a very selective way.' Composites such as carbon fibre will also exhibit difficulties, however last year it was proved that a form of carbon fibre can now be 3D printed (see left).

Similar to the soluble supports used in FDM, 3D printing processes can also print soluble tools which aid in the manufacture of complex parts. 'You 3D print your part in soluble material, which you can then wrap in carbon fibre. After curing, the material simply

all into one machine so that complicated parts, with integrated electronics and metal supports, can be manufactured in one machine. 'On the smaller end of the scale, and something we are aiming to achieve next year, is implementing inspection services while printing parts, so that bar codes and serial numbers can all be completed while the part is printed,' explains Salter. 'On the larger scale, you could 'print' assemblies. For example, you could print the strain gauge to go on a spring and the corresponding electronics and the battery all in one go. As these processes are software driven it means you could make thousands or one with no effect on cost.'

Infinite customisation

The unique aspect of 3D printing is the level of customisation it offers, which opens up a new area of application within the medical arena. 'In prosthetics, if you break your leg, you don't want to buy one off the shelf, you want one that fits specific to you. It is the same with hip joints and skull replacements. We are working on projects where we scan the joint, engineer the specific replacement and 3D print it using FDM, making it perfect for the client and so exploiting the benefits of additive manufacturing rather than using it for the sake of it,' reveals Salter.

'The next stage is the printing of living cells and human parts. In theory, if you create the stem cells you can then harvest and encourage them to grow in a 3D shape, and then you can start to produce full organs. It is the same with the membrane that breaks down in the knee and hip joints causing arthritis. If we can 3D print that shape we can implant this membrane into the joint way before arthritis develops.'

3D printing is adding significant value in speeding up the design optimisation process

dissolves away and you end up with the shell of carbon fibre that you want,' explains Salter. 'Now imagine making this complex tool using traditional moulding processes, it would be too complicated – 3D printing allows the making of parts such as pipes and ducts very easy and low cost.' As ever, there are limitations. The soluble material cannot be cured above 80-100°C and carbon fibre curing is much higher. Therefore, two cures have to be conducted with the initial cure securing the shape of the part, and the secondary cure destroying the soluble part, but also finalising the cure of the carbon fibre. Another difficulty is narrow cross sectional areas – it is difficult to flush the soluble material away so holes need to be incorporated into the design to wash from the inside out, rather than simply relying on erosion.

The real opportunity for additive manufacturing processes and 3D printing is combining these processes and building them

We are seeing the very early stages in the development process of 3D printing, and additive manufacturing and the capabilities go far beyond printing figurines at home. The recent advances in materials, along with the continual demand for customisation, mean that we will continue to see the integration of 3D printed parts in almost every aspect of our lives.

For motorsport, 3D printing adds significant value, speeding up the design optimisation process, enabling teams to go faster and develop quicker. However, there still needs to be that final revolution in material technology that allows large scale high quality carbon fibre parts to be made reliably and efficiently. Once this has happened we will see race teams adopting such technologies on a large scale, but with the world's first carbon fibre printer developed last year and the continual appearance of small printed parts on racecars, this might not be as far away as we once thought.

What you get out of Simulation

The dark art of using simulation to effectively setup, quantify and properly understand racecars

By DANNY NOWLAN

Simulation allows engineers to quickly and cost-effectively determine the fundamental kinematics of any racecar

Over the last year one of the recurring themes of my articles has been why you would be crazy not to use simulation. Taking this one step further, once you truly get your head around simulation it will transform the way you engineer a racecar. Again, I say this not because I have a vested financial interest in the end result. Instead I say this because I have seen first hand how using simulation has changed race teams. In this article we'll be presenting some case studies to illustrate this so that you can comprehend what simulation brings.

Again, let me apologise if you were expecting one of my brain sapping articles on vehicle dynamics. The reason I need to hammer home this point is that I am continually alarmed about what I'm seeing in the dumbing down of motorsport. The other trend I am seeing is race teams giving simulation a go and the simulation not initially working as they they'd hoped, or they get too busy and they see this as a nice optional extra. Make no mistake setting up the model yourself and using simulation is the best way you'll quantify and understand a racecar – once you see what happens when you do the modelling yourself you'll never go backwards.

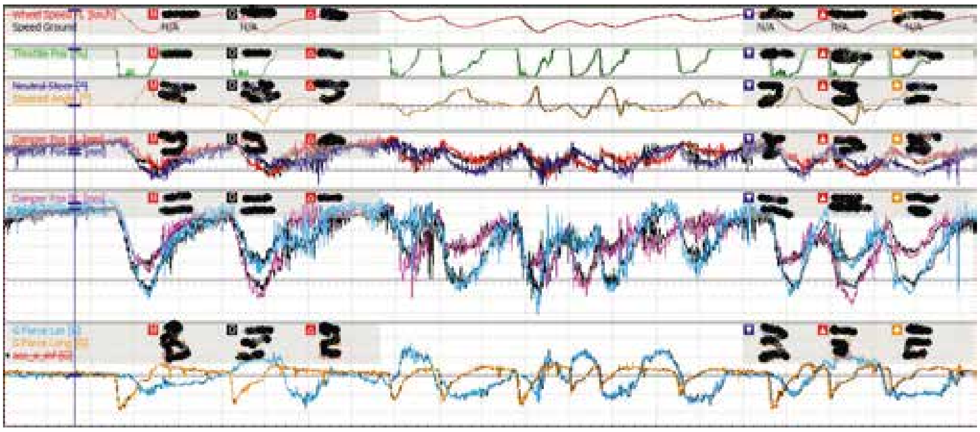


Figure 1: Actual vs simulated data for the ChassisSim track replay simulation

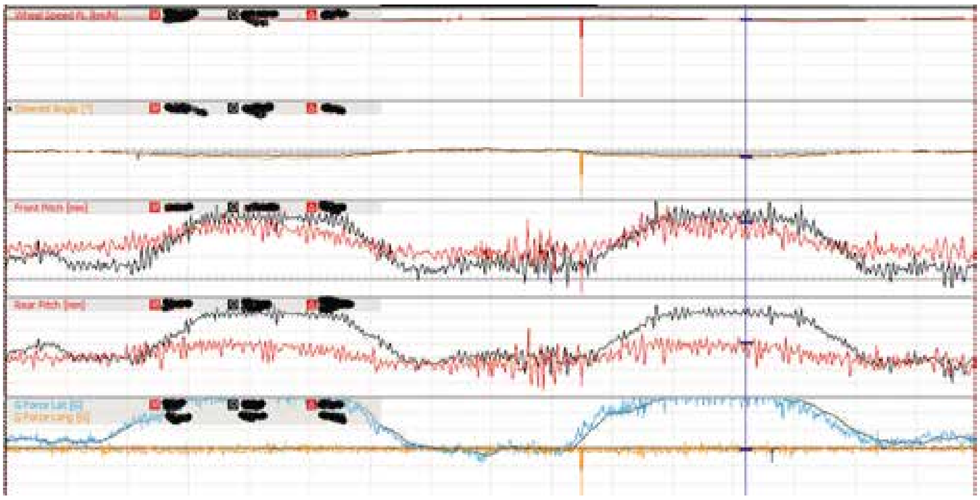


Figure 2: Simulation of a high downforce racing car

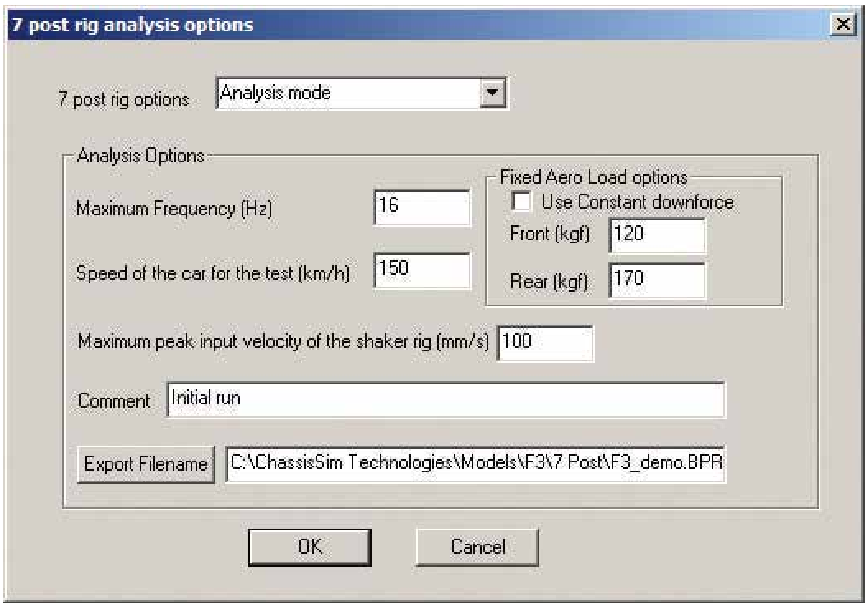


Figure 3: Setting up a frequency run

Once you get the track replay sorted you have a powerful tool to look at the variables that would be either very difficult or impossible to log on a racecar

The first thing you get from simulation before you even look at a lap time is that it validates what you have underneath you. To illustrate this, let me present some correlation with the ChassisSim track replay simulation. This is presented in **Figure 1**.

As always, actual data is coloured simulated data is black. The track replay simulation replays the lap. Looking at the damper traces we can see that what the car is doing the simulated data is also doing. It's also doing it very closely. What this means is that you have nailed the fundamental kinematics of what is happening underneath your car. All of a sudden you have a very powerful tool to see what the lateral load transfer is going to be when you make changes, and you can truly nail down what is going on rather than relying on somebody else to tell you.

