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Force India VJM11

The F1 car that was never meant to be

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Ricardo Divila's shock absorber master-class

Formula 1 goes big

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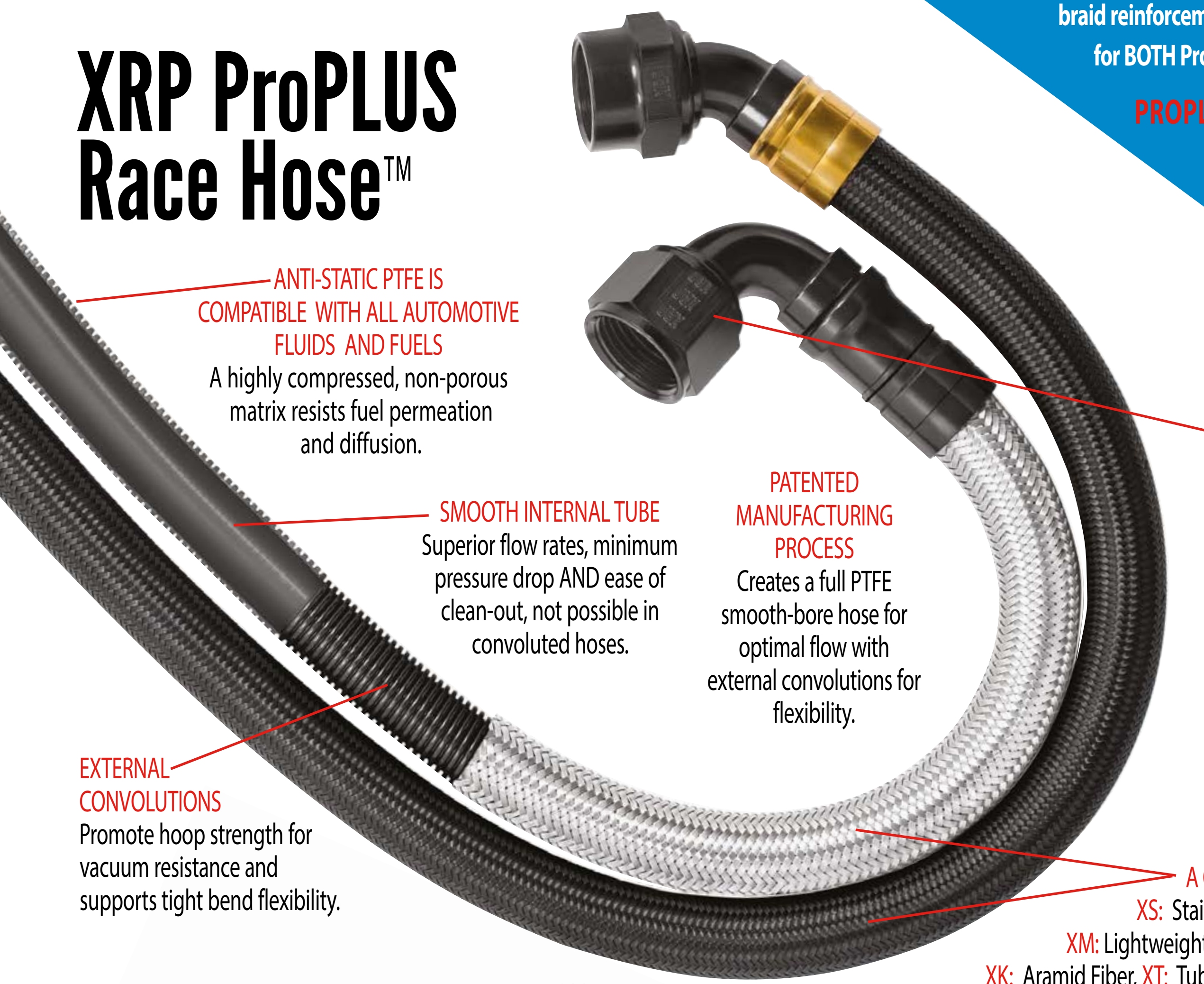

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Formula 1 is to switch to 18in wheels with low profile tyres in 2021 – as tried out on this Lotus in 2014. Turn to page 16 for more on this and other rule changes

Blanket coverage

Why Formula 1 could be making a serious mistake with its tyre warmer ban

Were one the archetypal *Daily Telegraph* reader one would be fulminating in the letters column about another insidious proposal on tyres for Formula 1. That's the ban on tyre warmers, but before I get to that, let's talk a little about the new tyre rules in general.

The proposal for 2021 is to have rim sizes growing to 18in diameter against the current 13in (for more detail on this turn to page 16 - Ed). The 13in diameter was brought in some time ago to reduce braking capacity, all part of attempting to give overtaking opportunities to following cars, a recognised problem and one still with us, made worse by the difficulty of generating balanced downforce on the following racecars.

Specific rim

As it turned out, brakes have improved so that being restricted to the space inside a 13in diameter rim is not a problem, and the retardation on Formula 1 is only restricted by tyre capacity. We shall return to this later.

It has several corollaries. The almost non-existent current suspension travel due to the carcass deflection, most of the movement being on the tyre, makes platform control an undamped variable, apart for structure hysteresis.

The only road vehicles that have an equivalent aspect ratio are truck tyres; most other means of transport use a lower aspect ratio. Just the work being done to simulate carcass deflection and its corollary aero effect have brought us to new heights in manufacturing expertise of wind tunnel model tyres to be able to measure values correctly.

In philosophical terms this has as much relevance to road tyres as knowing the number of angels that could sit on the head of a pin.

The fall-out from bigger rims and lower aspect ratio tyres is mostly on the plus side, making suspension geometry pertinent again and giving more control of the platform for aero purposes.

As a side benefit some information might seep back into production tyres to improve the breed, but I'm not holding my breath in anticipation as road tyre technology is a mature subject, more geared to durability, all-season capability and working under entirely different constraints.

On an interesting side note, the bid the tyre manufacturers have been invited to tender for is for 2020 to 2023, but the 18in rim sizes will only be introduced in 2021, which tends to favour Pirelli, the current contracted company in Formula 1, as anyone else would have to develop a 13in rim tyre for 2020 equivalent to the current tyre, then move to have the 18in ready for 2021.

The sheer cost of the development necessary to come up with two distinct designs will be a good gauge of the commitment of the manufacturer, but one questions this awkward transition.

Making 18in rim tyres is not a great mystery to any manufacturer, and the mandated diameter of '700 to 720mm' falls squarely in the current LMP tyres. But on the chassis side we are heading for a new era on suspension and vehicle dynamics, and aerodynamics will also be changed, aero maps less constrained by the need to cater to the aforementioned undamped tyre deflections.

XPB

F1 tyres are kept nice and toasty before they're fitted to the cars thanks to the blankets, but this practice will be banned from 2021

Comfort blanket

So, that's all well and good. But the point where one goes into a finely tuned rant is the banning of tyre warmers. Several classes ban them, but as a practical point one is rather partial to them, if only to reduce costs. Tyre blankets impose additional costs, but having been through this cycle several times with Super Touring, GT500, LMPs and GTs, not to mention single seaters, I can unequivocally state that it is a cost saving using them.

Tyres that take a couple of laps to warm up are losing you track time when testing. When testing is limited this makes life more difficult. In Super GT in Japan one campaigned for years for warmers to be used on the basis that at Okayama, site of the pre-season winter testing, we saw one car destroyed practically every year, due to a low grip track at winter temperatures. Eventually tyre warmers were allowed for testing, but not for the races.

When carbon discs were brought in it brought the silly situation that now two rolling laps are required to bring tyres up to make them usable, as the low cold tyre grip coupled with the extra bite of carbon makes them very difficult to use.

Part of the new F1 spec is that 'tyres should provide safe performance when leaving the pits cold. The glass transition temperature must be chosen so that the tyres are never in a glassy state when either the ambient or the track temperature is above 10degC.' So, much like a production tyre we hope. Interesting times for the manufacturer, but it probably will fall foul of the 'there is no free lunch' rule.

Slick and tyred

So we are now expected to see tyres with a wide window, built-in degradation that will come back after dropping off when stressed, plus having a cliff drop-off in performance after a certain distance, plus 'in order to stabilise at a pressure that provides peak performance, the tyres must be capable of commencing running at cold pressures compatible with achieving suitable stabilised pressures'.

This will at least reduce the amount of work required to choose correct initial pressures to achieve desired hot pressures, but will change the deflection characteristics at different pressures, altering set-up requirements and suspension parameters. Then again the lesser air volume and stiffer carcass with low aspect ratio will reduce the effects. We don't know enough about the new tyres yet to say if these changes will cancel out or bias set-up for new paradigms.

In a nutshell, then, there will be a lot of work for the teams and Formula 1's tyre supplier for both these proposals, the only question is; why? We will keep the prescribed three compounds, with a prescribed degradation – by the way, it still escapes me why a supplier of OEM equipment will subject itself to demonstrating publicly that it's product does not last – but tyre warmers? What is the goal here apart from complying with Parkinson's Law? Which states that 'work expands so as to fill the time available for its completion'.

Tyre blankets mean additional expense, but having been through this cycle many times I can unequivocally state that it is a cost saving using them

No holds barred

How Porsche's stunning 919 Evo reminds us of the technical freedom racing has lost

Has Porsche produced the fastest-ever 'racing car' in the 919 Evo? Having set stunning record lap times at Spa (quicker than Lewis Hamilton's fastest-ever Formula 1 pole lap last year in the Mercedes) and around the Nurburgring Nordschleife, I have little doubt that, with a trimmed-out and correctly-set up version of this special Porsche LMP missile, even IndyCar super-speedway records would succumb.

This is somewhat academic, of course, but fascinating nonetheless. Anyone who has watched the onboard footage of Timo Bernhard around the 'Ring cannot fail to be blown away by the sheer velocity displayed when over 1150 of usable bhp is deployed. The old axiom of the camera having seemingly been speeded-up is close to the truth. Just a shade under 229mph could be seen on the screen readout along the main straight, despite (even with DRS enabled) the prototype running a great deal of downforce. However, it is the acceleration and cornering grip that is most stunning with this car.

Evocative Evo

Full marks to Bernhard, and to Neel Jani at Spa. Accolades also to Porsche. This has been clever marketing and has demonstrated the awe-inspiring potential that unfettered technology can bring, and Porsche's engineers have confirmed that still more speed could be made available.

This 919 Evo is a wicked machine and puts me in mind of the brutally-powerful pre-WW2 Silver Arrows monsters fielded by Mercedes and Auto Union. There is a link, of course, in that Ferdinand Porsche, founder of the famous marque, was instrumental in the design of the latter's fearsome and ground-breaking grand prix cars. Not everyone is aware that Porsche's first automobiles were powered by hub-mounted electric motors, another connection, even if a little remote, to the hybrid element of the 919. Subsequently, apart from some specific projects, due to the inherent and still present drawbacks of heavy batteries and the means of charging them, he abandoned electric motivation in favour of the internal combustion engine, especially air-cooled. I imagine that Porsche liked its simplicity, something evident in a lot of his designs. However, another example of the autocratic man's ahead-of-his time genius is that along the way he coupled both forms of energy, calling it 'mixed-drive', a forerunner again of hybrid power, even if rather primitive. This included a military 'road train', in which the tractor unit possessed a constant-speed IC engine powering a dynamo. In turn, via cables, this supplied electric motors, again hub-mounted, driving each of the multiple trailers hooked-up behind.

What makes Porsche stand out against many other talented engineers of his epoch is his tremendous versatility. Cars – passenger, racing and land speed record – aero engines, military tanks, agricultural tractors and more were the product of his restless brain, many of which did not bear his name but certainly carried his engineering DNA.

The Porsche 919 Evo was quicker than Formula 1 around Spa, which just goes to show what can be done when the rule book is consigned to the bin

Total contrasts of course exist between Dr Porsche's work and the 919 Evo. It is a fantastically complex piece of kit resulting from an army of engineers and technicians, almost every element software-driven in its design and operation.

Free spirit

All involved in the Evo's construction can be rightly proud of their contribution. What satisfaction there must have been, however, to work as an engineer in the environment of Dr Porsche's time, without dependence on digital technology and the like, aerodynamics still in its infancy on air and land and relying on first-principle engineering and imagination. With almost unlimited potential ahead for new and fresh ideas, the mind could soar. One person with vision and ability could create a radical concept and inspire those around to execute it successfully, something which is impossible in the racing car design offices of today.

A little motor company in Austria could enter its lightweight aerodynamic coupe, designed principally for the road, in the world's greatest endurance event and beat better-known and wealthier manufacturers fielding purpose-built racers. Other minimally-funded marques, to be fair, did much the same, Alpine being just one example. Probably only Ferrari, however, demonstrated as well as Porsche did how racing success in that epoch could found an ongoing performance car dynasty with such allure; Porsche being taken forward firstly by Porsche's son, Ferry, with the 911, and then the Porsche-Piech family with the company's now extensive range of sports and luxury vehicles.

Cry freedom

Sadly perhaps, no such freedom exists under present-day regulations concerning Le Mans. Balance of Performance means that GT cars are forced to run to the level of the slowest car. Those entrants whose aspirations turn to LMP2 cannot any longer design and build their own chassis to run; and only one make of engine is permitted. There exists a veritable encyclopedia of technical and sporting rules, including penalties, that almost demand a pit wall lawyer for each team. The racing sometimes resembles as much of a high-speed chess game as an outright competition of man and machine.

There is good reason to argue that these reflect the realities of 21st century life, not just motor racing, that this is the only way in which costs are containable. Days in which a competitor could just run steadily to keep out of trouble and win are gone, and there's no doubt that Le Mans now is a hard-fought battle from lights to flag. Mechanised sport, especially, has to keep in step with contemporary standards of professionalism and expectation. Equally arguable, though, is that some of the attempts to achieve the above have gone too far, with artificial influencing of performance and results. It has meant significant quashing of the opportunities to be gained from superior driving, better machinery, clever team tactics and speed in reacting to situations as they develop. Motor racing should not be a board game.

There exists a veritable encyclopedia of both technical and sporting rules, including penalties, that almost demand a pit wall lawyer for each team

A **Force** to be reckoned with

While Force India's brush with financial ruin has made all the headlines its technical team has kept its focus through it all and has produced and developed a typically effective Formula 1 car. *Racecar* talked to the team's tech boss to get the remarkable inside story of the VJM11

By SAM COLLINS

TECH SPEC

Force India VJM11

Chassis: Carbon fibre composite monocoque with Zylon side anti-intrusion panels.

Power unit: Mercedes AMG HPP M09, V6 turbo 1.6-litre with ERS.

Transmission: Mercedes AMG F1 8-speed, semi-automatic seamless shift, composite outer casing, metallic inner cassette.

Suspension: Aluminium alloy uprights with carbon fibre composite double wishbones all-round. Pushrod actuated torsion bars with anti roll bar and inerter at the front, pullrod actuated hydro-mechanical system at the rear.

Wheels: BBS.

Brake system: 920E calipers with Carbon Industrie friction material.

Tyres: Pirelli.

Force India has made a habit of turning out great cars for the budget it has to work with over recent seasons and, after a tricky start, this year's VJM11 has proved to be no exception

'To accommodate the Halo for a team of our size was a huge drain on our resources'

It is a car that was never meant to exist, as the Force India VJM11 is actually the result of a late rule change aimed at improving driver safety. Yet in 2018 its creators hope that it will finish fourth in the Formula 1 World Championship for constructors.

Originally the team had planned to race in 2018 using a modified and improved version of the competitive and reliable VJM10, but in September 2017 it became clear that this plan would not be possible. 'Everyone was working towards modifying the chassis to fit a screen as that is what the expected driver safety system was,' Force India technical director Andrew Green says. 'So when the decision to use Halo was made we had to make a very quick change to having to have the fully structural part on top of the chassis. We had to move to design a chassis very quickly and it was an incredible effort to do what the team did. To get a design out, manufacture a chassis and pass the tests first time was a fantastic bit of work.'

Fiscal issues

One of the main reasons that Force India wanted to avoid building an all-new car was a simple one; it could not really afford it. For years it has been dogged by rumours of financial trouble. Its owners, Vijay Mallya and Subrata 'Sahara' Roy, have been embroiled in a fiscal scandal in their native India, which has seen the latter imprisoned and the former fighting extradition proceedings in Britain. Just before the mid season break the team entered administration, but it was quickly rescued by a consortium headed by Canadian Lawrence Stroll.

Meanwhile the technical team based at Silverstone had continued working regardless. They had no real option as the late chassis change had increased the to do list substantially. 'I think the year-on-year changes would have been relatively small in terms of the concept and the monocoque had we continued with VJM10,' Greens says. 'We would have made some modifications to the mould. So to have to accommodate the Halo for a team of our size was a huge drain on the resources.'

But while the core of the VJM10 would then have been carried over new tubs would have been built for 2018 regardless, as a number of minor but important design changes had been decided on. Most notable of these was the relocation of the steering rack from the top of the front bulkhead to near its base. Otherwise the front bulkhead of the VJM11 looks very similar to that of the VJM10 with the torsion bar mountings, for example, almost identical.

'We planned that change to the steering rack all along on the modified VJM10 so it simply carried over to the VJM11,' Green says. 'I don't think there was anything else as significant as that. We did it solely for aerodynamic reasons. We actually carried over very little in terms of wider mechanical parts from VJM10, the front suspension change and the relocated steering rack meant that we could not carry the uprights over, and the outboard suspension was fully redesigned. At the rear the suspension changed too, as we do a new rear suspension every time we get a new gearbox from Mercedes.'

Forced hand

The team has a long standing partnership with the Mercedes F1 team, dating back almost a decade. This arrangement means it uses an identical power unit and transmission to the front-running Mercedes W09. Such a supply deal has a number of limitations in terms of car design and a philosophy forced on the team for 2017 was carried over to the 2018 design. 'That was another big factor with this car, as normal we didn't get to see the design of the transmission until quite late,' Green says. 'We had to develop a completely new rear suspension outboard and inboard as well. For the 2017 season, and again in 2018, Mercedes made a choice about the way it runs the rear suspension on its cars. They took out any traditional mechanical component mounting points in the transmission casing; there was nowhere to put torsion bars, for example.'

Faced with this, Force India was left with a dilemma; develop an entirely new hydraulic rear suspension system from scratch or utilise an obsolete transmission. 'It was forced upon us really and it probably pushed us into it quicker than we would have liked to have done it as it is such a big change, but ultimately it worked out fine and we are happy with it,' Green says. 'Mercedes gave us the heads up, though without details; essentially they told us that they were taking away the option to run a mechanical suspension system, so be prepared. I went to the design team and told them what they were proposing. If I had got negative feedback from them, if they felt it was beyond us or would take too long, for example, then we would have had to have carried on running the previous year's gearbox. But the team were all up for it and not only had the desire to do it but we also felt we had the capability to do it.'

Hydraulic suspension

While nobody in the team is willing to disclose details of the layout and operation of the inboard rear suspension on the VJM11, Green is willing to discuss the benefits of the design. 'The big advantage of a hydraulic rear suspension like this is weight, it is an incredibly light system,' he says. 'If you did a side-by-side comparison with a conventional layout you are probably saving 1-2kg. But the other advantage of the layout is that you can add different layers to it, to add complexity and modify its characteristics. That adds additional weight, so it probably ends up being about the same or just slightly lighter, but gives us a huge amount of flexibility in setting up the rear of the car. We believe Mercedes are doing something similar as we get the gearbox from them and that is what we had to do with it so we can only assume that they are doing something similar. But we have not seen much of the solutions on other cars.'

While the system is clearly complex it has not been a major cause of concern for the team in terms of reliability or performance. 'It ran for the first time in the Barcelona test, and ran without a single problem, but in 2017 we did a lot of learning, and re-optimised everything for the second year of these regulations,' Green says. 'We are still learning and optimising now. It is the first time we have ever done a hydraulic rear suspension and when you are new to something like that you are on a steep learning curve.'

Brute Force

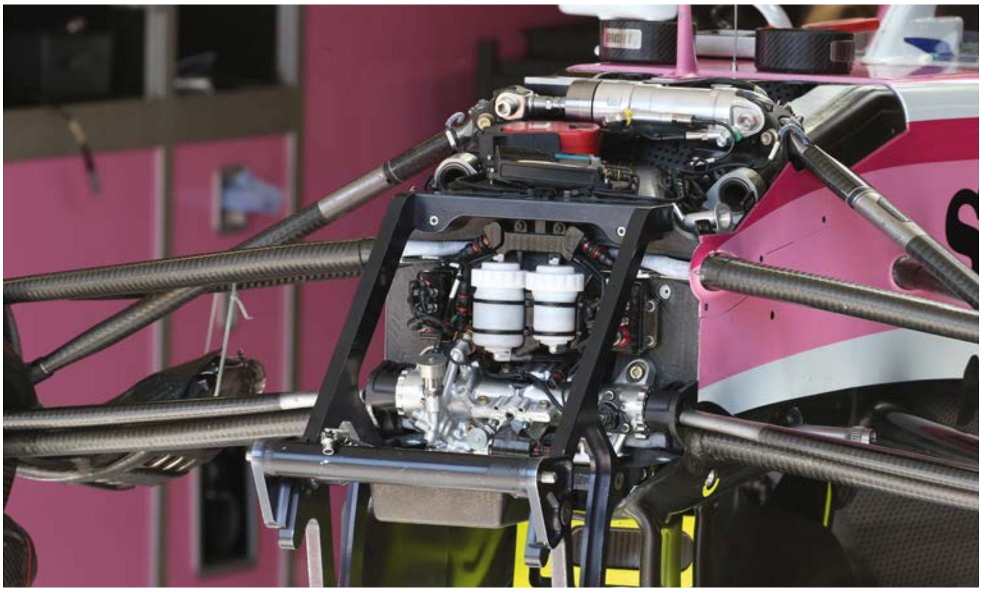
While the suspension system has not caused issues on the VJM11, the car has not been without its faults, and from the start of the pre-season tests in Barcelona it was apparent that it was not working as well as it should. 'There has been a lot of development this season, some of it in the suspension area, but the majority of work has been on the aerodynamic side,' Green says. 'We started off with quite a poorly balanced car in pre-season testing, but we were regularly bringing updates to the car right from Melbourne in order to get the level of performance up to where we wanted it to be. I think we got to that point around the Spanish GP. Since then the updates have been a bit thin on the ground, and we have to rectify that.'

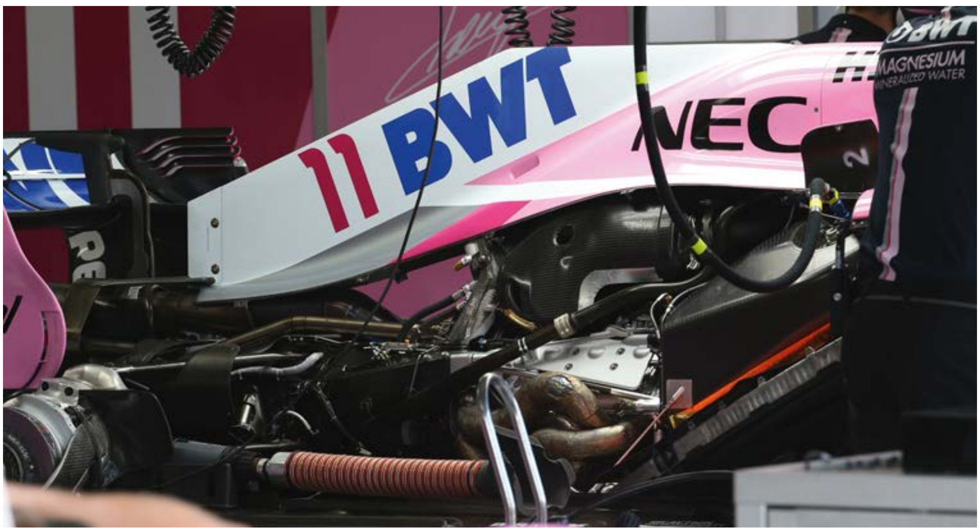
In Barcelona and the early races the team's drivers complained about the way the car was handling in the corners and claimed that it was preventing them from extracting the best from it. 'It was clear that the driver feeling was not good,' Green says. 'What we want, and they want, is a nice neutral balance, through the corners and through each different type of corner. That is something which is hardly ever achievable in reality. We started off being particularly poor on the entry to the corners, oversteering too much on turn-in meaning that the drivers could not attack the corner, so they had to take different lines on entry which meant in turn that the mid corner saw a lot of understeer, which itself had a knock on effect on exit as when the driver tries to get back on the throttle he had poor traction. It was the worst of everything, the comments from within the car were incredibly bad, so we had to think about how to fix it.'

Driving Force

Faced with this problem the small team of engineers at the team's base opposite the main gate at Silverstone set out to try to understand what was causing it. 'We went into the simulator, to understand what we needed to fix in the first part of the corner. Once we understood that the second part of the corner would start to improve, and the drivers could

The arrival of the Halo forced the team to develop a completely new chassis for 2018; Force India had not planned to do this


The front bulkhead showing the relocated steering rack. Torsion bar position has been carried over from last year's VJM10

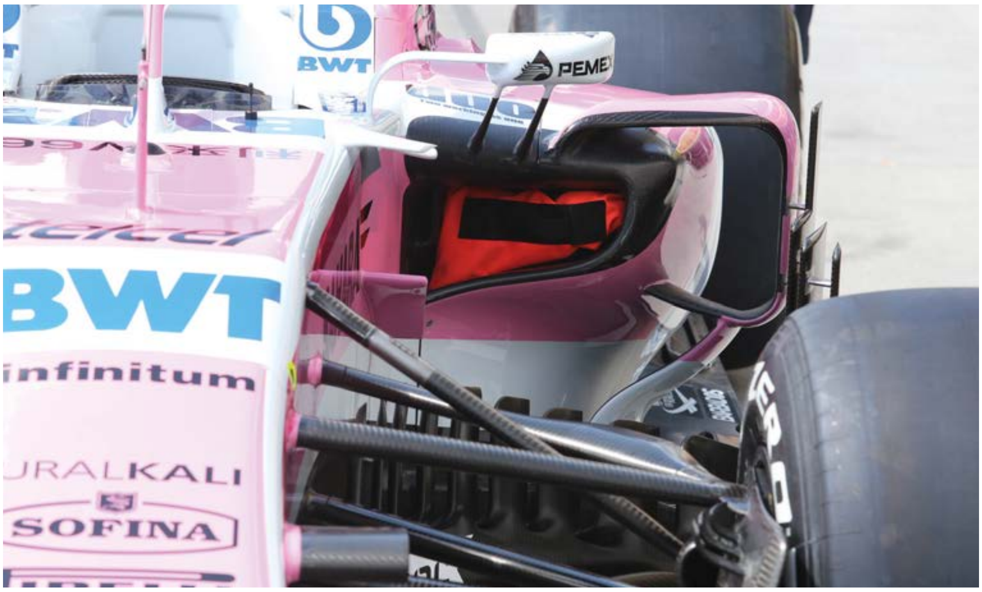


Mercedes power unit and transmission installation. Force India has been a Mercedes partner team for almost a decade now

'We had to design a chassis very quickly and it was an incredible effort'

Use of the Mercedes transmission has meant Force India has had to develop a bespoke hydraulic rear suspension system

The flow around the sidepod was not behaving as expected and the team identified a correlation issue with the wind tunnel



There has been work on the parts around the leading edge of the sidepods to keep the flow attached around the car's sides

start to attack the corners more and take a better line, and that means less understeer and better traction on exit. We made some big steps quite quickly this year,' Green says.

Force of nature

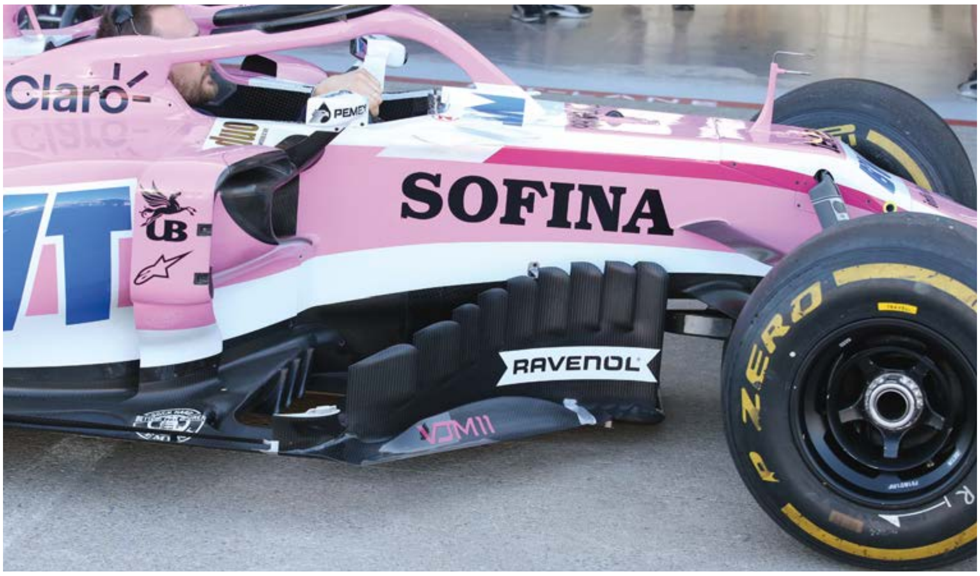
But as one problem was solved another started to become apparent, and this one proved not only harder to identify but also much harder to understand and fix. In some races the amount of rear downforce was changing in unpredictable ways and certain parts of the car's bodywork were simply not functioning as expected.

'There were some issues around the sidepod area, the flow wasn't staying attached when the wind tunnel said that it should stay attached,' Green says. 'So that meant we had to make some changes around the details at the front of the sidepod. After about two iterations it all fell back into line again. There is always a difference between what happens in the wind tunnel and reality. A wind tunnel cannot always replicate what happens at full size. We were looking more to CFD to understand whether those differences we saw between the real car and the tunnel were expected. We wanted to know if we should expect the differences given that the wind tunnel cannot fully replicate realistically what the full size cars do. We found that in many cases that the mis-correlation could be expected and predicted but in a few other cases there was some unexpected mis-correlation as well. It wasn't apparent in the CFD so we went about fixing that. I don't like having the car running round with a portion of it mis-correlating badly, as it could negatively impact updates a bit further down the line. We need to have full confidence in what we bring to the car doing what we expected. Since then the car has been developing quite strongly in the wind tunnel, and hopefully you will see the fruits of that work some time after the summer break, I'm quite excited about that. It will put us back in the race.'

Force field

Aerodynamic development around the front of the sidepods has been a major theme in Formula 1 car design since the current aerodynamic regulations were introduced at the start of the 2017 season, and that is something which is set to intensify even more through 2018 and right up to the start of 2021. 'There has been a big focus in recent years on working on the front wheel wake, so the turbulent flow behind the front wheel has been what us and a lot of other teams have been working on,' Green says. 'We want to try to move that wake out of the way. If you can move it out, the rear the car performs better, but it tends to be sucked in, so that is the challenge. That's what the front wing development is all about, and the bargeboards behind it. That is one of the changes for 2019,

'The driver comments were bad, so we had to think about how to fix it'



The area behind the front wheels is crucial for performance and its importance will grow in 2019 with the new aero regs

The car completed laps with a 2019 spec front wing at the Hungaroring just ahead of the Formula 1 summer break in August

The roll hoop's design was one of few carry overs from the successful VJM10 after the late change in the chassis concept

'Mercedes took out any traditional mechanical component mounting points in the transmission casing, there was nowhere to put torsion bars'

the front wing regulations sees a lot of the gains we have made in that respect lost. So the wake is all going back in again so we have to start on different solutions. There is a big playing field in the middle of the car which is still open. There is a box effectively where we can do whatever we want in, which is great, and that is where the focus will be.'

Air Force

Force India was one of a number of teams to trial a prototype front wing in testing at the start of the mid-season break, something it hopes will give it a head start for 2019. Indeed, the effect of the front wheel wake has had a number of impacts on other areas of the car, not only for 2019 but also on the VJM11. 'That area has a lot of influences, wheelbase is a consideration for example, sometimes you want to move the turbulent flow as close to the aerodynamic elements as possible, if you leave it to form it gets bigger,' Green says. 'In other words, if you wait for it to go further rearward before it hits the aero parts, you are dealing with a bigger issue. If you are working on that wake closer to the tyre you are dealing with a much smaller area, so having the wheel close to the devices is a good thing. The other thing that happens is that if you move it further away it has more time to come in on itself and go to the rear of the car, which is exactly what you want to avoid.'

This effort to get the dirty flow in the front wheel wake away from the floor has also seen a shift in the cooling layouts of most cars and the new front wing regulations for 2019 are likely to make that an even bigger shift. 'Aerodynamically the benefit of relocating the coolers is part of that, while you do increase the centre of gravity height, a couple of points better on rear load make it a net gain,' Green says. 'We will move even more heavily to that next year, I think you will see a lot of the teams moving coolers to the centre of the car and slimming the sidepod. It allows that free area around the bargeboard and sidepod to develop more and more, it is a very big area of performance.'

Gale Force

For the aerodynamic development of the VJM11 Force India has exclusively used the 60 per cent wind tunnel at TMG, in Cologne, Germany, something which may seem surprising when you consider it has its own tunnel in Brackley just a few minutes drive from its HQ. The fact is that in this case, size really matters, and Force India's wind tunnel is a 50 per cent scale facility.

'Frankly, we would still be happy running in our own tunnel with a smaller size model,' Green says. 'But the problem is really the tyres, which are supplied at 60 per cent scale. The 60 per cent model simply did not fit in the working section at Brackley. It's still a great tunnel, we maintain it and it ticks over from time to time and does some running. We do have a few customers using it and we have been reluctant to lose it or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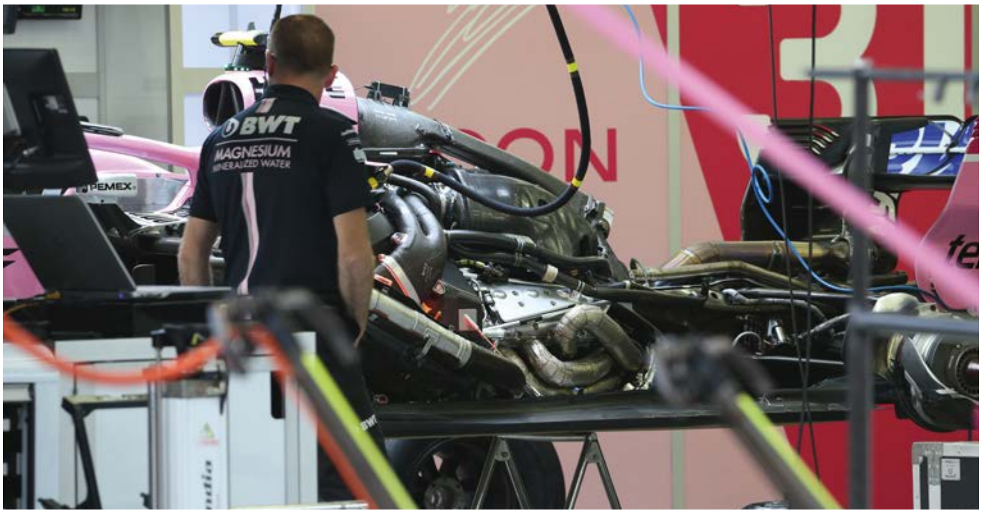
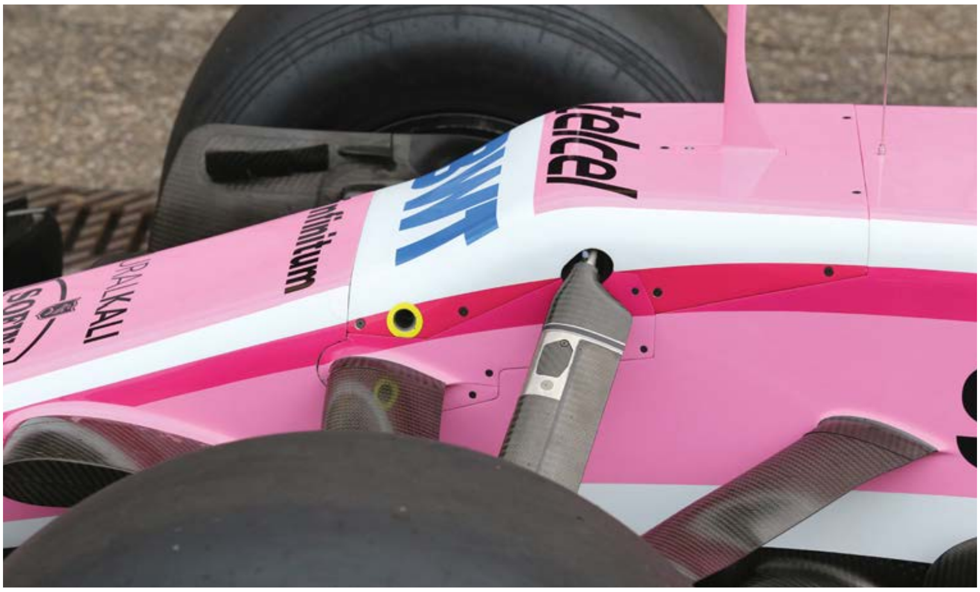
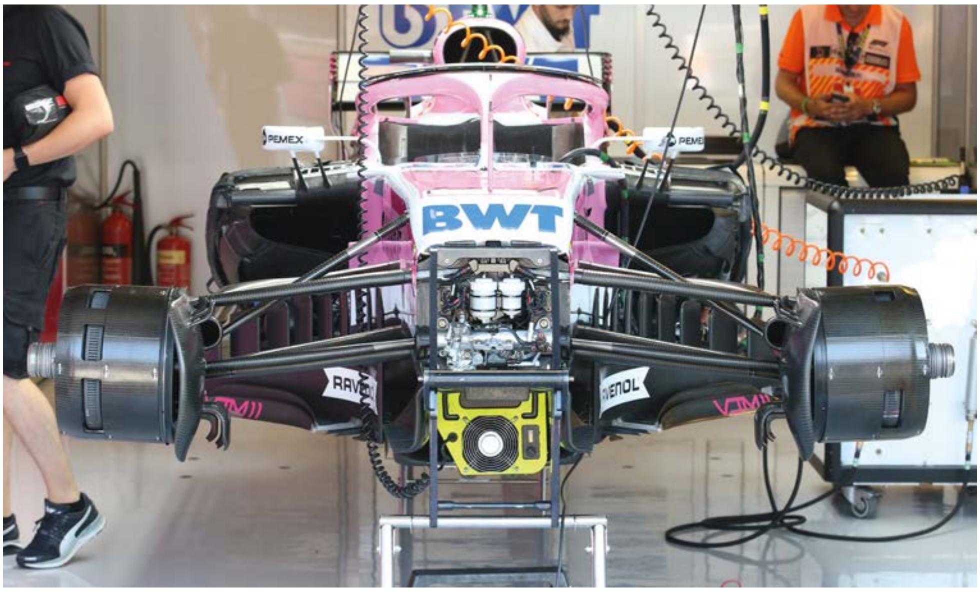


Rear end of VJM11 with cooling ducts visible. Force India says it will move cooling even more to the car's centre next year



VJM11 retains the VJM10 nose with its slots either side of the front impact structure and unsightly hump on the chassis



Force India had hoped to extend the life of the VJM11 monocoque into 2019 but new fuel tank regs have scuppered that plan

sell it on as it is a very niche market. There are a lot of wind tunnels in Brackley, it must be the wind tunnel capital of the racing world. We are up against some steep competition in terms of renting it out. It was a very, very good tool. If there is ever the opportunity to go back into it again, I have no issues with that. The correlation work we did between the two tunnels showed that they were a very good match. It's just the way the rules are written means we have to be at 60 per cent. It would not be worth building a new tunnel or enlarging ours to 60 per cent, especially as the noises we are hearing about the future suggest that wind tunnel testing may be further reduced with more emphasis being placed on the virtual world. It would be a big risk to spend all that money on a tunnel when in four years time it could all be wound down.'

Untapped potential

At the time of writing Force India sits sixth in the constructors points, behind Haas and the works Renault team, but Green feels that this position does not truly reflect the potential of the VJM11 design. 'We struggled with some bad luck in the races, which means that we have not scored the points that we probably should have,' he says.

'The best thing about this car is that it has a relatively large operating window, it does not abuse the tyres, it is now very good in medium speed corners and medium downforce tracks, it seems to be super efficient around corners which are about 90-100 degrees,' Green adds, before highlighting the main weakness of the car. 'As the corner length gets longer we start to lose out; then that strength becomes a weakness. Medium speed, medium downforce tracks we are strong, we tend to struggle on very high or very low downforce tracks. We have to solve that problem and we will.'

But the VJM11 will not be in as many races as the team hoped when they had to hurriedly design it last year. In order to further save money Force India had again intended to carry over the monocoque and core of the VJM11 design for the 2019 season, but once again the plan was foiled by a minor rule change. Along with the planned aerodynamic changes for 2019 the maximum race fuel allowance for a grand prix will be increased by 5kg, and that enlarged fuel cell is enough to require the team to develop yet another new chassis.

The Force India VJM11 is very likely to be the last car to bear both the 'Force India' and 'VJM' labels as the team's new owners are almost certain to want to re-brand the organisation and take it in a new direction. For the time being, though, Force India has its sights set on getting on terms with F1 'B class' rivals Renault and Haas to be best of the rest at the races.

