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After an impressive debut in 2016 many expected Haas to suffer from second season syndrome this year. But with its VF-17 the US squad has produced another solid car. Turn to page 26 to find out more

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Stature of Liberty

What should Formula 1 expect from its new global media giant owner?

The 21st century has been a rather ho-hum century so far. Not much good news anywhere; the wholesale crumbling of institutions, the probable runaway change in the world's environment leading to a wholesale die-off of entire species, possibly even our own. The collapse of democracy is not entirely impossible and the bright hope of the Enlightenment is dimming. Theocracy is raising its head and so are rabble rousers everywhere. One is even president of the most powerful nation on Earth.

But against all this we can see a small bright hope, at least in motorsport, for racing is now under new management at its highest level.

Hooray! We shall have a new, modern, social media aware management that shall bring motorsports to new heights, having wrested it away from Bernie Ecclestone, a dinosaur from the black lagoon, who manipulated the sport against the fans wishes and cowed teams into submission, all while stealing soiled bank notes from their ragged pockets.

A new era, then, the dawn of exciting racing and sporting behaviour, where superheroes will make the crowds gasp at their derring-do and behave like principled men, true examples to our youth...

Profit or loss?

An idyllic view, very Panglossian, but reality does tend to impose itself. The hard facts are that the price paid for the entire F1 circus was an investment by a media company, whose modus operandi is to view it as a financial transaction, giving a return on the investment in a fixed time-frame.

There are synergistic effects in providing content for the media company by having a sport to display, but the profit element will still be there. Obviously, the teams will want to get more of a return than what has been offered previously, so there will be some horse-trading backstage, some blood will flow, it just depends on what side.

The public may, and this is a very hypothetical presumption, get more entertainment for the cost expended, but there we also have to factor in the vested interests of the manufacturers who invest in the sport to publicise their technical prowess, and incidentally win races, as being a backmarker does not enhance your image, and the cruel reality is that there is only one winner in a race.

So how does the beautiful view of the future square with the facts? The hard facts are that Liberty Media will expect its investment to pay off in five years, 10 if we consider them to be reasonable and not the carnivore American companies tend to be.

The manufacturers will expect their returns to also be on the monetary side, not only in kudos. What of the governing body? It was once led by Max Mosley, probably the most intelligent man I've met in motor racing. He had a vision and did have long-range planning nous. Unfortunately the FIA is now gelded by the actions of this very same man.

The sale of the commercial rights of the FIA for a laughable sum for a century and more has relegated it to a supervisory and regulatory role and singularly absent from managing the sport adequately and having a strategic vision.

Then we have the teams. To expect them to agree on anything without being beaten senseless with a baseball bat is delusion right up there with believing that when certain rites are performed, bread turns into human flesh after it is swallowed.

XPB

F1's new era has got off to a good start with some fine racing in 2017 but the core financial problems that plague it have still to be addressed

Brawn again

Having Ross Brawn included in the management of Formula 1 has still to show what a proven track-record participant can bring to the structuring of the hardest to understand and administer part of the whole shebang, the technical side. Also, will he be able to provide a long-range plan and a genuine strategic group of independent, experienced racers, uncoupled from any team vested interest?

Cost containment must be part of this strategic model, too, if only to allow fresh blood in. The aborted cost cap brought new teams in on the expected benefits, but they are mostly gone by now for obvious, predictable reasons. The strategic group track record so far has given us mainly knee-jerk reactions in several directions aided and abetted by the mahouts of Max and Bernie, nudging the elephant with off-the-cuff solutions.

Treaded tyres, then frangible tyres, DRS, diverse engine formulas that see-saw between concepts, trying to please the manufacturers, the bankers, the media and the spectators, and eventually pleasing none, with the consequent loss of spectators, and incidentally teams from lack of sponsors or money.

Escalating quickly

The main victims of the direction Formula 1 has been headed in the last decades has been the teams and race organisers, shackled to a profit driven model that brings race contracts with a built-in escalator clause of 10 per cent.

Basic understanding of the power of this growth is simple but it eludes most people. Ten per cent a year growth responds directly to the rule of 70, which states that the doubling time for whatever percentage growth (or percentage decline) is the number 70 divided by the percentage. Ten per cent implies a doubling period every seven years.

This is exponential growth, and considering the revenue sources it means that organisers have to double their income by doubling spectators, charging double, or getting more income from TV and media, all unattainable logically in the first two cases, and in the third because the TV rights belong to FOM.

The result is that putting a grand prix on is well nigh impossible without some government funding, which is anathema in today's political and financial climate.

Improving the spectacle, arguably, does not seem to be the result of all the changes for 2017 so far, so we will have to see if new management has the self-control and vision to have a long-range plan to bring spectators back, give teams a viable business model outside manufacture funding, and likewise make race organisers survive without depending on governments to pick up the bill.

Grassroots motorsport and a realistically priced ladder for the future racers are an integral part of the planning also, and if these not implemented well then the supply of race drivers will be starved out by the sheer costs to get there.

But who knows, maybe those flying pigs flying in formations are not a hallucination and the moon really is made of green cheese!

Liberty Media will expect its investment to pay off in five years

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Beauty and the beasts

Would more aesthetically pleasing racecars attract new fans to F1 and the WEC?

Television aerials and coat hangers are just a couple of the uncomplimentary descriptions applied to this year's crop of new and wobbly F1 aero appendages. It's not surprising that the comments are so derogatory. Equally numerous are the complaints regarding the shark fins that have sprouted on the engine-covers. As they are so unpopular, make the cars more sensitive to side winds and are not a structural part, it wouldn't require much effort of will among all concerned to just agree to get rid of them, immediately.

Partly due to the above, and the return of complicated bargeboards which, together with Christmas-tree front wing assemblies, make it look as though the cars have had a shunt even before they are rolled out of the garages, there has been a deal of focus recently on the aesthetics of F1 cars. This season's bigger tyres and wider rear wings together with some more colourful liveries have contributed markedly to an improvement in this respect in all the 2017 designs, but still these cars remain far from pretty.

Pretty quick

Form should follow function, it is true, in an activity as competitive as motor racing, but going back over time it is often also true that the best cars are among the most pleasing to the eye. Whether your fancy lies with a pre-war Mercedes W154, 1950s Maserati 250F, 1500cc-era Lotus 25, the Lotus 72 and Ferrari 312B, or the McLaren MP4/4 of the Senna/Prost era, it would be hard to admit otherwise, although these are just a handful of examples. To be fair not many would put the bulky late-1950s Vanwalls on this list, despite their successes, or even the great Fangio/Moss Mercedes W196 (except in its beautiful but soon-abandoned enclosed wheels version), but exceptions often prove the rule. Likewise, some of the best-looking cars – Dan Gurney's Eagle and the Jordan 191, for example – were not overly successful, although limited resources played a part in both cases.

As remarked upon by Ricardo Divila in last month's *Racecar Engineering* (V27N6), the increasing dominance of aero through the 1980s to present times (and additionally some ill-thought safety regulations, which surely promoted the nadir of F1 aesthetics in the 'snout' year of 2014) have led to function far outweighing form, and any semblance of clean lines and balanced proportions – the two elements that most matter in car styling – almost completely disappearing. For similar reasons the same can be said for modern combat aircraft like the Typhoon or Lockheed-Martin F-35a. They are mightily impressive in their capabilities, but any idea of flowing lines probably ended with the Hawker Hunter fighter jet of over 60 years ago.

Bad air day

I had hoped when the new PUs were introduced in 2014 that the adoption of turbochargers would negate the need for airboxes. They came into use to produce ram effect for the atmospheric IC engine but are not relevant to forced-induction of this kind and do nothing for aesthetics. Clearly I had underestimated the total amount of cooling required for all the hybrid elements and the airbox remaining as the most efficient means of contributing to this. Shame, because the previous-generation turbo F1 cars looked much sleeker (see Brabham BT54) without these scoops above the drivers' heads. Therefore, should technical regulations take much more account of aesthetics rather than just fishing around the edges if F1 wants to attract more followers? I for one would love to see a grid full of the futuristic concept racers (but with open-cockpits) revealed by Ferrari and Red Bull last year. Over to you, Ross Brawn and co.

Supporting this view are the latest plans by IndyCar to re-invent the appearance of its high-speed machines. Finally acknowledging the importance of the wow factor in attracting a new audience, and having mucked about endlessly with regulation changes, the series' rule-makers have commissioned design studies to arrive at far more racy bodywork for its Dallara chassis. Not hard, on the face of it. As well as being a one-make formula, thus negating complicated negotiations, the current cars look as though someone had messed about with plasticine and Meccano after supping a few jars. Weird is a kind description; F1 cars are swans compared to these ugly ducklings. But let's hope that they get it right, for on the superspeedways such as Indianapolis, aero over-sensitivity is always a big crash waiting to happen.

Not all contemporary single-seater cars are ugly. The exclusively-used Dallara F3, for instance, is a little jewel of a racer, even if its droop-snoot breaks its lines somewhat and is a little reminiscent of Concorde in landing mode. It has a visible air-restrictor plenum, but it's discreet, on the side.

XPB

Jordan's 191 was one of the most beautiful cars to grace Formula 1 but the pursuit of aero performance has cluttered up more modern F1 machines

Le monsters

Of course, it's not just open-wheel cars that can cause controversy. One can separate the lovely classic post-war front-engine sportscars, typified perhaps by the Aston Martin DBR1, from later mid-engine closed prototypes with the advent of Eric Broadley's ground-breaking Lola GT, itself the inspiration for the Ford GT40. These two may not be stunningly good-looking in the way that the glorious P4 Ferrari and much-coveted Lola T70 coupe were, but they had a purposeful, compact and muscular presence that still attracts attention and defies age. As did the Porsche 917.

Conversely, Le Mans Prototypes from Porsche, Toyota and before this year Audi, have developed into exciting, brutal-looking but big and hardly stylish machines. Most of this is a ruthless drive for maximum aerodynamic efficiency coupled with the direction forced on the designers by the regulations. Admittedly, they would look a whole lot better without the awful slab-like engine-cover fins – a better solution to help prevent take-off while spinning should be possible in this technically sophisticated age.

But funny, isn't it, that shark fins are mandated in LMP, yet marked-down for removal in F1?

Form should follow function in racing, it's true, but going back over time it is often also true that the best racecars are among the most pleasing to the eye

Street smart

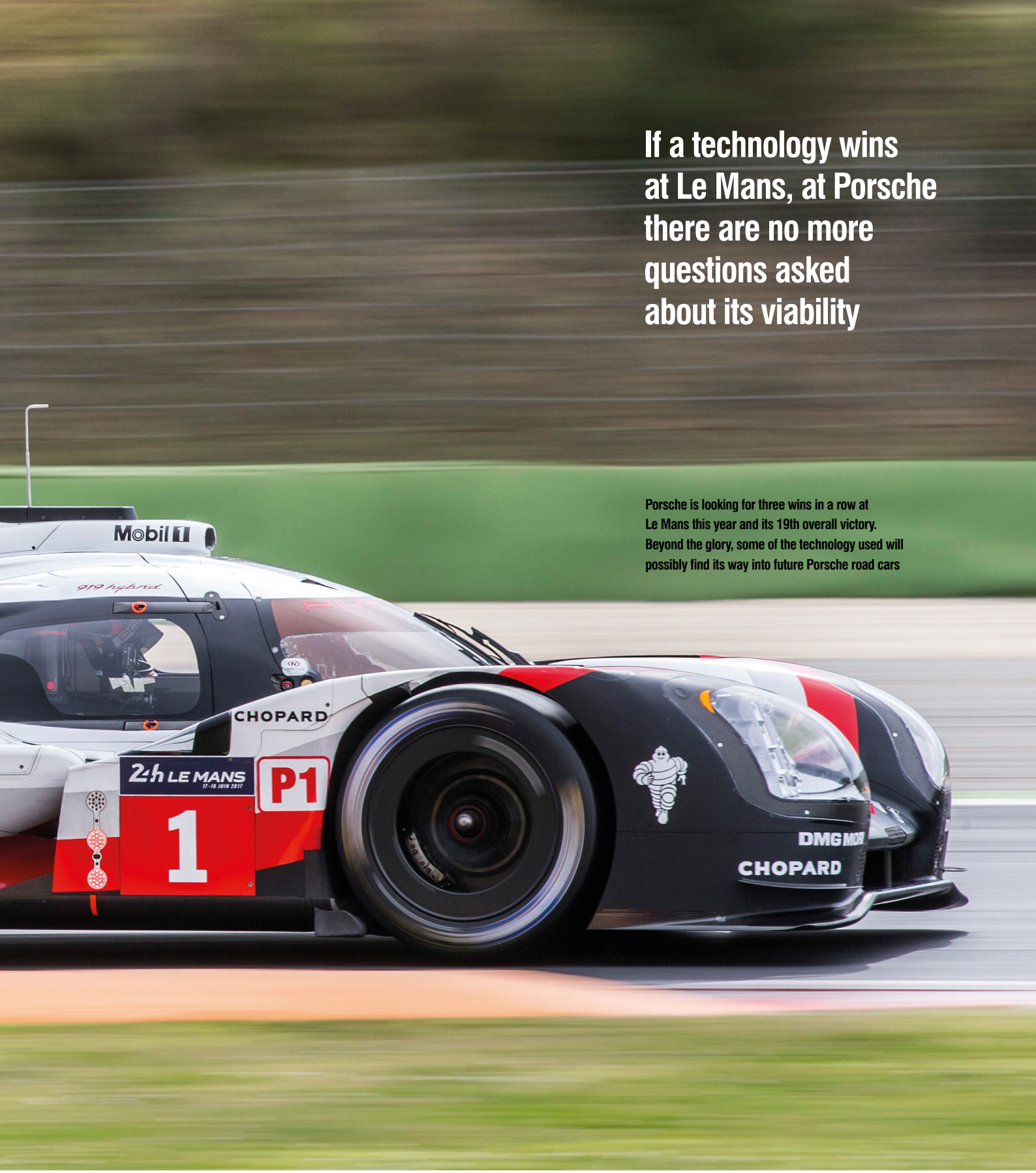
When Porsche made the decision to return to Le Mans in 2014 it was never *just* about adding to its impressive tally of wins – there was road car technology to develop too

By ANDREW COTTON

To those outside endurance racing, and particularly those involved in Formula 1, Porsche's involvement in the World Endurance Championship makes little sense. Why would you spend a Formula 1 budget, an estimated €150m, to compete in the WEC, which has just one race that really returns value on investment, the Le Mans 24 hours, while Formula 1 delivers that same investment more than 20 times per year?

There are a few responses to this argument. One is that Le Mans is a special race, and the fact that it is just once a year gives it the kudos that demands such a big investment. The other is that there is a large cross-over of technology between production car development and sportscar racing, and that actually the racing programme can accelerate learning, and save money, for the manufacturer overall. While many might argue that the latter point is now redundant, and is actually a thing of the past, Porsche's 919 Le Mans programme can trace a clearer path between the racing and road car development than ever before.

While rumours circulate about Porsche's continued involvement in the LMP category beyond the 2017 season, pay a visit to the Weissach Research and Development centre, where production and racecars are developed on the very same campus, and it is actually



If a technology wins at Le Mans, at Porsche there are no more questions asked about its viability

Porsche is looking for three wins in a row at Le Mans this year and its 19th overall victory. Beyond the glory, some of the technology used will possibly find its way into future Porsche road cars

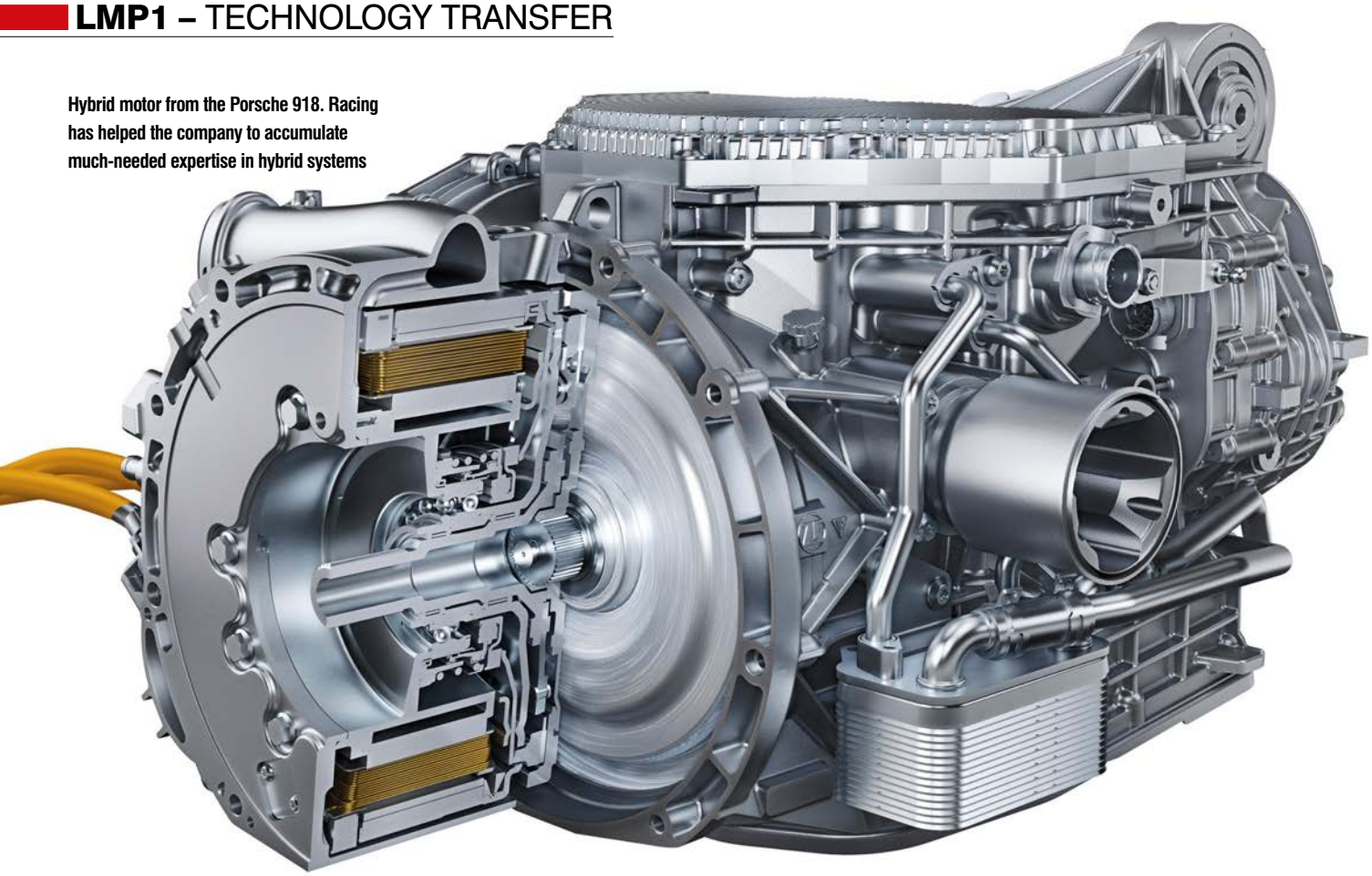
more difficult to imagine that this racing programme will stop any time soon.

The real key is in the development of hybrid systems, a new technology that does not have experts in either field. With the arrival of the Mission E, an electric car in the brand line up, and the LMP1 programme in full development mode, the crossovers are now clear to see, and it starts with the personnel. Porsche's end of season motorsport party is traditionally held in the 'Casino', more commonly known around the world as a lunch hall, the building and others like it provide a clear link between the two programmes as all the 5000 employees on the campus are encouraged to socialise together.

Social network

'I am a good example of how things can go,' says Martin Fuechtner, head of hybrid systems development within the LMP1 programme. 'I started my diploma work here in advanced powertrain development working on the concept of the Cayenne hybrid module. After that I did some prototypes and during that time in advance development I heavily investigated electrical machines and gearbox structures such as multi-mode gearboxes as well as axle drives.

'One of these projects led to a sportscar prototype, which is not public, but the derivatives of it were the 918 Spyder and the



Hybrid motor from the Porsche 918. Racing has helped the company to accumulate much-needed expertise in hybrid systems

The development of Porsche's 918 was headed by Frank-Steffen Walliser, now the head of Porsche Motorsport GT. It has a 4.6-litre V6 engine developing 447kW, and two electric motors producing 205kW. The whole car develops 887 horsepower

The LMP1 programme allowed engineers to start with a fresh sheet of paper and a whole new budget

911 GT3 R Hybrid.' The GT3 R Hybrid, based on the 997 model, was Porsche's first attempt at a hybrid car and, although it did race at the Nurburgring 24 Hours – and nearly won the race – and also in the USA at the Petit Le Mans, it did not go on to have the race programme that might have been hoped for.

The car used a flywheel storage system, an earlier version of the technology used in Audi's hybrid Le Mans cars, and the second version of the car, that raced in 2011 at the 24h Nurburgring, produced 75kW from each of the electric motors mounted on the front axle (up from 60kW in the first version and this was worth up to 200bhp; with batteries the system now produces more than 450bhp in the 919 hybrid). The second version of the car had shed 50kg from its base weight and with the greater electrical power, fuel consumption also improved. However, it was still a very early attempt at a hybrid racing car and there was still a lot of development to be done in the future.

'We did the first studies into storage systems that have a high rate capability with comparably low capacity,' says Fuechtner. 'They were lightweight with the potential of almost an infinite number of high power cycles – for a sportscar this is what you are looking for. We ended up with a kinetic energy storage with this because in those days the battery cells were not as good as they are now.

'The next question was how to integrate the electric traction drive into the comparably small body of a sportscar. We developed our ideas and came up with a design of an axle drive unit that incorporated a low centre of gravity and a high speed machine with individual final drives and short driveshafts for each wheel – the inverted portal axle. That led to a patent forming the technical base for the 911 R Hybrid front axle which suits the 911 perfectly.

Charging ahead

'This was one project, the other was the 918,' Fuechtner adds. 'Within the 918 road car development I was responsible for the electrical drive systems which was the next step in learning. It was not only one machine, or electric axle, but two machines which could be used for electric all-wheel-drive and many different driving strategies. From that, when the thing was driving properly, looking properly, you

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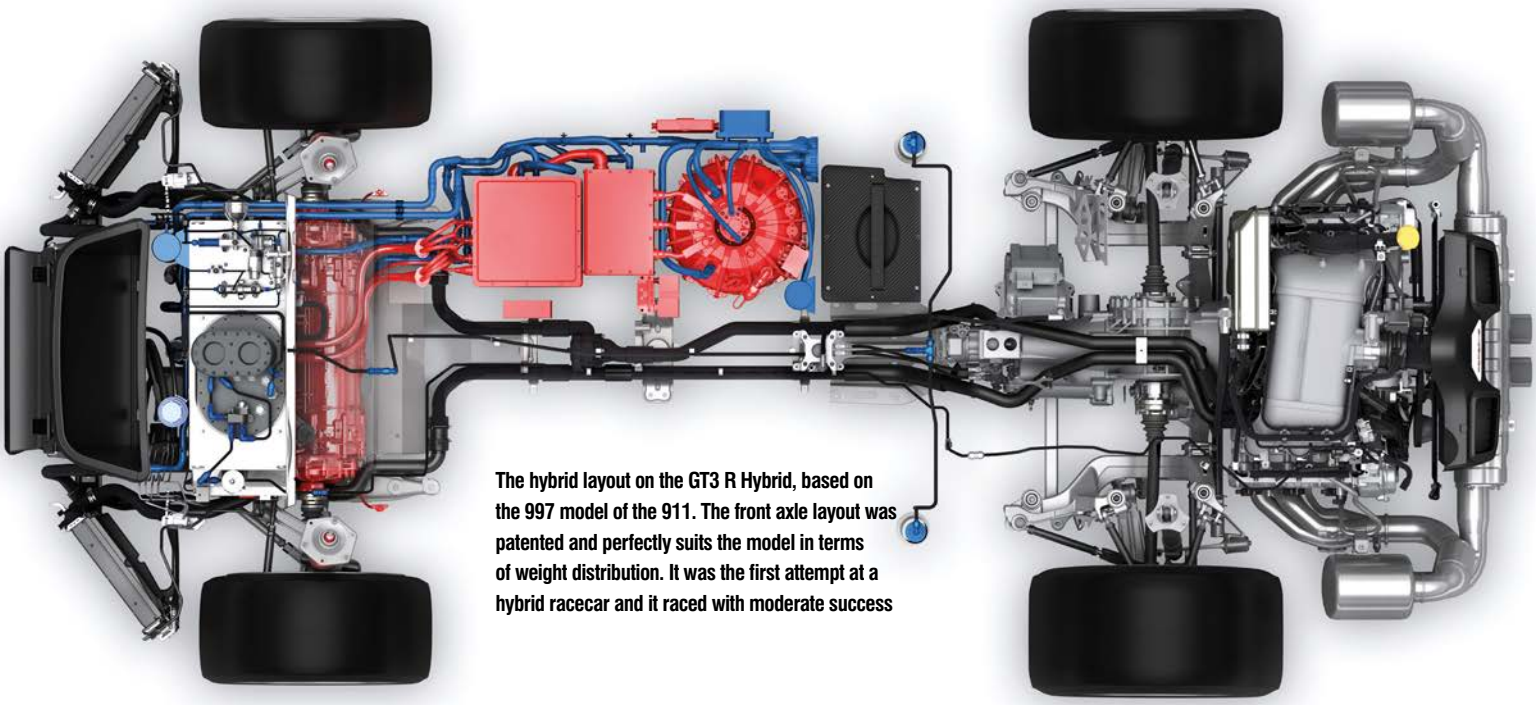

The hybrid layout on the GT3 R Hybrid, based on the 997 model of the 911. The front axle layout was patented and perfectly suits the model in terms of weight distribution. It was the first attempt at a hybrid racecar and it raced with moderate success

The Porsche Mission E has been developed with input from the 919 racing programme with the test bench developed for LMP1 helping enormously. When it goes for its fast lap at the Nurburgring it's likely to use race-derived power strategies

finally could have the benefit of driving a super sportscar at the weekend. I left because I was asked to do the LMP1. Of course, you don't think twice as a proper engineer if you are asked to participate in Porsche's return to Le Mans.'

Transfer window

While the 918 programme, Porsche's hybrid hypercar, was headed by Frank-Steffen Walliser, who is now the head of Porsche Motorsport GT, Fuechtner moved to the LMP1 project, a move from road to race that is becoming more common within Porsche's Weissach facility, as is race to road. 'You have people leaving the motorsport department and taking jobs in the road car development and the social network and links are still there,' explains Fuechtner. 'By having lunch together, you discuss things and exchange ideas which is positive for the same sort of problems that you are having.'

One of the key crossovers is in the electronics and software of these hybrid cars. Dealing with large voltages and with fast-rotating machines, managing power and delivering it safely is a primary concern across both disciplines and the knowledge of how to do that efficiently is both rare and critical to the success of both programmes.

'Before, everyone had the same background,' says Fuechtner. 'There were guys in the road car department who could build engines, and there were guys in the racecar department who could build engines, and both had different demands although each was a specialist.

'In the electric drive story, there is no such big wealth of knowledge of how to do high performance drives. The complexity of the technology is quite high and when you start that up, even though it was some years ago, you could only begin with going to suppliers and saying "Okay, I want this machine with this inverter", and integrate it in the best way possible. Then, obviously you are not happy with what is available and you start to ask questions, and we had many questions early on. With the 918 we made a big positive step, but there was still room for improvement.'

The LMP1 programme allowed the engineers to start with a fresh sheet of paper and a whole new budget. It gave them the opportunity to create a facility that was cutting edge in terms of hybrid system development and while the learning was painful, with a lot of destructive testing, the racing mindset and ability to build as well as test quickly in a working prototype accelerated learning to new levels.

Crossover tech

'In motorsport you can gather knowledge quickly, and this knowledge can be transferred very easily to, for example, 800V systems of the new electric car that we are developing because they had the same issues,' says Fuechtner. 'We are not where I want to be in terms of exchange, there is still room for further action, but one of the points where we did the exchange was with the test benches. We started with the first 800V structure and in the whole company – not even in the Volkswagen Group – there was no such infrastructure.

'On the dynos, the battery simulation infrastructure starts with the whole electrical net, and it was not meant to deliver 500kW so we had to develop that.'

The company also developed a four-wheel-drive test rig to simulate driving cycles and to help perfect its traction control systems with a live battery in it. There is still some work to

One of the key crossovers is in the electronics of these hybrid cars

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Porsche is not shy about showing off race to road success when it comes to hybrid technology. Pictured is 918, 919, and 997 GT3 Hybrid (left to right) with Panamera Hybrid behind

be done on this, but the intention is to keep up the development on it.

'We learned from series car development, how to do the testing and develop reliability, but we took it to the next level,' says Fuechtner. 'Giving back, how do you handle certain types of fuses and live battery systems in a test bench environment? An 800V system is a different story to the formerly known systems. For example, we had to do a lot of partly destructive tests to see what type of fuses is cutting multiple thousand amps safely and how to handle the voltages and thermodynamics within our electrical machines.'

Mission possible

Fuechtner adds: 'We now have the situation where when it was decided to do the Mission E car they already had the test bench ready, where they could test the whole drive system, and the approach of how you could put a battery in the test bench; what do you have to do? For safety containment, their choice is to not to do it full scale, but the dyno structure is the same, and the control assembly is the same. This had a tremendous effect on development speed.'

The battery used in the 2014 919 Hybrid was actually over-speced for the 8MJ maximum delivery that can be used at Le Mans, so for the 2015 season it was reduced in size and weight by a quarter, which was a significant performance boost for the 2015 car that went on to win at Le Mans that year. What the racing team has discovered is that, thanks to Porsche's successful racing history, if a technology wins at Le Mans, there are no more questions asked about the technology's viability!

'What is happening at the moment is that having learned to handle drives and batteries and inverters that can do track racing with very high duty cycles, we can also transfer approaches like cooling to road car development,' says Fuechtner. 'Basically we are facing problems that have solutions that are not racing specific. You have materials that you cannot use in road car development because of cost restrictions, but the cooling approach and the principle of machine design – this can be transferred. We managed to double the constant power output of these drives with a different cooling approach, which is tremendous. We showed that it is not that difficult.

Race-honed

'Generally, in road car development you have to think and evaluate a lot before you take steps because they quickly get expensive,' Fuechtner says. 'So it is beneficial to have a racing programme where you can push boundaries for new technologies. Development speed in racing is quite high which means it takes us usually two to five years from pre-development of a very new technology such as power semiconductors on a laboratory level to a racing application. If the technology is performing well you have also answered some fundamental questions for the road car development. In road car department a lot less questions are asked if you win races with this bits of new technology.'

Some of the parts that are developed for the racecar are not far away from a possible integration into production cars; others need

'In road car development you have to think quite a lot before you make steps, because they quickly get expensive'

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Porsche has traditionally run a customer programme with its prototypes, even with its 917s, but the complexity and IP of the 919 means that's no longer possible

more work, although the majority of that is around materials and reducing costs for the mass market rather than in concept. Another area of crossover, although the delineation between the two is blurred, is how to make the Mission E car lap the Nurburgring Nordschleife as quickly as possible. Being a Porsche, the Mission E has to go to the Nurburgring. There is no question about that. The target lap time has already been set (although this has not yet been revealed).

'To achieve the maximum performance over several laps or with a given energy you can directly transfer the driving strategies developed for the 919 Hybrid because the key question of how to use the available energy in the most effective way in order to maximise the performance is quite similar,' says Fuechtner.

'What you could put into the driving modes is the knowledge learned from LMP1, where to use the energy, how to use it, how to handle the electrical components in order not to have thermal deratings. On the other side, the methodology developed in the 919 programme could help to quickly determine the bottleneck for overall performance in order to set the development priorities correctly. That is an example of the knowledge that we can transfer.'

Electric hyper car?