Also once you get the track replay sorted you have a powerful tool to look at variables that would be either very difficult or impossible to log on a racecar. If the truth be told it was actually the primary reason the track replay simulation was created in the first place. One of my European customers requested it a couple of years ago and it took me about two seconds to recognise it was a good idea. You can use it to log ride heights and look at variables such as roll centres, pitch centres and cambers. Also, just for the record, if you want to log cambers on a car you wind up a car that looks like a teenager with braces gone out of control. With a tool like the track replay feature of ChassisSim you have this at your finger tips. I really don't understand why more race teams don't use tools like this.

The other thing advantage of simulation is that it is a fantastic tool to validate what your aero is doing. Take this comparison of a high downforce racing car, as shown in **Figure 2.**

Figure 2 has been taken from actual data so I've had to blank out scalings and data numbers. However, let me guide you through the channels. The top trace is speed, the second trace is steering, the third trace is front pitch (average of the front dampers) the fourth trace is rear pitch (average of the rear dampers) and the final trace is acceleration. In rough terms what we are seeing here is that the correlation down the straights is OK, but in the corners the simulated pitches indicated by the black traces diverge significantly. When most people see this they would think the simulation is rubbish. However, when you are seeing this you have an aeromap that isn't performing as advertised and it is your signal to fix the aeromap.

Aeromap issues

Before we discuss how to fix **Figure 2** it would be wise for us to reflect on what **Figure 2** is telling us. What **Figure 2** shows is that when the rear ride height drops below a certain value it actually stops producing downforce. This screams out at you when the simulated rear pitch keeps on going when the actual pitches level off. Typically what is happening here is the rear diffuser is becoming choked and it's effectiveness at producing downforce has diminished – something I have seen happen far too often for my liking with many of the current generation of racecars.

The harsh truth of this is that, if something is wrong with the aeromaps, the racecar manufacturer isn't about to put their hand up and say sorry – there are a few exceptions but expect this behaviour to be the norm. This wouldn't bother me that much except this tends to make its way into cut price simulations and this does annoy me. The great thing about simulation when you do it yourself is that all of a sudden you have the tools at your disposal to validate it yourself. This is a powerful asset, so don't leave home without it.

A question of frequency

The other big element of simulation is the frequency-based shaker rig simulation. This has been used in anger in the ChassisSim community in fields as diverse as FIA GT, V8 Supercars and IndyCar. It also formed a central plank in the engineering of the Maranello Motorsport F458 entry that won the 2014 Bathurst 12 hour. To jog everyone's memory here is the crux of the technique:

The first part of the toolbox is setting up the frequency test, as illustrated in **Figure 3**. The comments and filenames are pretty self-explanatory. Just put in something relevant to the setup and store the log file for test where you are going to remember it. However, the controls you need to pay attention to are the speed of the test and the peak input velocity of the road input.

You then choose the speed of the test and choose the corners you want to simulate. If you want to simulate a low speed corner choose say 100 km/h or if you are looking at a high speed corner you choose say 150 – 170 km/h. You'll also notice you have an option to set the downforce at a fixed value. This is suitable for validation work, but personally I prefer to leave this off. The reason is the ride height map will impact on the frequency response of the car and this will have an effect in high speed corners.

Identifying resonance

In terms of the peak input velocity, choose a value that represents the peak input velocity that is representative of the road input. There are a number of ways you can do this. For a rough rule of thumb, 50mm/s approximates a relatively smooth surface, 100mm/s is middle of the road, and 150mm/s represents a pretty bumpy circuit. Another way you can do it is by looking at the data. Look at the peak damper velocity and divide the results by roughly a third. It's a rough measure but it will get you by. If in doubt start the test at 100mm/s.

In terms of what this toolbox is, it will return a plot of output amplitude on input amplitude. The output of the toolbox is shown in **Figure 4**.

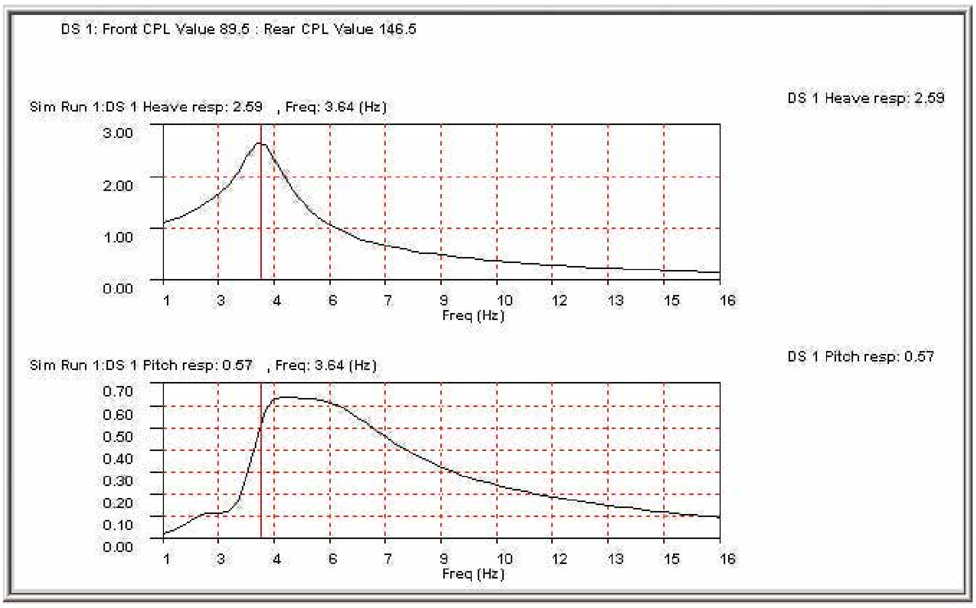


Figure 4: Output of the shaker rig toolbox

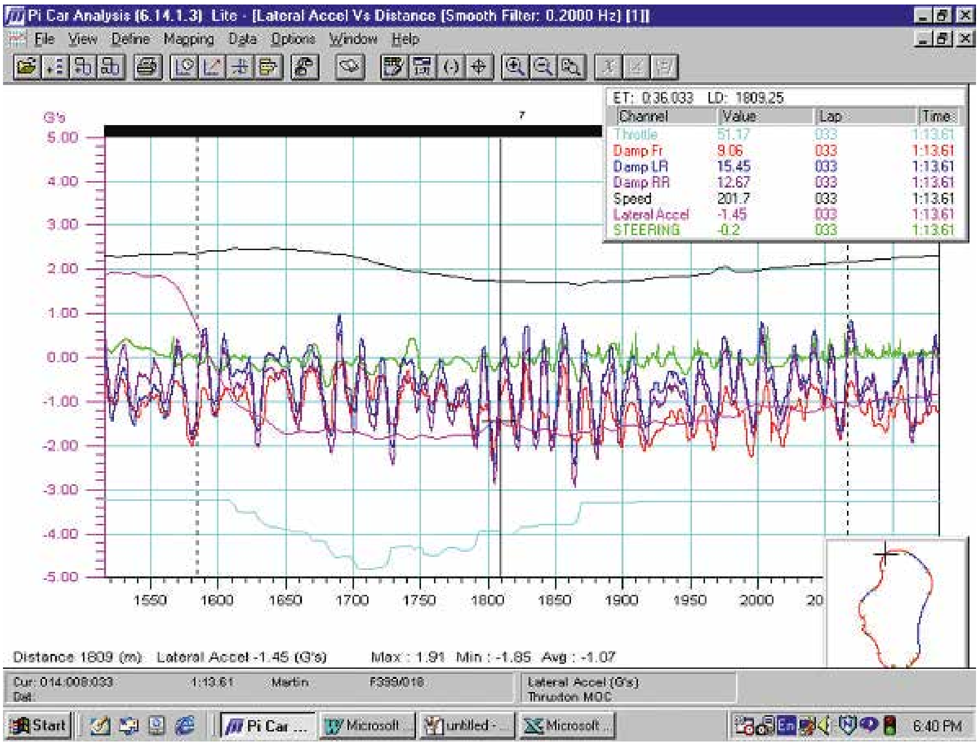


Figure 5: Resonant behaviour for an F3 car

You'll see that the Contact Patch Load variation (CPL) is shown in the top of the graph. This is averaged over the whole frequency run and the units are kg. This is the delta load variation from the static load for the conditions specified for the test. The plots shown are the ratio of output vs input amplitudes and they represent heave and pitch for a heave input to the racecar.

The first thing will this tell you are the frequencies you need to be looking for in the data. The frequencies we need to be watching for are the frequencies at which you see the peak responses. This is called resonance, and this data is useful if you have a particular handling problem. The first thing you do is look at the data in the time domain – you are looking for damper frequencies that correspond to the resonant frequency. If you see this, then that is your cue that you need to do something in the setup. An example of what to look for is the situation illustrated in **Figure 5.**

Note here how the dampers are oscillating like mad and the steering response is responding in sympathy. If you have a car handling like this, typically the driver will be referring to you in negative terms.

