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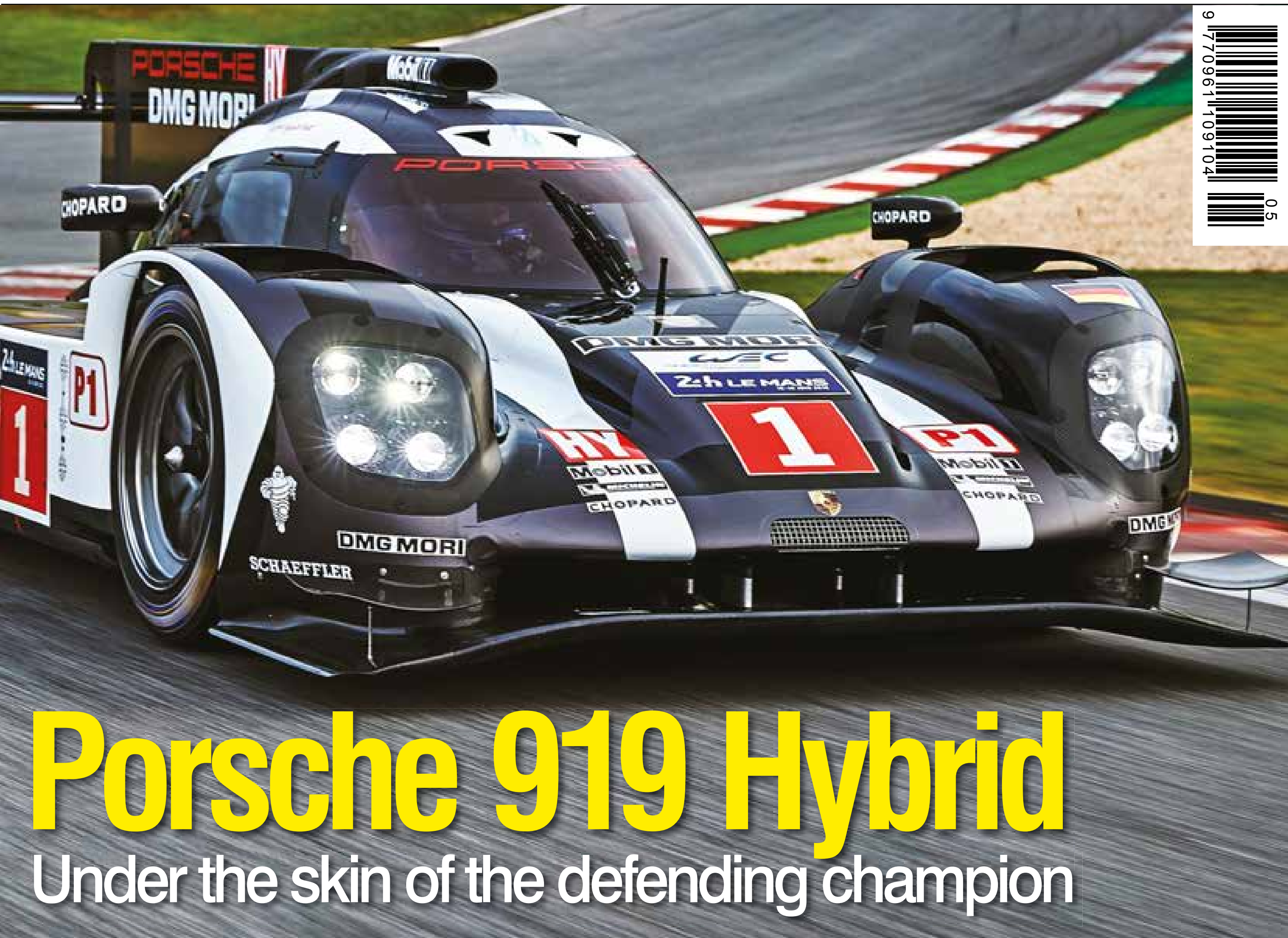

Porsche 919 Hybrid

Under the skin of the defending champion

Formula 1 2017

Teams facing race against time as new rules are delayed again

Manor MRT05

F1 underdog goes up a gear with new Mercedes-powered racecar

IndyCar 2016

Why series changed tech regs for 100th running of Indy 500

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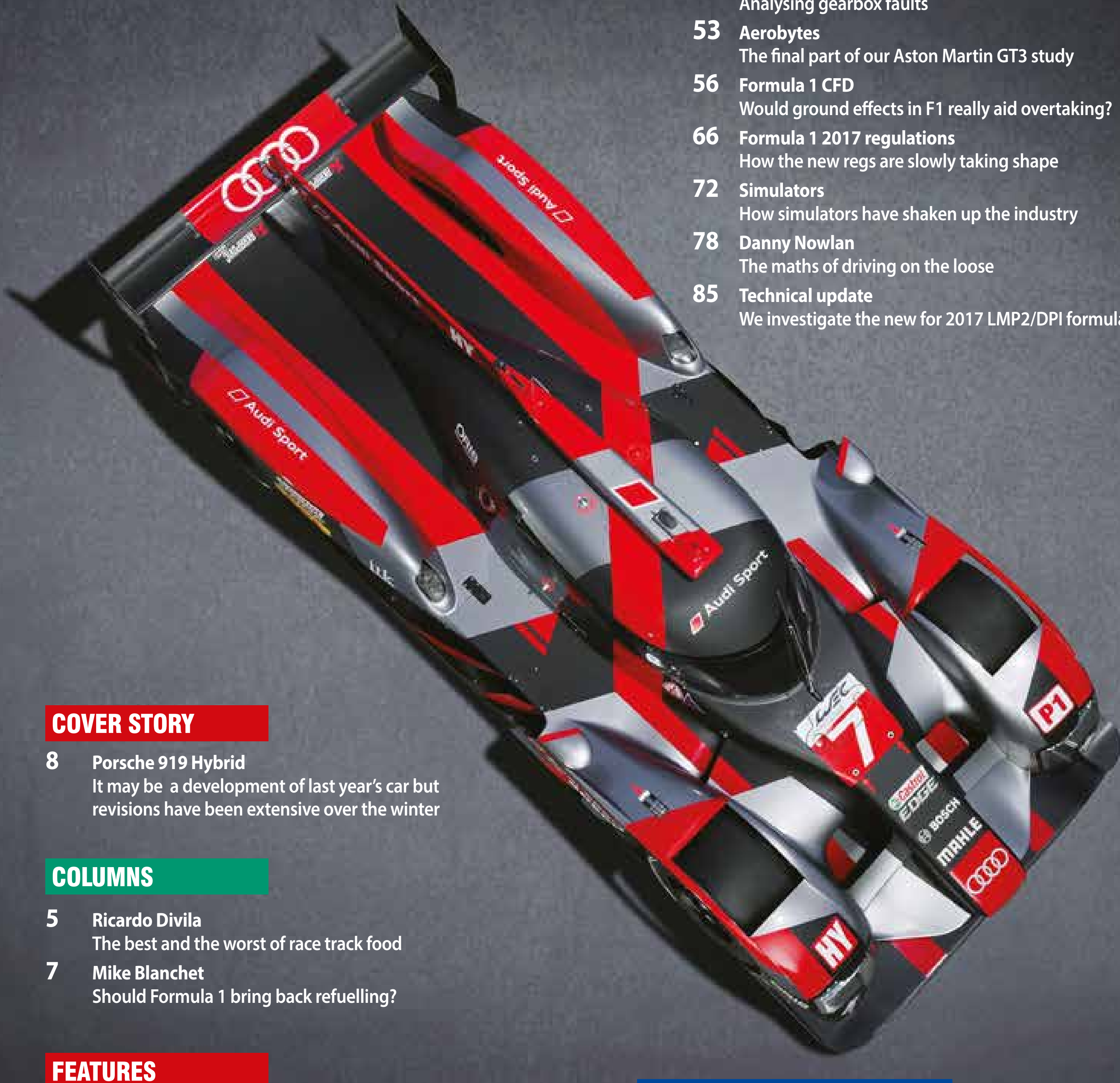

Audi and Toyota launched their new 2016 LMP1 challengers at the WEC pre-season test at Paul Ricard. Both will be featured in forthcoming editions of *Racecar*

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Fast food fables

Sometimes what you eat at a race track can linger long in the memory

If you spend a lot of time in race paddocks you develop a routine of searching for what is available to prop up your caloric necessities. This is commonly called food. *Cordon bleu* chefs at lavish VIP suites now assuage the needs of the *few* in F1 paddocks, while the team members are adequately nourished. But it was not always so.

One of the nightmarish memories that still sends shudders down my spine is of the most horrible concoction – worthy of being included in a culinary section of Dante's *Inferno* – which was offered at a British circuit some years ago. For some reason it was called a 'burger', yet it was in fact a grey patty of some minced matter, probably unrelated to meat, plonked on bread after being fried in oil recycled from gearboxes. That is not a hamburger.

And don't get me started on Scotch eggs, sausage rolls and sundry other concoctions that populate British paddocks.

Wholly cow

There are places, however, that combine the pleasures of competition with our basic needs, and casting memory back some meals certainly stand out, not the least being the whole cow on a barbecue at Taruma circuit in the south of Brazil; the aroma of its cooking permeating the pits during the qualifying session. Bliss. Then there was repairing to a local restaurant outside Nogaro track in the Landes, and savouring a magnificent *Foie gras d'oie poele aux fines herbes*; or prime wildebeest steak in Kyalami; tapas at Jarama – not forgetting the local white asparagus, at its best for the Spanish Grand Prix when it was held there …

Also, wandering into any churrascaria on the Calle Florida in Buenos Aires to partake of roasted kid; eating at the *Treppiedi* in Monza, just by the roundabout exiting to Lecco, whose *Tris di pasta* and *bistecca ai ferri* must be noted under unmissable, as is the world's best white truffle risotto at *Vutantot*, near San Ciro stadium in Milan.

Or, sitting on the tail-lift of a transporter at Brands Hatch with Ken Tyrrell and Rob Walker eating salmon sandwiches from Rob's Fortnum & Masons hamper; eating *Likocsi Pork Gulyas* in Budapest on the banks of the Danube; *pesce spada* in Misano. Delicious *Angulas al ajillo* in Cadix when racing at Jerez – these are baby eels bubbling in oil and garlic – and whilst we're in Spanish territory, enjoying *jamon Pata Negra* and *chuletas* at *Los Caracoles*, just off Las Ramblas in Barcelona.

Then there was the kangaroo steak at the Phillip Island track in Australia, *Nasi goreng pattaya* in Sepang; fresh *obentos* in Fuji, and *sakuraniku* (horse meat carpaccio) at a ryokan in Kiushu, when racing at Autopolis, also in Japan.

And let's not forget what can be classed as the ultimate Chinese food experience, an 18-course meal at the Hotel Lisboa in Macau, as a guest of Teddy Yip – local grandee and owner of eponymous Formula 1 and IndyCar teams – during the Macau GP; with dishes from Anhui, Cantonese, Fujian, Hunan, Jiangsu, Shandong, Szechuan, and Zhejiang cuisines. Teddy knew his food, as he also

Prime wildebeest steak in Kyalami and tapas at Jarama

XPB

Race meating. If you are lucky enough to travel the globe as a race engineer then you are sure to sample a wide selection of cuisines

knew the other fine things in life, which is attested by the story of his 80th birthday, when he flew in a Jumbo jet-load of his previous wives and mistresses for the party. My hero…

All the above in many ways overlay the memories of the races themselves, and it proves that one can survive in a race circuit paddock in most places around the world.