'The VJM11 has been developing quite strongly in the wind tunnel, I'm quite excited about that. It will put us back in the race'

Reinventing the wheel

With Formula 1 announcing a shift to 18-inch wheels in the first of its 2021 regulations to be revealed, we examine the technical implications for F1 teams, brake suppliers and its future tyre manufacturer

By SAM COLLINS

It is no secret that Formula 1 will introduce an entirely new set of technical and sporting regulations for the 2021 season. However, until now the rules themselves *have* largely been a closely guarded secret. But the veil was partially lifted at the German Grand Prix where the first solid elements of the new regulations were revealed. These were that in 2021 F1 will adopt 18in wheels, low profile tyres, and it will also ban the use of tyre warmers.

This change has substantial implications for the overall car design in 2021 and the announcement took teams completely by surprise. The revelation came in the form of an official invitation to tender posted on the FIA website. The tender is for the Formula 1 tyre supply contract from 2020-2023 (inclusive) and in the documents uploaded to the website there is an unprecedented level of detail about what the FIA wants from the new F1 tyres.

At the pre-race press conference in Germany none of the four technical directors present (from Williams, Renault, Red Bull and Force India) were actually aware that the decision to change wheel size had been taken and it was clear that they were somewhat taken aback that the media were aware of a major change to the technical regulations before the teams were.

'We were not aware of that,' Paddy Lowe of Williams said after the tender document was shown to him. 'I know the idea of 18in wheels has been debated many, many times over the last 10 or more years. So, it's an interesting thing to make a commitment to that because it's not absolutely clear that's a great way forward, and I think we need to analyse the implications

Formula 1 tyres are to go low profile from 2021 to fit new 18in wheels, while F1 will also be banning tyre warmers

Paddock rumours suggest that there is interest from both Michelin and Hankook

technically before going in that direction. Certainly, it makes a very different tyre. A much heavier package as well, and quite challenging to design and manufacture.'

Switching to 18in wheels is by no means a new discussion in F1, as Lowe suggested it is something which has been under consideration for years, with tests of prototype wheels and tyres taking place on both F2 (GP2) and F1 cars.

Tyre change

Developing the new low profile tyre for 18in wheels will fall to the nominated tyre supplier, currently Pirelli, but this could well change for 2020. At the time of writing the Italian company had not decided if it would put in a tender or not, while paddock rumours suggest that there is also interest from both Michelin and Hankook. The change of tyre shape and size is something that the rule makers feel will increase road relevance, in theory, but in reality this has been done more for aesthetic reasons, and it's known that this is something that Michelin favours.

The tender document states that from the start of the 2021 season all cars will use larger 18in wheels and the front tyres will be sized at 270/D1-18, the rears 405/D2-18 (D1 and D2 are two uncertain dimensions, left up to the tyre makers but which must be ranged between 700mm and 720mm). Notably, this means that the front tyres will be 35mm narrower than present but have a slightly larger diameter. The rear tyres will also have a larger diameter than at present but will remain the same width. This means in terms of tyre weight alone that the rears will be heavier, while the fronts may be slightly lighter than the 2018 rubber.

'The thing which is really important is the volume of air inside the tyre because [of] the variance in the loading capacity of the tyre,' Pirelli racing manager Mario Isola says. 'The front tyre will be narrower than now, while the rear is the same width. Don't forget we do 18in tyres for sportscar racing, and we did it for F2 in the past as well as doing the prototype tyre for show and testing with a Lotus F1 car, so we have investigated this to some extent.'

The changes are of particular interest to car designers, with an increase in unsprung weight inevitable, something they always strive to avoid, despite Isola's claims of lighter front tyres. 'I think what will make a huge difference to the packaging inboard of the front of the car will be mainly what we do with uprights, brake drums and all the outboard kit, understanding what the tyres need, in terms of suspension kinematics, all of that,' Bob Bell of Renault F1 says.

One detail of the new regulations which is also included in these tender documents is that the mandated weight distribution will shift rearwards by three per cent, though the reason for this is not provided.

Wonder wall

A low profile tyre also gives teams a much smaller sidewall to work with, something which both complicates and simplifies some car development tasks. Currently the sidewalls of F1 tyres play a major role in the suspension system and that role will change substantially in 2021.

'The influence on the inboard suspension will be higher in terms of tyre deflection,' Red Bull Racing technical director Pierre Wache says. 'For sure, the spring will take more load. I think that it might give more control for the chassis people of the ride height of the car. So it is not so bad from that aspect, and the tyre deflection will have less of an influence on the aerodynamics of the car.'

But what degree of influence the sidewall change will really have on the design and layout of the suspension system on the 2021 cars is uncertain, as it is not yet clear if a conventional system will be used at all, as there are ongoing discussions around the reintroduction of active suspension for 2021. If this happens then the system will likely be a common set of components shared by all teams.

Black art

As Wache mentions, the reduction in sidewall deformation will have a major impact on the aero development of the cars. Currently every team is struggling to accurately model the behaviour of the Pirelli product, especially in the wind tunnel, and the lower profile tyres could well make that task a lot easier.

'Wind tunnel tyres are a real black art, to try and replicate reality is very hard,' Force India technical director Andrew Green says. 'You end up in a situation where you can try and replicate a condition on the track, say a high speed corner, you can have a wind tunnel tyre that replicates that, but it is no good for replicating a low speed corner. You are always stuck with the compromise of which tyre do you develop around. So we have to be quite smart about that and know where the limits of the tunnel tyres are at, where it is reporting good correlation, and where it is reporting bad correlation, and make sure we are not developing around something which does not exist. Pirelli give us updates through the year to mitigate that but it's a real challenge, especially as they are busy developing the full size tyres too.'

‘We don’t know what the rules around the brake disc size will be yet’

Pirelli tested 18in wheels fitted with low profile tyres on a GP2 car during a demonstration run at Monaco three years ago

Tyres are already mounted to 18in rims in LMP1. Low profile tyres are said to be more road relevant than current F1 rubber

Mario Isola, Pirelli racing manager, alongside an 18in low profile tyre. These were fitted to a Lotus to test the idea in 2014

Modelling the real tyre is a major job for all teams not just in terms of physical shape but also thermal performance, and it is something that may be eased in 2021 simply because with a lower profile there will be less deflection. ‘We have an FEA model provided to us by Pirelli, and we use that as a basis then modify and tweak it to match the data that we see on the real car,’ Green says. ‘We do on-car measurements of the tyre behaviour, feed that to the tyre modeller, then that into the FE model, and finally those shapes go into CFD and that is when we start looking at where the wind tunnel tyres are deficient and when we have to turn the attention to CFD. You start getting creases and all sorts as the tyre changes shape.

‘We have to look at sidewall deformation, the way the contact patch changes shape at high speed, low speed, medium speed, and what it is doing on the inside wheel and outside wheel, front and rear,’ Green adds. ‘At times some of the tyres are barely touching the ground as they go round corners, other times they are planted so hard you think that they are about to pop. Steer, slip, roll, all of that factors in as well and it’s an incredibly complex equation and you can get yourself lost very quickly if you are not incredibly clear about what you are trying to achieve.’

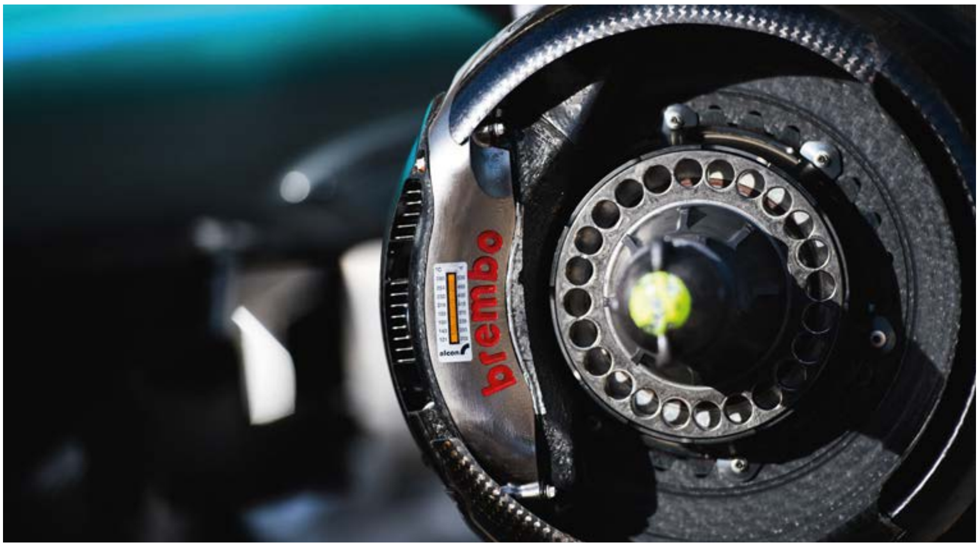
Big brake

However, before Pirelli or any other organisation can even start to consider the design of the new tyres it needs to understand more about other areas of the car; not only the weight distribution but also aerodynamic performance as well as some mechanical parts, and key among them is the braking system. When the 18in wheels were originally tested by Lotus the brake system carried over from the current 13in rims, but there is great uncertainty over what the 2021 rules will include in terms of brake disc size.

‘I would welcome bigger brakes,’ Bell says. ‘I think for the new formula we will need them as we are getting close to the practical limits with the current brakes. I think it does represent an opportunity to redress some capacity in the braking system.’

Disc discussions

But to date it seems that the group developing the new rules has yet to turn its attention to the braking system, and at the time of writing had yet to consult with the brake manufacturers about what the new rules could bring, and there have even been suggestions that the current brake regulations will carry over to 2021. ‘We don’t know what the regulations around the brake disc size will be yet,’ Andrea Pellegrini, Brembo’s F1 brake engineer, says. ‘We expect to talk with the FIA about the rules, I know there are some meetings coming up, as was the case



The rules relating to brake systems have yet to be announced yet the brakes play a key role in the performance of the tyre

LMP brake discs have a larger diameter than those used in F1; it is possible the latter might use similar discs from 2021

Just how much a current F1 car leans on its tyres during hard cornering is clear in this image of the McLaren at Silverstone

with the thickness change for 2017, but we have not spoken to them yet. With the big rims we can increase the diameter of the discs, so it would be like GT or LMP1 where they have a similar rim size. I personally think that the diameter of the disc will increase, in fact I hope it does because from my point of view the big rim and a small disc would not look good.'

Science friction

There are a number of variables which will need to be decided in terms of the brake system design before any serious work on the tyres can begin, as Pellegrini highlights. 'In terms of the friction material, nothing will change. The discs we use on LMP1 cars are the exact same material we use in Formula 1, we change just the diameter, the thickness and the cooling. But these are options to consider; you could have a bigger diameter disc, but to keep the weight down maybe it would not be as thick as now, perhaps back to 28mm thickness or 30mm. The radius would increase with a bigger disc so you can reach more torque without any problem. The current discs are on the limit because we cannot increase the diameter, and 32mm is quite a thick disc. With the current regulations the braking torque is really high, and in terms of safety it would be better to have a bit of margin. If there was a significant performance increase it could be a problem.'

Brake time

However, time could be an issue in terms of developing new brakes, as much work will be needed to be done by the brake manufacturers to be ready for 2021. 'For us it is really important to know the regulations in advance as the work required to get the discs ready in time is very long,' Pellegrini says. 'It takes around eight or nine months just for the manufacturing. There is also the cooling design, and the calipers too. The sooner we get the rules the better.

'To give you an example, for the 2017 season the brake disc thickness increased from 28 to 32mm,' Pellegrini adds. 'This was done because the energy of the cars with the new tyres and increased downforce would have been too much for a pre-2017 brake disc, so the only way to increase the performance was to increase the thickness as we could not increase the diameter then as the discs are already as close as possible to the wheel rim. That change may seem from outside like it was not such a big deal, but in truth we had to design the caliper from scratch. That small change was a big job. Changing the diameter means you have to redesign the upright, the disc, the pads, the calipers, everything, so it is an incredibly big change. Just take the disc cooling; the extra 4mm in

Currently the sidewalls of F1 tyres play a major role in the suspension system and that role will change substantially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thickness meant that we went from 1000 holes to 1450 holes, and that was a major project. That would be a bigger challenge for a bigger disc.'

Brembo and the other brake manufacturers also need to feed information on the disc design to the teams well ahead of time so they can design the cooling package around them, and the size of the disc could have a fundamental impact on how that package might look.

'The cooling systems around the brake discs are very sophisticated these days. Originally these were just used to control the temperature of the caliper and disc, but now there are a lot of things being done to warm up the rims, for example, a lot of things are done for tyre temperature,' Pellegrini says.

'If it drives us towards tyres that have a much wider window to operate in, that could be good'

Talking of tyre temperature, this is another major consideration for 2021, with tyre warmers to be banned from that season on. This is actually not something that is entirely unknown in motor racing, as Super GT, for example, has a total ban on tyre warmers, while the WEC has a ban on tyre blankets but uses tyre warming cabinets. However, for Formula 1 the challenge could be quite significant.

Blanket ban

Isola certainly thinks it will be: 'The pressure evolution is going to be important, with the tyres starting cold, the temperature and pressure difference will be a lot bigger,' he says. 'You can't just start the tyres at 5psi cold because this is F1 and there has to be a certain performance level. It will be important to have a minimum pressure which is enough for the car in the first few laps. We need to understand how the tyres will work and how the temperatures and pressures will evolve. It is not easy to make a tyre like that, but it is a technical challenge. We do it in F2, they start from cold, but the performance level of F2 is much lower than F1.'

Tyre warmers will be banned for 2021 bringing challenges for both the chosen tyre manufacturer and the Formula 1 teams

The tyre supplier will need to provide three different compounds for each race, with large performance gaps between them

This change will require a completely new approach to the tyre compound development, according to Isola: 'It is really difficult, as without blankets we will have to change all the compounds,' he says. 'Right now the cars leave the garage with the tyres at 110degC but now if they roll out with the tyres at 20degC it is a completely different challenge. Then, additional to that, we have to design a number of compounds to meet the tender. It will be more than the four specified by the FIA, it will be six at least and we have to be able to deliver certain specified performance gaps at 20 or 21 different circuits. That is not easy.'

Cold comfort

While some have questioned the value of this change, it has been met with cautious optimism by others in F1. 'If it drives us towards tyres that have a much wider window to operate in, that could be a good thing,' Lowe says. 'I know at the same time they are talking about moving qualifying perhaps to formats where there are less laps, more criticality around doing single laps and, again, if that's around tyres that aren't prepared with blankets that would drive us towards tyres with a wider window, then I think it would be a good thing for the sport.'

The tender (see box out) also specifies that there must be three different tyre compounds available at each race; a hard, medium and soft. One of the requirements of the tender document is that the performance gaps between these compounds will be significantly larger than they are at present and the degradation will be higher. The hard tyre will lose about two seconds a lap in terms of performance through degradation after 22 per cent of the race distance; the medium tyre will be around 1.2 seconds a lap faster than the hard but will lose two seconds of performance after 18 per cent of the race distance; while the soft will be the quickest tyre, around 2.2 seconds a lap faster than the hard but will lose two seconds a lap in performance after 10 per cent of the race distance. This tyre performance is expected at 75 per cent of the races, as it is clear that it will not be possible at every race circuit. This is all intended to force the F1 teams to move away from a one stop strategy and towards two and three stop races, something the rule makers believe will 'improve the show'.

On the edge

Additionally, the degradation of the tyre will be non-linear, so the tyres will be designed to fall off the cliff part way through the degradation. It is suggested that an under-layer of a lower performance compound is designed below the main tread compound to achieve this. The tyres will also be required to quickly recover performance after a period of following another car closely or some aggressive driving over a lap. The tender document states: 'It is anticipated that to achieve this, for any given compound,

‘The degradation of the tyre will be non-linear, so the tyres will be designed to fall off the cliff part way through the process’

the deviation of grip under a particular condition of surface macro and micro roughness and at a typical slip velocity will not drop by more than five per cent in a temperature range of plus/minus 15degC from that which achieves peak grip. Furthermore the cross linking of the compound polymers must be robust enough to resist permanent damage due to high slip or surface temperature conditions.’

As the contract also covers the 2020 season the winning tyre maker will also have to supply high profile tyres to suit 13in rims for a single Formula 1 season, something some have said favours Pirelli as it already has a product at this size. Though the tyres will have to comply with the new performance criteria, in 2020 tyre warmers will still be used.

But Isola says of this: ‘For 2020 we have to design a new tyre anyway, so it is no advantage for us to already have a product. We have a new tyre every year, there has not been a single season where we have not done a new tyre.

‘The tight deadlines should not be an issue for us as it is the same as it was for us when we came to Formula 1 in 2011,’ Isola adds. ‘We were only appointed at the end of June 2010 for the following year, and we track tested in August. It’s not a problem for a tyre maker to react like that, it’s unfortunate but in Formula 1 everything is always quick.’

Race against time

Quick or not, Formula 1 still faces a race against time to get everything ready in time for 2021, with many areas of the regulations still undecided and a number of deadlines fast approaching. By the time this is published the initial selection of the tyre supplier will have been made subject to commercial arrangements, but the details the tyre makers will require are not likely to have been finalised.

‘We need additional details. We need to know what the brakes are, what the downforce levels are, anything that will help us start designing the tyre,’ Isola says. ‘Right now with no information it’s quite difficult. Ideally, it is already too late for 2021, we need at least a draft set of technical regulations which are not too far from the final rules really by the time we would be fully appointed, which will be September or October time, once the commercial deals are done. Then we will have to start immediately as it is not only the tyres we have to design. We will have to upgrade the machinery in the factory, we need to change our indoor test equipment. There are a lot of other minor factors which will result, too. When they changed to the wider tyres in 2017, we had to increase the number of trucks we have and the number of flight cases, because you cannot fit the same number of tyres in the trucks if the tyres are bigger, we need to consider all of those things.’

Testing headache

When Pirelli became the sole F1 tyre supplier in 2011 it tested its products extensively using an unbranded Toyota TF109, and ahead of 2017 it used a number of specially adapted mule cars from various teams to try out the new wider rubber. For 2021 the problem is somewhat more challenging with no car available at all which will be fully representative of the new rules.

‘It’s like 2016, when we had mule cars, we need cars that are designed to test 18in tyres, but I’m not sure we will get that,’ Isola says. ‘A NASCAR style test programme would be the ideal, we have it in GP2 and GP3 where the organiser has a test car with a small team and we can test when we need to, and that gives no advantage to any team. But in F1 it seems unrealistic to have a test team just for the tyres.’

The first data from the new tyre supplier is expected to be shared with teams just two weeks after the contract is finalised, with the first rig testing tyres for the 2020 season delivered to teams on 1 January 2019.

In 2016 Pirelli used ‘mules’ to test the 2017 rubber, but it seems unlikely there will be a suitable test car for the 2021 tyres

Tyre performance targets

- Tyre stiffness should vary monotonically with working range. In addition tyres with the highest compound stiffness should also have the highest working temperature range and the tyre temperature working range should reduce as the tyre compound stiffness reduces. The variation in working range between the compounds should not be excessive. Suggested values are shown below where ‘working range’ is defined as the temperatures above and below optimum at which grip is reduced by five per cent on typical micro and macro roughness tracks and sliding velocities.
- For 2021 the ratio of cornering stiffness of the tyres should be compatible with a rearward shift of the longitudinal centre of gravity position of three per cent from current values. Furthermore the change in cornering stiffness ratio must remain a constant plus/minus two per cent with respect to normal loads encountered during operation and must maintain these limits within the normal variations in tyre wear.
- Peak cornering force in low speed corners should be achieved at six to seven degrees of slip angle on the rear tyres and in high speed corners at around eight degrees. Peak cornering force on the front tyres should be achieved at slightly lower slip angles.
- Tyres should provide safe performance when leaving the pits cold. The glass transition temperature must be chosen so that the tyres are never in a ‘glassy state’ when either the ambient or the track temperature is above 10degC.

Variations in working range

Compound	Optimum bulk temperature	Working range
A (hardest)	(x + 10 to 15)ºC	Optimum bulk temperature ±15 ºC
B	(x + 5 to 10 ºC	
C	x ºC	
D	(x – 5 to 10) ºC	
E (softest)	(x – 10 to 15) ºC	

Peak voltage

When VW's ID R shattered the Pikes Peak record it marked yet another milestone in the rise of EVs in motorsport. We talked to the company behind the car's power unit – Integral Powertrain – to get its take on this project and the state of electric racing in general

By ANDREW COTTON

The march towards electrification seems inexorable

Volkswagen is the new record holder for the Pikes Peak hill climb, in Colorado, using a bespoke prototype powered by the latest motors and inverters from British company Integral Powertrain. The British company elected to become technical partners for the project in order to promote its technology, which was critical to VW achieving its record.

The details of the programme are well documented: French driver Romain Dumas' Norma chassis was adapted by VW and its technical partners in record time, just eight months, to run as an EV, and then he turned down an offer from Porsche to run its 919 Hybrid Evo up the hill to instead set a new record of 7m57.148s in the all-electric VW ID R, comfortably faster than Sebastien Loeb's old record of 8m13.878s for Peugeot.

This latest achievement is yet another example of electric cars proving performance over a relatively short distance, and the hope for motorsport governing bodies is that, now the perception of electric cars is changing through such projects, they will lead to longer lasting batteries, longer races, and eventually a long-term electric future.

Integral to success

Integral Powertrain is at the forefront of the development of this technology, supplying major racing series, as well as developing its automotive and aerospace market supply. But before we look at the part it played in the VW Pikes Peak project, it's worth looking at the rise of electric motorsport in general.

At student level, electric cars are developing quickly. For years now electric vehicles have dominated FS events in Europe, with more effort and expertise being built up, while Cranfield's Group Design Project this year was to create an electric Dakar rally car. At international level, Formula E will introduce new technology this calendar year and will not need to change cars mid-race, and at national level the British Touring Car Championship has announced that it will introduce hybrid technology, perhaps as early as 2020. One-off achievements include the fastest ever lap around the Nordschleife by Porsche with its 919 Hybrid, and now the Pikes Peak record is also held by an electric car. The march towards electrification seems inexorable.

Yet there are clear issues facing the technology; teams must be able to afford this equipment and the technology has to develop at greater speed to allow it to become relevant and offer a value to manufacturers. Regulations

VW's all-electric ID R Pikes Peak racer is powered by motors and inverters produced by British company Integral Powertrain

need to accommodate the needs of the different series, allowing technical development within a tight cost framework, or a spec part for all, which is effectively green paint on a racing car rather than a valuable development piece.

It is this balance between cost and development that has become such a major stumbling block for the international series, sending manufacturers and private teams to the wall in both the WEC and in Formula 1.

Max power

Hybrid technology was introduced into F1 in 2008 to give manufacturers corporate responsibility to continue racing under FIA president Max Mosley's vision. Since then the concept has extended, albeit slowly. The thinking now is that all new top-level racing regulations written by the FIA should feature hybrid technology, and the BTCC announcement means that the mood has started to trickle down into national series also.

'This concept was very much welcomed at our recent TWG meeting and now the real work begins as to the technical implementation,' said BTCC series director Alan Gow in a press statement. 'But different to hybrid development within the likes of Formula 1, this certainly shouldn't – and won't – be an extreme technical exercise, but rather one which we will introduce within our NGTC technical regulations relatively seamlessly and very cost-effectively. Just as importantly, by incorporating hybrid it keeps the BTCC absolutely relevant to manufacturers, sponsors and the public.'

Notably, this is all driven by the FIA, Gow's links with the body well known – as a former president of the FIA Touring Car Commission. Meanwhile, series outside the FIA's control continue without electrification, such as IndyCar, IMSA, the DTM, GT racing and Australian Supercars – Japanese Super GT manufacturer Honda flirted with hybridisation before abandoning it after a season of problems adapting the standard DTM-based car.

BTCC push

Arnaud Martin, chief engineer, motorsport, at Integral Powertrain, said of this: 'Introducing hybrid technology into touring car racing means that the technology almost certainly will come from production cars to meet with the cost requirement.' The BTCC did announce that it would be a specified unit, providing reserved power, likely used as a push to pass system.

There is much within the regulations that needs to be looked at to push through cost

Integral motor and inverter. The front package weighs just 30kg while the rear is 5kg under that. Performance for the front motor is 270Nm and 270kW, while at the rear it is 460Nm and 280kW

The technology surrounding motors and inverters, as well as batteries, is reaching impressive levels

controls, though. 'Reducing losses, even within the boundaries of the regulation, there is still a lot that you can do,' says Martin. 'We are talking of minimum [carbon] lamination thickness, but depending on how you manufacture your laminations you can have a price difference of up to 10 times the cost. The cost cap is the interesting point. All the FIA should do is cost cap things, and allow people to come up with solutions that allow you to make the best motor for the minimum price. That way racing would truly contribute to the development of the technology rather than constrain it.'

Cost control

For Martin, the future of hybrid and all-electric in racing is solely dependent on costs, and some companies have over-inflated theirs to make hybrid look expensive. Integral, he says, produce motors and inverters that are below even the cost cap proposed by e-WRX, due to their low mass. Less material means less cost. 'Hybrid in motorsport has a future as long as a championship can sustain the costs,' says the Frenchman. ' Even at the cost cap that they are talking about [in the BTCC], some formula such as touring cars, are always struggling for budget. For the competitors, assuming that hybridisation cost them £20,000, it is already a lot of money but at the same time it is going to be difficult to make a battery, electric motor and controller under £20,000.

'In some instances, the technology has to be extracted from road cars and redeployed with limitation for racecars,' Martin adds. 'For more premium categories there is more flexibility and yes hybridisation may be a bit more technical, with systems more suited to the application with less compromises.'

Current affairs

Meanwhile, all-electric racing is starting to gain credibility with the new Formula E cars that will race from December 2018, with the ability to complete the race with one car. Despite clear drawbacks, the series is still the market leader in electric racing, and some in the industry believe that this could become the new Formula 1.

Others are less successful thus far; the Electric GT series has yet to get off the ground, and the Smart EQ FourTwo E-Cup series is still in its infancy. For e-WRX, at time of writing there were too few manufacturer entries to get the project off the ground, with only Peugeot and Ford declaring their interest. For the series to really take off, four needed to have signed up.

'For pure electrical cars, batteries are difficult to deal with. Formula E is doing a fantastic job with it,' says Martin. 'The new battery is very impressive, [but] it still is a low level of power. We can't hide that fact, but what has been achieved is outstanding. But if you scale that to a touring car, it is a much heavier car so you need more power, with more power more energy, the battery therefore needs to be bigger and it is a downward spiral. e-WRX is the ideal platform because it has shorter races, so it makes total sense. But long races, pure electric, I can't see until there is a major breakthrough in battery technology.'

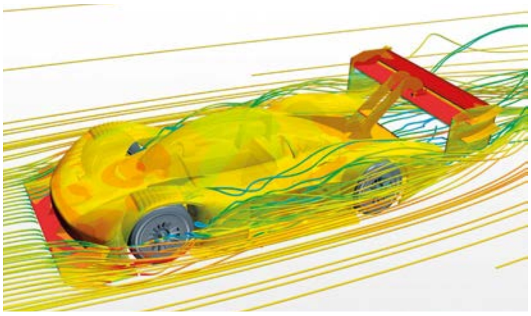
Electric light

The technology surrounding motors and inverters, as well as batteries, is reaching impressive levels. Integral Powertrain has undertaken a lot of work regarding cooling of motors and inverters, allowing it to produce machines of lighter weight with more power.

The VW Pikes Peak car had a front motor that weighed just 25kg (19.5kg for the motor, 5.5kg for the inverter), while the rear weighed 5kg more. The performance target for the front motor was 270Nm, and peak power could be 270kW whilst the rear motor was 460Nm and 280kW. For the rear motor peak power was reached at 5800rpm, while the motors could rev up to 17,000rpm. Ultimately the power was limited at 250kW to protect the battery for the duration of the run at the end of June, but it was still fast enough to obliterate Loeb's record,

‘Although people look at this and say it is only a 500kW car, it is 500kW nearly all the time and that is why it is accelerating so quickly’

The VW ID R smashed the Pikes Peak record back in June with a 7m57.148s, comfortably faster than Peugeot’s old record of 8m13.878s. Electric cars work very well at high altitude



With very little in the way of regulations at Pikes Peak VW was able to fashion a hugely effective aero package. The ID R was adapted and developed from a Norma chassis in just eight months

set in a Peugeot that was upgraded from the company’s LMP1 spare parts bin.

‘Although people are looking at this car, and saying it is only a 500kW car, it is 500kW nearly all the time and that is why it is accelerating so quickly,’ says Martin. ‘For an ICE car, you talk about a peak number which you normally only reach at the top end. Here, straight away you are on peak torque from zero speed and reach peak power at 5800rpm. As a result, you look at the climb and we were about 250kW front and rear. The reason for the difference in torque between front and rear is the weight transfer, especially as we were going uphill. The front motor was quite often in traction control mode trying to limit the speed of the axle in order to regain grip. The main reason for sizing differently was weight saving, so it was 25kg at the front, and at the rear it was 30kg for the bigger motor/inverter, so quite respectable numbers.’

Peaky blinder

The benefit of EVs up the hill is well known; at altitude the electric motors do not rely on air density as much as an ICE, and therefore do not lose as much power at the extreme altitudes. The temperatures at Pikes Peak are rarely high either, with the runs taking place in the morning, so overheating is less of a concern than it otherwise might be. This helps with the cooling of the motors; increasing current increases power and torque, but heat build up is rapid. But there are some other issues with running an EV at altitude, of course.

‘One aspect of electric design at altitude is the ability for electricity to jump across polarities or ground increases at altitude, so as the ambient pressure decreases you need bigger clearances to ensure that you are electrically safe,’ Martin says. ‘One consideration was ensuring that the insulation in terms of the motor and inverter was suitable for Pikes Peak because at 4200m compared to 2200m, which is a more common altitude that you design for, there was some work to be done.’

Core technology

That work started in October, 2017 and Integral had to draw on its existing technology as there was little time. ‘If you consider a motor, especially a radial flux motor, you can scale them by just increasing the length of the rotor, a longer or narrower rotor allows you to increase or decrease the torque easily,’ says Martin. ‘[We did] re-use some of our core technology, which meant that we were not going to design ourselves into a dead end considering the time scales. There was no opportunity to do another development cycle. It had to work there and then, and it did. We could have saved weight if we had more time, yes, but if you consider 25kg for motor and inverter, that is world class for the performance rating.’

Another key aspect of Integral’s design, says Martin, is ‘the ability to keep the rotor cool so if you have a heavy-duty cycle you don’t demagnetise the motors. That is a big advantage, as there are more eRacing series that are lasting longer. We have made a lot of iterative gains, so the inverter and motor are now peaking above 98 per cent efficiency. Now we just need to push the battery.’

The next stage of development is also to reach a continuous power rating that is very close to peak power, and maintain the temperature of the motors, inverters and batteries. If the regulations allow this to happen for a low cost there could be a future for electric development in racing. Right now, the march of e-machines through all areas of the sport, setting records along the way, continues.

Integral Powertrain

Integral Powertrain (IP) was formed in 1998. At the time, IP was a young and very active company using Dassault Systemes CATIA V4 software. As an experienced user, it was approached by the company to become a development site for its new parametric design software, CATIA V5. Integral Powertrain put the new software to work immediately and helped Dassault with feedback on performance, early teething problems and ways it could make it an even better product. IP’s enthusiastic use of V5 spurred Dassault on to offer it the opportunity to sell and support its software in the UK, and so Intrinsys was formed.

Integral Powertrain has continued to grow, supported by Intrinsys. It is now a globally-known and respected powertrain specialist that undertakes key design and development projects supporting OEMs and tier 1 suppliers in delivering competitive products to market.

Integral has more recently extended its strong ICE presence into the hybrid and electric motor sectors, delivering world class products and services into the automotive, motorsport, aerospace, defence and marine markets. This capability has now led to the manufacture of high performance electric motors.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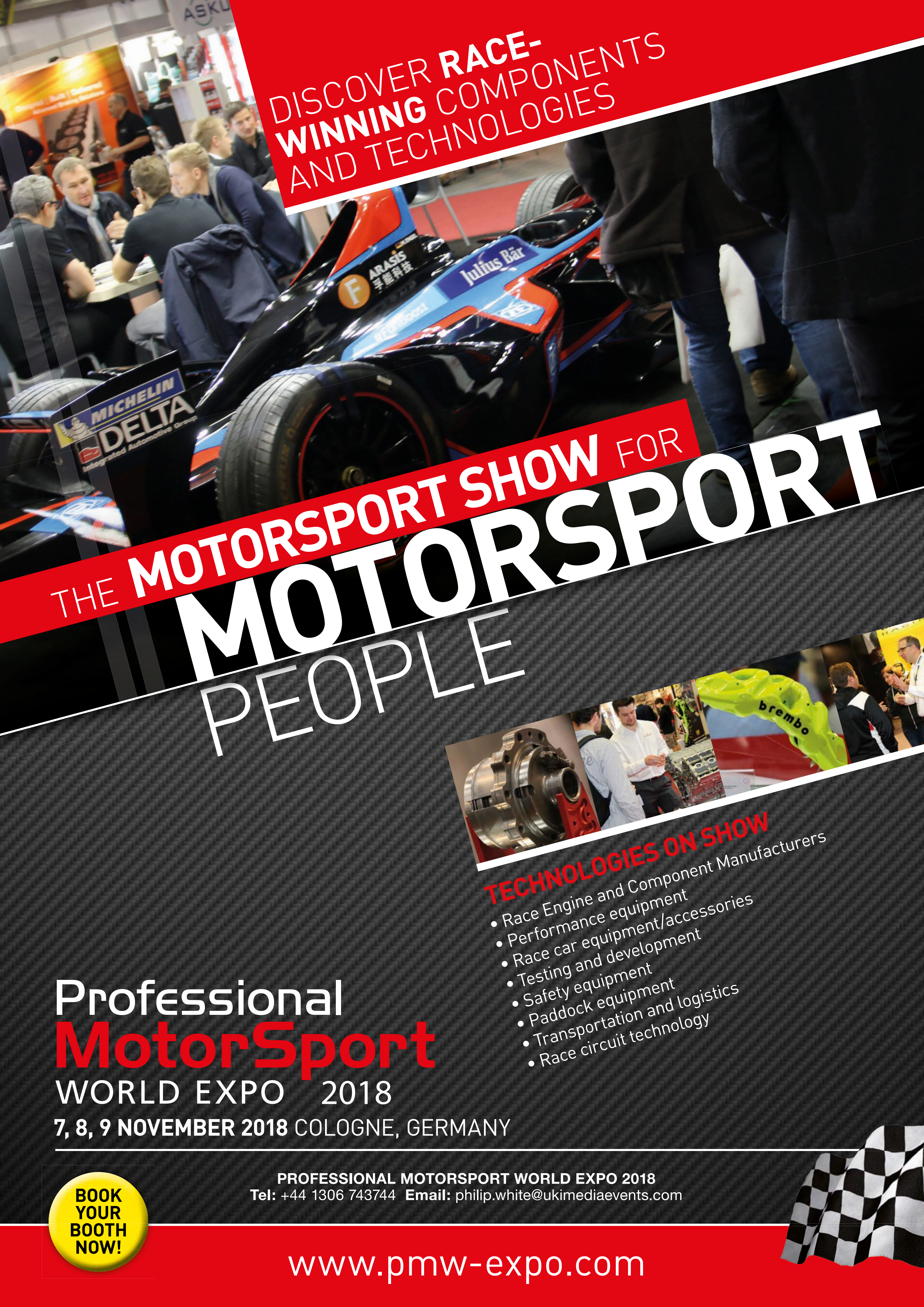

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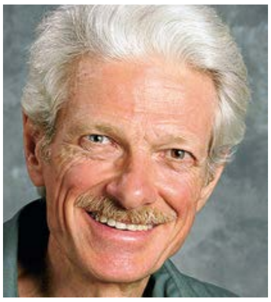

Busting the myths of damper location

Why you're freer than some think when it comes to placing shocks

QUESTION

I came across a post on the internet that tried to relate coilover mounting height to load transfer characteristics. I was wondering what your take is on this? It's called 'coilover location'.

'Rear coilover should be mounted at an angle between three and six degrees,' it said. 'If you can measure the max body roll, mount the shock so they are pushing straight up and down at this point. Coilovers can affect weight transfer if they are not mounted properly. [If] the top of the coilovers (this applies to springs as well) are mounted too high on the chassis they will hinder weight transfer.

'The top of the coilover should be mounted as close as possible or below the centre of gravity height (rear CGH ball park 10in to 12in),' it goes on. 'Most common is a 9in stroke shock and what we do not want is to run out of travel. Try to mount the bottom of the coilover as low as possible under the axle centreline. I think 7in is about the lowest you can go before you start to spark the asphalt.

'Don't forget, if you cut a tyre you don't want to screw up mounts and chance losing the mount for that race. This bottom mount location helps forward bite during acceleration. When you nail it off the turn, the weight is transferred from front to rear and is resisted by the coilover top mount. If you have the top mount higher than the centre of gravity height, the weight transfer loads the suspension links and not the coilover where it can assist forward bite. Same applies to coil springs.'

THE CONSULTANT

This is largely nonsense, except for the advice about making sure nothing drags if a tyre goes down. Provided a spring or damper doesn't serve as part of the suspension linkage, its location doesn't matter at all, except as it affects the effective rate at the contact patch: what force change corresponds to what vertical or *z* axis displacement change, where the rubber meets the road.

There is no simple relationship between this and the coilover height or location within the racecar. The coilover could be at the opposite corner of the racecar and operated through 20 rods and bell cranks. The tyre doesn't know. The actual force/displacement relationship is all that counts.

Total rearward load transfer under power is likewise unaffected. For a given total car mass and a given forward acceleration, rearward load transfer depends on only two things: overall cg height and wheelbase length – nothing else! The suspension can have a small effect on overall cg height by causing the car to lift a bit under power, but that's all.

Load distribution

However, the suspension can considerably influence the left/right distribution of the rearward load transfer: make more of it occur on one side of the car than the other. If one side has more overall pitch resistance than the other, it absorbs proportionally more of the longitudinal load transfer. That changes the dynamic diagonal percentage, and the dynamic rear percentage on each side of the car, but not the dynamic rear percentage for the whole car. This is directly analogous to the effect of front/rear roll resistance distribution upon lateral load transfer distribution.

Inclined bars and wedge

A plan to run sloping Panhard bars on US short oval cars raises some questions

QUESTION

I was wondering if you could help me on a jacking force question I had after reading one of your technical articles.

I prepare and drive asphalt Sprint Cars and Midgets, obviously with beam axles on the front and the rear. My current thought process is to have the front axle Panhard bar inclined with the right side low and the left side high with several inches of split in it.

The plan is also to offset the Panhard to the left of chassis centreline. In your technical features on asymmetrical racecars you talk about sloped Panhard bars and say that they can effect wedge. What I am wondering is, is all that I'm doing effectively de-wedging the car in steady state cornering? Is the same amount of total load transfer still happening from the two left side tyres to the two right side tyres? Or am I reducing some amount of the total load transfer through jacking force?

THE CONSULTANT

An upward jacking force at the left front corner does de-wedge the car, and it does not reduce total rightward load transfer. It reduces the geometric component of the load transfer. The elastic component increases to make up the difference. Assuming no changes to the springs or the rest of the racecar, that means the car rolls more. The springs accordingly deflect more and exert greater roll resisting forces. These necessarily act through the tyres and affect their loading.

An upward jacking force just at the left front reduces the geometric roll resistance and load transfer only at the front of the car. The increase in elastic load transfer occurs at both ends of the car, in proportion to their relative angular elastic roll stiffness.

Thus, the rear sees an increase in elastic load transfer and no change in geometric load transfer, for a net increase in load transfer. The front sees an equal decrease in load transfer. That's what de-wedges the racecar.

An upward jacking force at the left front corner does de-wedge the car

Does it make sense to run sloping front Panhard bars on US short oval asphalt racecars, as is shown here on a Midget?

So there is no magic reduction in load transfer from this sloped bar, but does it make sense to run with it anyway?

We can get the same wheel load distribution by other means, so the question really is whether we would like the front ride height to be a little higher in the turns than it would be with a level Panhard bar.

Generally, there is no ride height rule in Sprint Car or Midget racing. On pavement, we run the car as low as we can without having it bottom excessively in the turns. The turns are invariably banked, often steeply.

If the front jacks up a little with cornering force, that means we can run the front a little lower statically, and it will ride a little lower down the straights. That might confer a slight aerodynamic advantage. A coast-down test should reveal whether that's the case, without any need for a wind tunnel.

Roll playing with the Fiat 600

How could raising the front roll centre on a 1950s city car help with its handling?

QUESTION

Referring back to the discussion on snap oversteer and the Lagonda (V28N9 and others), recently I came across a copy of the 1957 *Proceedings of the Automobile Division of the Institution of Mechanical Engineers* which included a copy of a James Clayton lecture presented at the March 1957 General Meeting of the Automobile Division by D Giacosa, director of vehicle engineering at Fiat, entitled *Some Important Problems Concerning the Small Utility Car*. The car in question was the Fiat 600 which had a problem with oversteer during development. To overcome the oversteer problem, Fiat raised the front roll centre as far as possible along with moving the rear swing arm pivots as close to the car centreline as possible, and increased the roll stiffness of the front axle (using a transverse leaf spring). Also mentioned was the inclusion of some roll understeer in the front steering geometry.