The next stage could see the Mission E development programme working with the race team to develop batteries, inverters and machines in much more detail, although the relationship between the two has 'decoupled a little bit', but the engineers are now keen to extend the product line and produce an updated 918. Following the time-line of new cars, from the 959 to the Carerra GT and the 918, there are a few years before the next hypercar is due. However, the rate of development for new technologies is now so accelerated that the schedule could change. 'The questions that are pressing are: is it an electrical hypercar or a hypercar that is still combining a combustion engine and electrical drives? If it is the second, then the electrification will be with more power. If it is the first, then we will see racing technology in that car. But both cars will quite certainly have the ideas of the LMP1 in there, *if* there is a car like that!' says Fuechtner.

The whole LMP1 programme is different to Porsche's traditional values. From the 917 onwards customer versions of the cars have been made available, but it is clear that this 919 programme carries a complexity and such restricted intellectual property that a customer racing programme is not likely.

The level of development also clearly shows why Porsche, and Toyota, are pushing to retain the very high level of technology in LMP1 as the WEC organisers look for ways to reduce the cost of competing in order to attract a new manufacturer for the 2020 season under a new set of LMP1 regulations. And, as far as Formula 1 is concerned, it is clear why Porsche elected to go to Le Mans. The learning that has been developed from racing to production cars, and back again, is a clear indication of the value of this programme, so even without a customer racing programme, customers will likely still drive the technology.

'You have people leaving the motorsport department and taking jobs in road car development and the social network and links are still there'

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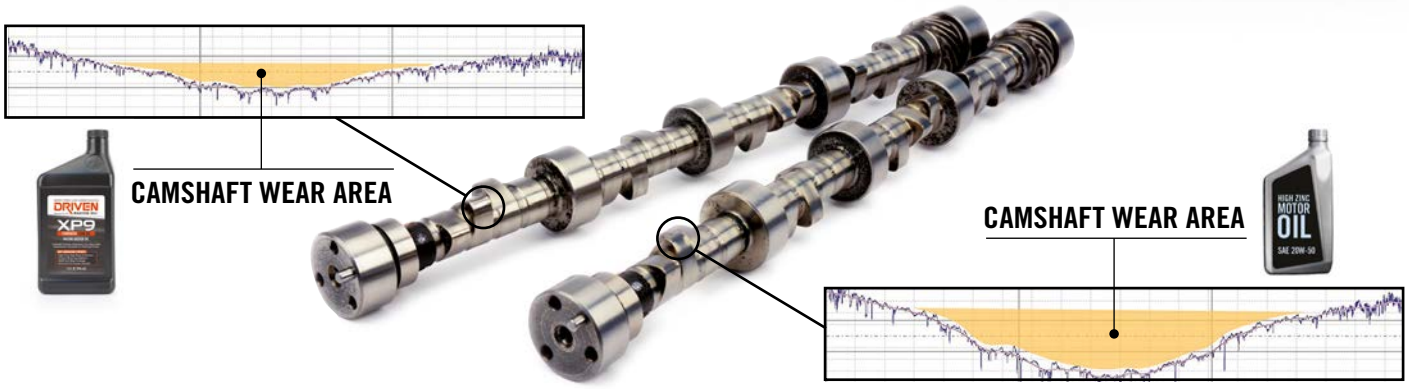

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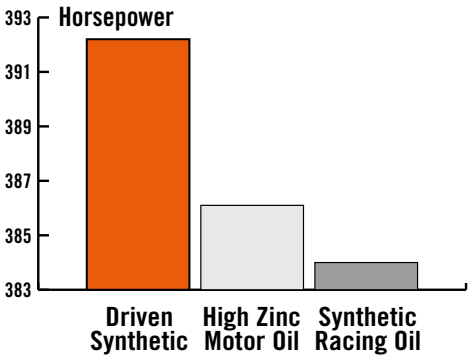

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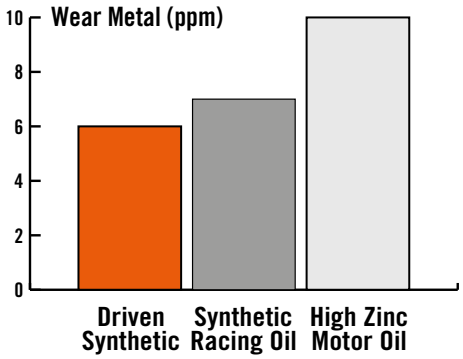

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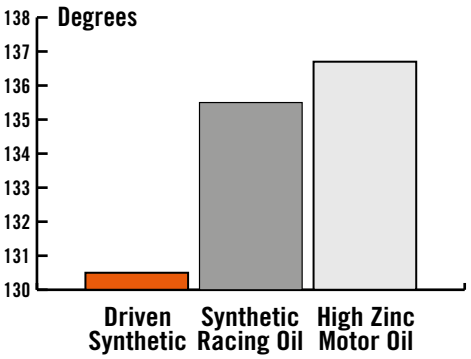

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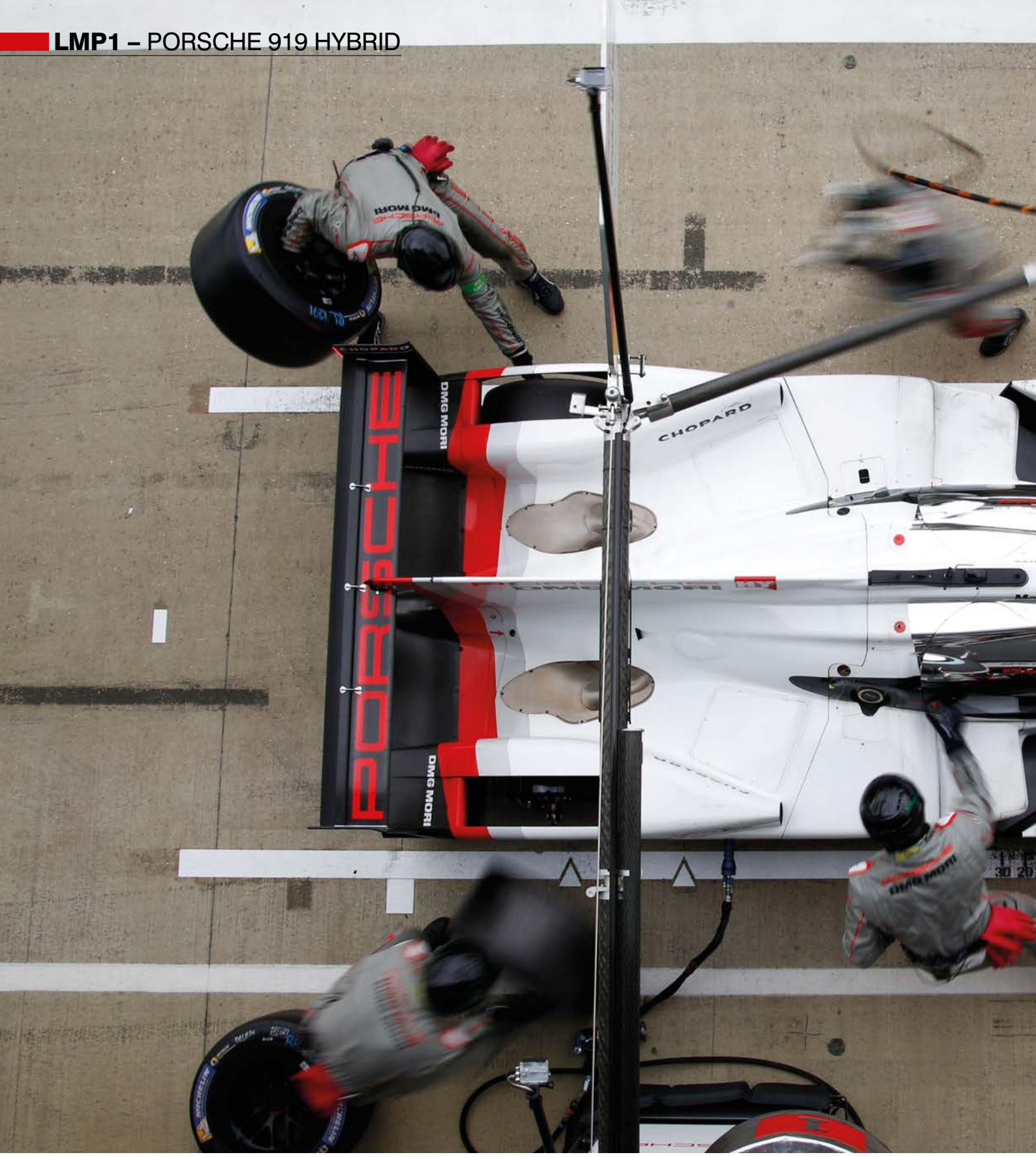

The theory of evolution

Its 919 Hybrid has found buckets of lap time this year compared to 2016, yet Porsche insists this is purely down to evolution rather than wholesale change. *Racecar* went to Weissach to unlock the secrets of this car's development

By ANDREW COTTON

Porsche may not have won either of the two opening rounds of the World Endurance Championship, but the team goes to the Le Mans 24 Hours in confident mood having run only its low downforce kit at Silverstone and Spa, and yet still gained a podium at both races as well as a wealth of experience with its Le Mans package.

New regulations this year have forced manufacturers to reduce the number of kits to two for the season, low downforce intended for Le Mans and high for other tracks in the WEC. However, Porsche took the decision to concentrate on its Le Mans kit despite Silverstone being suited to a high downforce package and to delay its 'kit two' until after June's 24-hour race.

The headline change to the LMP1-H regulations at the start of the year was one that was designed to slow the cars at Le Mans by up to two seconds. A raised front splitter, reduced width rear diffuser and a reduction in the number of tyres available to the teams were all supposed to reduce performance. But what the change in regulation has actually done is force both Porsche and Toyota into a programme to claw back that lost downforce – and now the cars are faster than ever.

Counter revolution

Aero work has of course contributed heavily to the improvement in performance, with much of the work between the front wheels and from the nose to midship taking priority and providing huge gains in performance. However, the aero team also points to other departments when it comes to taking credit for the improvement that has seen the 919 Hybrid drop only a few points to Toyota's high-downforce cars at Silverstone in April and Spa Francorchamps in May.

The engine and drivetrain engineers say that they have made huge gains in performance this year, with a higher compression ratio than ever before, and with more fuel efficiency and power. Reliability has also been a key development area.

Porsche approached this year with an evolutionary method rather than the revolution applied by Toyota. While Toyota has gone for a new aero concept and directed more air through the car, Porsche considered that to be of less importance and has stuck to its original concept of flow over the bodywork of the car.

Car concept

Porsche team principal Andreas Seidl says of the overall aerodynamic concept: 'Compared to Toyota, at the rear our step looks less extreme but we were mainly focussing on the front and towards the middle of the car. Most of this was the new fenders at the front, which are quite wide, and the channelling of the air from the front to the mid-section of the car, to the radiator inlets and so on. That came together with the basic cooling concept. The arrangement of the radiators is different, and the position is obviously different, plus the way that we were guiding the air through simply to need less to do more cooling. In general we didn't have an issue so we could cope with the ambient temperatures, but the less cooling, the less drag. The loss of downforce by the regulations was the biggest target; to get the downforce back without increasing the drag too much.'

Christos Pashias, leader of LMP1 aerodynamics at Porsche added: 'There was a huge downforce loss

New regulations have seen the front splitter raised in the centre to reduce downforce, but Porsche and Toyota have both developed this area heavily to regain performance

The low-downforce 'kit one' rear wing is ready for Le Mans. Porsche has experience of adjusting it for different track conditions and temperatures after Silverstone and Spa

Mirrors are embedded in the wheel arch. Toyota challenged this, on whether it could affect driver visibility, but Porsche says this has improved thanks to reduced vibration

Porsche has introduced an F1-style wheel nut retention system that is supposed to increase speed and accuracy of its wheel changes. It's a risk with new tyre limits this year

due to the regulations front and rear and there was no getting around it. We started [the development cycle] with a hybrid of our high downforce package [of 2016] on the low downforce kit. The front was much closer to the sprint package than the Le Mans kit to get the loads back. We spent a lot of time working to get the car to work as a good package, and make sure the front is behaving in a suitable way.'

Rear view

Pashias continues: 'At the rear it is more challenging. As with all racecars, it is difficult to break the lift to drag ratio that is inherent in the rear. It is more challenging to find the downforce for free. We had to recover downforce from other areas. We did quite a bit of work on the front area between the wheels to maximise the clean flow to the rear, and the sidepod is substantially different which was also done with the aim of helping the rear, as well as details next to the wheels, where small changes make a big difference.'

'We have achieved all of the goals that we have set for ourselves in terms of development'

As Pashias says, the sidepods are radically different to those of previous years, not least due to a regulation change that calls for a channel between the cockpit and the wheel arch that helps to increase the take off speed for the cars in the event of an accident. A lot of work has also gone into the radiators and the air that is expelled from them, and around the wheels to reduce the wake signature of the car, and improve efficiency. One key difference to previous designs is that the sidepods now house the mirrors. While they are tucked away, helping to reduce the drag, their location had an unexpected benefit. 'We worked hard to do that, and we are happy with the result,' says Pashias. 'It is a small drag gain, but a side-effect is that the mirrors vibrate a lot less now, so you can actually see through them!'

While Pashias acknowledges the potential advantages of the 'through-flow' concept, he was put off by the potential drawbacks, including changes to cooling. Porsche has instead developed last year's concept and worked particularly hard on the underfloor, between the front wheels and the mid-floor section. One of the weak points of the 2016 car was a rubber build up in the front wheel arch that upset the balance of it, which the team appears to have fixed in the 2017 version.

'Having the confidence of the previous cars, we could push harder in the areas that we were confident in and go even more extreme, and back off in some areas where we thought we pushed too hard,' says Pashias. 'It is more the front and the middle [of the car] which is where all the big gains come from. At the rear there is a standard diffuser. You can do a lot under the wheel arches with small details, which have a big effect, but the front is where, if you get it right, the car behaviour is good [when the driver is] pushing to the limit.'

Pitch perfect?

Pashias was particularly coy when talking about the pitch sensitivity and weight distribution of the 2017 model. Clearly a lot of work has been done to improve the balance of the car, particularly to accommodate the new tyre regulations that have seen a reduction to four sets, plus two joker tyres, for qualifying and race. This is designed to encourage double stinting and reflect the endurance element of the sport, and has been particularly relevant to Porsche's low-downforce approach at the opening two races. 'We worked on the pitch sensitivity, but

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Sidepods have been revised to improve air flow to the rear and a new channel has been opened up between the cockpit and wheel arch to improve safety at high speed

A great deal of detail work has been undertaken to reduce the wake signature of the racecar and clean up airflow to the rear, particularly around the front wheel arches

Braking systems in hybrid cars have been developed to prevent a driver from noticing when the system is in recovery or not; this system can also be adjusted by the driver

The manufacturers agreed to retain their monocoques until 2019, although Porsche says it could have saved a lot of weight had it changed it. It introduced current chassis in 2015

what we did I cannot talk about,' says Pashias. 'When you change the regulations, the first step looks like a disaster and it was a big hit, four to five seconds at Le Mans, but with the work that you do you recover a lot of it. If you divide how many months by wind tunnel sessions, if you gain five seconds and divide it by the number of sessions, say 10 sessions for the development a year, every session is worth half a second. If I have an extra session and that's half a second, it's a game changer.'

Porsche has introduced a Formula 1 style retained wheel nut system this year in a bid to speed up wheel changes. It is a risk, particularly with the new tyre rules that also encourage sets to be kept together for a second stint, and a cross threaded nut would be particularly problematic, but Porsche believed that this was the right time to introduce it.

ICE sage

One of the major achievements of the race engine department is the development of the exhaust heat recovery system. But the ICE has, by the team's own admission, been the area of the most development. Seidl says: 'The MGU side of it is almost at saturation. From our engine side we had two main points to tackle. One was reliability because we had some areas last year where we didn't feel 100 per cent safe so we worked on that. It was affecting basic parts of the engine, and on the other hand, we saw from the development testing on the dynos that we could manage a big step in terms of performance and efficiency coming from various areas of the engine. We could reduce the friction side of the engine, working on things like bearing friction, oil system and so on. We could make a good step on the gas exchange and on the combustion side we made quite a good step and that increases the efficiency of the engine even with the given fuel flow. That is also a reason why we can make these steps.'

Porsche has rather underplayed the introduction of 'jet ignition', though, and is coy about when the team started to use it, and while Stefan Moser, leader of LMP1 engine testing says 'we have made the biggest step ever this year,' he didn't provide too many details as to what they have improved. 'Obviously we worked on combustion, as did everyone, and there was a lot of talk about 'jet ignition', and this we also worked on for quite a while,' says Moser. 'We never really talked so much about it because what you read in the newspapers, that it was developed in F1, actually this technology is around for almost 20 years in gas engines, and the technique is nothing new. It is just applied to race engines now and this is important. We could talk about improving efficiency and higher pressure but all of these phrases are out already. The important thing is durability, and in 24-hour races that becomes a big issue.'

Durable parts

Moser's colleague, Thomas Kramer, leader of LMP1 engine design, says: 'We just took the parts and applied them to the engine. That was the easy bit. The most difficult bit was the durability and for doing this for 24 hours, for 6000 to 7000km, that's the most challenging [task] we had in the last few years or months.

'There are some components in the engine, when you look at the conrod bearings they are the first ones to suffer from the higher pressure,' Kramer adds. 'The usual methods to solve these things don't apply anymore. Diesel engines in the past had higher pressure but with the revs

The sidepods are radically different to those of previous years

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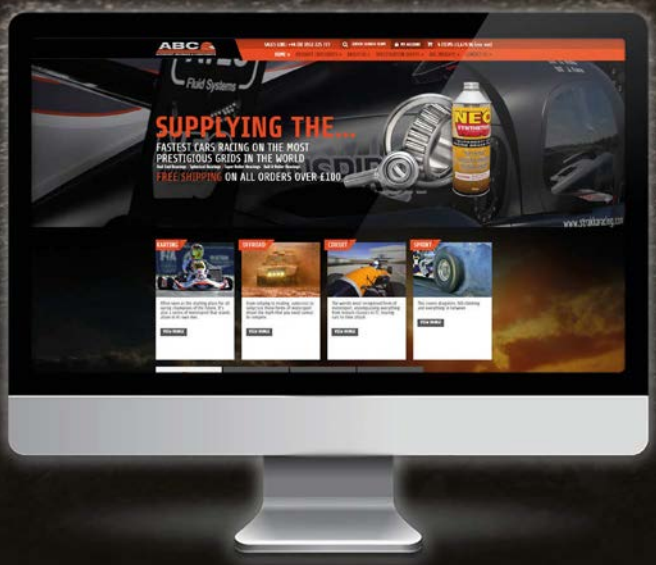

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The engine team is particularly proud of the fact that the 919's intake is so small, and they can't work out why it isn't smaller

Much of the development has been focussed on the tiny V4 internal combustion unit that sits at the heart of the 919, Porsche working on its reliability, performance and efficiency

TECH SPEC

Porsche 919 Hybrid

Category: LMP1-H competing in the World Endurance Championship, including the Le Mans 24 Hour race

Monocoque: Composite material structure consisting of carbon fibre with an aluminium honeycomb core. The cockpit is closed.

Combustion engine: V4 engine (90-degree cylinder bank angle), turbocharged; 4 valves per cylinder; DOHC; one Garrett turbocharger; direct petrol injection; fully load-bearing aluminium cylinder crankcase; dry sump lubrication. Displacement: 2-litre. Max revs: 9000rpm. Power 500bhp at rear axle.

Engine management: Bosch MS5

Hybrid system: KERS with a motor generator unit (MGU) mounted on the front axle; ERS for recuperation of energy from exhaust gases. Energy storage in a liquid-cooled lithium-ion battery (with cells from A123 Systems). MGU power: 400 PS, front axle

Drive system: Rear-wheel-drive; traction control (ASR); temporary all-wheel drive at the front axle via the electric motor when boosted; hydraulically operated sequential 7-speed racing gearbox

Chassis: Independent front and rear wheel suspension; pushrod system with adjustable dampers

Brake system: Hydraulic dual-circuit brake system; monoblock light alloy brake calipers; ventilated carbon fibre brake discs (front and rear), infinitely variable control of the braking force distribution by the driver

Wheels and tyres: Forged magnesium wheel rims from BBS; Michelin Radial tyres, front and rear: 310/710-18

Dimensions: Length, 4650mm; Width, 1900mm; Height, 1050mm

Weight: Minimum 875kg

Fuel tank capacity: 62.3 litres

like a gasoline engine, and to combine these things, it was completely different. Therefore we had to work in new ways, and find out the hard way to get these things to work.'

Lean machine

Like the car itself the engine development is an evolutionary process, with higher compression ratio, lean burn (which has been a feature of the engine since 2014 when a major step was taken that brought it close to the limit of the window in which the engine can work without major redesign) and driving efficiency all at the centre of the development programme. 'The lean burn is nothing new,' says Moser. 'We are talking low numbers of per cent improvement, but still you can optimise that level of how lean the engine is with the BSFC [brake specific fuel consumption]. We have been running lean since 2014, and in 2014 we had changed this quite dramatically and it took some time, but then we have been at the level where we run as lean as is most efficient and we couldn't change much. That has not changed since jet ignition. We have been looking at this for a long time now. You always have to change the entire engine around it. You cannot just put one thing up. You have to change the intake ports and exhaust otherwise it doesn't bring a benefit.'

Breathe easy

One of the key visual features of the car is the small air intake above the cockpit, particularly when compared to that of Toyota. The engine team is particularly proud of the fact that the intake is so small and can't work out why it isn't smaller. The engine design work started in 2011, before the regulations were fixed, and so it was originally designed for an air-restricted engine. However, once the rules were finalised in 2012, it was clear that there would be a fuel flow limit instead, and that meant the air was free … which then led to a far larger turbo. Clever design has reduced the size of the turbines, which helps to reduce turbo lag. 'For us, this is efficient, no question,' says Kramer. 'For the bigger turbo, we had the AER, the exhaust heat recovery system. To package this in the rear is a bit challenging. Christos [Pashias] wants a tight engine cover that tails off early in the line, so we had to package everything [tightly]. The bigger turbo because of the change to the fuel flow meter did not make a big difference.'

Another change that is coming to the regulations involves the fuel supplier. Shell has supplied the fuel to the WEC as the sole supplier, with fuel that is close to pump values, which has rather limited the power that can be developed compared to, say, Formula 1, where the fuel blend can be adapted to the particular needs of the engine. 'Formula 1 can develop their own blends,' Kramer says. 'We had to find a compromise. Of course, because of the knocking it is a different thing. You have more freedom if you can do your own blend. From a design point of view, for us it is a maximum load which occurs, and in the V4 the cylinder pressure and load is very high. If you can spread this on more cylinders it is easier.'

Moser adds: 'In terms of fuel, in Formula 1 they have the fuel flow meter and can develop their fuel and they try to get more energy from every kilo, and this we couldn't do. The MJ per kilo is fixed but then we tried to optimise the engine best for that fuel, so injector, compression ratio and combustion chamber.'

Lag reduction

One other difference is that Formula 1 uses the hybrid power to reduce turbo lag, but Porsche's solution to the lag problem is a special design for the compressor layout, which is very light and able to be made extremely small. The turbo sits between the bank of cylinders while the hot exhaust flows around the side of the engine, and so is not the 'hot side inside' concept that was favoured by Audi.

An element of the design of which the engine department is particularly proud is the development of the exhaust heat recovery system, which is all done in-house. 'The heat exchanger is done at Porsche from the drawings to building it,' says Kramer. 'The whole process of building these, the balancing of the shafts because this thing is turning at high speed, and to bring this to a 24 hour race and be durable was a separate big challenge, but it was done in-house and it is something that we are proud of. We did the turbine, the housing, the electrical elements. It is all done and developed here, and we test it, and do the balancing, so it is quite demanding. It has quite a high power output and from a weight point of view it is nothing. We are quite proud of this and the whole team, from the mechanics to the guys building it, it is a nice chain.'

When Porsche first returned to Le Mans in 2014 there was a power struggle between the two VW brands competing. Porsche and Audi were vying for overall technical development rights for the group and while Audi bought in much of its technology other than the diesel engine, Porsche was clearly geared up to providing much more expertise in-house. Perhaps this is why it is still in the WEC?

As for Porsche's own thoughts on its 2017 car, Seidl has the last word: 'I am happy that we have achieved what we set out to achieve. Whether that is enough, we will only find out on Sunday afternoon at Le Mans.'

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Haas will be reflecting on a decent start to its second season, where it has built on its first year form to cement its position in the F1 midfield

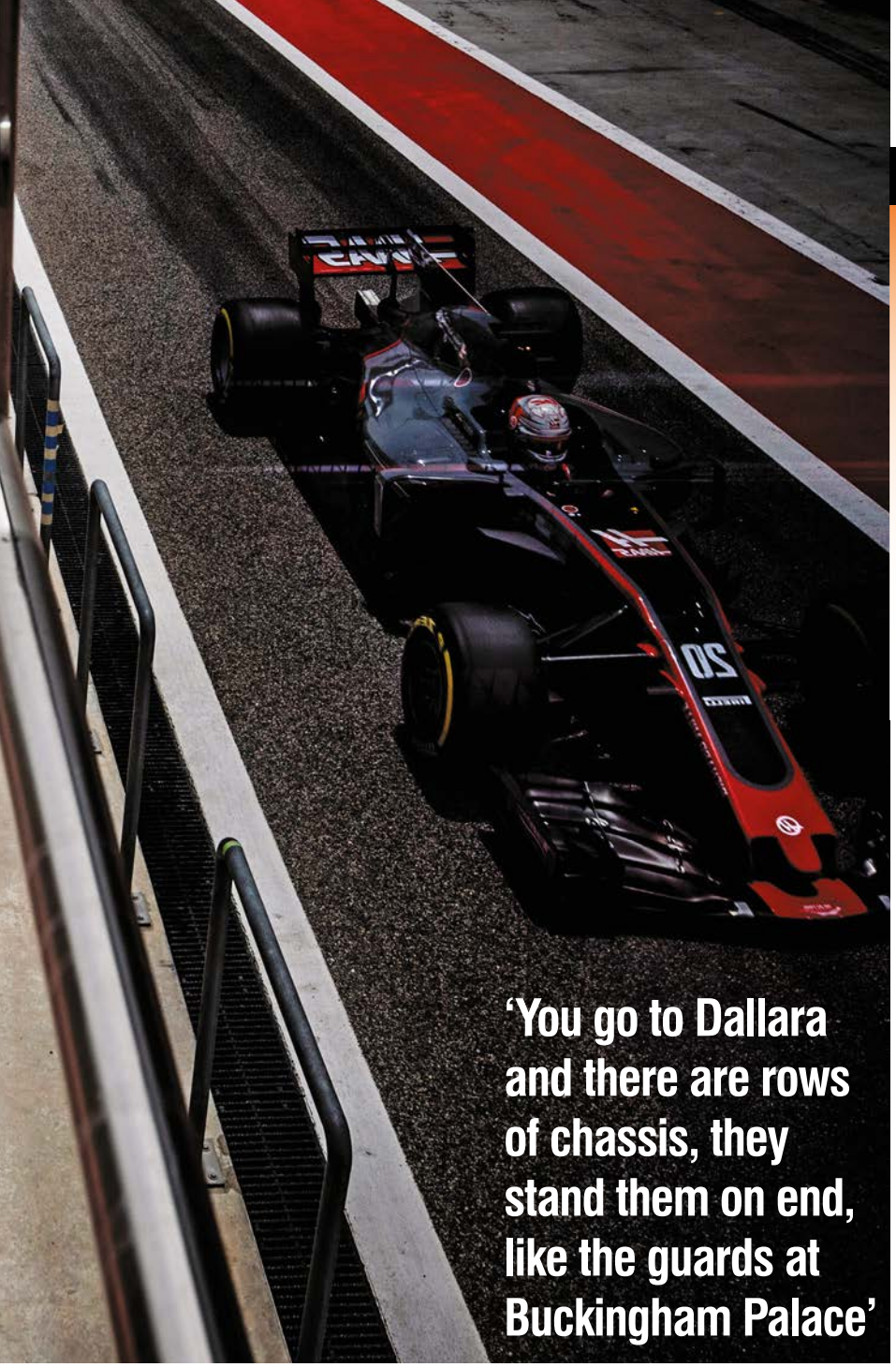
Classy Chaassis

While its links with Ferrari are well known Haas relies on another Italian motorsport legend to help it shape its chassis – *Racecar* examines the unique approach Haas and Dallara have taken with the very capable VF-17's monocoque

By SAM COLLINS

When Gene Haas announced that he was going to enter F1 it was immediately clear that the machine tool entrepreneur was going to do things differently. Eschewing the traditional route of building all but engine and transmission, Haas and his team principal Guenther Steiner decided to take advantage of a discrete change in the rules, and build the minimum amount of bespoke components allowed, namely monocoque, front crash structure and bodywork. Everything else would come from Ferrari and would be largely identical to that used on its own racecars.

Yet even those bespoke Haas parts were outsourced somewhat with the team forming a partnership with Dallara in order to help manufacture and design them. A technical team headed by former Red Bull Racing man Rob Taylor was set up with operations in Kannapolis,



'You go to Dallara and there are rows of chassis, they stand them on end, like the guards at Buckingham Palace'

USA, Banbury, UK, and at Ferrari and Dallara's factories in Italy. In terms of the design of the chassis it is very much a joint effort between the Haas engineers and those at Dallara.

'Dallara does all the chassis manufacturing,' Taylor explains. 'Of course, every one knows it is a big organisation, but it makes loads of chassis, I mean loads. For me it is really alien walking into the factory, I don't think I've ever worked anywhere which has made more than five chassis, or at least that being the plan before drivers shunted some and wrote them off. It's come down in recent years, too, without testing; now we only make three. But you go to Dallara and there are rows of them, they stand them on end, like the guards at Buckingham Palace: GP3, GP2, Super Formula, LMP, F3, IndyCar, Indy Lights, Formula E, it is astonishing.'

While Dallara is used to mass producing tubs for spec series Formula 1 requires a rather different way of working. 'Our chassis don't get stacked like those spec series racecars do, we have our own special area of the factory. We have our own assembly area and stores. It would be too difficult to work through the main Dallara stores, as you can imagine there is just loads of stuff in there, so our parts are channelled separately,' Taylor says.

But this does not mean that Dallara's wealth of knowledge in constructing competition cars cannot be applied to the Haas F1 project. Indeed according to Taylor it allows the team to use some manufacturing techniques that its rivals would probably not even consider. 'The way our tub is laid up is similar to Dallara's normal process, similar but at the same time different. The real eye-opener for me was that Dallara have come at manufacturing monocoques from a completely different perspective than anything I have done before.

TECH SPEC

Haas VF-17

Chassis: carbon fibre and honeycomb composite structure. Carbon fibre bodywork.

Engine: Ferrari 062, turbocharged 1.6 litre V6; max revs 15,000rpm

Suspension: Independent suspension, push-rod activated torsion springs front and rear. Sachs dampers.

Transmission: Ferrari servo-controlled hydraulic limited-slip differential with semi-automatic sequential and electronically-controlled gearbox, quick shift (eight gears, plus reverse).

Clutch: AP Racing.

Steering: Ferrari.

Brakes: carbon-fibre disc brakes, pads and 6-piston calipers

Cockpit: instrumentation, Ferrari; seatbelts, Sabelt; steering wheel, Ferrari.