Food bites back

But there were low points, too, of course, such as a meal in Mexico when there for the GP, scrumptious *Cochinita pibil* and rice brought on a severe case of Montezuma's revenge – probably caused by that common mistake, ice in the drinks. Likewise in Enna, where *frutti di mare* were consumed with relish, only to pay the price over the entire race weekend, having to work lying down, and then occasionally crawling to the Enna lake shore beside the paddock to elegantly vomit into the sulphurous waters.

The usual good food to be found in Montreal can be offset by the discovery of the local *poutine*, too, which is basically, French fries covered with lashings of brown gravy, and topped with cheese curds. Cholesterol, here we come.

This is only beaten by the notorious – and one uses the word advisedly – culinary product of Le Mans, the *rillettes*, which can only be described via the process in which it is made; namely dropping a whole pig into a 50-gallon drum, accompanied by a hand grenade, and slopping one hundred litres of lard into the resulting mess.

Once tasted, this is never forgotten. My taste buds have been blunted by years of surviving on it during 24-hour races at La Sarthe. It does have its uses, should one be suddenly short of bearing grease for any reason during the race, though.

Corn in the USA

The Indy 500 can be quite impressive, but my strongest memory seems to be the discovery of the 'corn dog', which is now very, very high on my list of *Why eat this*? It consists of a fat sausage, made of MRM (Mechanically Recuperated Meat) and pink slime (this is no joke, look it up), wrapped with mashed corn, fried in oil – just maybe used engine oil.

Most other American race tracks seem to be similarly afflicted. The only places that stand out in the USA are what are probably the best barbecued spare ribs one has wrapped one's lips around in Charlotte – which were worthy of a small prayer for the said pig's soul in thanks – and at Watkins Glen, the pancakes and maple syrup at the Seneca Lodge for breakfast. That, sirs, is a real breakfast, and the smoked bacon and free range scrambled eggs also on offer will set one up for the chilly day to come.

Sebring surprised me last year, too, having had an excellent meal at the *Chateau Elan*, while Laguna Seca has some acceptable places, but cannot really be considered the US …

But in case it seems one is a foodie, I can also wax lyrical about *Rookwurst* at Zandvoort accompanied by *stamppot* (basically smoked sausages and vegetable mash). While Argentinean chorizo sandwiched between freshly baked bread in the paddock at San Juan, nestled in the Cordilleras under a baking sun, eaten with delicious freshly squeezed lemonade, might not be *Maxims'*, the experience sits in my own *great moments of simple food* list, not to mention the local *chuletas*.

One was going to write something about racing here, but I must go off and get a snack, for some strange reason. *Bon appetit* …

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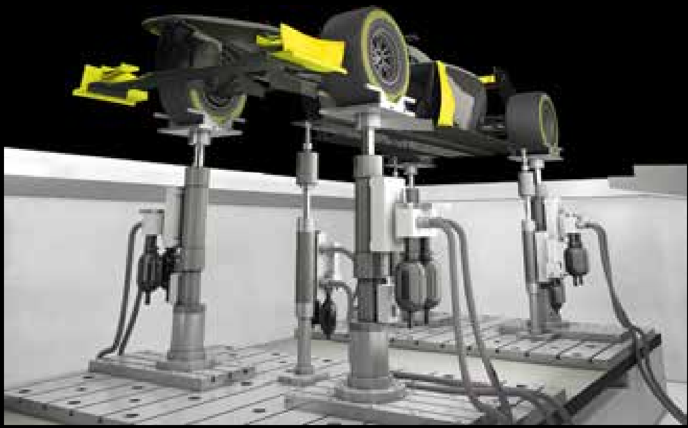

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Fuel for your loving

Is there a case to be made for the reintroduction of refuelling stops in F1?

The intellect of Einstein is not needed in working out why F1 is going through the series of domination-by-one-team scenarios that have prevailed for the past six seasons, causing understandable disquiet. Given the (way too-restrictive) technical regulations resulting in almost identical car and engine specifications, one-make tyres for all, cars that are arguably too easy to drive and incredibly reliable, plus – above all – the adoption of the enormous power of digital technology including very accurate simulation, can it be a surprise that when one team gets all the key elements in place better than its rivals it will be almost unbeatable until a significant change occurs? Therefore, in order to attempt to break this inevitable monopolistic hold and introduce a degree of randomness, a big spanner-in-the-works approach is urgently needed.

Fill it up

For example, I favour a return to refuelling stops. Bear with me here. The arguments against – primarily safety and cost but also that it will not change the status quo – just do not stand up to examination.

Refuelling is of course a necessary part of endurance racing and is carried out – as often as 24 or more times at events such as Le Mans, Spa, Nurburgring etc. – as a matter of course. To the best of my knowledge there has not been a major fire incident among all these events for at least the past dozen years. Granted, the regulations do not permit the kind of super-fast pit stops that F1 would likely entail and which would introduce a little more risk, but then again just two or three refuels per race with highly-trained mechanics and effective policing should negate this.

As an additional benefit, one cannot dispute that the less fuel a racing car carries the lower the danger of fire in a big shunt, even though, mercifully, the likelihood of this happening has been hugely reduced. But it hasn't totally gone away and should not be ignored, especially as collisions are always more likely at the start of races when tanks are full – as they have to be under current no-refuelling regulations. Cost? Well, it's not as if the equipment has to be replaced each race or even every year, just properly serviced. If F1 followed the lead of WEC in stopping clever but expensive ways of speeding up the refuelling time, then the financial impact would be negligible. Privateer sportscar and GT teams with a fraction of the smallest F1 budgets manage well enough, including carting the equipment all over the World.

Strategy shake-up

The greatest advantage is that, contrary to some naysayers, it does allow more strategic and tactical options. The biggest cheer from F1 followers last year, alongside Ferrari's race victories, must have been when the two Williams cars streaked into the lead at Silverstone and held on to it for a good many laps. They didn't eventually win, but it gave the spectators and TV followers (not to say the drivers and team) a big boost that lasted well beyond the race. Track position is increasingly important and teams not normally in the hunt for a win, or even just points, might like to take a gamble. Start with a very light fuel load, especially if the weather conditions appear uncertain, jump your opposition in the first few laps and give your sponsors invaluable TV exposure as well as the outside chance of a better race result.

There's nothing wrong with showboating, and if it mixes up the positions for part of the race, it's worth it, not least for the positive effect on morale. There's nothing like seeing your car and driver in the hunt, even if only temporarily.

In addition to the double points for certain F1 races proposed in my previous column, why not combine the above refuelling initiative with awarding Drivers' Championship points (three, perhaps?) for whoever is leading the race at half-distance? This would have a good chance of livening up the current fixed-order significantly and reduce the excitement-sapping predictability of the overall result. Consider a situation whereby, say, Hamilton and Vettel are vying for the race win, both of them very close on championship points. Half-distance is quickly approaching but the race-leading driver's tyres are even more swiftly degrading. Does he (a), hang on in the hope of still being ahead to take the valuable half-distance points and then pit, but risk not succeeding while also losing pace and possibly vital track-position to his rival? Or (b), pit immediately to lose the minimum amount of lap time in favour of a better opportunity of the race win? Could be nail-biting stuff, while the extra tyre options being brought in this year would add even more variables to the gamble.

XPB

Refuelling was last a part of Formula 1 from 1994 until 2009 (this is 2007). Could its reintroduction provide the sort of unpredictability the sport craves?

Not a gimmick

Anyone who is charitable enough to regularly read my column will have perceived that I tend towards the purist view of motor racing, and consequently I dislike gimmicks to liven up the racing. However, I do not look on the above suggestions as gimmicks. All have been used in various forms of the sport over very many years – including NASCAR – precisely to add excitement and, in the right circumstances (such as F1's unloved predictability at present), they have a proper place. I believe this would genuinely, not artificially, enhance the competition and require alternative approaches and some quick-thinking in the cockpits and on the prat-perches. Despite the amazingly clever computer programmes prepared to handle every scenario, I doubt that they can cover all, especially when changes occur fast and unexpectedly.

Of course, there will be wails of protest from those who lack the willingness to take on new challenges because they are currently sitting fat-cat-pretty with things as they are. Tough – a shake-up is just exactly what is needed. It now simply requires somebody at the top with the passion and authority to get the job done. That, as they say, is another story.

The arguments against refuelling – primarily safety and cost but also that it will not change the status quo – just do not stand up to examination

Defence

Having won both Le Mans and the WEC title last year Porsche is banking on relentless development to keep its 919 Hybrid at the top of the LMP1 pile in 2016

By ANDREW COTTON

Porsche took a huge step forward between the 2014 and 2015 season with its 919 Hybrid, accelerating an 18-month battery development programme to complete it in just six months, and developing a new chassis. It led to victory at the Le Mans 24 hours, the company's 17th overall win and first since 1998, as well as the World Endurance Championship title.

For the 2016 season, the development programme is not as dramatic. The WEC manufacturers tend to carry the same chassis over two seasons and Porsche is no exception. The 919 Hybrid has the same monocoque as in 2015, which already featured a compromise in terms of the packaging around the battery system. The battery development was so hurried for the 2015 season that the team was not confident that the smaller, more powerful battery would work. Its 2015 chassis was therefore developed to accommodate the 2014 package as a back-up.

With new LMP1 regulations due in 2018, Porsche had the option to produce a new car again this year, or use the same monocoque for 2015 until 2017. Ultimately, it opted to run the chassis for a second season in 2016, and is likely to carry that same chassis into 2017 as well.

This 2016 development includes a brand new front suspension and all-new KERS on the front axle, a revised rear suspension, improved efficiency from the engine, as well as new aerodynamics to accommodate the 2016 energy regulations. The 919 Hybrid continues to use the exhaust energy recovery system in combination with the front-mounted KERS. The amount of fuel used by the LMP1 teams has been reduced by 10MJ, an eight per cent reduction, and that has an effect on the lift over drag targets set by each of the LMP1 manufacturers.

'For the first to the second year we had to make a new car because we had to save a lot of weight, so we needed a new monocoque,' said team principal Andreas Seidl. 'Now we have kept the basic structure, but we touched every area of the car around the monocoque. The plan is to do another evolution [of the monocoque] for next year, and

PHOTO©ADRENALMEDIA.COM

Ultimately, Porsche opted to run the same chassis for a second season, and develop the car through 2016

mechanism

a new car for 2018. You cannot stand still for 2017, but you have to start early for 2018. That will be a new monocoque with the safety updates. The road map discussions are still on-going and there will be big updates.'

These updates are expected to include a change to the driver seating position, as well as further safety updates, which may include a separation of the energy storage package and the cockpit. The 2016 cars have new driver headrests as part of the safety drive, and will also have larger cut outs over the front wheels to further reduce the possibility of cars taking off and flipping, as now more pressure is released in this area.

Regulation changes

The sporting regulations have also changed slightly this year, with new pit stop regulations and a change to the minimum penalty system, with the race director allowed to issue a drive-through penalty for minor infringements rather than a one minute stop and go. A ninth race has been added, in Mexico in September, and there teams will be allowed to change their cooling requirements for that race only, as it was a late addition to the schedule.

There have been two major changes to the Porsche programme in 2016. One is that lead engineer Alex Hitzinger abruptly left the company in March having been offered a post with another company, and Porsche is looking for his replacement. Hitzinger made his decision after having developed the 2016 car, and after already giving an indication on the way the 2017 car should go, too.

The second change is that the company will run only two cars at Le Mans after Porsche and Audi agreed to the cost saving measure. It is a change that Seidl has welcomed, due to a reduction in the number of cars to set up on track, and because they can now concentrate on preparing just six drivers instead of the nine used last year.