However, the real power of this toolbox is tying the CPL figures with the frequency response. This technique was actually pioneered by a colleague of mine, Pat Cahill, when he was engineering a GT car at Bathurst in 2011. The technique is breathtakingly simple. The first part of the process is that you play with

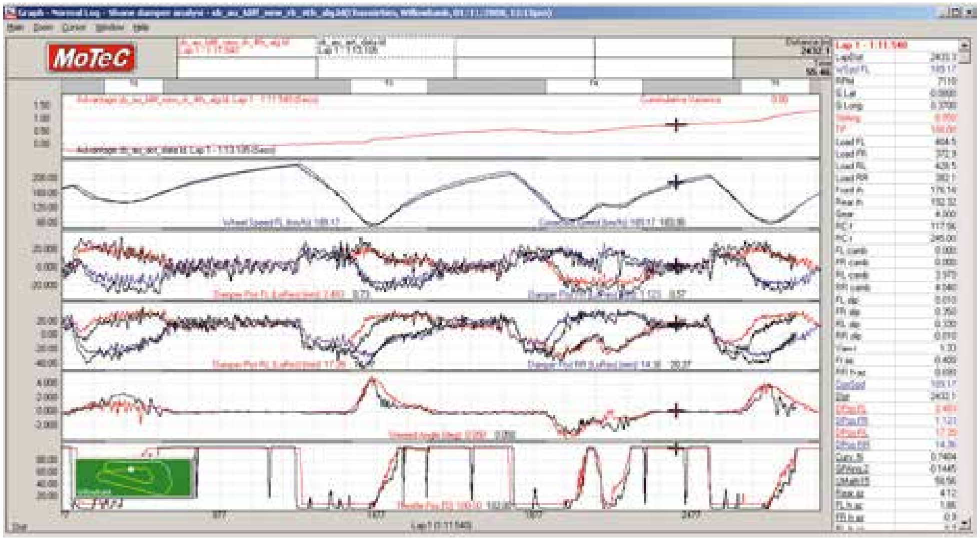


Figure 6: Net result of doing the job properly

springs and large damper adjustments to minimise CPL. What will happen is when you get into the zone the CPL will hit a minimum and actually won't vary too much. Once you hit this you then start playing with minor spring and damper changes to get the shape of the frequency response that you want. It's actually that simple. This technique has been used very successfully in racecars with CLA numbers from 1.2 – 2.7. The result of this has been a significant improvement in mechanical grip without compromising driver feel.

Again, let me re-iterate what we have just discussed has been used in anger across categories from low downforce (V8 Supercars) to high downforce race cars (IndyCar). The results from shaker rig simulation are proven and it's a powerful weapon in your arsenal.

However, the big pay off of all this is that once you have done your vehicle modelling properly and used tools such as the ChassisSim tyre force modelling toolbox, you should expect as business as usual, as shown in **Figure 6.** Again, actual data is coloured and simulated data is black. If you look at the speed, steer and damper traces, the results speak for themselves. What you have is a tool that you can use to quantify what the setup changes will do to the racecar, so it would be foolish not to consider investing in such a tool.

In closing simulation tools such as ChassisSim need to be an integral part of your race engineering process. As we have discussed tools such as the track replay simulation play a key role in allowing you to truly validate the kinematics driving your racecar. It allows you to predict loads and look at a range of channels such as cambers and roll centres that would be very difficult to validate on logged data. Following on from this the pitch correlation you get is an absolute must to validating and quantifying your aeromaps. Also when employed correctly the shaker rig toolbox and lap time simulation components yield invaluable information. These are the results you get out of simulation and are why you'd be mad not to use it.

Simulation tools need to be an integral part of your engineering process

IndyCar's aero issue

Three crashes at the Indy 500 force IndyCar to re-evaluate its 2015 aerodynamic regulations

By MARSHALL PRUETT

Verizon IndyCar Series manufacturers Chevrolet and Honda rose to the challenge of creating bespoke aerodynamics to aid and enshroud their respective powerplants in 2015, and with the marquee event at Indianapolis serving as the debut for those Speedway kits, the month-long narrative became focused on aero.

Compared to the abundance of winglets and tack-on downforce bits found on their road course/short oval aero kits, Chevy and Honda crafted specific kits for Indianapolis with drag reduction and overall efficiency in mind. Using Indy as their base design platform, new front wings and adjustable end plates, new multi-configuration sidepods with cooling inlet and outlet options, new rear wheel pods, and new rear wings were created to fit the base Dallara DW12.

Their original Speedway concepts were designed to improve upon Dallara's Speedway package, but those plans were soon derailed when the series made wholesale changes to the DW12's spec underwing.

With great concern to prevent nose-first blowovers, IndyCar worked with Dallara to replace the 2012-2014 floor with a new 2015-spec underwing, featuring triangular cutouts made to the outer section of the floor's leading edge. In a nose-up condition, the holes in the floor are meant to act as a stalling agent that bleed pressure and keep a car earthbound, but this preventative measure also robbed downforce and added drag. Approximately 300 pounds of downforce was pared from the car with the holes. While the drag figures are harder to quantify in Speedway trim, the added turbulence caused by the apertures meant that significant wind and air spilling off the front tyres as they turned hit the floor's leading edge and were found to hinder both car's ultimate drag-reducing potential envisaged by the manufacturers.

Despite the gains made by both manufacturers with their topside Indy aerodynamics, IndyCar's 2015 floor ensured that gains in straight line speed were all but impossible. Within the wholesale Speedway aero kit changes, numerous options were homologated by both manufacturers which provided a wider range of L/D tuning than anything at Indy in more than two decades.

A single day of testing was granted at Indy prior to the start of official practice, and with the test coming just eight days before the "Month of May" commenced, teams were afforded the bare minimum of time to learn their Indy aero kits at the sport's fastest, most setup-dependent track.

Concerns of aero kit instability appeared to reach fruition when Helio Castroneves took flight on the second day of practice. His Chevrolet spun in Turn 1 at almost 230 mph, glanced the wall, and carried most of its speed backwards into the short chute. At

'Did the holes in the floor constitute movement of that centre of pressure? For sure they did'

180 degrees, and with a full head of steam, the Brazilian's car complied with the laws of physics as its underwing went from creating downforce—while facing forward—to creating lift. Combined with the building pressure in the diffuser, the car lifted off.

Centre of pressure

Many theories followed regarding the reason for the flight and, while supporting data was nowhere to be found, the blame was placed on Chevrolet's aero kit. Team Penske technical director Ron Ruzewski was quick to correct any of the knee-jerk reactions that relied on assumption, rather than science and data, to draw conclusions.

'He [Castroneves] got loose going into Turn 1, the car rotated and ended up traversing backwards while still at 195mph,' said Ruzewski. 'Physics comes into play. If you take away the top side– the Chevrolet kit – and you look at the underbody of the ground effects car, the tunnel has a shape which develops a centre of pressure. Did the holes in the floor constitute movement of that centre of pressure? For sure they did. They were designed under a different set of circumstances which would have moved the centre of pressure rearward. Was that the sole reason that the car flipped over? No. It's a surface area, it's an angle of attack. I don't believe the bumper pods are to blame, nor do I believe the wing or any of the bespoke Chevy parts are to blame. I think it's purely surface area, it's a kite.'

The crash resulted in one regulation change and IndyCar called for Chevrolet's removal of the centre chassis 'wicker', which became mandatory at the beginning of the month, after it was believed to trip the air and pin the nose, therefore accelerating the car's moment of lift. Honda's teams were instructed to keep the centreline wicker for the rest of the event.

Chevrolet's Josef Newgarden was the next to fly after a cut left-rear tyre sent the CFH Racing entry spinning into the Turn 1 wall with the left side of the car. Like Castroneves, the car lifted at the rear and flipped, but Newgarden's flight was aided by the car climbing backwards up the wall and exposing the underwing to high-speed air that entered the tunnel from behind. Newgarden's left rear tyre pressure was said to be 18psi, almost half of its desired inflation.

His CFH teammate and co-owner Ed Carpenter mirrored the No. 21's spin and crash, but did so at Turn 2 when his No. 20 Chevrolet climbed the wall while travelling backwards and went higher and further before crashing down on his roll hoop.

Three spins, crashes, and flights by cars carrying Chevrolet's aero kit seemed to cement the belief of many that its Speedway aerodynamics were flawed, and with Carpenter's accident taking place while on a

Data from both Chevrolet (top) and Honda (bottom) exonerated the aero kits after multiple crashes in testing, with different causes in each

qualifying simulation, the low-drag sidepods drew plenty of attention. Lacking simulation data of its own to form a solid conclusion, IndyCar informed Chevy of its intent to ban the low-drag sidepod option, but quick work by the manufacturer – CFD and Sim runs overnight—gave them the factual data to put in front of the series and prevent the low-drag ban.

Testing times

The three aerial incidents inspired the series to ask Chevrolet and Honda for a new round of virtual testing to be carried out. Both complied, while also preparing for qualifying and the race. As Carpenter's engineer Matt Barnes explains, real world testing was always going to be an integral part of learning the Speedway kits, and he also raises an interesting question about the underlying chassis that carries the aero kits.

'You're not going to test going backwards at 180mph' he noted. 'I think for those things, maybe more testing would have exposed the crash sooner and given them more time to work on the problem, but I think the main lesson has been perhaps that the metrics and the standards that were set were inadequate as far as the safety characteristics were concerned.

'I think we are pushing the boundaries in safety. There are many, many cases to look at, so they're going to have to define more closely what it means to be safe.'.

Shortly after the crashes, IndyCar began looking at possibly reverting to 2014 floors for oval events

After Carpenter's crash, the series made sweeping changes to its qualifying regulations. Qualifying boost was taken away, lowered to race spec, and teams were told they would be required to race in the trim they used for qualifying. That move effectively forced the field to switch to higher downforce configurations, and average lap speeds were taken from a peak of 233mph, to 226mph.

All three flights appeared to have unrelated causes, yet one of the popular beliefs tying all three together is IndyCar's new floor. The three spins weren't tied to floor-related issues, but with the cars turned backwards, it is thought that the effect of the holes added a third dynamic which promoted flight.

Feeding high-speed air backwards through the tunnel and the pressure build/lift in the diffuser is cited for most rearward flights, and with the holes in the floor shifting the centre of pressure rearwards while travelling in the right direction, the CoP shift to the front of the floor in a rotation contributed to the fulcrum point moving further back than is optimal.

Shortly after the crashes, IndyCar began looking into capping the holes with carbon fibre plugs or, possibly, reverting to 2014 floors for the remainder of the oval events.

More data came in from Chevrolet and Honda between qualifying and the race. Both reported their findings, which exonerated the Speedway aero kits and highlighting the disruptive nature of IndyCar's floor.

The final major crash of Indy 2015 involved Honda's James Hinchcliffe, who drove headfirst into the Turn 2 wall at over 228mph. The popular Canadian survived the 125G impact, yet suffered lower leg injuries and damage to his pelvis when a right-front wishbone punctured the DW12 chassis. Shortly after the crash, the Schmidt Peterson Motorsports team and the series identified the reason for the crash; the right-front rocker arm failed when the bearing housing and the blade-like rocker separated.