Wheels: OZ Racing

Tyres: Pirelli P Zero

Fuel cell: ATL

Full and lubricants: Shell

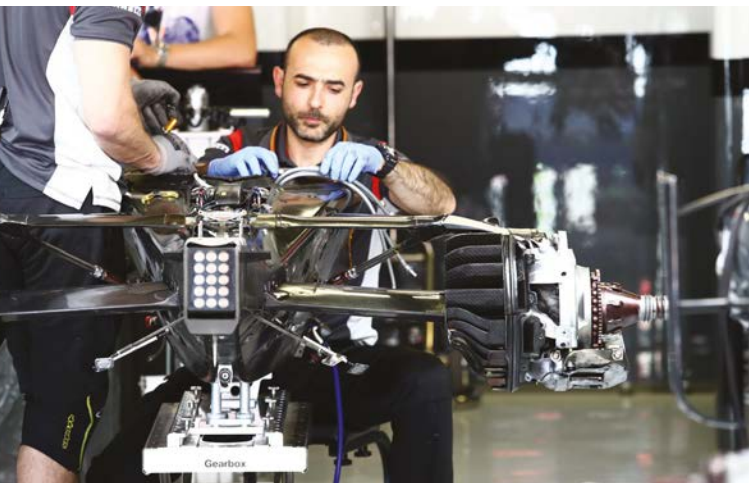
Weight: 782kg (including driver)

In F1 there is the temptation to be the arch conservative as you don't want to mess up a monocoque. It is on the time-line and if you get it wrong you are in a world of pain, but Dallara are doing things which when you first see you think are really risky, but they have done it hundreds of times and have total confidence. They have evolved from a completely different place, a different mentality to what is normal and I find it really enlightening at times. Some of the techniques they use are really cutting edge and extremely good. But they have come at that from making chassis for the last 50 years, their ability and confidence level, which might seem marginal to a typical F1 team, is really high.'

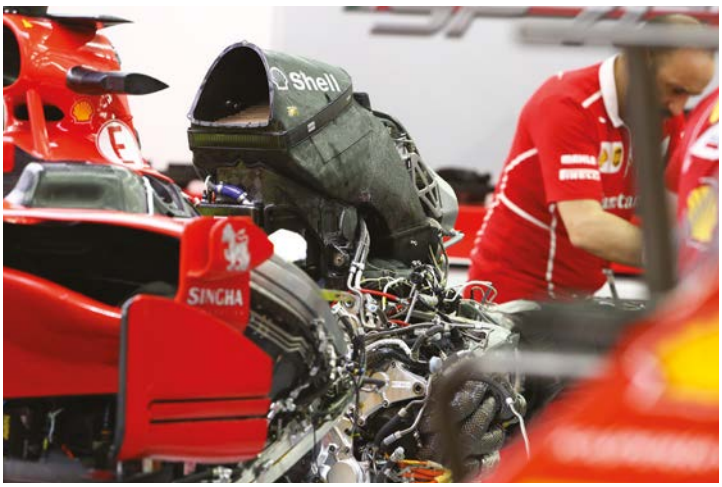
Haas you like it

Despite the unique set up of the Haas team with some staff working in the USA, others in England and Italy, it is clear Taylor values the input and face to face time he has with some of the Dallara engineers. 'It is how design works. I can walk in to see Luca Pignacca (Dallara's chief designer) and chat to him, and we can exchange ideas. That is the Holy Grail really of factory design, you have the aero guys sitting with the structures guys and the suspension team or whatever, and they can all chat to one another,' Taylor says. 'There are things that Dallara does on other cars which we can learn from, that's the core of it. I don't mean we just go and nick the design of the Super Formula bulkhead, or whatever, but the concepts, the principles, the spark of an idea, that all feeds in. It is an interactive process, and good design engineers have a catalogue of good ideas in their heads and when they all sit together they can exchange those ideas. Dallara has a wealth of those ideas.'

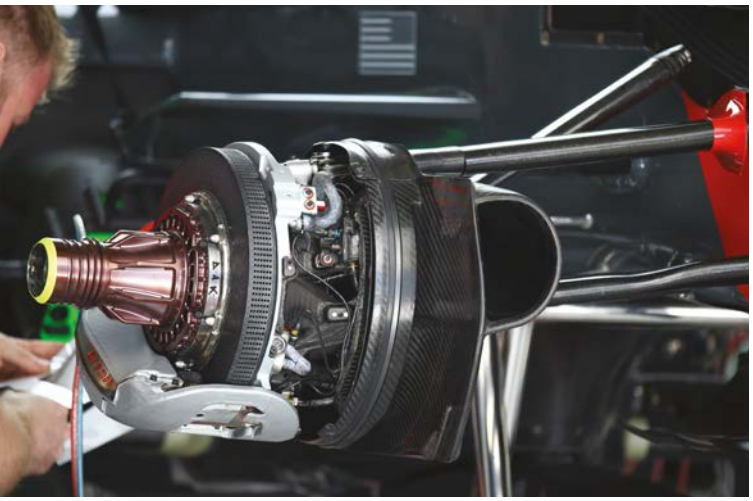
This approach worked reasonably well in 2016 with the team scoring points on its race debut and ultimately ending up eighth in the constructors' championship. However, the new



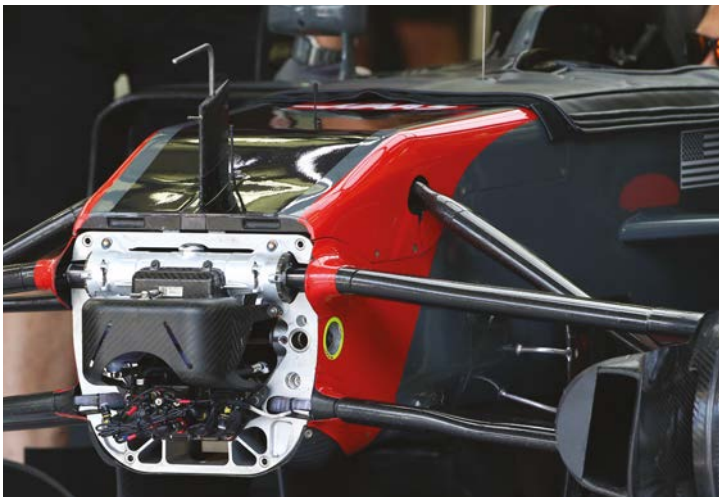
The Haas VF-17 is packed with Ferrari parts including the gearbox. This reliance on Ferrari ties the hands of the Haas design team early in the process, to a certain extent



The real ace up the Haas team's sleeve is its 2017 spec Ferrari power unit based around the V6 ICE, a very potent package this year. The PU is seen here in the Scuderia's SF70H



Brakes have been the headline issue for Haas thus far this season. The team has experimented with different suppliers but the problem has yet to be fully resolved



Haas chassis is made by Dallara. The famed Italian concern is well-known for its one-make lower formula racecars but Haas has found its experience and nous to be invaluable in F1

season would be a very different challenge to that debut year, not least because of new technical regulations which increased both aerodynamic and mechanical grip. This meant that the loads going through the chassis would be significantly increased in turn, but the trouble was nobody was quite certain exactly what those loads would be. Tyre manufacturer Pirelli was unable to test its 2017 tyres on representative cars in 2016, so its tyre data was really an estimation at best. It meant that every F1 team faced the choice of designing parts to deal with the highest possible load cases, and risk being overweight if the loads were lower than expected. Or designing to a lower set of loads, but run the risk of mechanical failure.

Strong or stiff?

'From our perspective it was quite difficult to calculate things for this year,' Taylor says. 'We had some idea of the suspension loads but it wasn't entirely clear. What you find though is that you are designing your monocoque not for track running but more for how it crashes. By that I mean you design your monocoque for the strength component and you throw in the stiffness where you think you have a problem. There are certain pickup points which are quite sensitive to stiffness, but most of them are strength derived. You need to make sure that if you have an accident the suspension arms cannot punch through, you need to make sure that the chassis is stronger than the wishbone and that is a strength derived thing, not stiffness'

Taylor feels that some engineers in motorsport, especially some of the younger ones, misunderstand the difference between strength and stiffness. 'So here is the thing, strength and stiffness are two different things and a lot of engineers glaze over at this. Lots of people say make it stronger and what they mean is make it stiffer. The vehicle dynamics guys may say that if you make the chassis this stiff then you can use this or that type of spring as it is a spring-series system. But it is a historical data thing, you look at previous designs and look to see where you can make improvements. The drive in the past was to always make everything ever-stiffer, but that was the less informed way of doing things. Techniques and materials were getting better and better so you could increase stiffness and efficiency, too. But we don't have a historical database to refer back to, so we have to rely a bit on experience floating around in your head, and other cars that Dallara are doing.

Forza habit

Designing a chassis to uncertain loads was not the only challenge for Haas, for its approach of utilising a substantial amount of parts from Ferrari means that its engineers do not have full control over all elements of the car's design. 'In lots of ways, working with Ferrari is just more of the same, every customer team has some black box design to a greater or lesser extent,' Taylor says. 'The engine, transmission, driveshaft has been common for at least a decade. Going back further people would just buy in a Hewland, or

'Good design engineers have a catalogue of good ideas in their heads, and when they all sit together they can exchange those ideas'

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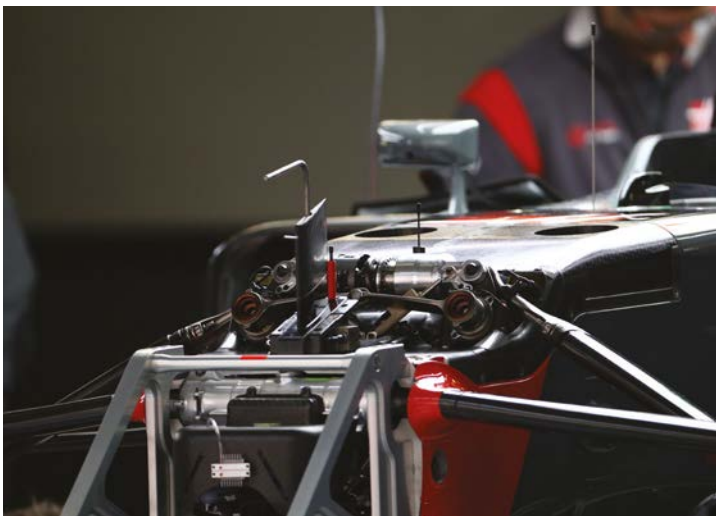
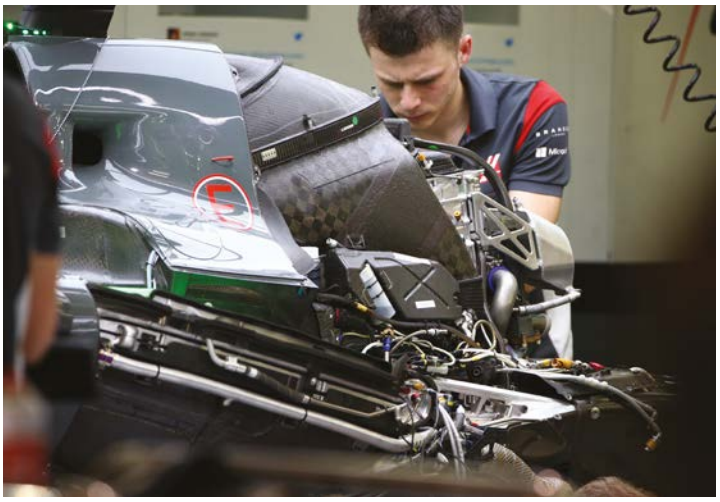
Front wishbone is just one of the Ferrari-supplied components. VF-17 features pushrod-activated torsion springs front and rear. Damping comes courtesy of Sachs



Haas has a machined aluminium front bulkhead which carries some of the inboard front suspension, although the torsion bars are mounted above and behind the main bulkhead

Haas has carried over its 2016 roll hoop but the charge cooling layout has changed, with now just a single duct within the hoop. Lower duct behind it cools electrical parts



The power unit installation in the VF-17. The way Haas has worked with Ferrari has been an undoubted success, to the extent that other teams are looking at using this approach

a bit later get Xtrac to bespoke it. Now we get the suspension, the steering and some fiddly bits around the edges that nobody ever talks about, like the electronic boxes. Strangely, they are the most challenging thing to deal with. The suspension, for example, is not so difficult, you could think of it this way; that our suspension designers are down in Maranello and not here with us, but there is feedback from us to them and they do change bits to suit our needs. It's a bit less than you would get in a normal team set-up, but we can request small things and sometimes they say yes, other times no.

'Fixings for the steering rack, for example, we can influence them,' Taylor continues. 'In terms of the lead times we do take a bit more of a risk as we start off manufacturing the monocoque at the very same time as they do, pretty much, but we are working to information that we are aware could change subtly.

'Having the chassis guys talking to the fuel cell guys is a big one for us, as that greatly impacts the pattern work for the chassis,' Taylor adds. 'If you want to move a suspension pickup point on the tub you will be typically talking about a millimetre here or there, but the fuel system really does have a big impact. The chassis guys and fuel system guys in Maranello are working together, but for us at Dallara we only get to see it with some latency, so we have to commit at some point. That is a risk we have to take. That said, fitting the fuel system is a whole lot easier now than it used to be as we now have a big opening in the bottom of the tub to put the battery in. But in the past I think some teams used to try to install the fuel tank through the filler opening!'

Smart Haas

The result of all the work rolled out for the first time at Barcelona just before the start of winter testing. The VF-17 was at first glance a fairly conventional design with pushrod actuated torsion bar suspension at the front and a pullrod layout at the rear. Ferrari's V6 power unit is fully stressed and drives the rear wheels via the Italian team's transmission, which features a composite casing. The cooling system is largely a carry over from the VF-16 with a distinctive V shape arrangement of heat exchangers in the sidepod, something that is also a feature of Ferrari's 2016 and 2017 designs.

'The cooling system is different to 2016 but still reasonably similar, the charge air cooling layout has changed a bit, for example,' Taylor says. 'I think we have what Ben Agethangelou [head of aerodynamics] would call a reasonably coherent solution. I think this year we are working on what our prediction was, but the information we had changed a bit after testing. With the tyres performance differing a bit to what we expected the engine performance is different too, so that effects your lap average and end of straight temperatures.'

The VF-17 is not all Ferrari derived though, and it has some interesting features of its own.

'Dallara have come at manufacturing monocoques from a completely different perspective to anything I have seen before in Formula 1'

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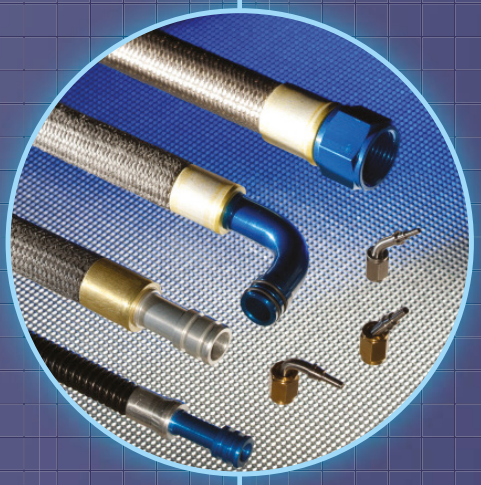

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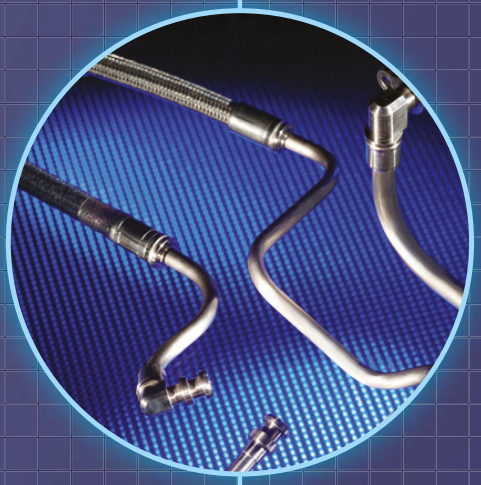

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The Haas VF-17 has slavishly followed Formula 1's fashion for 2017 with a shark fin, while it has also topped this off with one of the controversial, and wobbly, T-bars

The cooling system is largely a carry-over from the VF-16 with a distinctive V shape arrangement of heat exchangers in the sidepod; a feature of Ferrari's 2017 car, too

Haas uses Ferrari wind tunnel and not its own Windshear facility (as advertised on endplate) as full scale testing is banned

As was the case with the VF-16 the car is fitted with a machined aluminium front bulkhead. This carries some of the inboard front suspension components, though the torsion bars are mounted in a composite section above and behind the main bulkhead.

In terms of suspension components most of them are supplied by Ferrari and the Haas engineers have to make the best use of what they are given. 'The front suspension is 90 per cent the same as the Ferrari SF70H, but the way it mounts to the chassis is different, some of the interfaces are different and we make some of our own bits. Some of the internal parts we fiddle around with for adjustability purposes to get what we want out of them too,' Taylor says. 'In terms of hardware and the catalogue of settings and the way the part reacts to those settings, yes we get that information from Ferrari. But what we don't get is why would we want to set it in this way or that. For example, if we wanted a particular component to end up with effect No.64 you have to do this, the information we get tells us that – what it does not tell us is why we might want or not want to do it. That is down to us to work out.'

Haasta la vista

One area where Haas has begun to deviate slightly from the Ferrari SF70H parts is with the brake material. During the 2016 season the Haas drivers complained about brake performance and that was something that continued into 2017. Curiously, it is not something that seems to have troubled the Ferrari drivers. At the Russian GP Haas found itself swapping between friction material suppliers to try to improve this.

'We started off with Carbone Industrie brakes in Sochi but we weren't getting enough cooling for them, and if you don't cool them enough, you overheat the brake itself and the pedal gets long,' Guenther Steiner explains.

'Also, we found that the wear was very high. We looked into it to see if we could survive a race, but we realised we could not. Therefore, the decision was taken to go back onto the Brembo material. Romain Grosjean was pretty happy with the latest iteration of Brembo material. Kevin Magnussen liked the Carbon Industrie better, because the bite is better. He just has a better feeling with that material. Everybody needs to understand that this is a very sophisticated brake system and it is not easy to fix. The obvious question, and rightly people ask, is that it cannot be this difficult to fix a brake. It actually is. It isn't easy. This is because they're highly complicated technologies.'

Taylor adds: 'Trouble, issues or problems are generic terms, what is the actual trouble, how do you know? Because the drivers are complaining. The brakes are very high up on the list of things affecting the drivers' mental well-being, so it is important to get things working as they want, but there is a 24 week lead-time on brake material. Your choices are very limited in that area.'

'I think it is important to say that the brakes are not exactly the same as Ferrari, and the process that goes into bringing them to the car is different,' Taylor says. 'Some of the part numbers are obviously the same, but the understanding of the parts, the ability to tune them around and the base knowledge is different between the two teams.'

Despite the brake issues Haas has started the 2017 season reasonably well and scored points in three out of the first five races. But perhaps a greater measure of its success is that the establishment of Haas F1 as a solid midfield runner has resulted in speculation that another existing, or even new, team, is poised to adopt the same approach to Formula1 car build as the American-owned outfit.

'Everybody needs to understand that this is a very sophisticated braking system and it is not an easy thing for us to fix'

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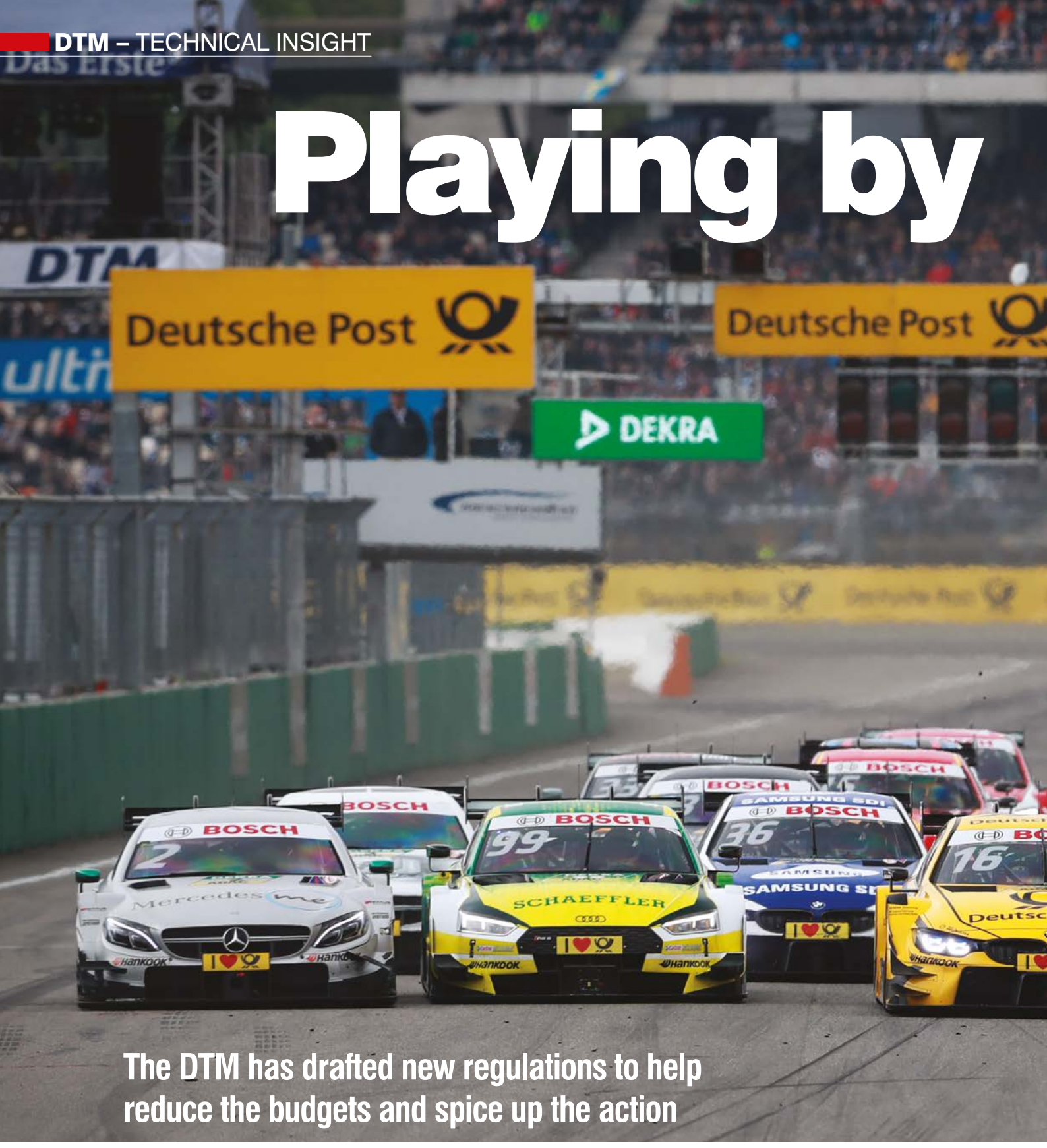


The DTM has drafted new regulations to help reduce the budgets and spice up the action

Superficially, the DTM has been in a good place in recent years. In BMW, Mercedes and Audi, it's had three prestigious manufacturers involved, while it's enjoyed championship battles that, more often than not, gone down to the wire, producing tense conclusions.

Yet, despite all of the above, criticisms regarding the on-track product and also that familiar motorsport bugbear of rising costs, have forced the series to draft updated regulations to help reduce budgets and spice up the action. Meanwhile, the three manufacturers have, for their part, also looked to cut costs, and have opted to drop from running eight cars each to six, reducing the car count to 18 – its lowest since 2011, when only Audi and Mercedes were involved. There have been changes to the sporting regulations, too. Both races over a weekend now last for 55 minutes plus one lap.

Controversially, the DTM has also introduced several control parts into the regulations while it has also worked at closing loopholes in other areas. The series has also adopted 'aggressive aerodynamic stylings', while reducing downforce and increasing the power output in order to create a greater spectacle.

All in all this has created a whole new set of issues for its manufacturers to respond to in 2017. We looked in detail at Audi's new RS5 DTM challenger in May's issue of *Racecar* (V27N5), but in this feature we will investigate how its rivals have also met the challenge of DTM 2017.

the rules

Racecar takes an in-depth look at how the manufacturers in the DTM have risen to the challenge of the new regulations in Europe's fastest tin top series

By LEIGH O'GORMAN

BMW M4

Since 2014, the basis of the BMW DTM has been the M4, and it remains the base car this year. Rudolf Dittrich, general manager of racecar development at BMW, explained the rule changes: 'The DTM regulations were updated with the aim of creating more action on track and focusing the attention even more around the driver. In light of the new regulations, the BMW M4 DTM has been given a work-over and undergone significant development,' he says.

'The BMW M4 DTM now generates over 500bhp of engine power, while the aerodynamics have also been subject to extensive modifications. Innovative technology was used when manufacturing components. The diffuser is now shorter and the plank height has been increased in line with regulations,' Dittrich tells us.

The nature of the new regulations means very little has been carried over from the road going car, but some concepts do cross over. 'The requirements for the racecar are very specific and quite extreme. Therefore, carry-over on component level is rather limited. The main synergies we generate these days between road car and racecar development are methodologies, tools and advanced development areas; where we can take more risks, exploit limits, and feedback our findings to partnering departments within the BMW Group,' says Dittrich.

Although DTM is, to all-intents-and-purposes, silhouette touring car racing, its

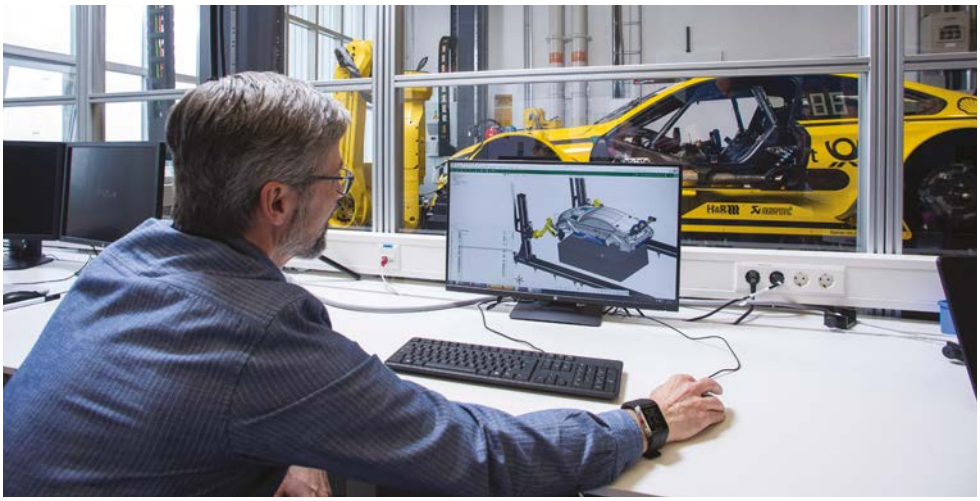
'There is a very precisely defined trade-off between engine coolant temperature, engine power and external aero with this racecar'

aggressive stance with regards to aerodynamic regulations ensure manufacturers can go beyond the standard touring car profile, creating striking cars that create large amounts of downforce – although this has the more negative knock-on effect of stifling overtaking.

'With aero being so apparent and almost the dominant aspect, the development rate and resulting implications need to be carefully monitored,' says Dittrich. 'To allow overtaking, despite the severe aero levels, changes were made to the latest iteration of the regulations to address the implications when following another car, for example by raising the car with a 5mm increase of plank thickness.'

The regulations have also introduced a number of control parts to the series in order to reduce R&D costs. However, there is still some small room for manoeuvre. 'The front splitter became a standard part, so not only is the basic shape defined by the regulations, but they are produced by the same supplier for all cars. Even the splitter fixation has become common to avoid teams benefiting from advantageous deflections,' Dittrich says, adding that manufacturers can still add flat elements to the splitter to integrate the resulting flow structure in the overall car concept. 'These strakes can also be used to influence the pitch sensitivity of the racecar,' he says.

The new regulations also reduce the effect of the side mirrors somewhat – an element of development that many in DTM felt had become excessive in recent years – by creating a common housing and glass for the mirror.

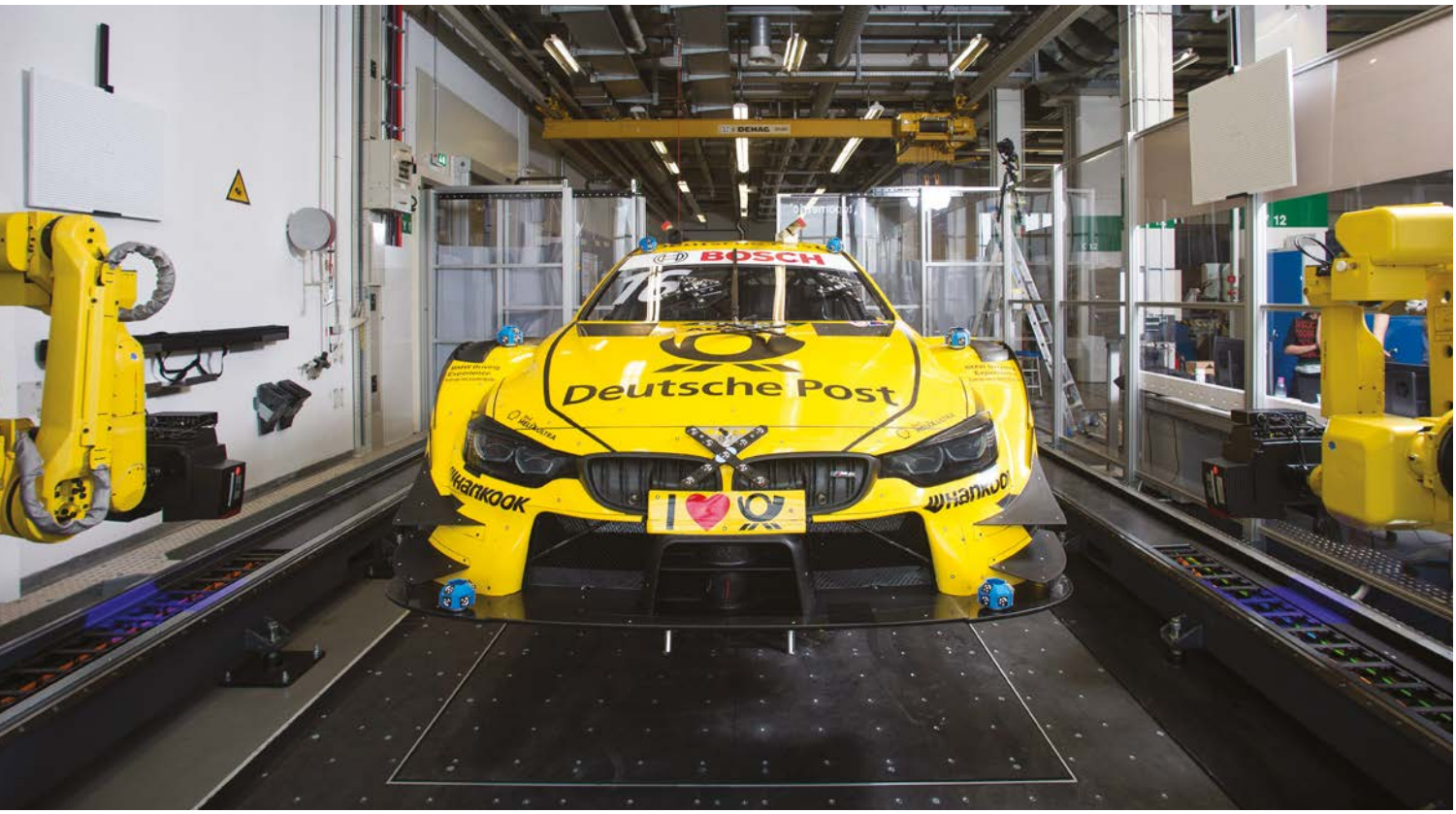


The new DTM regulations have resulted in slightly heavier suspension systems. Pictured here is the BMW M4 on the test rig

Rear aero

As well as the wooden plank now being thicker, other components of the floor have also become standard parts. Meanwhile, the rear diffuser has a completely new shape and is shorter and flatter than that of the previous M4 DTM racecar. Dittrich also confirms that the rear diffuser is one of the big contributors to reducing overall downforce, while also nullifying the amount of dirty air that pours from the rear of the machine. He tells us: 'As the rear diffuser has changed, the rear wheel arches were adapted to the resulting flow structure and the revised aero targets for the vehicle. This resulted in us opening the rear wheel arch venting duct for the first time since 2012.'