'Last year we showed up with three cars, which was a challenge for us,' said the German. 'As a motorsport guy you manage two cars, but suddenly when you

Porsche is using the same chassis as last year, while rivals Audi and Toyota have all-new cars this season, but Porsche has not stood still and the 2016 version of the 919 Hybrid is bristling with developments

This year Porsche will run just two cars at Le Mans after it made an agreement with sister VW Group manufacturer Audi. Porsche was quickest in LMP1 at the Paul Ricard pre-season WEC test (pictured)

PHOTO©ADRENALMEDIA.COM

have three cars, like at Spa in FP1, when you are setting up the hybrid, and you get the overflow of three cars, you start to respect what is happening and you are happy when the session is over. This year, it is not really a big change to not have the third car. Numerically it reduces the chance of a good result at Le Mans, but it is the same for everyone; we all have two cars.'

Pre-season testing has gone well, and for the first time since the project began the team was able to enjoy a proper break over the Christmas period. The new front suspension was tested back in October and the team has since run successful endurance tests ahead of its title defence this season.

The team has run successful endurance tests ahead of its title defence this season

On the subject of suspension, Seidl says: 'If you look at the suspension, obviously there is a lot of interaction with how we use the tyres. We did a brand new front suspension in terms of kinematics. The rear axle was an update. We changed it to have more freedom in how we can set up the car. You always have constraints with the pick up points.

'We saw that we had some limitations in how we could set up the car in terms of tyre usage, and this is something that happens very closely with Michelin. There is a lot written that we can do updates with the basic concept, but this is only the third year for us, and even with a fixed concept there is a lot that we can learn. The suspension is a good example.'

Changes to the pick up points at the front, as well as the uprights, mean that the suspension is easier to set up, improving the options for tyre choices as well as for the sensitivity of the car. One of the key areas of development was improving feedback to the driver, and the team is confident of having achieved this. Driver Marc Lieb says that the changes are not that noticeable as the improvements have been introduced incrementally, although the overall lap time is vastly improved compared to 2015.

'It still drives like a 919 Hybrid,' says Lieb. 'It didn't change much although you can feel a little more performance in the car, a little more grip, less understeer in some areas, but it is the same behaviour, the same car. It is not a huge change of driving. It is small steps in different

areas. We were just updating the '15 car once in a while, and you adapt to the new car. It is an evolution. With small steps at each test you can't feel the steps, but when you see the lap times, there is a big change.'

Tyre pressure

Tyre choices are critical over the winter as teams must nominate which compounds best suit their car for the season ahead. The team initially struggled with tyre usage in the opening races of 2015, although it had the problem sorted by Le Mans, and the high downforce package was a further step in the right direction. 'Reliability is the key, and running four stints at Le Mans,' says Lieb. 'You are looking for more performance, and reliability. We struggled with reliability in 2014, but after three or four races we were quite good, and the others had a lot more experience than we did. I think that it will be pure speed that will decide races.

'If you have more aero you are better on tyres. The change between 2014 and 2015 was big, and made our life a lot easier on tyres. When you see how we struggled at the first two races, and particularly at Spa, then at Le Mans we could run four stints, and with the high downforce package we had better tyre life than Audi. Now we have taken another step, but everyone is improving. It is going to be challenging this year for everyone. The competition will be bloody awesome.'

Aero development is another key area for Porsche. The reduction of 10MJ from the fuel allowance has changed the emphasis for the lift/drag ratio slightly. 'We had to work on the efficiency of the aero,' continues Seidl. 'The target is to interact as much as possible, especially with losing engine power on the straights. That is only one point of the whole thing. The second point is that we learned that the car was quite sensitive in certain states on the track, and very wind dependent. Balance was dependent on the steering angle, so we worked not only on the efficiency of the aero package but also the sensitivity to make it more driveable.'

As in 2015, the team has three aero packages for the season; a development of the high downforce package produced in the second half of the 2015 season and which was tested at the pre-season meeting at Paul Ricard at the end of March; the Le Mans low downforce package, and an all-new high downforce package for the races post Le Mans. The team has not yet made a decision on whether or not to run the low downforce package at the Spa 6 Hours in May.

'With small steps on each test you can't feel those steps, but when you see the lap times, there is a big change'

'At Spa, [the package performance between low and high downforce] is close, but we have to see once we get the first figures,' says Seidl. 'We want to bring [the low downforce configuration] to the track in Aragon, and once we have the numbers we will make a decision what we do there. You have to decide whether to run the Le Mans package to get race experience on it.'

The engine development programme is on-going. The car retains the 2-litre V4 architecture (see P16), but with the reduction in fuel allowance emphasis has been placed on reducing the weight of the unit, and the efficiency. 'On the engine side, the basic concept is the same but we worked on the efficiency and on how to get more power out to compensate for the less energy,' says Seidl. 'You work on the gas exchange of the engine, the weight, the friction components on the engine, and I think that we made a good step on that.

'Apart from the monocoque, weight reduction was a big push for the engine, gearbox, hybrid system and suspension, because it gives you more freedom to play with the weight distribution. It can be moved accordingly, so that it can be track specific.'


The nose of the Porsche 919 Hybrid, featuring the larger cut outs over the front wheel and strakes in the splitter under the nose. Teams are directing more air through the car as they deal with a reduction of 10MJ from the fuel allowance in 2016

The team has elected to stay with the Gill fuel flow sensor and says that it has had no problems with the aliasing issue. 'We are happy with the Gill sensor,' confirms Seidl. 'We never had an issue. We had an issue [with the maximum fuel flow rate] at the Nurburgring but that was our own problem. We never had a big issue. We didn't look too much into the Sentronics side, because we are happy with what we see with Gill. If you look at how many times we changed it, I don't think that we changed it any time.'

The aluminium gearbox is the same as in previous years, housed in a carbon frame at the rear that fills the large gap between the small engine and the rear suspension.

However, there are two other key areas of development; the hybrid system and the electronics, both of which are pretty much free in terms of development restrictions. Large gains can be made in these areas and they are a target for each of the LMP1 teams.

'We are always making a push in electronics,' says Seidl. 'It is efficiency on the system itself, but it is a permanent development on the software side of the strategies that you apply for how to use the combustion engine, how to use the hybrid system, and traction control. It is an open field in terms of the regulations. It is not

At the pre-season test, Porsche ran an updated version of the 2015 high downforce bodywork seen post Le Mans. It will race this kit at Silverstone in April and Spa in May

PHOTO©ADRENALMEDIA.COM

Porsche believes it is in a good shape for this year's Le Mans 24 Hours, as the 919 Hybrid concept is entering its third season and most reliability issues have now been ironed out

like Formula 1 when you have a standard ECU. Here there is a big battle.'

Although the carry-over of the chassis means that there was no need to change the size of the battery, the team has still made big gains in that department. Porsche has also increased the efficiency of the front-mounted KERS. Although the headline figure for energy boost is 8MJ, that is reduced according to track length for the rest of the WEC season and completely charging the battery has in some places been difficult.

Porsche suffers less in this regard than the other LMP1 manufacturers perhaps, as it remains the only manufacturer to run an MGU-H. Toyota has stuck to a twin-KERS to recover 8MJ, while Audi has a single KERS on the front axle to achieve 6MJ. 'In terms of cell development, we worked to reduce weight, increase power and energy density,' Seidl says. 'But the power stages and so on, we have made steps, and the amount that we can recuperate on the front axle, and also on the amount that we can release. We made huge steps in the way we apply the hybrid because that is an open field. You learn at the race weekends how you can set the hybrid usage.

'We have set some targets over the winter in terms of updates on the car. With the testing that we did and the results that we saw in terms of feedback from the drivers and the handling of the car, we achieved everything that we wanted to achieve and now we have to see whether that's enough or not. That's the performance side. The other is the reliability. In the third year it helps that we have a stable concept, so for the six hour races we should be quite well sorted. For Le Mans, we still have some topics to tackle but it is under control and we still have two more endurance runs.'

In 2014 Toyota had a speed advantage that it hoped to maintain through 2015, but the pace of development of Porsche and Audi took it by surprise. By the end of 2015, Porsche still enjoyed a clear speed advantage in qualifying, securing pole position for every race, and it will be hoping that it will retain at least some of that advantage. But, with the pace of development, it will not be until the wheels turn in anger that the true picture will be clear.

'The car was quite sensitive in certain states on the track, and very wind dependent. Balance was dependent on the steering angle'

TECH SPEC

Porsche 919 Hybrid LMP1

Monocoque: Composite material structure consisting of carbon fibre with an aluminium honeycomb core. The monocoque was developed on the basis of the 2015 LMP regulations and was tested in accordance with the 2015 FIA crash and safety standards. The cockpit is closed.

Combustion engine: V4 engine (90-degree cylinder bank angle), turbocharged, four valves per cylinder, DOHC, one Garrett turbocharger, direct petrol injection, fully load-bearing aluminium cylinder crankcase, dry sump lubrication
Max engine speed: 9000rpm

Engine management: Bosch MS5

Displacement: 2.0-litre

Output: Combustion engine: 500PS, rear axle
MGU: 400PS, front axle

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

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

Suspension: Independent front and rear wheel suspension, push-rod system with adjustable dampers

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

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

Dimensions/weights
Minimum weight: 875kg
Length: 4650mm
Width: 1900mm
Height: 1050mm

Fuel tank capacity: 62.5 litres


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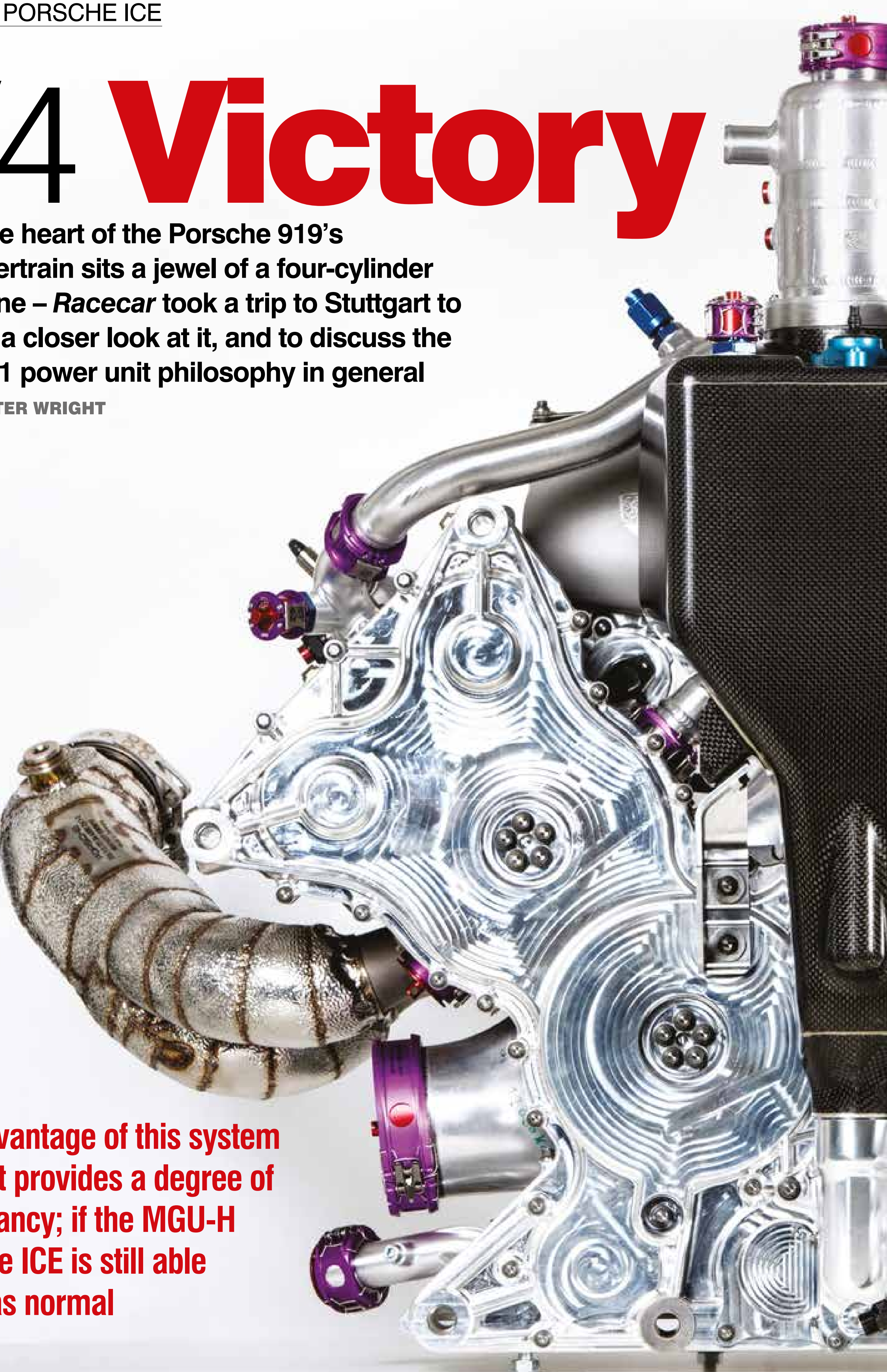
V4 Victory