My question is; wouldn't the high front roll centre move the problem to the front end of the car, resulting in serious understeer and also cause lateral thrust at the wheels under single wheel bump? Maybe the roll understeer geometry masked the lateral thrust by steering the wheel in the direction of the track change due to the high roll centre?

THE CONSULTANT

The Fiat 600 *had* a problem with oversteer, *after* development. In fact, every car with equal size front and rear tyres and the engine hung behind the rear axle has oversteer at the limit, even without swing axles. When the car is that tail-heavy, good cornering balance can only be achieved with larger tyres at the rear. However, the oversteer can be tamed a bit with appropriate suspension design and tuning.

I have seen race prepared Abarth versions of the 600 sedan that didn't have visible oversteer, but I'm pretty sure those had widened rear fenders and wider rear tyres. They definitely cornered on three wheels.

Roll reversal

I don't think the car actually has a high front roll centre. At normal ride height, the front control arms are pretty close to level and parallel. With any droop, the front view instant centre moves to the outboard side of the wheel. The roll centre is at or near the ground. There is very little front geometric roll resistance.

However, there's a lot of elastic roll resistance, thanks to the spring. Just using a transverse leaf spring wouldn't do that, but this one anchors to the floor pan at two widely spaced points, making it act considerably stiffer in roll than in ride or two-wheel heave. When the ends of the spring go up with respect to the sprung structure, the middle goes down, and vice versa, with the spring deforming in a U shape. When one end goes up and the other goes down, the middle of the spring stays in about the same place and the spring deforms in an S shape. In that mode, the rate at the ends is considerably higher. The result is a suspension that acts like it has an anti-roll bar, but has fewer pieces. In the 600, the spring serves as the lower control arms as well, completely unassisted by any additional struts or other members. Similar springs (not serving as control arms) have been used in Maseratis and Corvettes. In the latter used in conjunction with anti-roll bars. For an example of a rear-engined sedan that does have a high front roll centre, check out the Hillman Imp: swing axles in the front; trailing arms in the back.

The Fiat 600 rear suspension really does resemble that on the Lagonda; arguably a semi-trailing arm layout but it has front view instant centres approximately at the car centreline, like the Lagonda, making it behave like a swing axle system. The driveshafts have four joints (two each) and do not locate the wheels. However, Fiat took advantage of the fact that the outer joints have to accommodate only a small amount of angularity and plunge, and used a relatively inexpensive elastomeric coupling at that location. The Abarth-bodied coupes had a real semi-trailing arm layout with a longer front view swing arm length, which tamed the oversteer considerably.

CONTACT
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Ground zero: post ban F1 car in focus

Examining Tyrrell's response to the loss of ground effects in 1983

This month we start our new project on Tyrrell 012-5, a Formula 1 car from 1983, the first year after the FIA's ban on the ground effect sidepods; the fitting of which had seen cornering forces increase to what were deemed to be unacceptable levels.

Like the Brabham BT52 and one or two others on the grid in 1983, the Tyrrell's design basically abandoned sidepods altogether. It was as though the designers considered that it was now only worth using wings to generate downforce. Yet, as we shall see later in this new mini-series, even the small amount of floor at the rear of this car did make a downforce contribution, albeit a modest one. And as subsequent history shows, flat floors could be made to develop a great deal of downforce.

However, we're getting ahead of ourselves, so let's first take a tour of Tyrrell's initial response to this major rule change and look at the baseline numbers from the car's set-up following the 2018 Silverstone Classic.

The Tyrrell's aerodynamics are, by today's standards, disarmingly – some might say refreshingly – uncluttered, with a large chord single element, gently cambered front wing which has a Gurney, complemented by a thick section, heavily cambered three-element low aspect ratio rear wing, also sporting a Gurney. Sidepods as such do not exist; instead the water radiator and other coolers on the opposite flank are mounted in cowlings ahead of the rear tyres and the Cosworth DFV's exhaust headers. Simple scoop ducts help to cool the front and rear brakes, and the engine inhales through a flat air filter in the top of the vestigial engine cover. **Table 1** gives the usual coefficients from the baseline runs at 80mph in MIRA's full-scale wind tunnel.

The first impressions from these numbers were that drag was typically high, comparable to other F1 cars that we have had the pleasure of testing at MIRA; that downforce was pretty modest and at levels that must have pleased the FIA back in the day, considering their mission was to make drastic cuts in the downforce levels of the previous generation of cars; and thirdly that the downforce balance seemed very rear-biased, given that the car's static weight distribution with simulated driver's weight on-board was almost exactly 40 per cent front, 60 per cent rear. This rear-biased balance was possibly down in part to the fixed floor of the wind tunnel leading to an underestimate of front wing downforce, whereas the other main downforce generator, the rear wing, would be essentially unaffected by the fixed floor.

By way of comparison, back in 2007 we tested another 1983 car, an Arrows A6. We undertook to keep the coefficients on that car confidential, but they were close to those of the Tyrrell 012, with the drag being just a few per cent lower and total downforce in the Tyrrell's baseline trim being almost identical.

However, the Arrows' %front value was just under 41 per cent, with more front downforce and less rear downforce than the Tyrrell. As we progressed through the session on the Tyrrell the balance was progressively moved further forwards, and it will be interesting to hear back from the driver when he next competes in this racecar on whether this improved its behaviour and balance on track.

Winging the changes

With the adjustable part of the Tyrrell's aerodynamics being dominated by the rear wing, and drag being a concern at the previous event, time was initially focussed on adjusting flap angle, slot gap and removing the Gurney.

The effects of reducing rear flap angle (and hence, overall wing angle) are shown in

Table 1: The baseline coefficients on the Tyrrell 012

	CD	-CL	-CLfront	-CLrear	%front	-L/D
80mph	0.856	0.698	0.142	0.557	20.3%	0.815

Table 2: The effects of reducing rear wing flap angle (overall wing angle shown)

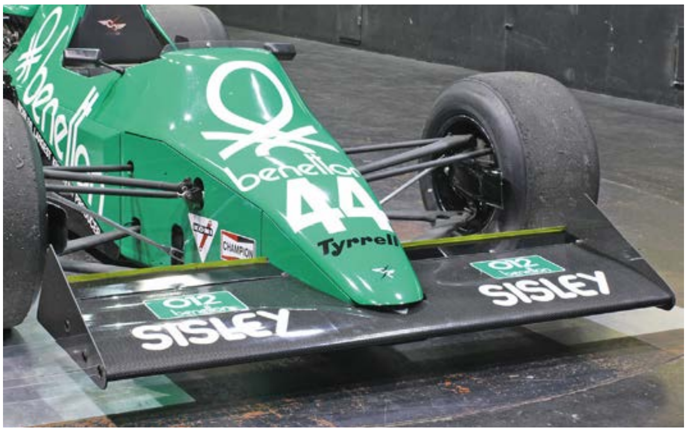
OA angle	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
24deg	0.856	0.698	0.142	0.557	20.3%	0.815
21deg	-32	-36	+10	-40	+2.4%	-2
18.7deg	-39	-36	+15	-50	+3.6%	-5

**Changes in %front are absolute, not relative*

Tyrrell's 012 was the team's answer to the banning of ground effect sidepods for 1983. It featured a simple wing package, no sidepods and minimal floor area. Note the trip strips fitted to the wheels to better simulate the flows when wheels rotate

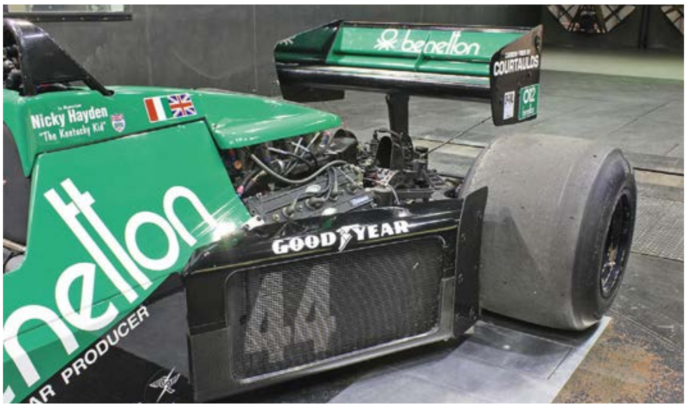
Downforce balance shifted forwards with each flap angle decrease

Note disrupted flow on centreline; one reason why low aspect ratio wings can be inefficient



The Tyrrell's front wing is remarkably simple in contrast to those on current F1 cars

The 012's rear wing features a thick main element as well as a pair of steeply inclined flaps



With no real sidepods the car's coolers were mounted in simple cowlings at the rear

Table 3: Effects of increasing rear wing main slot gap

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
+5mm slot gap	-12	-12	+4	-16	+1.1%	-3

Changes in %front are absolute, not relative

Table 4: Effects of removing Gurney at different wing angles

OA wing angle	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
23.2deg	-37	-37	+15	-51	+3.5%	-8
18.4deg	-40	-51	+20	-70	+6.0%	-26

Changes in %front are absolute, not relative

Table 2 as delta values (Δ) in counts, where one count is a coefficient change of 0.001.

The big changes were the reductions in drag and rear downforce, but of equal interest were that the downforce balance shifted modestly forwards with each flap angle decrease, and that there was only a very small change in the car's efficiency, as given by the –L/D value (downforce divided by drag).

Put the other way around, the downforce gains with increasing flap angle were not very efficient, and this is a typical response from a narrow aspect ratio, heavily cambered wing operating at the top end of its angle range. The small increases in downforce at the front end of the racecar as flap angle was reduced would have been down to the decrease in the rear wing's leverage behind the rear axle.

The gap between the rear wing main element and the flap (the slot gap) is known to alter wing performance; DRS systems in modern F1 is an extreme example. So what difference would a few millimetres of adjustment make?

The flap assembly trailing edge fixing was retained and the leading edge was raised to increase the slot gap from 10mm to 15mm, with the delta values shown in **Table 3**.

Even a 5mm slot gap increase produced a 12 count (1.5 per cent) decrease in drag but, because the flap angle reduced with this adjustment, rear downforce reduced (by 3.4 per cent). Had the flap angle been kept fixed and the whole flap been translated upwards by 5mm the results would have been somewhat different. But this might be a useful fine adjustment for a low downforce track.

Trailing edge Gurneys are also often used to squeeze more downforce from a wing and are particularly applicable when the racecar is running with a steep rear wing. We examined the effects of removing the 10mm Gurney at two different overall wing angles, with the results shown in **Table 4**.

The effect on drag was roughly similar at both wing angles, but the effects on downforce, balance and efficiency were more pronounced at the lower angle. Again, put the other way around, the gains from fitting the Gurney were more efficient at the lower angle, the wing itself becoming less efficient at steeper angles as we saw previously. Nevertheless, it always impresses how much difference a small section of right-angled aluminium can make.

Next month we will look at adjusting the Tyrrell's front wing angle.

Thanks to Martin Adams (the car's owner), Nigel Rees at GSD Racedyn and Martin Stretton and Russell Sheppard at Martin Stretton Racing

Trailing edge Gurneys are often used to squeeze more downforce from a wing

CONTACT

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

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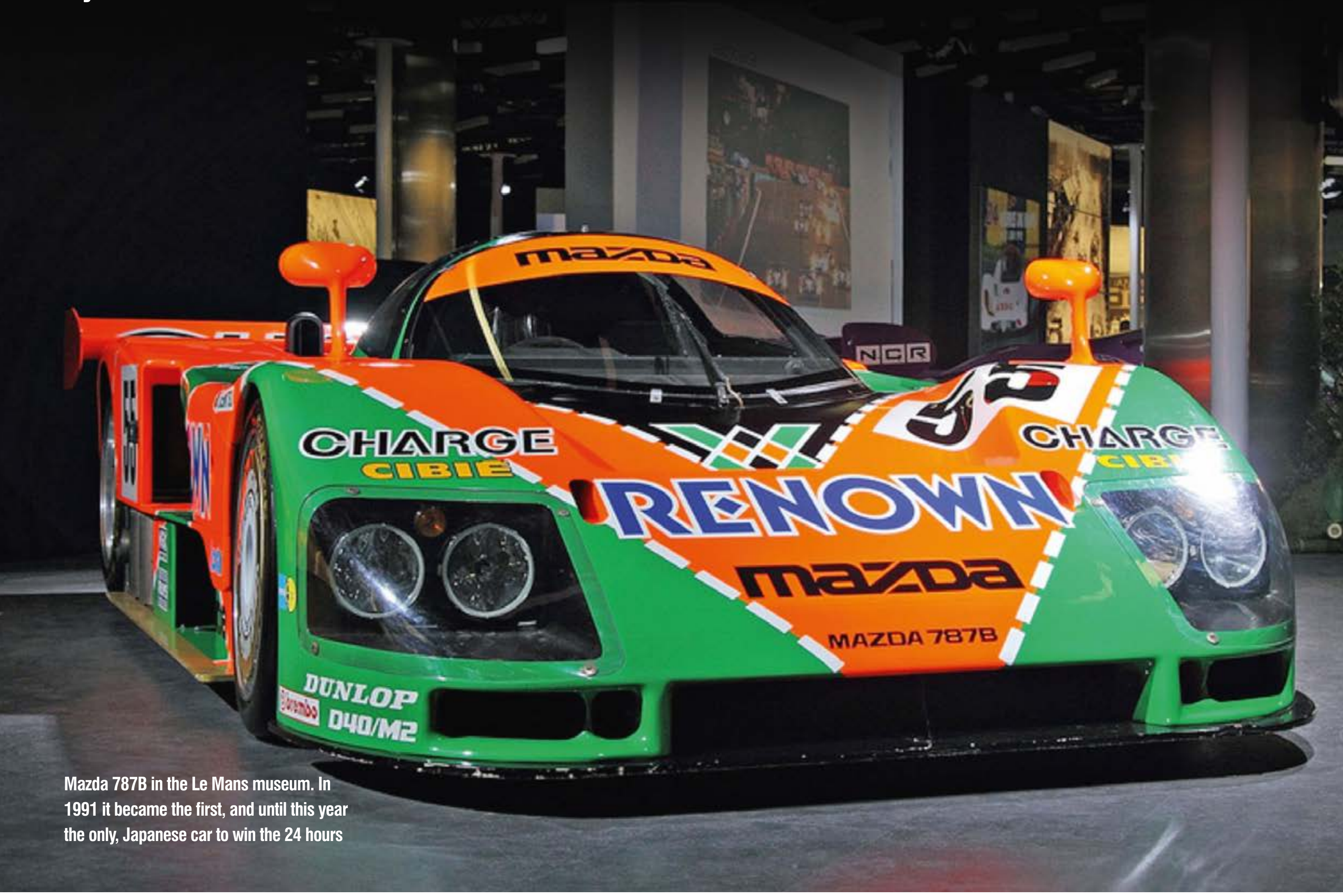
Send in the clones

How one man's determination to build a track and road-going replica of Mazda's 1991 Le Mans-winning 787B has provided some illuminating insights into Group C aerodynamics

By SIMON MCBEATH



Mazda 787B in the Le Mans museum. In 1991 it became the first, and until this year the only, Japanese car to win the 24 hours

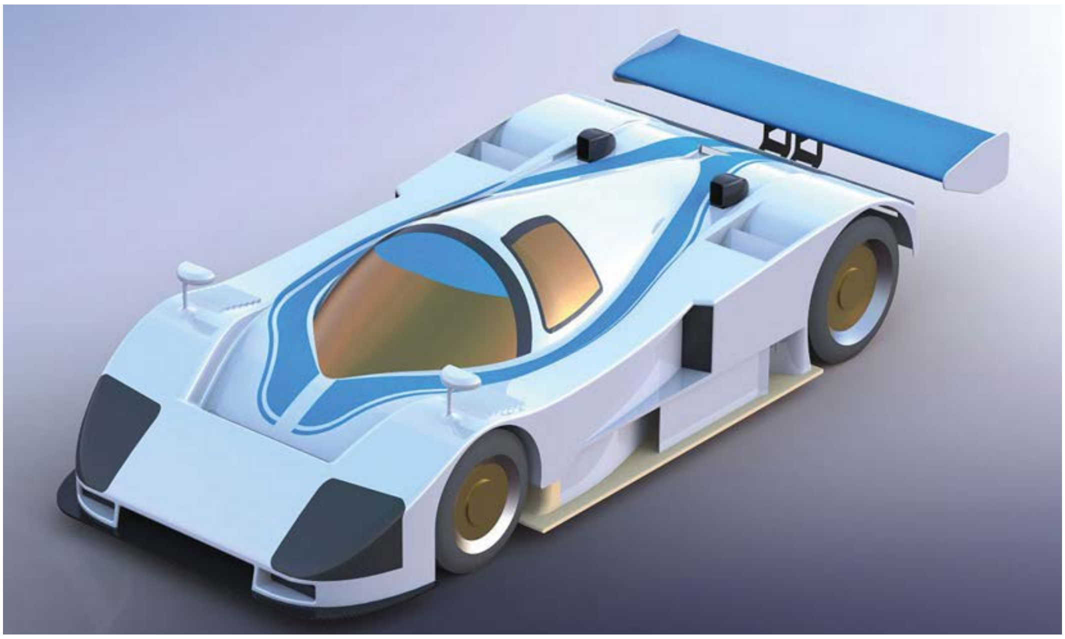
MARK PETERS

Until June 2018 the only Japanese manufacturer ever to win the Le Mans 24 hours was Mazda, with the wailing rotary engined Nigel Stroud designed 787B in 1991.

If not the quickest car in the entry that year, this car had good pace and, crucially, was reliable. With a cleverly negotiated weight break enabling reduced brake and tyre wear it was well-placed to take advantage of the lesser reliability of the front-running Mercedes C11, which retired three hours from the end, to take the coveted title of Le Mans winner.

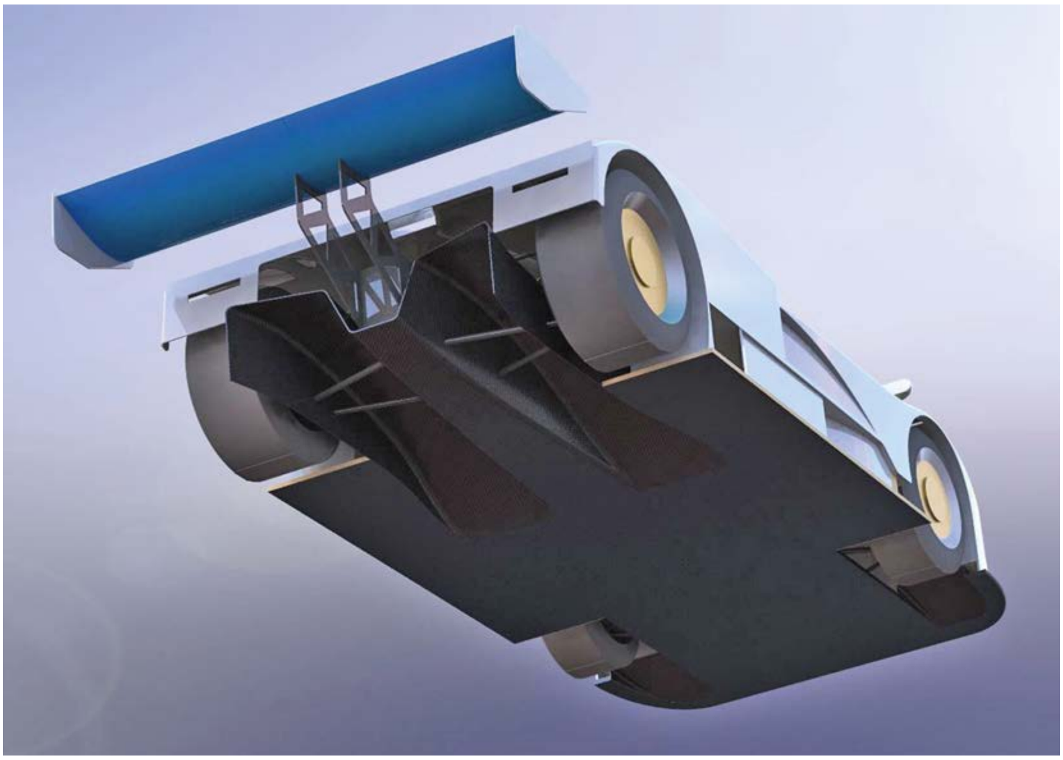
The occasion, and the car, lodged firmly in the memory of one sports prototype enthusiast who recently decided to recreate a replica of the Mazda 787B for road and track. But Mark Peters is not your average petrolhead. He determined that, although an engineer himself who runs a metal fabrication company making prestigious architectural components, he would need assistance to ensure that the whole project and all its individual aspects could be managed and implemented to the highest standards affordable. It's early days as this is written, but some hardware has already been purchased, such as the 3.5-litre V6 twin turbo Ford Eco-boost engine that will make for quieter and certainly torquier progress than a rotary engine. That said, currently most work is conceptual or validatory in nature as detail designs take shape. The chassis will probably be carbon composite, the transmission an Elite Racing Transmissions transaxle, and the suspension layout is being worked on in conjunction with the chassis design.

The external bodywork, however, will be based closely on that legendary Mazda 787B, which is where the connection with your writer began. Having worked with Peters on improving the aerodynamics of previous cars, the initial question on 'Project MP787B' was how to establish what the aerodynamics are doing and apply that to road and track versions? There were two options; guess, or create a 3D CAD model and do some CFD. As regular readers will know, it has been possible to do valuable CFD projects on reduced detail CAD models using the high quality software that Ansys UK provides to illustrate such projects



JAMES KMIECIAK

CAD rendering of Project MP787B's upper surfaces. The car is to be a full scale replica of the 1991 Mazda; MP stands for Mark Peters



JAMES KMIECIAK

CAD rendering of Project MP787B's lower surfaces. When it's finished it will pack a Ford 3.5-litre V6, rather than a screaming rotary

Table 1: Baseline aerodynamic data on Project MP787B

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.411	1.440	0.518	0.921	36.0%	3.504

in these pages. And the CAD work was already underway.

To recreate the Mazda's body panel moulds Peters had commissioned his friend Nasser Mushtaq to generate a 3D CAD model from scans of a high-fidelity scale model of the racecar. This produced a good quality surface model which was then refined into a 'watertight' CFD-friendly model by my colleague James Kmieciak at Black Art Customs. A single element rear wing was drawn by your writer, along with simplified wheels and suspension.

The overall model incorporated the major features as faithfully as the scale model and scores of photos of the original car in the Le Mans Museum (and elsewhere) allowed. One minor difference between CAD model and original reality was that to enable use of a half-car model to keep CFD solution times within reason, the cooling arrangements along the car's flanks were drawn symmetrical. This was not the case on the original racecar, but would be on MP787B, with twin intercoolers plus engine and gearbox oil coolers.

This provided the opportunity to illustrate Group C aerodynamics in a way that was unavailable in 1991. Numerical simulations of motorsport aerodynamics had barely begun then, and were certainly not widely accessible as they are now. Scale model wind tunnel testing was carried out (see box out) but the insights possible with CFD didn't appear until much later.

From the viewpoint of Project MP787B the model incorporated the major external and internal details necessary to capture the key aerodynamic flow features around the original racecar. This would enable an idea of the overall forces to help with initial estimates of suspension requirements, the generation of data trend and, importantly, the aerodynamic balance response to modifications.

CFD parameters

As usual the process started with determining a set of CFD parameters that produced acceptable quality solutions in a sensible time-frame. Let it be stated that, like your writer's previously published CFD studies, these are not high level simulations; the CAD model is necessarily simplified to enable the available computational resources to cope, although the Ansys software is obviously top drawer.

CFD runs were performed at 100mph air and ground speed with wheel rotational speeds to match, and the 'general purpose' k-epsilon turbulence model was invoked. Runs were done to a number of iterations that was deemed to generate satisfactorily stable force data.

The baseline run, in reference road car configuration, featured 80mm front and rear ride heights, with ride height and rake adjustments coming later. The data are given as coefficients calculated from the forces derived in CFD with frontal area measured from CAD at 1.793 square metres, see **Table 1**.

First findings

These first values showed relatively modest downforce compared to published data on comparable racecars, but rarely are ride heights quoted with published data, and 80mm was somewhat higher than would be run in track specification. In force terms, these coefficients represented around 900N (202lb) of drag and 3160N (709lb) of downforce at 100mph, which nevertheless would be a significant amount of downforce for a road car.

With a target static weight distribution of 40 per cent front, 60 per cent rear, our model's initial aerodynamic balance was in the

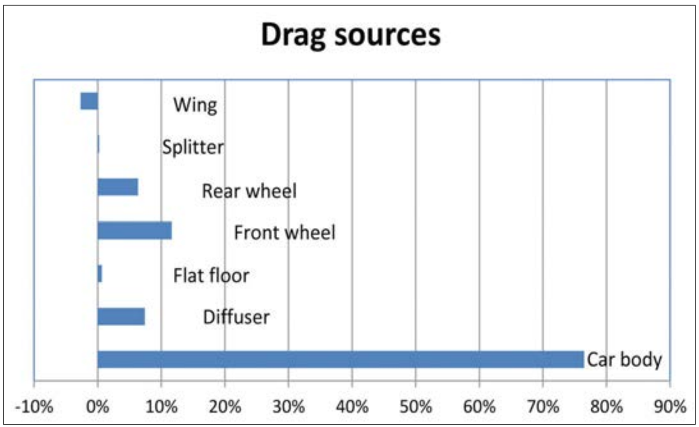


Figure 1: The sources of drag by major components; note the high number for car body

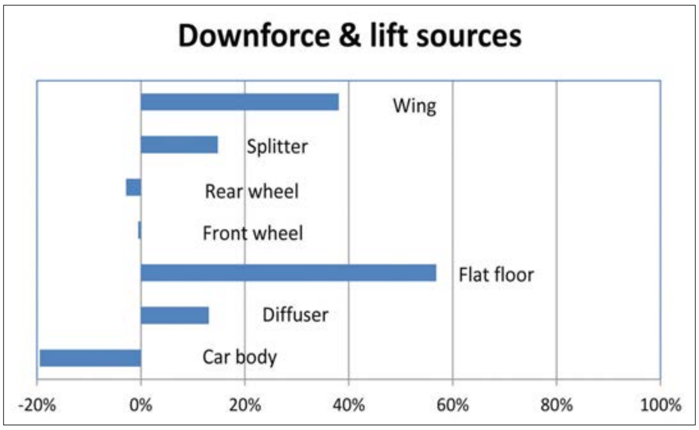


Figure 2: The sources of the downforce and lift; the car body also generated some lift

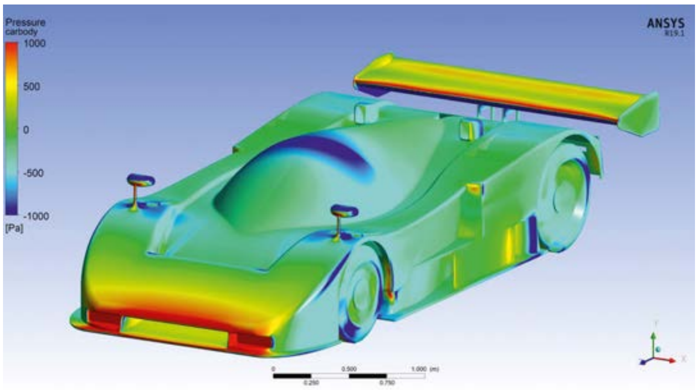


Figure 3: Surface pressure distributions; reds and yellows show the increased pressure

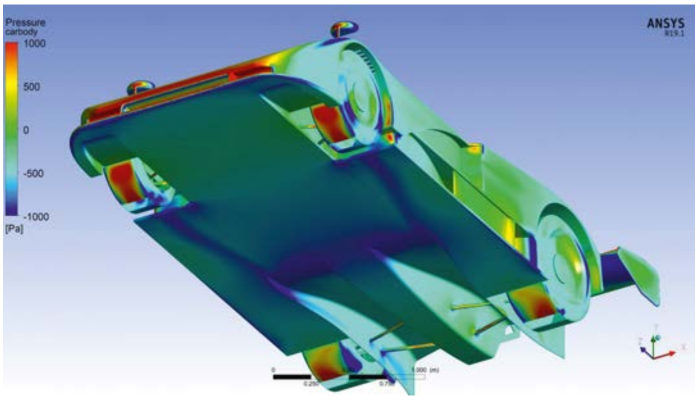


Figure 4: Pressure distributions on underside. Blue and green is decreased pressure

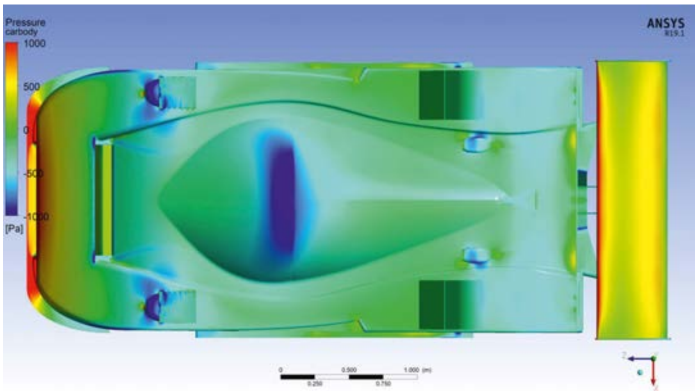


Figure 5: Top view shows where lift is generated over convex surfaces like wheel arches

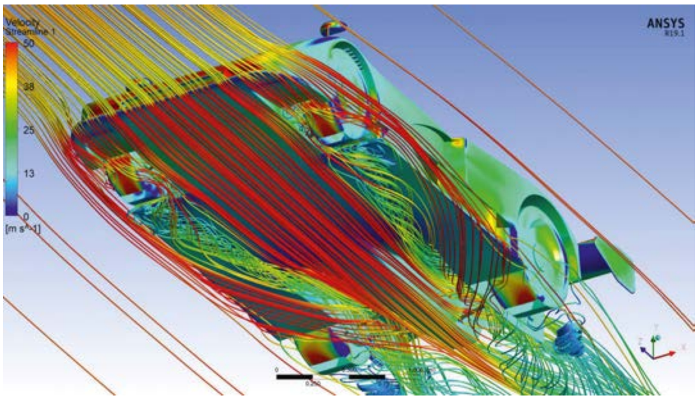


Figure 6: The streamlines show the 3D nature of the flows. Note the front wheel wakes

ballpark, and no attempt was made to refine balance yet. Instead a few changes were made to the underbody to explore the basic shape. These included increasing splitter length and adjusting tunnel width and length. Interestingly, we soon returned to the original baseline shape. Longer splitters increased %front but reduced total downforce, and none of the changes to the tunnel dimensions or shape brought improvements. So we concluded that the shape of the original underside was perfectly satisfactory!

Figures 1 and **2** show drag and downforce contributions of the major component groups. The car body generated over three quarters of the total drag, the wheels and the diffusers (tunnels) making most of the rest. The splitter and flat floor contributed little drag, while the rear wing appeared to defy the laws of physics by generating a few Newtons of 'anti-drag'! If only this were normally the case.

The static pressure distribution plots showed that the wing generated its suction peak well forward on its lower surface which, in this configuration and location, combined with the pressure field around the wing, produced a small forwards-acting force on the wing and, hence, 'negative drag'.

The downforce contributions in **Figure 2** show that as well as generating the most drag, the body also generated positive lift, as did the wheels, though to a much lesser extent. The biggest downforce contribution came from the flat floor, and then the wing, the splitter and the diffusers (tunnels).

Top and bottom

Figures 3 and **4** show the static pressure distributions over the model's upper and lower surfaces, reds and yellows indicating increased pressure, blues and greens showing decreased pressure. There were clearly areas of suction on the upper surfaces as well as the lower surfaces, the net result of which was negative lift, or downforce. There were also areas of increased pressure on the forward upper surfaces, generating drag and, on non-vertical surfaces, downforce as well. **Figure 5** highlights where lift was created over convex upper surfaces such as the wheel arches, the roof and the area ahead of the tail. A rear body Gurney was installed, as on the original car, and it increased the pressure just ahead of the central tail area.

Our model's initial aerodynamic balance was found to be in the ballpark

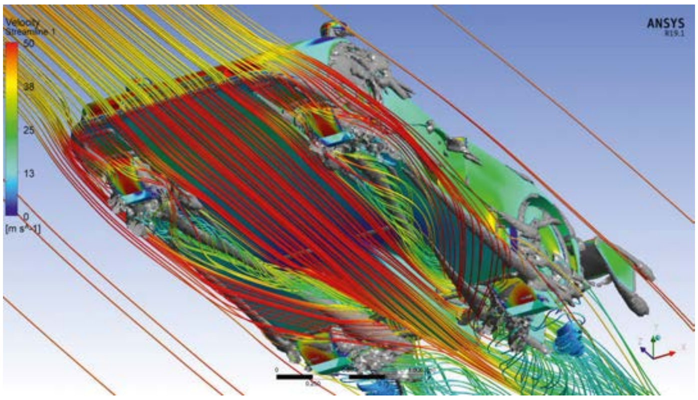


Figure 7: Superimposing the 'vortex core' feature highlights the vortices on underbody

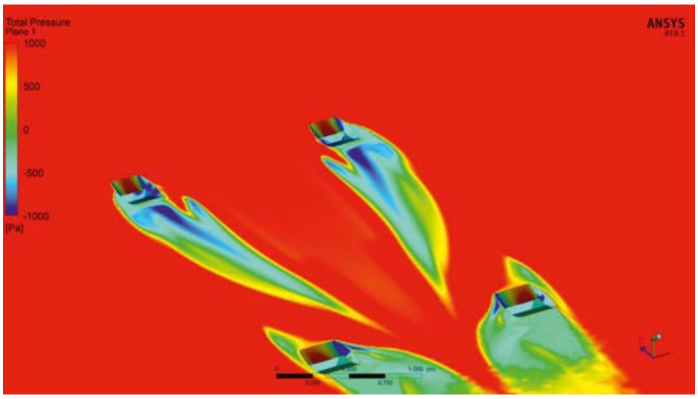


Figure 8: Plotting total pressure on a plane at 50mm above ground shows wheel wakes

Figure 9: Vortex cores can be seen in the front wheel wakes; note the inward flow here

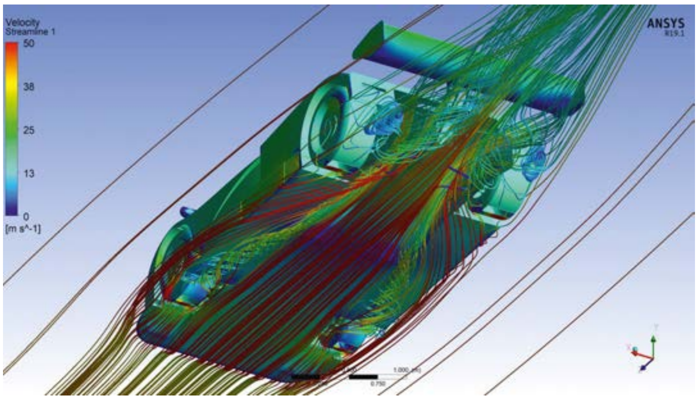


Figure 10: The inflow into the underbody along the car's sides is quite clear in this view

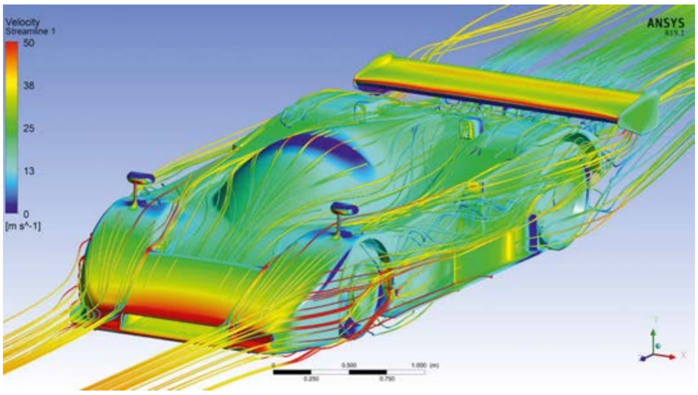


Figure 11: While the flow over the top of the car was tidy, it was less so along the sides

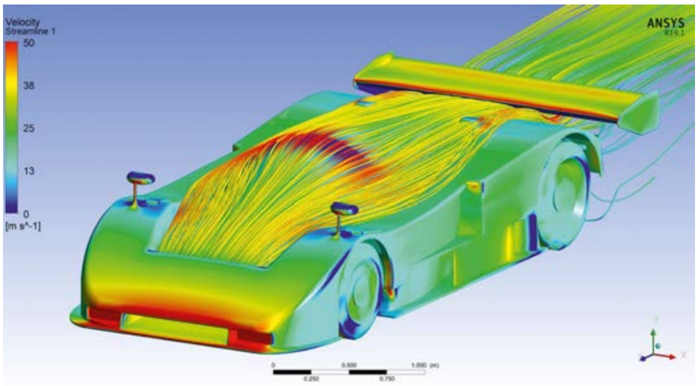


Figure 12: Streamlines from the car's radiator outlet impinged on the rear brake cooling

Figure 6 demonstrates that the flows under racecars, especially where suction is generated with shaped underbodies, are never simple. Streamlines projected on a plane 50mm above ground show that under the front the flow was initially relatively two-dimensional but, other than down the car's centreline, soon became more complex around, between and especially behind the front wheels and along the sides.

Among notable features is the low velocity vortex behind the front wheel that was drawn into the tunnel inlet. Notice also the fast flow that was drawn into the tunnels from the rear of the sides, which formed a potent vortex rotating in the opposite direction to the weakening one from behind the front wheel. **Figure 7** superimposes a visualisation feature that Ansys calls 'vortex cores' (here using the 'swirling strength' option) and the major vortices can be seen coinciding with the swirls in the streamlines and also the streamwise 'suction peaks' in the underbody, that is, the pronounced blue trails that are seen in **Figure 4**.

The biggest area of suction was at the flat floor to diffusers (tunnels) transition and across the floor ahead of the diffusers. However, significant downforce was also generated by the outer, rear part of the flat floor where fast flow was pulled in from the sides, which also created some 'vortex downforce' along the rear, outer edge.

Wheel wakes

Figure 8 shows total pressure on a plane 50mm above ground level. This illustrates where losses in the energy of the flow occur, shown by colours other than red, which here clearly highlights the wheel wakes as areas of reduced total pressure. This total pressure reduction in the front wheel wakes also caused the static pressure reduction shown by the streamwise blue trails highlighted above, while **Figure 9** shows the vortex cores behind the front wheels coinciding with the areas of reduced total pressure.

Figure 9 also highlights how the inwards flow along the sides ahead of the rear wheels brought freestream energy flow into the underbody again, in a sense refreshing the energy of the flow in the diffusers. Without that inwards flow from the sides, the flow through the underbody system as a whole would have been quite different, and fitting car-to-ground side skirts might be an interesting – if admittedly wholly academic – experiment.