The new rear wing has been designed with DRS as an in-built concept. This differs from the original DRS on the DTM cars, which was effectively designed into an already existing rear wing. This makes the work at the rear of the



The front splitter is now a standard part in DTM. Other aerodynamic changes include a 5mm increase in plank thickness plus more control components on the floor area of the car

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BMWs old and new. The new, to the rear of the picture, is supposed to be more aggressive looking. Among the changes to the regulations is a common wing mirror housing after aero development in this area got a bit out of hand in recent seasons

Mercedes initially homologated its C63 for DTM last year and so did not design from a new base car as did Audi and BMW

The engine remains the same 4-litre V8 unit that has been present in the DTM for many years

TECH SPEC

BMW M4 DTM
Chassis: Carbon-fibre monocoque.
Engine: BMW Power P66 4.0-litre (244 cu. Inch) V8, 90-degree naturally aspirated, front-engined, longitudinally mounted. Power: 500bhp (approx).
Transmission: Hewland 6-speed sequential semi-automatic gearbox
Suspension: Pushrod with double wishbones coupled with Sachs dampers
Brakes: AP Racing carbon brakes
Fuel: Aral Ultimate 102 ROM
Lubricants: Shell Helix
Tyres: Hankook Ventus
Wheels: ATS forged aluminium wheels.
Dimensions: Length, 4775mm; Width, 1950mm; Height, 1200mm; Wheelbase, 2750mm
Weight: 1120kg (including driver)

car one of the most recognisable changes to the 2017 racers, a single element wing having been replaced by a double element rear wing, which features a more powerful DRS as the upper element now rotates by up to 40 degrees. The wing also features a generally wider adjustment range and, unlike before, the end plates no longer rotate with the wing on DRS activation.

While Dittrich acknowledges that a large portion of the downforce has been lost from the M4 DTM because of the changes, he was not willing to tell us the percentage of that loss.

Power hike

The engine powering the M4 DTM remains the same 4.0-litre V8 unit that has been present in the DTM for many years, but the two air restrictors have been widened from 28mm to 29mm, increasing the power output to approximately 500bhp. But while the output is greater, Dittrich is not overly worried about any extra stresses on the unit. 'The base engine is robust enough that it didn't require updates. The power increase also comes with increased revs, so the internal stress remains unchanged, it just occurs more often, which is not necessarily increasing the mechanical stress on the engine. Apart from the adaptation for the revised gas exchange, only the head gasket was updated.'

As the engine requires slightly more cooling, the air intakes towards the front of the racecar were modified and the dimension and packaging was adapted to the new requirements. 'There is a very precisely defined trade-off between engine coolant temperature, engine power and external aero,' Dittrich says. 'After establishing the respective sensitivities, targets could be derived for each of the parameters and then they could be optimised.'

No updates were necessary for the gearbox, as the original book of requirements included scope for a power increase when this was developed, but the driveshaft has been modified to compensate for new uprights.

The brake materials have been updated, and the DTM manufacturers have now adopted the material specification from the Japanese firms competing in the GT500 class of Super GT – these brakes are manufactured by AP Racing.

Mercedes C63

Unlike Audi and BMW, Mercedes initially homologated the C63 coupe for the 2016 season, meaning its machine could only be updated, rather than reintroduced, as Herbert Hugle, head of Racecar Development at Mercedes AMG, explains. 'Our base car is the C-Coupe, which is called the C205. The baseline for this car was given in 2016, so we have to work around the given shape – we are just allowed to scale the general shape, because the goal of the DTM regulations is that the frontal area, length, width and height is the same.'

So, while Hugle and his team scaled the C63, they were unable to influence the base

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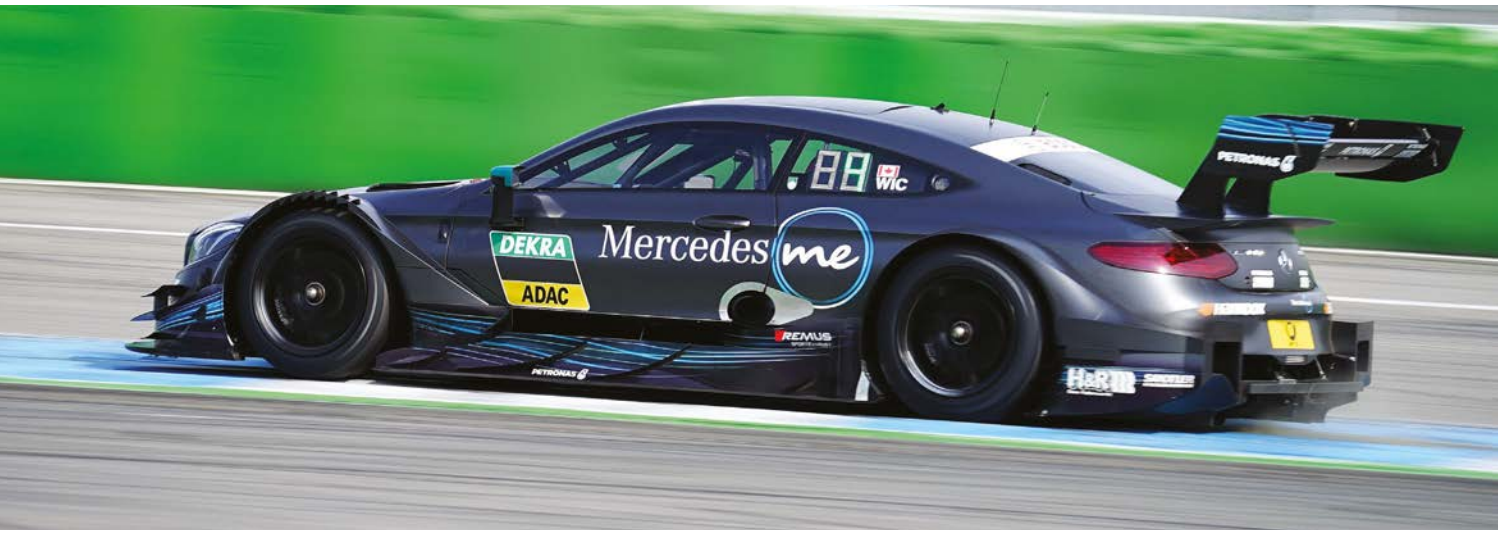
The clutch is also a control part and teams are limited to three clutches per driver per season



DTM now has an F1-style DRS system and the rear wing is a single element device rather than the double element wing of previous seasons. The diffuser is now shorter and flatter

Drivers have more power to play with this season following a decision to increase the size of the two air restrictors from 28mm to 29mm. This brings power levels up to about 500bhp

TECH SPEC

Mercedes C63 DTM

Chassis: Carbon-fibre monocoque/.

Engine: Mercedes-Benz AMG 4.0-litre (244 cu. Inch) V8, 90-degree naturally aspirated, front-engined, longitudinally-mounted, Power: 500bhp (approx).

Transmission: Hewland 6-speed sequential semi-automatic gearbox

Suspension: Double wishbones with H&R spring/damper units to front and rear axles, actuated by pushrods.

Brakes: AP Racing carbon brakes with 6-piston calipers and pads.

Fuel: Aral Ultimate 102 ROM.

Lubricants: Petronas Syntium 700.

Tyres: Hankook Ventus.

Wheels: ATS forged aluminium.

Dimensions: Length, 5010mm; Width, 1950mm; Height, 1210mm; Wheelbase, 2750mm.

Weight: 1120kg (including driver).

car; however the Mercedes-man says the C205 was already a good base for the C63. The design line – a sector split by an imaginary line that runs along the top of the wheel arches and approximately halfway of door's height that regulates the areas that can receive 'additional development' – is the same as in previous years.

The overall level of aerodynamic development has continued to rise, though, with Hugle citing the intricate louvres in the front 'mudguards' as a good example of this, while he adds that this development has also improved the aesthetics of the car. 'That aero development, especially the amount of CFD we have now put in, is growing more and more, and that's why the car looks fantastic and a bit aggressive,' he tells us.

As mentioned, the control parts are common designs agreed by all three of the manufacturers. With a new DRS system as well, Hugle says 'the aero balance has changed completely from last year's car.'

Fenced off

Although the front splitter itself is a control part, there is room for development around the area, although it is still relatively limited. Hugle says that fences are allowed on certain areas and that the number of fences is not regulated, but adds: 'The area where you can put them and the total amount of surface is regulated and, as well, there is an area on the outer side of the front diffuser where we are allowed to put on some geometry, but if you move the geometry, you must still see the shape of the control part.'

As mentioned earlier, the underfloor has been raised by 5mm in the regulations, with the C63 using a spacer underneath the wooden plank. 'The goal of this was to reduce the aero downforce by about 25 per cent overall and the big amount of aero loss is through this 5mm of more ride height.' Hugle says, adding that another goal was to avoid damage to the underfloor when runing over kerbs. 'The 5mm ride height gives you at least 50 per cent less wear on the parts under the car, and these are the most expensive and sensitive parts.'

Aero balance

The C63 also has a shallower rear diffuser in an attempt to control the aero balance along the car. Hugle confirms that this was a reaction to the loss of downforce at the front of the car, prompting an adjustment of rear downforce to keep the balance within a certain percentage.

When the previous set of technical regulations were introduced in 2012, the rear wing was not designed with DRS in mind, so when added a year later, the concept was rather makeshift. 'Last year when we used the DRS, the whole wing was turning. It was not as effective and not as nice from a visual point of view,' says Hugle. 'We decided for the new DTM to have a fixed main wing and we use DRS simply on the [top] flap, so it is close to the Formula 1 design. There is more efficiency in the DRS now and this was the goal.'

Hugle admits that areas, such as around and inside the rear wheel arches, remain very sensitive, but he did tell *Racecar* that: 'The air which is entering the rear wheelarch is led by a 'diffuserino', as we call it, and the goal is to bleed the rear wheelarch as much as possible.'

Bigger restrictors

One of the biggest changes for Mercedes has been the decision by the DTM to increase the two air restrictors from 28mm to 29mm, and while this alteration sounds minor, Hugle claims it will prove significant. 'The goal was to give the drivers more power. This 1mm more in diameter gives you about 25 to 30bhp more, so

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'The aero balance has changed completely from last year's car'

the latest version of the DTM engine is around 500bhp.' Hugle also reveals that his design team was allowed to modify parts of the air intake and adapt the rest of the engine to the higher output. 'This was the main focus of the winter to develop the cooling and get the maximum cooling with the minimum aero influence.'

Unfortunately, Hugle is unable to tell us the torque numbers, except to say the revs are 'a little bit higher, so the torque is also increasing a bit'. Despite the increase in power output, like Dittrich at BMW, Hugle is also confident there is no issue with the reliability of the 4-litre V8. As far as putting that power down on to the track is concerned, there are no changes to the gearbox or differential, although the propshaft has been modified slightly. The clutch is also a control component and teams are now limited to three clutches per driver per season.

Suspension control

There are also new regulations regarding suspension systems in the DTM. At one stage, the suspension was one of the very few completely open areas in the regulations, but this now falls under the banner of control parts and while there remains some variability in terms of set-up, the new suspension also comes with disadvantages, Hugle tells us. 'On our side, it is no secret this is a disadvantage from a weight point of view, so the weight of the suspension increased just a bit. This is normal when you design for three manufacturers some control parts, and you have to consider all the needs from all the manufacturers, it normally turns out to be a bigger part and it is normally a heavier part, too.'

Hugle tells us that one of the goals for the suspension was that it is should survive 25,000km of running – that's approximately three seasons – whereas previous concepts were designed for 5000km.

Set-up freedoms

Of the set-up options, Hugle points out that, 'there is still a big level of variability, because from the kinematic point-of-view, we have a lot of options to move the wishbone points, the rocker points and the casters. There are a lot of opportunities, especially with the new common third element at the front of the car, it gives you a lot of ways to set up [the suspension].'

As mentioned above the brakes are control parts. 'We had to improve these parts, because the speed is higher,' Hugle says. 'When we have a look at the lap times at [the last pre-season] test in Hockenheim, we talk about two seconds [quicker] per lap – and this is quite a lot. The brake material itself is the same, so there were no big modifications there.

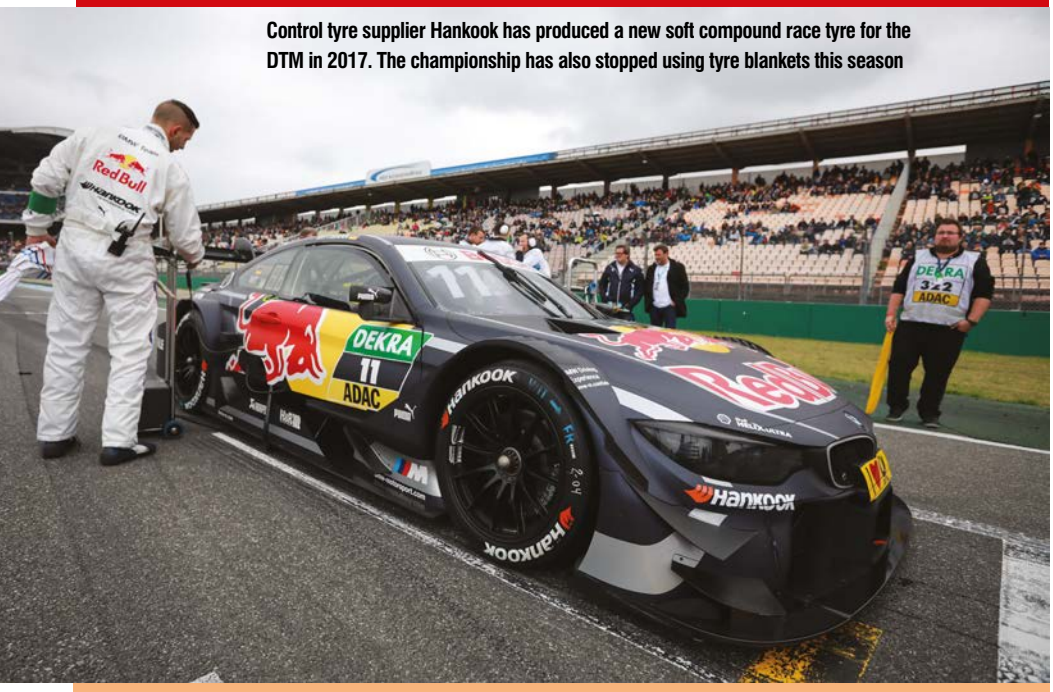
'The air for the brakes is completely from the sidepod area. It is not allowed to have it channelled from underneath the car to the brakes, [so] the brake air and the hub air is from the sidepod area,' Hugle says.

Testing of the 2017 C63 DTM car went very well for Mercedes, with its updated machine completing some 19,000km over its three-winter tests. Hugle also believes there are many positives on the horizon, thanks to this intensive testing: 'I think we never tested as many kilometres as we did this winter season. This was one of the goals of the development during the winter season, to get as much data as possible around the tyres.

'The conclusion is I think we improved a lot our reliability of the whole racecar,' Hugle adds. 'So we have fewer safety critical failures in the car and as well, we collected a lot of data around the tyre and this was the main goal of this big amount of testing.'

At the first event of the DTM season at Hockenheim both races had cars from all three manufacturers on the podium. Which seems to suggest, that when it comes to the racing at least, the DTM might be on the right track with these new regulations.

Blanket coverage



Control tyre supplier Hankook has produced a new soft compound race tyre for the DTM in 2017. The championship has also stopped using tyre blankets this season

One of the biggest changes to the 2017 DTM season is the reworked tyre compounds from Hankook. After multi-compound weekends were dropped at the end of 2015, the South Korean manufacturer delivered a hard compound for 2016, which, while generally allowing drivers to push through stints, also ensured races where tyre wear was less of an issue and track position became king.

This year Hankook has produced a soft compound tyre for each weekend in an attempt to increase strategy options and create dynamics of variable wear throughout races. Of the two races over a DTM weekend, both are now scheduled to last 55 minutes plus one lap, with one mandatory stop in each.

Hankook's DTM race engineer, Thomas Baltes, says: 'Despite the unchanged dimensions the new DTM dry-weather tyres are a complete redevelopment. The drivers and engineers who are particularly good when it comes to running the tyre in to get it to its optimum temperature area as fast as possible without a too aggressive approach will have a clear advantage in the 2017 season. And the way the tyres are dealt with in the qualifying session also will make a bigger impact on the performance in the race than it did in the past.'

Audi's DTM Project Leader Stefan Gugger explains how things have now changed for the drivers and engineers. 'The focus [in testing] was to understand the new tyre, because it is completely different. We are running without blankets and therefore the peak grip is quite high in the first two or three laps and then you have to manage the drop.' Degradation of the tyre is set to be quite high and will force teams to find a suitable set-up compromise between qualifying and the race. Gugger continues: 'Driving style is a very important thing. The driver has to feel [the grip], maybe more than with the old tyre, but still he has to go for the maximum, and this will be very difficult this year.'

Herbert Hugle at Mercedes says that the withdrawal of blankets will play a large role. 'It is the first time that we will not use tyre blankets in the DTM, so this is a big challenge for all the engineering team and also for the driver. Maybe more for the driver because he is the one who has to take care of the tyres, especially when they are cold and low pressure.'

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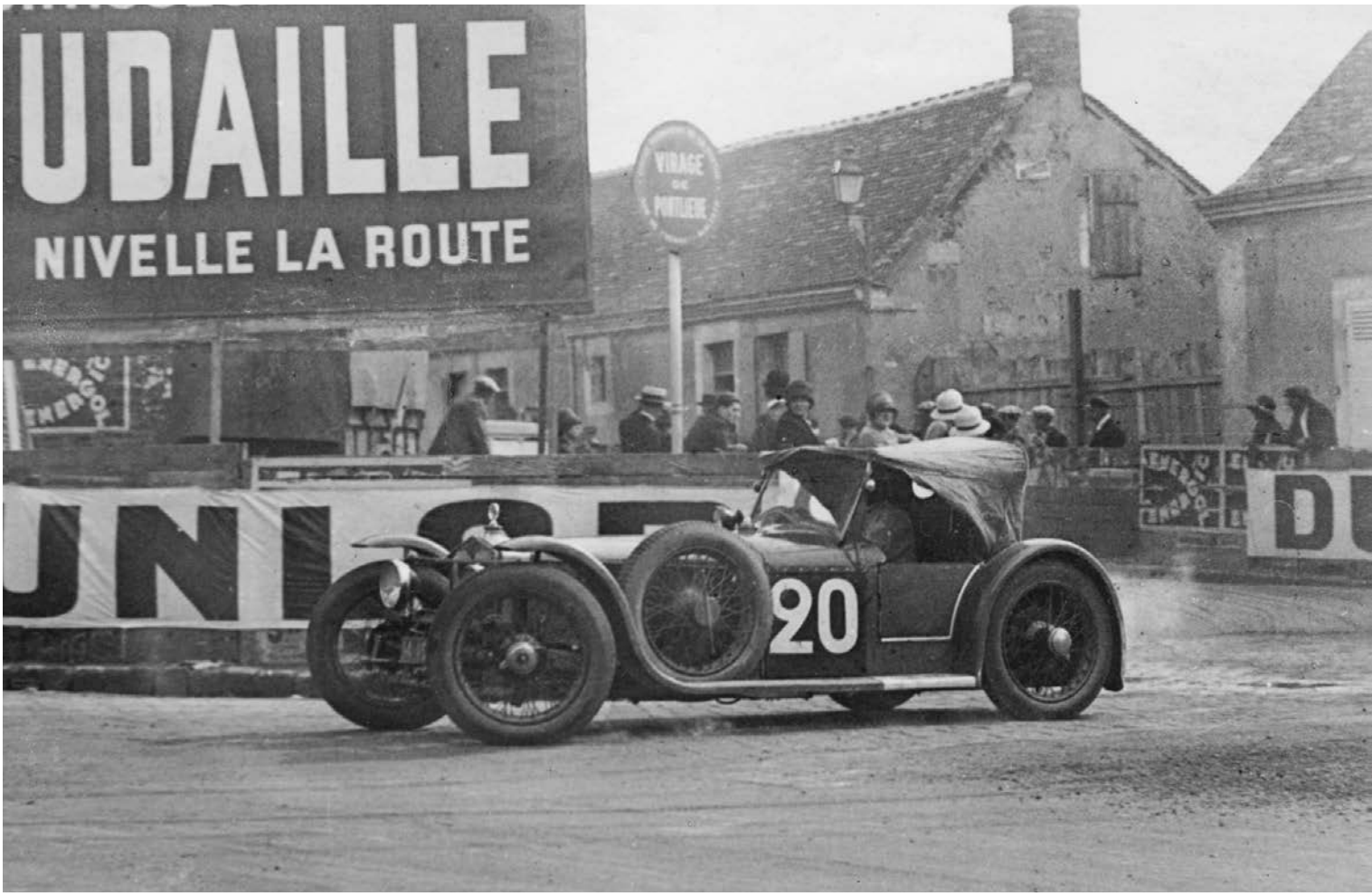
Proving ground

It's not just about finishing first at Le Mans, sometimes it's about *being the first* too. *Racecar* looks back at some of the emerging technologies that have been tested in the 24-Hour classic over the years

By **SERGE VANBOCKRYCK**



The 4-cylinder 1.1-litre Tracta-SCAP was the first front-wheel-drive car to race at Le Mans in 1927. It finished in seventh overall, 40 laps down on the winning Bentley (ACO Archive**)**

Back in 1923, almost a century ago, Le Mans had been conceived first and foremost as a 24-hour challenge for automobile manufacturers to showcase their products and put them to the ultimate test. Now, 84 editions later, this still is very much the case, and in that respect Nissan's much-publicised 2015 campaign, though ultimately flawed, was spot-on: front-engined, front-wheel-drive cars were what they sold most, while hybrid power was the future.

Though never in combination with each other, all three of the features which made the Nissan unique had already been tried and tested many times before at Le Mans. Indeed, all pre-war competitors and many post-war vehicles, were front-engined. The first front-wheel-drive car to enter Le Mans, however, was Jean-Albert Gregoire's Tracta in 1927. With its 1100cc, 4-cylinder engine made by the Societe de Construction Automobile Parisienne, or SCAP, Gregoire and Lucien Lemesle finished a competitive seventh overall with the car, albeit 40 laps down on the winning Bentley.

Two years later, Pierre Fenaille – Gregoire's business partner at Tracta – entered four cars, this time equipped with 1-litre engines packing Cozette superchargers, the first time blown engines ran at Le Mans. The Tractas weren't the only ones to look for extra horses in 1929. So, too, did the American Stutz company – which supercharged the big 8-cylinder, 5.3-litre engine of its Stutz DV32 – and British car maker Alvis, adding a supercharger to the 1.5-litre engine of its 12/75. Guy Boriat and Philippe de Rothschild brought their Stutz home in fifth overall behind four Bentleys, while the first Tracta finished in ninth and the sole Alvis retired. The first supercharged Le Mans victory was inked in

The Delettrez brothers' entry had power provided by a 4.4-litre straight-six 91bhp diesel engine from a US Army GMC truck

Left: In 1952 the Mercedes 300SL was the first closed-cockpit car to win Le Mans. The gullwing featured sleek aluminium bodywork and a lightweight aluminium spaceframe (ACO Archive)

The Mazda rotary engine made its Le Mans debut in the back of a Chevron in 1970 but it was later seen in the first Japanese racecar at La Sarthe, the Sigma (above), in 1973 (DPPI)

the books just two years later when Lord Howe and Sir Henry Birkin beat a similarly-engined Mercedes-Benz SSK in their privately-run Alfa Romeo 8C 2300 Tipo Le Mans.

Out of the ashes

The rest of the pre-war period saw few technical innovations, but following a 10-year break because of the Second World War and its aftermath, the 24 Hours was run again in 1949. The ACO, in an attempt to attract as many teams as possible, had done away with production quota for the cars, thus opening up the race for prototypes for the first time. Despite the fact that economically Europe was still very much in ruins and supplies were short, the race still attracted 49 cars. Some were brand-new, such as the winning Ferrari 149 MM. Some were adapted pre-war concoctions showing the creativity of the entrants, such as the car of the Delettrez brothers, Jean and Jacques. They used a pre-war Unic chassis in combination with Delahaye 145 bodywork of the same vintage and had power provided by a 4.4-litre, straight-six, 91bhp diesel engine from a US army GMC truck, the first time a diesel raced at Le Mans. The brothers hoped to compensate for the racecar's lack of power and speed with some fabulous fuel economy, but they had to retire after some 20 hours of racing … when they ran out of fuel.

That same year another concept – and make – made its debut when Camille Hardy entered his personal Renault 4CV, the French version of the German Volkswagen concept. Renault tried hard to prevent the entry, arguing the Le Mans 24 Hours was too grueling an exercise for the tiny sedan with its signature suicide doors, rear-wheel-drive and small 747cc, 4-cylinder, air-cooled engine mounted at the rear, but to no avail.

Come the mid to late 1960s aerodynamics was the new buzzword, and few had embraced it as wholeheartedly as Chaparral's Jim Hall

Despite running a 4-speed gearbox instead of the standard 3-speed version, the little Renault blew its engine after seven hours of racing.

However, another manufacturer would soon make the rear-engined concept its trademark: in 1951, a small family-owned German make by the name of Porsche entered the race. Like the Renault 4CV, its nimble 1.1-litre Type 365 coupe was also based on the Volkswagen concept, which the company had developed 15 years earlier. The small sportscar won its class first time out and a Le Mans legend was born.

The year Porsche made its debut, the race was won by the Jaguar XK 120 C – more commonly known as the C-type – driven by Peter Walker and Peter Whitehead. Jaguar boss William Lyons had been buoyed by the performance of a trio of near-standard XK 120 S roadsters he had entered in 1950 and figured he could seriously improve their performance if the XK 120 S was turned into a proper racecar. Thus the 1951 C-types featured a more powerful engine; a streamlined body made of aluminium instead of pressed-steel and, for the first time, a steel spaceframe chassis, which was stiffer than a conventional chassis.

The spaceframe concept had already been looked into by the aeronautical world at the turn of the century, but it was Ferdinand Porsche who had first used it in racing when he designed the Cisitalia F1 car for an Italian customer in 1947. But the car never raced, so it was left to Jaguar to prove the theory four years later. Lyons' strategy worked to perfection and it beat a pair of Aston Martins and a couple of Talbot-Lagos by between nine and 11 laps.

The following year Mercedes entered the legendary gullwing 300SL with a sleek aluminium bodywork and a lightweight aluminium spaceframe. It won, at the same time scoring the first win for a closed cockpit car.

Thierry Perrier's Porsche 911SC ran on a 52/48 mixture of petrol and beetroot ethanol in 1980. The car qualified dead last but it did win its class. The following year Perrier's similarly-powered 934 repeated the feat (Porsche Historical Archives)

Lola-Cosworth T600 was the first car to run ground effects at Le Mans in 1981. Since the Group 6 category only catered for open-top cars, an inelegant hole had to be cut in the roof of what was actually an IMSA GTP machine (Jean-Marc Teissedre)

Disc drive

Defeated by Mercedes as much as by a lack of reliability, Jaguar returned with a vengeance in 1953 and with the next big thing in racing: the three C-types were now equipped with disc brakes, developed by Dunlop and tested earlier at the Mille Miglia. The Jags' speed and reliability, combined with the new superior stopping power, secured a 1-2-victory for the Coventry make and sent drum brakes to the history books double quick. Confident about their technical prowess, the engineers at Jaguar prepared another novelty for the following year, when their new D-Types were equipped with monocoque chassis. Like so many motorsports 'inventions' the monocoque had its roots in aviation. Duncan Hamilton and Tony Rolt came close to repeating the previous year's success, but in the end lost by just a lap to a Ferrari 375.

The next big technical innovation on Le Mans racecars was in 1963. BRM entered a car equipped with a 150bhp, 2-litre Rover turbine for Graham Hill and Richie Ginther. Since the car lacked a heat exchanger, and also because it ran kerosene numbers way outside the fuel restrictions the ACO imposed, BRM-boss Alfred Owen had asked and received permission from the organisers to race his car outside of the official competition, hence it wore the racing number 00. For safety reasons, the Rover-BRM had had to start 30 seconds after the other competitors, but Hill and Ginther had an almost trouble free – and very silent – run which allowed them to cover 310 laps and which would have placed them in seventh overall.

Come the mid to late '60s aerodynamics was the new buzzword and few had embraced it

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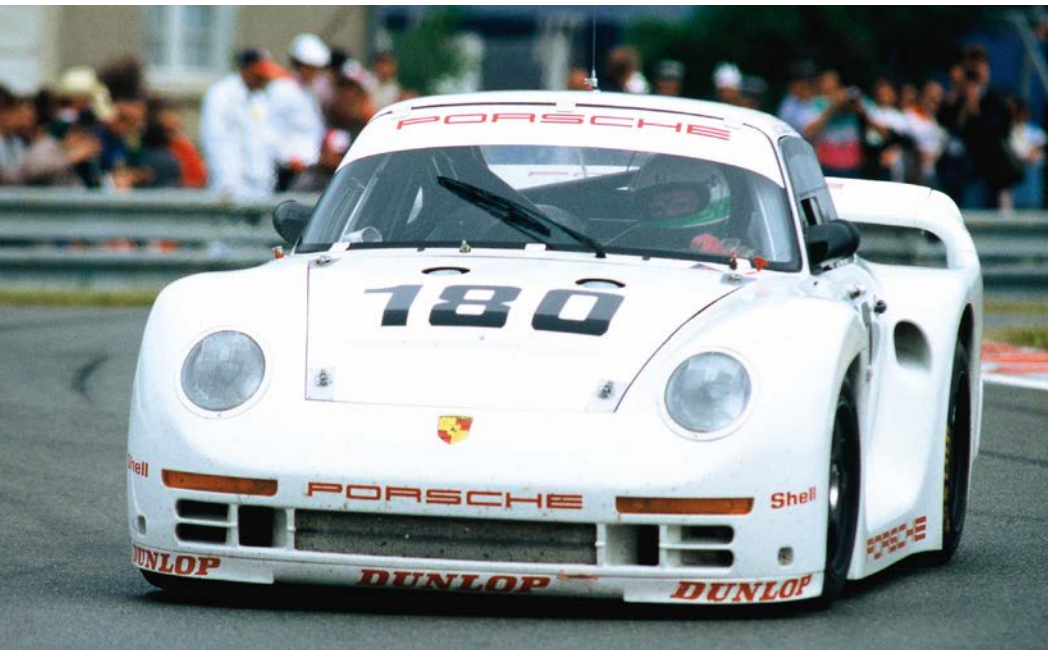
The GreenGT H2 would have been the most complex technological innovation to have ever competed at the Le Mans 24 Hours

as wholeheartedly as Chaparral's Jim Hall. With the CanAm race-winning Chevrolet-engined Chaparral 2E, Hall had not only introduced an even better aerodynamic body than on his previous cars, but also introduced the adjustable aerofoil, soon to be known as a rear wing. The device sat over the rear axle and by adjusting the inclination an amount of downward pressure could be achieved.

While the Chaparral 2E had been an occasional race winner in the USA the year before, the new 2F model, entered in the entire 1967 WCM, arrived in Le Mans with exactly zero finishes on its score card. It didn't lack speed, though, since the second fastest qualifying times at Daytona and Sebring were followed by three consecutive pole positions. At Le Mans, too, the Chaparral started from the front row, but once again the net result for the two cars was two DNFs. Despite the poor results, the trend was set and the following year the works Porsche 908/8s all sported adjustable rear wings. In 1972 Henri Pescarolo and Graham Hill in their Matra-Simca MS670 scored the first overall win for a car equipped with a rear wing.

After 1967 it was rather quiet on the technical innovation front for a while, until in 1970 a pair of Belgians by the names of Yves Deprez and Julien Vernaeve decided to enter a Chevron B16 prototype with a 982cc, type 10A, 200bhp, twin-rotor Mazda engine in the back. It was the first time a Japanese engine raced in Le Mans, and a wankel engine at that. German Felix Wankel had patented the concept for a piston-less engine in the late '20s but it wasn't until he worked for NSU that he got a first prototype running 30 years later. Apart from NSU, few manufacturers produced road going cars with wankel engines, but Mazda would become the concept's staunchest defender. The Belgians' race didn't last long, but their choice of powerplant had served as a wakeup call in Japan.