At the heart of the Porsche 919's powertrain sits a jewel of a four-cylinder engine – *Racecar* took a trip to Stuttgart to take a closer look at it, and to discuss the LMP1 power unit philosophy in general

By PETER WRIGHT



One advantage of this system is that it provides a degree of redundancy; if the MGU-H fails, the ICE is still able to run as normal

It was pure coincidence that the opportunity to interview the architects of the two most successful hybrid racing programmes to date, and to find out how they achieve this under the radical F1 and LMP1 regulations, occurred within two weeks of each other. Having talked to Mercedes HPP's Andy Cowell (see April's *Racecar* V26N4) it was an even greater coincidence to meet him again on the plane to Stuttgart as I made my way to meet with Alex Hitzinger, Porsche's LMP1 technical director at Weissach. By the end of the visit it had struck me that perhaps this latter meeting was not such a coincidence, and that there was some other force at play, which has meant that the two companies to have mastered efficiency racing and electrification, both stem from one city in Germany – Stuttgart. On top of which, these two architects both worked at Cosworth in the early 2000s, when it was still at the forefront of F1 engine design.

While Hitzinger, who has now left Porsche, avoided criticising F1 and its regulations, it quickly became clear that he, and many of his colleagues and competitors in LMP1, fervently believe that the WEC regulations are more relevant to the automobile industry than those of F1, and that they fully endorse the way that they, the FIA and the ACO, have developed them to provide a showcase for the manufacturers' technology, and a popular and highly competitive championship.

Hitzinger was at pains to establish that there were two subjects he would not discuss in any detail

Other than it being a V4 the ICE element of the Porsche 919's power unit is fairly conventional

The MGU-K (front) and MGU-H (rear) in the 919, and how they connect to the battery. Front generator is operated as a single motor and drives the front wheels via a differential

Table 1: Energy distribution in LMP1 and F1

Powertrain	Fuel	ERS1	ERS2	Deployment/max.
Porsche LMP1	Spec gasoline	2nd turbine	Front axle	Front axle / 8MJ
Toyota LMP1	Spec gasoline	Front axle	Rear axle	F&R axles / 8MJ
Audi LMP1	Spec diesel	Front axle		Front axle / 6MJ
Formula 1	Regulated gasoline	Turbocharger	Rear axle	Rear axle / 4MJ

Table 2: Gasoline fuel specifications and regulations: How each championship regulates fuels

Championship	Specific energy (gasoline) MJ/kg	Bio. Source content %	Fuel flow regulation:	
			Mean	Peak
LMP1	39.55	20%	MJ/lap	kg/hr
Formula 1	43-44	>5.75%	kg/race	kg/hr

or give numbers for: power and efficiency; and the control laws for the powertrain and ERSs. The first of these needs some explaining, when all the competitors basically know what each other's power output are, and hence can deduce the efficiency of their powertrains. First, for some basics, see **Table 1 and Table 2**.

Thermal efficiency

Hitzinger said: 'To compare efficiency between cars with different ICE powertrain cycles, and between formulae with different fuels is a waste of time. F1 is reasonably free to do research on gasoline fuel, whereas LMP1 uses a single spec gasoline.' So that's that then.

Thermal efficiency in an IC gasoline engine will be affected by a number of factors, and a review of these may yield some clues about LMP versus F1: the reduced number of cylinders chosen by Porsche in LMP1, four versus the mandated six in F1, will increase efficiency due to reduced friction and pumping losses; the greater capacity Porsche has chosen – 2.0-litre against the 1.6 litres mandated in Formula 1 – results in lower RPM for a given fuel flow rate, and hence reduced friction and greater efficiency; the higher bio-sourced content of the fuel hydrocarbons will tend to increase the RON of the fuel, allowing a higher compression ratio and/or turbo boost pressure, all leading to improved efficiency.

No powertrain engineer would argue the first two features, but they might dispute the value of the bio-sourced content of the fuel. Generally bio components (ethanol, butanol-1, etc.) raise the knock rating, i.e. RON. Cowell stated he was happy with the F1 fuel developed by Petronas, and it is believed that Porsche was influential in the specification of the LMP1 fuel. There's to be a new fuel for 2018 in LMP1.

In general, it would seem that the LMP1 regulations favour a higher thermal efficiency than F1, but that Porsche is the only constructor to capitalise on the ability to recover energy from the exhaust, to turbo-compound the engine and raise overall powertrain efficiency.

Hitzinger believes this is missing the point: 'LMP1 is about overall efficiency; powertrain, plus chassis, plus aerodynamics. We optimise the whole system to give the best efficiency around a lap; this is much more meaningful in terms of the relevance of what we are doing to the automobile industry than the F1 approach.'

Harvesting energy

The different selections in LMP1 was explained by Hitzinger: 'Toyota's two systems, one on each axle, is an advantage in energy harvesting, but it is heavy. It is not too expensive to develop. Porsche's systems, the second exhaust turbine/ MGU, and the front axle, is lighter, harder and more expensive. The harvested energy can only be deployed via the front axle, while Toyota can share between both axles.' Audi confirmed at the WEC 'prologue', the pre-season test, that it will harvest 6MJ from the front axle only, and store the energy in a battery rather than a flywheel.

'Audi's 6MJ and diesel fuel is just as quick as 8MJ and gasoline', Hitzinger said. 'It has avoided having to develop two systems. Their stint length is also longer than for the 8MJ gasoline cars.' The MJ incentive built into the LMP1regs seems to just about work when balanced against weight, cost, and reliability.

The two premier FIA championships run on a number of the same circuits, and so it is possible to make overall efficiency comparisons. Both sets of regulations allow some freedom from fuel-used limitations over a qualifying lap and enable the cars to start that lap with a full energy storage system. This is also potentially true during the race, but if the fastest lap is one from a series of fast laps, it is unlikely in both cases that the driver is taking advantage of this. Thus it should be possible to make a reasonable comparison between the overall efficiencies of

'LMP1 is about overall efficiency; powertrain, plus chassis, plus aero'

Both F1 and LMP1 are generating and proving relevant technologies

Table 3: Silverstone energy budget

Energy available - source	LMP1	Formula1
MJ/lap - Fuel	59.9	83.8
MJ/lap - ERS	5.4	2.0
Total	65.3	85.8

Table 4: Spa energy budget

Energy available/source	LMP1	Formula1
MJ/lap - Fuel	71.3	101.4
MJ/lap - ERS	6.4	2.0
Total	77.7	103.4

the two formulae. The energy budget for each at Silverstone is shown in **Table 3.**

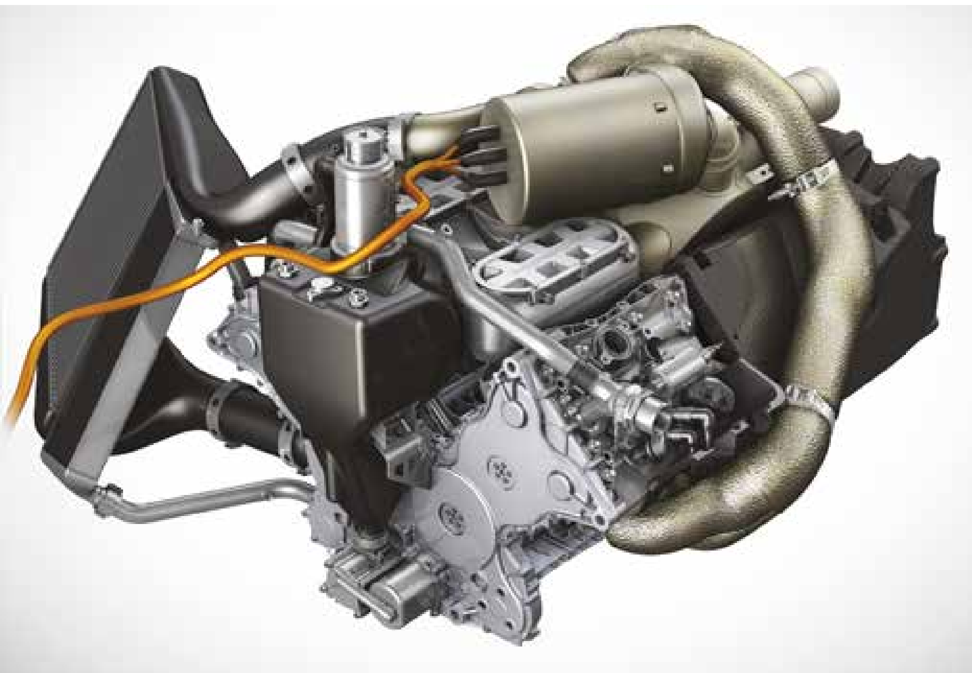
The fuel energy for Formula 1 is calculated from the permitted 100kg for the race divided by the number of laps. For LMP1, it is the figure for Le Mans, factored by the circuit length, times 1.11. For ERS energy, F1 has 2MJ typically (limited by the recovery/lap maximum allowed); Porsche's LMP1 is 8MJ, factored for circuit length relative to le Mans, times 1.59.

The F1 car's fastest race lap is 3.7 seconds faster than the best LMP1 race lap. Simulation indicates that the MJ/lap time sensitivity is 1.7MJ/sec. This figure is calculated at the flywheel, which yields around 45 per cent of the fuel energy used, so the fuel energy use sensitivity becomes 3.8MJ/sec.

To reduce the Formula 1 time to that of the LMP1 car, it would use 14.0MJ less, i.e. 71.8MJ. Comparing the LMP1's energy consumption for a lap at Silverstone at the same 210kph average speed as the Formula 1 car, 65.3 MJ, it uses nine per cent less. These numbers require certain assumptions, particularly about both the fuel and ERS energy used by the drivers on those particular fast laps. Using the same approach for Spa, see **Table 4.**

The race fastest lap difference was 5.6 seconds and the fuel MJ/lap time sensitivity is 3.4 MJ/sec, giving a Formula 1 reduction in MJ used to achieve the same lap time as the LMP1 car of 19.0MJ. Thus energy use for the same average speed, 214kph, at Spa is F1: 84.4MJ versus LMP1: 77.7MJ, or eight per cent less.

Porsche's system uses the second exhaust turbine/MGU coupled to the front axle, and is complex and expensive, Hitzinger admits. Harvested energy can only be deployed via the front axle while Toyota can share between both axles with its system



The exhaust turbine arrangement that is mated to the dinky little V4 internal combustion engine is unconventional. There are a pair of turbines involved, one of which drives the induction air compressor, while the second drives the MGU-H

Impressive tech

Depending on your point of view, one can either hail the success of getting a man around these two high-speed circuits at over 200kph average, in an open cockpit, open wheel car at less than a 10 per cent efficiency deficit compared to a closed cockpit, closed wheel car; or one can hail the success of LMP1 in developing a formula that potentially takes two people around at nearly 10 per cent higher overall efficiency than a car that only takes one person. For me, they are both mightily impressive, and both are generating and proving relevant technologies.