Figure 10 shows the underside from the rear quarter, along with

A range of ride heights was evaluated, from 100mm down to 50mm

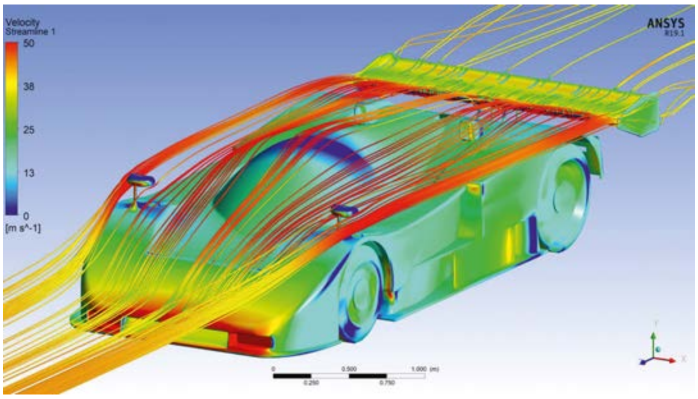


Figure 13: Rear wing received more or less freestream velocity flow despite low position

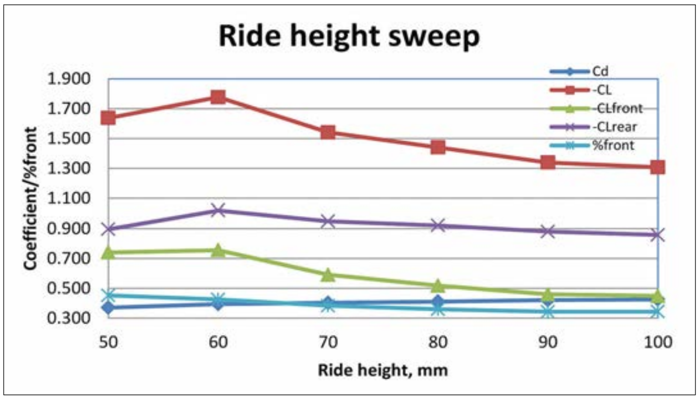


Figure 14: The effects of the ride height changes on the car's aerodynamic coefficients

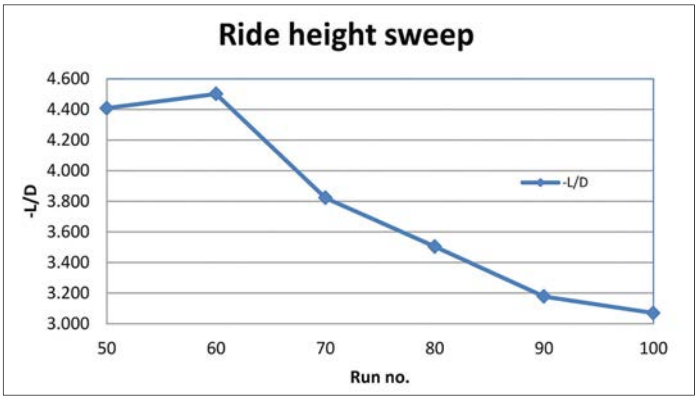


Figure 15: Ride height versus efficiency (-L/D). Drag reduced with each height reduction

Table 2: Ride height data (ride heights in mm)

FRH	RRH	CD	-CL	-CLf	-CLr	%front	-L/D	Df, N	Drag, N
50	50	0.371	1.637	0.741	0.896	45.3%	4.408	3592	815
60	60	0.395	1.777	0.756	1.021	42.5%	4.501	3900	866
70	70	0.403	1.541	0.591	0.950	38.3%	3.823	3382	885
80	80	0.411	1.440	0.518	0.921	36.0%	3.504	3159	902
90	90	0.421	1.339	0.460	0.880	34.3%	3.178	2939	925
100	100	0.426	1.307	0.449	0.858	34.4%	3.070	2868	934

Table 3: Trimming the balance with a wing angle increase

Wing	FRH	RRH	CD	-CL	-CLf	-CLr	%front	-L/D	Df, N	Drag, N
5deg	60	60	0.395	1.777	0.756	1.021	42.5%	4.501	3900	866
7.5deg	60	60	0.426	1.909	0.724	1.185	37.9%	4.478	4189	935

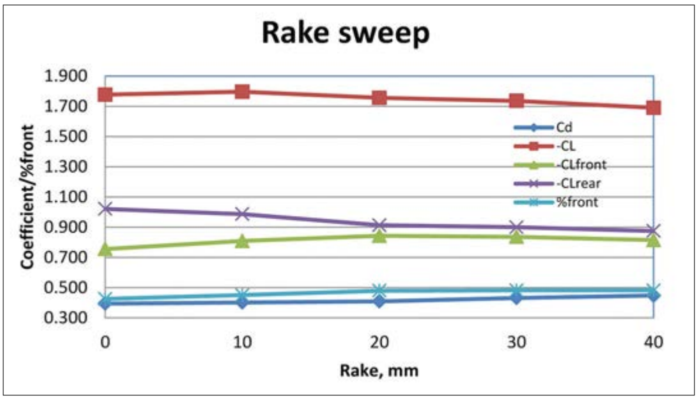


Figure 16: The rake at 60mm front ride height versus the car's aerodynamic coefficients

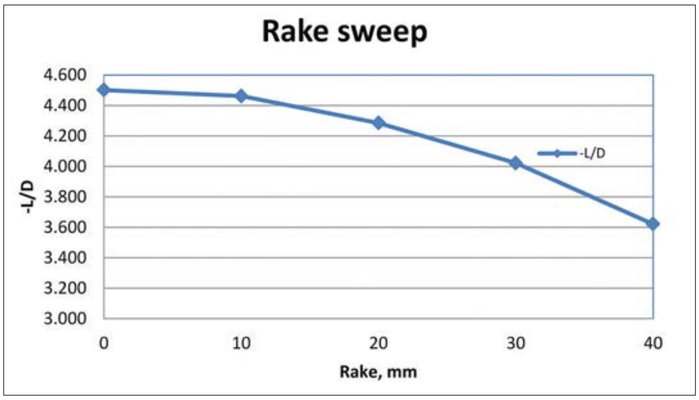


Figure 17: The rake at 60mm front ride height versus the aerodynamic efficiency (-L/D)

streamlines projected on a plane 50mm above ground, again highlighting the contribution of the fast flow that came inwards from the sides into the rear underbody.

Upper surfaces

Illustrating the general flows around and over the car's upper surfaces are **Figures 11** to **13**. **Figure 11** shows streamlines projected from the car body revealing the generally tidy nature of the flows over the top surface, although the flow from the front wheel wells and along the sides was more complex. While **Figure 12** shows streamlines projected from the radiator outlet and shows that some of this air entered the rear brake cooling ducts; doubtless it would have cooled significantly before it entered the brake ducts, but this is something that will be checked out during subsequent simulations. **Figure 13** shows the streamlines projected from the rear wing and illustrates the downwash that the wing induced, ensuring that despite its relatively low mounting height it received freestream or close to freestream velocity (44.7m/s = 100mph) flow across most of its span.

With downforce-induced suspension compression in mind, and with an eye to ride heights to be used on the race track, a range of ride heights was evaluated from 100mm down to 50mm. The aerodynamic coefficients and forces are shown in **Table 2** and the data are plotted in **Figures 14** and **15**.

There were clear trends among all parameters. Drag reduced with each ride height reduction, and this was in part because wheel drag reduced as the wheels were progressively enveloped by the lowered car. Total downforce increased until 60mm ride height, then decreased again at 50mm. Both front and rear downforce followed the same generic pattern as overall downforce, peaking at 60mm ride height.

However, because front downforce only reduced slightly at the lowest ride height, the aerodynamic balance (%front) moved forwards with every reduction in ride height. The drop in total downforce at the lowest ride height was sufficient to see efficiency (-L/D) also decrease at 50mm.

Optimal height

Taking all parameters into account, the optimal ride height for maximum downforce and efficiency appeared to be 60mm, although the balance was too far forwards in this guise. However, the car was increasingly sensitive to changes in ride height as the ride height was lowered. So from

The rake sweep produced different responses to the ride height sweep

It seems that increasing rake initially prompted increased acceleration of the airflow under the splitter but simultaneously starved the diffusers

Table 4: The effects of rake at 60mm front ride height (rake in mm)

Run no	Rake	CD	-CL	-CLf	-CLr	%front	-L/D	Df, N	Drag, N
1	0	0.395	1.777	0.756	1.021	42.5%	4.501	3900	866
2	10	0.402	1.796	0.809	0.987	45.1%	4.462	3941	883
3	20	0.410	1.756	0.843	0.913	48.0%	4.285	3853	899
4	30	0.432	1.736	0.836	0.900	48.2%	4.022	3809	947
5	40	0.448	1.690	0.815	0.875	48.2%	3.621	3708	983

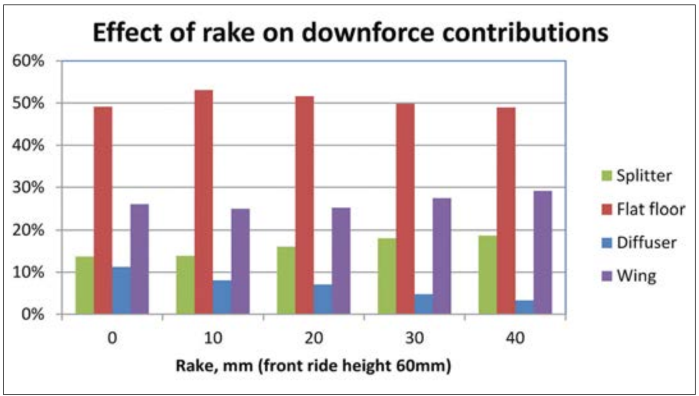


Figure 18: Contributions of main downforce producers with 60mm front ride height rake

the road car perspective, running at the higher end of this ride height range would reduce aerodynamic sensitivity to heave changes (as well as being practically more sensible). From the racecar perspective, good control of heave would obviously be required if the car was to run near its peak downforce height.

A further run was done at 60mm ride height with the rear wing angle increased from 5 to 7.5 degrees, and the results are shown in **Table 3**. Increasing the wing angle brought the balance into the desired ballpark, and clearly had other influences. Total downforce increased by 7.4 per cent but drag increased by 8.0 per cent, so –L/D decreased by 0.5 per cent. The wing's former 'anti-drag' had become a very small amount of actual drag! Furthermore, wing downforce increased by over 13 per cent, while diffuser downforce increased by 10 per cent and floor downforce increased by 13 per cent and its centre of pressure moved 100mm rearwards. So the wing angle change had fairly global effects.

Rake it in

A matrix of rakes was evaluated but for clarity and brevity we will look at a range of rakes with the front ride height, measured at the side running board just aft of the front wheel, fixed at 60mm. Thus, increasing rear ride height (measured at the rear of running board) had the effect of lowering the leading edge of the splitter, a fact to be borne in mind when analysing the rake data – in **Table 4** and plotted in **Figures 16** and **17**. Note that rear wing angle was back to five degrees.

The rake sweep produced somewhat different responses to the ride height sweep. Drag behaved similarly, increasing with each extra increment of rake. Total downforce, however, peaked at just 10mm of rake, while front downforce peaked with 20mm rake and rear downforce peaked at zero rake. Balance (%front) initially shifted significantly forwards over the first two increments but then levelled off, while efficiency (-L/D) was at its maximum at zero rake and declined more rapidly beyond 10mm rake.

Slight slope

The conclusion would be that at this front ride height, rake should be minimal and in any case no more than 10mm. **Figure 18** shows how the relative contributions of the primary downforce-generating component groups (ignoring lift-inducing components) varied with rake at 60mm front ride height. The splitter's proportionate contribution increased with each rake increase, though in force terms it actually peaked at 30mm rake. The flat floor's proportionate (and absolute) contribution peaked at 10mm of rake. The diffusers' contribution peaked at zero rake, while the wing's contribution was roughly constant until 30mm rake or more, and then it increased slightly.

Peckish diffusers

It seems that increasing the rake initially prompted increased acceleration of the airflow under the splitter but simultaneously and progressively starved the diffusers. And once at 20-30mm rake the decrease in mass flow under the splitter, which was getting ever closer to the ground, also saw reductions in the flat floor's contribution. Eventually, at the highest rakes, when the splitter was 40mm or less above the ground, splitter downforce levelled off and wing downforce increased, possibly in part because mass flow over the car had increased but also because the wing angle increased with rake.

There's more work to be done, including an upgrade to a high downforce package and we'll return to Project MP787B in future issues.

Racecar's thanks to Mark and Stephen Peters, and to James Kmieciak at Black Art Customs.

Nigel Stroud on the 787B

Now fully retired from motorsport, the Mazda 787B's designer Nigel Stroud spoke to *Racecar* (the day after competing at the other end of the speed spectrum, in a ploughing contest!) about the aerodynamic development of the 1991 Le Mans winner.

'We did lots of wind tunnel testing on a quarter scale model at MIRA [the scale model tunnel is now defunct] and we validated the forces and tyre deflections by logging ride heights on track with a Pi Research data acquisition system,' he says. 'We saw [the scale equivalent of] 4739lb of downforce at 943lb of drag at 200mph in one particular wind tunnel run before the race [equivalent to 5283N and 1051N at 100mph, -L/D = 5.03]. This was with the wing at 4.5 degrees and with a 2.5mm Gurney. We also measured the drag BHP and when we arrived at Le Mans we were asked how fast the car would go. I estimated the maximum speed would be 212mph, which proved to be spot on.'

Low downforce

Did the car run higher downforce settings at other venues? 'Remember that the whole purpose of the project for Mazda was Le Mans,' Stroud said. 'And the engine had less power and torque than the others. But we did have a different front under-panel. Rear wheel spats were effective but caused high brake temperatures. And we ran more rake and more rear wing Gurney, but we lacked the power to run [high drag] high downforce.

'The front suspension incorporated rising rate and anti-dive to control pitch without making the springs too stiff for the slower corners. And we ran the rear relatively soft so the car feathered off to zero rake at 200mph to reduce drag.

'Because the rear was soft we tested the wind tunnel model at 10mm nose up to ensure the car wasn't going to flip if the rear came down low after a bump, I was always worried about that [eight years before the Mercedes CLRs actually did flip].'

The maximum downforce figure achieved in our CFD runs to date was 4441N at 100mph, with 856N drag (-L/D = 5.19). Nigel Stroud remarked that 'your CFD model is somewhat simplified so I'm quite surprised that your forces are not so different from the wind tunnel figures.'

We hope to bring more input from the designer in subsequent phases of this project in future issues.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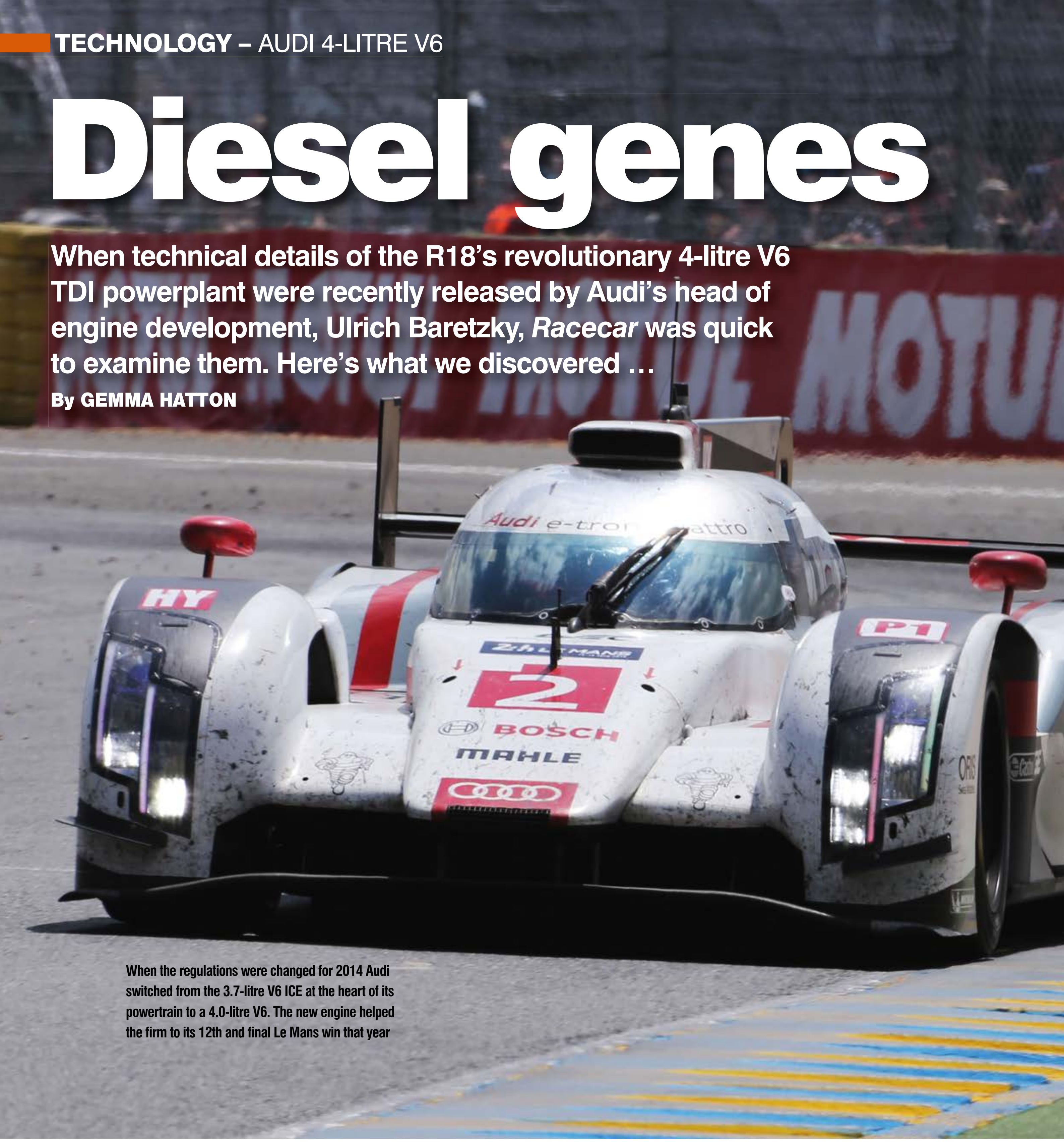
Diesel genes

When technical details of the R18's revolutionary 4-litre V6 TDI powerplant were recently released by Audi's head of engine development, Ulrich Baretzky, *Racecar* was quick to examine them. Here's what we discovered …

By GEMMA HATTON



When the regulations were changed for 2014 Audi switched from the 3.7-litre V6 ICE at the heart of its powertrain to a 4.0-litre V6. The new engine helped the firm to its 12th and final Le Mans win that year

A marque that will forever hold a special place in the history of Le Mans is Audi. At the start of this century, with its R8 prototype, it dominated. It then went on to change the face of the race, too, when in 2006 it arrived with its revolutionary R10, featuring a 5.5-litre V12 TDI diesel engine – the first diesel powered racecar to win the 24 hour race.

The R10 went on to win Le Mans the following two years and in 2009 was superseded by the R15, which ran a 5.5-litre V10 TDI engine, winning in 2010. In 2011, the regulations changed dramatically, introducing hybridisation, forbidding open cockpits and reducing the engine displacement down to 3.7-litre. Audi responded with the R18, which took on several forms from 2011 to 2014, and this car scored the historic first victory for a diesel-hybrid racecar at the race.

But Audi's expertise in integrating its pioneering diesel combustion technology into a hybrid powertrain arguably faced its biggest challenge in 2014, when the regulations shifted towards restricting the amount of total energy a car could use per lap. Prior to 2014, equating the performance of all the various engine and powertrain concepts was achieved through restricting the air quantity into the engine and therefore limiting maximum power. Maximum torque was also controlled through regulating engine displacement and boost pressure for the turbocharged configurations.

Get rich quick

Naturally, all this led manufacturers to develop engines that exploited the energy potential of every molecule of air, which resulted in running very rich air to fuel mixtures. This is

Audi arguably faced its biggest challenge in 2014, when the regulations shifted towards restricting the amount of total energy a car could use per lap

where the air to fuel ratio (AFR) contains less air than the stoichiometric AFR. In other words, there is not enough air to completely burn all of the fuel and although this can generate high amounts of power, it is inefficient and leads to increased fuel consumption and carbon monoxide emissions. Therefore, to align racing with modern road car developments, the new 2014 regulations aimed to prioritise powertrain efficiency rather than performance and, to achieve parity across the grid, this had to be done through energy restrictions which were controlled in three main ways: 1) Maximum

Table 1: The energy restrictions that govern Formula 1 and WEC compared using data from 2016

	Formula 1	Le Mans / WEC
Electric	**Released MGU-K energy:** Max 4MJ /lap from ES to MGU-K Unlimited/lap from MGU-H to MGU-K	**Released MGU-K energy:** Max 2-8 MJ/lap from ES and MGU-H to MGU-K (dependent on hybrid class)
Fuel	**Released fuel energy:** Unlimited/lap	**Released fuel energy:** Gasoline: 136-125 MJ/lap Diesel: 130-117 MJ/lap (dependent on hybrid class)
	Tank size: 100kg of fuel for the race	**Tank size:** Gasoline: 50kg of fuel for one stint Diesel: 40kg of fuel for one stint
	Max fuel flow: 100kg/h	**Max fuel flow:** Gasoline: 88-81kg/h Diesel: 76-69kg/h (dependent on hybrid class)

Table 2: The EoT table from the 2016 season including the fuel (FTF) and weight (KTF) correction factor

ERS OPTIONS LE MANS			
<2	<4	<6	<8

LE MANS *length=* *13,629 km*

		No ERS	ERS OPTIONS			
			<2	<4	<6	<8
Released Energy	MJ/Lap	0	<2	<4	<6	<8
Maximum Released Power	kW	0	300	300	300	300
Car Mass (2)	kg	858	878	878	878	878
Petrol Energy	MJ/Lap	204,4	136,3	131,7	127,2	124,9
Max Petrol Flow	kg/h	110,0	87,9	85,0	82,0	80,6
Petrol capacity carried on-board	l	75.0 (1)	62.5 (1)	62.5 (1)	62.5 (1)	62.5 (1)
Fuel technology Factor Average	-	1,069	1,069	1,069	1,069	1,069
Fuel technology Factor Pmax	-	1,066	1,066	1,066	1,066	1,066
K Technology Factor	-	1	0,981	0,980	0,979	1
Diesel Energy	MJ/Lap	-	130,0	125,8	121,6	116,9
Max Diesel Flow	kg/h	-	76,3	73,8	71,4	68,6
Diesel capacity carried on-board	l	-	49.9 (1)	49.9 (1)	49.9 (1)	49.9 (1)

$$FTF = \frac{BSFC_G \cdot LHV_G}{BSFC_D \cdot LHV_D} = \frac{\eta_D}{\eta_G} \quad FTF_{max} = \frac{BSFC_{G,@Pmax} \cdot LHV_G}{BSFC_{D,@Pmax} \cdot LHV_D} \quad FTF_{Av} = \frac{BSFC_{G,Av} \cdot LHV_G}{BSFC_{D,Av} \cdot LHV_D} \quad KTF = \frac{E_G/FTF}{E_G/FTF + E_{Add}}$$

LHV = Lower Heating Value, BSFC = Break Specific Fuel Consumption, D = Diesel, G = Gasoline, E = Energy

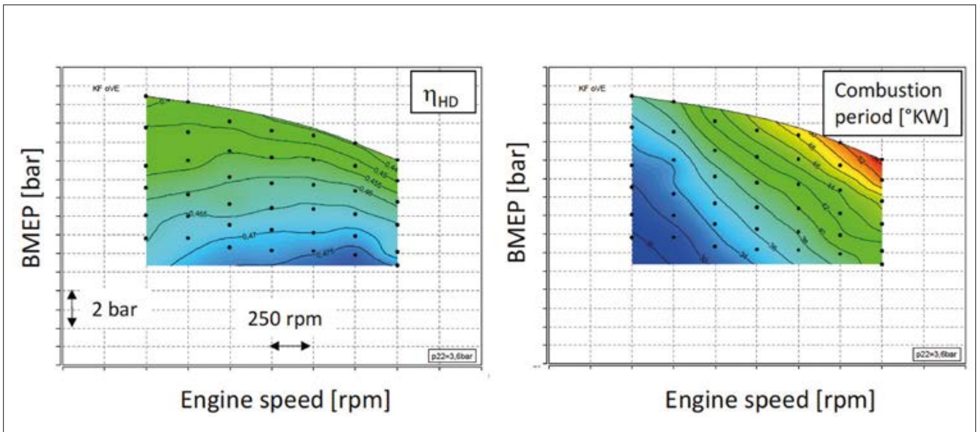


Figure 1: Typical map of 2013 unit. Left shows indicated combustion efficiency; right shows the period in the engine map

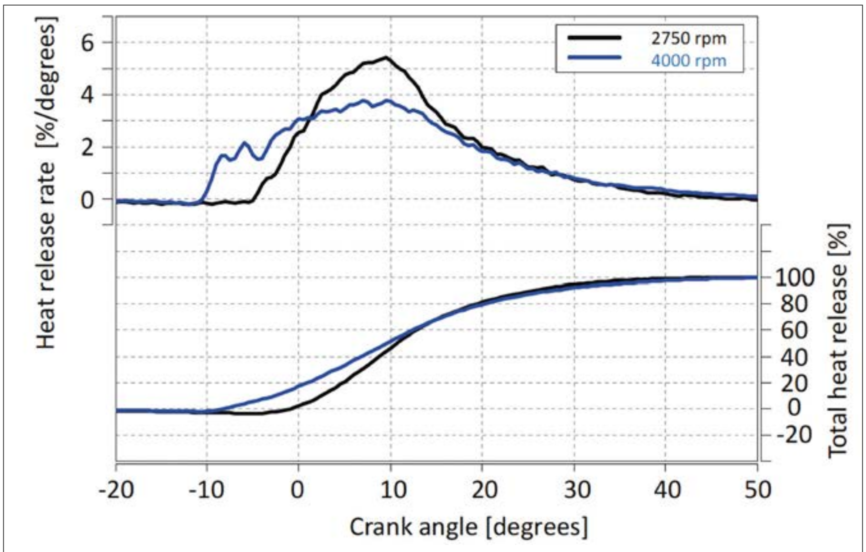


Figure 2: Heat release rate comparison between 2750rpm and 4000rpm. This shows optimum crank angle for maximum efficiency is 50 degrees which equates to 50 per cent mass fraction burned point of the combustion

total energy per lap from the fuel and hybrid system combined. 2) Fuel tank capacity. 3) Maximum fuel flow rate.

Firstly, the total energy from the fuel and hybrid systems combined was restricted to a maximum value per lap so the more electrical energy a team used, the less fuel energy it was allowed. To quantify the amount of electrical energy, the LMP1 manufacturers had a choice of four different hybrid systems, which were categorised by the amount of megajoules of electrical energy each system could deliver throughout the duration of one lap.

Therefore, a team could choose either a 2, 4, 6 or 8MJ hybrid system. To promote the development of hybrid technology, Appendix B of the regulations, or the Equivalence of Technology (EoT), also included an 'ERS incentive' which aimed to give teams a theoretical gain of 0.5s per lap per additional MJ of hybrid energy. For example, a team which chose a 6MJ system would go 1s faster per lap than if it had selected a 4MJ system.

Tank battle

Secondly, the fuel tank capacity was restricted and this together with the maximum fuel energy allowed per lap defined the number of laps in a stint. This meant that cars within the same hybrid class should be capable of achieving the same number of maximum laps per stint. However, because cars with a higher MJ hybrid system gained a disproportionately larger fuel tank, they could run one to two laps longer per stint compared to those racing with the lower MJ hybrid systems. Due to the weight of Audi's diesel it was not possible for it to compete in the same hybrid class as its competitors and so it raced in the lower 2MJ/lap category. Therefore, this led to the rather bizarre situation where despite the lower fuel consumption of diesel, Audi had to stop to refuel earlier than the petrol cars.

Third and finally, the regulated maximum fuel rate; which led to the adoption of fuel flow meters. Similar to those used in F1, fuel flow meters use ultrasonic pulses which are measured by piezoelectric transducers to determine the velocity of the flow and therefore the fuel flow rate. The precision, stability and speed of the measurement device throughout a race quickly became a critical factor.

EoT factors

In addition to the three main energy restrictions defined above, further factors were applied in the EoT. These included a Fuel Technology Factor (FTF) and a K Technology Factor (KTF) which accounted for the consumption and efficiency advantages of Audi's diesel as well as its weight disadvantage respectively, compared to the other gasoline powered competitors.

Big gains were found in the injection strategy and mixture generation

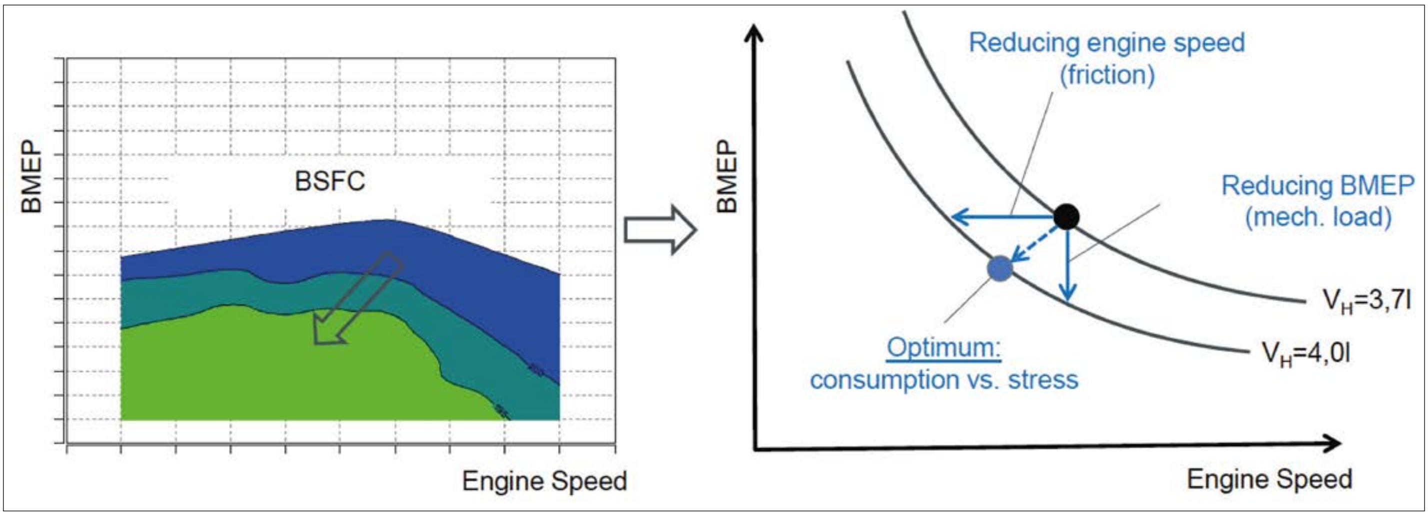


Figure 3: The increase in displacement from 3.7 to 4.0 was chosen on the basis that it not only improved fuel consumption for the same power but also reduced mechanical loads

Further details of the EoT are in **Table 2**. The FIA adjusted this EoT table each season to correct for the increase in track performance as each car continued to develop and to further promote the use of larger hybrid systems.

The R18 powertrain

Audi's R18 E-tron Quattro contender for 2014 featured a brand new 4-litre V6 TDI engine, while its hybrid system initially consisted of two elements. Firstly, there was an MGU-K on the front axle, recovering braking energy which was then stored via a flywheel. This effectively gave the R18 four-wheel drive, as the MGU-K drove the front wheels, while the IC engine delivered power to the rear. Secondly, the R18 originally included an F1 style MGU-H to recover energy through the exhaust gases, although this was later dropped before the start of the season due to the associated weight implications. Audi's calculations showed that the most efficient architecture for its turbo diesel was to remove the MGU-H and move down to the lower hybrid class of 2MJ/lap, rather than racing in the 4MJ/lap class and consequently having to manage the additional weight of the MGU-H. Therefore, the R18 arrived at the first race in Sebring with a revised MGU-K only (see box out).

Power point

So how did the philosophies underpinning these new 'efficiency' regulations drive the design choices of Audi's R18 powertrain? Luckily for us, Ulrich Baretzky, head of engine development for Audi Sport, revealed all at this year's International Vienna Motor Symposium.

As is the case with any new design, data from the previous iteration is analysed to determine areas of improvement. Although with the 2014 regulations so different from those of 2013, Audi first had to replicate the performance of its 2013 3.7-litre V6 TDI engine under these new constraints. The results identified that to develop a highly efficient diesel combustion process under the 2014 rules, Audi had to consider the following requirements: an extremely lean combustion process; maximum efficiency through thermodynamics, charge exchange, friction and cooling; minimising weight; future energy reductions; mechanical load limits; and displacement *vs* complexity of the turbocharged system, including boost level and response characteristics.

One of the fundamental benefits of diesel is improved fuel consumption and so the factors that affect this, as well as the efficiency, needed to be defined and understood. The engine's overall efficiency is a combination of the combustion efficiency, charge exchange efficiency and friction efficiency.

Valuable data

Considering the data from the 2013 engine, **Figure 1** illustrates a typical map of the combustion efficiency *vs* load and engine rpm. The contours in the left graph highlight that the maximum efficiency this engine could achieve throughout the entire rev range was 47.5 per cent. The graph on the right shows that the efficiency continually decreases from 31bar onwards, which is due to the reduced combustion lambda as engine load increases.

The heat release rate and the total heat release throughout combustion is shown in **Figure 2** and from this we can deduce that maximum efficiency is achieved at 50-degree crank angle, or 50 per cent mass fraction burned (MFB) on the point of the combustion. To expand this load range whilst maintaining the highest efficiency at 50 per cent MFB, the peak pressure needed to be increased.

New targets

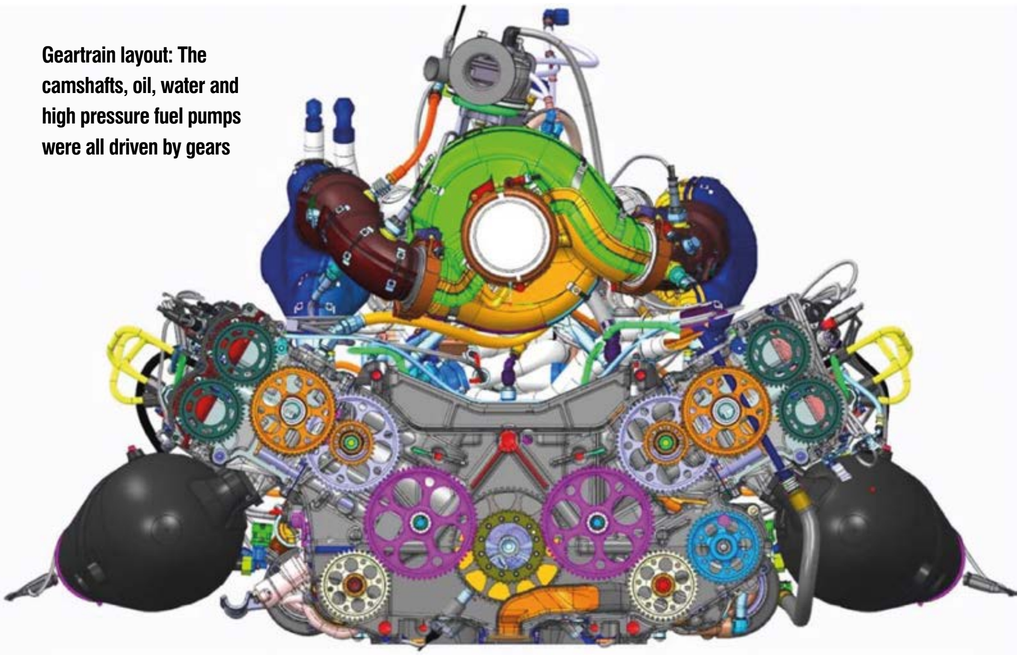
Overall this analysis determined a few potential avenues to improve performance. Firstly, for enhanced fuel consumption, the combustion period needed to be reduced throughout the entire map. Secondly, to ensure high specific power whilst maintaining high efficiency, the boost level needed to be increased. By increasing the flow of air into the engine, the AFR or lambda increases, resulting in an extremely lean combustion process at high loads and therefore an improved efficiency. ↳

Fuel flow meters

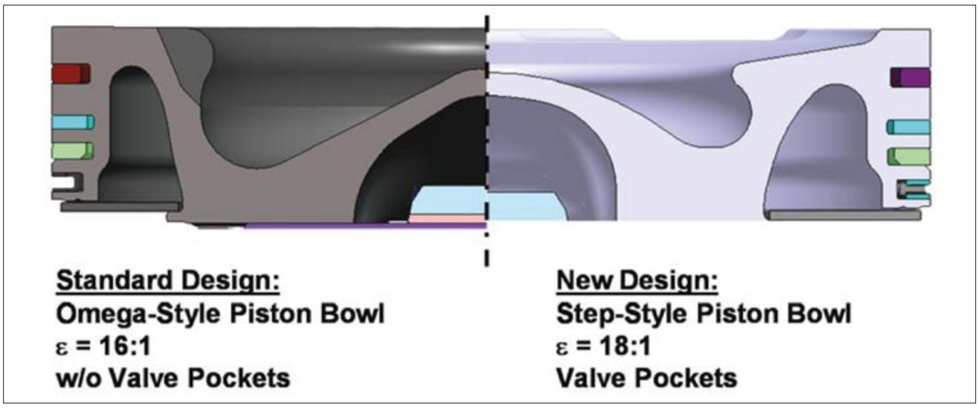
The introduction of fuel flow meters caused further headaches for Audi. The way the regulations were written meant that the maximum fuel flow rate during one lap restricted the engine output while the integration of this flow during one lap restricted the amount of fuel energy. Therefore, two fuel flow meters, a supply and return, were fitted within the fuel supply line to the engine to achieve better comparability, where the device measuring the highest value became the benchmark. So any drifting values or offsets were easily identified and could then be changed during a pit stop, if necessary.

One of the differences between a diesel and gasoline engine is that a large proportion of the diesel that flows into the engine, including the amount required for cooling and lubrication of the fuel pump, flows back to the fuel tank hot. This fuel temperature increase in the engine feed line exceeded the limits of the fuel flow meter, which led to inaccurate measurements. Therefore, a third fuel flow meter had to be installed within the fuel return line to establish the fuel mass that was actually injected.

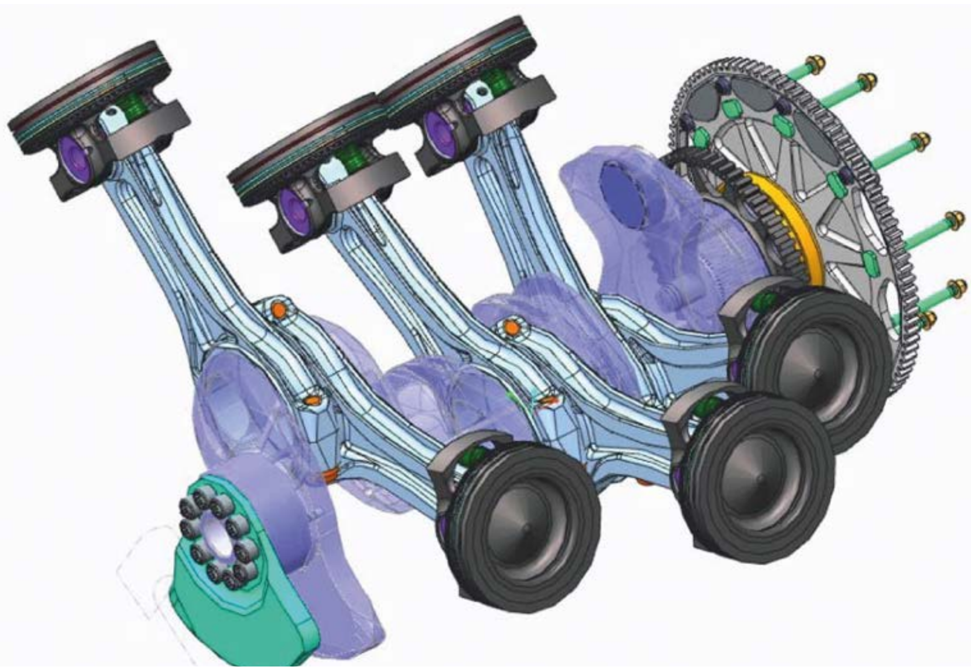
For enhanced fuel consumption the combustion period had to be reduced throughout the entire map



Geartrain layout: The camshafts, oil, water and high pressure fuel pumps were all driven by gears



Cross section of the piston head showing development of piston bowl profile from the original (left) to new iteration (right)



Engine architecture showing crankshaft and connecting rods. The location of the piston bowl (designed to ensure that fuel reaches the outer reaches of the combustion chamber) can be clearly seen along with other design elements of the piston

Other areas of development included the single stage turbocharger (Mono-VTG), where further analysis discovered that the radial compressor could not operate constantly in the optimum efficiency range and therefore a further improvement in turbocharger efficiency had to be developed too. Frictional losses are also a major factor on engine efficiency. After a series of tests, unsurprisingly, it was proven that the friction of the reciprocating piston accounted for the largest percentage of frictional losses. Furthermore, this amount of power loss increases with engine rpm due to the piston reciprocating faster and so this also needed to be optimised.

Stepping up

But arguably the biggest design change for Audi in 2014 was the increase in engine displacement. By simulating the potential performance of the 2013 3.7-litre V6 engine under the 2014 rules, it was found that a 4-litre engine was the best compromise. This not only allowed the reduction in revs to reduce fuel consumption, but the decreased effective mean pressure also reduced the mechanical loads, despite achieving the same amount of engine power. This is illustrated in **Figure 3**.

Following on from the results of the 2013 V6 engine simulations, Audi focused its development on four main areas to improve its 'efficiency lean burn combustion process'. These were specified as the fuel system, piston design, airbox and camshaft timing.

An 'efficient combustion process' can be defined as one which maximises the amount of energy from the air and fuel mixture whilst achieving minimal losses. Unlike gasoline engines, diesels do not use spark plugs. Instead, combustion relies on compressing the air during the compression stroke, raising its temperature, and this together with effective atomisation of the fuel ignites the mixture. Furthermore, the mixing phase only occurs during the compression stroke, whereas in most gasoline engines the air and fuel is premixed, apart from those which run direct injection which Audi pioneered in roadcars. Therefore, the biggest gains in a diesel is to optimise the injection strategy and mixture generation.