In 1973, the Japanese Sigma Automotive team ticked another few 'first' boxes for Japan. With its home-built, Mazda-equipped Sigma MC73 (this time a 250bhp type 12A twin-rotor) driven by Tetsu Ikuzawa and Hiroshi Fushida, Le Mans witnessed the arrival of the first Japanese team, car and drivers. They only made it to the halfway mark, but returned the following year to finish what they had started, even if they weren't classified at the finish. Sigma turned to Toyota power for 1975 (another first for the team's last appearance in Le Mans), but by then Mazda had taken the bait and started sending works teams to France from 1979 onwards, always running rotary engines. In 1991, Mazda became the first and so far only Japanese manufacturer to win Le Mans, with its trademark powerplant (by then a 700bhp, type R26B, quadri-rotor), the only ever win for a piston-less engine.



Porsche adapted its 959 supercar for the 24 Hours in 1986, thus entering the first ever 4WD racecar at La Sarthe. The car finished seventh overall but the following year a botched gearshift wrecked the engine (Porsche Historical Archives)

In 1986 Porsche also entered a 962C equipped with its PDK transmission, the first and only time a PDK-packing Porsche ran at Le Mans. It took a quarter of a century for PDK to become a feature on Porsche's road cars (Porsche Historical Archives)

Turbo boost

In 1974 Porsche decided to give its serial class-winning Carrera a steroid treatment and enter it in the prototype class. The factory wasn't interested in fighting their many Carrera customers for GT class wins, and with new regulations coming up for 1976, Porsche figured it could already prepare for the future by taking the Carrera RSR to the next level. For that, the Porsche engineers decided to add an exhaust gas turbocharger. The principle of turbocharging to increase engine power had been patented in 1905, and the idea was not new to motor racing either; Porsche itself had already used it to good effect on its CanAm 917/10s and 917/30s in 1972 and 1973. However, now turbo power was to run down the Hunaudieres Straight for the first time. With the 3-litre engine rule for prototypes, the Porsche engineers used a 2.1-litre flat-6 with a single KKK turbocharger; turbocharged engines needing to multiply their capacity by 1.4 to calculate the normally aspirated equivalent.

With some 500bhp on tap for just 830 kilos, the two silver Porsches looked menacing, especially with their massive wheels, body extensions and huge rear wings. Porsche came

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Nissan R90CP in 1990, when the company debuted carbon fibre brake discs at Le Mans, as produced by Carbone Industrie. The car also had 1100bhp on tap! (Jean-Marc Teissedre)

close to beating the four-car works Matra squad for victory. The first turbo win then came just two years later when Porsche won with its 936. Between 1976 and 2016, turbo engines would score another 32 victories at Le Mans.

The mid-1970s were not only marked by technical innovations, but also by the first global oil crisis. The western world suddenly realised it was far too dependent on oil and just as soon the search for alternative fuels was on.

The ACO, too, was interested in aiding the development of alternative-fuel engines and decided to cater for this type of fuel in 1980. From 1949 onwards the club had already pioneered fuel consumption limits by imposing a minimum number of laps to be covered between fuel and oil stops, and anything thought to be helping to reduce the need for unlimited fossil fuel consumption was good news as far as the club was concerned.

Perrier power

Unfortunately, only one car running on biofuel was entered in 1980: Thierry Perrier's normally aspirated Porsche 911SC. Perrier had his car's engine converted to accept a 52/48 mixture of petrol and beetroot ethanol. For a privateer it was a risky as well as an adventurous undertaking into the unknown.

Perrier qualified his car dead last on the grid, some 13 seconds slower than the next Group 4 Porsche, and knew that the race wouldn't be easy. Yet 24 hours later, Perrier and teammate Roger Carmillet not only finished the race but also won the Group 4 class. The following year Perrier repeated his challenge, this time entering a turbocharged Porsche 934. The petrol/ethanol mixture had been changed to 85/15, but after 24 hours of racing the result was the same as a year earlier: Perrier's 'alcoholic' Porsche again won the Group 4 class.

Ground zero

Meanwhile, in the US the IMSA organisation had also introduced the GTP class for prototypes, similar in look and feel to what the ACO had created in 1976 and to what the FIA's new Group C was expected to become in 1982. British constructors March and Lola were the first to respond to the call from overseas; the former with an exclusive car for the works BMW team, the latter with its T600 model intended for customers and to be used with a variety of engines. What both cars did have In common, though, were the novel ground effects.

When Lotus had set the world of F1 alight with its wing car in 1978, every engineer rushed to his drawing board to add an inverted wing to his design. Lola's Eric Broadley had done so too, and rather successfully so. The T600 – with its massive up-sweeping venturi and elegant body with covered rear wheels designed by Frenchman Max Sardou – had been created to service the needs of customers in both the IMSA and world championships, even though the Group C regulations hadn't been finalised yet in early 1981. Two of the cars were entered in Le Mans in 1981, one did not qualify but the other made it to the finish in an honourable 15th overall and third in Group 6.

With the arrival of Group C in 1982, extreme engineering eased off a bit as manufacturers were first and foremost trying to get to grips with limited fuel consumptions and ground effects. Still, in 1986 something new was presented to the ACO's scrutineers: one of the three works Porsche 962Cs ran with a so-called PDK gearbox, short for *Porsche Doppel-Kupplung* or double clutch transmission. The idea behind PDK was to reduce the time shifting gears, thus reducing the time no power was transferred to the wheels. Porsche had already looked into this in the early '70s when it ran the 917, but while the mechanical concept of the PDK was hatched then, the embryonic state of electronics meant the idea had to be put aside for a later date.

Pretty Damn Kwick

A PDK gearbox is a slightly bigger-than-normal gearbox, in which first, third and fifth gear are on one shaft, and second and fourth gear on a second shaft. Both shafts have their own clutch and one of the two clutches is always engaged. The actual shifting of the gears is controlled electronically so that the transmission of power to the wheels is uninterrupted. The PDK thus not only improved acceleration but also allowed the drivers to change gears mid-corner, which with a classic gearbox was not easily done as the kick of the power being transferred to the wheels again after the idle pause when actually shifting could catch out a driver quite easily. Shifting gears with the PDK was still done with the stick sitting in the same position, but now the drivers just had to pull the stick towards them to go up a gear or to push away to go down one. The stick was later supplemented by two push buttons on the steering wheel. With the buttons, precursors to paddles, the drivers could keep their hands on the steering wheel while shifting in corners; an additional bonus.

In 1983, Porsche again started working on the PDK and from 1984 onwards entered a 956 in a few shorter races to test the system. The

For three years Alain Lebrun tried to qualify the first-ever gas-powered racecar, but never quite succeeded. The project was eventually shelved in 1998 (Jean-Marc Teissedre)

many teething problems prevented any decent results, but the tens of thousands of testing miles the team ran at Weissach and elsewhere led to the PDK being deemed race-worthy by the start of the 1986 season. A win at the opening 360-kilometre round of the WS-PC in Monza and at the Nurburgring Supercup sprint race validated the PDK, but a win in a classic 1000kms race so far had eluded it. To gather more data over a longer distance, the No.3 Rothmans 962C of Drake Olson and Vern Schuppan ran with the PDK; the other two cars running conventional gearboxes. Unfortunately, at Le Mans the PDK 962C retired long before sunset on Saturday evening when the gearbox broke after just some 550kms, while the No.1 car of the works team won the race. It would take another 25 years of development before the PDK finally made it in to Porsche road cars, but it would never be seen at La Sarthe again.

Four sight

The PDK 962C wasn't the only novelty Porsche had brought to France in 1986, for in the back of one its trucks sat an all-white, unsponsored GT car: the four-wheel-drive 961, the first 4WD car to run at Le Mans. In the early 1980s, four-wheel-drive had been the exclusive domain of Audi and its formidable Quattro, which dominated the WRC, but by the mid-1980s other manufacturers had caught up. Porsche had developed a 911-based 4WD, called the 953, to win Paris-Dakar in 1984 and prepare the future for the 961, the motorsports version of their 959 supercar. Another Dakar win, this time with the 961 four months earlier, bode well for its first appearance on asphalt. The car had been intended as the successor to the 934 to run against the BMW M1 in the Group B class, but, in contrast to its success in rallying, Group B had not been embraced in sportscar racing. Thus the 961 was entered in the more liberal IMSA GTX class; the only car in this class.

The big white car – with 1169kgs on the scale the heaviest of all the cars running that year – featured the same engine as its prototype 962C cousins, but coupled to a 6-speed, computer-aided, 4WD-transmission. In standard set-up the power was transferred 20/80 between the front and rear wheels, but three other pre-defined programmes allowed the driver to change the front/rear power ratio should the weather conditions require it. Dakar-winner Rene Metge proved Porsche's point by qualifying the car just three-tenths of a second slower than the Mazda prototype setting fastest time in the GTP class. In the race, Metge and Claude Ballot-Lena enjoyed a stroll in the park to a fabulous seventh place overall. The following year, the 961 was back, this time with bigger wheels, a reworked engine, more power, a wider body and bigger rear wing and decked out in full works colours. This time, though, the race ended in tears, as one of the drivers downshifted to a wrong gear, which broke the engine and set the car on fire.

Stopping power

Run from 1982 till 1990, Group C was arguably the most spectacular period in sportscar racing. To master the fuel consumption limits, the engine engineers had to pull out all stops, but the teams' technical suppliers weren't exactly sitting still either. By 1990 composite materials had slowly replaced the GRP for the bodyworks and some monocoques were now also being made of carbon fibre rather than aluminium. The next items to get the carbon treatment were the brake discs, developed by French company Carbone Industrie and used for the first time in Le Mans by Nissan. With a reported 1100bhp on tap for qualifying, the Nissans could very well need the extra and longer-lasting stopping power, especially now the Hunaudieres Straight had been cut up by two chicanes, thus creating two more major braking zones. In fact, with the carbon brakes only operating at their best at a certain temperature, it would have been impossible to use them without the chicanes for they would have cooled off too much to be operational arriving at Mulsanne Corner after a four-mile flat-out blast down the straight. Only three of the five works Nissans (plus one of the two privateer cars) ran the carbon discs.

The three British racing green C-types were now equipped with disc brakes developed by Dunlop

But Nissan's bid for 1990 Le Mans glory started falling apart on the formation lap when the first car broke its gearbox, and 24 hours later a single fifth place was all Nissan could take home. The following year, in 1991, compatriots Mazda not only scored the first-ever Japanese win and the first victory for a rotary engine, but also for carbon brakes and pads.

The first half of the 1990s was marked by a major crisis in sportscar racing. After the failure of the 3.5-litre F1-engine formula, the world

In 1998 American entrepreneur Don Panoz entered the first hybrid in the Le Mans 24 Hours. The Panoz Esperante GT1-R, which was nicknamed 'Sparky', didn't qualify but raced later that year in the Petit Le Mans at Road Atlanta (Serge Cailler**)**

championship had disappeared and with it the big-spending manufacturers. With Le Mans now run as a standalone event, the ACO had opened its race for GT cars to headline again. Needless to say Porsche was more often than not the weapon of choice for those teams trying their luck at Le Mans in a GT car, and both the development and production facilities at Weissach were working overtime to supply the numerous customers with the right tools. As such, the Porsche works team entered a one-off super-911 based on the 964-generation of the Stuttgart classic, the 911 Turbo S Le Mans in 1993. As well as featuring huge wheels and massive power the car was also equipped with ABS, as was now allowed per the rules. Unfortunately, a collision with a slower car halted the car's remarkable progress up until that point. The development of ABS in racing would continue, however, and Porsche's 16th overall Le Mans victory came courtesy of a 911 GT1 98 equipped with an ABS system in 1998.

On the gas

The second half of the 1990s had seen the rebirth of an international, FIA-sanctioned GT championship and the manufacturers returned to Le Mans, with exotic prototypes thinly disguised as road cars. At the same time, privateers got even more creative in their quest for technological diversity. In 1995, Frenchman Alain Lebrun used a 1993-spec WR (the small single-seater sportscars the ACO had allowed in to swell the grid a few years earlier) equipped with a Peugeot engine running on liquefied petrol gas, or LPG. The idea was to prepare for the future by having a first green car on the grid. Unfortunately, the underfunded project didn't make it past the pre-qualifying session where the car was slowest by minutes. Another attempt the following year yielded the same result, though now the deficit had been brought down to about a minute. A third attempt in 1998 ended in a third disillusion and it was the last time an LPG-powered car was seen in Le Mans.

Frontal assault

Awareness for the environment and the effects of global warming and green house gasses had sent many people thinking about solutions, though the automobile industry was traditionally slow in trying to set an example. Once again, it was left to the spirit of Le Mans and the entrepreneurship of individuals to lead the way. One such individual was Dr Don Panoz, an American business tycoon who had decided to create his own make of supercars. Designed by Adrian Reynard, the front-engined Panoz Esperante GT1-R made its Le Mans debut in 1997 – the first new American manufacturer to come to France since Dodge in 1976. It had been nearly two decades since a front-engined car was last seen in Le Mans, but Panoz was a firm believer of the concept. Though none of the cars finished the race that year, the good doctor came back in 1998 with yet another daring idea: one of his cars ran a hybrid electro-fuel engine. Finished on-site and driven by James Weaver and Perry McCarthy, 'Sparky', as the car was affectionately known, unfortunately failed to pre-qualify. By then, however, Panoz had reached an agreement with the ACO to create his own American Le Mans Series States-side and Sparky would still get to race at Petit Le Mans later that year. The hybrid Panoz never came back to Le Mans, but a decade and a half later the first overall victory for a hybrid car was fact when in 2012 Audi scored its 11th win with the hybrid-diesel R18 e-tron Quattro. From 2014 onwards, LMP1 factory teams would be required to only run hybrid cars and in 2015 Porsche scored a first hybrid-petrol win.

With the fast pace of car development in the 21st century the ACO come up with a specific one-car class for experimental vehicles, called Garage 56. The candidate entry did not have to conform to specific regulations but had to present new ideas or technologies in racecar development. That idea then developed, and a manufacturer could use it to demonstrate a new technology that it planned to run in LMP1. In 2012, the first tenant of the 56th pit box was the Nissan-engined DeltaWing. The car didn't feature new technology, just a new way of thinking and packaging, and it was quite successful at that. A side-swipe by a faster car prevented it from finishing in the top 10.

Racing Green

The 2013 candidate selected by the ACO was a different beast altogether. A team of Swiss engineers had developed and built a hybrid electric/hydrogen fuel cell racecar, dubbed the GreenGT H2. The GreenGT H2 racecar was based on a 2009 concept of an electric competition vehicle powered solely by lithium-ion batteries. When a greater autonomy was needed, the engineers turned to a hydrogen fuel cell to provide additional energy to power the electric engines. When that seemed to work, GreenGT set about developing a more powerful yet more compact fuel cell and applied for the Garage 56 ticket for 2013. The ACO agreed, but the GreenGT H2 would only be seen in Le Mans in static form. Persistent overheating issues meant the team had to throw in the towel just three weeks before the race. The GreenGT H2 would have been the most complex technological innovation to have ever raced at Le Mans, but in the end it would be nothing but a photo opportunity despite further development.

Since then, the likes of Porsche and Toyota have fine-tuned their hybrid technology. But while it is anybody's guess what the future of car technology will bring, it is very doubtful the car makers' technical achievements will match in any way the human challenge of the first quadruple amputee to race at Le Mans last June. Yet another first for La Sarthe.

It would have been impossible to use the carbon brakes without the new chicanes in place for they would have cooled off too much to be operational when the car arrived at Mulsanne Corner

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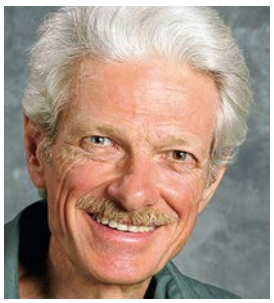

Suspension mods on US Late Model racers

Why run a soft spring on the right front of a short-oval dirt car?

QUESTION

I have a question about the theories of pinning the RF on a dirt Late Model. I stopped racing in 2006 and just being a spectator now has me curious. I've asked a handful of people about this and really have got nowhere. It appears many guys are running a really soft RF spring to allow the car to fall on to some form of a bump stop (bump spring, bump rubber) and then they have a very high rebound shock to hold the car there. My question is (or theory, I guess) why all the shock technology? Could you not just lower the static ride height and run what would be considered an overly stiff spring to get the wheel load there without all the movement? I feel it is the dynamic ride height (where the car stops rolling) that is important and not the movement to get it there. In other words why aren't they just setting the car up in a dynamic state of roll/hike and leaving/keeping it there? Or am I simply misunderstanding something?

(*This second, related question, also about dirt Late Model, comes from a different reader*).

Lately I have been reading that many dirt late model and modified racers have been adding non-rotating weight to the left rear axle.

For years people have been trying to get unsprung weight as light as possible, aluminium axle tubes and spindles and aluminium radius rod brackets, etc. Now there are steel axle tubes as thick as can be without interfering with the spinning axle. I would like to hear your understanding of this.

US Late Model stock cars on the dirt. Some pin the front right down with a soft spring and a very high rebound damper

THE CONSULTANT

When you see suspension strategies that really don't seem to make sense by ordinary reasoning but seem to be popular, there are two possible explanations.

The first explanation is 'trick of the month effect': people are blindly copying something that is rumoured to be the hot set-up, without understanding. The second is that the seemingly anomalous strategy allows us to get around a regulation, or work a rule, quite often for aerodynamic advantage.

Sometimes we see a combination of the two reasons: a technique is useful due to a rule in one series but gets adopted imitatively in another series that doesn't have the rule.

ARCA cars use very soft springs and bump rubbers or small coil bump springs, with hold-down shocks, at all four corners. This used to be done in the upper NASCAR divisions. The reason was to get around a ground clearance rule. NASCAR did away with the ground clearance rule, so we don't see such set-ups there anymore. ARCA still has the ground clearance rule so we still see soft spring/bump stop set-ups there.

There are a number of sanctioning bodies running dirt Late Model races in the US, and they all have their own rules. Somewhat similar cars also run in Australia and New Zealand, also under local rules.

Stops stopped

IMCA has new rules this year prohibiting any kind of suspension stops whatsoever on the front, and also requiring only one constant-rate spring per wheel. It even prohibits spring rubbers (between the coils). There is one exception allowing a 'take up' spring on the left front. In dirt Late Models such springs have been used with a droop stop on the shock body that makes the rate increase toward the droop end of the travel, as opposed to the 'tender springs' seen on lowered production cars in road racing, which provide a very soft spring that is coil bound in normal operation and is just there to keep the main spring in place when the car is jacked up.

IMCA also has a new rule requiring 'standard weight aluminium or steel axle tubes only'. I don't see those provisions in the WoO or WISSOTA rules. WoO and WISSOTA do have 'catch all' rules saying anything 'non-standard' or innovative in any way is to be submitted for approval in advance. I don't know if they actually check for heavy axle tubes. WoO does prohibit any separate insert inside an axle tube.

Soft option

So, okay – why would you want to run a very soft RF spring? Wouldn't it do the same thing if you just set the RF ride height lower? It would, pretty much – but you couldn't get the car through tech. All the sets of rules have very stringent requirements about the height of the left rear corner of the body, the amount of tilt in all the horizontal surfaces, the radius of the edges, the amount of dish in the quarter panels – anything that could affect the car's ability to generate downforce and lateral force when running in aerodynamic yaw.

From a normal suspension design standpoint, a lot of what's done on dirt Late Models is nonsensical. That is, it doesn't help the wheels follow the road surface or minimise camber change or bump steer. Rather, it's about aero. It's about having the car level and at legal heights when it goes through

Wouldn't it do the same thing if you just set the RF ride height lower?

It's about having the car at legal height when it goes through inspection

inspection, and at the same time getting it to run as nose-down, tail-up, sideways, and tilted as possible at speed, to get lateral force and downforce out of that big slab-sided body.

So how does a soft RF spring play into this? It makes the right front corner drop more, and the right rear and left front rise less, when the left rear hikes to full droop or close to that. The bump rubber is then necessary just to provide at least a little cushioning and prevent destruction of parts when the suspension goes to full compression. The soft RF spring also makes the car gain less wedge when the LR hikes. The car corners with the left front lower, so less air gets under the car there. That helps overall downforce. The RF will drag the nose on the ground, but that's dealt with by trimming the bottom edge. This could probably work without a hold-down shock. The car would just come up a lot at the RF on the straights.

The heavy axle tube makes less sense. It probably doesn't hurt much if the suspension is topped out and the entire left rear corner is effectively unsprung anyway, but I can't see it helping. I don't see any rules that restrict ballast location other than requiring it to be within the frame and not on the bumper, so a heavy axle tube doesn't offer any advantage in terms of centre of gravity location. I could maybe see some point in hiding ballast by using heavy tubes, and then adding phony ballast weights made of aluminium rather than lead in wacky locations, just to fake out the competition. But I think I'd rather have heavy frame tubes instead of axle tubes. Of course, adding or removing a heavy axle tube would be easier.

The right attitude for a Late Model dirt car: nose down, tail up and sideways. This generates downforce from the car body

CONTACT

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Nailing the aero balance on a GT-R

Our Nissan 'Ring racer study continues with tweaks fore and aft

The subject currently under the MIRA full-scale wind tunnel spotlight is the Nissan R35 GT-R of London-based Australian Anthony Gaylard, who is targeting a sub-seven minute lap of the Nurburgring's Nordschleife circuit. The car, which will be road legal for the attempt, has been assembled and developed by UK-based Litchfield Motors, and features 1000bhp, Ohlins-tuned suspension, Alcon brakes and an aerodynamics kit based on NISMO GT3 components.

As a brief reminder, we established last month that the baseline configuration of the aerodynamics saw downforce heavily rear biased, but by the end of the session the car had a decent aero balance along with respectable downforce compared to the wind tunnel-derived data we obtained on an earlier GT3 car, the Ferrari F430 Scuderia. **Table 1** summarises the baseline and the balanced data. Getting to the balanced set-up initially involved decreasing rear downforce but good steps were also made at realising the front end's downforce generation potential too. This month we will we focus on some of those big steps towards achieving that balance.

Nurburg-wing

With the initial balance so heavily rear biased, substantial steps needed to be taken to tackle the issue, the first of which was to reduce the wing's flap from maximum to minimum angle. This was followed by reducing the overall angle of attack of the whole wing assembly to the minimum setting available in the main element's adjustment range. The changes to the coefficients and balance arising from these wing changes are shown in **Table 2** as 'delta' or Δ values in 'counts' where 1 count is a coefficient change of 0.001. **Table 3** shows the car's overall data after the rear wing changes.

Dropping the wing to its minimum angle had a substantial effect on all parameters then, and in the context of the pursuit for balance it brought front downforce up to just over 18.3 per cent front, in absolute terms, from the starting point of modest front lift. The mechanism for this increase in downforce at the front wheels is primarily the reduction in the rear wing's downforce and hence its leverage from its overhung position some way aft of the rear axle, which takes weight off the front wheels. But reducing the rear wing's downforce contribution also proved that the splitter and dive planes were generating downforce, just not enough to balance the rear wing at maximum angle, nor yet at its minimum angle. The next step was to move to front end modifications in the expectation of adding front and total downforce again as well as still further improving the car's balance.

Keeping cool

The GT-R featured a large intercooler and behind that a water radiator, fed by the front apertures. Initially there was no ducting

Substantial steps needed to be taken to tackle the issue, the first of which was to reduce the wing's flap from maximum to minimum angle

The Nurburgring-bound Nissan R35 GT-R LM1 RS being readied by the team at MIRA

The rear wing was large, high and set well back – which made it a challenge to balance

Table 1: Baseline and optimised coefficients on the Nissan R35 GT-R

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.543	0.896	+0.061	0.957	-6.78%	1.651
'Optimised'	0.426	0.561	0.241	0.320	42.91%	1.316

Table 2: The effects of rear wing angle adjustments

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
Flap to min angle	-81	-205	+77	-282	+9.1%	-155
Overall to min angle	-61	-218	+71	-288	+16.0%	-315
TOTAL Δ	-142	-423	+148	-570	+25.07%	-470

**Absolute rather than relative difference in percentage front.*

Table 3: The GT-R's data after the rear wing angle reductions

	CD	-CL	-CLfront	-CLrear	%front	-L/D
After wing angle reductions	0.401	0.473	0.087	0.387	18.3%	1.181

Main front aperture was reduced in size by taping a foam board with smaller inlet over it

The internal ducting inside the aperture was mocked up with tape and foam boards

Final step was to tape over the upper aperture completely, further reducing the inlet area

Table 4: The effects of reducing the size of the front main aperture

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
Reduced aperture	-8	+21	+31	-11	+5.60%	+78
Ducted aperture	-5	+19	+31	-11	+5.06%	+65
Taped over upper aperture	-3	+9	+21	-13	+3.52%	+34
TOTAL Δ, counts	-16	+49	+83	-35	+14.18%	+177
Total Δ, %	-4.0	+10.4	+95.4	-9.0	-	+15.0

**Absolute rather than relative difference in percentage front.*

Table 5: The GT-R's data after the front duct modifications

	CD	-CL	-CLfront	-CLrear	%front	-L/D
After front duct modifications	0.385	0.522	0.170	0.352	32.47%	1.358

to channel air from the inlets through the coolers, but the Litchfield Motors team had experienced the benefits to cooling and aerodynamic performance that are achievable with ducting to the coolers on its 2006 UK Time Attack Championship-winning Subaru, and so had come equipped with materials to make changes to this area on the GT-R.

The first modification was simply to reduce the size of the main, lower aperture by taping a foam board panel, with a smaller aperture, over the front. Next, the internal sides, top and bottom of this reduced aperture were ducted to the front of the intercooler with tape and foam board. And then the upper aperture was taped over completely, representing a further reduction in the overall inlet area. The results, as the changes for each step and as a cumulative change, are shown in **Table 4**, with the overall data following these modifications shown in **Table 5**.

If there was ever any uncertainty about the benefits to the aerodynamics of ensuring that air entering the front apertures goes through the coolers, and not around them and into the front compartment, then this data should eradicate that doubt. Even with the array of louvred outlets in the bonnet, air that previously was bypassing the front coolers was obviously generating significant drag and lift. However, each simple step here brought tangible benefits to drag, to total downforce and to efficiency (-L/D) and, of most importance in this context, to front downforce, helping further to realise the front end's potential to generate good downforce. It's not hard to envisage that with properly manufactured inlet ducting fully sealed to the cooler faces that even more benefit could be had in reality. But 10 per cent more total downforce for four per cent less drag along with a very useful forwards shift in balance was a very good step forwards. And as Litchfield Motors' previous experience bears out, ducting also makes big improvements to cooling efficiency, itself of some importance when you have 1000bhp propelling a 1400+kg car around a 20km lap.

Ten per cent more total downforce for four per cent less drag was a very good step forwards

One additional ducting trial was put together, which saw side panels installed that extended from the inlet apertures right up to the water radiator, and tape was also applied above the intercooler and radiator to see what would happen when the air was more thoroughly ducted to the radiator. In fact, this last duct modification saw very little change to the aero numbers and a very slight reduction in the %front value. So even though more air was being channelled through both coolers, which would probably improve cooling efficiency, perhaps some of the forward bonnet louvres were now effectively being blanked off as well, which meant there wasn't a net benefit to the aerodynamic numbers. Nevertheless, the overall gains from this phase were very valuable.

Next month we'll focus on a range of smaller but nonetheless important changes to the front of the car; some rake adjustments; and we will fit some rear diffuser fences, all in the quest for more downforce while achieving that vital aerodynamic balance.

Thanks to Anthony Gaylard, Iain Litchfield, and all the team at Litchfield Motors.

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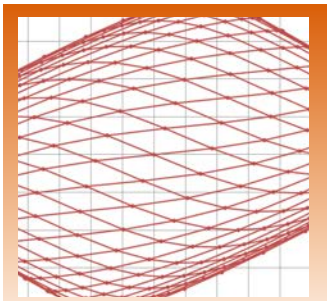
In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers



Slip Angle provides a summary of OptimumG's seminars

Slide rules: analysing an oversteering car

What makes a car quick in steady state and in transient? Claude Rouelle develops his analysis of lateral acceleration and yaw moment variation

Days of yaw: too much yaw moment at the apex and you have oversteer, too little and it's understeer. For drifters too much yaw moment is obviously a good thing

In April's *RE* (V27N4), we saw that there are 12 causes for the yaw moment: four tyre lateral forces *Fy*, four tyre longitudinal forces *Fx*; and four tyre self-alignment moments *Mz*. Let's now imagine a car cornering and braking in a left-hand corner entry, and consider this anti-clockwise yaw moment as positive.

The yaw moment equation is as follows: (*FyLF cos δLF + FyRF cos δiRF*) *a- (Fy LR + Fy RR) b + FxLF Tf /2 + FxLR Tr /2 – FxRF Tf /2 + FxRR Tr /2 - MzLF – MzRF - MzLR – MzRR = Izz* (*dr/dt*) (*7*) **(Figure 1)**. In this case, the two front tyre lateral forces *Fy* as well as the two left side braking forces *Fx* create a positive yaw moment, while the two rear tyre lateral forces *Fy* and the two right side braking forces *Fx* create a negative yaw moment. Except for some exceptional cases of very high slip angles, tyre self-alignment moments *Mz* are most often negative. This equation is made in the chassis coordinate system, which is why the cosines of the inside and outside front steer angle are used. We will consider any possible static front and rear toes (we could call those 'pre-slip angles') and any possible bump steer and steer by compliance as negligible.

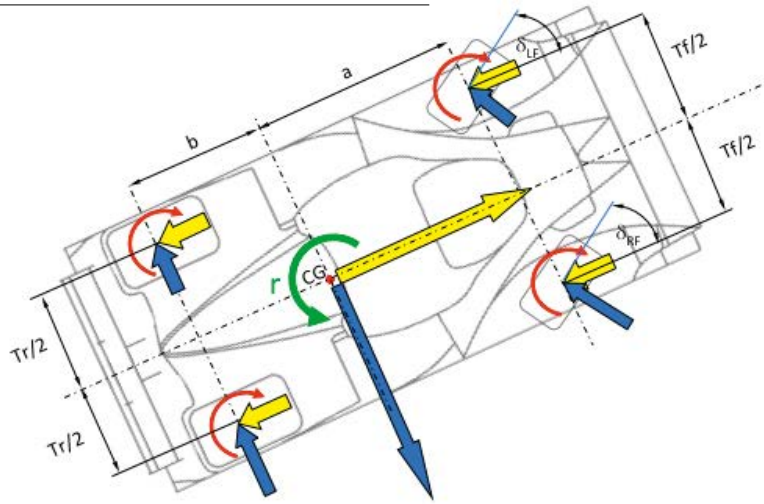
Electronic Stability Programming (ESP), front and/or rear differential control or torque vectoring (especially in the case of cars with four electrical motors) are often used to control the tyres *Fx* and, consequently, the yaw moment. However, it is important to notice that on practically all cars, the distances *a* and *b* (that are the leverages of the tyre lateral forces) are bigger than the front or rear half-track (that are the leverage of the tyre longitudinal forces). In the case of a tyre friction ellipse that is a circle (as much potential *Fx* as potential *Fy*), tyre braking or acceleration longitudinal forces will always have a smaller effect on the yaw moment than the tyre lateral forces.

Lateral thinking

Several factors such as slip angle, dynamic vertical load, camber, speed, pressure, and temperature influence the tyre lateral forces. Tyre slip angles have three causes: car side slip angle *ß*, yaw velocity *r*, and steering angle *ß*. As *ß*, *r* and *ß* evolve in a turn so do the four slip angles, the tyre vertical loads, cambers, temperatures and lateral forces.

We will now analyse the evolution of both lateral acceleration and yaw moment along a turn, and to simplify our thoughts here, we will only consider the tyre lateral forces' influence on the yaw moment and the lateral acceleration.