SPM confirmed the part had 14,000 miles of service before the failure, which accounts for roughly one-and-a-half seasons of use, and while the mileage is large, it was the first time a rocker failure was recorded with the DW12.

The Hondas were not as competitive as the Chevrolets in race trim, and with near dominance in qualifying and again in the race, the team at Honda Performance Development and Wirth Research concluded Indy without incident, but also without victory.

Following the form found with its road course/short oval aero kit, Honda's wide range of Speedway variations left its teams searching for answers instead of working on race setups. Honda teams also struggled with its Firestone tyres more than the Chevys, compounding the workload.

'If I could put my finger on it we would win, 'said Andretti Autosport engineer Garrett Mothersead. 'It's a difficult tyre to work with. It's very susceptible to track conditions.

With more questions than answers on its new embrace of manufacturer-based aerodynamics, the series finds itself plagued by unimagined issues. Beyond the possible return to its former underwing specification, the series also floated the idea of using the entire 2014 Dallara Speedway aerodynamic package for the remaining speedway events.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Top Formula 1 teams refuse to tear up contracts as money dispute continues

The bosses of F1's top two teams have reacted angrily to suggestions by former FIA president Max Mosley that the sport should tear up its existing contracts with teams in order to distribute the cash they receive more equally.

Mosley, who was in the FIA's top job from 1993 until 2009, has said he believes F1 was on the cusp of collapse because of the contracts that tie the teams to the sport, which largely favour the bigger outfits. 'Half the teams simply can't compete because they haven't got enough money,' he said. 'To me that is wrong.'

However, Mercedes team principal Toto Wolff pointed out that Mosley's intervention ignores the fact that these contracts are already in place. 'It's an unrealistic scenario,' Wolff said. 'The contract is in place, you can be happy or unhappy but the contract is there. If you want to do it better, [then do it] next time around.'

Ferrari team principal Maurizio Arrivabene agreed, and added that Ferrari would not race if the contracts were discarded. Unsurprisingly, the smaller teams were more receptive to the idea

Currently F1 payments are based on performance but five teams (Mercedes, Red Bull, McLaren, Ferrari and Williams) also get further payments after making a long-term commitment.

Meanwhile, refuelling and improved tyres are at the heart of a set of proposals aimed at spicing up racing in 2017. During a meeting hosted at the Biggin Hill, England, offices of FOM, the Formula 1 Strategy group agreed a number of measures to 'improve the show'. A large number of ideas were tabled including customer cars, cost caps and an increase in the use of single spec parts, but most of these were rejected during what was described as 'an exchange of views'.

Resistance to some ideas, such as a return to the obsolete 2.4 litre V8 engines, ensured that the regulations in 2016 will remain largely stable, with the only change being a free choice of which Pirelli tyres to use, something the Italian brand says could lead to safety issues as the teams push the boundaries.

The bulk of measures will be implemented in 2017 if the FIA World Council agrees to implement the proposals. This will see a relaxation of aerodynamic regulations with the cars getting a more aggressive look, a lower minimum weight and wider tyres in an attempt to ensure that the cars are five to six seconds a lap faster than they are now. Refuelling will be introduced, although the maximum fuel allowance will be maintained. The details of exactly how all of these targets will be achieved are not yet available, and it is likely they are not yet fully worked out.

A number of other measures were tabled such as a revised race weekend format and a ban on driver aids at the start of the race, although these were felt to need more investigation. Finally an agreement on improving the sustainability of Formula 1 was also agreed, but the finer points were still to be worked out and there were no details as *Racecar Engineering* went to press.

Ferrari will stop racing if the current F1 contract isn't honoured

World Cup plans confirmed as Class One regs firm up

The future collaboration between the German DTM series and the Japanese Super GT took a step closer with the agreement that the new generation cars will feature four cylinder turbocharged engines. It is the latest in a series of agreements between the ITR, Super GT and IMSA organisations that are bidding to globalise the regulations in keeping with BMW's original criteria for joining the DTM.

At a meeting of the steering committee, which includes representatives of the Japanese GTA, the American IMSA organisation and the ITR immediately following the Nürburgring 24 hours, the aerodynamic specification was agreed, with details now having to be tested and developed to confirm that they can technically be realised. The plan to introduce a 'World Cup', as detailed in *Racecar Engineering* V24N12 was also agreed, with the first race to take place at the end of the 2017 season in Japan, and a second race at the start of 2018 in Germany.

Masaaki Bandoh, Chairman of GTA rights holder and promoter of Super GT, was happy to reach the agreements regarding basic features of Class One regulations. 'I believe that the agreement will mutually further the development of us, Super GT, DTM and IMSA from 2017. I am very excited that we are moving a step closer to one of our major reasons to establish the cooperative relations with DTM and IMSA.'

Singapore developer planning Valencia GP

The Valencia Grand Prix, which was last held in 2012, could be back on the F1 calendar if a Singapore-based development company gets its way.

Valencia's race, which took place in the Royal Marina district situated in the old port of the Spanish city, was on the F1 schedule for five years from 2008, but then fell victim to the global financial downturn, which hit Spain particularly hard.

But now ARC Resorts, which is based in another F1 street race host city, Singapore, has included the return of the GP in its ambitious plans to develop the Royal Marina area, which also include a golf resort, shopping centre, casino, six-star hotel and concert venue.

According to reports, ARC intends to run the F1 race every other year, alternating it with a Formula E counter, which would presumably use a different layout.

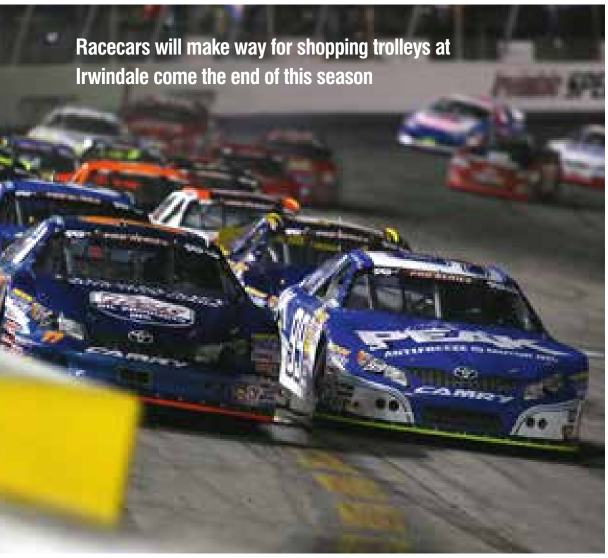
ARC has told the Spanish press that it intends to invest around €200m in the project, which it claims will generate 8000 permanent jobs in the area. It has also claimed it has 'an excellent relationship' with the Formula 1 organisers, and that it would be prepared to invest the necessary capital to bring the grand prix back to Valencia.

The company already has similar complexes up and running in Sri Lanka and Kazakhstan, and another built in Singapore itself has turned the former commercial harbour area of Marina Bay into a successful tourism and residential centre.

Valencia's regional minister of economy, industry, tourism and employment, Maximo Buch, has said the city will examine the ARC proposals in detail.

The Royal Marina district was developed for the America's Cup yachting competition.

Irwindale Speedway to be demolished


Racecars will make way for shopping trolleys at Irwindale come the end of this season

The popular Irwindale oval in California is to be torn down and replaced with a shopping mall after the local council approved plans to demolish the venue.

Irwindale Speedway opened in 1999 and it hosted NASCAR K&N Pro Series West and Whelen All-American Series events until NASCAR announced it was dropping the track from its schedule in 2011.

In 2013 the property on which the Irwindale Event Center [as the facility is now known] stood was acquired by Irwindale Outlet Partners LLC for $22m. The lease for the track continued on a year-by-year basis, but this year plans were made to demolish the speedway and replace it with a mall, and these have now been approved.

Work on the demolition of the facility is not planned to begin until early 2016 and racing will continue at the venue – which boasts half- and one-third mile banked ovals plus a drag strip – until the end of this season.

While there are a number of petitions circulating which aim to put pressure on the local council to save the track, Jim Cohan, president and CEO of Irwindale, actually issued a statement urging fans not to sign petitions or become involved in other protests.

Cohen said: 'We have a wonderful group of very loyal and very passionate, fans, sponsors, racers and car owners who all really enjoy our drag strip and our oval tracks, and we truly understand their concerns for us and for this facility. But this is not the time for talk about starting any petitions nor of staging any sort of protests against the City of Irwindale or the owners of this property. The fact of the matter is that our landlords could have closed this facility the day after they purchased it. They did not.

Audi confirms 'no' to Formula 1 with Red Bull as Piëch resigns

The F1 paddock has been awash with rumours that Audi engines will power the Red Bull F1 team

Audi has comprehensively ruled out a return to Formula 1 despite the resignation of VAG Chairman Ferdinand Piëch from the Supervisory Board.

Piëch, 78, who has long resisted suggestions he place either Audi or VW in Formula 1 and has gone on record to say that VAG would not join the sport as long as Bernie Ecclestone is still involved, was ousted from the Supervisory Board after he made remarks criticising VW chief executive Martin Winterkorn in the German magazine *Der Spiegel*. Wolfgang Porsche, chairman of Porsche and the second most powerful member of the supervisory board, went on record immediately, saying that Piëch had expressed a "personal opinion" that did not represent the majority view. It became clear that Piëch had driven himself into a corner from which he could not escape with his customary, unquestioned authority, and that led to his decision to resign his position. Berthold Huber, who will now serve as interim chairman, said: 'The uncertainty had to be ended. The steering committee was, and is, conscious of its responsibility to Volkswagen and its many thousand staff.'