The right mix

The aim of the injectors is to spray the fuel droplets into the combustion chamber. Unlike gasoline engines which generate homogenous mixtures, in a diesel the droplets of fuel begin to burn when the temperature is high enough. Therefore, ignition is unviersal throughout the mixture and a high reaction rate is desired. To achieve this, the injector's hydraulic flow

The Audi R18 was effectively four-wheel drive, as the MGU-K drove the front wheels while the IC engine delivered power to the rear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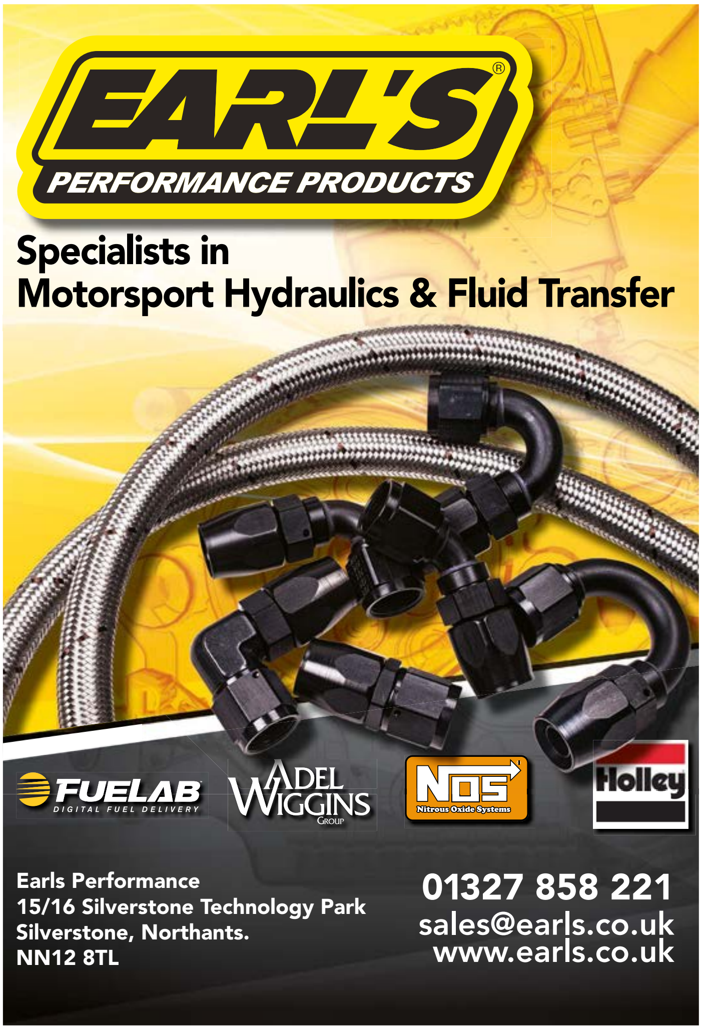
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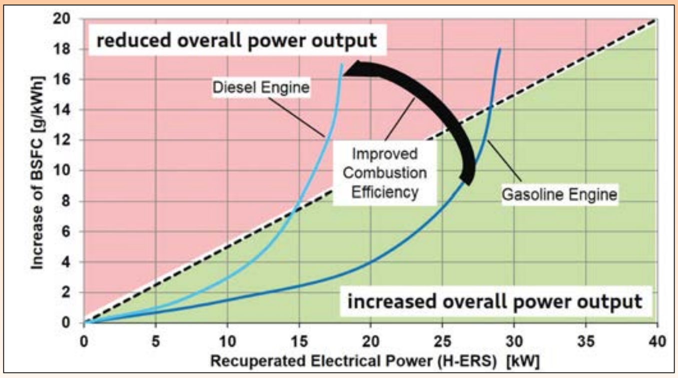
MGU-H

Harvesting electrical energy through recovering heat from the exhaust gases entered motorsport via F1 in 2014 when the V6 era commenced. Originally, Audi launched its 2014 R18 E-tron Quattro with its very own MGU-H. This unit was integrated into the turbocharger bearing housing and, in principle, the energy from the exhaust gases spin the turbine, which in turn spins the compressor. This generates electricity via a motor which is then stored in the flywheel in a similar way to the energy from the MGU-K. During acceleration this electricity can then be used to spin up the compressor resulting in immediate additional power with no turbo lag effect.

In Formula 1, the maximum amount of electrical energy available per lap was only limited by the amount of energy released from the storage system (ES) to the MGU-K. Meaning that the electrical energy generated by the MGU-H could then be transmitted directly to the MGU-K without any restrictions. Whereas, in LMP1, the total electric energy to the MGU-K was limited regardless of whether that energy came from the ES or directly from the MGU-H. Therefore, it was not practical for Audi to pursue this form of hybridisation and so it dropped its MGU-H before the start of the first race.

Furthermore, by developing such a highly efficient lean combustion process, the available energy from the pressure and temperature within the exhaust gas is much lower than that of a petrol engine. So there is insufficient energy to make recuperation worthwhile. Although this can be improved by increasing the exhaust backpressure, this leads to a decrease in brake specific fuel consumption (BSFC) and an increase in charge exchange losses, which have a larger negative effect on overall performance as illustrated in the chart (left).

By dropping the MGU-H Audi also removed the headache of where to locate its associated weight. Diesel engines are notoriously heavy, which is why the EoT designed the K factor to try and equate the weight of the Audi against its gasoline rivals. Overall, Audi decided that the most efficient route for its turbocharged diesel powertrain was to compete in the lowest 2MJ/lap hybrid class with an MGU-K only.



For a diesel engine the amount of electrical power that can be recuperated can lead to an increase in BSFC, resulting in increasing losses and overall lower power output

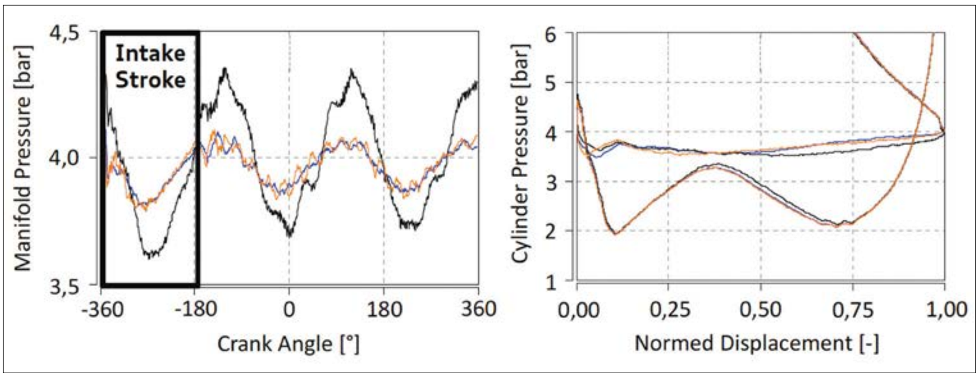


Figure 4: Comparison of the Y-cone airbox (blue) and single cone airbox (orange) against the original (black); see Figure 5

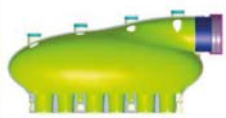
	Airbox	Volume	Intake Pipe Configuration	Intake Pipe Cross-Sectional Area
Basis		3,5 Liter	Tulip Y-cone	1134 mm²
Y-cone		7 Liter	No Tulips Y-cone	1963 mm²
Single cone		7 Liter	No Tulips Single intake pipe	1838 mm²

Figure 5: Single cone airbox was chosen as it ensured uniform flow distribution and minimised losses through its rear end

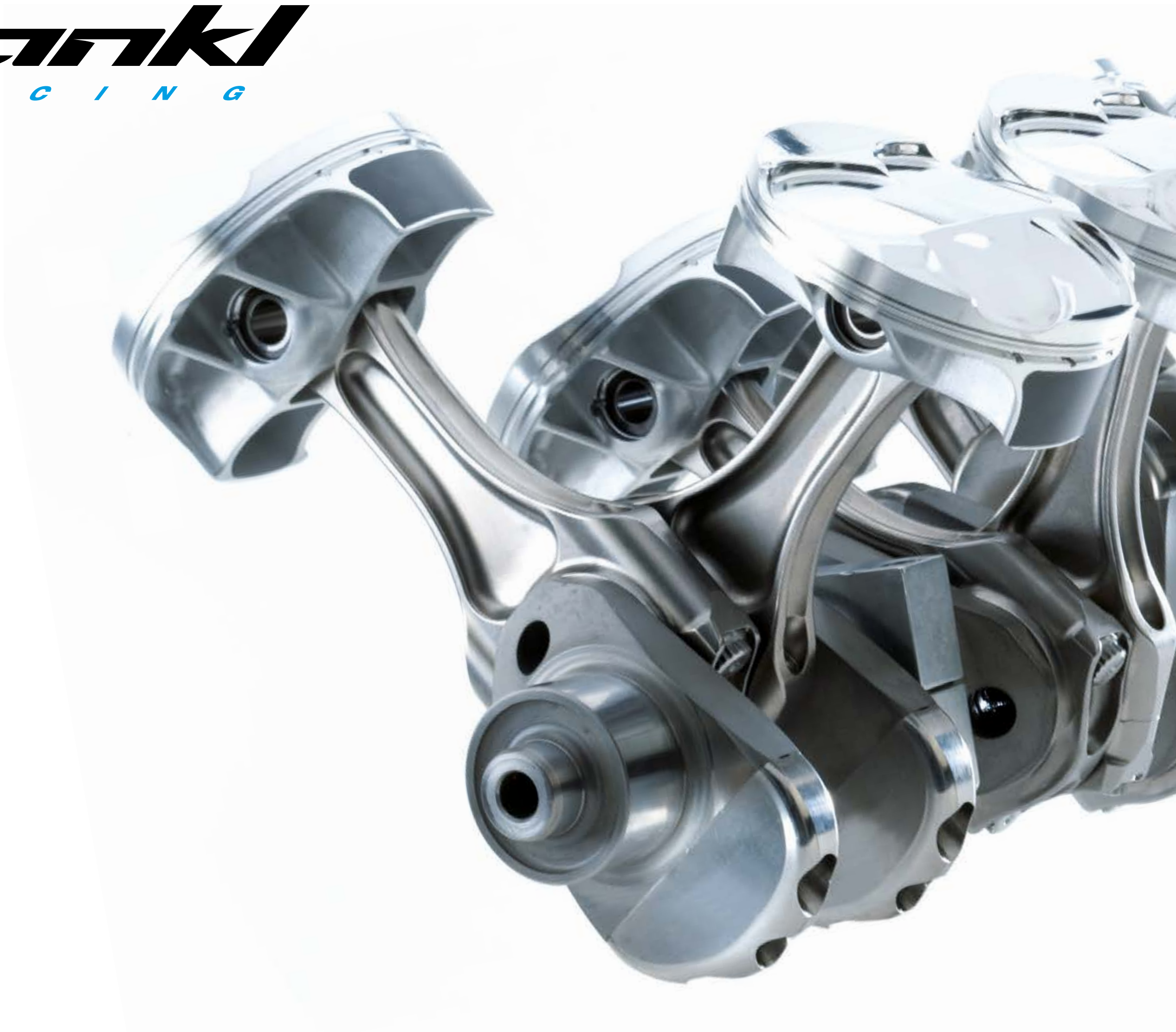
rate was first increased to 2050cm^3/min to ensure that maximum fuel was injected within the shortest time period. This meant the cross section of the holes on the injector nozzle needed to be enlarged. Secondly, to guarantee effective atomisation of the fuel (which is of paramount importance in diesel engines), the injection pressure was also increased to 3000bar and therefore required additional spray holes. Overall, the final design of the injectors consisted of a combined nozzle layout (CNL) with double hole rows including nine blind holes and nine seat holes. This layout not only creates good atomisation of the fuel, but it achieves this around the whole radius of the fuel injector nozzle.

Inner workings

The mixing of the fuel and air in a diesel engine needs to be achieved almost instantaneously during the compression stroke and so the design of the internal components are essential in achieving this. These include the surface finish of the cylinder walls and valves as well as the design of the piston bowl. This is where an indentation has been machined out of the top of the piston head and its profile dictates the swirl of the mixture and the generated vortices as the piston moves upwards during the compression stroke.

The profile of the piston bowl was completely redesigned so that the throat of the bowl runs downwards to ensure that the fuel quickly reaches the outer regions of the

Focus was on the fuel system, piston design, airbox and camshaft timing



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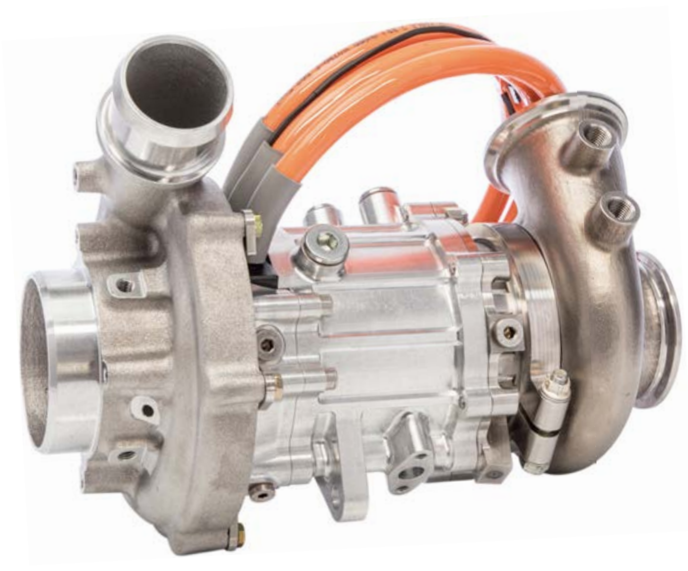

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By simulating the potential performance of the 2013 engine under the 2014 rules it was found that a 4-litre unit was the best compromise

combustion chamber where the majority of the oxygen is found. Therefore, a step was added which moved the newly designed conical area further downwards. Valve pockets were also incorporated into the inlet and outlet side of the piston. This helped with valve overlap and the associated optimisation of the valve timing, whilst having no negative effects on swirl.

New airbox

With the 2014 energy efficiency regulations shifting the focus to limiting the amount of fuel mass, rather than air mass, the airbox needed to be redesigned. Prior to 2014, it was beneficial to maximise the volumetric efficiency and therefore the development focused on balancing the intake manifold length and diameter as well as having an optimised trumpet design. However, for 2014 the biggest gains were in the optimisation of the charge exchange efficiency, which was achieved in several ways.

Firstly, the resonance effect of the charging inlet system needed to be minimised and so the length of the manifold was designed to be as short as possible and any inlet trumpets removed. Next, the volume of the plenum chamber was increased which helped to dampen the pressure amplitudes within the inlet manifold, the effects of which can be seen in **Figure 4**. Two iterations of airboxes were developed and investigated in CFD and in 1D charge exchange simulation before testing on the dyno. The details of these are shown in **Figure 5**. The single-cone configuration was found to have the most performance as the plenum design allowed for a uniform distribution of the flow and reduced losses caused by the airflow through the rear end.

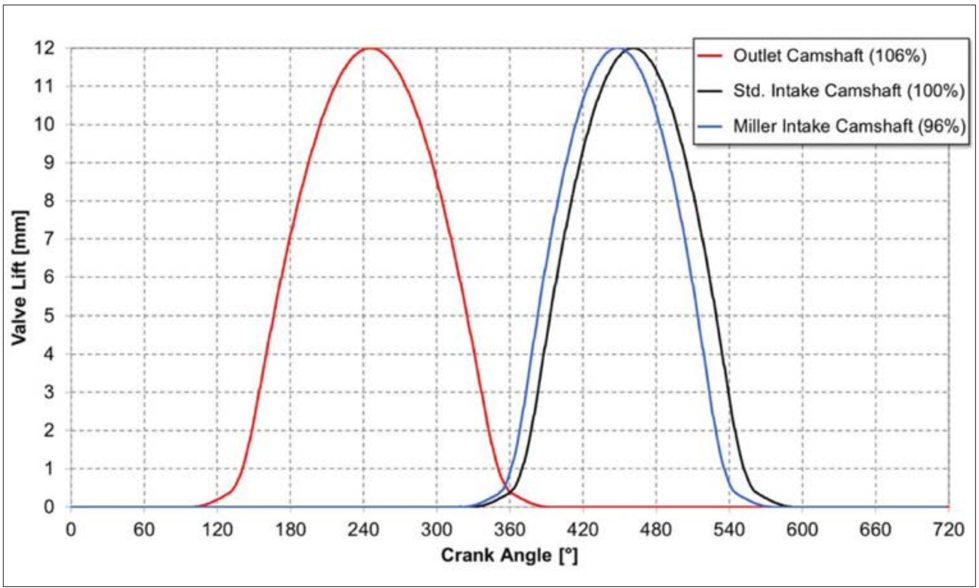

Figure 6: Valve lift curves comparing original inlet camshaft timing (black) with Miller inlet camshaft timing (blue). The latter opens the inlet valve earlier, allowing it to be larger and therefore maximising the inlet airflow into the combustion chamber

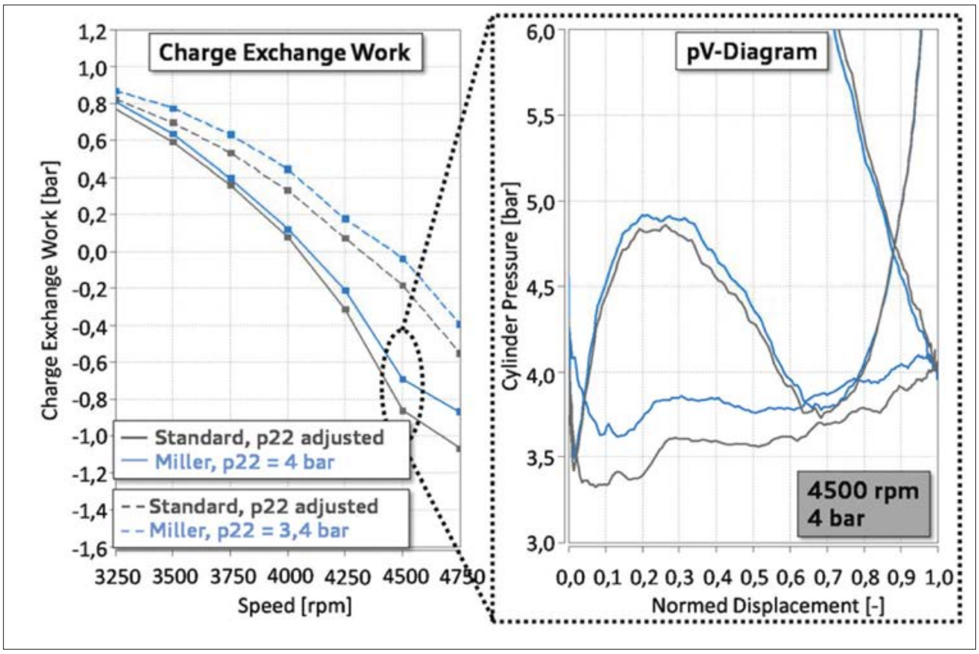

Figure 7: Comparison of the charge exchange work and the gas exchange loop of the original and the Miller camshaft timing

Volume control

From 2014 to 2016 the regulated fuel flow rate reduced by approximately 11 per cent due to performance adjustments and the fact that Audi had moved into the higher hybrid classes, starting at 2MJ and rising to 6MJ in the final iteration of the project. Consequently, this led to less air being required from the engine and therefore the volume of the plenum chamber could be decreased to half the volume (3.5 litres) of the 2014 design (7 litres).

However, the effect of reducing the fuel flow rate did not only impact the airbox design, but the inlet valve timing as well. With the regulations forbidding variable camshaft timing, a compromise needed to be found between the timing and the event length throughout the rev range.

Figure 6 details the valve lift curves of the original inlet camshaft compared to that of the Miller inlet camshaft. As you can see, the Miller camshaft not only reduces the width of the event, but also moves the inlet opening forward by almost 10 degrees crank angle. This allows the inlet valve to have a larger cross-sectional area which is desired during the induction phase to maximise the amount of inlet airflow into the combustion chamber.

Miller time

The charge exchange loop is also illustrated in **Figure 7**, where at every rev, the same air mass flow was set by adjusting the boost pressure. Therefore, with the original timing, the boost pressure had to be reduced slightly whereas the Miller timing required a higher boost pressure. This contributed to the higher pressure experienced during the induction phase which was also a consequence of the early inlet opening. However, during the exhaust stroke, the Miller timing only showed a slightly higher exhaust back-pressure, with the overall conclusion being that the Miller timing optimises the charge exchange.

Also, Miller timing essentially decouples the effective compression ratio from the geometric expansion ratio and has a further benefit of shifting some of the compression from the piston to the turbocharger compressor, which is then cooled by the intercooler.


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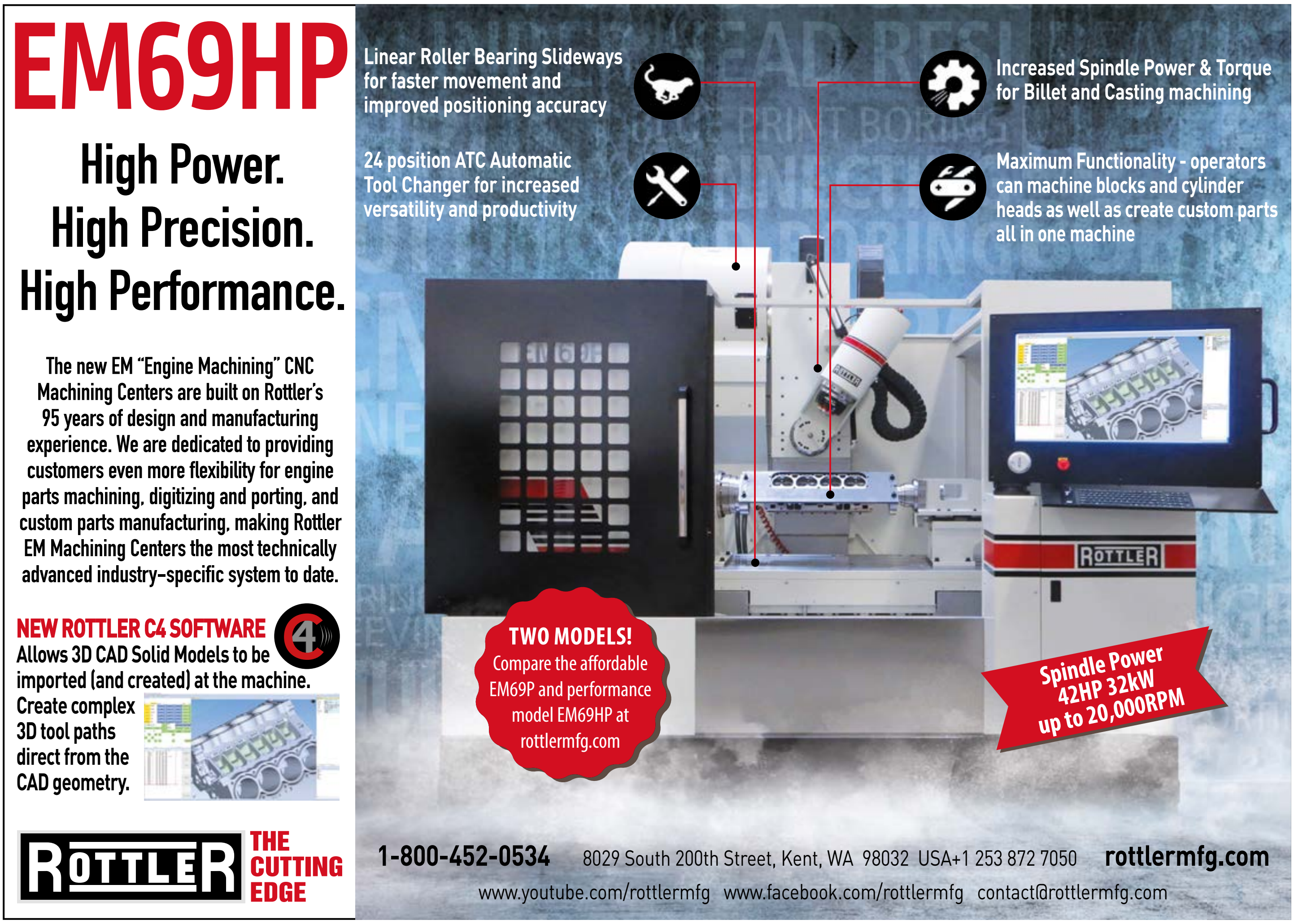
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The volume of the plenum chamber was increased which helped to dampen the pressure amplitudes within the inlet manifold

The 2014 efficiency regulations also increased the demands on the turbocharger. The boost pressure limit was increased, which in turn amplified the maximum air mass flow by 46 per cent to 2000kg/h compared to the 3.7-litre V6 of 2013. However, the leaner operation of the fuel in 2014 did result in lower exhaust gas temperatures, which decreased by approximately 400degC.

New turbo

A completely new turbocharger featuring variable turbine geometry (VTG) was developed in collaboration with Honeywell. The new requirements for the compressor also meant that a new turbine had to be designed and the overall development focus for the turbocharger was to optimise efficiency, minimise weight and achieve an excellent response.

One of the most crucial ways that the 4-litre V6 achieved such impressive engine efficiencies was due to the VTG turbocharger. Its low exhaust gas back-pressure and regulated rev-fall behaviour meant that the unit itself was extremely efficient. Good response characteristics were achieved through good boost pressure build up and the overall efficiency increases of the compressor and turbine at peak power can be seen in **Figure 8**.

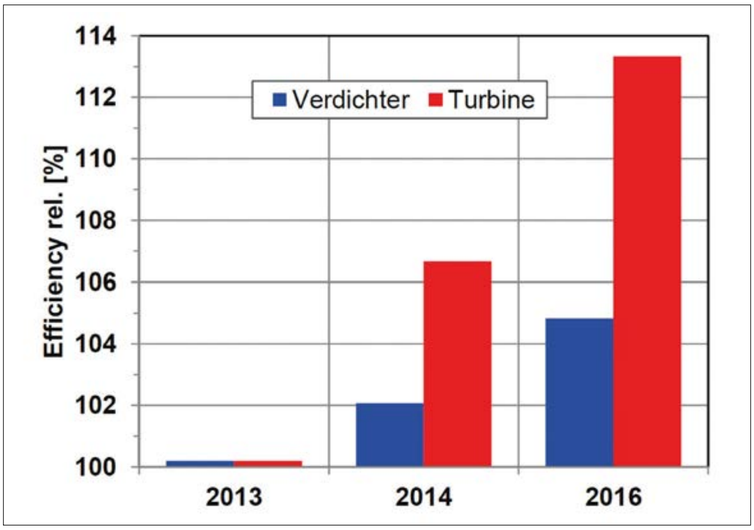
The turbine housing was developed to be extremely lightweight, while magnesium was used for the compressor housing. This not only reduced the weight of the unit but also benefited the centre of gravity of the racecar. To improve response, the original electrical linear actuator that actuated the VTG was switched to a dynamic hydraulic actuator which achieved even higher adjustment speeds as well as a reduced weight. Overall the VTG for 2014 was 3.7Kg lighter than 2013.

On track

Maximising engine performance is not just down to the innovative designs generated by the engineers at the factory. It also relies on the driver to exploit the performance in the most effective way, whilst driving within the regulations. With the 2014 rules limiting the maximum fuel flow and amount of energy each lap, it was found that driving under full power at all times, would exceed the allowable fuel mass and thus cost the team a penalty. Therefore, it was necessary to define a driving strategy that would be within the regulations, but achieve maximum performance. This was achieved through the driver lifting off the throttle just before the braking point which would deactivate the fuel injection. This required the fuel to be balanced just before the expected cut-off.

Therefore, every race circuit was divided into several segments with each assigned an optimum amount of energy to achieve the best lap time, as shown in **Figure 9**. During acceleration, both the engine and hybrid system provided power in parallel. The off-throttle lift off phase occurred at the end of most straights, with the MGU-K recuperating energy under braking. Then, where appropriate, a short cut-off of fuel or part load phase occurred just before the acceleration period started again. To achieve this track conditions such as temperatures and head or tail winds all had to be considered. Furthermore, any effects on fuel consumption caused by overtaking, traffic and safety cars meant that the allowable fuel had to be redistributed throughout the rest of the lap. A driver over-ride function also needed to be factored in.

Figure 8: Comparison of the improved efficiencies achieved by the compressor (blue) and turbine (red) of the VTG turbo at peak power from 2013 to 2016



Effective solution

Overall the 4.0-litre V6 TDI engine that Audi developed to meet the new energy efficiency regulations of 2014 proved that diesel was, and is, an effective solution for not only maximising engine efficiency, but also achieving maximum power and performance whilst reducing fuel consumption and, perhaps most importantly of all, winning the Le Mans 24 hours.

In all, Audi's turbo diesel concepts clocked an incredible nine Le Mans victories. The paper concludes: 'Even though the chapter of diesel appears to be over for now after Audi concluded its involvement in the 24 hours of Le Mans after 10 years, the development of this powertrain is still far from over.'

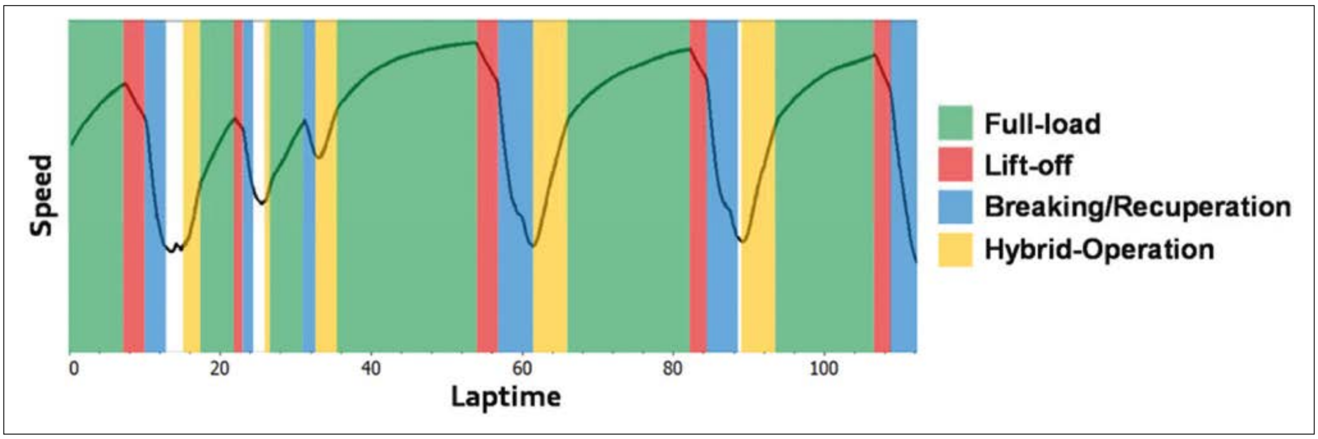


Figure 9: The driving strategy used during a Le Mans lap to stay within the regulations while achieving optimum use of the allowable fuel and hybrid energy restrictions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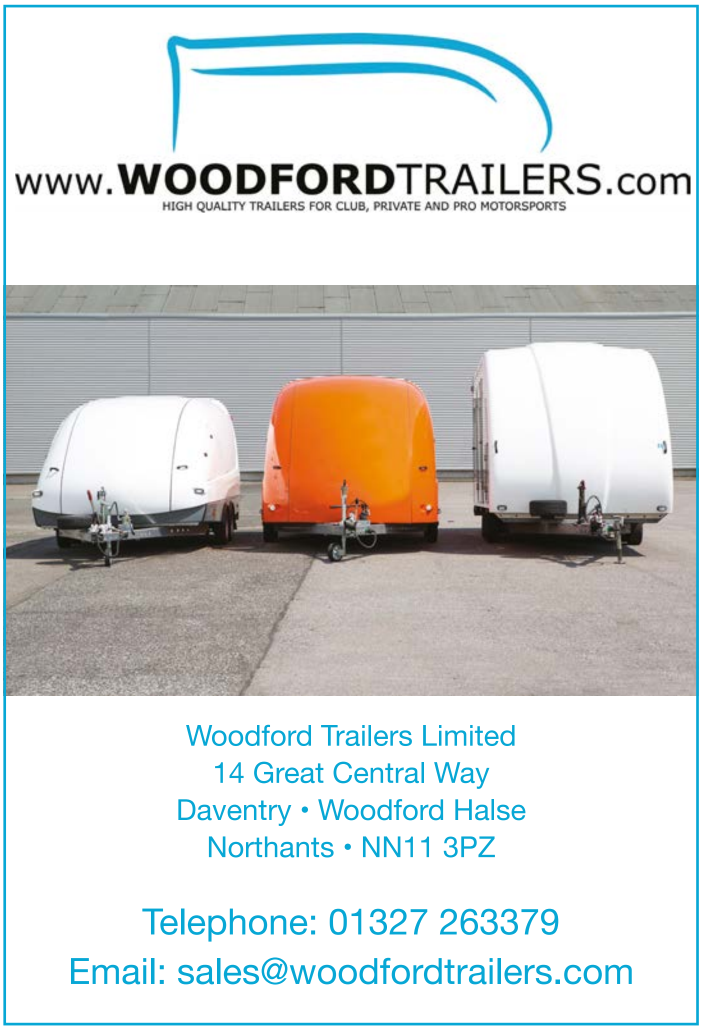
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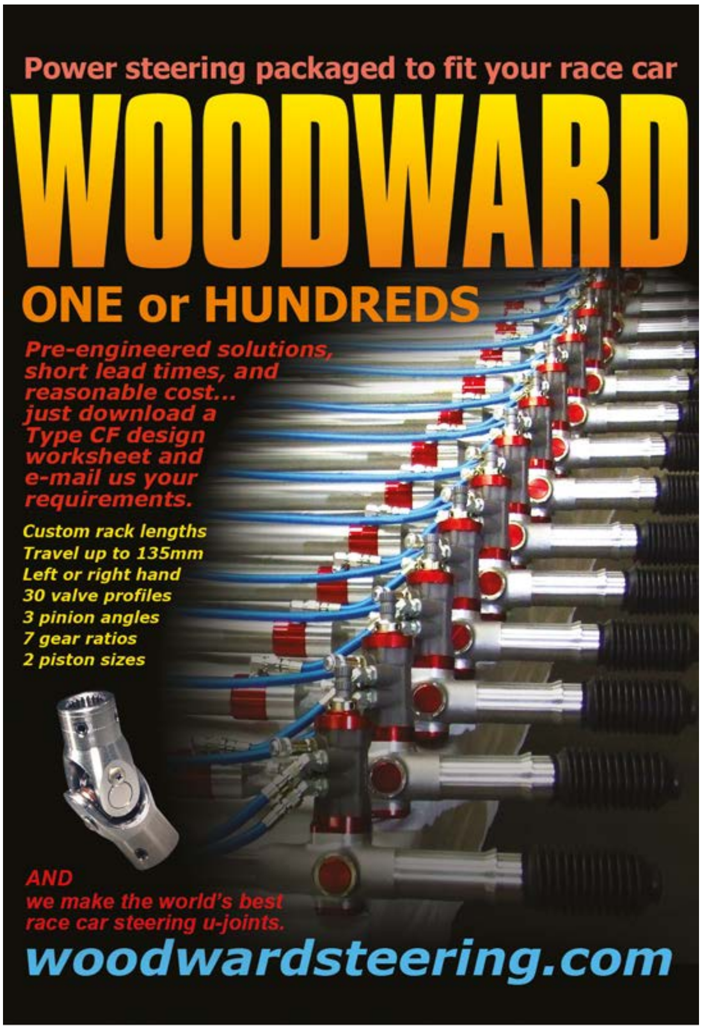
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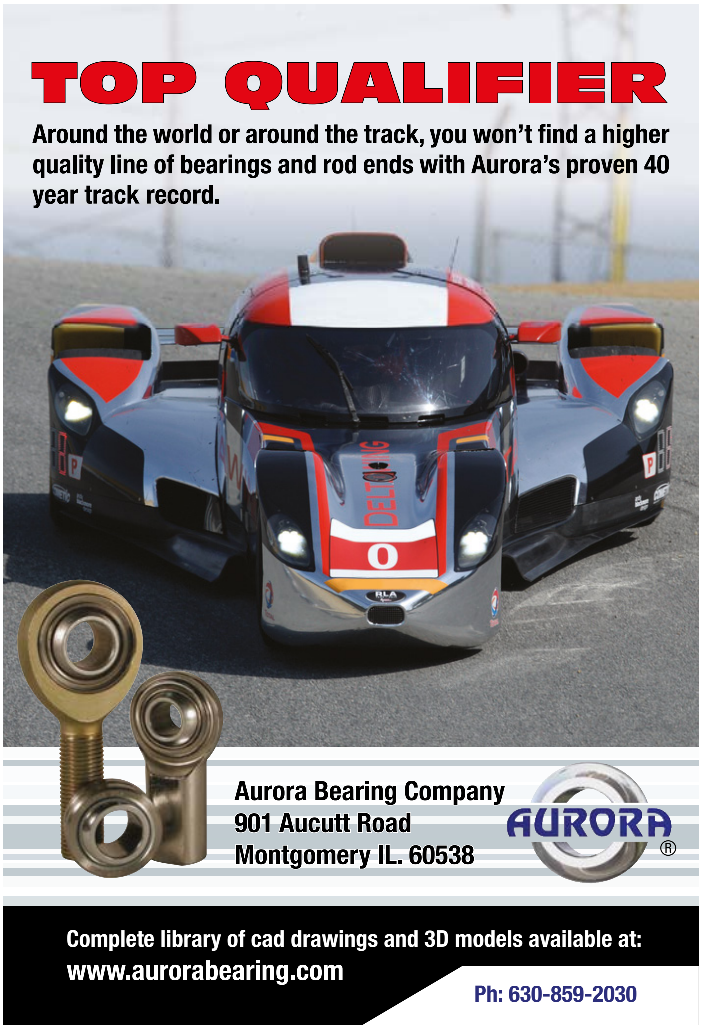
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Shock revelations

Dampers are talked about by many but understood by few; so how do racing shock absorbers work and, more to the point, how do you go about getting the very best from them?

By RICARDO DIVILA

Dampers can change the balance in many sectors of the corner, but the first priority will be to find the best setting for overall grip

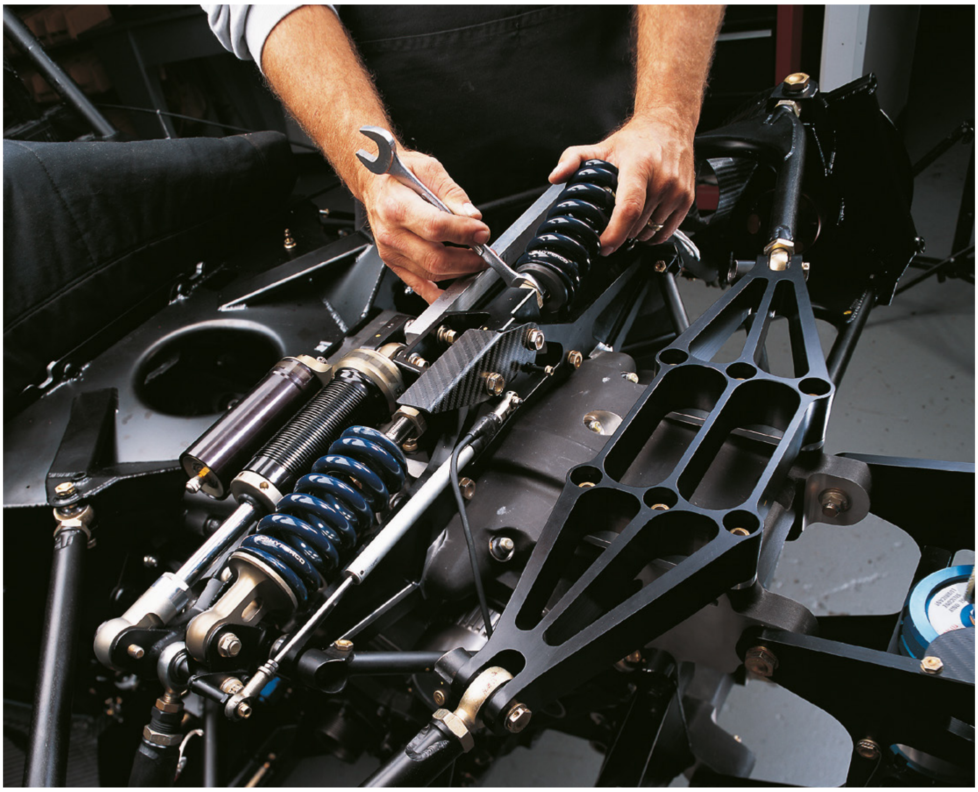
The term 'black art' is often used as a title for a piece on tyres, but the other unknown is oscillatory phenomena damping – AKA dampers or shock absorbers. Both titles are applicable for what they do, but mainly dampers dissipate energy by friction, in modern cases the friction being viscosity, more specifically fluid viscosity.

In this feature I will not go into the mechanics of viscosity and the physics of liquids. The basics will suffice here, and then I will move on to explain how to use your dampers.

When I started racing, dampers were just an accessory bolted on the racecar to control the springing, and not much was touched except to see if anything was leaking, or the shafts were bent after a grass cutting exercise, and they were not adjustable. Going from the ubiquitous Armstrong dampers of the late 1960s to the then new Koni adjustables opened my eyes to the possibilities of trimming the racecar with a simple click, or clicks.

Only when one of the Formula 1 teams I worked with started manufacturing and testing its own dampers in the late 1980s did I have the opportunity to delve inside and see exactly what was actually happening, which led to modifying the characteristics and seeing the changes it could make to the racecar's handling in detail. Most teams went through that phase but then returned to sourcing dampers from manufacturers, as we all had other fish to fry, and it was one less item on the work menu.

Again, F1 budgets being what they are, it did give the opportunity to go to a given test track (In this case Estoril, a notoriously bumpy circuit,



Main picture: Coilover damper. A shock absorber controls the spring by means of dissipating energy by friction, usually in the form of fluid viscosity **Right:** A race engineer adjusting dampers. This is done by clicks, which alters the valving within the shock absorber to increase or decrease resistance

and the birthplace of the 'bumpiness' math channel on the data logger analysis software) with four different manufacturers with their support trucks at the same time, each supplier changing specs and churning out variations on their products according to the data generated and analysed in real time. The flow control valves were all different, but what emerged from the shoot-out was that each system had a particular section or corner on the track where it was better than another, but the absolute lap time between them was very similar.

After all these years playing with dampers, I still have a lot of trouble really understanding them, but empiricism can at least give some rules on how to use them profitably. But a big red alert warning note here; dampers are very good for tuning your handling and transition, but they only work when your springing and tyres are working well. A good indication that your set-up is wrong is when huge changes in damping give no noticeable results. On the other hand, if you are on the sweet spot a couple of clicks can tune the handling to the driver's desires. As nobody understands dampers – including me – they get blamed for an infinity of handling problems where often the problem is elsewhere.