Starting from point A seen on **Figure 2,** the driver turns the steering wheel and creates front tyres steering angle, always with some delay as even the best designed and manufactured cars have some steering compliance.



A reaction force to the front tyre lateral forces is created at the car's CG

$$(Fy_{LF} \cos \delta_{LF} + Fy_{RF} \cos \delta i_{RF})\, a - (Fy_{LR} + Fy_{RR})\, b + Fx_{LF}\, T_f/2 + Fx_{LR}\, T_r/2 - Fx_{RF}\, T_f/2 + Fx_{RR}\, T_r/2 - Mz_{LF} - Mz_{RF} - Mz_{LR} - Mz_{RR} = Izz\, (dr/dt)\ (7)$$

Figure 1: Equation of the yaw moment with its 12 causes

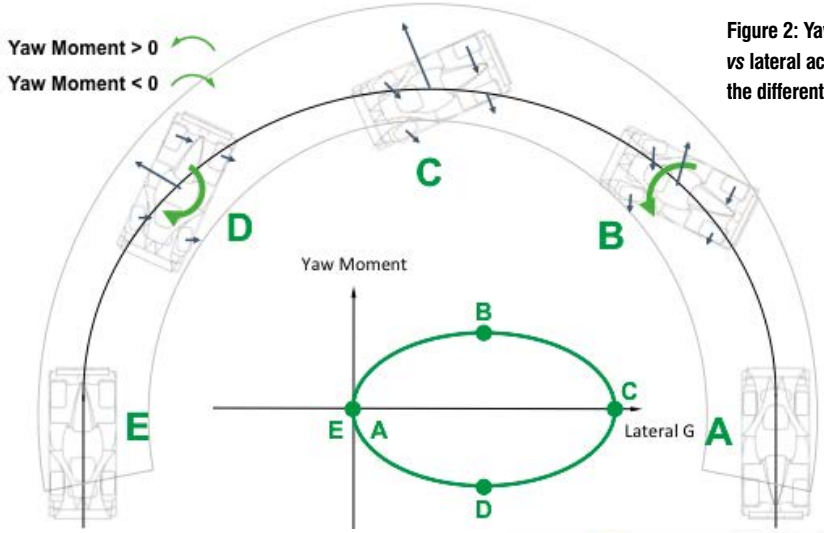
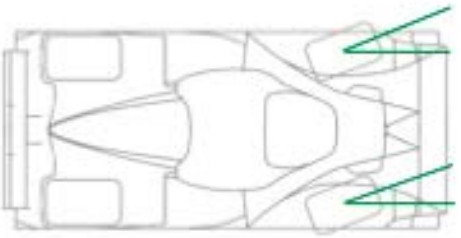
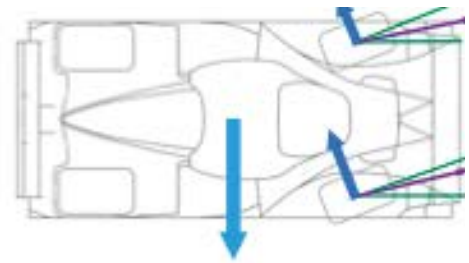


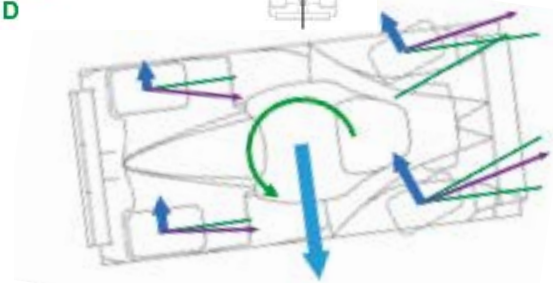
Figure 2: Yaw moment *vs* lateral acceleration in the different turn phases



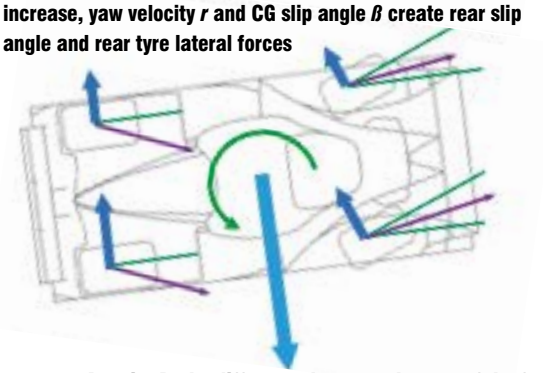
Point A: Steering wheel input



Right after point A: Front slip angle, front tyre lateral forces, lateral acceleration, and yaw moment increase



From point A to B: While front tyre lateral forces continue to increase, yaw velocity *r* and CG slip angle *ß* create rear slip angle and rear tyre lateral forces



At point B, the difference between the sum of the front tyres and the sum of the rear tyre lateral forces is the biggest: the yaw moment is at its peak. At point C (the corner apex), the front and rear lateral tyre forces will reach their peak and the yaw moment created by the front tyres will equal the yaw moment from the rear tyres. The yaw moment is 0

Figure 3 (above and right): The different phases of tyre lateral forces and yaw moment in the corner

Front tyre lateral forces are created, again with some delay that we often define with the tyre relaxation length. A reaction force to the front tyre lateral forces is created at the car CG. The front tyre lateral forces are not yet balanced by any rear tyre lateral forces, as for a very short time there isn't any rear slip angle. However, there is a yaw moment. Without it, the car wouldn't enter the corner. That yaw moment will make the car slip (angle *ß*) and yaw (yaw velocity *r*), and so are the rear slip angles and rear tyre forces being built, again considering some reaction time due to the rear compliance and tyre transient behaviour. The process will continue until point C where the yaw moment generated by the front tyres will be equal to the yaw moment generated by the rear tyres. The yaw moment is now 0.

Let's suppose for a moment that the car was driven on a huge surface without any obstacles. If at point C the yaw moment would remain 0, the car will put itself on a skid pad. We need to create a 'de-yawing' moment to extract the car from the corner. The driver will reduce the steering wheel angle. The front tyres steering angle, front slip angles and front lateral forces will be reduced earlier than the rear ones and a negative yaw moment will be created. The apex is the region of the corner where the yaw moment is 0. If you are not convinced, just look at the trace of your gyro signal. It will be flat for a short time, which means no yaw acceleration and no yaw moment. In a simplified way, we could look at the apex as the place where the racecar is close to the steady state definition. But this is also where the gyro slope and, therefore, the yaw moment sign change.

Figure 3 shows the evolution of both yaw moment and lateral acceleration in a left-hand corner.

Apex speed

Let's now suppose that an engineer wants to increase his car speed at the apex. If he could increase all corners'

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Some engineers say there isn't such a thing as understeer or oversteer – for them there is only under or over yaw moment

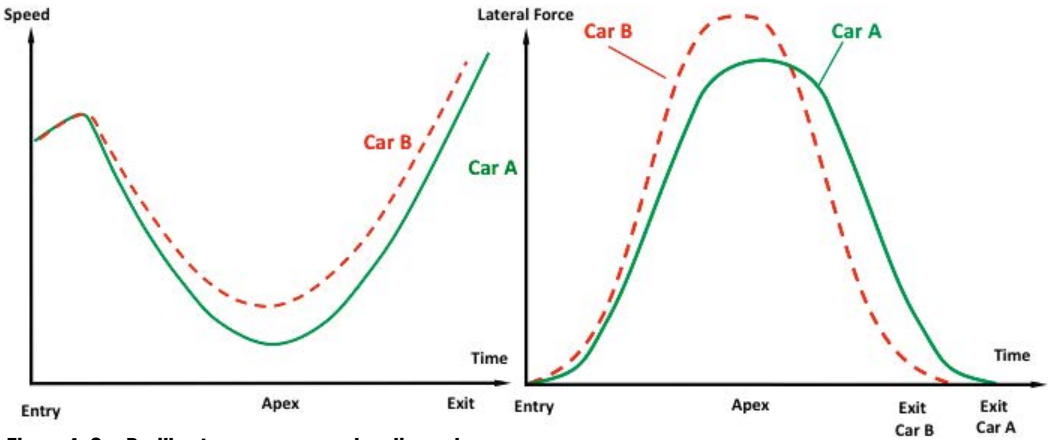

Figure 4: Car B will get more apex speed earlier and, therefore, also earlier and more lateral acceleration

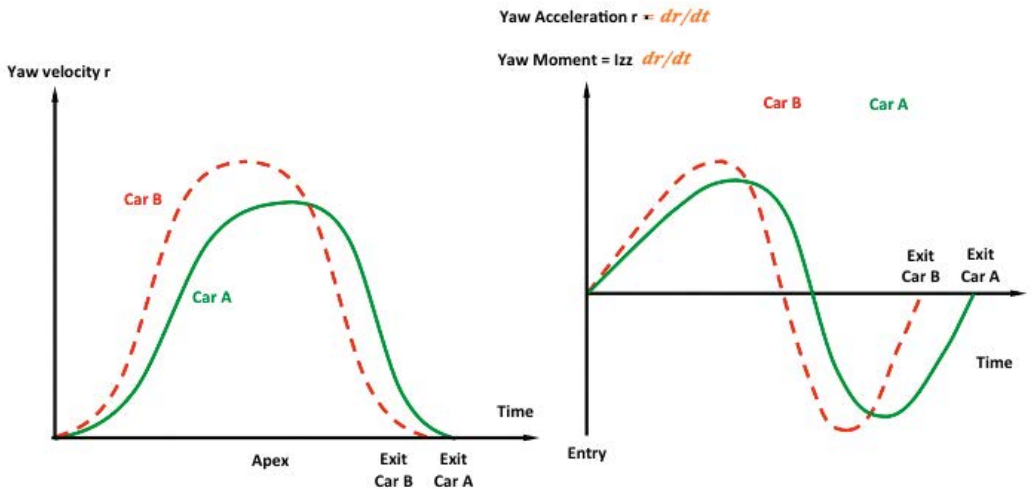

Figure 5: Car B will get more yaw velocity, more yaw acceleration, and more and earlier yaw moment

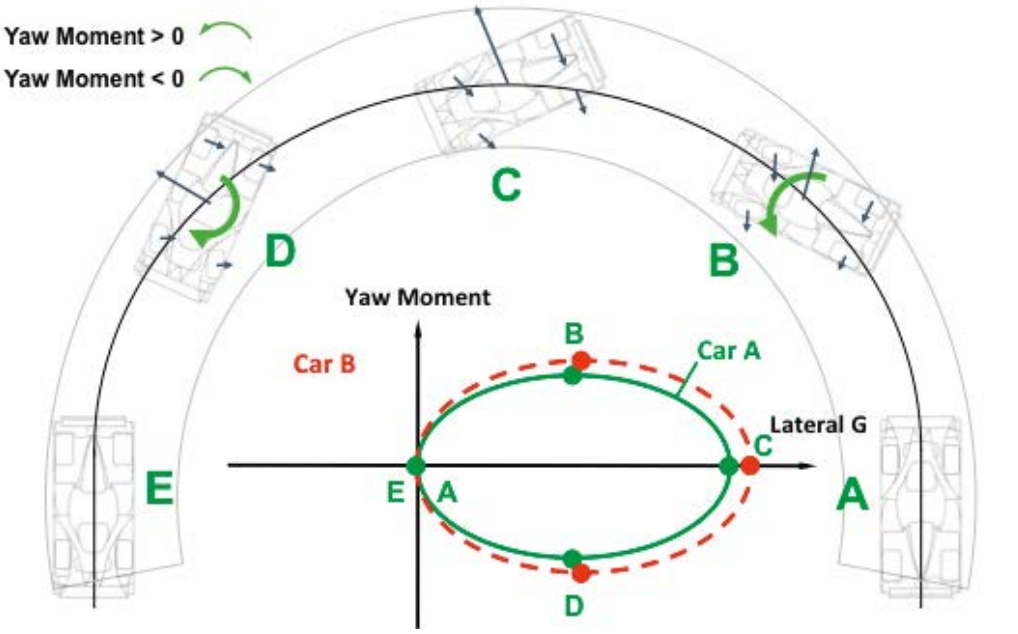

Figure 6: Going faster not only requires more tyre grip but also the right amount of yaw moment, which means the right difference between front and rear tyre grip (or left and right tyre grip)

apex speed by 0.5 per cent, the lap time gain would be significant. Let's imagine that the driver is on the same trajectory with car B that he was with car A so we can make an apple-to-apple comparison. More apex speed on the same given radius means more lateral acceleration at an earlier time and a necessary increase in tyre grip **(Figure 4).** There are many ways engineers could reach this goal: better tyres; the same tyres with more vertical load from aerodynamic downforce; or better use of existing tyres with appropriate slip angle, pressure, camber, temperature, etc.

That is for lateral acceleration. But what about the need of yaw moment and yaw moment variation? More tangential speed on the same radius implies more yaw velocity. A bigger yaw velocity in less time implies a bigger yaw acceleration. Bigger yaw acceleration for a given yaw inertia means bigger yaw moment **(Figure 5)**. The yaw acceleration (or yaw moment) *vs* lateral acceleration diagram will be different **(Figure 6)**.

Yaw the boss

Some engineers often say that there isn't such a thing as understeer or oversteer – for them there is only under or over yaw moment. Going faster is not only about getting more tyre grip, it is also about getting the right amount of yaw moment at the right place in the corner. Too much of it, and you have an oversteering car. Too little of it, and you have an understeering car.

Everybody understands that to gain more speed we need better tyres and/or better use of tyres. But going faster is also about getting the right amount of yaw moment and, consequently, the right amount of difference between front and rear tyre lateral forces (or left and right tyre longitudinal forces).

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Supporting cast

At the circuit there's an entire network of engineers and specialists who are not part of the team yet play an essential role during the race weekend. Meet the unsung heroes of trackside support

By GEMMA HATTON

F1 rolls into Monaco. The principality is a challenge for those involved in logistics while it also presents issues for companies working in comms. Both sectors provide crucial support to Formula 1 teams

Formula1 had its busiest season last year. The 21 race calendar required teams to travel approximately 160,000km, which is almost equivalent to four times round the world. This can lead to logistical costs in excess of £12m for each team – which is why the FIA restricts the number of trackside personnel to 60 for each F1 outfit.

But, as ever, F1 teams see regulations as an opportunity to drive development in other areas; achieving their original goal, whilst remaining legal. In this case, they have invested heavily in communications, electronics and data transfer, to establish their very own 'mission controls' back at their factories.

Another way in which teams efficiently spread their trackside-manpower is by utilising their suppliers, whose role has become increasingly important over recent years. Whether it's radios, tyres, engines or electronics, teams have access to their own trackside support engineers, and this is becoming common throughout the tiers of motorsport.

These suppliers fall into two categories. First, there are the championship suppliers who usually have an agreement with the FIA to supply all teams with the same products and services. These include the likes of Pirelli in F1, Cosworth electronics in LMP2 and radio companies such as MRTC. In most cases, these manufacturers will provide each team with a trackside engineer, which will not count towards the team's trackside member allocation. 'In terms of what we do, we're more there to assist in the background,' says Neal Bateman, technical manager at Cosworth (see case study). 'We're involved with answering technical questions. No one comes to us and says 'Can you engineer our car to go faster', usually they want help with their maths channel to do something, so we will get involved with helping them with that.

'Some of the teams have come from other championships using our stuff, others have come from using completely different electronic equipment, so there's a learning curve there for everybody, so we try and make sure we're available and we have a support forum which we use where teams can ask questions, while in LMP2 we have an email address that everyone in our office monitors so we can give responses in that way as well. So it's not to help them go

Pirelli will have its own people at the F1 grands prix and will also have an engineer and a tyre fitter embedded within each team, thereby two of the 60 trackside personnel permitted by the FIA to work at a Formula 1 race

This season's bigger F1 tyres have not just been a challenge for teams, they have also caused headaches for those transporting them to the races, and in terms of storage at the track and space in the pit garages

There can be a downside to having a high profile involvement in Formula 1 as Pirelli discovered back in 2013 when there was a spate of tyre failures during the British Grand Prix. Shredded rubber on TV is not good PR

Communications are vital in modern F1. Riedel is responsible for much of F1's radio traffic as well as other comms technology

One way in which teams efficiently spread their trackside manpower is by utilising their suppliers

faster, it's to help advance the tools to enable them to do that. Everything is very similar for these guys in the LMP2 paddock, they don't want to [reveal to] outsiders anything they do which they think might give them an advantage.'

Then there are the team suppliers, who have secured contracts with specific teams and are therefore competing against other manufacturers. The likes of Mercedes HPP, Honda and Renault Sport are developing powertrains in open competition in Formula 1, as well as brake suppliers Brembo and Safran and gearbox manufacturers Xtrac and Williams. Depending on the potential performance gain of the product, these suppliers may provide trackside engineers to work within their race teams (and therefore are included in the team's member allocation).

Embedded personnel

Let's take the example of a Formula 1 team. Formula 1's suppliers will provide each team with one Pirelli tyre engineer and one tyre fitter, as well as a Riedel engineer and a McLaren Electronics engineer. Then you have the engineers and technicians who are working within the team from the engine and gearbox suppliers who are in open competition.

The role of the supplier is actually very complex. To develop the performance of their products, companies need data and there is no substitution for real world conditions, which

To develop the performance of their products companies need data, and there is no substitution for real world conditions

means race data. However, this means suppliers can have access to several teams' data which breaches the confidentiality teams guard so jealously. Yet teams demand better products from their suppliers. So there is an element of both cooperation and trust here.

In F1, for example, Pirelli is a technical partner and therefore the technical directives require teams to send specific data channels from FP1, FP2, qualifying and the race which helps it set its minimum pressure and camber prescriptions. If Pirelli can't access this data then these prescriptions have to be set based on rig and track tests, but if teams co-operate then there is the possibility Pirelli will decrease the minimum pressures and increase the minimum cambers – which is what the teams want.

Of course, Pirelli is a very familiar suppler, but there are many others to be found at the track. Riedel supplies radio equipment to teams in F1, for example. 'Not all the teams use our system,' says Dario Rossi, head of Motorsport Division at Riedel (see case study). 'We don't have McLaren, as they have a different supplier due to sponsorship for the radio. They do use our intercom, but don't have a support engineer. We have six support engineers in the teams, the other teams do it themselves, and then we have seven support engineers in the FIA.'

Communications console on the pitwall. The team at the track needs to be hooked up to each and every important member of the operation, whether they are at the circuit or calculating strategies and monitoring data back at its HQ's mission control

Radio heads

Rossi adds: 'As teams now only have 60 people on track and a lot at home, they need to use an intercom, so every morning our engineers perform a test and they have a checklist and they go through the connection. We have a WAN MPLS connection, which is very fast, its on optical fibre. Remotely we can access the system and make sure all the communication is up and running. The team itself is normally asking to change configurations because there are different people every event, so sometimes they want to connect another remote connection, or people connected by cell phone or Skyping, and we ensure that these are up and running before the session. The same for the radio because there are different people on track and so they make sure that all the radios are configured, reprogrammed, and performing, basically.'

There is also the issue of brand awareness. Suppliers work in motorsport because it offers the opportunity to push their products to the

The teams arrive at flyaway grands prix to find their equipment ready and waiting thanks to Formula 1 partner DHL. The organisational effort is immense yet it rarely goes wrong

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Depending on the potential performance gain of the product, suppliers may provide trackside engineers to work within the race teams

DHL is responsible for making sure the vast paraphernalia of a grand prix is in place throughout the Formula 1 season; including media and broadcast equipment and some 600 tonnes that make up the Paddock Club. It uses 170 trucks for F1

Case study: Cosworth

Cosworth was selected to supply electrical components for the LMP2 category at Le Mans. Part of the fixed price support package means that there is trackside support for the teams at the start of the year, and the Le Mans 24 hours will also be well staffed by Cosworth.

'We attend the track to assist teams with using our electronics and to provide spares to teams if during an incident a unit is damaged,' says Neal Bateman, technical manager at Cosworth. 'There isn't much difference between practice and race to us. We aim to be there and available when required by the teams but not to be in their way whilst they run the cars.'

Cosworth has attended many of the key LMP2 and DPi tests in preparation for the 2017 season, including the first rounds of the IMSA WeatherTech Sportscar series and the WEC. 'Our role in LMP2 is to ensure that the cars are running reliably and to assist teams with any questions, these tend to not be performance related, the teams all have experienced engineers for this and the system is locked down to the teams so it is an easy system to run,' says Bateman. 'The manufacturers supply a locked configuration for the IPS Power Control module and also the TC and gearbox strategy is locked. The engineers all come from different backgrounds and some haven't used our equipment so we will assist them in learning Cosworth configuration and analysis software packages, Toolbox, Caltool and Toolset.'

Switched on

Cosworth also provides spec electronics to the BTCC, which while it has a different package shares similar software and analysis tools with LMP2. 'We have testing rigs that we use to validate our designs before they appear at the track,' says Bateman. 'Of course there is no substitute for on-car track testing and this can still present the unexpected, however we are able to respond quickly if problems arise and have a very dedicated and passionate engineering and support team to react fast to provide solutions.'

One of the major things with the new LMP2 system is the teams' ability to programme the electronics. 'The difference between WEC and ELMS is there is a range of abilities, a range of funding behind them, or range of set-ups, and so the questions you get from the higher end LMP2 teams will be completely different to what the other end teams are asking,' says Bateman. 'There are teams that are new to the car, new to everything, they have new people involved, they struggle and so we end up spending more time with them to make sure their car is running reliably, and making sure you pass on any information that we've got off our experience to try and help them. The other end of the spectrum is you don't get asked so many questions, you get exposed to very little of the team, as obviously they've got their own electronics guys in house.'

limit and a fast development rate. However, if suppliers under-perform, not only are they exposed quickly, but on a global stage they risk damaging their reputation. Take the current PR nightmare at McLaren Honda, or the Pirelli tyre failures at Silverstone in 2013. Yet, if it's not safety related, the supplier engineers can only advise teams on what to do; the team has the final say, which can lead to situations where the supplier's reputation suffers for a team's mistake.

Travelling support

Each F1 team transports 40 to 50 tonnes of equipment per race, which equates to the entire Formula 1 paddock filling up the cargo hold of six jumbo jets. This pop-up Formula 1 circus is transported to 20 different countries around the world within approximately eight months and this is only possible with the help of a logistics partner, such as DHL.

In addition to handling the overseas move of racecars, engines, tyres and other equipment for the teams DHL also completes the logistics for all the media and the broadcast equipment. Its staff has to flat pack the 600 tonnes of towering VIP hospitality structures into 170 trucks and ensure that all dangerous liquids such as fuel, oils and coolants are transported safely in fireproof canisters, so as to withstand the range of extreme global temperatures.

As soon as the race calendar is confirmed, the planning for this mammoth task begins, to ensure all the logistics and documentation requirements for each event are mapped out. DHL's race weekend starts around two weeks beforehand, when the first ocean freight begins to arrive and is unpacked throughout the days directly before the race. During the race weekend, the workload shifts to further planning and scheduling of route itineraries for the next race along with all the associated paperwork for custom clearance and border inspection. The second the chequered flag drops, team mechanics, truckies and 20 to 30 DHL people start disassembling the paddock.

'With so many back-to-back races this year, we have to work on the operational side of things straight after the race,' highlights Julian Blackman, UK motorsport manager, DHL Global Forwarding. 'We support the teams to disassemble their equipment and package it up on pallets to either load it into trucks for the intraregional races, or transport it to the airports where the aircraft are waiting. Typically, by Monday night all the equipment has arrived at the next destination – we transport everything within 24 to 48 hours on average.'

This is obviously impressive, however we all know that things don't always go to plan.

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Each F1 team transports 40 to 50 tonnes of equipment per race, which equates to the entire F1 paddock filling up the cargo hold of six jumbo jets

CP Autosport has developed this labour-saving laser-aligned setting up system which allows a single mechanic to complete the first set-up on a racecar in as little as 20 minutes. The Setup Wizzard is currently being developed for use in Formula E

Case study: Riedel

Riedel supplies radio support to Formula 1, which sounds simple right up until you look at the detail behind it. Formula 1 has changed, so that the radio in the car this season is over telemetry. Riedel picks up the drivers' voices and with the radio the team can communicate, but there is no longer a Riedel part in the car.

'The difficulties sometimes is the back-to-back races because of dismounting on Sunday and then you start again on Tuesday and obviously some countries have more challenges than others,' says Dario Rossi, head of the motorsport division at Riedel. 'Of course, with the FIA we have a lot of infrastructure because we also have an installation team which comes one week in advance to put the fibre in the pitlane, garages and paddock. with back-to-back races, we do it one week in advance and then go to the other event with a second kit, come in Monday after the race and then go back to doing the other one.'

It's a long way from the old days at Le Mans, where 'Crackly Ken' was a familiar sight in the pitlane as teams struggled to speak to their drivers as the signal bounced off trees, although natural foliage is still an issue at some circuits. 'Some of the tracks such as Spa and Monza needs a lot of adjustment in how you propagate the signal and construct the signal,' says Rossi. 'For example we supply the medical car, the safety car, all the marshals and everything has to be connected to race control, so it takes a little bit of experience and time to make it work flawless. It also depends on the weather. If its raining or dry you have to change the setting. It's not the signal physically, it's how you propagate it in the same way.

City limits

'In the city you have different problems,' Rossi adds. 'You have more reflection due to the buildings in the inner city races such as those held at Baku, Monaco and Singapore.'

The company is also using racing to develop its broadcasting product, and to investigate future technologies. 'There is a lot of work on MPLS (Multi Protocol Layer System) connection – it's a special internet dedicated system,' says Rossi. 'All the F1 teams use it and we're starting to use it in DTM and other championships because it can connect people in real time, they don't have to be at the track. Instead of sending 60 people on, we send the signal home and then they only need to travel with five people. This kind of technology in Europe, the latency is about 10ms, in far away countries such as Australia it is about 60ms. If you have to go to Australia to Italy then to the UK it's 60ms.

'The challenge is all the infrastructure for the FIA. In race control we supply a lot of equipment and developed a lot of software to manage the race, recording signals, cameras for pits stops and pitlane and that has to be 100 per cent reliable. Working in real time is really a challenge.'

Add to that, the transportation of dangerous liquids through international borders along with unpredictable weather and a short time-frame, and you begin to appreciate just some aspects of the challenge DHL faces every week.

'A feature of our work, especially when operating within the fast-moving environment of F1, is that things don't go exactly according to plan,' explains Blackman. 'Flights are regularly delayed or teams need components more urgently than originally agreed, so we always have a range of contingencies that we can put into action if something doesn't work out.'

Streets ahead

The established races in the calendar are now more of a routine for DHL in some respects, but the new grands prix always present challenges as they have to navigate through new custom requirements and deal with specific cultural and logistics demands. And then there are the peculiar demands of street tracks.

'Monaco and Baku probably differ the most from the other races due to their inner-city locations, which require more careful planning for the last-mile delivery and bring more time pressure for unpacking and packing,' says Blackman. 'However, this is our bread and butter work – as a project logistics team, we specialise in managing the quick and efficient delivery of major motorsports events to different locations around the world in challenging time-frames.'

Space race

This year's 25 per cent wider tyres and larger front and rear wings has had a huge knock on effect for DHL as well as the teams. The garages at some circuits such as Monaco and Montreal are extremely small and so with all the equipment, engineers and mechanics that are required to be next to the race bays it results in a very cramped environment. This reduces the efficiency of the mechanics simply because they have no space. This can be crucial in the panic of qualifying where every second counts to release the car in that sweet spot where the track has evolved and there is still time to get a run in. For DHL, the effect of the 60mm width increase on the front tyres and 80mm increase on the rear is multiplied, as they transport approximately 42,800 tyres around the world. Add to this the larger tyre blankets and trolleys, the larger spare front and rear wings, and DHL have a monumental challenge to overcome this year.

To help manage the scheduling and tracking of all the cargo worldwide, logistic companies have had to develop their own software. Woodland Group, the logistics partner for World Rallycross, have a track and trace system which

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'With so many back-to-back races this year we have to work on the operational side of things straight after the race'

allows it to have tracking of all its freight for 24 hours a day and seven days a week.

'We have a first class operating and communication system which not only gives teams access to costings, but also the ability to see exactly where their goods are at any given time,' explains Kevin Stevens, CEO of Woodland Group. 'We have a strong team of IT developers to ensure our systems meet the requirements of the teams, and event organisers, rather than insisting they fit in to our system.'

As well as transporting equipment, another dimension to logistics is, of course, getting the teams, suppliers and organisers to the racetracks. This not only involves the organisation of flights and hotels, but transfers, visas and passports. Traditionally, this would require colour-coded, mass spreadsheets, but a system called TravelCheck has been developed by Trenchant Technologies to accumulate all this data into one central hub. This can then be used to break an event down into multiple stages which can be manipulated individually, but combined to form a coherent itinerary. The interaction between the stages can be defined and staff can be assigned to specific tasks to ensure they are completed. TravelCheck also has an advanced checking capability to maintain traveller's details such as passports, visas, driving licenses, vaccinations, emergency contact details and even flight preferences, with any issues or conflicts immediately flagged up.

'By keeping all this information in one place, TravelCheck minimises the scope for mistakes creeping in, which can often happen when you are moving details from one system to another,' highlights Chris Drew, director and co-founder of Trenchant Technologies. 'To ensure TravelCheck satisfies real-world requirements, we spent last year working with the travel offices of several F1 teams, improving the functionality and integrating additional features, so effectively the system has been designed by the very people who will use it daily.'

Case study: CP Autosport

CP Autosport has designed a laser measurement tool that takes string out of the equation when measuring up a car. The system can be used to measure chassis alignment, the width of the car, the toe and camber angle, while there is also a caster angle measurement that is currently in development.

The company is relatively new, and has been developed in conjunction with race teams who have been consulted over their own requirements. 'With our system the first set up of the system is 20 minutes compared to first set up with normal scales which might be more than an hour,' says Sebastian Bleil, manager of CP's Setup Wizzard. 'The second measurement with the adjusted system at the race track is about five minutes or so. We have tried to make the system more easy to use and quicker which is essential.'

The system comes with a laser leveller, which is able to produce a flat surface even if a car is on a racetrack with an uneven surface. It also has a height adjuster in case of working on grass behind a paddock. Height adjustment is around 45mm for the scales, and the adjustment range is 135mm.'We're offering four different options; Module Easy which is our entry kit for semi-pro' racing or hobby racers. Then the Module Basic, Module Basic Plus and then our top notch Module Pro which is used in different GT3 series and 24 Hours of Nurburgring and Le Mans,' says Bleil. 'Currently we are developing a new system for Formula E cars, so we are adapting the system from the heavy GT cars to lighter cars. We're trying to minimise weight in this new design as our system needs to be heavier and more stable for the GT cars.'

Setup Wizzard has been developed in GT racing but will have wider applications

Inspector's gadget

The company is also targeting scrutineers: 'Our system is tailor made for each team and each car. You need to change the adapters for all the different cars, so you could measure all the Lamborghinis, switch the adapters and then measure all the Porsches. So it's not a clear advantage for the FIA to use our system to improve their process as there is not much time saving. But we were targeting the best possible solution for a specific car within a team and we are state of the art in that respect.'

CP has just begun to sell the system, so two engineers attend at the races to help with technical support, but that will change as the system is sold further afield. Cost will be contained, too: 'With our cheaper systems we designed them so teams could still use their own scales and not have to sell them, which also reduced the cost of our system so they could afford it in their budget,' says Hannes Plesse, manager of performance parts at CP.

For good measure

There are personnel advantages to be found in equipment, too. For example, CP Autosport (see case study) has produced a measurement system that requires fewer mechanics to use than before. 'It is an all in one solution,' says Sebastian Bleil, manager of its Setup Wizzard, which is a chassis alignment system that can measure the width of the car, the toe angle and the camber, while its is also developing a caster angle measurement too. 'It should be the only system currently on the market that is able to measure all the correct width, ride height and camber, toe measurement. We are the only one in the market who are offering this solution. The biggest advantage is it's able to operate with one person, so you don't need two mechanics, only one mechanic. Everything is computer based, information is transferred to the system itself to store the measurements. It's easy to use at the racetrack because it saves lots of time.'