Louise Kessling and Julia Kuhn-Piëch, Piëch's nieces, were appointed to the board in place of Ferdinand and his wife, Ursula Piëch. Several members of the board may be considered for the chairman's post, principally Winterkorn, but also Porsche's CEO Matthias Muller, 61, Audi CEO Rupert Stadler, 52, and Skoda chairman Winfried Vahland, 58.

Piëch's resignation set the rumours flying that the way was now clear for Audi to enter Formula 1, and Red Bull upped the pressure by threatening to withdraw from the category unless engine partner Renault improved, or Audi joined. However, mid-May, an unnamed spokesperson told Reuters that 'this is not a topic for us,' and later, Stadler was quoted in German press *Handelsblatt*, saying 'Formula One needs to solve its problems on its own.'

BMW eyes Le Mans return with new technology

BMW is reported to be evaluating a return to Le Mans for the first time since it won in 1999, entering the race in the Garage 56 for alternative drivetrain technology before a full assault on LMP1. BMW withdrew from endurance racing after its Le Mans win to concentrate on its Formula 1 involvement in 2000.

BMW withdrew from Formula 1 in 2009 and has not had a global programme since. According to German magazine *Sport Auto*, it is now considering a return to Le Mans, and may take the Garage 56 route into endurance racing.

BMW Motorsport boss Jens Marquardt refused to deny the speculation surrounding the firms 2017 Le Mans project but made it clear that for the brand to enter the rules would likely have to change. 'If you take BMW as a global brand we are setting new paths, which we have shown with 'i' so I don't think we need to follow what everyone does,' he said. 'The WEC is still following and what we need to figure out is a new path that suits BMW, like with 'i'. If a global return on investment is balanced with your investment it can make a lot of sense but it has to be balanced. Some of the championships are a huge investment and a return on investment calculation sometimes in those respects are difficult, but it depends how close these things are to your brand.'

BMW is developing an engine that could be suitable for Le Mans, with a four-cylinder direct injection turbo that will be used in the new 'Class One' cars of 2017, while Holzer and Adess have a track record in LMP1 and Formula 1 car construction and development.


XPB

BMW may choose the Garage 56 route if it decides to return to a global series

SEEN: Porsche 911 GT3 R

Porsche has launched its brand new GT3 contender, the 911 GT3 R, that features light weight components carried over from the production car, a more powerful and fuel efficient DI engine, and better aerodynamics as the company bids to return to true GT3 competition against Audi, Mercedes, Lamborghini and Nissan. First examples of the new car will be delivered to customers by December, 2015, ready for competition in 2016.

Amid rising concerns at the cost and performance of the new GT3 cars, the new Porsche was launched at the Nürburgring 24 hours mid-May at an eye-watering €429,000 ($487,000USD), plus country specific tax.

The 911 GT3 R features the distinctive double-bubble roof, and the wheelbase which had been lengthened by 3.27 inches (8.3 centimeters), ensures a more balanced weight distribution and more predictable handling particularly in fast corners. The engineers optimised the centre of gravity due in part to the lightweight body design of the production car featuring an intelligent aluminium-steel composite construction. The roof, front cover and fairing, wheel arches, doors, side and tail sections, as well as the rear cover, are made of particularly light carbon fibre composite material (CFRP).

The new engine operates at pressures up to 200 bar and features variable valve timing technology. The normally aspirated engine offers significantly better driveability and a broader usable rev range.

Williams applies Formula 1 aero know-how to fridges

Williams Advanced Engineering, the division of the group that brings Formula 1 derived technology to market, has helped to develop a new aerodynamic device that can significantly reduce the energy consumed by supermarket refrigerators.

Energy consumption makes up a huge percentage of a supermarket's operational costs, with open-fronted multi-deck refrigerators the biggest culprits. On top of that, some of the cold air that spills out into the aisles from these fridges also results in what's called 'cold aisle syndrome', which can make for a chilly shopping experience.

With the above in mind, start-up company Aerofoil Energy and Williams are developing a new retro-fit aerofoil system that attaches on to each refrigerator shelf to help ensure more of the cool air stays inside the cabinet.

Aerofoil Energy is working closely with Williams to refine the concept, making use of the F1 team's expertise in aerodynamic design and testing, with Williams using CFD to model and simulate new designs before extensively testing them at its factory in Grove, Oxfordshire.

It's been estimated that supermarkets and convenience stores account for up to 10 per cent of the UK's total energy use, while between 60 to 70 per cent of that energy is expended by the refrigerators.

A number of supermarkets are now evaluating the technology. Sainsbury's, the UK's second largest supermarket chain, has been testing the product at a number of its stores and John Skelton, its head of refrigeration, said: 'We're proud to be giving our fridges a turbo boost with this fantastic aerodynamic technology. Aerofoils help the airflow around Formula 1 cars and can improve their performance – and that's exactly what they can do for the fridges in our stores by helping to keep the cold air in.'

IN BRIEF

Quarter smile

International Speedway Corporation [ISC], the track-operating publically-owned arm of NASCAR, has issued its financial results for the first quarter of 2015. Total revenue for the first quarter was $136.6m, compared to revenue of $131.8m in the same period last year. ISC's chief executive officer Lesa France Kennedy said the results exceeded its expectations.

Manor debut set

The Manor Formula 1 team expects its new-for-2015 F1 car to make its debut after the summer break. The team once known as Marussia, which was rescued from administration just before the start of the season, has been making do with its 2014 car, modified to pass the tougher 2015 crash tests. After failing to make it out on track at the first race in Australia Manor has subsequently qualified for every Grand Prix.

R&D spending up

The value of the research and development undertaken by businesses in the UK increased by eight per cent in 2012-13 to £18.4bn, according to the latest figures from the Office of National Statistics. Meanwhile in 2013 total R&D by all sectors – including government and universities – rose by seven per cent to £28.9bn. This represents an increase of five per cent and corresponds to 1.67 per cent of GDP, compared with 1.62 per cent in 2012. However, despite the increase, the R&D spend in the UK still remains well below the EU average of over two per cent and the OECD [Organisation for Economic Co-operation and Development] average of 2.4 per cent.

Race course

Renowned NASCAR engine builder Roush Yates has entered in to a partnership with the Universal Technical Institute [UTI] which will see it contribute to the Power and Performance training courses the UTI offers at its campuses across the USA. These nine-week courses give students training in designing, building and modifying high-performance engines.

MIA to create 2020 vision for motorsport industry

The Motorsport Industry Association is to create a master plan to help the UK's world-beating motorsport industry to maximise future business growth by working with the new Conservative British Government.

With a working title of 'Motorsport 2020' the project will bring together ideas from leaders of UK motorsport businesses about the approach they wish the new government to take over the next five years – the usual term of a UK government – to bring further growth to the sector.

As part of the Motorsport 2020 project the MIA is asking all UK motorsport organisations to share their best ideas for business growth through the website – www.the-mia.com – and by attending an industry workshop.

Prodrive gets new base

Prodrive has started to move in to its new headquarters in Banbury, UK, which will see many of the motorsport and advanced technology group's diverse businesses operating under the same roof for the very first time.

The company has started manufacturing its first parts in the new facility. Prodrive's new HQ will be home to its motorsport businesses – the Aston Martin Racing team as well as its Mini and VW Golf rallying projects – and its advanced technology division, which works in the automotive, aerospace, defence and marine sectors. This means that race and rally cars will now be built alongside advanced active aero systems for super cars and control systems for electric vehicles.

Women in racing

The Institute of Mechanical Engineers is organising a National Women in Engineering Event on Tuesday, June 23 2015 at the IMechE in London. The evening will be presented by Radio 5 Live presenter Jenny Gow, panellists include Claire Williams, Leena Gade, Bernadette Collins and Gemma Hatton. The event is free to attend. To register visit http:/ow.ly/Nin3v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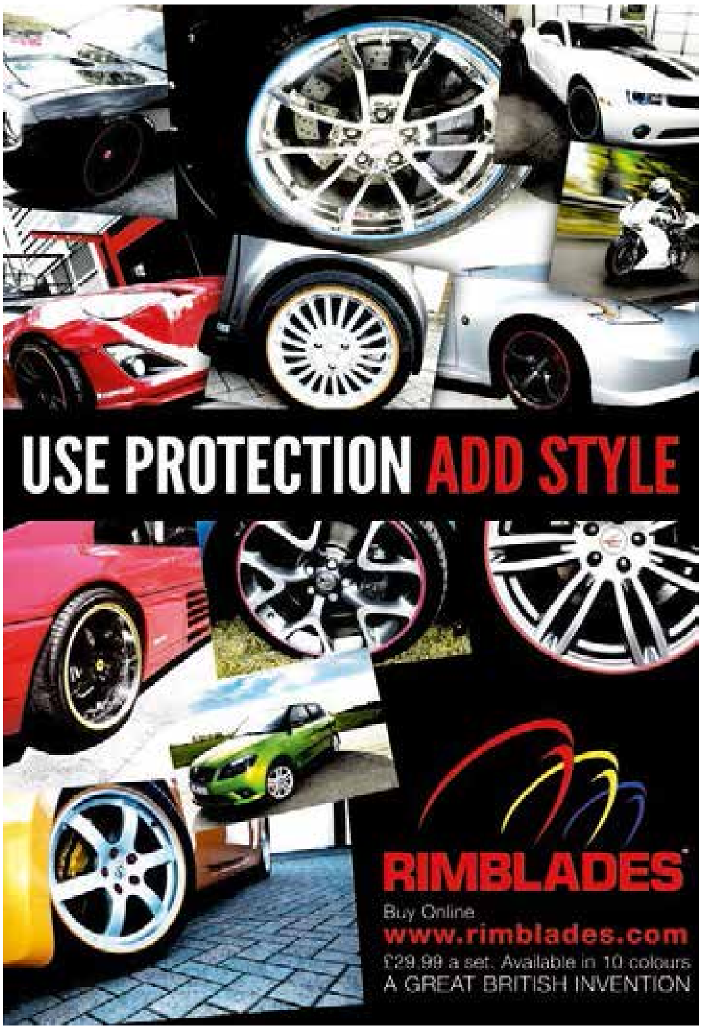
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INTERVIEW – Pierre Fillon

Once upon a time in the l'Ouest

How the ACO is walking the fine line between improving track safety while maintaining the spectacle that makes the Le Mans 24 hours race so special

By ANDREW COTTON

XPB

'With the 3m15s barrier in danger of being breached this year, the track changes are vital to maintaining the visual spectacle of the race'

The Automobile Club de l'Ouest is synonymous with the Le Mans 24 hours, yet this is a club with more than 30,000 members, has a financial impact on the local Sarthe region of more than €90 million per year and which organises races throughout the season for a multitude of different categories.