Hitzinger feels that the time is nearly right to go to the next regulatory step toward improved efficiency. He believes that increasing the influence of the electric power system, and reducing that of the ICE is the way to go. Also he would welcome some freedom in variable aerodynamics, such as rear wing drag reduction and variable geometry cooling systems that would allow even greater overall efficiency.

Different approaches

If the WEC does go this way, it will emphasise the different commercial philosophies of that championship compared to F1. In WEC, the manufacturers wish to promote their technologies, particularly those relevant to road cars, and to demonstrate that drive for efficiency, even if it is at the expense of entertainment and a large fan base. They obviously believe that car buyers are aware of what they are developing through endurance racing and the WEC, and do not need non car-buying fans to fund their racing.

F1 has not managed to make this distinction, and this is at the root of the manufacturers versus the promoter power struggle. F1 has not achieved significant cost reductions to

This cutaway gives a perfect perspective on just how small the V4 ICE is and on where it sits in relation to the rest of the 919's power unit components

Most of the components and systems of the V4 engine follow normal racing practice – the valve closing is by springs, not pneumatics

date, and the relentless R&D needed to remain competitive requires more funding than the manufacturers involved are prepared to provide. Hence the need for F1 to be entertaining to a wide audience, and the manufacturers to be rewarded with a larger share of the proceeds.

The engine

The tiny V4 Porsche ICE is a jewel, but it is at the same time fairly conventional for a racing engine. Hitzinger confirmed that architecturally there is nothing unusual, apart from the V4 configuration, and most of the components and systems of the piston engine follow normal racing practice. The valve closing is by springs, not pneumatics. However, the exhaust turbine arrangement is anything but conventional. Two turbines are involved, one driving the induction air compressor, the second the MGU-H. Hitzinger would not be drawn on how these two are controlled by the energy recovery control laws, but did provide insight into the actual control mechanisms involved.

The turbocharger turbine does not have a VG intake, nor can the speed be controlled due to the absence of an MGU coupled to the shaft. The ER turbine, however, has both VG and speed control. Thus the exhaust flow can be distributed by bleeding off gas to the ER turbine, and using the speed to control the backpressure. One advantage of this system is that it provides a degree of redundancy; if the MGU-H fails, the ICE is still able to run as normal.

A second advantage is that if full throttle power is not needed to drive the car, for example under braking, mid-corner, or if it is rear wheel traction limited, exhaust gas can be

The exhaust turbine arrangement is anything but conventional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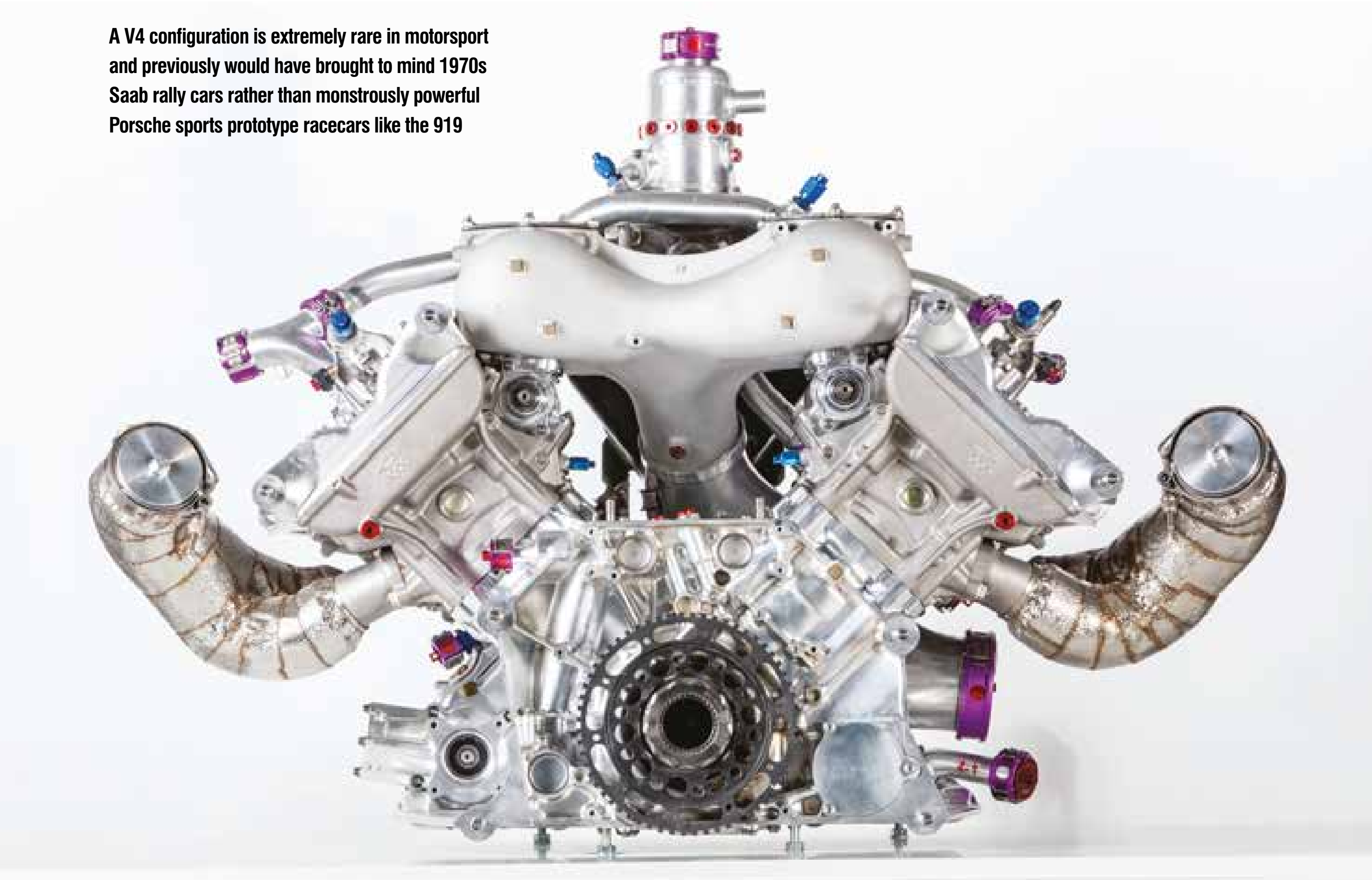
A V4 configuration is extremely rare in motorsport and previously would have brought to mind 1970s Saab rally cars rather than monstrously powerful Porsche sports prototype racecars like the 919



diverted to the second turbine, and the energy sent to either the front wheels or the battery. Of course this consumes fuel energy, but the fuel flow rate will be below the max under these circumstances. Stint length may be reduced, but strategically it may still be an advantage, depending on the number of laps possible on a tankful. The acceptance of traction control in WEC makes this process more straightforward to control. Porsche does not feed-back torque from the mandatory torque sensor, as Hitzinger feels this device is not reliable enough.

Technology crossover

All Porsche's racing activities are located within the main factory at Weissach. The LMP1 division employs about 260 people, and it has access to all the other Porsche departments. Technology transfer between the LMP1 hybrid programme and road cars is a big part of it, and this is certainly a two-way street: from the road car division comes calculation (simulations), dynamometers, material sciences and FEA, and the use of the full-size wind tunnel.

The racing programme is much more able to take risks, and the road car engineers are able to observe and learn from these. An example is the use of 800V in the hybrid system on the 919, where the maximum to date on the road car is around 400V. All the power electrical systems are at the leading edge of this automotive

Alex Hitzinger believes the internal combustion engine will be redundant in road cars by 2050

technology and the race programme is an integral part of Porsche's R&D.

Hitzinger believes that by 2050 the range and cost of electronic vehicles will have made the gasoline and diesel ICEs redundant for cars, except for niche applications. Formula 1 and the WEC's drive towards internal combustion engine efficiency is extremely relevant and useful to those manufacturers that are brave enough to participate, and is exactly the sort of technology to which top-level motorsport must continue to make a contribution. Lessons learned today will find their way into the ICE's of bread and butter road cars within a decade. But it is the electrification and energy storage side of both these formulae that paves the way for the future. In 10 years time, road car powertrains will, according to Hitzinger's predictions, be a third of the way through the transition to full EV and the eventual demise of the ICE as a prime mover for automobiles.

Relevant technology

The FIA and the ACO are fully committed to pursuing this relevant strategy in WEC, and in doing so they have attracted the two largest automobile manufacturers in the world: the Volkswagen Group and Toyota. That alone tells them they are right to do so.

The fact that VW has fielded Porsche as their standard bearer of gasoline engines tells us a great deal about the company. Porsche may be a manufacturer of niche, high-performance sportscars and SUV's, but it has demonstrated that it is also right at the leading edge of relevant, bread and butter road car technologies, and it is its commitment to competing at the highest level in endurance racing that has put it there.

The race programme is an integral part of Porsche's road car R&D

Good **Manors**

After campaigning an interim chassis last season Manor has now hit the ground running with its promising MRT05 and, as *Racecar* discovered, the team now has real grounds for optimism

By SAM COLLINS

When the Manor team filled the back row of the grid at the Australian Grand Prix it was in many ways business as usual. From its foundation in late 2009 as Manor (later Virgin and Marussia and then back to Manor again) the team has always occupied the lower reaches of the field. But when in the opening part of the Melbourne race one of the two Manor MRT05s raced its way up to 14th on pace, it was clear that something had changed.

The team collapsed financially before the end of the 2014 season and that looked to be the end of the FIA's failed new teams experiment of 2010. Almost everything the team owned was sold off at auction, with the Haas team separately acquiring its factory in Banbury, England and its CFD cluster. There was almost nothing left, but a last ditch rescue attempt by a British electricity supply entrepreneur saw the reborn 'Manor-Marussia' team make it on to the grid in 2015. All the team had to work with was the pit garage equipment and a pair of 2014 specification Marussia MR03 chassis, as well as a supply of obsolete Ferrari power units. The team modified the MR03s and managed to survive the 2015 season with a deeply uncompetitive machine, but throughout that season it was clear that the focus was really on 2016.

Marussia had completed the design of an advanced new 2015 car, revealed exclusively in these pages in late 2014. What this magazine dubbed the MNR1 was to have been fitted with a 2015 Ferrari power unit and a carbon fibre transmission from the same source. When the team collapsed, much of the design was lost with the wind tunnel model being sold off to collectors and the CAD model rendered at least temporarily inaccessible. 'We managed to keep a copy of all the important CAD from when we were Marussia,' John McQuilliam, Manor's technical director, says. 'That being said the initial design of the MRT05 and the updates package of the MR03 was done from A4 print outs of the old car. So I sat down at my kitchen table to work out how to handle the new regulations with what had been done before.'