On top of all this, as modern technology continues to develop the capabilities of electric vehicles this will also help logistic companies such as DHL to utilise electric trucks and forklifts to make their efforts more efficient. 'We believe the biggest future improvements will come from technology that allows us to capture and review performance data more efficiently in both IT systems and also Internet of Things applications,' explains Blackman. 'This will help us to plan routes, select suppliers, consolidate shipments and track goods in transit even more efficiently than we do today.'

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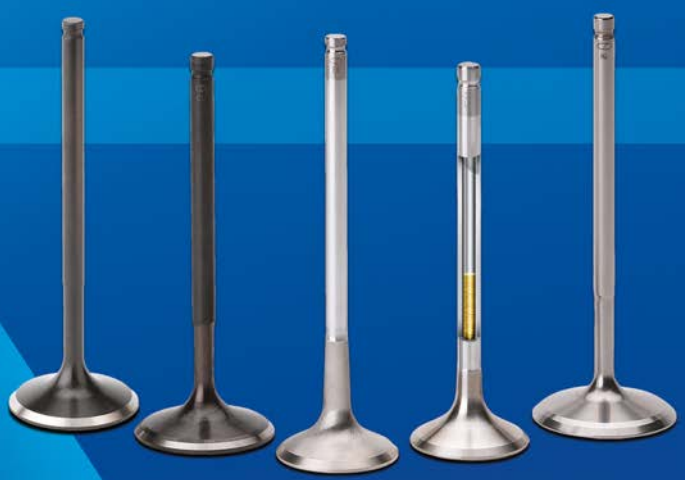


In charge **of charge**

A battery is just dead weight in the car without a fully functioning battery management system to ensure it works correctly. *Racecar* gets plugged in to the current thinking on all things BMS

By LEIGH O'GORMAN

Formula E in Paris. The racecars in the all-electric series rely heavily on complex battery management systems. A BMS monitors the state of charge, temperature and the health of the battery

While investigating the future of battery technology last year (December's issue, V26N12), it became clear that there are currently experiments being carried out on developing battery chemistries, but some of these are a long way from mass production and even further away from use in motorsport.

For the time being, then, the focus appears to be at looking at developing the cells and packaging that is now in use. But also very much under the microscope is the area of battery management system (BMS) design.

A director at Rockfort Engineering, Angus Lyons, has spent much of his motorsport career developing battery and powertrain technologies. With experience working as a control engineer with the Renault Formula 1 team and as the head of control systems testing with the short-lived but hugely successful Brawn GP team, before becoming chief engineer of Drayson Racing's electric drivetrain division, Lyons is well versed in this technology.

Conceptually, Lyons considers motorsport relatively risk averse with regards to certain forms of battery technology, and while that may not sound positive upon first consideration, he does think there is a good reason for this. 'Motorsport these days has got to be pretty careful, because any accident that happens does so at a high profile level – particularly when technology companies get involved, so they are not as keen to push the boundaries with technology as maybe they were back in the '60s.'

Despite the huge budgets Formula 1 throws at design and engineering efforts, Lyons believes modern battery management technology is still something absorbed from road car technology, rather than being developed within the motorsport environment. But he also feels things are beginning to change. 'We see in F1, WEC (LMP1) and Formula E, the first incarnations of electric racecars were taking technology that had been developed elsewhere and really just optimising and tweaking it. There have been design modifications to make them more appropriate for motorsport and that has seen some pretty big steps.

Formula E power pack with hi-vis warning for mechanics. Part of the reason motorsport has been slow to develop both battery and battery management technology is because of the safety issues that are involved

Electric power is making its presence felt at all levels of motorsport these days. The ETH Zurich Formula Student car has 220 cells in its battery pack and its BMS can adjust the voltage to each cell individually

Formula E (pictured at Monaco) and LMP1 both have more complex battery management systems than those that are currently seen in Formula 1. This is mainly down to the fewer cells that are used in the F1 batteries

‘The most important job of the battery management system is for it to allow us to have every cell at the same voltage’

Naturally enough, battery management system development is a big part of the Formula E series. Paul McNamara is technical director for Williams Advanced Engineering. Having supplied batteries to FE since its inception, McNamara and his team are well versed in the methodology behind BMS. He says: ‘BMS is [about] looking after and doing a lot of safety type functions and deciding when to intervene, [while] allowing the battery to do its thing. One of the prime things about BMS is managing the temperature, state-of-charge and state-of-health of the battery, because in many ways the battery operates relatively passively in terms of delivering its current.’

Terminal velocity

Prins Doornekamp is the founder and chief technical officer of Super-B Batteries, a Dutch-based battery technology company that has been in operation for a decade and supplies to motorsport outfits in many categories. Doornekamp and his company project a straightforward concept to the BMS technology. ‘Safety and longevity,’ he states. ‘The primary goal if you look at the whole battery system technology, you design the battery for safety. The BMS makes sure that you have a safe battery and that you don’t overcharge it. You don’t want the battery to catch fire. A really good BMS with good balancing systems also prolongs the life of your battery,’ he says.

A focus student with ETH Zurich, Tobias Zunsteg is its Formula Student team’s cell connection specialist. Zurich runs an electric vehicle, so Zunsteg’s position and understanding of the BMS balance of performance and safety is of critical importance. ‘The most important part of the battery management system is for us to have every cell at the same voltage,’ he says. ‘We have 220 cells in our battery pack. Our system goes so far that we have monitoring on all our cells and can balance them, so we can adjust the voltage of each cell individually. We are required – but it’s also good for our own safety – to look at all cell temperatures, and it is an important part of our battery management system to watch this key data all the time.’

As mentioned above, Lyons believes that motorsport is still being a bit conservative in its

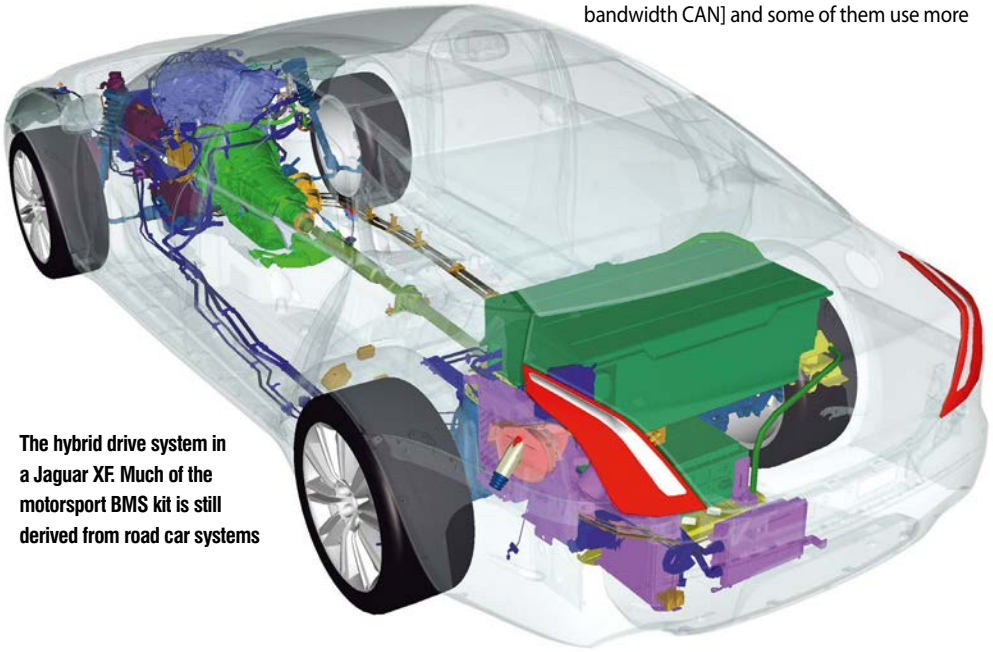
‘Motorsport these days has got to be pretty careful, because any accident that happens does so at a high profile level’

application of battery technology. He expands upon the reason for this. ‘When you take a battery that is being used in a fairly benign environment of road cars, and you push it into a much harder environment, the main thing you are trying to do is protect the chemistry and protect the battery from a safety point of view, so what tends to happen is that battery management system technology almost comes with the batteries themselves.’

Current affairs

According to Lyons, the battery management systems currently used in the Formula 1 arena are simpler, compared to those used in the Formula E or LMP1 cars, due to the fewer number of cells used in F1 battery packs.

Lyons also cites developments in the area of data communication as key to the progression of battery management systems. Whereas he considers CAN as the standard go-to communications system, it is a low-bandwidth system – a factor underlined further when the number of cells that are being measured increases significantly. ‘You want to measure the parameters of all of them [and] you need a higher bandwidth, so there are some systems out there,’ says Lyons. ‘Certainly in the next five years we will see systems using possibly Ethernet, possibly fibre optic, certainly we’ll see some of the next generation CAN FD [higher bandwidth CAN] and some of them use more traditional computer architecture, such as an SDI bus. It’s just using next generation technologies to help get information moved around a bit more quickly.’



The hybrid drive system in a Jaguar XF. Much of the motorsport BMS kit is still derived from road car systems

This is an area that Zunsteg also believes is developing. However, his focus looks more towards lightweight concepts and design. ‘For the future, this may even have light transmitted data,’ says the ETH Zurich man. ‘Previous years, there had been a bunch of wires going through accumulator boxes. We have improved the connection between the different sensors and that was a big challenge. For the management system to have CPUs that are able to transmit a lot of data, [while] the sensors are getting smaller, transmission of all the data is difficult and it is easy to create errors in the path of the data. In our case, we have 200 cells [which send data] and around it are other electronic parts in the car, which also send data and for our system, it needs to distinguish between data from the cells and other data and other noise.’

As a battery constructor, Doornekamp believes an increase in the standards applied by the IEC (International Electrotechnical Commission) – specifically the IEC 62619 – has significantly improved BMS design. ‘That gives guidelines about proper BMS design. For example, if you measure the temperature, how do you know you have measured the accurate temperature? It’s the same for voltage. Because of those guidelines, the BMS has improved and the overall battery, reliability, performance and safety will dramatically increase.’

Chemistry set

McNamara adds that while Williams Advanced Engineering is not looking into long term chemistries it is examining the possibility of making battery management systems specific to cell chemistry. ‘You do the testing at a cell level for a specific chemistry to understand how that cell behaves, especially temperature, voltage and duty cycle. The battery management system hardware can stay the same, but you can programme the parameters within those algorithms. I don’t think anyone is doing it yet, but we are seeing signs of it in high performance batteries. We’re thinking, with better algorithms, you can predict and forecast trouble with cells and manage it earlier, so we can live with a less stable cell chemistry. What we also research is technology to monitor the cell.’

The development of hybrid regulations in motorsport has added an extra layer of complication for racing teams in recent years, but engineers have adapted and are readily applying the battery management knowledge to this very modern aspect of motorsport. Zunsteg doesn’t consider this aspect a particular

One of the big challenges with the Zurich BMS was to make sure the data that was coming from the cells was easily distinguishable from the other data in the car. Light-transmitted battery cell data could be the future

‘Batteries are a little bit like tyres in that they are extremely difficult to model accurately and consistently’

Electric GT is poised to join Formula E in the international motorsport firmament. BMS development will continue so as to meet the growing demand for battery-powered racecars

barrier, as ‘it’s just like charging our batteries, but 10 times a higher current,’ he says. ‘This extra current is not detected specifically by the BMS, but rather the input sensors, which log output and input current as well as overall voltage. This is connected then with our vehicle control unit where each cell values get collected, as well as the input/output sensor – we call it ‘The Shunt’ – where we have control over the whole current and whole voltage, before it continues to the inverters.’

Lyons has a different take on the proposition. ‘It’s knowing how to use that [energy], because ideally by the end of your journey, if you know the car is going to be plugged in, you should try to make sure that battery is empty, and it’s the same with racing applications,’ says Lyons. ‘We know the conditions that the car is going to be driving in, we know the length of the race, we know the likely conditions, but using that energy to the best and making sure that wherever you are able to recover energy under braking, you to have capacity in the battery.

‘It’s pointless to come up to the biggest braking point in a lap and the battery is still full up, because you can’t recover anything; you are just wasting energy,’ Lyons says.

Development of IT infrastructures and computing systems has also helped engineers get a better grasp of BMS technology, particularly as cloud-based IT solutions become more prominent. In the automotive world several manufacturers gather data from cars sold to customers, allowing them to understand how internal systems are being used.

While Lyons admits that this is not as popular a concept in motorsport, due to the level of secrecy that the teams desire, cloud-based systems are being used on a more regular basis, he says. ‘We are seeing more and more that using cloud-based tools gives you quick and easy access to very powerful computing hardware, very powerful data analysis software, [and] that helps with the analysis in the learning and the understanding and subsequently the optimisation.’

Trickle charge

In our previous study in the December issue of *Racecar*, we saw that burgeoning chemistries, such as lithium sulphur and lithium air and solid-state batteries were many years away from mass production, a point once again acknowledged by Lyons. ‘The chemistries are really dangerous on the R&D side of things. Motorsport pushes things quite hard, [so] the batteries have got to be fairly advanced before the manufacturers are happy to apply them to motorsport applications,’ he says.

‘Where we are seeing things evolving in terms of BMS is the intelligence of the software and thinking about what is done with that data, so in the early days it was a fairly simple application of just calculating the parameters in which the batteries have got to be kept in order to maintain safety margins,’ Lyons adds. ‘Where we are seeing most of the development is more intelligent buffer algorithms to track, model and understand both the short term and the long term charge and health of the battery, and then work out how hard the battery can be pushed based on that improved information.

‘A lot of the more dedicated developments relate to the algorithms and they go with the chemistries, so you could pretty much throw away your algorithms when we move to lithium-air or sulphur,’ Lyons adds. ‘Some of the underlying algorithms might be carried over, but the knowledge and the chemical system modelling all starts again, so as a learning exercise where, as an industry, the battery and electric car industry is getting better, is being able to get to where we were with all the chemistries more quickly.’

Doornekamp, too, believes that new chemistries may well alter BMS design in the future and he thinks the change will be significant. ‘Most of those systems are designed for high energy density and a low discharge rate. In vehicles, we don’t need so much energy, but we need high discharge currents and high charge currents, so it has to be seen whether those technologies are suitable for application.’

Zunsteg, however, contends that while he believes that the actual battery management system would unlikely change, this may depend on the construction of the accumulators and how it may alter the packaging.

Battery modelling

There are still weaknesses to be addressed in modern battery management systems, particularly when it comes to the understanding of what is happening inside the battery during live running. ‘Batteries are a little bit like tyres; they are extremely difficult to model accurately and consistently. You can’t measure what’s happening right inside a battery, so there are lots of technologies being developed, which are attempting to infer what’s happening by external measurements and external

‘There will be more and more processing power required and we might well see that the computing power will steadily increase’

characteristic changes,’ says Lyons. He also believes modelling will play a greater part in BMS design, potentially forcing the motorsport industry to grapple problems head on. ‘There’s a lot more in terms of testing and characterisation of mathematical modelling of the chemistries. In the old days, it might have been you were 20 per cent modelling and 80 per cent experience to get to the point where you had a good BMS; now it’s far more towards the modelling and simulation and less reliant upon the experience and testing side of things. I think that’s where over the next five to ten years we will start to see some really quite interesting technologies coming out where people will be able to better track what is happening inside the battery.’

Chain reaction

Lyons also points to other potential challenges, such as the management of the chemical reactions and the manner in which information is communicated internally. ‘If you thump down a straight taking power out of your battery hard, you get various accumulations and chemical reactions occurring and building up,’ he says. ‘You get chemical accumulations from the cathodes and anodes of the battery and that changes what actually happens in terms of the chemical conversion process.

‘Thrown into the mix you have got resistant properties, thermal properties, you’ve got aging properties and tracking and understanding that is an extremely big challenge,’ Lyons says.

Lyons compares the current challenges to those faced by engine designers in Formula 1 a decade ago, where complex and intelligent algorithms were developed that could track, predict and estimate the internal wear of an internal combustion unit.

‘I think it is much the same, but with quite a different challenge in what you are trying to understand,’ Lyons says. ‘Motorsport has got to be socially responsible these days and people do generally accept that if a battery lasts a season in racing, that’s pretty good. It’s developing techniques and understanding that help us get the best of it … but if you start off with a battery that has got ‘just’ enough capacity to do a race and you lose 10 per cent or 20 per cent of that capacity through the course of the season, then clearly you will have a problem at the end of the season.

‘The hardware and the electronics will just evolve in a logical sense, but there probably won’t be anything that is totally bespoke to batteries or to motorsport,’ Lyons adds. ‘It will be the application of new technology in terms of communication transfer. Where the bespoke developments will be is the modelling and understanding, so there will be more and more processing power required and we might well see the computing power will steadily increase. Looking at real time modelling right down at a chemical level, you will probably need a lot more processing power.’

Chemical future

Lyons is excited about the possibilities presented by the future of battery management systems, though he believes this future will really be driven by developing chemistries. ‘BMS is a tool to get the best out of the battery,’ says Lyons. He also says the batteries that push Formula 1 or LMP1 machines are very much about power, but with very limited energy, and that it is still difficult to get the right balance of power and energy from chemistries used at this time. ‘What I am excited by is some of the new chemistries I see. We are seeing some very exciting chemistries coming along, which are going to allow us to get much better range and much better performance.’

Distance learning

However, Lyons also notes that these developments are still in their early days and that it may be some time before they make a tangible difference to the motorsport world, but he thinks the combination of chemistry changes and BMS development will see a two-to-three times range extension within the next decade.

‘In terms of batteries and battery management, we will see some pretty cool technologies – not necessarily unique, but still pretty cool technology, just in terms of how the data is all gathered and pulled together into the one place and analysed. We will then see some very, very complex and intelligent systems in terms of the tracking analysis and understanding of the algorithms, and I think that’s going to make a difference,’ Lyons says.’

McNamara adds that controlling the complexity and cost of batteries and battery management systems design is an important focus and something that Williams Advanced Engineering is keen to achieve.

‘I think the future of BMS design is about us getting to what is really important for the cell and being able to come up with very compact and simple ways of detecting and controlling, so we can make the battery management systems simpler and lower cost than they are now, and doing more,’ McNamara says. ‘The challenge overall in the battery industry is to make batteries cheaper and lighter.’

Meanwhile, Doornekamp is excited about the complex mathematical solutions that are possible. ‘As an engineer, it’s all in the algorithms. To be able to accurately [project] state-of-charge, state-of-health – very complex algorithms, that’s what I like the most.’

Certainly, there is plenty to come with battery management system technology, but although it may be some time yet before we see a sea change on the technology, with batteries, and in turn battery management systems, becoming such a major facet of modern international motorsport, the spark is surely there for ongoing development.

The Porsche 919 Hybrid LMP1 car uses an A123 Systems battery located in the cockpit. Really big developments in battery systems are likely to be focussed on chemistries rather than the BMS; the latter simply a tool to get the most from the battery

Committing sims

Racecar's numbers man not only argues passionately in favour of the use of chassis simulation, but also does the maths to back it up

By DANNY NOWLAN

Many are guilty of taking a blinkered approach to racecar engineering that does not include using chassis simulation. But is that a big mistake?

When we are caught up in the day-to-day running of a racecar, things that we should be doing tend to slide. It's a symptom I see from club level motorsport right up to the big end of town, and more often that not it is a symptom of just being too busy. One of those things that tends to slide is racecar simulation.

However, if you are serious about attaining and maintaining a competitive edge then simulation needs to be one of the first things you do. But I must add here that I don't write this because I have a vested interest in everyone using simulation. No, what we are about to discuss is based on hard-won experience that would be foolish to ignore.

Before we get started, though, one myth we need to dispel immediately is the attitude that using simulation is not important when running a racecar. The reason I need to address this is because of one of the great tragedies in motorsport. That is that there is a resident technophobia/hysteria that is always just bubbling beneath the surface. This pretty much says something that smacks of anything more complicated than 1+1 = 2 is evil for the sport. You see this in the knee-jerk reactions of regulatory bodies to new technologies and the attitude that technology has destroyed the show. If you actually agree with this then I suggest you Google some of the wheel to wheel action of Audi *vs* Porsche in the WEC.

Nothing can be further from the truth, because simulation and running your car are two skills that not only go hand in hand, they are essential if you want to succeed. As a case in point, no one has ever been able to explain to me why measuring up a racecar is a bad idea. Also, no one has ever successfully explained to

The irrational attitudes I see towards data acquisition totally baffle me

No one has ever successfully explained to me why understanding your tyres is somehow not useful when you're running a racecar

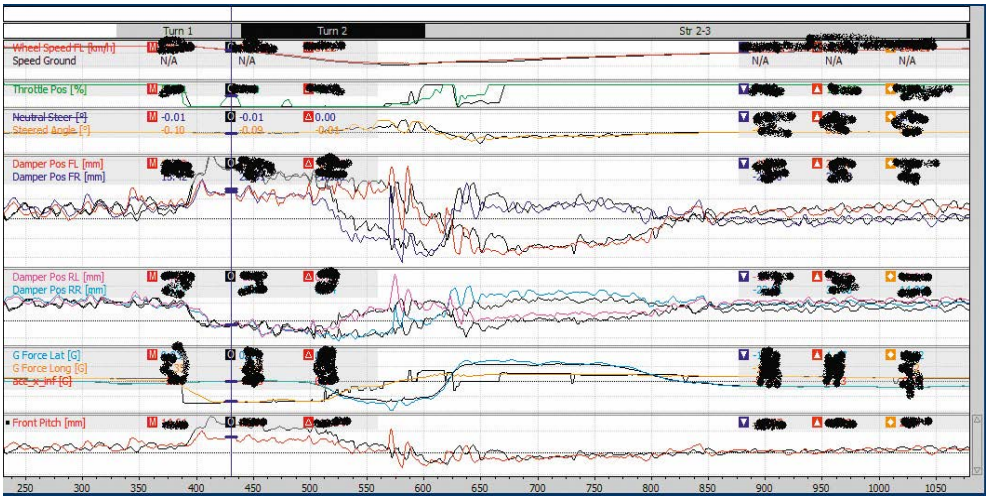


Figure 1: Pitch correlation from a touring car; front pitch behaviour under braking is not adding up. Sim trace is in black here

Table 1: Suspension geometry parameters

Variable	Value
Front Motion Ratio (Damper/Wheel)	0.63
Front spring rate	123N/mm
Front braking force	1224.5kgf
Rear braking force	885kgf
Front pitch centre	50mm
Rear pitch centre	180mm
c.g height	0.43m
Wheelbase	2.794m

EQUATIONS

Equation 1

$$LT_{SM} = \frac{F_{BF}\cdot(h - pc_f) + F_{BR}\cdot(h - pc_r)}{wb}$$

$$= \frac{9.8*1224.5\cdot(0.43 - 50e-3) + 9.8*885\cdot(0.44 - 180e-3)}{2.794}$$

$$= 2408N$$

Equation 2

$$\partial Damp\_ft = \frac{0.5*LT_{SM}}{k_f \cdot MR_f}$$

$$= \frac{0.5\cdot 2408}{122.6\cdot 0.63}$$

$$= 15.6mm$$

Equation 3

$$TC_{RAD} = k_a(1 - k_b \cdot F_z)\cdot F_z$$

Here we have:

TC_{RAD} = Traction circle radius of the tyre (N)

k_a = Initial coefficient of friction

k_b = Normalised friction coefficient with load (1/N)

F_z = Normal load

Equation 4

$$L_P = \frac{1}{2\cdot k_b}$$

me why actually understanding your tyres is somehow not useful when running a racecar. Or let me put it another way. If someone offered you a tool where you could quantify what your car can do and allowed you to mathematically articulate what you could do with a set-up, why would you say 'no'? This is exactly what you have in your hands with racecar simulation.

Irrational attitudes

To kick things off we need to outline where simulation fits into the motorsport food chain. It goes without saying that the first thing you do when running a racecar is to ensure it's reliable, it runs and it doesn't fall apart. The second item on the agenda is to put some data acquisition on the car. Think of this another way. Let's say you're sick and you need to go to the doctor. You walk into the doctor's office and rather than seeing a wise doctor with a white coat and stethoscope, you see an individual dressed up in some crazy witch doctor's get-up who comes to his/her diagnosis by chanting some weird songs and shaking their body parts over a very suspect looking voodoo doll. I don't know about you lot, but I would be heading for the nearest exit. So it baffles me on a daily basis the utter and total irrational attitudes I see towards data acquisition. The next step is to measure up the car and then that's where simulation fits in. The reason simulation fits in at this point is that it allows you to makes sense of everything else.

To illustrate this, let's consider when you don't have correlation from the simulated *vs* actual model. This is really powerful because when you don't have correlation the simulator is trying to tell you something. The pitch correlation shown in **Figure 1** illustrates this point very well. As always actual is coloured and simulated black. This is powerful because it gives you the opportunity to explore numerically why something in the data isn't adding up. As we can see the speed, steer, acceleration and rear damper correlation is very good. What's not adding up is front pitch under braking.

Summer's time

When faced with a situation like that shown above the first thing you do is hand calcs. I can't speak for other simulation packages, but ChassisSim returns all the applied forces and force based pitch centres and roll centres. What this means is that you can now sanity check what it's doing. Let me illustrate via example by sanity checking the simulated pitch under braking. The parameters we where dealing with are shown in **Table 1**. Now that we have this information to hand, calculating the simulated pitches is very straightforward. This is illustrated

The bulk of what we do as race and performance engineers is balancing the terms of what I like to call the racecar grip and balance equation

in **Equation 1.** So, crunching the numbers on the damper movement it is seen in **Equation 2.**

While this may look like a trivial calculation this gives you the tools to validate if the simulation is working as advertised or not. If it is working and you do have a discrepancy it opens a window of opportunity to actually see what is going on. This illustrates one of the great powers of simulation and it's why the above example is a staple at the ChassisSim boot-camps.

Super model

The second reason why simulation needs to be one of the first things you do is with the understanding of your tyres. The basic building block of any tyre model is the second order traction circle radius *vs* load equation. Mathematically this can be expressed as **Equation 3**. The nail with **Equation 3** is that any tyre can be approximated by **Figure 2**. Here we have the peak load, *Lp*, that can be expressed mathematically by **Equation 4**.

What this means in plain English is that the maximum force of any tyre can be expressed as a peak load with a peak force of half the initial coefficient of friction multiplied by the peak load. It doesn't give you the full story but if gives you more than enough to form the basis of good correlation. The great thing is that sim packages like ChassisSim can help you fill in these details.

The reason we are going to all this trouble is that this gives you the ability to numerically quantify what a set-up is doing. The bulk of what we do as race and performance engineers is balancing the terms of what I call the racecar grip and balance equation. This can be illustrated graphically in **Figure 3** and **Figure 4**.

Sim-plified

What we as race engineers do is to try to arrive at a lateral load transfer distribution that gives us good grip but ensures the car is drivable. The power of simulation is that it gives you a tremendous short cut. The reason for this is that in the past the shapes of **Figure 3** and **Figure 4** were unknown and you had to get there with a lot of track time. With tools like ChassisSim's tyre force modelling toolbox you can start to answer the questions in a fraction of the time.

So the critical question to ask right here is: just why wouldn't you want to make use of a tool like this from day one?