On one hand, the club caters for the sporting motorist, a person who pays to become a member and receives benefits at all the races, and on the other, a political lobbying group that campaigns for the rights of the average motorist. Both roles combine to make the ACO a strong political force in the French motoring world but in racing circles, it is the endurance 24 hours, held in June, that puts the club on the world map.

Started in 1906, the Automobile Club de l'Ouest was tasked by the Automobile Club de France (ACF) with organising a race, the first ever Grand Prix. It was won by Ferenc Szisz, but it was not for another 17 years that the idea to organise an endurance race, over 24 hours, was first formed in 1923. '[The first race] was in 1906, on the open road and it was the first Grand Prix,' says the ACO President, Pierre Fillon. 'Then they organised some motorcycle races, and in 1923 my predecessor had the idea to organise the 24 hours of Le Mans as a test for the industry. It is important for the 24 hours to stay as a laboratory for innovation. [Racing] is an accelerator for innovation.'

The ACO is the driving force behind the European Le Mans Series, the Asian Le Mans Series, and backed the American Le Mans Series, now called the Tudor United Sports Car series. Above that sits the FIA World Endurance Championship which, according to the ACO, provides the link between the national series and Le Mans.

'The ACO is probably the only automobile club that can write its rules,' says Fillon. 'We continue to write the rules with the FIA, but when we began the championship with the ILMC, we created the rules.'

Friends with benefits

Members of the ACO can turn to the club for help lobbying the government for motoring issues, such as the price of driving on the motorways and parking fines. 'It is lobbying to protect the drivers in France against some laws,' says Fillon, whose political clout was no doubt strengthened as his brother, Francois, was president of France between 2007 and 2012. 'After that, you have all the economy around the track in Le Mans. You have the 24 hours, for trucks, go-karts, motorcycles, the MotoGP for France, the Le Mans classic and we have all the other races, such as GT tours from the FFSA. We had the DTM maybe eight years ago, but it was not good. We had about 10,000 people attend and we were very disappointed in that. We host Val de Vienne, French superbikes and other little races.

'When you want to race you have to have a licence and be part of a sporting association. We have the ACO sporting association with 4000 members. After that, we have the driving school, and we have the Pescarolo prototypes, the Porsche driving school, (the only one in France), we will have soon the Porsche experience centre, which is being built in the Raccordement just outside the track and by Maison Blanche we have some skid school and off road tracks.'

New buildings

Many believe that the ACO owns the famous 13.6 mile circuit, but this is not the case. It doesn't even own the Bugatti circuit on which the bikes race. The ACO owns the building with its own offices outside the main grandstand, but the rest, including the pit buildings, is rented from the local government. This means that changes to the circuit, such as the installation of the chicanes in 1990, the reduction of the hump at the end of the Mulsanne Straight in 2000 and proposed changes to the ground around the Porsche Curves, have to be carefully negotiated.

It is this last section that is particularly controversial. The Porsche Curves are considered to be a danger, particularly following Marc Gene's crash there in the Peugeot in 2008, Guillaume Moreau in 2012 and Loic Duval in 2014. With speeds anticipated to be far higher in 2015, the ACO has a balancing act to conduct – maintaining speeds, managing development and keeping the circuit safe. The Porsche Curves are the subject of the biggest planning and restructuring programme around the circuit, with the overall ambition to retain the layout of the curves, but make them much safer, using the US-style SAFER barriers and introducing run off areas at the entry to the corners and mid-way through, just before the White House corner.

'This year we changed the first of the Porsche Curves, and improved the run-off at the entry to the first curve,' says Fillon. 'We change the barriers inside the curve, the bridge, and this year we will have some tyres but next year we will have the SAFER barrier. We have removed the grass and the next we have the project to improve the run off at the end of the Maison Porsche just before Maison Blanche where Loic Duval had his accident last year. But, there is a problem with the river that flows under it.' French law is notoriously difficult to work around water, and the ACO says a solution could be two years away.

'We don't want to change the layout of the circuit,' says Fillon. 'This curve is something important for the track and it is important for the drivers. They don't want to change the Porsche Curves. It is easy for us to make a chicane before the entry, but that is not the spirit of the race.' With the 3m15s barrier in danger of being breached this year, the track changes are vital to maintaining the visual spectacle of the race.

'I don't know if we will slow down the cars,' says Fillon. 'We cannot make it dangerous so you have a lap time limit in Le Mans.' Previously this was 3m30s in race conditions. That marker has now been reduced to 3m15s. 'For sure less than 3m15 is not reasonable so we will have to do something,' says Fillon. 'I think 3m30 was a little bit exaggerated. We changed a lot of things on the track, but under 3m15 is not reasonable.'

Those who drive around the public parts of the circuit every year will notice construction work around the Indianapolis

XPB

The character of the full Le Mans circuit has to be protected, says the ACO, including the Arnarge corner and Porsche Curves.

corner, too. 'We need to make a roundabout in Arnage, because the crossroads is very dangerous for the public during the year,' says Fillon. 'The first project was to make a roundabout in Arnage corner, and that would finish the corner. We worked with the local government to move the roundabout to 100m after. The public road will continue straight on at Indianapolis, and you will then have a roundabout. We work to protect Arnage corner, because it is very important.'

Anyone who has watched the start of Steve McQueen's film, Le Mans, may remember the 'hero' stopping his rather nice Porsche 911 by White House, a part of the old circuit that is still used by the public. The actual house is now run down and hidden behind a wall but often the spectators gather around the area to encourage burn outs. Often those who refuse to participate are shot with water pistols, particularly if you drive a convertible.

The ACO wants to buy the actual house and restore it, but there is a slight problem. 'Maison Blanche is part of the heritage of Le Mans,' confirms Fillon. 'But, it is owned privately and we don't know where the owner is. There are some fantastic stories about the owner, maybe he was in jail in Australia. We want to buy it, but we can't because we don't know where the owner is!'

Government ties

Maintaining a close working relationship with the local and national government is critical to the survival of the circuit itself, and there have been occasions and decisions that don't go the way of the ACO. 'The owner of the track is the government department, the regional government and the city government,' says Fillon. In 2011, the government opened a stadium inside the Tertre Rouge corner, within the confines of the circuit and built a tramline to the stadium. 'We didn't choose to build the stadium inside the track,' says the Frenchman, a little ruefully. 'The city decided to do that, so we have to live with it. However, during the 24 hours of Le Mans, the stadium is inside the track, so you need to have a ticket to go there, and we help the stadium to find some clients. Last year we did a hotel in the stadium and that will also be the case this year.'

Regardless of the ownership, the ACO is protected by, if nothing else, the money that is brought in around its activities. 'We just finished a really interesting study on the economic place of the ACO in the departments, and it is 90m Euros for the department,' says Fillon. 'It is like a permanent company with some 2,000 people.'

However, the club harbours ambitions to be included in the FIA as a politically active group. 'In each country, normally within the FIA, you have the sport federation and you have a club for the mobility; two members in the world council for each country. You have the French federation with Nicolas Deschaux, and another club based in Strasbourg that is a mobility member in the FIA. However, with our links to the FIA through the World Endurance Championship, we work on mobility with [FIA President] Jean Todt. As an Automobile Club, we have a mission to join the world council. It is better to work with the FIA because it is a bigger organisation than us. In France, we work on security with the local government, the ministry of transport and so on, but it will be better and we will have more power if we do that with the FIA.' The ACO is very aware of its heritage, and very aware of its responsibility, both to the racing world, and to the French motorists and clearly has an ambition to become more a powerful force in France.

The club harbours ambitions to be included in the FIA as a politically active group

Motorsport millionaires fall down UK wealth chart

This year's *Sunday Times Rich List* features its fair share of personalities from the motorsport industry but the majority – while not seeing their money-worth diminished – have dropped down the rankings, largely because others have overtaken them.

Rich List 2015, described as 'the definitive guide to wealth in Britain and Ireland', lists the 1000 wealthiest people or families in the UK. This year the fortune required to simply appear in the Rich List was £100m, which is a 100 per cent increase on 2005 (£50m). In 1997 the 'poorest' on the list was estimated to be worth a mere £15m.

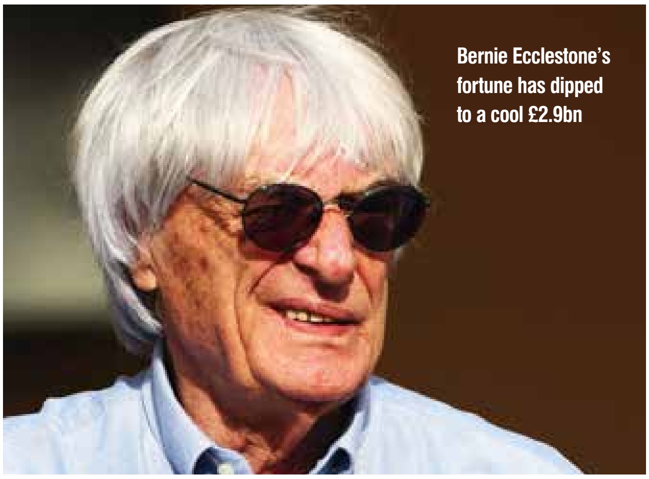
Unsurprisingly Bernie Ecclestone tops the motorsport names on the list, placed at 33rd with an estimated fortune of £2.94bn (a drop from £3bn in 2014 due to the £60m he paid Bavarian prosecutors to settle the bribery trial he was embroiled in last year). Interestingly, Ecclestone's former wife Slavica is listed at 150 with a fortune of £740m, which comes from her divorce settlement six years ago.