The three- or four-way damper adjustments which were made available, and canister pressures, only compounded the problem, throwing more variables in; low speed, high speed bump and rebound and blow-offs stacking up factorialy as the number of inter-related adjustments mushroomed. The fact that changing low speed bump or rebound also affects the high speed corresponds to Shakespeare's Macduff quote in Macbeth: 'Confusion now hath made his masterpiece.'

How dampers work

The mechanical aspect of a damper is given by a piston attached to a shaft. One side is connected to the chassis, the other to the wheel. The inside of the cylinder that the piston is moving through is filled with incompressible (to all intents and purposes) hydraulic fluid. This hydraulic fluid is forced through small orifices in the piston causing a resistance, which in turn creates a pressure differential across the piston (front face and back face, depending on the direction of movement), therefore producing a damping force. As the volume of the shaft side of the piston will be less because of the volume displaced by the shaft, the modern single tube damper usually has pressurised gas (usually nitrogen) behind a second piston or in a remote canister to cater for this, but the main reason for the pressurisation is to reduce aeration, which usually occurs due to the rapid pressure loss after passing through an orifice at high rates of speed (which is the same pressure loss that gives the damping force).

For better control of the shaft oil displacement we have seen through-rod dampers. The downside is extra seals and friction, but the piston is kept in position even at full extension, not being prone to cock over as the support points are at either end and fixed, whereas the singe shaft damper has a diminishing base as the distance between the piston and the shaft seal is reduced.

Bubble trouble

Aeration reduces damping forces because the minute bubbles formed in the liquid are compressible, therefore reducing the forces produced to damp the movement. Aeration can still occur even with canisters or reservoirs running over 35bar (507.632psi).

Reservoir pressure can also be used to change the damper characteristics, and will also raise your car slightly – you can calculate the added lift given by the pressure by multiplying the canister or reservoir pressure by the piston diameter, spring rate will not change as the pressure does not vary by much unless you have major aeration.

Third element dampers are now quite usual, to control pitch damping

There is a different aeration recovery rate in bump and rebound, but to be honest, unless you are designing dampers you cannot change this, so don't worry about it.

As the shaft moves it forces the fluid through the piston orifices, the shaft orifices and the canister or reservoir orifices. The piston has orifices for bump and rebound, covered by a stack of steel shims, which deflects when there is a pressure differential. The rate of deflection can be altered by, respectively, the thickness of the shims, their number, and the amount of deflection can be also varied by having them pre-loaded by having the piston surface flat or coned at different angles.

Shaft speeds

The piston shape where it meets the shims can give you linear, progressive or digressive curves for the forces generated. Progressive curves can also help in stiffening the suspension up at close to end of stroke, and when coupled with position sensitive damping, as on off-road cars, will keep it from bottoming. For most circuit racing we use digressive curves, as we are interested in the slow shaft speeds (**Table 1**).

As the shaft moves, the piston in the bore pushes the fluid through the shim stack, a series of thin, diminishing diameter circular steel washers, assembled much as a leaf spring, and working as such, which cover the holes on the top and bottom of the piston.

These holes connect to slotted sections which are also on the top and bottom of the piston. When the shim stacks lift (or deflect) by the pressure differential on the top or bottom of the piston the fluid can pass through the narrow slots exposed. These are drilled in such a way that there are different holes for bump and rebound.

Needle valve

There is also another hole, which allows the fluid to bypass the shim stack. It can be in the piston or on the side and end of the shaft. The flow can be controlled by using a tapered needle that can be screwed in and out to vary the orifice effective area.

Dampers with needle valve adjustment will require careful matching, if only due to the part tolerance build-up, as the diameters and tapers are very sensitive to this, and also the shape of the taper, which is not really a cone, strictly speaking, but a particular shape due to the hydraulic characteristic of the oil being used that flows through it.

Remote control

When using a remote reservoir, not at the foot of the damper but piggy-backed on it or connected by a flexible hose, there is another opportunity to add another couple of orifices to the fluid path, being more effective as the shaft diameter increases in relation to the bore, as the canister or reservoir only operates by the flow of the volume displaced by the shaft. The through-shaft damper mentioned above does not have this characteristic, so obviously you cannot use the canister if you are using this.

The bump and rebound valves can be of shim stack pre-load adjustment in bump and rebound; twin-hole shaft with one-way valves and twin tapered needles for bump and rebound; a rotating drum with increasingly larger orifices on the outer circumference of the drum, which, when rotated, aligns them with the flow path. You can move the entire needle and seat assembly to add a third adjustment. All of the methods listed below are to control the flow path and the pressures.

Flow methods

1. *The fixed orifice flow method*. When the damper shaft is moving slowly, the pressure differential across the piston is not enough to lift the shim away from the face, forcing the flow across a fixed orifice, so flow resistance obeys the law of velocity squared; that is, doubling the velocity will quadruple the force.

Therefore, the only adjustment to increase the damping force will be to reduce the effective orifice by screwing the tapered needle in, or in the case of a drum adjuster, rotating the drum so the flow goes through a different, smaller orifice. The characteristic curve diagram for this would be a parabola, force values increasing with speed exponentially.

2. *Variable orifice flow method*. If the shaft speed is high enough, it will lift the shim stack off the piston face, thereby creating a supplementary flow route. Increasing resistance force in the flow will lift the shim stack further, again increasing the area of orifice. As the damping force does not follow the velocity-squared law due to the increased area for flow, it enables the shim stack shim diameters to be sized to give a linear force/velocity graph. Thicker shims increase the slope of the curve, thinner decreases it.

Piston faces are machined with a slight cone angle ranging from 0.5 to 2.5 degrees, deflecting the shim stack when clamped on the piston. Adjusting the clamping load on the shim stack changes the pre-load, as the offset of the

Table 1: Shaft speed ranges

Shaft speed	Influence	
<5mm/s	Friction	(Shaft, seals, ball joints)
5-25mm/s	Chassis motion	(Roll, pitch, heave)
25-200mm/s	Road input	(Bumps)
200mm/s>	Kerbs	(Blow-off area)

Figure 1: A sample of damper forces at same setting, different temperatures

Shaft speed analysis

Shaft speed		25degC	Kgs	60degC	Kgs
MM/sec	IPS	BUMP 25˚	REB 25˚	BUMP 60˚	REB 60˚
101.6	4	250	80	260	50
203.2	8	320	210	340	170
304.8	12	350	320	360	270

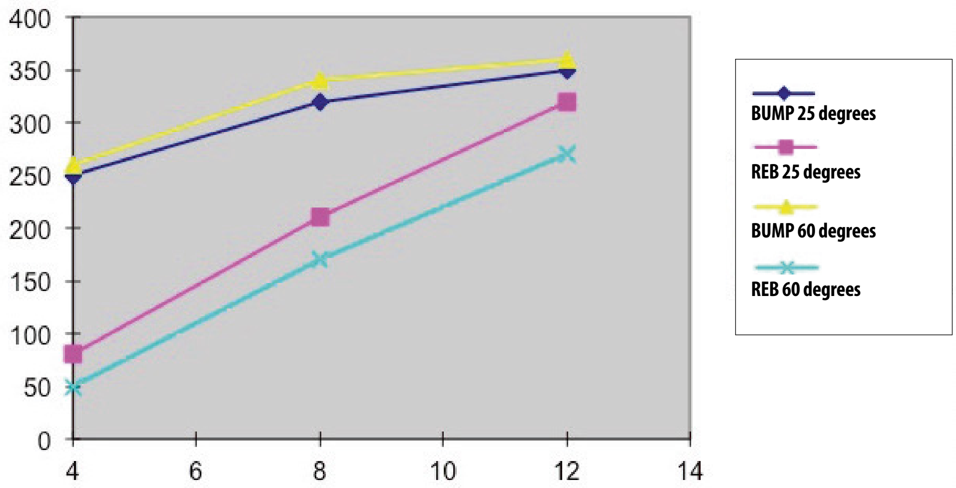


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Figure 2: Weight transfer in different phases of cornering

Load Limits(connected to inputs)

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Inputs from previous sheet			
Wheelbase (m):	Wb	2.795	
Front track (m):	tft	1.605	
Rear track (m)	trr	1.565	
Heigth of CG (m)	hCG	0.313	
Drive F/R/4		r	
(Front/Rear/4Wdrive)			% ft.
Front roll stiffness (%)			72.60
Mass (kg):	M	972	43.59
Aerodinamic load (kg)	A	604.44001	33.0

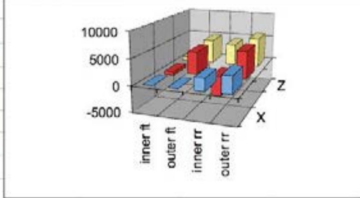
Constants		
rad=deg*	0.0174533	57.295781
N=kg*	9.81	0.1019368
N/mm=lb/in*	0.1753	5.7045066
lb/in=N/mm*	5.7045066	

Per wheel:			Load Transfer per G (N)	
Weigth (N)	Aero load. (N)		1 G long	1 G lat
2078	978	Ft	-534	1350
2689	1986	Rr	534	523

Load cond	1	2	3	
G long X	0.6	0.6	-2	>0 in acceleration, <0 in braking
G lat Y	1.5	0	1	>0 on outside wheel, <0 on inside wheel
G vert Z	1	1	1	>0 if compressed

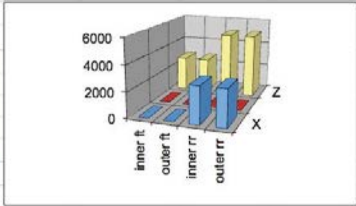
Load cond 1

Wheel load (N)	X	m long.	Y	m lat.	Z	% lat.	% long.	% tot.
inner ft	0	0.00	-658	0.92	711	13.00	ft	4.60
outer ft	0	0.00	4404	0.92	4761	87.00	35.39	30.79
inner rr	2412	0.57	-3896	0.92	4212	42.16	rr	27.24
outer rr	3309	0.57	5346	0.92	5780	57.84	64.61	37.37
S	5721		14303		15465	100.00	100.00	100.00
Equal?	5721		14303		15465	All wheels on gnd?		TRUE



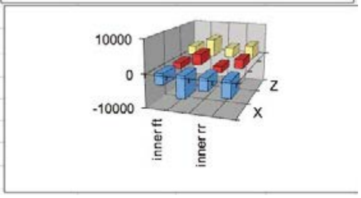
Load cond 2

Wheel load (N)	X	m long.	Y	m lat.	Z	% lat.	% long.	% tot.
inner ft	0	0.00	0	0.00	2736	50.00	ft	17.69
outer ft	0	0.00	0	0.00	2736	50.00	35.39	17.69
inner rr	2861	0.57	0	0.00	4996	50.00	rr	32.31
outer rr	2861	0.57	0	0.00	4996	50.00	64.61	32.31
S	5721		0		15465	100.00	100.00	100.00
Equal?	5721		0		15465	All wheels on gnd?		TRUE



Load cond 3

Wheel load (N)	X	m long.	Y	m lat.	Z	% lat.	% long.	% tot.
inner ft	-3421	-1.23	-1711	0.62	2774	33.63	ft	17.94
outer ft	-6751	-1.23	3375	0.62	5474	66.37	53.34	35.40
inner rr	-3805	-1.23	-1902	0.62	3085	42.76	rr	19.95
outer rr	-5094	-1.23	2547	0.62	4131	57.24	46.66	26.71
S	-19071		9535		15465	100.00	100.00	100.00
Equal?	-19071		9535		15465	All wheels on gnd?		TRUE



force versus velocity line. More pre-load equals more damping force at higher shaft speeds. Shim stack pre-load does not affect low speed damping apart from changing the force at which the shim stack will open. Usually the shim stack opens at 50 to 120mm/sec shaft speeds depending on the pre-load.

3. *Mixed flow method*. When the flow is through both the shim stack and assorted orifices we have a mixed flow case, so we can consider the fixed orifice area has effect through the entire shaft velocity range, and the primary cause for LS (low speed) bump or rebound altering the HS (high speed) bump or rebound, however it is your primary instrument for low speed control, and is usually referred to as that by the manufacturers; much as stack pre-load is referred to by them as high speed adjustment.

Any given lap involves going through corners and running down the straight. Both these actions will move the piston up and down (or back and forth in lay-down layouts) as the racecar runs over the micro and macro bumps, and usually the same portion of oil, aerating them and heating them up, so canister or reservoir pressure and keeping dampers cool are your two weapons to control this phenomenon. Plus an almost fanatical devotion to the three methods listed above.

The then new Koni adjustables opened my eyes to the possibilities of trimming the racecar with a simple click

Short hoses

Other elements can reduce your damping force and increase hysteresis. I prefer 'piggyback' reservoirs, as the remote ones with a flexible hose will introduce losses to the system. If you have to use them, then keep the hoses as short as possible. If the canister has orifices of any sort in it, the length of flexible hose connecting it to the damper housing should also be as short as possible – a hose is akin to another spring in the system, and we have trouble enough controlling the spring/tyre/chassis deflection on the mounts and structure as it is.

As we have stated above, the damping forces are produced by friction or shear in the fluid, and that produces heat. So always monitor your dampers for temperature; front ones not being a major problem, but rears have a hard life, as they are usually bolted to a gearbox which itself is around 100degC, and with exhaust pipes running close on rear engine cars. Front engine cars are less of a problem, but can still be an issue. On a related note, rear bump rubbers will also have a short life for this reason. So make sure you check them regularly.

On a racecar there is a lot more than just this and, by virtue of their dynamic character, dampers are hard to quantify. So much so that through the years dampers and damper tuning developed into a black art, and we can say that the whole operation and build of dampers seems to have evolved on an empirical, or test it and see, method. Trial by error is also a valid development method, I believe.

Damping motion

The classic way it should work can be examined in a simple corner model of a car – a body and hub mass separated by an ideal spring and damper, with the hub attached to ground through a tyre, which is another (undamped except through rubber hysteresis) spring.

The damper is there to dampen motion of both the body and the hub. Unfortunately, the higher frequencies of the hub oscillations will always be damped more than the lower frequency body motion because the friction in the fluid is velocity dependent due to the friction of the fluid through the orifices, the opposite to what you want; a well damped body and softly damped hub.

So the compromise is to set hub damping with the bump-adjuster and body damping with the rebound-adjuster, and work with the characteristics of the damper.

A good indication that your racecar's set-up is wrong is when you make huge changes in damping which give no noticeable results

Where circuit racing is concerned, the main concern is platform control and force transfer fore and aft, and transversally and diagonally for handling response as a car is not only the four corner masses. But going over bumps with front and then rear axles will also introduce complex interactions between the front and the rear, plus the individual bumps only acting on the left and right wheels.

Add in kerb strikes and then you have a complex matrix of countermeasures to compose. Kerb strikes are usually >300mm/sec, whereas transients are below 50mm/sec. Ignoring the dampers and bumps, just the weight transfer in different phases of cornering will give you the values in **Figure 2**.

Frequencies

This, of course, only gives us the relevant forces, but not the deflections it will cause. Those values will be gleaned from further calculation, and the result will give us the wheel rates and will be used in the formula below to find the frequencies. As stated before, you have to take care of the front and rear ride frequencies. The ride frequency is the undamped natural frequency of the chassis at each corner. This is given by the formula:

Wheel rate Kw

Kw = Ks*(MR)^2

Where:

Ks = spring rate

MR = motion ratio

(Incidentally, one of the traps in using motion ratio is that it is commonly confused with installation ratio or velocity ratio. To clarify motion ratio is defined as MR = wheel displacement/spring displacement and Installation ratio (IR) or velocity ratio (VR) is VR = spring displacement/wheel displacement).

Wheel rate with the tyre spring rate and spring rate in series:

Kw' = (Kw*Kt)/(Kw+Kt)

Where:

Kw' = combined spring rate

Kt = tyre spring

Kw = wheel rate from suspension (spring acting through the suspension)

NF = 1/2π(Kw'/Sm)^1/2

Where:

NF = natural frequency

Kw = spring rate at the wheel

Sm = sprung mass of corner

We can thus see that a stiffer spring will have a higher frequency and will give a stiffer ride. The usual ranges will go from 0.5 to 1.5Hz (Hertz) (30CPM [cycles per minute] to 90CPM) for passenger vehicles, 1.5Hz to 2Hz (90CPM to 120CPM) for racing saloons, GTs and medium downforce single seaters rising to 3Hz to over 5Hz (180CPM to over 300CPM) on high downforce cars. Incidentally, most racing tyres will have a natural frequency between 3.5 and 5Hz, which brings several other problems, notoriously when coupled with aerodynamic forces which sets the car into porpoising – another article in itself.

Lower frequencies will produce more mechanical grip, but they will also have slower transient response, as forces are transferred in pitch, roll – be it transversal or diagonal – and heave. You will then have different damping ratios required for heave (ride), single wheel bump, roll and pitch.

As most racing cars have a damper for each wheel, trying to combine them to cater for all the different damping ratios ends up being an act of compromise, as ideally you would need at least eight dampers to cover most of the requirements – four heave dampers on corners,

Figure 3: Force/velocity diagram

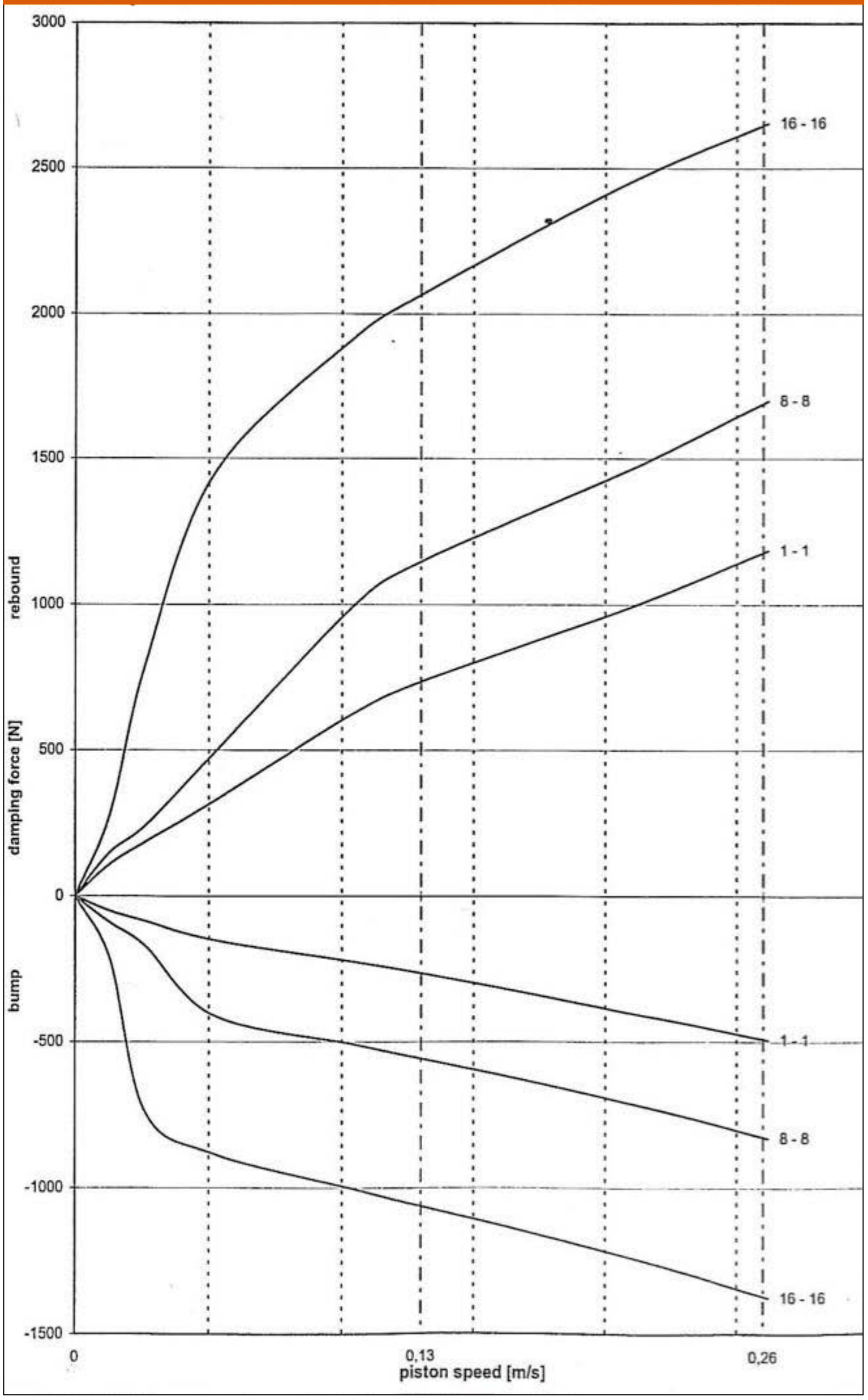


Figure 4: Egg plot – single setting

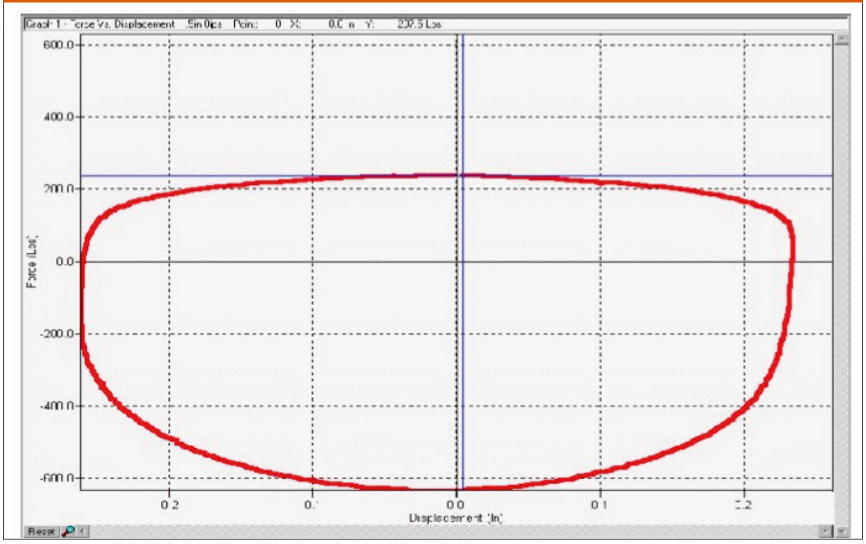


Figure 5: Egg plot – multiple settings; force *vs* displacement

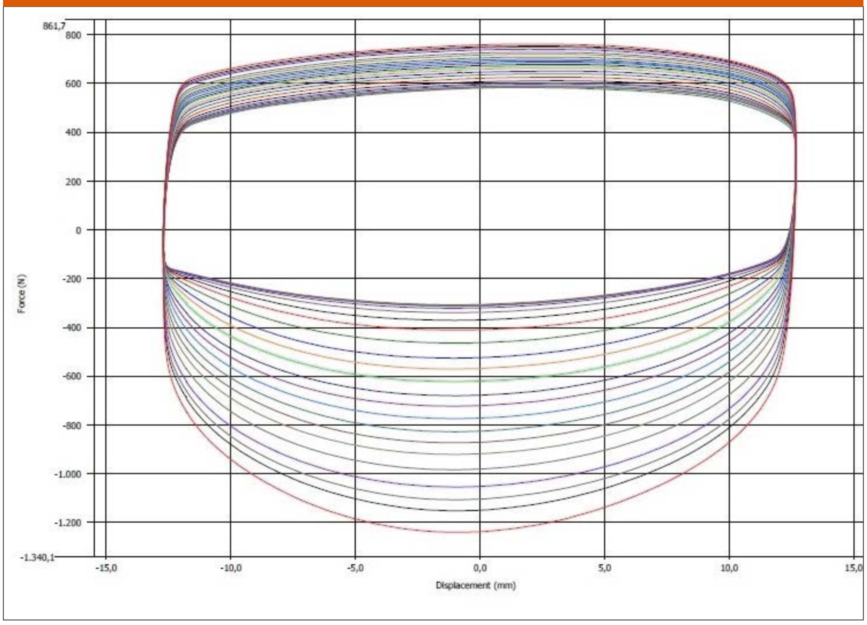
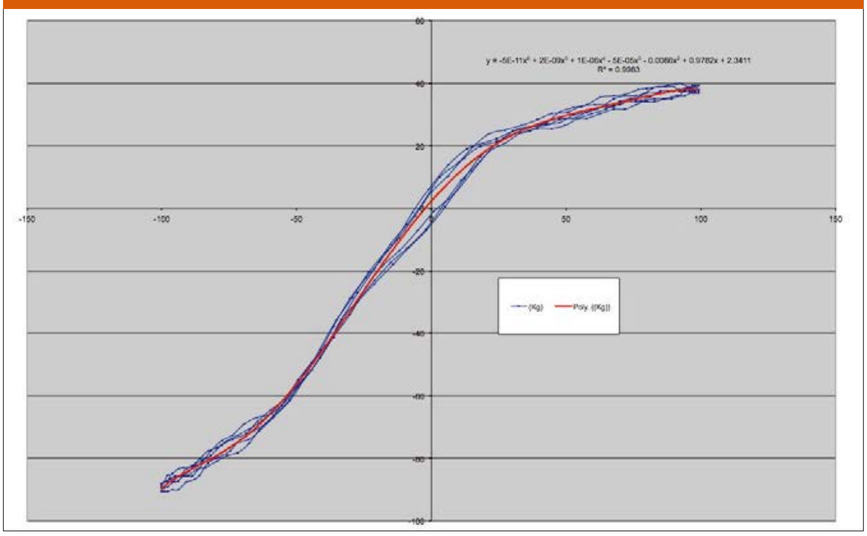


Figure 6: Series of sweeps smoothed by software



two pitch dampers on front axles and rear, and two roll dampers for the same.

Third element dampers are now quite usual, to control pitch damping, especially if coupled with *g* sensitive valving, say working only on rebound at the front and bump and rebound on the rear. Rear control is the most useful, as usually you have bigger suspension travel on the rear, and on most cars you are also controlling a bigger mass. As a bonus it makes a useful holder for bump rubbers and packers, allowing snub bottoming on the straight, where you will hit the bumps faster and thus have more deflection, and allowing you to free off your bump rubbers on the side dampers and run softer springs. In the higher classes decoupling roll, pitch and heave damping has been used, as have inertia dampers, but once again, we will keep to the basics here with the most commonly used damper configurations.

Force/velocity

Usually dampers will come with the specified force/velocity diagrams or values. The force/velocity diagram in **Figure 3** shows the value rising almost exponentially in the early stage of the curve, dropping off with increasing velocity as the shim stack opens, then turning slightly digressive. Just the sort of curve we need.

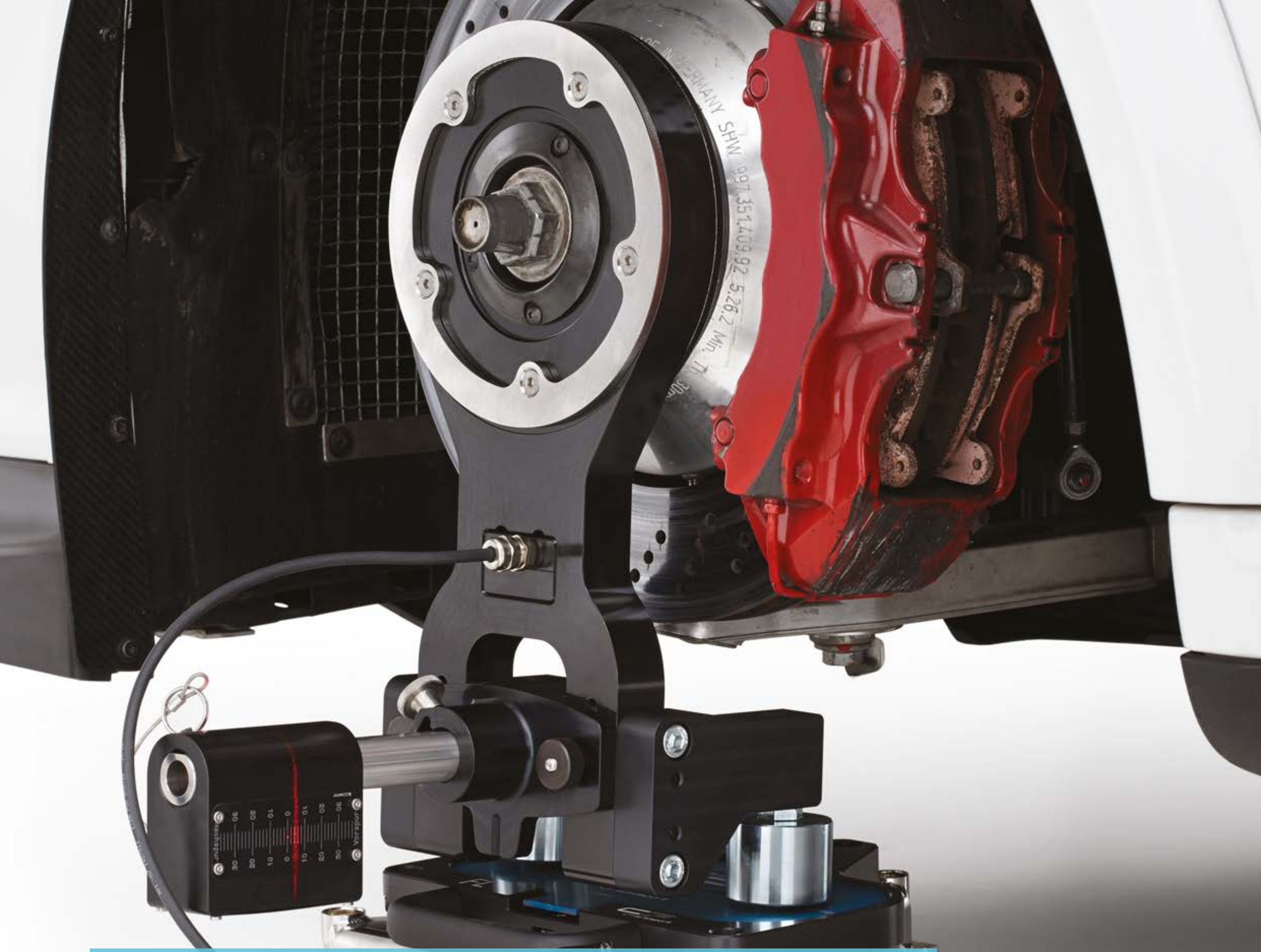
The common 'egg plot' you get from a sinusoidal damper rig of the sort commonly found in many racing teams is a force/displacement graph and is very misleading to read, even if corrected by software to produce the first example of a plot. It uses an electric motor with a mechanism to produce axial sinusoidal movement, much as a crank moves pistons. To test a damper they run at a fixed speed for a few cycles, the maximum force and velocity reached measured through the sweep in bump and rebound. The speed is increased in steps and the force and displacement measured **(Figure 4, 5,** and **6)**.

Note the variations produced by the series of sweeps shown in **Figure 6**, which end up being smoothed by the software to give the red line, also the hysteresis in the change of direction as bump moves to rebound.

Damper rigs

Hydraulic or electric rigs can sweep through a bigger range of movement, either replicating data inputs or running through varying curves and frequencies, furnishing you with a better and more correct read out. With practice and experience, and by learning to understand how the software works, you can glean some information on the critical points, and it is very useful for matching damper pairs (note that equal clicks does not always mean equal forces) and finding a defective or failing damper, but give me a hydraulic rig for measuring correctly. It will cost you, though.

Figure 7 is a force/velocity plot in bump and rebound with phases identified – note hysteresis



Rear dampers have an especially hard life, usually bolted to a gearbox which itself is around 100degC, and with exhaust pipes running close

in mid part of graph and residual forces given by friction and canister pressure.

Hysteresis is actually akin to compliance, adding a non-linear complex spring in series. It can be seen on the **Figure 7** graph that its biggest effect is at low speed and going past TDC and BDC, precisely where we need most control. This is not immediately apparent in egg plots, only turning up in force/velocity plots, provided you are logging at a fast enough rate and do not fall into the trap of smoothing your data; because this can change that part of a graph considerably, and certainly not in a good way. So please repeat this after me: 'No data is better than bad data.'

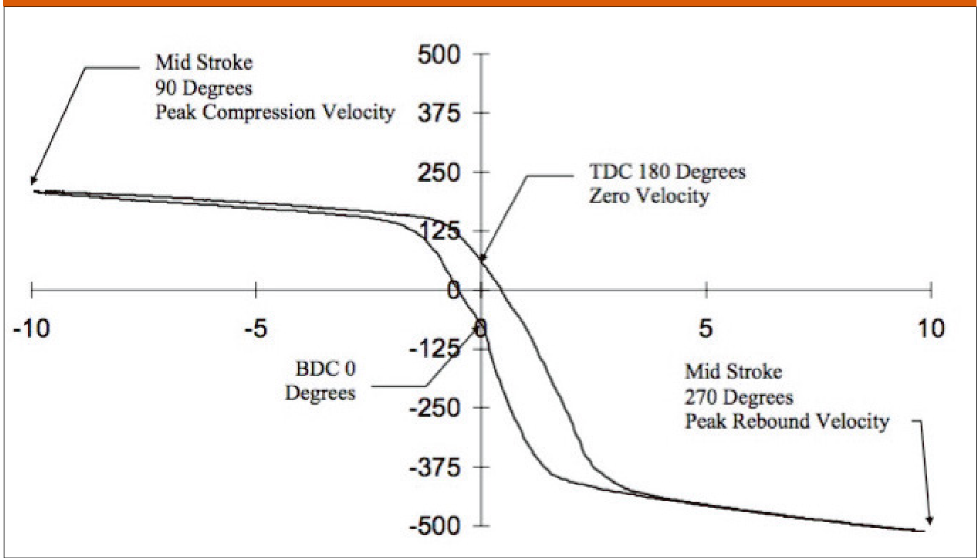
There are a few steps to grasp when setting up dampers. Step one is: if it is not moving, it produces no force, so let us look at the different sections of a corner and see the dynamics.

Assuming we have control of the spring on the base characteristics of the damper, that is, when we run over a bump the energy stored by deflecting the spring will be returned by it and will set the whole corner into an oscillating mode, so if set correctly it will create an apposing force that will decay the oscillation to zero in a short period (theoretically a spring will oscillate at a characteristic frequency forever if undamped) the main use of dampers in tuning handling will be in transmitting forces to each of the four corners in one of several modes.

So practically you will use the low speed settings (below 100mm/sec) to control your transients (loading or unloading a tyre) and never forgetting that a damper will only transfer forces if moving, and as platform movement is slow, it will be the low speed clicks that will get the results. High speed only gets touched to control big bumps and correct kerb strikes, and if you have blow-offs it will help even more.

Different cars have different values for what we call high speed and low speed (always bearing in mind it is relative to your shaft speeds, not car speed, although obviously the faster you go, the faster your dampers will move over a bump). The second thing to bear in mind is that your wheel velocity in relation to damper velocity depends on the motion ratio (or velocity ratio, it's in there on the label).

Figure 7: Force/velocity plot in bump and rebound with phases identified



Fernando Alonso strikes a kerb hard in 2012. Reducing your high speed bump can help when kerb hopping is unavoidable

High and low speed

On the examples we have let's assume we have a motion ratio of *one*, where for, say, 5mm wheel travel, we have 5mm damper travel – it will save confusion on what is already an intricate, complex phenomenon.

In real life due to packaging constraints, geometry layouts, weight distribution and wheel travel requirements we can have motion ratios of under-driven or over-driven dampers.

Because of the motion ratio, an under-driven damper will have stiffer springs, but the downside is that because of the high spring rate, the damper will be working harder, for apart from controlling the mass on the corner, it will also have to control the spring force itself, and as it will move slower the hydraulic damping will be less for a given wheel velocity. For that reason most top flight formula cars end up having over-driven dampers, which enable them to better control low speed damping and the important change of motion, as the shaft is shuttling between bump and rebound. A secondary benefit to all of this is the use of softer springs for the same wheel rate, which will tend to weigh a bit less.

Spring time

The only advantage of under-driven dampers is they allow you to use higher rate springs, which are easier to pair, manufacturing tolerances for a coil spring being sadly wide, even from reputable suppliers, and the stroke required is shorter, useful on some very tight installations. If you are not involved in the car design this parameter should be put in the 'It is what it is' file and you will have to learn to live with it.

There is also the peril of having your bump/rebound settings too offset, which could conceivably 'pump down' the car on a straight, as it gets snubbed in rebound, but with a too soft bump value. It might lead you to raise ride heights needlessly to counteract the bottoming, when it is a dynamic effect of your settings.

High speed is only touched to control big bumps and correct kerb strikes

Dampers can change the balance in many sectors of the corner, but the first priority will be to find the best setting for your overall grip, and then you will use your low speed settings to fine tune the transient feeling.

But as stated before, you have to take care of the front and rear ride frequencies. The ride frequency is the undamped natural frequency of the chassis at each corner.

Beware of drivers

Bear in mind that sometimes a better 'feeling' for the driver is not really improving the lap time. Any comment along the lines of 'it feels better' without faster lap times can be ascribed to a less harsh feeling or a less peaky racecar. Go back to base settings. If the car is too harsh over some kerbs – and running over them can improve lap times – reducing high speed bump or blow off valve values can be beneficial (I do not believe I just wrote that!).

An undamped system will always vibrate at its natural frequency. Increasing the damping ratio will make the oscillation trail off, thus bringing the system to a steady state value. When critical damping is attained it gives the fastest response time without overshoot.

Under critical damping, the system is slow responding. Remember that when setting the shock absorbers on the racecar, that is when damping is present, the amount of damping does not change the steady state value, it only changes the amount of time it takes to get there and the overshoot response.

Critical appraisal

Most racing cars operate with damping ratios at least 30 per cent over critical (CCrit); up to twice CCrit is mainly the higher downforce racecars. Under critical will have more mechanical grip (part of the less damped hub paradigm) but over critical damping can help aero platform control. Downforce values will more than make up for it. Likewise, setting your dampers on a seven post rig will need at least a 30 per cent increase in values found ideal on the rig for the track, again an empirical observation, which will need a little bit more research to build the equations to attempt to explain it.

The cornering balance is affected by the distribution of load between the two front tyres. As the efficiency of a tyre is reduced with increasing load, a larger difference in load between the two front tyres tends to increase understeer. Also, a smaller difference will decrease the understeer. The same reasoning applies to the two rear tyres.

A quick word here about reservoir gas pressure. Gas pressure can be like spring rate; a quick fix to increase spring rate slightly. This is more used for a fine-tuning adjustment – 3.5bar (50psi) is roughly similar to 0.5 to 1.2N/m (5-10lbs of spring rate). It's a quick way to get some more grip for qualifying, as it will heat the tyres up a bit quicker. The downside to this is slightly increased wear, so if this is an issue then trim back to base when it's time to race.

Damp and sweaty

To finish, it's worth going over some equipment issues you might encounter, for instance, signs of fluid. 'Sweating' fluid around the shaft bearing and shaft is normal; shaft seals are not too tight, to reduce friction. But if big amounts pool on top of a cylinder, inspect the seal and replace.

All the above is an entry level run through dampers, though. You are encouraged to read several damper design and build books, or research on the internet, as this is an inexhaustible subject – in that respect like tyres and driver motivation.

Quick troubleshooting applicable to most damper systems

Initially try to work on the car's weak end. Increasing grip through settings should always be additive. If a car is too unbalanced and you have run out of adjustment to increase grip, reduce grip on the other end, but this is more of a 'no choice' move.

Too much bump force can give you understeer, reduce bump four or six clicks, or more, until your race driver feels he is losing support, then go back a couple of clicks. As aero is dependent on front ride height and rake, too much rear rebound can reduce front *Fz* transfer, softening rebound can help turn-in.

In the case of entry oversteer, a particularly nasty response, stiffening the rear rebound can help reduce the sharpness, this is really the opposite of entry understeer.

If you have mid-entry understeer, check if the chassis is taking a set, then going into understeer, or if it is simply understeering. If it takes a set, then understeers, then you need more front bump, to support the front and slow the transfer. If the chassis doesn't feel like it is pitching, soften front bump, this will make it more compliant, increase front downforce through the lower front ride height and increased rake, transferring weight faster to the front, and also helping to increase grip.

With mid-entry oversteer, if it's set off when getting on the throttle, soften the rear rebound. The aero effect is a mirror to what you do at the front with mid-entry understeer.

With exit power-on understeer, add front rebound, to keep front splitter or front wing working, or to slow down rake change to nose up. Adding front rebound is the universal panacea, it helps in all the phases. If not enough, or you are running out of adjustment, increasing rear bump will help for the same reasons.

If it is still oversteering, increase the rear compression. This will balance out the chassis by taking some grip away from the rear of the car.

With exit oversteer, reduce rear bump; faster transfer to the rear tyres, creating more grip through *FzRr*. If this proves to be not enough, then slacken off the front rebound.

Violent turn-in oversteer can be quelled a little by stiffening the rear rebound. Conversely, softening rear rebound can promote turn-in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Typical examples of Custom Quantum TMR suspension rocker position sensors as used in IMSA DPI sportscars. Left is rear rocker sensor and right is front rocker sensor

Some like it **hot**

Leading motorsport design and development company Reventec reveals how the highest spec motorsport sensors are produced to withstand the ultra-extreme temperatures found in modern racecars

The sensors feature integrated electronics capable of operating continuously and accurately at temperatures of up to 150degC

The extreme temperatures found in and around the engines of motorsport vehicles make for a tough environment for sensor operation. Electronic devices not up to specification will suffer drastically reduced lifespans, become increasingly inaccurate, or fail outright, with obvious disastrous consequences.