The initial idea was for the updated MR03 to be a stop-gap measure until the 2015 design could be built, but for various reasons it was clear that the new car, the MNR1, would never be completed. But, that work was not to go to waste, and the similarities between the 2016 car and the stillborn 2015 version are clear to see. 'There is a lot of the old car in it,' McQuilliam says. 'We never built the 2015 car, although it was fully designed. That was the starting point

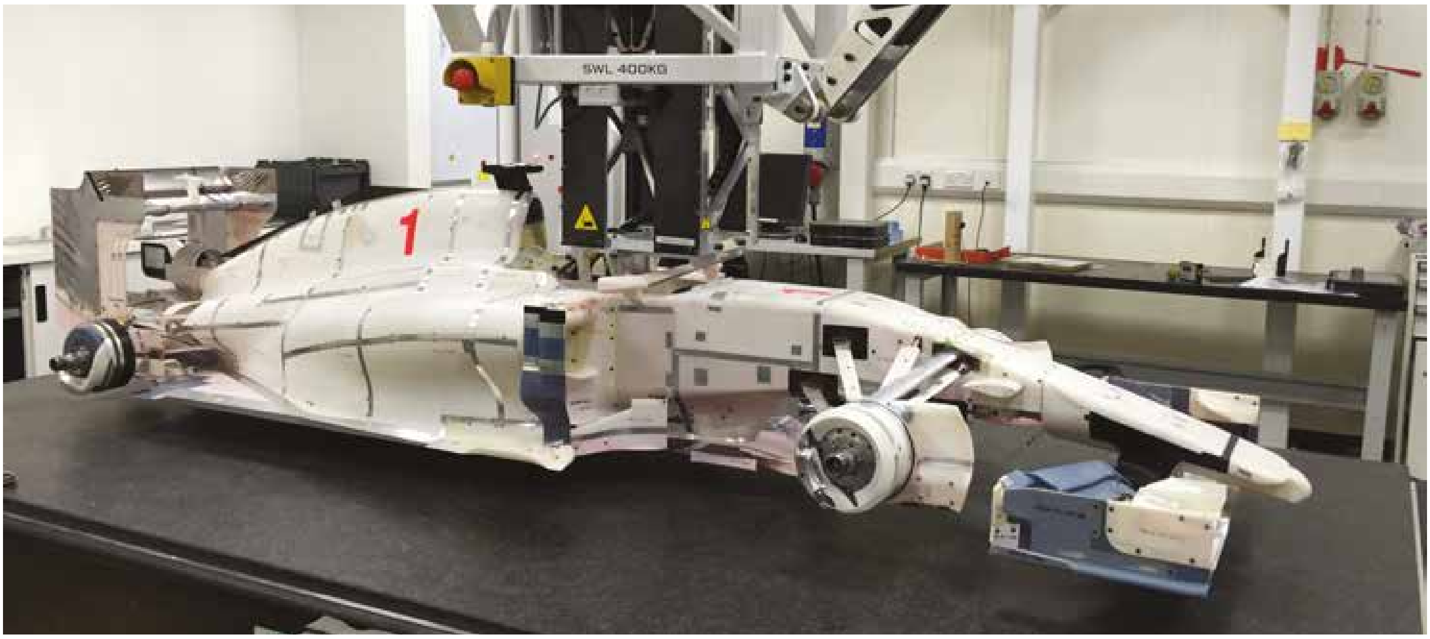
The use of the Mercedes power unit had a major impact on the layout of the rear end of the car, necessitating a change to almost everything from the driver back

While Manor filled the last two places on the grid at Melbourne for the season-opening Australian GP the MRT05's race pace was promising

for this car when it became clear that we could not introduce it during 2015.'

Using the 2015 car not only advanced the 2016 project substantially in terms of time, but it also led to many of its core concepts being carried over, with the stability of regulations. 'The new car benefits from the performance we would have got out of what you call the MNR1. It never got built so it never got a name, but we called it '115' internally, that's how I remember it. That was the starting point and it was similar to the MRT05 mechanically,' McQuilliam says.

One of the main issues with continuing with the 115 as a basis for a new car was that all of the wind tunnel model parts had been



The wind tunnel model of the stillborn 2015 car was sold for £2000 at auction but the Manor team was able to buy it back and it was used to jump start the development of the MRT05

The rear brake assembly on the MRT05 has a different ducting to that on the stillborn Manor 115, but it uses the same caliper position. The rear suspension is pullrod actuated

The inner face of the front upright; the red cables are the mandatory wheel tethers. Front suspension is actuated by pushrods, as it was on the MRT05's predecessor

sold off at auction. But there was still a way, says McQuilliam: 'Aerodynamically speaking this car started life with that [115] model. Most of the mechanical bits of the model we managed to keep, the spine and the metallic parts underneath, as that was effectively joint property between us and McLaren whose tunnel we use. We had modified some of their parts and also they had loaned us some things. That element was safe in Woking, but what was lost was all the bodywork parts you hang off that. The quickest way to get ourselves back in the wind tunnel was to buy back those parts from those who won them at auction, and continue developing from there. That saved us quite a lot of cash and time.'

In terms of overall design the MRT05 is understandably very similar to the 115 with a long, wide nose leading back to a pushrod actuated front suspension. The chassis and central portion of the car is largely conventional with pullrod actuated rear suspension. Overall the car is the result of the lessons of the past, says McQuilliam: 'We made a big step between the MVR-02 and the MR03 in terms of aerodynamics, but the MR03B of 2015 was neutral at best. Because of time constraints we had to modify the nose and front wing quickly. We just drew it and made it. The regulation changes and the way it came together meant that intrinsically that car was a bit less efficient aerodynamically. After in-season CFD work we tweaked the design a bit and that got us back to where we had been with the MR03.'

Original thinking

The team had placed a lot of hope on the 115, it was expected to be a far stronger design than the MR03 and finally move the team up the grid. 'There was a big jump between the MR03 and the 115 anyway and we have taken that on. This year development has come on really well. We have a really good group of people in the aero department now and I'm proud of what they have achieved,' McQuilliam says.

Despite all this, the MRT05, however, is not a simple development of the 115. It is a very different car. During the 2015 season the team's new owners looked around for new partners and eventually decided to part company with Ferrari. And this had a major impact on the car's mechanical design. 'With the uncertainty about the engine we started at the front of the car looking at the aero and the front impact structure,' McQuilliam says. 'Although it's similar in concept we redesigned the front suspension again over the 2015 design to improve kinematics and things. We were basing it on the feedback we had from the 2015 season rather than the 2014 season, which had defined the original front suspension layout on the 115.'

The front suspension of the 115 was claimed to have unique features not found

In terms of design the MRT05 is understandably very similar to the 115

'There is something quite clever with the front suspension on this car'

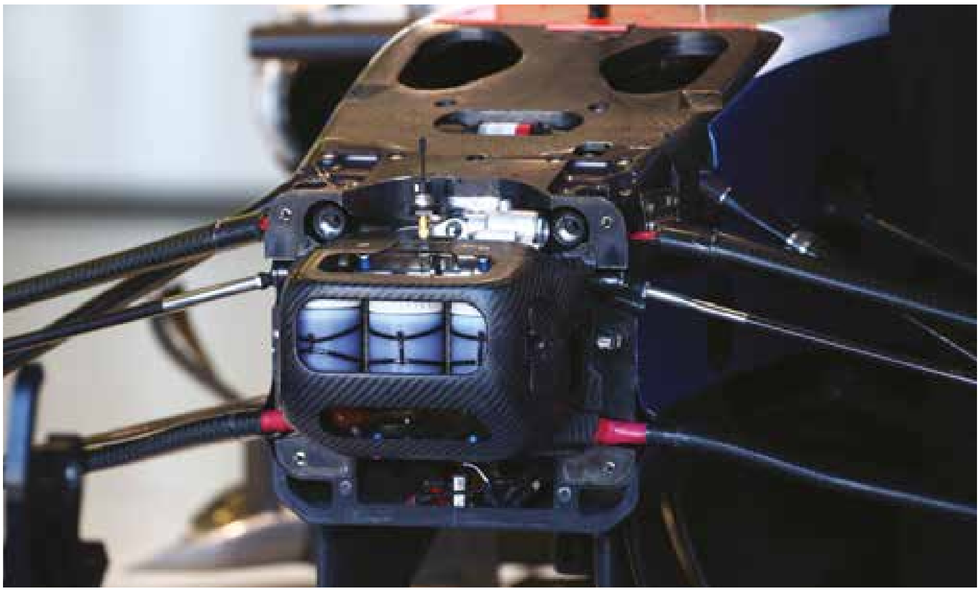
on other cars, though details of the layout have yet to emerge despite much of the car's design finding its way into other teams via staff movements, and into the public domain via the auction process. While McQuilliam will not be drawn on specifics he is willing to admit that the concept has carried over: 'There is something clever with the front suspension on the car. It's a bit special and that has carried over from the 115, though we have moved things around a bit in that area. We have changed the external geometry, but the clever bit we have retained.'

Those suspension parts are housed in another stand-out concept: the aluminium front bulkhead introduced on the MR03 and copied by Red Bull. 'We have retained the aluminium front bulkhead though it's not obvious as we have anodised it black this year,' McQuilliam says. 'It's much easier with aluminium to go through a couple of iterations of it in terms of manufacturing. The bulkhead is not really changeable though, that is a misconception. It's laminated and bonded into the chassis. The internals of that part are extremely complex. We believe it to be a really elegant way of doing it as we have all of the mounting brackets for the internal suspension parts and things machined into that single part bulkhead. It's better doing that than trying to get those mounting points all on the back face of a composite moulding.'

Once the front end of the car was completed the design team at Manor had to wait for the team's senior management to do various behind the scenes deals, complicated perhaps by the fact that a number of teams were uncertain about power unit supply during the summer of 2015. The management eventually pulled off something of a coup by securing a supply of the best in class Mercedes-Benz power units.

'It was a bit of a waiting game to find out which power unit we would have,' McQuilliam explains. 'Once it was settled on Mercedes we had to look at the installation of that, and the Mercedes is quite different to the Ferrari, it has very different architecture. We then moved on to create the installation for that, and the rear of the car, and the aerodynamic team carried on working with that package.'

The roll hoop ducting of the MRT05 is quite different to that of the MR03 and the 115, as to install the new Mercedes power unit the coolers, which had been positioned here, had to be relocated to the car's sidepods



The front bulkhead of the Manor MRT05 is made from machined aluminium, a concept that was carried over from the MR03 used last year. Manor says the front suspension has some very novel features but the team will not tell us what these are

PU implications

The use of the Mercedes unit had a major impact on the layout of the rear end of the car, necessitating a change to almost everything from the driver back. 'The energy store is not that different between the two units but the front of the engine really is, so we had to put in a much bigger cut-out at the rear of the tub in order to install the Mercedes,' McQuilliam reveals. 'That made us move away from the philosophy that we had on the 115 and the MR03, where the coolers were alongside the rear legs of the roll hoop, and those coolers are now back in the sidepods.'

Ironically, while the installation of the Mercedes unit forced Manor to revert to a conventional cooling layout, the works Mercedes team has relocated some of its coolers to a similar arrangement to that on the MR03. 'I'd like to think the works team saw what we and Toro Rosso did and copied us on that! They have the advantage, of course, of having more time. I think our installation is very good, but we did have to keep it simple in that area,' McQuilliam says. 'Our cooling system is very traditional, with a charge air cooler which is an air-to-air cooler, it makes life simpler from a packaging point of view and it's more weight efficient.'

With the Mercedes power unit supply confirmed it was clear that Manor could no longer use the Ferrari transmission and had to find an alternative supplier, and the aluminium cased Williams gearbox was selected. But the switch of transmission and power unit brought with it major design considerations beyond the simple installation of the German-branded but English-made turbocharged V6.

'The Williams casing meant we had to use the same inboard pickups as they do. If you change the rear suspension you then have to change the front, so when we got the geometry from Williams we had a little tweak of the front end just to make sure that the roll stiffness front to rear, and the roll centre heights front

The endplates are a direct carry-over from the stillborn 115 but much of the MRT05's rear has had to be radically redesigned to house the new engine and transmission

One of the major factors that the Manor team has going for it this year is that the MRT05 is fitted with the latest specification Mercedes power unit, plus the Williams transmission

TECH SPEC

Manor MRT05

Chassis: Manor Racing moulded composite with aluminium honeycomb core

Bodywork: Moulded carbon fibre with Nomex core

Safety structures: Cockpit survival cell incorporating impact resistant construction and penetration panels, front impact structure, prescribed side impact structures and forward and rear roll structures.