But the ultimate proof of all this is in the eating. This was graphically illustrated at the World Time Attack Challenge in 2016. On this weekend I was looking after the NA Autosport Evo 6 entry in the open class. I spoke about this at length in my *Racecar Engineering* article in November 2016 (V26N11) where I outlined

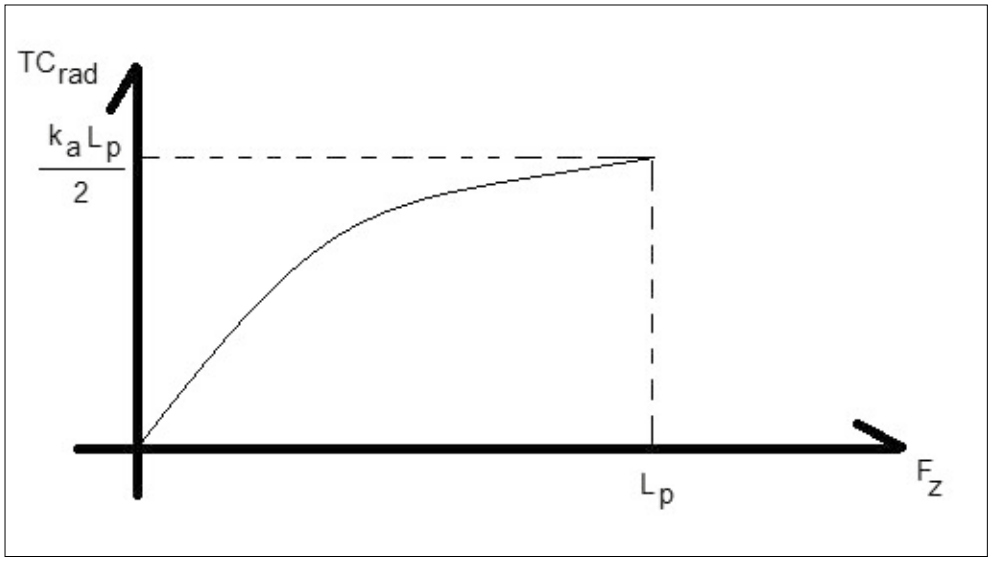


Figure 2: Tyre model visualisation. The basic building block of any tyre model is the traction circle radius *vs* the load

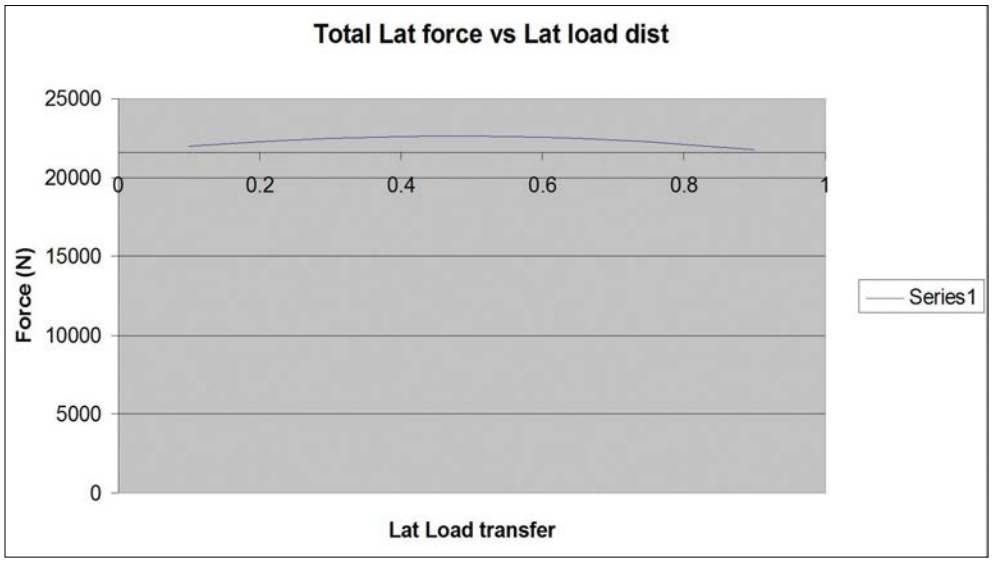


Figure 3. This chart illustrates the total grip *vs* the lateral load transfer distribution at the front end of a racecar

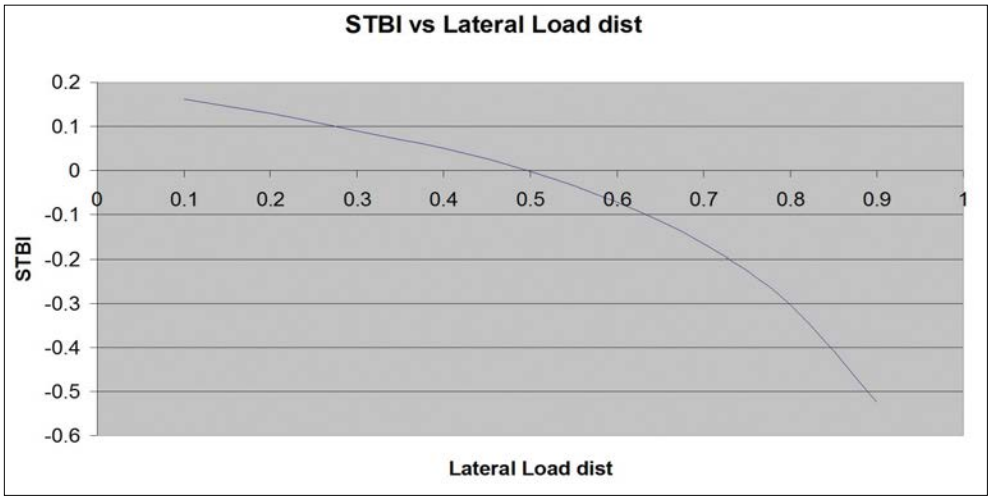


Figure 4: This chart illustrates the stability index (STBI) *vs* the lateral load transfer distribution at the front of a racecar

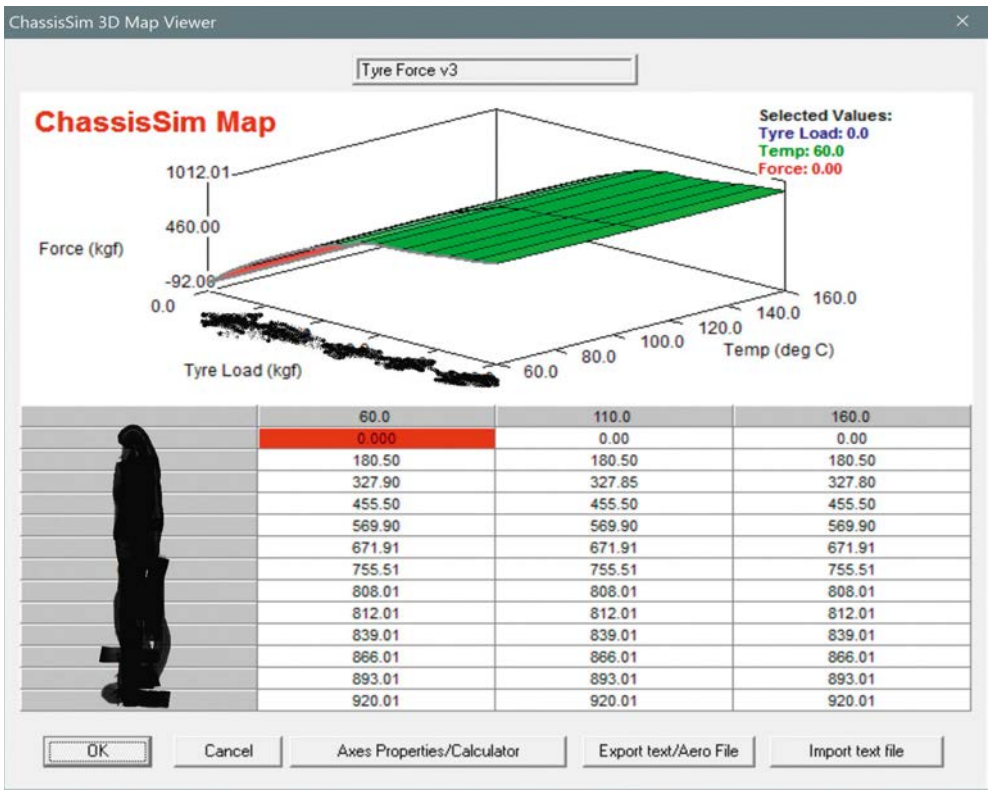


Figure 5: The tyre model for the NA Autosport Mitsubishi Evo 6 that competes in Australia's World Time Attack Challenge

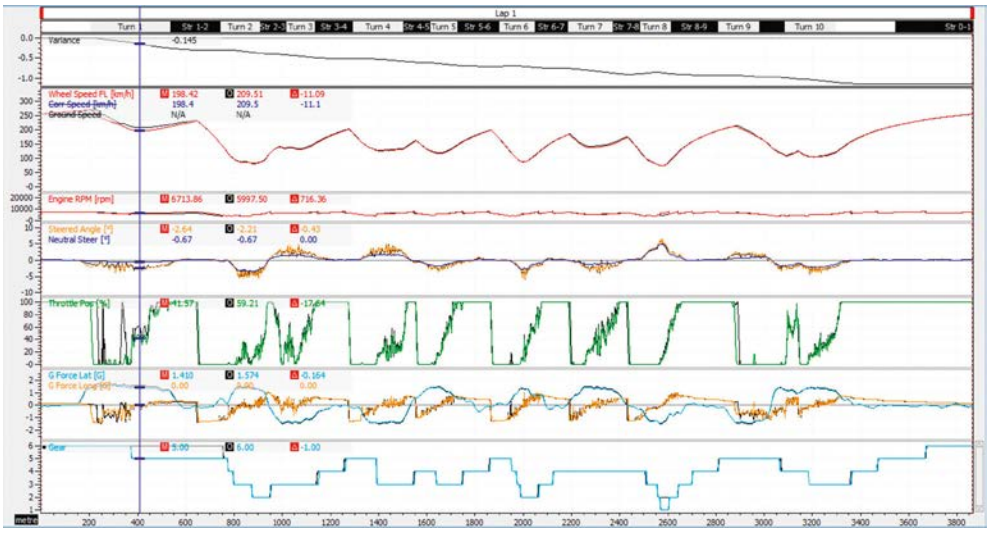


Figure 6: Front dive plane simulated changes – this analysis was key to the Evo's improved performance in the WTAC in 2016

exactly what we did. However, just to give you a highlights package of all that, it was actually thanks to all the running we did in previous years that we had a really good tyre model. This is illustrated in **Figure 5**.

Ultimately, this laid the bedrock for being able to call the key changes to the racecar on the weekend. A key example of this is the front dive plane change that was crucial to the car's success. This is illustrated in **Figure 6**.

The end result of all this was going from 17th in 2015 to third in 2016. What laid the foundation for this success was all the simulation work that had gone on through the years previously to understand what the tyres needed. Indeed, I would go as far as to say that without this we would have been flying blind. This illustrates the power of simulation. It gives you that ability to numerically nail down what you are doing which is why it needs to be on the top of your to do list.

To wrap things up, one of the best descriptions of luck I've heard is 'when preparation meets opportunity'. Simulation has the preparation bit hard-wired into its DNA, which is why when running a racecar it needs to be one off the first things you do.

As we have discussed in detail, simulation tools force you to look at the racecar when things aren't adding up, and more importantly it gives you the answers. Also, simulation allows you to quantify what is going on with the tyre. This forms the bedrock for achievements, such as the NA Autosport entry in World Time Attack Challenge in 2016. So the question you need to be asking is: 'if it's not one of the first things you do, why is this the case?'

Interview – Oliver Oakes

Driving ambition

The boss of crack Formula 3 operation Hitech GP tells us what a former race driver can bring to the role of race team management

By MIKE BRESLIN

XPB

'At the end of the day if you cost cut too much you take away the good bits that people were paying for anyway'

In a remarkably short time Hitech GP has established itself as one of the top teams in the ultra-competitive FIA Formula 3 European Championship, to the extent that it was branded one of the three 'super teams' last season; along with Van Amersfoort Racing (VAR) and Prema Powerteam. But what sets Hitech apart from the other two is that it is run by a former driver, rather than an F3 stalwart with many decades of experience in the category, and a relatively young former driver at that.

Oliver Oakes (29) came to team management after his single seater career stalled at F3. Always interested in business he took time away from the sport to work in finance, though he kept his hand in by coaching current F3 hot shoe Callum Ilot in karting – Oakes is a former karting world champion. He then went on to form a karting operation which subsequently grew into the current F3 squad. 'It began as a sort of test team or small academy project to help drivers step up from karting to cars [in Formula Renault]. Then in 2015 I saw that in F3 there was a lack of teams to compete with Prema and a lot of drivers coming through the system from F4. We had in the team a few people with F3 knowledge and it kind of made sense to step into FIA F3, which at that time was enjoying the Verstappen effect [Max, who had jumped from F3 to F1 that year].'

Driver aids

While Oakes' team management experience might have been limited, what he did have was a very good insight into the mind of the driver, though he admits that can be a double edged sword. 'I guess some things are positive and others can frustrate my engineers! I believe a lot in our drivers. As a result I am always pushing the race engineers to work more for them,' Oakes says. 'In general, though, I think what I bring is the ability to see things from two or three different scenarios and that's important, especially with a bigger operation. On the human side it helps to see things from a driver's perspective. It is also useful to be not so much older than some of the drivers; I can relate to what they are going through on and off the track.'

Thus far this season Hitech has not had the best of starts after a stellar showing last year. But in 2016 there was also a perception that Hitech, Prema and VAR were spending huge amounts on aerodynamic development and that as a result other teams could not compete, nor attract drivers. Whether that is true or not, because of this aero development has been restricted this season and a bespoke aero kit has been brought in with the intention of bringing costs down.

'This season we have seen the banning of the expenditure the teams were making in development on car parts in wind tunnels etc.,' Oakes says. 'But on the other side we have also spent a lot of money on update kits for each car which were 40 per cent more expensive than we initially discussed. So it was a bit of a Catch 22.'

Those update kits and aero restrictions also chip away at what is the *raison d'etre* of Formula 3, its relative freedom when it comes to engineering and development. 'It is still an engineering challenge in some respects – it is one of the most complex cars outside of F1 in terms of options of aero, geometry, and components you can choose to run,' Oakes says, before adding: 'However, it is also heading a little towards the modern day formula of one-make and being highly controlled by the regulators.'

Balance of power

Yet despite this increasing level of control Oakes has some concerns that all is not quite so equal in F3 this year. 'I think, as most people who have followed the first two rounds will have seen, it is clear that one engine brand has now had a big input on the drivetrain side. So it looks like 2017 might be the year of a big engine disparity,' he says.

Races at those first two rounds at Silverstone and Monza were mostly won by Volkswagen powered cars, after VW's tuner, Spiess, was allowed to modify its unit on reliability grounds late last year (all Formula 3 engines are homologated from 2014 until 2017). However, Monza has always been a VW circuit, so the jury is still out to a certain extent.

But beyond that, Oakes also questions the wisdom of cost cutting in F3. 'Sometimes you have to accept that there just aren't people out there with lots of money, and at the end of the day if you cost cut too much then you take away all the good bits that the people were paying for anyway.' Incidentally,

Hitech, pictured at Macau at the end of last season, has quickly become one of the teams to beat in FIA European Formula 3

XPB

despite the recent changes the budgets have not reduced and still sit in the €650,000 to €750,000 region.

All that said, Oakes is a Formula 3 man through and through, and like many in the category he doubts there is a better place to race right now: 'F3 is probably the strongest in the market in terms of quality of drivers, quality of teams, mileage given to drivers and the events we support. It is also a series full of Formula 1 or manufacturer-linked young drivers which shows they all believe in it,' he says.

At the moment Formula 3 is the only category Hitech's involved in, for unlike its rivals it does not have squads competing in lower formulae or in Formula 2, although this all eggs in one basket approach does not overly worry Oakes. 'This was a conscious decision when we started Hitech,' he says. 'We had to get up to speed quickly during 2015/16 in an operational sense and therefore we will still have some growing pains lingering during 2017. At the end of 2016, after a strong season in F3, there was a lot of talk about us adding a team in F4 to feed into the F3 team and also to expand with a car in LMP2 or Formula E, so our F3 drivers had a step up into those arenas, to keep them in the Hitech family. But I made the decision to keep focusing on what we are doing in F3 for 2017, as we knew with the new rule changes and the way the world economy was looking it would be a transitional year.'

Formula 1 input

It's not quite all F3, though. 'We have recently began some R&D projects for a manufacturer and that is an interesting area to expand into, with support from the racing side, but also using the development skills we had built up during 2016 that we are now no longer allowed to use in F3,' Oakes says.

To this end former Formula 1 technical director Mark Smith has been drafted in to help out as Hitech's head of research and development, which is the sort of high profile hire that shows the undoubted ambition of this organisation. As Oakes says: 'My long term goal is to win championships with the great group of people we have put together at Hitech. Whether that be in F3 or another series. I think if you look at recent teams outside of F1 there has only been two organisations that have managed that year after year at the highest level, ART and Prema. For the moment they are the benchmark we need to surpass. No UK team has managed that and I feel that as extra motivation.' With the above in mind, just maybe what a driver also brings to the role of team manager, is *drive*.

RACE MOVES

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Romain Grosjean is the new director of F1's Grand Prix Drivers' Association, replacing **Jenson Button** in the role, the latter having retired from his full-time position as a driver at the end of last season. The Haas driver was voted in to the position by GPDA members during the Russian Grand Prix.

The engineers for **Tony Kanaan** and **Charlie Kimball** at IndyCar outfit Chip Ganassi Racing have been switched, with **Todd Malloy** moving from Kanaan's Honda to work on the Kimball car, while **Eric Cowdin** has moved in the other direction. Cowdin and Kanaan have worked together in the past, winning the Indianapolis 500 in 2013.

One of rallying's first major stars, **Timo Makinen**, has died at the age of 79. The Finn won a number of top level rallies, initially at the wheel of BMC cars such as the Austin Healey and more famously the Mini Cooper, while he also starred in Ford Escorts. He also drove Toyotas, BMW and Peugeots before retiring in 1981.

Eric Bretzman was given the job of race engineering **Fernando Alonso** for the Spanish Formula 1 star's highly publicised one-off outing in the Indy 500. Bretzman, who moved from Chip Ganassi Racing to Andretti Autosport to be its technical director in the winter, achieved huge success at CGR as **Scott Dixon's** engineer, a partnership that chalked up 34 IndyCar race wins, three championships and the 2008 Indianapolis 500 over a 12-year period.

Dr Jens Ludmann is now the chief operating officer (COO) at McLaren Automotive, where he will report to chief executive officer (CEO) **Mike Flewitt**. Ludmann holds an International C race licence and regularly competes in the Nurburgring 24 Hour race.

Willie 'The Cork' Davis, the US race engineer who had a hugely successful partnership with driver **Gary Bettenhausen**, has died at the age of 87. Davis was involved in US single seater racing for five decades. He was elected to the Sprint Car Hall of Fame in 1996 and the USAC Hall of Fame in 2016.

Cole Pearn, the crew chief on the Furniture Row Racing No.78 car in the NASCAR Cup Series, was fined $10,000 after one of the lug nuts on the Toyota he tends was found to be improperly installed at post-race scrutineering for the Bristol Motor Speedway round of the championship.

NASCAR Xfinity Series crew chief **Greg Erwin** was fined $10,000 after the No.22 Penske Racing Ford he looks after failed post-race inspection when the left-front of the car was found to be running too low at the Bristol Motor Speedway round of the series.

Billy Scott, who served as an Indianapolis 500 crew member before going on to compete in the race as a driver in 1976, has died at the age of 68. Scott competed in drag racing before switching to single seaters.

Well-known sportscar team boss **Preston Henn** has died at the age of 86. Henn won the Daytona 24 Hours both as a driver and as a team owner. His race team was usually backed by his Swap Shop business empire, which was kick started with his idea of running flea markets in drive-in movie lots when the spaces were not used to show films during the daytime.

Holly Job, who alongside her husband Alex set up sportscar outfit Alex Job Racing in 1988, has died at the age of 60 after a battle with cancer. IMSA president **Scott Atherton** said in a statement: 'All of us at IMSA are heartbroken to hear of Holly Job's passing. Alongside Alex from the beginning, Holly was instrumental in building Alex Job Racing into one of the most successful professional sportscar racing teams in the industry.'

Jean Todt to stand for third term as the FIA's president

Jean Todt, the president of the FIA, has announced he is to stand for election for the position once again in December, meaning he would go in to a third term as the FIA's boss should he win.

Former Ferrari Formula 1 chief Todt first became president of the FIA back in 2009, when he beat legendary ex-rally driver Ari Vatanen to clinch the position. Todt announced during the Spanish Grand Prix in mid-May that he now intends to stand once more. At the time of writing there was no word on whether he will face any challengers.

'Today I was proud to announce to all FIA club presidents my decision to run for a third presidential term at the FIA,' Todt said.

Earlier this year the Frenchman said he was under pressure from his supporters to put himself forward for the role once more, and he told reporters: 'A lot of people who voted for me are pushing me to go for another mandate. It is very important, because if I had a lot of resistance not to go for election, my decision would be much easier because I will then decide that I will go [step down].

'As I get a lot of pressure, it will be a lot more difficult to resist, so I will take that into consideration with my choice,' Todt had said.

Todt has an impeccable motorsport CV, having spent 13 years at Scuderia Ferrari, first as general manager and then as CEO, while before that he was director of Peugeot Talbot Sport from 1982 to 1993, leading it to success in the WRC and at Le Mans. He started his career as a rally co-driver in 1966 and helped win a manufacturers' title for Talbot in 1981 from the navigator's seat of a Sunbeam.

F1 bolsters PR and management teams with further appointments

The shake-up of the F1 management team that has been a feature of the new Liberty Media era has continued in to the European part of the season with some high profile hires and promotions across Formula One Management.

On the PR side Formula 1 has announced the appointment of well-known ex-Ferrari media man Luca Colajanni who, as senior communications officer, will now attend all the Formula 1 races.

Colajanni joined the Ferrari communications department in 1992 and managed the Scuderia's press office from 2001 to 2012. After a short stint with the Marussia F1 team, he became head of Communications at Formula E. He then moved to the FIA in October 2015.

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Former Ferrari and Formula E PR man Luca Colajanni has returned to grand prix racing in a new position working for Formula 1

Meanwhile, Yath Gangakumaran has been hired as global head of strategy. He will be responsible for advising on strategic decisions across all commercial operations within the Formula 1 business, reporting to Sean Bratches, managing director, Commercial Operations. Gangakumaran joins F1 from Sky Sports.

Internally, Chloe Targett-Adams has been promoted to global director, Promoter and Business Relations for F1, where she will lead race promotion operations. Targett-Adams joined F1 in 2009 as an in-house lawyer, following her early career at leading media and entertainment firm, Harbottle & Lewis LLP. Since 2012 she has worked closely with the Formula 1 leadership team providing senior counsel on the negotiation of all race promotion deals.

F1 has also promoted Joanne Revill to the post of communications officer. She joined FOM in 2001 as a TV producer. As well as scriptwriting, interviewing and working in both live and post production, she has been responsible over the past 16 years for creating exclusive content across traditional Formula 1 broadcast media and digital platforms. She will now be in charge of the Formula 1 press office.

RACE MOVES – continued

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Vijay Mallya, the boss of the Force India Formula 1 team, was arrested in London in late April by officers from the Metropolitan Police extradition unit, after India had formally requested Mallya's extradition back in February. Indian authorities claim Mallya owes around £900m following the collapse of one of his businesses, Kingfisher Airlines, in 2013.

Paul Wolfe, the crew chief on the No.2 Penske-run Ford in the Monster Energy NASCAR Cup Series, has been fined a whopping $65,000 and was suspended for three races after the car he tends failed the post-race rear wheel steer test on the LIS (Laser Inspection Station) at the Phoenix Raceway round of the series. Brian Wilson took Wolfe's place during his suspension.

Former US single seater star **Joe Leonard** has died at the age of 84. Leonard started in motorcycles then switched to Indy cars, racing at the Indianapolis 500 for the first time in 1965. His driving career came to end after a massive shunt in Ontario in 1974. Leonard saved the life of a fellow competitor at Langhorne in 1965 when he pulled the unconscious driver from a burning car.

At the time of writing it had been reported that former Ferrari F1 boss **Cesare Fiorio** was in a critical condition after a cycling accident. As well as leading Ferrari at the end of the '80s and beginning of the '90s, Fiorio headed the Lancia WRC assault in the '70s and '80s.

Drew Blickensderfer, the crew chief on the No.43 Richard Petty Motorsports Ford in the NASCAR Cup Series, has also been fined $65,000 and suspended for three races after the Aric Almirola-driven car failed a rear wheel steer test at post race scrutineering at Talladega. Director of engineering **Scott McDougall** will be the interim crew chief for Almirola during Blickensderfer's suspension.

Former Formula 1 car designer **Mario Tolentino** has died at the age of 68. He penned cars for Alfa Romeo (where he replaced Gerard Ducarouge in 1982), Eurobrun and also Scuderia Italia's Dallara in the 1980s. He was also responsible for both the Lamborghini and the AGS Formula 1 cars that raced in 1991.

Well-known UK engine builder **Phil Cornish** had died. Cornish started out as an apprentice at Cosworth and then moved on to **George Whitehead's** WRA concern in the late '60s. He was renowned for his skills with American V8s in drag racing, while he also built Ford BDAs for rallying and rallycross.

Sir John Whitmore, a star in Minis and Lotus Cortinas in 1960s saloon car racing and also a former Le Mans racer, has died at the age of 79. Whitmore retired from race driving in 1966 and went on to become a pioneer of, and a renowned expert in, the business performance coaching industry.

Dr Preston Calvert has been appointed as the medical adviser for US GT and touring car series the Pirelli World Challenge, where he will work with the series' safety team. Calvert, a well-known neurologist and neuro-ophthalmologist, will also work closely with **Marcus Haselgrove**, the vice president (competition) of PWC promoter WC Vision.

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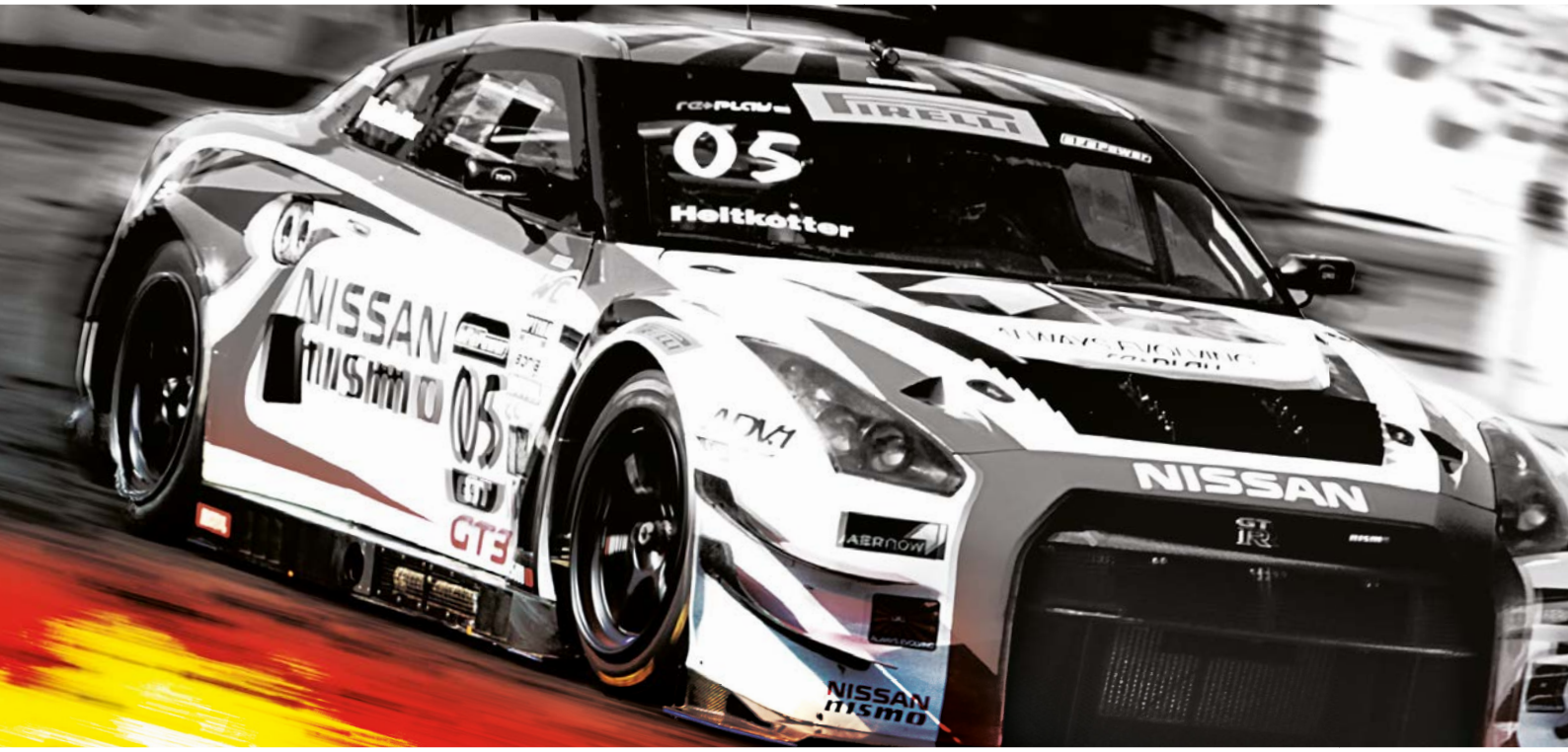

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Electronics
Better get yourself connected

A new ultra-small 8STA circular connector series along with a package of lightweight 8STA compatible accessories has been announced by Lane Motorsport.

The Souriau size 01 8STA connector forms the core of the package and offers a 20 per cent saving in size and weight over the size 02 connector series.

According to Lane Motorsport, these size 01 connectors accommodate three removable No.26 contacts that can handle wires from 24 to 30 AWG. Other key features include seven colour-coded orientations, PCB options and a boot termination feature. A single flange version is also available.

The range of accessories is made by Hellermann Tyton and Weald Electronics and includes protective caps, gaskets, nut plates and heat shrink boots.
www.lanemotorsport.com

3D printing
Rubber stamped

CRP Technology has launched Windform RL, the first thermoplastic elastomer material within the Windform family of materials for professional 3D printing.

It is a durable thermoplastic elastomer material with exceptional rubber-like distinguishing features, CRP tells us. Its mechanical characteristics make it particularly suited for additive manufacturing applications requiring complex geometries, and where flexible characteristics is a key requisite.

Flexible parts manufactured in Windform RL and stiff parts in Windform materials can be bonded together by epoxy resins or with mechanical joints.

The material is said to show excellent durability and stability. It accommodates chemical and heat resistance and combines superior tear resistance with burst strength.

This material is already being used for functional rubber-like prototypes and parts (e.g. gaskets, hoses, and durable components).
CRP-group.com

Measurement
Covering all the angles

B-G Racing has announced a Digital Dual Axis Angle Gauge which can measure angles through a full 360 degrees in single axis mode, and plus/minus 40 degrees in dual axis mode.

A five-face magnetic construction with V -shaped grooves allows for mounting to the required surface, while a rechargeable, extended life, lithium-ion battery and auto-off function allow for up to 40 hours operating time before recharging will be required.

The backlit LCD screen displays measurements to an accuracy of 0.1-degree with a resolution of 0.02-degree, and rotates through 4 x 90 degrees to ensure the display remains upright at all times.

Additional features include a hold button to freeze the display, and a programmable audio alarm to notify the user when a measurement is either within or outside of a pre-set range either side of the chosen angle.
www.bg-racing.co.uk

Fluid transfer
The Kryptalon factor

Aeroflow has launched a range of hoses and fittings for competition use.

The Kryptalon Series hoses feature a Kevlar braid and Teflon liner that has a convoluted outer and a smooth inner bore design which eradicates boundary layer entrapment and minimises flow disruption. They are available in sizes -4AN through to -20AN and are suitable for a large range of applications – fuels including E85 and E10, methanol, oils, lubricants and coolant systems.

The patented one-piece fitting design is claimed to be easy to assemble with a pipe olive that sits on the outside of the braid; this unique design also helps save valuable time during assembly, we're told. The hoses are machined from 6061 T6 aluminium and hard anodised in a black or titanium finish.
www.aeroflowperformance.eu

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Honda made an interesting comment in the paddock at Monza, saying that it would be trying to win the final World Touring Car Championship title this year. A little further digging, and it seems that they may be close to the truth, with the FIA rumoured to be working closely with Hans Werner Aufrecht, formerly of the DTM organisation, to deliver DTM cars into the WTCC, the only global touring car platform under direct FIA control. The current WTCC cars are going to be obsolete, and its manufacturers are now looking to TCR.

According to paddock rumour, the WTCC is set to take a two-year sabbatical at the end of this season if new regulations cannot be agreed. At this stage this means that the WTCC has two options; stick with its current cars for a fifth season, or go with other cars that are already built; DTM. The TC1 cars that currently compete in the WTCC were introduced in 2014 with the highest technology that the WTCC had ever seen, and the cost reflected that. A customer Chevrolet Cruze was around €600,000 for the chassis, plus the engine. The running costs, accident damage with the carbon bodywork, and with the global programme, has meant that the privateer teams are seeking, and receiving, subsidies to continue racing, a short-term solution to a long-term problem, while the alternative, the low-technology TCR, is becoming ever-more attractive in terms of competition and costs.

Touring car racing with such expensive hi-tech racecars makes no sense

TCR is following a very similar path to the Blancpain GT3 series. Promoters Marcello Lotti and Stephane Ratel worked together on the Super Racing Weekend project from 2001 to 2004 and both have built up internationally successful series and concepts. Their concept is simple; customer racing provides a manufacturer with global exposure and they can sell cars, while manufacturers can choose to promote or ignore a series according to its own interests. The WTCC has seen entries fall, with Citroen and Lada leaving as factory efforts at the end of 2016, leaving Honda, which is already heavily involved in the TCR, and Volvo, which is also rumoured to be building a TCR car, although the World title is attractive to the Swedes. With TCR also attracting the likes of Renault, Hyundai and Kia, and having more spaces on grids around the world than can be filled, it's an interesting turn of events.

But apparently there is some momentum from the German manufacturers and one Japanese manufacturer to compete on a global platform under the Class 1 rules with DTM cars, but these won't be ready to use in a race series until the engine regulations are brought into line, and that could be in 2019 at the very earliest.

In the meantime, the TCR series is looking to expand into the UK and into France, as well as the US in California, that last being particularly significant as the DTM was trying to secure a North American berth as part of its global expansion but the Americans were not interested. That gives it more of a global presence than before, and the fight with the FIA over the naming (TCR versus TCN2) seems to have been won in Lotti's favour. The WTCC could do a deal to run the DTM cars, but that then leads to another set of problems; especially one of cost. If manufacturers are investing in a domestic series, taking those same cars around the world involves more money for transport of goods and personnel, and that's a tall order before the issue of the three continents is even addressed; Europe and Japan would be relatively simple to sort out, but a third with a suitable track and a desire to have 4-litre naturally-aspirated hi-tech carbon cars? That's a challenge.

There is no doubt that the FIA would grease the path a little to make it easier for all this to happen, but the activation costs for a global series, when actually there is already a facility to do a customer-based programme, does not seem, on paper, to make sense.

Touring car racing with such expensive cars also makes no sense. A conversation with Lotti at Spa yielded this nugget of motorsport wisdom. The most popular global sport in the world is soccer, and for less than £20 it is possible to buy a ball, find a field and play the same game with the same number of players, to the same rules as in the World Cup. Why is motor racing so different that we actually need touring cars to be somewhere up there at the pinnacle of the cost pyramid?

There is a different argument for Formula 1, the WEC and even Formula E, where the advancement of technology is the prime reason for the series, and the world has caught on to the concept with amazing loyalty. Porsche's race to road programme featured in this magazine (page 8) is a testament to how a manufacturer can positively view a high technology racing programme. But touring cars was never designed to achieve that same goal. That was always the go-to place for highly entertaining racing and big personalities, while it was also meant to be accessible to a wide variety of teams and brands. The DTM and the WTCC put themselves up there at the top of the pyramid and, perhaps, have convinced themselves that they have made the right choice. In the meantime, Lotti and Ratel are quietly plying their trades, very successfully, and the manufacturers seem to have grasped their concept rather better than a factory race programme.

ANDREW COTTON Editor

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