While delicate conditioning electronics can often be separated from the main body of a sensor, isolating them from potential causes of overheating, this can bring its own share of potential problems. A separate electronics enclosure adds extra weight to a vehicle, occupies more space when mounted, and requires additional wiring to be routed around the body of the car – resulting in extra complexity and potential points of failure.

In the electronics world, the temperature ratings of individual components from different manufacturers vary, as do the ways in which these ratings are determined. Most commercially available electronic components, however, fall into one of several temperature grades depending on their intended use and the desired level of performance (**Table 1**).

Higher grade components than these do exist, but once you get into this territory the cost increases dramatically, and even more importantly, there are no functional equivalents of many off-the-shelf components commercially available at these ratings.

Reventec has risen to the challenge and met the industry's demand for higher temperature-rated electronics with its new range of sensors. Designed around a common electronics architecture, the new sensors feature integrated electronics capable of operating continuously and accurately at temperatures of up to

Table 1: General summary of commercially available electronic components

Range (degC)	Usage
0 to +70	Lowest cost and therefore most common. Generally suitable for consumer electronics, as well as industrial equipment which is used in relatively benign environments.
-40 to +85	'Industrial' temperature grade, suitable for equipment which needs to operate outdoors, or where ambient temperatures can be higher and where cooling is an issue.
-40 to +125	'Automotive' temperature grade. These parts are generally specified for use on road vehicles, where severe heating can occur as a result of being exposed to direct sunlight, or in under-bonnet applications. The range of parts available in this range is often restricted.
-55 to +150	Typical 'military' specification; reserved for a small number of parts with limited specification and functionality.

Isolating delicate conditioning electronics from potential causes of overheating can bring its own share of potential problems

150degC, utilising the latest state-of-the-art commercial temperature-resistant electronics.

In addition to developing various off-the-shelf motorsport products which can now be offered with new high temperature electronics, Reventec specialise in providing bespoke sensing solutions with customised mechanical engineering. Unusual fuel tank profiles, custom housings/flanges with unique mountings as well as specific wiring details and electrical outputs can all be catered for to a customer's exact specifications on any quantity from a 'one off' to a volume request. In addition, testing and calibration requirements can be fine-tuned for specific customer needs, ensuring the end user ultimately receives a product tailored to their exact application without any additional time/effort spent during sensor installation.

Sense-ability

Accurate linear and rotary position sensing is crucial for a wide variety of operations in a racecar. Throttles, brakes, suspensions, steering, gears and clutches are just some examples that all require reliable reporting of position data, sometimes down to the micron level of precision. Solid-state, non-contact measurement methods are now often considered one of the most reliable ways to achieve this, as a lack of moving parts means less wear-and-tear and allows for greater flexibility with installation.

A physical property called magneto-resistance – the changing value of a material's electrical resistance when subjected to a magnetic field – is often leveraged for non-contact position sensing. The first discovery of ordinary magneto-resistance was made by William Thomson, better known as Lord Kelvin, in 1856 but only in recent decades have further discoveries been made with specific variants of the effect. There are several different types of sensor that make use of magneto-resistive effect. Among these, some of the most common and commercially important include: anisotropic magneto-resistance (AMR), giant magneto-resistance (GMR), and tunnelling magneto-resistance (TMR). Although the origins of these different effects can be traced back to what Lord Kelvin discovered, only in recent decades have GMR and TMR techniques been developed for commercial use.

Tunnel vision

Reventec's latest Quantum position sensors make use of tunnelling magneto-resistance. As the product name suggests, TMR is a quantum mechanical effect, occurring when electrons tunnel from one ferro-magnet to another separated by a thin insulating layer. The tunnelling effect can only occur if the insulating layer is thin enough, typically only a few nanometers in thickness. Since this process isn't possible in classical physics, the tunnel magneto-resistance is therefore classified as a quantum mechanical phenomenon.

Reventec has developed this technique to detect the position of a target magnet through large sections of non-ferrous materials, including stainless-steel, aluminium, titanium and carbon-fibre, thus making it one of very few position measurement methods available that able to offer this capability.

The field sensitivity achieved with TMR is typically over 1000 times that of a standard Hall effect sensor, resulting in a highly accurate, low noise signal that allows precise position measurement even if the target magnet is up to 50mm away from the sensing head.

Table 2: Magnetic sensor technology advancement

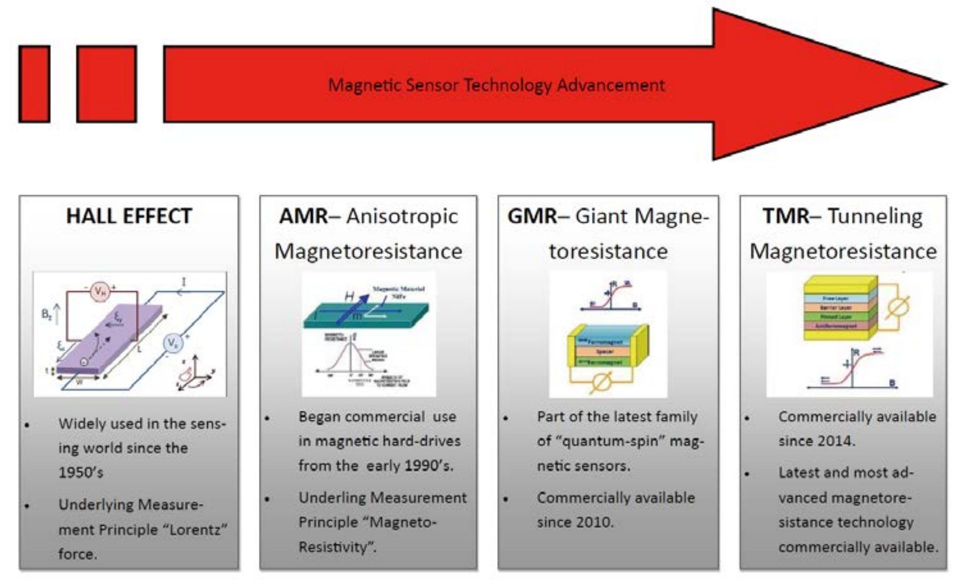


Table 3: Magnetic sensor performance comparison

	Hall Effect	AMR	GMR	TMR
Power consumption (mA)	15-20	1 ~ 10	1 ~ 10	0.001 ~ 0.01
Field sensitivity (mV/V/Oe)	~0.05	~1	~3	~100
Resolution (nT/Hz^1/2)	>100	0.1 ~10	1 ~10	0.1~10

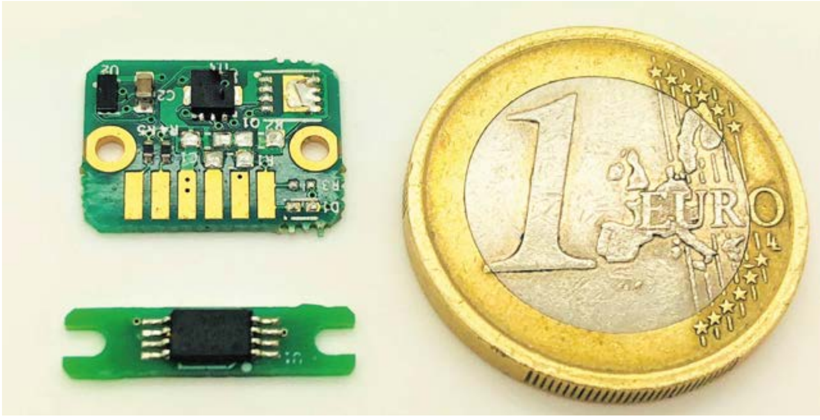
Table 4: Quantum 360HT headline specification

Quantum 360HT	Spec
Supply voltage	5VDC or 6-31VDC
Power consumption	25mA (14mA eco mode available)
Measurement rate	5kHz (2kHz in eco mode)
Measurement range	0-360 degrees
Temperature rating	-40 to 150degC
Accuracy	+/-0.1 degrees
Output Options	CAN, 0-5V Analogue

Table 5: Quantum Custom HT headline specification

Quantum Custom HT	Spec
Supply voltage	5VDC or 6-31VDC
Power consumption	25mA (14mA eco mode available)
Measurement rate	5kHz (2kHz in eco mode)
Measurement range	Linear: 0-150mm Rotary: 0-360 degrees
Temperature rating	-40 to 150degC
Accuracy	+/-0.1 degrees or +/-0.1mm linear
Output options	CAN, 0-5V analogue

Quantum 360 position sensor



Top: Reventec's 2015 TMR sensing head. Bottom: Its tiny new 2018 150degC rated TMR sensing head

Table 6: ProSense HT summary specifcation

ProSense HT	Spec
Supply voltage	6-31VDC or 5VDC options
Power consumption	15mA @ 12VDC
Measurement rate	100Hz
Probe measurement temperature range	-40 to 150degC
Temperature rating	-40 to 150degC
Accuracy	+/-0.5degC
Output options	CAN, 0-5V analogue


ProSense oil level sensor with integrated connector


ProSense oil level sensor with three hole flange

This breakthrough technology has been a game-changer for several different motorsport applications, from in-cylinder piston position measurement to highly accurate rotary measurement where space is at a premium.

Over the past 30 years many applications have relied on Hall effect devices in applications where high mechanical wear from repetitive movements have been present but these can often limit an engineer's design freedom due to Hall technology often requiring the magnet target to be in close-proximity to the Hall device. The developments made with TMR technology now enable greater design flexibility with enhanced accuracy with numerous customers in championship such as F1, WEC and IMSA deploying it to good effect in applications such as brake-by-wire, hydraulic accumulator piston measurement, suspension rocker measurement, pedal and throttle position applications.

Quantum leap

The Quantum range is now rated from -40 to 150degC and is available in an infinite number of design packages from an off-the-shelf 360-degree rotary position sensor to bespoke integrated 150mm stroke linear designs to multi-channel non-concentric rotating gimbal applications.

Meanwhile, Reventec's ProSense liquid level sensors use solid-state capacitive measurement technologies to accurately measure the volume of fuel, oil, water and other liquids in harsh

The developments made with TMR technology now enable greater design flexibility with enhanced accuracy for many customers in F1, the WEC and IMSA

Taking the strain

Strain gauges measure downforce loads. The primary use is to get the balance of the racecar set up correctly for each given race circuit and to understand the changes that are made to the car in practice sessions, with regards to changes in ride height and wing configurations.

To achieve the accuracy required, First Sensors has designed and developed its own strain gauge system called Thermalock, which uses patented strain gauges which make use of a special temperature sensor built into the strain gauge. Thermalock is a digital system that actively compensates the strain gauge's auto temperatures as high as 250degC.

This is achieved in combination with a miniature strain gauge amplifier that gives analogue or CAN based output .

First Sensors makes a large range of infrared sensors for measuring temperatures contactless on a car. Products range from simple one-spot tyre measurement up to 80-pixel arrays, giving engineers up to 80 separate temperatures across a tyre in real time via a CAN bus.


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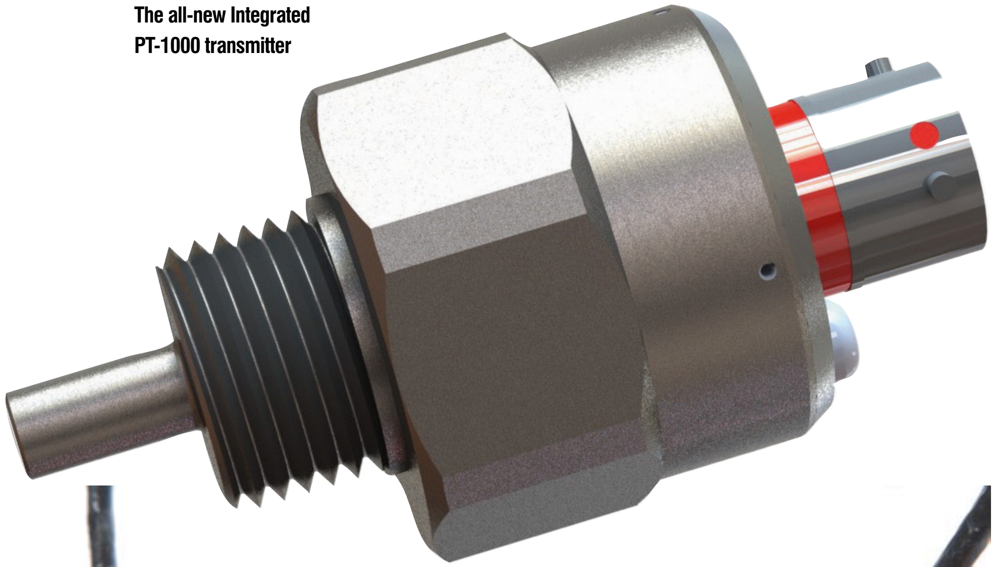
Table 7: PT-1000 transmitter spec	
Integrated temperature transmitter	**Spec**
Supply voltage	6-31VDC or 5VDC options
Power consumption	17mA @ 12VDC
Measurement rate	100Hz
Temperature rating	-40 to 150degC
Accuracy	+/-0.5degC across measurement range
Output options	CAN, 0-5V Analogue



The all-new Integrated PT-1000 transmitter

Reventec's military spec temperature transmitter

motorsport environments. The new ProSense HT now utilises integrated electronics which are rated from -40 to 150degC. This has been designed as a direct drop-in replacement for its 125degC rated predecessor.

Weighty issues

The new electronics boast the same reliability and robustness common to the ProSense range and adds a CANBus output option in addition to the standard 0-5VDC analogue output. 'This advance in elevated temperature capability stems from a continued development with our capacitive technology,' says Reventec director Neville Meech. 'We've responded to customers who have previously used our sensors with remote electronics for high temperature applications such as gearbox oil measurement and requested weight and wiring reductions.

'Developing the 150degC electronics now enables us to continue to offer the customer the same design of sensor, but now with integrated electronics, preventing them from needing to re-design their tank to accommodate a new product,' Meech adds. 'In recent years we've seen many applications increase in temperature especially where measuring oil is concerned and this latest development from us now dramatically improves what we can offer.'

So solid

Reventec's robust solid-state temperature sensors are based around a high-accuracy PT-1000 sensing element. A built-in transmitter converts the sensor measurements to either an analogue or digital CANbus output, both of which are fully configurable, mapping the outputs to any temperature range from -40 to 150degC. Two standard products are available with integrated electronics, one suited to 5V supply only and the second suited to 6-31VDC input. Each sensor is a compact stainless-steel design offered with a standard 5/8UNF thread and integrated Deutsch AS connector.

In addition to these standard designs, Reventec also offer this configurable temperature technology in custom housings for specific applications. One such example was for an overseas military customer who requested a oil temperature sensor that would provide an accurate 0.25VDC – 4.75VDC over a mapped -50degC - +170degC temperature range.

This was achieved by developing a custom back-shell that was fitted to a 38999 series military connector, in which the temperature sensor electronics were housed. This enabled the sensor probe to be exposed to temperatures up to 250degC, if required, but without compromising the reliability of the electronics converting the PT resistance to the required matched voltage output.

Other examples of the temperature sensing customisation include inlet manifold air temperature measurement, again offered with a programmable analogue output.

Accurate linear and rotary position sensing is crucial for a wide variety of operations in a modern racecar

Pressure scanner

Evolution Measurement has launched a new pressure scanner platform which is unique in enabling users to make critical measurements in previously inaccessible areas. Pressure scanners are essential in aerodynamic testing of a wide range of items from wind turbine blades and aircraft wings to Formula 1 cars.

In consultation with many customers in motorsport, the need was identified for a scanner that could measure pressures accurately and quickly in a very confined space, that is also often subjected to high temperatures and much vibration. Evolution Measurement developed a rugged scanner that could operate in such arduous conditions. Weighing in at less than 15g and fully encapsulated in carbon fibre, with a single communications and power lead, the EvoScann P8 is ideal for a wide range of applications, often being inserted directly inside an aerofoil section where it provides no disturbance to the airflow.

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First sensors IR range are designed to measure the temperature across a tyre and single spot temperatures for brakes and clutches.

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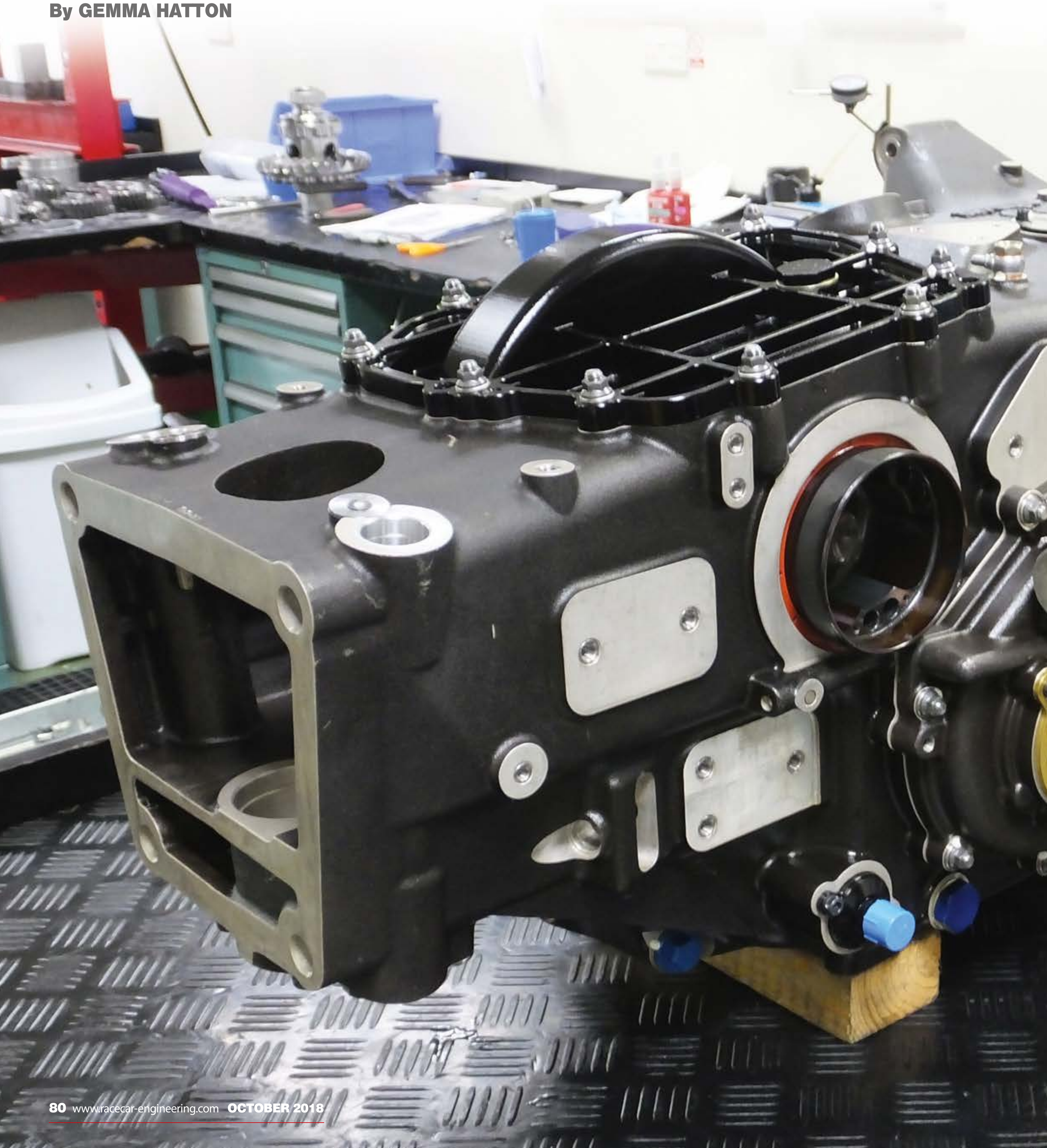
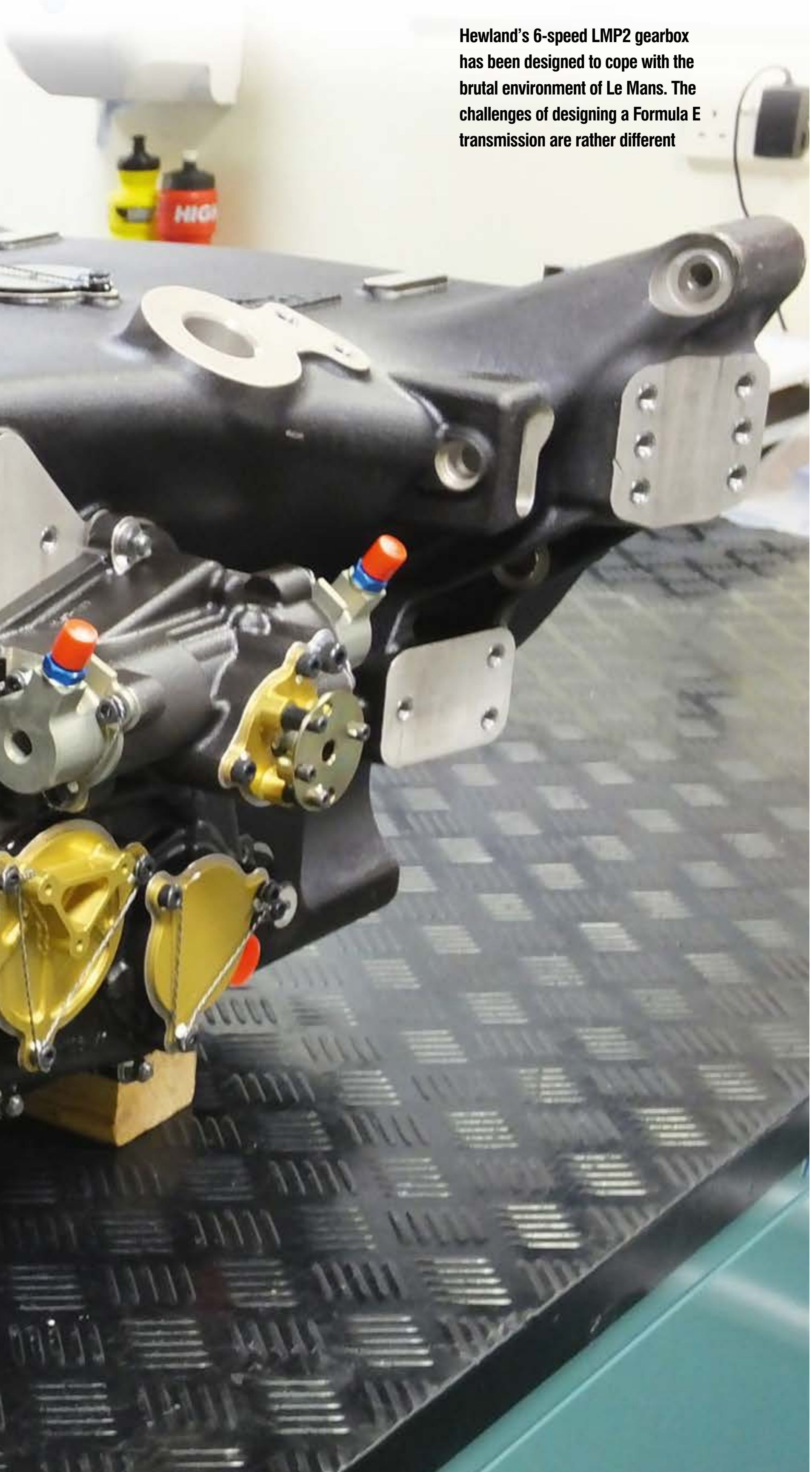
Shifting perspectives

Ever wondered how a transmission manufacturer meets the vastly different challenges of supplying both electric and internal combustion championships? *Racecar* visited Hewland to find out

By GEMMA HATTON



'LMP2 and Formula E present different durability challenges and are both equally tough in their own way'



Hewland's 6-speed LMP2 gearbox has been designed to cope with the brutal environment of Le Mans. The challenges of designing a Formula E transmission are rather different

Whether it is a 200kW Formula E car, or a 450kW LMP2 car, the amount of power an engine produces is useless if it cannot be transmitted to the wheels. This is where gearbox technology comes in.

For a conventional engine, its speed is defined as the number of revolutions of the crankshaft per minute (RPM) while engine torque is defined as the amount of twisting force it generates at the crankshaft. There is a narrow window where the engine speed generates the right amount of usable torque for the engine to perform within its optimum condition, referred to as the power band.

Shift work

Keeping within this power band is key for maximum performance, and having a range of gear ratios to allow you to stay within this power band whilst accelerating is why cars change gears. Transmissions use different ratio gears to provide the required amount of torque to the wheels to allow the vehicle to operate at top speed whilst providing sufficient torque to launch the car from stationary.

But for electric racecars, the challenge for the transmission is somewhat different. The gearbox is no longer dealing with torque from the engine and the associated power bands. Instead, the gearbox is driven by electric motors which provide a near-constant and instant torque. This range of the motor means that theoretically only a single gear is required, so why do electric racers have transmissions?

Motors have specific rev ranges where they operate most efficiently, and this efficiency varies hugely depending on the motor architecture and design. Some motors can rev over 30,000rpm, whereas others only reach a maximum of 9000rpm. Motors can deliver very different torque bands, then, and so utilising a transmission ensures that the motor is always operating in its most efficient range possible.

Single speed

But when a driver completes a gearshift, there is an instantaneous drop in power, causing inefficiencies, which is not ideal in energy conserving formulae such as FE. Therefore, the transmission design needs to balance maximising efficiency through the race while maintaining maximum acceleration from stationary. This has resulted in a varied approach from the FE teams which has changed each year as the rules continue to allow more freedom.

'Generally, in Formula E there are fewer gears and we have seen the trend where year-on-year the number of gears has dropped to now where there are only a handful of teams that are running gear shift systems at all because they are running single speed transmissions and rely on the range of the motor,' says David Warner, technical consultant to Hewland.

Hewland Formula E gearbox. Despite the slower speeds in FE designing a transmission to cope with the high regenerative loads from the electric motors has been a real challenge

'Another lesson we learnt from Formula E was how different the shift strategy needs to be when you have to change gear and cope with the high regenerative loads from the motors,' Warner adds. 'Teams have been going to higher speed electric motors resulting in extremely high input speeds so we have to keep as many components within the transmission at those high speeds whilst reducing the inertia and weight of the shafts to then go to a final drive and this is a very large ratio change. It has been interesting dealing with very large and narrow gears, which is something we have had to develop. There has also been a lot of innovative engineering work around the casing and casing designs because each team has very different gears and configurations which all need to be packaged effectively.'

Sports *vs* sparks

Perhaps nothing highlights quite so well the different challenges presented when designing a transmission for a combustion powertrain compared to an electric powertrain than a comparison between LMP2 and Formula E.

'LMP2 and FE are opposite ends of the spectrum,' says Warner. 'In Formula E you've got short sprint races where the cars haven't got that much power, but high regeneration and drive loads. Whereas in LMP2 the power is massive and the gearbox has got to be robust enough to last the distance, so you are balancing a completely different set of performance criteria. It's an interesting challenge because our products need to serve the requirements of both these categories.'

With its bespoke 6-speed transmission, Hewland supplies sportscar manufacturer Onroak Automotive, which has five LMP2 cars in the European Le Mans Series, plus two DPIs and one LMP2 car in the American IMSA series, and one LMP2 car in WEC. Hewland also supplies multiple Formula E teams with complete bespoke transmissions.

Plugged in

Hewland's involvement in sportscar racing dates all the way back to the 1960s while its first electric racing project was over a decade ago. 'When Formula E was first launched we supplied the entire grid with a pretty much off the shelf product and our involvement with Formula E has continued ever since,' says Steve Robins, CEO of Hewland. This off the shelf product was a 5-speed sequential gearbox which worked together with motors from McLaren.

'Year-on-year Formula E is becoming more competitive, especially with some of the big manufacturers now involved,' Robins adds. 'Everybody is looking for that *nth* per cent performance improvement and the regulations are not so restrained as in F1. So Formula E has actually been a platform for lots of new technologies that we have looked at for the casting processes, coatings, gear steels and tooth geometry. A lot of these were first applied in Formula E, which is a good demonstrator for us to then carry these over into other industries. Considering the race series that we get involved in, LMP2 is the pinnacle of what we do from a complete transmission perspective, but Formula E is definitely pushing the boundaries in terms of technology.'

Boxing clever

Regardless of the type of gearbox, the design starts in the virtual world. Hewland use software from its partner Romax to analyse the gears and bearings, and take the gear loads that are seen and feed this data into the FEA software to analyse the design of the casings. In this way, the most efficient layout can be defined.

'We are able to put a duty cycle into the software, such as the 24 hours of Le Mans, to understand the loads that the gearbox will be subjected to,' Warner says. 'We can then define the precise bearing and mesh positions within Romax, so we create the gearbox in a 3D virtual form which we link to the duty cycle. At the end, the software tells us exactly which bearing might be the limiting factor within the gearbox or which gear mesh might be experiencing the most deflection. You can also investigate adjustments, such as the effect of changing the pre-load of a bearing on the life of the gearbox.'

Of course, with any simulation tool, the results need to be taken with a pinch of salt and the correlation with reality is an ongoing and iterative process. It is the same with wind tunnel and CFD data, which both need to be validated with track testing. All that said, simulation does provide an excellent tool for

'LMP2 is the pinnacle of what we do in terms of transmissions but FE is definitely pushing the boundaries in terms of technology'

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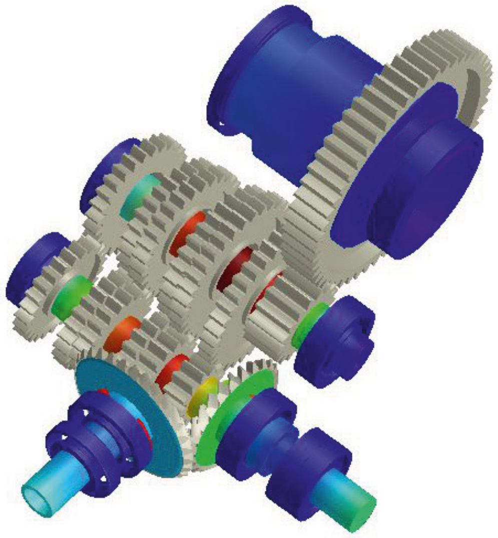


Real duty cycle data can be put into the Romax software which then helps Hewland determine exactly which bearing or gear mesh could be a limiting factor

The gear cluster from Hewland's LMP2 transmission. The contact patches between the gear teeth need to be designed so the gears do not deflect or slide under load as this can generate heat, leading to inefficiencies

comparisons, where trends can be defined, rather than precise values.

But this virtual testing can also translate into real world results, as Warner explains. 'Recently we received results from a test in America where we improved the efficiency of the gearbox. This amounted to an average gain of efficiency of 2.5bhp, which is quite an improvement. This was simply based on looking at the gear loadings, exporting them into the FEA and understanding the deflections, which we could then analyse to improve the efficiency of the gearbox.'

Quality assurance

This refining approach has allowed Hewland to develop robust and reliable gearboxes which are a necessity, particularly in endurance racing. So much so that Hewland now actually gives a warranty on their LMP2 products, just like you might have on your road car.

'Efficiency' underpins every design, simulation and test in motorsport and in gearbox terms that efficiency relates to bearing design, weight and temperature. 'We need to ensure that we are using the most appropriate bearings and components,' Warner says. 'So the gearbox isn't carrying extra weight which can cause additional drag through the gearbox.

'But perhaps more importantly, it is the rotating inertia of these parts as well,' Warner adds. 'For example, we are very specific on the geometry of the input bevel gears. This is because when you go through a 90-degree directional change on a shaft you have worse losses than you do with a conventional spur gear set. This is due to increased sliding between the bevels, which generates heat, so you have to analyse how they are loaded and the corresponding deflections. You are effectively looking to put the contact patch between the gears in the best position possible to achieve maximum efficiency and strength.'

Hot cogs

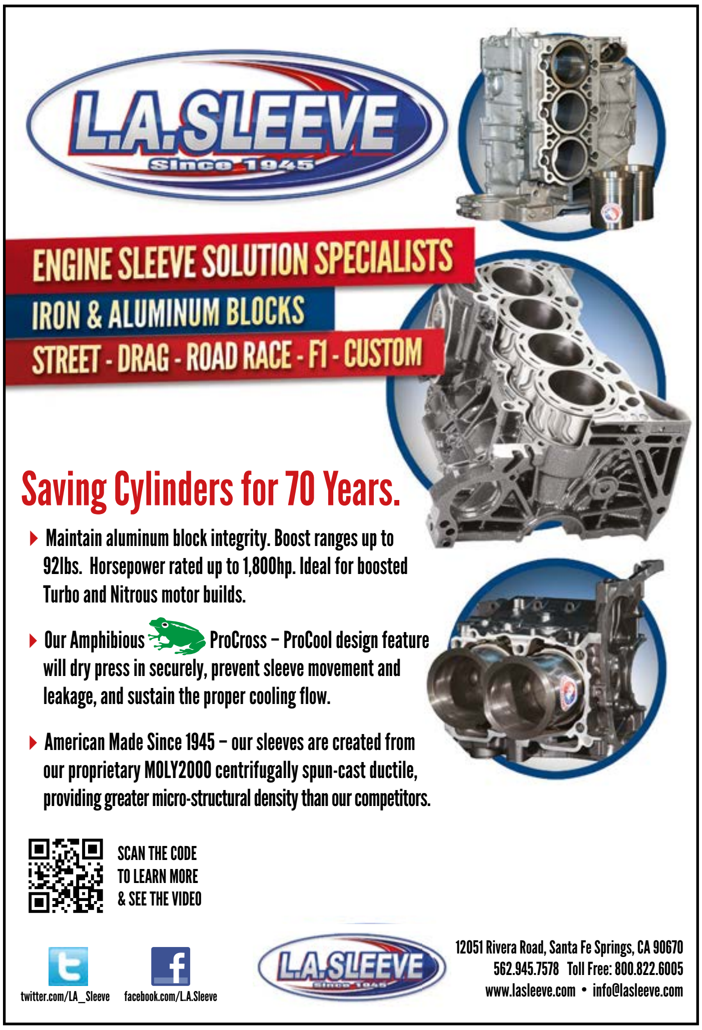
Heat, as ever, is the enemy, because any energy dissipated as heat is energy wasted and therefore a loss. Add to that the fact that heat results in accelerated wear of components, reducing life, and you can understand why every measure is used to mitigate those temperatures. This brings us to another major difference between Formula E and LMP2. Although both transmissions are oil cooled, the chemistries of the oil used is vastly different between the two. This is because in Formula E the gearboxes start from cold and suddenly have to cope with the maximum torque almost instantaneously. Whereas in LMP2 the gearboxes can take up to several laps to warm up, and the temperatures reached are much higher due to the higher power. Hewland recommends not to run at oil temperatures above 110degC in LMP2, because then you start getting towards the tempering temperatures of the gear steels.

'The gearbox oil reduces the amount of heat that is generated by creating a film on the contact patch of the gears which improves the lubricity of the surface,' says Warner. 'The viscosity of the film changes with temperature and if you look at standard gearbox oils then you can get a major shift in the quality of that protective film across different temperature bands. This is why we have worked with our partner Millers Oil to develop special oils for both LMP2 and Formula E.'

Smooth coat

Another way to reduce the amount of heat generated is through the use of coatings. Unlike LMP2, coatings are allowed in Formula E and are therefore a significant area of development. These coatings add a layer of protection to the gear steels, to help minimise wear and allow components to run at hotter temperatures.

In Formula E the gearboxes start from cold and then suddenly have to cope with the maximum torque almost instantaneously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The LMP2 differential. Gear steels have remained pretty much the same for many years but Hewland is looking at new materials, while in Formula E it's been allowed to use hi-tech coating technology

Hewland now gives a warranty on its LMP2 products, just like on your road car

Modern coatings now have the capability to cope with temperatures of up to 200degC.

'The more protection we can build into the gearbox, the better,' Warner says. 'We want a solution for those categories that allow coatings, but also the metals themselves to be able to survive the extreme instances where there is a temperature spike in the gearbox, which is particularly important in endurance events. Gear steels have been a generic sort of chemical composition for a very long time now. Cleanliness is a high priority so as many impurities as possible are removed. We also look at changing the blend of chemicals to give the best characteristics of the metal. We are on a real push for new materials and we have some exciting projects in the pipeline.'

Call of duty

Out of the two, the lower power, shorter distances and overall less brutality of Formula E would seem to make this the easy option. But as mentioned above, the high input speeds are just one of the reasons why this is not the case. Add to this the fact that the upcoming season five (2018/19) will see one of the biggest changes in Formula E history – one car for the entirety of the race – and suddenly the duty cycle of the gearboxes has doubled. Therefore, these gearboxes will need further development to remain robust and reliable, especially as Formula E gearboxes are sealed for the season.

'As engineers, the ideal design is the one that finishes the final lap of the final race and then falls apart,' says Robins. 'Engineering is a task where you redesign something to fail, because you are continually pushing it towards that point of failure to reach the optimum weight and therefore the optimum performance. LMP2 and Formula E present different durability challenges and are both equally tough in their own way. It is not easy, otherwise everybody would be doing it.'

Up-shifting

Hewland's involvement in both these categories is set to continue, and could even expand in endurance racing depending on how the future of LMP1 and LMP2 is mapped out by the ACO and FIA. 'There are still a lot of question marks on how LMP2 will develop as a category going forward, so this is a period of change,' says Robins. 'Equally, in Formula E, the rate of progress in electric drivetrains results in lots of changes, but those changes are fairly well mapped out so we know what the technical challenges are. The question is how will LMP2 interface with the revised LMP1 regulations for 2020? We would certainly like to build on the platform we have now in endurance racing, as to what the product offering is and what it needs to be it is still a little bit up in the air, but we would certainly look to maintain our involvement within the category.'

Winning formula

Our resident number cruncher presents his must-read master-class on the fundamentals of effective racecar engineering

By DANNY NOWLAN

A DTM BMW on the limit at Brands Hatch. Grip and balance are the properties of a racecar that race engineers will find themselves dealing with the most

One of the most challenging things when we come to engineering a racecar can be how do you actually go about it? I realise that this, for a lot of motorsport professionals, is the question that dare not be asked, on account you might seem silly. However, a couple of weeks ago I was invited by Altair Engineering to be a keynote speaker at its inaugural Australian FSAE technical conference. I figured this was a fantastic opportunity to address this question.

What I will be discussing here is the text version of the presentation I gave. The goal was to give the budding engineers a road map on how to go about engineering a car. In particular, what you need to be thinking about in terms of hand calculations and when you bring in tools such as ChassisSim. All this allows you to make informed engineering decisions as opposed to just mindlessly using a CAE tool or sticking your finger in the air and hoping for the best.

Also, to set the scene, I will be tying together quite a few elements I have previously discussed. For brevity I will reference these as needed, because what we are about to discuss is quite literally a two-day seminar in its own right.

Grip and balance

To kick things off, if we think about the race engineering problem – that is, making a car go as fast as possible – our two main currencies are grip and balance. I should also add to that if you are in an unconstrained formula engine power as well. However, as race engineers we deal with the first two points the most. Make no mistake, if you are serious about having a car that is fast it must have grip and it must have balance. The ultimate incarnation of this, to paraphrase one of my fellow contributors Peter Wright, is not a racecar, but an aircraft, the Spitfire. It was said you didn't fly the Spitfire, the Spitfire flew you. That's the Holy Grail of what we are after as race engineers.

So the critical question is, how do we put numbers to all this? Grip is the easy part of the equation. For a given set-up, bare minimum you can get a very good estimation of the forces the tyres can produce. However, handling is a different ball game entirely.

To nail down handling your best friend is the stability index (see V28N2). What the stability index measures is the moment arm between the centre of the lateral forces of the car and the centre of gravity. This is illustrated in **Figure 1** and just to refresh everyone's memory the stability index (*stbi*) is calculated by **Equation 1**.