Paddy McNally, who made his fortune through F1 advertising sales company Allsport and the F1 Paddock Club, sees his wealth stay at £510m, although his place on the list drops from 196 to 214.

McLaren boss Ron Dennis is the only motorsport man to see his ranking increase. His fortune soared over the past year, from £260m to £350m. Dennis goes up 66 places from 353 to 297 on the list.

Donington Park owner Kevin Wheatcroft is ranked at 791 on £120m, while former Brawn GP and Mercedes F1 boss Ross Brawn is listed at 968 with the £100m he received from Mercedes in payment for the sale of the Brawn team at the end of its 2009 championship-winning season.

Meanwhile, Lewis Hamilton remains the richest sportsman in Britain with a fortune of £88m, but Manchester United and England football player Wayne Rooney has overtaken Jenson Button to sit second in the 2015 *Sunday Times Sport Rich List*. Hamilton's wealth has increased by £20m since last year.



Bernie Ecclestone's fortune has dipped to a cool £2.9bn

Automotive recruitment agency goes digital

Engineering recruiting specialist Jonathan Lee Recruitment has launched its own digital design office to support motorsport companies and automotive OEMs by offering design and prototyping solutions.

Located in Hatton Technology Park, near Birmingham in the UK Midlands, Jonathan Lee Design Services has the capacity to house 24 designers and digital modellers, using Alias, ICEM Surf and CATIA, and it is thought to be the first initiative of its kind in the design recruitment sector.

RACE MOVES

John Darby is leaving NASCAR after more than three decades at the organisation. Darby was director of the Sprint Cup from 2002 until the start of 2014, when he took up a managing director role at NASCAR's competition department.

Barry Ryan, general manager motorsport at V8 Supercars outfit Erebus, has taken on a broader role within the team. This will include the V8 Supercars side of the business plus his main focus with the Erebus GT and V8 Ute (Australian pickup truck series), as well as the organisation's driver academy.

Phil Casey, car builder, crew chief and senior technical director at the IRL (Indy Racing League, now known as IndyCar), has been selected as an inductee into the Auto Racing Hall of Fame by the Indianapolis Motor Speedway Foundation. Casey played a significant part in the development of the Steel and Foam Energy Reduction (SAFER) barrier.

Formula 1 design legend **Gordon Murray** has teamed up with former Honda F1 engine guru **Osamu Goto** to build a new super-efficient city car. The last time the pair worked together was with the ultra-successful McLaren-Honda MP4-4 F1 car.

Steve Byrnes, who worked in NASCAR as a TV reporter and host for over 30 years, has passed away at the age of 56. The cause of his death was said to be complications related to his ongoing battle with cancer.

The International Speedway Corporation (ISC), has appointed **Laree M Renda** to its board of directors. Renda worked as one of supermarket chain Safeway's top executives and has also been recognised as one of the '50 Most Influential Women in Business' by *Fortune* magazine.

Campbell Little has joined Mercedes-running V8 Supercars squad Erebus Motorsport as a consultant.

Greg Margetts, the UK engine builder, has died at the age of 63. Margetts started his career as an apprentice at Speedwell, before working on F1, F5000 and Le Mans engines through the 1970s. He set up Competition Engine Services with **John Middleton** in 1975. More recently Margetts-built engines have seen action in historic racing.

IndyCar team owner **Bryan Herta** has entered the Global Rallycross Championship. Bryan Herta Rallysport will field Ford Fiestas and it has teamed up with **Sean Jones** of 7R Inc for the new venture.

Mari Hulman George, the chairman of the board at Hulman & Co, the company behind the Indianapolis Motor Speedway and IndyCar, has also been inducted into the Auto Racing Hall of Fame. Now a philanthropist, George was also Sprint car team owner in the 1950s and 1960s.

Len Pullen, a long-time licensed official at the Motor Sport Association (MSA), has been awarded with a lifetime achievement award by the UK governing body. Since 1976 Pullen has served as competitions secretary at the British Racing Drivers' Club (BRDC) and is also a well-known chief steward and clerk of the course.

The Indianapolis Motor Speedway (IMS) Foundation Hall of Fame Museum has three new directors: former race driver and current team owner **Rod Dyson**, Hoosier Motor Club president **Kirk Hendrick**, and former IMS PR executive **Fred Nation**.

Victor Shapovalov, the team principal at WTCC works outfit Lada Sport Rosneft, has been named Russia's Motorsport Man of the Year for 2014 in a recent awards ceremony in Moscow. Shapovalov successfully led the Lada team to its first victories in the WTCC last season.

Pieces of Silver, the critically acclaimed novel written by *Racecar Engineering's* news editor **Mike Breslin**, is now also available as an eBook. The story follows the adventures of a fictional racer who drives for Auto Union in the 1930s and then flies with the RAF during WWII. Check out Amazon.co.uk for more.

◆ 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 email with your information to **Mike Breslin** at **bresmedia@hotmail.com**

Show stoppers!

Preparations for the 2016 Autosport International Show start here

With business conducted at the show having surpassed the £1bn mark in 2014, the Autosport International and Autosport Engineering Shows have proven themselves to be a critical point of the year for any engineering company involved in racing.

Stands and tickets are now available for those wishing to be part of a show that attracts more than 84,000 visitors and more than 27,000 industry buyers. The show, which has been held at Birmingham's NEC for more than 25 years, features two dedicated trade-only days (January 14 and 15, 2016) and is firmly established as an international business hub for motorsport, automotive and advanced engineering.

Autosport International includes a highly successful show within a show, Autosport Engineering, which is held in association with *Racecar Engineering*. This takes place on the trade days and more than 200 companies showcase the latest innovations and technology at the show. Already signed up to the show are long-term partners AP Racing, Motec, Xtrac, Brembo, Bosch, Eibach, Goodridge, Wirth Research, SPA Design, Holinger, ARP and Lifeline.

Haymarket Exhibitions plans to build on the Low Carbon Racing initiative started in 2015 with a dedicated area within the Autosport Engineering show, reflecting the growing trends within racing, particularly in Formula 1, the World Endurance Championship and Formula E this season.

Sixty three per cent of the exhibitors believe that this is the most important show for their business, and now is the time start planning the 2016 season by booking up a stand.

Ticket are on sale from June 1, 2015

AUTOSPORT INTERNATIONAL
Engineering Show
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In association with Racecar engineering

Useful information

Ticket prices:
- Trade tickets – £28
- MSA members – £23 (available later in the year)
- BRSCC members – free – available later in the year. Members will need to contact the BRSCC for tickets
- Live Action Arena – £11

How to book – www.autosportinternational.com/trade or call 0844 335 1109

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- 9m (3x3) – £3,638 plus VAT
- Space only – £320 per m² plus VAT

The shell scheme price includes a modern attractive shell scheme system with fascia board. All stands include carpet, cleaning, free stand listing in the official show guide and a hotlink on the Autosport International website.

The Autosport International and the Autosport Engineering shows are where the motorsport, automotive and advanced engineering industries gather to conduct their business

Throttle bodies
Omex launches own range

Omex has released a range of own-brand throttle bodies for high performance street and motorsport use. The first products in the range are the new DCOE / DHLA manifold compatible ITB. There are currently optimised inlet manifolds available for the Ford Duratec 2L/2.3L (45mm bodies), Duratec 2.5L (48 or 50mm bodies), Ford Zetec angled, Zetec straight shot (both 45mm) and Peugeot Mi16/GTi6 (45mm). Further manifolds are in development and the OMEX bodies will also fit all other DCOE flanged manifolds.

By staying with the motorsport-standard DCOE flanges, the Omex throttle bodies are compatible with the manifolds and air filters already on the market. This will enable the Omex ITBs to be used on nearly all engines and take advantage of the innovations in materials, finishes and detail design available throughout the market. The throttle bodies feature a two-step wall thickness design allowing the highest precision where it is needed by the throttle plate, and the lowest weight everywhere else. The Omex range boasts billet aluminium machined levers and linkages, a large volume one-piece aluminium fuel rail with various end fittings, protective coatings on all parts including non-stick coatings of all billet aluminium parts for longevity, stainless steel fittings and adjusters, and OEM specification throttle position sensors for proven reliability.

The Omex throttle bodies can be purchased in component parts or as complete sets assembled, ready to bolt to the engine.

www.omextechnology.com

Power steering
New fluid from KRC

KRC has introduced a new power steering fluid which breaks new ground in its reduction of fluid cavitation, noise and heat.

Surviving heat hazards is a crucial breakthrough in fluid longevity. Under-bonnet temperatures in racing vehicles can exceed 300degF, necessitating power steering fluid renewal before each race. KRC's new petroleum-based fluid also prevents corrosion and foaming within the system. Foaming causes an effect in steering systems similar to that of air in braking systems.

Racers can now purchase KRC's new fluid in a convenient six-pack or individually. The six 250ml containers usually complete three fluid changes.

www.krcpower.com

Head gaskets
MLS gaskets take the next step

JE has announced a new range of multi-layer steel (MLS) cylinder head gaskets for high-performance and racing engines. They are called the JE Pro Series.

Originating at the turn of the 1990s, the unorthodox MLS gasket shook the establishment – it was both complex and revolutionary by comparison to its forerunner. Its fundamental difference was its multi-layer construction and it consisted of at least three layers.

Kentucky-based World Products engine designer, Dick Boyer, says: 'MLS offer several significant advantages, particularly when situated between two different materials. Dissimilar metals, like a cast-iron block and cast aluminum cylinder head, for example, expand at different rates, but the MLS gasket is different as its multi-layer construction allows more movement than the conventional-style head gasket.' The conventional gasket is typically composed of a single steel core with paper gasket material attached.