Suspension
Front: Manor Racing full composite. Pushrod to rockers with torsion springs and inboard damping
Rear: Williams Advanced Engineering
Dampers: Front: Penske. Rear: Williams Advanced Engineering

Steering: Manor Racing power-assisted rack and pinion

Wheels: APP Tech forged magnesium

Tyres: Pirelli

Brakes: Brake system: carbon/carbon discs and pads; Manor Racing brake-by-wire
Discs: Carbone Industries
Pads: Carbone Industries
Calipers: AP Racing

Fuel cell: ATL Kevlar-reinforced rubber bladder

Electronics: FIA standard ECU and FIA homologated electronic and electrical system

Dimensions
Front track:1799mm
Rear track: 1799mm
Overall length: 5000mm
Overall height: 949mm
Overall weight: 702kg

Cooling: PWR

Cockpit
Instrumentation: MAT
Car to team radio transmission: FOM
Telemetry: FOM
Steering wheel: Manor Racing carbon fibre moulded
Seat: Manor Racing composite moulded
Seatbelts: Sabelt 5-point
Extinguisher: System FEV

Powertrain
Power Unit: Mercedes-Benz PU106C Hybrid
Exhaust: Mercedes-Benz
ERS: Mercedes-Benz
Fuel: Petronas Primax
Lubricants: Petronas Syntium
Functional Fluids: Petronas Tutela

Transmission
Gearbox: Williams Advanced Engineering; 8-speed forward gears, one reverse gear
Gear selection: Sequential, semi-automatic, hydraulic activation
Clutch: AP Racing carbon plate

to rear, were compatible. Once that was done, frustratingly, the suspension designers and aerodynamicists had yet another tweak on the front suspension, but that's life!'

With power unit, transmission and suspension changes, it is clear that the weight distribution of the car would have shifted and that's indeed the case. In Formula 1 the weight distribution of the cars is fixed in a narrow window of 7kg, with the minimum weight set at 702kg overall, the front axle minimum is 319kg and the rear axle minimum 376kg, in order to make life easier for the tyre supplier.

Short bred

'The Mercedes installation and the Williams transmission did impact the wheelbase of the car and as a result the MRT05 is slightly shorter than the 115 would have been,' McQuilliam says. 'When we first started talking to Williams they gave us an approximate length of the gearbox so we could work out what would be behind the Mercedes engine and what the weight distribution would be. To get that ideal distribution the main thing is where the engine is relative to the driver, and you can move that backwards and forwards, the front wheels backwards and forwards, and after a bit of that we found the answer was to go a little shorter.'

Getting that weight distribution right was one of the main objectives of the 2016 design, and it impacted almost every area of the car's design, especially as the Manor engineers were not certain. 'I would say the trend in terms of the weight distribution window is to bias things a bit toward the front, that is what we have aimed for,' McQuilliam says. 'But there has been some uncertainty; what is difficult with new partners is truly defining the perimeter. With Mercedes they are very good and will tell you the exact centre of gravity position and things, but you are not quite so sure about some of the pieces around the perimeter of that.

'The same is true with Williams, they know very well what they have done for their own purposes, but for us it's a bit different perhaps, with parts that we will mount in a different place,' McQuilliam says.

To be able to cope with the uncertainty of the component weights and positioning, the Manor engineers had to take extreme measures, something which if it worked could give the car a competitive boost in some situations, but has some inherent risks, too. 'We tried to increase the elegance of it all and made everything as light as possible so we are confidently under the weight limit. That let us put the ballast where it is required, and that gives you a few more tuning options race to race, so we get the weight distribution we want track to track. But there is the saying that adding lightness adds unreliability. I can't deny that, but the way round it, I hope, is good and elegant design. That also means good analysis and testing so we have been busy breaking things, making sure they're strong enough, lots of FE analysis.'

Once all of this was done, the chassis could be manufactured but Manor has not got the capacity to build its own monocoque: 'Our tub is outsourced, we can't make it ourselves so we are working with EPM. I know Graham Mulholland very well and when I was at Jordan we moved our chassis build there, so I go back 17 years with them,' McQuilliam says. 'Things have moved on since then and they have some very good technologies there and it means our designers can design and specify every single ply in the chassis; the perimeter of the ply, the orientation of the ply, and the material of each single ply. We are so pleased with the chassis, it is such a nice component.'

The Manor MRT05 is the first car from the team for two years and is without doubt the most competitive it has built. At the time of writing it has yet to show what it can do, the back row at Melbourne and a double retirement in the grand prix was a disappointment, but there is clearly more to come. 'The exciting part of Formula 1 is going faster and faster and faster, and we are in a position where the chances are we will go comparatively faster and faster for the next few years,' McQuilliam says.

Indianapolis **100**

The 100th running of the Indianapolis 500 makes this a big year for IndyCar – but both the series and the teams alike will hope that mods made to the aero kits will mean there will be no repeat of 2015's flips. *Racecar* examines these and other IndyCar developments

By MARSHALL PRUETT

IndyCar opened its new season with numerous technical changes in place for its Chevrolet- and Honda-powered Dallara DW12s. A variety of season-long updates for the 13 rounds of road course and short oval events were unveiled, with special aerodynamic allowances for the three events held on large ovals, including the Indianapolis 500. There are also bespoke updates expected for the 100th running of the Indy 500 this May.

On the engine front, IndyCar's homologation table allows a wider range of development to Chevrolet and Honda. With 2012's introduction of its 2.2-litre twin-turbo V6 engine formula, the series has alternated development years, with 2014 and 2016 targeted for more ambitious implementations. 'It is definitely an interesting year because some of the things that they have opened up have not been opened since we made the engine new in 2012,' says Honda Performance Development VP Steve Eriksen. 'It is a chance to go back and look at something that we just did not have an opportunity to look at before. An example of that, for instance, is fuel injectors. We had to fix our injector specification some time before the 2012 season. That is a neat thing for us to be able to mess with now, because we have now spent all that time with that spec, so we now pretty much know what that is going to do.

'The other things of interest are the port shapes, so inlet and exhaust and the shape of the combustion chamber can all change within the casting. You can't make a new casting but you can change the way it is machined.'

Engine limits

IndyCar maintains its previous engine life minimum of 2500 miles and a maximum of five engines per season with each lease for 2016. And with penalties in place for premature engine changes or going beyond five units per entry, Chevy and Honda spent considerable time on the dyno performing reliability runs during the off-season. After reportedly struggling to make the 2500-mile minimum at HPD, the brand confirmed it would start the year with its last specification from 2015 at the Sonoma finale, albeit with a few changes to the internals to increase durability.

Honda's 2016-spec motor should appear in time for the Indy 500: 'Essentially, we're allowed to [redo] the air passage below the throttle, so if we start there, from the throttle down to the cylinder head, that shape can change,' Eriksen said. 'Then, of course, following it through, the port itself can change. And then following through into the combustion chamber, that shape can change. So from throttles down into the chamber itself, the combustion chamber, it is able to change, which is interesting.

'The concept being, if you start out, and say, I want to be able to do the port, well, I'm going to do the port, I need the combustion chamber. If I'm going to change my port I have to change the piece it is connecting to. So that portion of the inlet tract up to the throttle can change. And then basically from the throttle up, that part stays the same. Really, the plenum itself isn't changing, it is just those portions of the inlet tract are considered part of the plenum.'

Among the changes reported by Chevy was 'upgrades to ports, camshafts, fuel system and installation – including a new, lighter exhaust system and a new wastegate with improved actuator cooling and valve head design.'

But with IndyCar's two-horse engine war taking a backseat to aero kits, the majority of

intrigue for 2016 can be found in the bodywork supplied to teams. Coming off a year where Chevy's aero kit proved vastly superior to its rival, IndyCar conducted wind tunnel testing to benchmark the kits and found Honda's road course/short oval (RC/SO) package was deficient. Exercising aero kit Rule 9.3, which allows the series to grant permission for homologated items to be redeveloped, Honda went to work on a new sidepod and rear tyre ramp design. That project, which was taken in-house by HPD after reducing its alliance with Wirth Research, produced RC/SO sidepods and ramps that bear more than a striking resemblance to Chevy's RC/SO package.

Aero updates

Aero kit Rule 9.2 opens another door for development where each manufacturer can develop items within three specific regions, and unlike Rule 9.3, special permission is not required from the series to release those pieces to the teams. Under 9.2, Chevy and Honda are allowed a total of three updates from the three regions, and in basic terms, the RC/SO regions are found at the outer front wing upper elements and end plates, rear wing upper elements and end plates, and the rear wheel pods. Outside of the RC/SO pieces, the superspeedway front wing mainplane and end plates, and the Indy 500 rear wing mainplane, mainplane pillars, and end plates are open for redesigns. With three total revisions allowed, aero kit manufacturers are forced to pick and choose carefully among RC/SO, superspeedway, and Indy 500 boxes to revise for 2016, and in an interesting twist, Honda was permitted to roll some of the 9.2 changes into its one-time 9.3 updates. Along with the RC/SO sidepods and wheel ramps, HPD made new front and rear wing end plates. Those items also could be easily confused wit Chevy's.

Continuing on the 9.2 changes, Honda used two of its three tokens to start the season as it stacked new front wing elements atop of the stock mainplane, and fashioned new modular rear wheel pods. Chevy, at the first round at St Petersburg, used only one token to replace its rear wheel pods with a low-profile shape and small wing elements that

Honda has taken advantage of opportunities to update its engine for this season and has developed the fuel injectors and ports

The rear of the 2016 IndyCar showing the approach from Honda (red) and Chevrolet (blue). The silver components are Dallara base car (image; Autodesk)

mirror those used by Honda in 2015. From the data found from its wind tunnel testing, IndyCar determined Honda's shortcomings on big ovals, while present, were not great enough to warrant changes under 9.3. It means Honda teams will be required to reinstall the 2015 sidepods and rear wheel ramps at Indianapolis, Texas, and Pocono, which could, at least at Indy, tip the scales in Chevy's favour.

Using last year as a reference, Chevy earned 16 consecutive pole positions, won 11 of those 16 races, and utterly demolished Honda at the Indy 500 thanks to an aero kit that was on a different level. Great gains have been made by Honda since Indy, but the return to 2015-spec body panels for the great race is unlikely to inspire confidence among its entrants.

Those teams, in addition to the series and its manufacturers, will also enter the month of May with vivid memories of the aero kit-related flights and flips that untethered three Dallara-Chevys from the 2.5-mile oval during practice.

Like a detailed script of how not to go about introducing new aerodynamics at the series' fastest and most prestigious event, IndyCar was caught off guard by the flights and how to react in the hours following those events. Winding the clock back, the series' restrictive policy towards testing at Indy meant manufacturers were unable to log adequate data in the various bodywork configurations and levels of drag reduction that are common in qualifying and race trim. Simply put, at a deadly circuit where average lap speeds above 230mph were expected, Chevy, Honda, its teams, and even IndyCar got the first taste of real-world Indy 500 aero kit data once practice began.

The return to 2015 body panels for Indy is unlikely to inspire confidence among Honda entrants

Lack of info

A lack of wind tunnel testing by the series also left IndyCar without information of its own on the aero kits it pressed into service, and once the trio of Chevys took flight after high-speed spins, the series had to rely on Chevy and Honda to perform simulations and CFD runs to assess the causes. Reliant on its manufacturers to fill its knowledge gaps, the call to qualify without higher boost settings, and to require teams to race in the aero configuration used in qualifying, was made. The net effect led teams to abandon the extreme low-downforce and low-drag packages in favour of slower, high downforce/drag settings that were needed for race day. Honda was required to run with a central wicker running atop the DW12's tub, despite its cars never having left the ground.