So, a quick recap of what the stability index numbers mean. If the number is less than zero the car is stable, so it will level itself off when an input is applied. When it is zero you give it an input and it just keeps going. If it's greater than zero you give it an input and it spins. The number the stability index returns is the moment arm between the centre of gravity and the centre

Figure 1: An illustration of the stability index

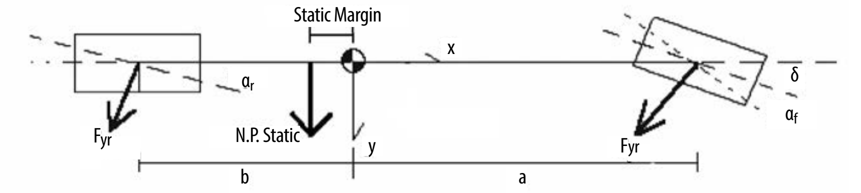


Figure 3: Visualisation of the meaning of a second order tyre model

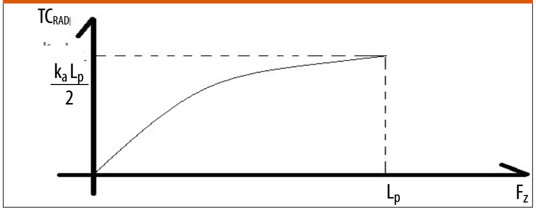
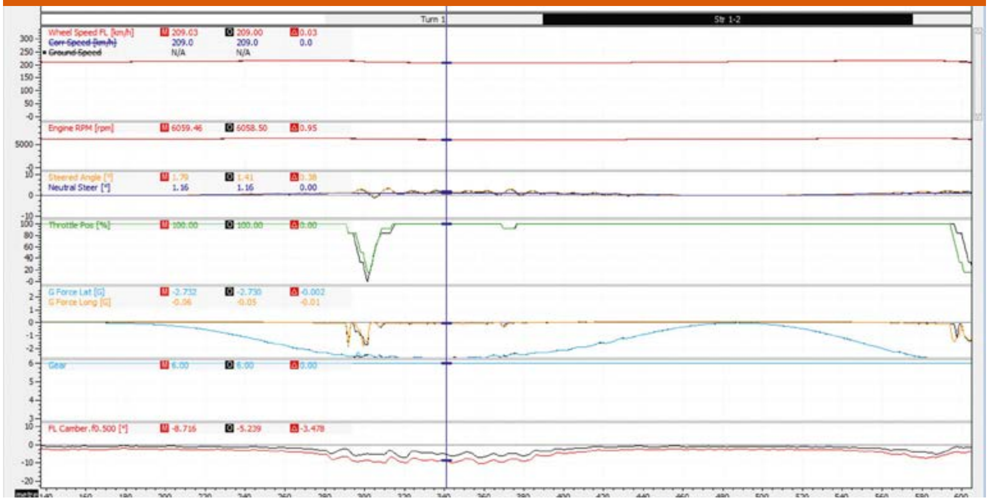


Figure 2: Simulated F3 front wing change



EQUATIONS

EQUATION 1

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\bigg|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2})$$

$$C_r = \frac{\partial C_r}{\partial \alpha_r}\bigg|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4})$$

$$C_T = C_f + C_r$$

$$stbi \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb}$$

Where:

$\partial C_F/\partial a(\alpha_f)$ slope of normalised slip angle function for the front tyre
$\partial C_R/\partial a(\alpha_f)$ slope of normalised slip angle function for the rear tyre
$Fm(L_1)$ traction circle radius for the left front (N)
$Fm(L_2)$ traction circle radius for the right front (N)
$Fm(L_3)$ traction circle radius for the left rear (N)
$Fm(L_4)$ traction circle radius for the right rear (N)

EQUATION 2

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

Where

TC_{RAD} traction circle radius (N)
k_a initial coefficient of friction
k_b drop off of coefficient with load
F_z load on the tyre (N)

EQUATION 3

rcm = rcf + wdr*(rcr - rcf);

EQUATION 4

hsm = h - rcm;

EQUATION 5

rsf = (krbf + kfa)*ktf/(kfa + krbf + ktf);

EQUATION 6

rsr = (kfb + krbr)*ktr/(kfb + krbr + ktr);

EQUATION 7

prm = rsf/(rsr + rsf);

EQUATION 8

prr = (wdf*rcf + prm*hsm)/h;

Where:

rcm mean roll centre (measured in metres)
rcf front roll centre height (measured in metres)
rcr rear roll centre height (measured in metres)
wdr weight distribution at the rear of the car
wdf weight distribution at the front of the car
h centre of gravity height of the car (measured in metres)
rsf wheel spring rate in roll for the front (N/m)
rsr wheel spring rate in roll for the rear (N/m)
ktf front tyre spring rate (N/m)
ktr rear tyre spring rate (N/m)
kfa spring rate of the front coil, acting at the wheel (N/m)
kfb spring rate of the rear coil, acting at the wheel (N/m)
krbr rear roll bar rate (N/m)
prm lateral load transfer through the sprung mass
prr lateral load transfer distribution at the front
tm mean track of the vehicle

of the lateral forces divided by the racecar's wheelbase. As rough rules of thumb you want to be aiming for mid corner values of 0.05 with the occasional venture to 0.1 on turn-in. However these are *rough* rules of thumb.

The reason the stability index is so useful is it succinctly quantifies what the car's handling is doing. The plot of a Formula 3 front wing change in **Figure 2** is a perfect case in point.

The coloured plot is the baseline, the black is the aero balance moved forward by five per cent. As can be seen, the speed, steering and throttle do not change by drastic amounts. The reason for this comes down to the nature of the tyre model and how simulators are like *The Terminator*. They know no fear, they have no concept of mercy and their only goal is speed. However, what has changed quite markedly is the stability index which is shown in the final plot. The baseline has a stability index value of -8.5 per cent and the change is -5.3 per cent. Consequently this forms a valuable tool for nailing down car handling.

Tyre models

So how do we quantify all this? Well the first step is to get yourself a tyre model. Now most people at this stage of the game will just throw their toys out of the pram and say it simply can't be done. But remember a previous article of mine on how to create tyre models from scratch (V26N2)? If so you'll know the key to any tyre model is nailing down the traction circle radius *vs* load characteristic. Its basic building block is shown in **Equation 2**. What this means in plain English is that any tyre model can be broken down into the visualisation shown in **Figure 3** (*Lp* is peak load).

So what this all means is that any tyre model can be described by its peak load and force. So if you know what your peak tyre loads are and what grip you're expecting you can get a representative tyre model very easily.

The way we tie this up through our set-up is the lateral load transfer distribution at the front. This is sometimes referred to as the 'magic number'. While this doesn't really have any magical characteristics it's a great tool to help us nail down our tyre load for a given mechanical and aero set-up. A quick summary of where this comes from is shown in **Equations 3** to **8**.

The real significance of the lateral load transfer distribution is that it gives us a first cut

To nail down a racecar's handling your best friend is the stability index

EQUATIONS

EQUATION 9

L1 = (wdf*mt*g + Faero_f)/2 + prr*(mt*ay)h/tm + other terms

EQUATION 10

L2 = (wdf*mt*g + Faero_f)/2 - prr*(mt*ay)h/tm + other terms

EQUATION 11

L3 = (wdr*mt*g + Faero_r)/2 + (1 –prr)* (mt*ay)h/tm + other terms

EQUATION 12

L4 = (wdr*mt*g + Faero_r)/2 - (1 – prr)*(mt*ay)h/tm + other terms

of what to expect with tyre loads. This is illustrated in **Equations 9** through to **12** – where *mt* is car total mass (kg); *g* is acceleration due to gravity; and *Faero* is total aerodynamic force (N). I go into much more depth on this in my article on tyre load analysis, so I would refer you to that to chase down the details (V28N1).

Even though this is all pseudo static approximations we now have a tool with which we can calculate both grip and stability index. I discussed this in depth in my article on the magic number (V26N9) but the end results of this are illustrated here in **Figure 4** and **Figure 5**.

Figure 4: Grip *vs* lateral load transfer distribution at the front

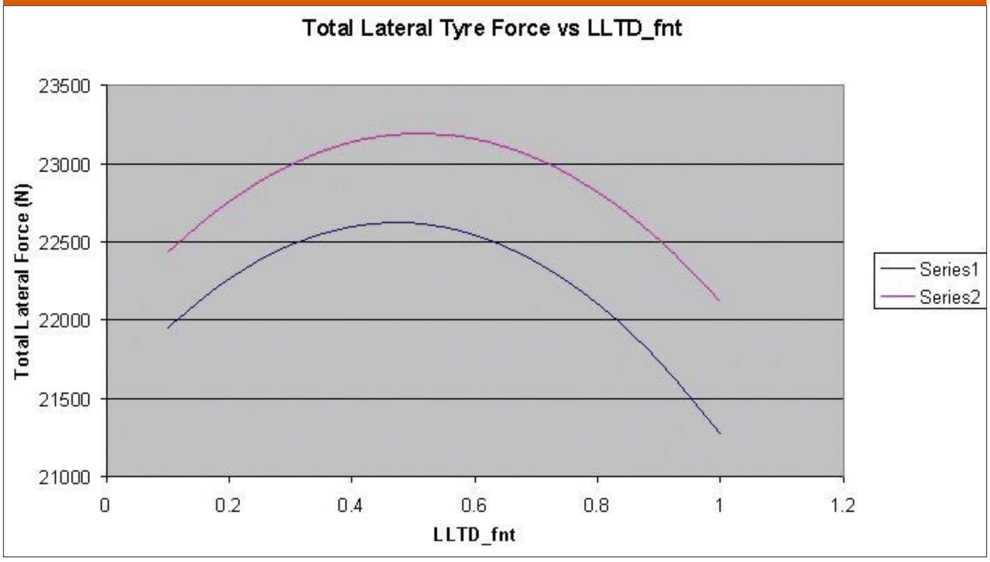


Figure 5: Stability index *vs* lateral load transfer distribution at the front

EQUATIONS

EQUATION 13

$$\omega_0 = \sqrt{\frac{K_B}{m_B}}$$

EQUATION 14

$$C_B = 2 \cdot \omega_0 \cdot m_B \cdot \zeta$$

$$\zeta = \frac{C_B}{2 \cdot \omega_0 \cdot m_B}$$

Where:

- K_b wheel rate of the spring (N/m)
- C_b wheel damping rate of the spring (N/m/s)
- m_b mass of the quarter car.
- ω_0 natural frequency (rad/s)
- ζ damping ratio

This is very powerful because for a given set of tyres it will tell you where you need to be for a given lateral load transfer distribution to generate the peak grip and what this will do for car stability. You ignore these figures at your peril.

The next step in the race engineering process is determining springs, roll centres and pitch centres and hot running tyre pressures. All of this determines the core temperatures/pressures the tyre needs to run at. The springs will be dictated by the aero and getting the core heating in the tyres you need. Also, the relationship between springs and suspension geometry will have a massive impact. There are two ways this can be facilitated. Firstly testing, which is pretty self explanatory, then the other method is using track replay facilities, like in ChassisSim, with the internal tyre temp flag turned on.

Quarter car model

Once you have determined your base spring rate your next port of call is damping. Your best friend in this regard is the quarter car model. While it is not the most exact thing out there the beauty of the quarter car is it allows you to articulate mathematically what your dampers are doing. The core sums you will have to get your head around are **Equations 13** and **14**. The key take away from this is the damper guide, as illustrated in **Figure 6**. The thing about this is it is a first cut, but it gets you in the ballpark.

Once you have done all of this you are now ready to turn on the simulator and your first port of call is the shaker rig simulation. The outputs of the shaker rig simulation are shown in **Figure 7**. The power of the shaker rig simulation is that it allows you to look at the car in the frequency domain and through the contact patch load (CPL) variation it gives you a really good gauge of tyre grip.

Simulation in action

In my 2014 article on simulation in action (V24N5) I described in depth how my Australian dealer Pat Cahill used this to engineer the Maranello Motorsport Ferrari F458 to victory in the 2014 Bathurst 12 hours. To summarise the first part of the process, you play with springs and large damper adjustments to minimise CPL. What will happen is you will get into a zone where the CPL will hit a minimum and actually won't vary too much. Once you hit this you start playing with minor spring and damper changes to get the shape of the frequency response that you want. It's actually that simple. This results in a marked improvement in mechanical grip without compromising driver feel. The other key thing to highlight again is that you choose a corner speed and input velocity that is appropriate for a particular corner you want to analyse.

Once you are done with the shaker rig simulation this is when you move on to the lap time simulation. What the lap time simulation does is it allows you to dial in ride heights, gear ratios, wing levels and in the transient simulation in ChassisSim's case it allows you to build on the good work done in the shaker rig simulation. I have written at length on how to use lap time simulation (V26N7) but let me summaries two key points. Firstly, when using lap time simulation you have to be as deliberate as when you are running the car and you have to look at the data through a slightly different lens. You always log the data and make a running record of it as if it is an actual test. Also, you are looking for small consistent changes. I discussed this at length in my article about how to use simulated data (V26N10) but your changes will show primarily as differences in cornering speeds.

But do not get tied up in correlation because correlation is a consequence, not the end goal. If I had $5 for every time I've seen someone obsessed with correlation in this business I would have retired as a multi-millionaire to a sub-tropical island long ago. What happens with correlation is that as your tyre and aero model evolves the correlation happens as a by-product. The better your driver, the quicker the process is, but never forget this. **Table 1** shows some rules of thumb for cornering speed correlation.

The exception that proves the rule is ovals, since you have to have representative speeds in order to match the tyre loads.

You also don't have to be perfect for something to be useful. For example, **Figure 8** is an example of the correlation I used to get a fair way down the road with a VdeV sports racer driven by an amateur driver. As always the coloured trace is actual, black is simulated.

Summing up

At this point it would be wise to summarise what we have been through here. First, you always need to remember that race engineering comes down to grip and handling, with the latter being quantified by the stability index. We then use data and a rudimentary vehicle model to derive the tyre model. Once this is done, we use this model to determine the lateral load transfer at the front we should be running.

After this we then move on to use testing/open loop simulation to see the combination of springs/pressures/suspension geometry we need to achieve to get the required tyre heating. We then determine our quarter car damper ratios using the damper guide. Finally we then finish the job off by using the shaker rig and lap time simulation tools.

The important thing to remember is that race engineering boils down to grip and balance and what we have presented here is the game plan for achieving this. We have articulated the method of how to use hand calculations, what to look for, and how to use simulation tools like ChassisSim as calculators, as opposed to magic wands. If you can get your head around all this then you are well on your way to figuring out how to get the best out of your car. Past issues referred to in this piece be purchased from: www.chelseamagazinescom/shop

Figure 6: Damper set-up guide

Region	Value
$\zeta_{LS-Bump}$	This is body control so, if it is a bumpy circuit the ratio is 0.5. If the circuit is smooth choose 0.7. If the tyres need to be worked hard then choose 1.2.
$\zeta_{LS-Rebound}$	This will be dependant on a number of factors. Where body control is not significant use 0.3. However where body control is significant use 0.5 to 0.7.
$\zeta_{HS-Bump}$ $\zeta_{HS-Rebound}$	This is the high pass area of the damping curve. The values here should be 0.3 to 0.4

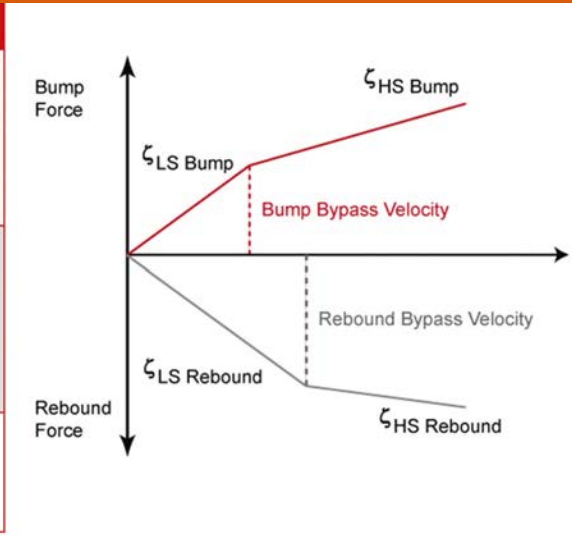


Figure 7: Outputs from the ChassisSim shaker rig simulation toolbox

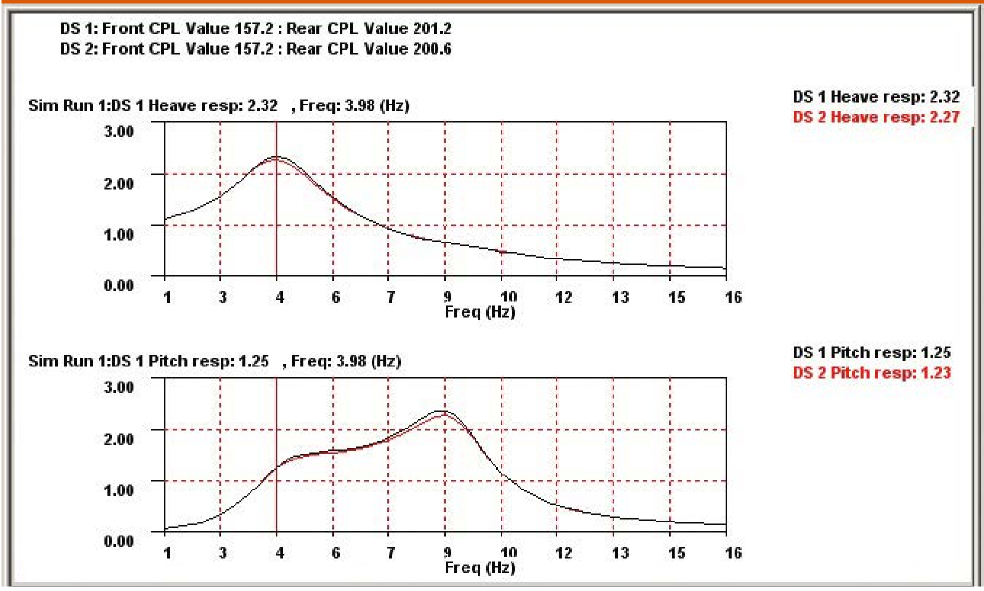
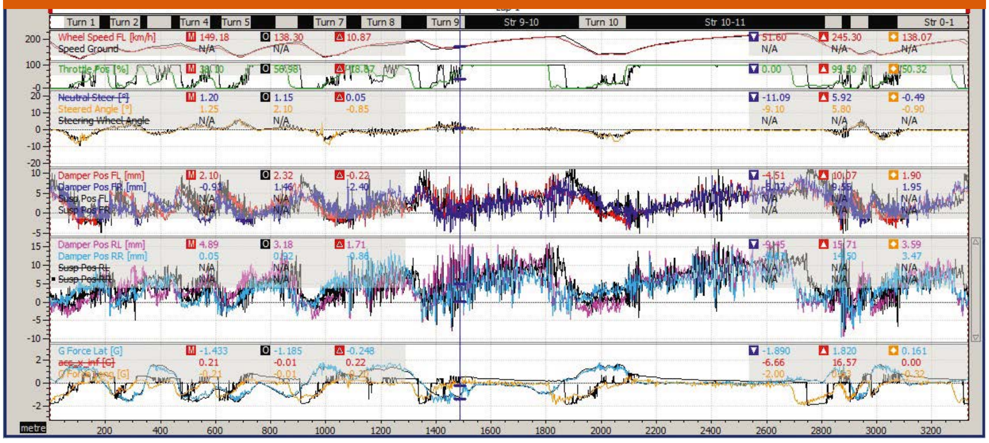


Table 1: Rules of thumb for lap time simulation correlation

Corner speed	Delta
80-120km/h	1-2km/h
120-160km/h	2-3km/h
160km/h +	3-4km/h

Figure 8: VdeV sportscar correlation with an amateur driver



Interview – Bobby Rahal

Indy right place

The IndyCar team boss tells us why he thinks the series is doing rather well right now, and also how he feels it might be improved

By MIKE BRESLIN

'The reality is that outside of Indianapolis the spectator turnout at the ovals is not very good'

If you were to ask IndyCar team owner Bobby Rahal when the top level US single seater series was at its very best he'll say: 'I think around 2001, and into 2002, that was the height.' And Rahal should know, as he's been around the scene in its many guises – through CART then ChampCar – for close on 40 years; as a driver (with an Indy 500 victory to his name plus three championships), as interim president of CART, and as a team boss since 1992. He is now the 'Rahal' in the triumvirate that owns Rahal Letterman Lanigan Racing (RLL), partnering with David Letterman and Mike Lanigan.

But just because he can remember a better time, this does not mean Rahal is unhappy with the current state of the series. 'I think it's doing pretty well,' he says. 'At Mid Ohio I think it was the largest crowd they ever had, it was a tremendous number of people. The racing's always been super competitive, so that's never been an issue. But I think it seems to be on a very positive slope now, we've got really good people behind the series, Mark Miles [CEO] and Jay Frye [president of competition and operations] in particular, and good support from the manufacturers and sponsors, so I think it's in pretty good shape.'

Body image

Part of that 'positive slope' is the new universal body kit that's been brought in this year, which has cut the downforce and made for a much better looking racecar. 'It's like anything, it probably has some shortcomings here and there but it's very good in other areas,' Rahal says of the kit. 'Clearly the cars are much faster in a straight line, with less drag than they used to have, maybe a little less downforce as a result, but at places like Elkhart Lake the lap times are quite comparable. I think it will always be a little bit of a work in progress but I would think that overall everybody's quite pleased with it. They look like proper racing cars again and I think the fans like it. It's still tough to pass, the wash, the disturbance from the car ahead is still a bit of an issue, but I think it's a work in progress and I'm sure there will be minor changes for next year.'

On the chassis side IndyCar is these days very much a spec formula, but Rahal believes the level of engineering freedom is still high enough. 'The teams are able to do more today than they were a year ago, or two years ago, and there's going to be a continual [freeing up] of certain components,' he says. 'The dampers and ride control are still free, and that I think is the big differentiator between the teams now … It's kind of an engine formula now, like it once was, but clearly the ability to develop and build your own dampers and your own ride control, that's a big thing, and what development money there is is mostly spent on this. On the aero side you have what you have, it's just a matter of understanding it, but on the seven post rigs and things like that, that's where you see the investment going, and increasingly you're seeing more and more money on simulation, that the teams are doing or the manufacturers are doing.'

Of course, the reason IndyCar is single make on the chassis side, with each team fielding the venerable Dallara DW12, is cost. Rahal tells us the going rate for a campaign is '$8m pretty easily; but a bargain compared to Formula 1 or a lot of other series for that matter.' This, he adds, also compares very favourably to budgets for CART at the start of the 2000s, which were around the $20m mark – so the current IndyCar beats that halcyon age in this respect, at least.

Third party

Of course, back then there was a great deal of sponsorship money sloshing around the paddock, largely from now banned tobacco and alcohol brands. There was also good manufacturer interest. These days it's a two-horse race on the engine supply front with just Honda and Chevrolet and Rahal agrees with IndyCar that another manufacturer could only be a good thing.

'Well I think it's important for the series,' Rahal says. 'The more manufacturers the better, it creates more awareness of the series, it creates more opportunities for the teams, it's more advertising for the series … a third manufacturer would improve it. There are rumours that a third one is close to making an announcement. The rumours are Alfa Romeo; you also hear of Korean company, Kia, who are getting more and more into the high performance side in their product line.'

But, as Rahal emphasises, these are just rumours. Beyond rumour is the fact that IndyCar is to have a new car for 2021 (see last month's issue V28N9). But what would Rahal like to see from

RLL Dallara in action at Long Beach. Rahal says he is pleased with both the performance and the aesthetics of the new-for-2018 IndyCar body kit the new chassis? 'I would like to see some weight out of the car as right now the cars weigh around 1500lb [680kg]. Some of that is because of the safety aspects for sure, but I think there are areas where the weight could be lessened and certainly I think the gearbox would be the most obvious piece to change.'

One change that seems likely to happen even before the new car arrives is on the cockpit safety front, where IndyCar is currently experimenting with a screen. 'I think it's a good thing,' Rahal says. 'Graham [Rahal, Bobby's son and an RLL IndyCar driver] once told me that a mirror came off the car in front of him and went right by his head and then it bent the rear suspension. So, especially when you're talking 230mph, I think it's definitely needed. I certainly like the windscreen that IndyCar is developing versus the Halo, I know they're tweaking that now, but clearly it's going to happen.'

On the right track

Where the screen will be of greatest benefit will be on the ovals that are a defining feature of IndyCar yet now only make up about a third of the calendar. Some believe that the series should look to its roots and embrace more speedways, but Rahal is not among them. 'The reality is that outside of Indianapolis the spectator turnout at the ovals is not very good. And the spectator turnout at the road courses and street circuits is quite good. If I look at it from a very commercial standpoint I want our team performing in front of the most people every weekend, because that's how I generate value for my sponsors.'

Beyond IndyCar RLL recently became the first team to sign up for the Jaguar I-PACE E-Trophy, a single-make production based electric series that is to support Formula E. 'I think the whole electric world is interesting, it's new, and it's not going away, so we might as well get in on the ground floor and see where we go,' Rahal says, though he adds that where the team *will* go will not be Formula E itself, as that's now pretty much sewn up by big spending manufacturers.

Where it *could* go, though, is Le Mans. RLL already runs the BMW GT effort in IMSA and Rahal is keen on one day fielding a team in the French classic. 'I would certainly like to see us involved in prototype racing, and go to Le Mans,' he says. 'That's something that's very attractive to me.'

RACE MOVES

XPB

Ferrari chairman and CEO Sergio Marchionne has died from complications following shoulder surgery. The Italian-Canadian came to prominence in the automotive industry through his work with Fiat and then later at Fiat Chrysler Group, an alliance he was largely responsible for. He had more recently become a major player in Formula 1. John Elkann replaced Marchionne as Ferrari's chairman and Louis C Camilleri as CEO just before he died.

Lawrence Stroll has led a successful bid to buy Force India, after it went into administration at the end of July. Stroll headed up a consortium comprising Canadian entrepreneur **Andre Desmarais**, **Jonathan Dudman** of Monaco Sports and Management, **John Idol, John McCaw Jr, Michael de Picciotto**, and **Silas Chou**. As a group they have now taken over the ownership of the team from **Vijay Mallya** and Orange India Holdings Sarl.

McLaren has said that it has hired Toro Rosso technical director **James Key** to fill the same position at Woking. However, at the time of writing it was not clear when Key would be able to start at McLaren as Toro Rosso owner Red Bull insists he is still under contract until 2020. Key started his career at Jordan in 1998 and stayed there, through its various name changes, until the end of 2009 when he left what was then Force India to join Sauber. He then moved to Toro Rosso in 2012.

Dave Maraj, the owner of the Audi-running Champion Racing operation which won Le Mans in 2005, has died following an accident at a marina. Maraj, who was from Trinidad and Tobago, built up a successful sports car dealership in Florida before setting up his race team, which with Audi backing dominated the American Le Mans Series in the 2000s.

Jakob Andreasen, formerly an F1 engineer at McLaren, Force India and Williams, has now taken on the role of chief race engineer at the Dragon Formula E operation. Andreasen, who also has experience in IndyCar, BTCC, sportscars and the DTM, will oversee all engineering operations for Dragon for the 2018/19 FE championship.

Frankie Parzych, the crew chief at the Performance Tech Motorsports IMSA operation, has died at the age of 58. Parzych, a popular figure within the team and in the paddock, oversaw the No.38 ORECA FLM09 which won the IMSA WeatherTech Sportscar Championship Prototype Challenge title in 2017.

Well-known NASCAR reporter and author **Tom Higgins** has died at the age of 80. Higgins, who was the recipient of the Squier-Hall Award for NASCAR Media Excellence in 2015, had been in poor health since suffering a stroke last year. He covered his first stock car event in 1956 and was credited as being the first writer to cover every race on the NASCAR schedule.

NASCAR Xfinity outfit JR Motorsports (JRM) has changed the crew chief on its No.5 Chevrolet with **Travis Mack** replacing Jason Stockert in the position. During the 2014-15 seasons Mack held the role of car chief on JRM's No.9 racecar and he returns to the organisation from Levine Family Racing, where he held the post of crew chief for **Kasey Kahne** in the Cup Series. Stockert, who has been with JRM since 2017, has now moved into another role within JRM.

Brian Sims has received an honorary doctorate from Birmingham City University in recognition of his 45 years in the motorsport business. Sims, a renowned sponsor hunter who has written two books on the subject, was once commercial director at the Benetton Formula 1 team while in 1994, supported by influential industry figures, he launched the Motorsport Industry Association (MIA).

Formula 1 fuel and oils supplier Petronas has announced a global search for a track-side fluid engineer to support its Formula 1 commitment with the Mercedes team. The talent search initiative is open until 7 October. For more details check out the Petronas Lubricants International LinkedIn page.

NASCAR boss relinquishes post after New York arrest

Brian France, the chairman and CEO of NASCAR, has stepped down from his position at the head of America's most powerful motorsport organisation and is to take an 'indefinite' leave of absence after he was arrested for drink driving in August.

France, who has now been replaced by his uncle Jim France – who was previously NASCAR's vice chairman – has been the chief executive officer (CEO) at NASCAR since 2003.

Brian France was arrested in New York for alleged 'aggravated driving while intoxicated and criminal possession of a controlled substance,' according to a press release from the New York Police Department.

A NASCAR statement said: 'Brian France has taken an indefinite leave of absence from NASCAR as chairman and chief executive officer. Effective immediately, NASCAR vice chairman and executive vice president Jim France has assumed the role of interim chairman and chief executive officer.'

Brian France has stepped down from his NASCAR role after he was arrested for drink driving in New York

Earlier this year Jim France played a key role in NASCAR's purchase of the ARCA organisation, which has gone some way to unifying high level stock car racing in the US, while he is also the president of IMSA, which organises and operates North America's top sportscar series. He is the son of NASCAR's founder William (Bill) HG France.

Brian France's own statement in the wake of the incident read: 'I apologise to our fans, our industry and my family for the impact of my actions. Effective immediately, I will be taking an indefinite leave of absence from my position to focus on my personal affairs.'

OBITUARY – Mo Nunn

Former F1 team boss and racecar constructor, and respected IndyCar race engineer, team owner and technical director, Morris (Mo) Nunn, has died at the age of 79.

Nunn started his motorsport career as a driver and drove for the works Lotus team in F3 in 1969, briefly graduating to a Formula 5000 Lola in 1970. This drive then fell through, which led to his decision to set up shop as a constructor.

His first product was an F3 car called an Ensign – as were all the cars that followed – in 1971. This car enjoyed some success and Ensign then made the huge jump up to F1 for 1973, with backing from wealthy driver Rikky von Opel.

Ensign was in Formula 1 until the end of 1982 ,running well-known drivers such as Chris Amon, Jacky Ickx and Clay Regazzoni along the way. Its best result was fourth at the Brazilian GP in 1981, but it was always short of funds and Nunn eventually gave up the unequal struggle and headed for the USA to start another chapter in his career at CART (IndyCar).

In the states Nunn found success as a race engineer before joining Chip Ganassi Racing (CGR) as its technical director, where he won a string of titles. He returned to team ownership in 2000, but then sold his Mo Nunn Racing outfit in 2005. Since then he had remained in touch with IndyCar as a technical advisor to CGR.

Nunn was highly-respected and well liked in both the F1 and IndyCar paddocks.

Mo Nunn 1938-2018

XPB

One of Mo Nunn's creations, an Ensign N177, seen in historic racing. The team's best F1 result was fourth

RACE MOVES – continued

XPB

Bob Bell is to step down from his post as chief technical officer at the Renault Formula 1 operation and will take on a part-time role as a technical advisor at the team. Bell joined Renault from Mercedes in 2016, but had previously worked for the Enstone outfit before leaving to join Mercedes in 2010. There will be no replacement chief technical officer, Renault says.

F1 driver turned commentator **Martin Brundle** has won the MIA's 'Award for Outstanding Contribution to the Motorsport Industry', a prize which is voted for by the association's members. Beyond his successful racing career, which included 158 grands prix and a Le Mans win, for three years Brundle was chairman of the BRDC, while more recently he succeeded **Jackie Stewart** as chair of the GP Trust, which offers welfare support to those employed in Formula 1.

The Australian Supercars series has begun a worldwide search for a new sporting and technical director following **David Stuart's** announcement that he is to leave the post at the end of the year. Stuart has been in the position since 2014 but is now moving to CAMS, the Confederation of Australian Motor Sport, where he will be division manager, safety and race operations.

Mercedes F1 non-executive chairman and three-time F1 world champion **Niki Lauda** has had a lung transplant operation which doctors in Austria have described as 'life saving'. The 69-year old was not expected to return to work for at least two months at the time of writing in late-August. Doctors have said the lung issue was not related to his 1976 fiery accident at the Nurburgring.

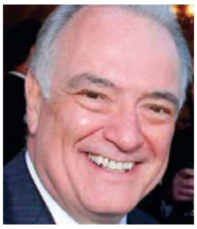
Darian Grubb, the crew chief on the No.24 Hendrik Motorsports Chevrolet in the NASCAR Cup, was fined $10,000 after it was discovered that lug nuts had not been properly installed at post-race inspection following the New Hampshire round of the series.

Mike Shiplett and **Eric Phillips**, both crew chiefs in the NASCAR Xfinity Series, were each fined $10,000 after their cars – the No.42 Chip Ganassi Racing Chevrolet and No.18 Joe Gibbs Racing Toyota respectively – failed the post-race body inspection height checks after the New Hampshire Speedway race.

Barnee Lloyd, a 25-year old Cambridge graduate and software engineer, has been selected by Formula E to become its first innovation manager, with the task of developing the all-electric championship's new software platform for the 2018/19 season. Lloyd landed the role after FE's IT and engineering partner Modis oversaw a four-stage selection process involving 2000 applicants from 62 countries.

Sauber's new technical director, **Simone Resta**, has said that the F1 team is planning to expand its workforce by 33 per cent in the near future. The former Ferrari man joined the Swiss outfit, which is backed by the Scuderia's sister company Alfa Romeo, at the start of July. Sauber currently employs around 400 at its Hinwil base.

◆ Moving to a great new job in motorsport and want the world to know about it? Or has your motorsport company recently taken on an exciting new prospect? Then email with your information to **Mike Breslin** at **mike@bresmedia.co.uk**



Waved yellows

The MIA's CEO explains why Vnuk is a genuine threat to motorsport's survival

Strangely, the holiday period has been an extremely busy one for myself and the MIA. We are very active on several fronts – some to save our industry and some to grow it.

Yes, Vnuk is back with us and getting more dangerous by the minute. The European Commission decided to ignore the many thousands of responses given to its last 'review' and its pressing ahead by recommending its proposal to the EU Council of Member States and to the EU Parliament itself, without any amendments. Unless through the concerted efforts of everyone across Europe in motorsport, then make no mistake, this current proposal spells the end for our industry and sport. It insists on there being extensive insurance provided for all kinds of motorsport at all levels, from junior karting to F1, and yet the insurance companies have made it clear that they are unable to offer such insurance. Without it, there will be no motorsport.

Action stations

The MIA is again leading our campaign to bring this to the attention of all European motorsport employers, drivers, competitors and all those trying to make a living out of our sport. In addition, the FIA and its ASNs throughout Europe are working to protect the sport. You need to act now and encourage any contact you have in the European motorsport business to do the same. You must contact your MEP and, in the UK for example, the Department for Transport and let them know the economic damage that will be delivered if there is no motorsport.

The job losses and destruction of so many businesses is a compelling message which the UK government is taking to Brussels, but we need all governments, in all EU states, to hear loud and clear from their local businesses, that with no insurance there will be no motorsport. These proposals for the Motor Insurance Directive *must* be changed to protect our sport and industry.

The MIA's website and our social media activity is going to move into top gear over the next couple of weeks, but right now, if you need any help, please just contact us via our website (www.the-mia.com). But please, please do not ignore this.

The MIA has also made a bid to the UK government on behalf of our industry, to secure £4m from UKRI and Innovate UK, to bring together the creative industry with our own, to build demonstrators using data from our race and rally activities, to create new digital entertainment using augmented reality for our audience. We hope we are successful so that we bring this money into our industry and we can introduce the creative companies to motorsport. The UK is the home to a £90bn creative industry and leads the world in its innovative and imaginative use of technology. Data, which you or your customers captured for years to be used by engineers in motorsport, will, if we are successful, be turned into real value by the creative partners. This engineering data is already serving its initial purpose in motorsport competition but now, with some control, it can be used widely to bring in more income to our sport, but most importantly, attract new audiences. This is likely to bring a real boom to our sector over the next couple of years.

XPB

All motorsport, from karting (above) to F1, will need extensive insurance if Vnuk goes through – and yet the insurance companies say they cannot offer such cover

Historical alliances

In my last column for *Racecar* (V28N8), I mentioned the importance of the 'pre-owned' (historic) marketplace in competition vehicles and we have taken new business groups to visit the Silverstone Classic, Bicester Heritage, and soon to JLR Classic, which is urgently seeking a wide range of new suppliers from the MIA membership. We have in fact set up a hotline to help it source short runs of high quality engineering solutions as its business is growing fast. The same can be said for Lotus, now part of the Geely Group, which is investing heavily and wishing to urgently recruit new suppliers, so again we are working with it through a hotline to help bring additional business to our members. So, whilst others have taken a summer break, we seem to have been busier than ever.

I am constantly contacted by readers of this magazine who ask me to explain more about the MIA and its membership, which is clearly explained on our website. But they are always surprised when I explain that membership costs are based on sales turnover and we charge approximately £3 per £1000 of turnover each year for the services we provide for members. We are pressed to create networking events to find new business, and last year we delivered 47 of these to our members around the world, not just in the UK. Our lowest category of membership costs only £1500 a year.

Call to arms

You can see that without increasing our membership, we struggle to lead the campaigns that we do, particularly one throughout Europe to overturn the Vnuk stupidity. This is an enormously expensive exercise and at the moment all the costs are being met by our current members, so it you want to find out the value of business networking, and at the same time ensure there is a future for your business, this could be the time for you to join the MIA. I must strongly encourage you to do so, so we can continue to promote and protect our growing industry, and you would be really welcome. So feel free to contact me directly at chris.aylett@the-mia.com or via our website.

Let me also direct you to the websites of Innovate UK (www.innovate.gov.uk) and also the Advanced Propulsion Centre (APC – www.apcuk.co.uk) as both of them are currently announcing substantial funds for the kind of work that the motorsport industry does so well, connected to the low emission future of automotive. By being creative and proactive you could well find that up to 70 per cent of your development costs will be met by a government grant, so please check these out and don't miss the opportunity.

Finally, let me remind you again to take the Vnuk threat seriously and make contact through our website or directly with your MEP. Tell your MEP that without the insurance motorsport will die and so will your jobs and your company.

This current proposal spells the end for our industry and our sport

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Amateur dramatics

While motor racing went through its shut-down in August, there were still emails flying around, questions being asked, and one of those was: what is the point of Stephane Ratel's new plan for GT2? The GT2 format was originally introduced as N-GT back in 2001 to bolster grid numbers in the FIA GT Championship and it was supported by first Porsche and then by Ferrari with its 430. The category evolved to become GT2, and further evolved into GTE in Europe, or GTLM as it is known in the US today. Ratel focussed on GT1 until the cars became too expensive, he had lost GT2 as described, and so then concentrated on GT3 before introducing the concept of International GT4 racing.

At the Spa 24 hours, which featured no fewer than 61 GT3 cars, and around one third of those was driven by all-pro driver line ups, Ratel unveiled a new plan for the future of GT racing. The new generation GT2 concept is to have powerful GT cars with little aero, and be allowed to race with GT3 cars in the Sprint races, as well as his GT Sports Cup for privateers. Ratel always had a privateer element to the Sprint format, but this disappeared as the racing became more professional, and so they headed out to his Endurance events, where they had the protection of the stewards – any pro that was involved in a shunt was held accountable.

The new generation GT2 concept is to have powerful GT cars with little in the way of aero

However, within the Endurance series his Silver Cup, for Silver graded drivers only, has proved to be a spectacular success, and his amateur drivers are increasingly finding it difficult to drive the high-downforce GT3 cars where time is made up in cornering and on the brakes. GT2 will allow them to feel like heroes on the straight, and that, hopes the Frenchman, is what will allow them to race.

Already we have manufacturers that have agreed to the concept, including Ferrari and Porsche, while McLaren has indicated that it would be interested in the very near future too. McLaren has a few issues to sort out in the interim, including concluding its legal wrangle with CRS for the customer racing, hitting its target of 4700 car sales this year, and sorting out its F1 programme. But it is looking to the future, and can see something quite interesting in GT2.

However, there is another reason why GT2 makes sense. Basically, this is Ratel's reaction to the convergence talks between GTE and GT3 that have been on-going, and now seem to be reaching a peak. Ferrari was the first to go this way with its 488, Aston Martin's cars share parts too, and behind the scenes, manufacturers have agreed on what can be common parts, and what cannot. Ratel's objection is that should GTE and GT3 cars share common parts, the cost of GT3 cars will surely rise as they will feature more expensive GTE components. Having initially blocked convergence at the GT commission level, and tolerated the latest incarnation of it, he needed a back up plan, and now he has one.

These convergence criteria may not be a problem for manufacturers, or their buyers, or even Ratel. With more than 1500 current GT3 cars racing around the world, and with a stable platform featuring Pirelli and Claude Surmont's balance of performance programme, it seems relatively peaceful in the Blancpain paddock these days. More manufacturers are looking at the Intercontinental GT Cup, which is where Ratel wants them, but GT2 is a nice back up, just in case.

Porsche has the label GT2 for its cars, not for entertainment, so it took a cup of coffee and a gentleman's agreement between the two bodies to make this work on a global level. There is a slight anomaly in the naming of the series; GT2 will sit alongside or slightly below GT3 for the time being, and GT1 does not exist in any racing context other than historic racing, but as a concept, it's fine. I suspect that GT1 may be for hybrid GT cars should the FIA's plan for hypercar LMP1s fail.

'There is a danger,' admitted Ratel, speaking to me at Spa. 'When you have spent 26 years building a business and you have seen the GT1 class fall, you think that just in case, [GT2] is an insurance policy for the SRO business. If it goes too close to GTE I have a fall back position.

'We had a new concept, which was based on GT4 and applied it to a powerful car,' Ratel added. 'Then I read an article that compared the McLaren 720 and the [Porsche] GT2 RS and these have tremendous performance, and we go full on. Let's go for real power, and with these guys and real power, I can revitalise my am class. The car will be as fast as GT3 in the hands of a pro, and in the hands of an amateur it will be a very good car. I spoke to a number of manufacturers about it and they liked the idea.'

The full details of this new concept will be announced in late September, but Ratel is relatively confident. He sees the cars primarily as track day vehicles, and they will be very exciting in that guise, but he also hopes that he can get them into GT racing in the very near future.

ANDREW COTTON Editor

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