The inner portion of the MLS, which is made of stainless steel, serves to provide the finished gasket thickness. It also acts as the layer on which the top and bottom layers press against and, importantly, it contributes to, and enhances, the gasket's sealing properties.

The outer layers, which are also made of tempered stainless steel, feature raised beads or embossments that encircle critical sealing areas, particularly the combustion openings and water jacket ports. The spring steel raised beads of the upper and lower layers resist flattening and it is this spring pressure that creates the seal, particularly when the engine is operating. Race engine builder Jon Kaase refers to the unique quality of the MLS gasket as "its springiness".

Unlike the conventional gasket, which cannot expand and contract, the MLS unit has spring tension when fastened to the correct torque loading. This allows the gasket to relax and compress as the cylinder head tends to move up and down slightly while the engine is operating. And it's in this area, in the sealing of the combustions gases of high performance and competition engines, where JE specialises.

www.jeproseal.com

Brake calipers
Wilwood

These ultra-strong forged calipers are fully detail machined and stress-analysis tested. According to Wilwood, they provide the lightest overall weight with the highest resistance to deflection – even when compared against much heavier and bulky cast aluminum parts.

The calipers feature an anodised finish, with low-heat conduction stainless steel pistons and positive retraction bore seals. Fluid inlets have been relocated to the centre of the piston bore to eliminate any possible interference with the slide pins. Bleed ports at both ends accommodate left, right, front or rear mounting.

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Subscription rates
UK £66 (12 issues)
USA $162 (12 issues)
ROW £84 (12 issues)

News distribution
Seymour International Ltd, 2 East Poultry Avenue, London EC1A 9PT
Tel +44 (0) 20 7429 4000
Fax +44 (0) 20 7429 4001
Email info@seymour.co.uk

Printed by William Gibbons
Printed in England

ISSN No 0961-1096
USPS No 007-969

www.racecar-engineering.com

Sound and fury

The relentless improvement in performance of the Le Mans Prototypes in the opening races of the World Endurance Championship should perhaps not be seen as too much of a surprise. At Spa in May, the pole position qualifying time was almost six seconds faster in 2015 (1m54.767s average of fastest lap of two drivers) compared to 2014 (2m00.334s average of two fastest laps of two drivers), signalling a huge step up in the development cycle of the Porsche 919 that set fastest time both years. Yet, qualifying in 2014 at Spa was not entirely dry, and the Equivalence of Technology will be revisited after Le Mans. Unlike the early 2014 qualifying sessions, there is no reason to 'sandbag' for fear of a change for the biggest race of the year, and so true performance is perhaps a little clearer in the opening races of the season.

New systems are featured in the cars, a FRIC suspension system for Audi and a new turbo and battery in the Porsche, while understanding of hybrid systems has dramatically improved across the board after a 2014 season of intense competition. This is a trend that we are expecting to see repeated for the remainder of the year. In favourable conditions at Le Mans, the ACO is expecting the 3m15s lap time to be breached in qualifying. That compares to its theoretical fastest lap time of 3m30s fastest race lap that has stood (and been broken) for years. There is scope within the regulations for a reduction in energy from the fuel of 10MJ (the current limit is 138MJ/lap of gasoline power in the 8MJ hybrid category) to ensure that the cars are not slower, but do use less fuel. It's a great marketing message and a relevant challenge, but there is another danger; that costs may run out of control.

> **The development in battery technology in particular will not come cheaply**

Looking at the current breed of Formula 1 cars, despite the criticism of the formula, the hybrid systems and power units are stunning pieces of engineering that shade the WEC cars in terms of efficiency. Around Barcelona, by regulation the F1 cars regularly harvest 4MJ of energy, and according to one leading German manufacturer, around Le Mans an F1 power unit could theoretically harvest 12MJ. Think of the performance advantage that would bring would that be in a sports car.

No one is suggesting that an F1 power unit should come to Le Mans and be competitive over 24 hours (although Nissan's engine is based on Cosworth's F1 unit), but what is does show is the level of development that still has to be undertaken by the WEC manufacturers, and that ultimately boils down to money. Formula 1 budgets for power unit development are eye-watering, some suggesting €400m in investment to create these engineering masterpieces. Will the ultimate performance in endurance racing go to the manufacturer that reaches higher levels of investment, fastest? Or, will there be a collaboration with F1 power unit providers? Or will a cost control implemented?

This is not a cost control formula; this is a technology development platform that is driven by competition. Yet there is likely to be some kind of limit as costs rising too high with WEC levels of return may scare off other manufacturers. The potenial arrival of BMW into LMP1 in 2017 could be a further boost in spending dependant upon what technology it brings. The FIA Technical Working Group is looking into cost saving measures, and this year has mandated more mileage on the engines (a limit of five this season per car entered), a limitation on tyres, a limitation on personnel and a limitation on testing. These are expected to go further in 2016, but I suspect they are scratching the surface. The development in battery technology in particular will not come cheaply. There is a strong suspicion in the WEC paddock that Audi will switch to battery technology, Porsche is clearly committed to it, and Toyota will also go to a more conventional battery system than their super capacitors. Nissan, too, may change its mechanical flywheel system, although how versatile the car is to accepting new technologies is yet to be established. Certainly the team had access to super capacitors before Christmas, 2014, but elected to keep the concept purely mechanical this year. Will they change to an electrical system next year?

One of the great selling points of the WEC is that there are so many different technologies competing on what has been proven to be a level playing field. Yet, as with all such experiments, one storage system (battery) appears to be better in competition, and the others will migrate towards it. That, in turn, will see battery development increase dramatically over the next five years and it is interesting to imagine where they will finish up. The road relevance of this technology will be a key selling point.

For now, though, let's enjoy this era of endurance racing, surely one of the best that has ever been. Next year the cars will be as fast on perhaps as much as 20 per cent less fuel, a fantastic message to send out to the world. I just hope that the message will be strong enough that the manufacturers can justify the increased spending, before cost reduction legislation steps in and curbs this incredible technical exercise.

ANDREW COTTON Editor

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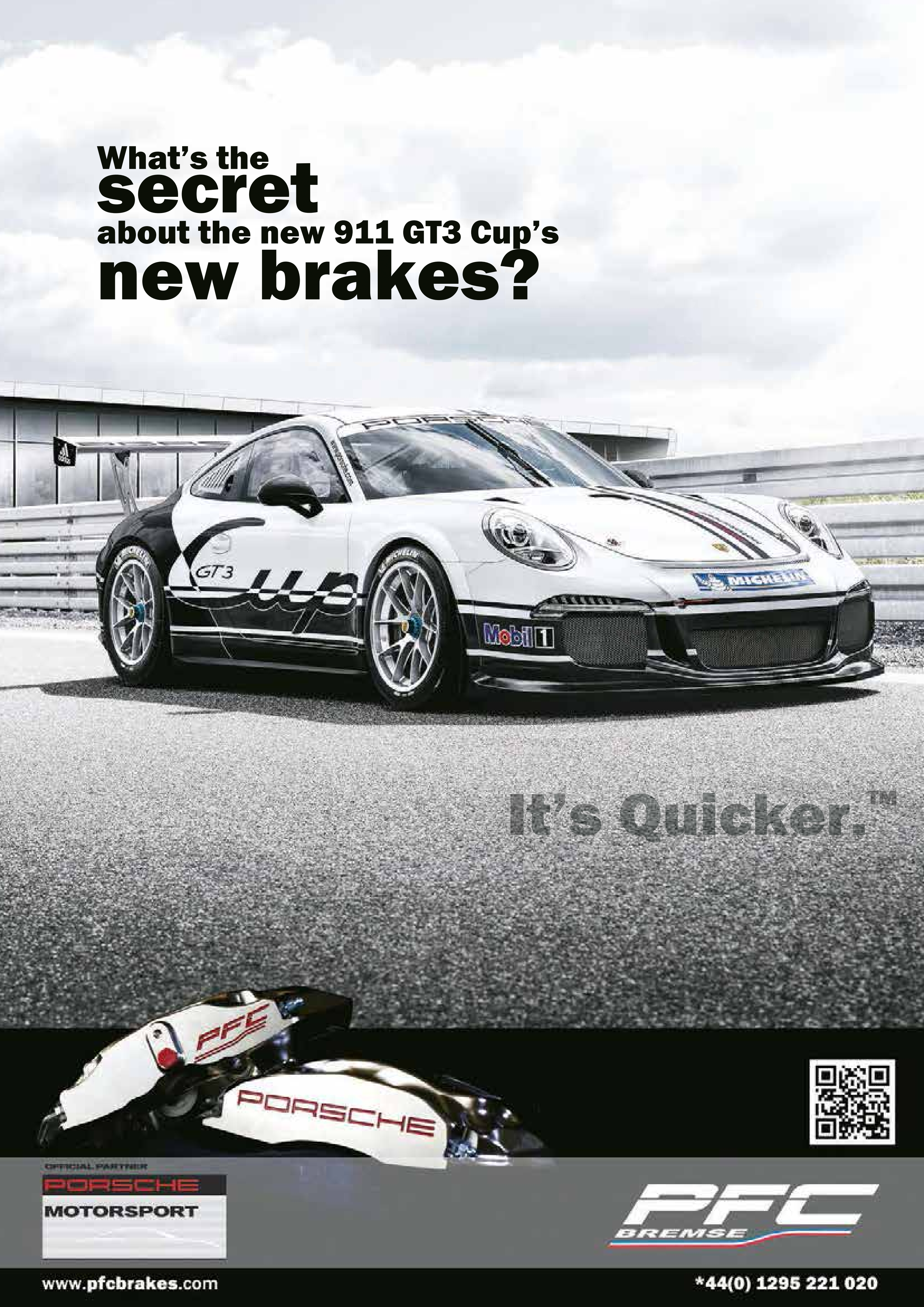
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