According to IndyCar, the flight experienced by Penske's car was aided by the central wicker on the Chevy, and as a result, the devices were pulled from the rest of the Chevys. Increased cornering stability was found and the flights ended. With more time to run virtual tests with the cars in states of significant yaw, or turned backwards, IndyCar made a change to the rear wheel pods in superspeedway trim after Indy.

Major changes within IndyCar's competition department for 2016, including a new president (Jay Frye, who replaced Derrick Walker), and a new VP of technology (veteran race engineer Bill Pappas, who replaced Will Phillips), have ensured the available lessons from a worrisome run-up to the 99th Indy 500 have not been overlooked. Post-season wind tunnel testing, and follow-up testing with the new aero kit pieces, has been ongoing, and in light of the lack of the Indy 500 aero kit testing mileage, an efficacy test was scheduled for April 6 where proof of concept – or any concerns – could be confirmed well in advance of the first official practice session.

Having Pappas, who has engineered the DW12 since its introduction and ran a car for KV Racing at Indy last year, in a position to use his experience and process-minded approach to preventing more flights has been seen as a boon for the paddock. 'Generally, we think we have clearly identified the issues that we came across last year,' he says. 'Last year we didn't have any type of test prior to showing up to the Speedway. So we're going to do that here coming up in April. If there are any issue, they will be seen. And we can make a change that we see fit for the month of May so we are not caught by surprise. That's the biggest thing; let's address the issues before May. And from a practical standpoint, we're just trying to be more proactive and thinking ahead. That is my style; I try to look out ahead, okay, what can potentially go wrong? Some would say I'm pessimistic but I'm realistic.

'I think the general sense here within the office is, okay, let's get on board with that and

Figure 1: Speedway configuration

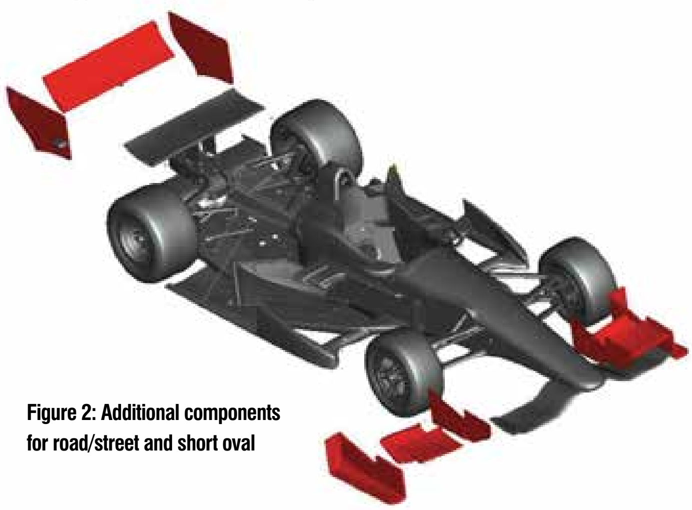


Figure 2: Additional components for road/street and short oval

try to be a little more realistic than, "oh, we will go there with the brand-new bits and pieces that haven't been run before and everything is going to go smoothly". I think it's super critical that we all understand that things don't always go the way you want so you have to be prepared and have plan B and plan C ready in case.'

New componentry has also been introduced by IndyCar to complement its procedural advancements. Titanium dome-shaped skids that mount below the standard plank skid plate have been reintroduced after being used on the previous Dallara chassis, and in a new development after the 2015 flights, a vertical flap system has been approved. In a rearward spin the flap pieces, which affix to the rear beam wings, deploy upward at 90 degrees and lock into place to prohibit lift.

Take-off speed

Those items, in addition to more extensive usage of tethers to hold the nose and rear wheel pods in place, are required for the three superspeedways. Pappas would not be drawn on the number, but the addition of the dome skids and flap system is said to push the take-off speed for a Dallara DW12 in superspeedway configuration to well over 300mph, which would be impossible to achieve. 'From a safety standpoint, we have [NASCAR-style] roof flaps but on the rear beam under the rear wings this year,' Pappas said. 'Obviously, the big one at this moment is introducing dome skids to the cars for Indy, Texas and Pocono.

'With the rear flaps, they are designed to engage and open up at about 130-degree of yaw and beyond. So as the car starts to turn around it will open up and it keeps the back of the car down. The dome skids, primarily, work in yaw past 90-degree to 135-degree, it's supposed to help reduce the spin rate of the racecar, to slow it down so that we don't get the cars rotating quickly.'

'I think the car is a lot more stable, last year it was difficult to get a handle on the balance'

Working with '16 aero

Working with the revised Chevy and Honda aero kits has been akin to starting from scratch, according to Target Chip Ganassi Racing's Chris Simmons: 'Obviously, Chevy did a good job with the aero kit last year and we had good adjustability,' he says. 'But to be honest, so far this year it has been a big change or maybe even bigger, the changes to the car don't look very big. So far we have run really with just one box changed, the rear bumper pods. But it has changed the car dramatically, not just in generating more downforce efficiently but also it's changed the ride characteristic of the car significantly. So I think everyone in a Chevy camp was scrambling a bit to adjust their mechanical set up to match the new aerodynamics that we haven't had a lot of time with, particularly the street course guise.'

Chevy's choice to trade its curved ramp atop the 2015 rear wheel pods for proper wing elements has added downforce to the back of the car, and as expected, shifted the dynamic centre of pressure in RC/SO trim. 'Yes,' Simmons continues. 'For us St Petersburg hasn't been our best track the last few years. We've always struggled with understeer there; I think most people do struggle with understeer at St Pete. But now the aero characteristics of the bumper pods and what it's done to the stability of the rear downforce has really affected how we had to set the car up to get it to piece the corner together so that the entry, the middle and the exit aren't so separated.

'To be honest, it is a little bit more like a sports car aero map now. And this isn't all because of the Chevy kit, but it is very front ride height sensitive as far as the total downforce, and it really reminded me of running prototypes with the big splitter on the front, which was also very front ride-height sensitive.'

Schmidt Peterson Motorsports' Allen McDonald is one of the leading engineers among the Honda contingent, and after going through the brand's well-documented aero kit struggles in 2015, he and driver James Hinchcliffe have found the 9.2 and 9.3 updates make a world of difference. 'There was just something going on with the whole kit last year that just made it unpredictable for the driver, difficult for the driver to be consistent, and I don't know if that was ride height sensitivity, or mechanical stiffness or integrity of the front wing that created our problem, but the whole thing was very complicated,' McDonald says. 'And after we put the new kit on and tested it, James came in and said it was immediately more fluid. He had a big smile on his face.

'Last year we really struggled to know what to do, or go where the historical set-ups were telling us to go, because they weren't working. And then if we made it, stepped out in different directions, we weren't really getting much response back from the car to tell us, yeah, that's the right way or, no, that's the wrong way. It was difficult for us to truly get our heads around it. But this year it is way better. The aero kit really is giving us a lot of feedback. Even after St Pete we got ideas on how to make the car better and better, which is great. Last year we left St Petersburg scratching our heads.'

More downforce

Honda has also apparently found more RC/SO downforce, and from the feedback provided by multiple drivers, the dire pitch sensitivity that plagued Honda's teams has been significantly reduced in 2016. 'I think it seems like there's a good chunk more downforce, which is good,' McDonald says. 'And I think equally importantly, the car is just a lot more stable. Last year it was very difficult for us to really get a handle on the balance of the car. If it wasn't understeering, it was oversteering. It was like five different cars in one corner. It just was very difficult to make any serious inroads into the car balance, and with all the little changes Honda has made, and even the big ones, the car is far more predictable to drive. That's helped immensely.'

As Simmons and McDonald prepared for the April 6 aero kit test at Indy, both spoke about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The well-publicised Indianapolis accidents were not the only car flips to hit IndyCar last year; this was at Fontana. The series has now worked hard to ensure its cars will not take flight when travelling backwards at speed and has made aero mods

what could be in store for Chevy and Honda at Indy. 'There's more developments to come from Chevy,' Simmons says. 'So far they have only used one of their three boxes. We were happy to see the performance that we saw at St Pete with just one of those boxes changed. It remains to be seen what the other two boxes they use will offer, but at least one of them will be focused on Indianapolis. There isn't an official homologation date for the three boxes. But effectively, the oval parts have to be homologated by the Indy safety test, so that would be April 6. For those parts to run at Indianapolis they have to be used by the teams during that safety test. Anything you see at Indy you will see in some way, shape or form at that test.

'The 500 is the biggest race that everybody focuses their programmes on,' Simmons adds. 'Sometimes to the detriment of the other tracks; the one reason both manufacturers used the bumper pod box for development was obviously because it is powerful but also it comes into play on the road courses an on the ovals. So that box, you'll see some of the modularity that was evident in both aerodynamic kits last year having different parts for different situations. That's going to hold true for the bumper pods also.

'There's a base part of the bumper pod that will be the same for road courses and at Indy. And then there's some add-on pieces that will be different for Indy, certainly for the Chevy and I'm sure for the Honda camp also. So you will see visible development and possibly some variations between the cars as we tune for different conditions. You saw last year in practice, although we didn't get to run them in qualifying, Chevy has some pieces to make our sidepod look a little more like Honda when we cut that last bit of drag for qualifying.'

Simmons adds: 'And we will see how powerful the bumper pods are. And the engine has an effect also, and also the weather. So what downforce level we need will depend on how much of a gain Chevy has made on the engine; it can depend on the tyres, how much the track grip has gone down this year, it tends to go down every year until they repave. And then where exactly the bumper pod fits in efficiency wise, downforce wise, will affect what we do with the modular parts of the bumper pod but also the modular parts of the sidepod and even on front wing angles and front wing end plate angles, and things like that.'

'I think IndyCar has also realised that the manufacturers were not against them'

Honda threat

With a year to learn the Honda aero kit, and a return to a similar package for the Indy 500, McDonald anticipates his team – and others under the Honda umbrella – will pose a greater threat to Chevy at the Brickyard.

'I think aerodynamically with the smaller changes that Honda have been able to make, it looks quite promising. I think those are definite positives,' McDonald said. 'I think from our point of view, we just have more time with the car to totally understand it. And I think one of our reflections from last year was that we just didn't really have enough time with the car to really understand it. 'Hopefully with all that we have done in the analysis over the winter and some of our testing, and some of the things we learned after Indy last year with the integration, I think we are in a significantly better position to get into the month of May. Towards the end of the year we started to get our heads around the Speedway set-ups better. When we look at what we did at Indy and reviewing over the winter, there were certainly some things, some lessons we learned that could be taken to this year. It should help us give us all a better start of it, for sure.'

If there's one final question mark facing IndyCar teams ahead of the Indy 500, it's the first-time use of dome skids with the DW12. Private testing with the pieces at Fontana produced scary and unpredictable handling due to the increased ride height required to fit the pieces below the car, and as Simmons shares, developing new set-ups for the 500 with the elevated chassis platform will now be a very high priority.

'There's no way to get around the fact that you physically have to run the car further off the ground because the dome is thicker than the flat skids we had there before,' he says. 'There's no way around that. We have to factor that into our preparation. It certainly isn't going to make the car better kinematic wise, the CofG is going to be higher and you can't get around that. Aero wise, I think there's going to be plenty of gains in other areas to make up for that.'

Simmons also says the trade-off with dome skids and the other new-for-2016 superspeedway safety devices is well worth the engineering hassle. 'We certainly can't have cars flying, mainly from a PR standpoint,' he continues. 'Luckily nobody really got hurt from the cars flying last year, but that's not a situation we want to have happening. A car that is in the air isn't slowing down very much. Safety wise, the information that we have been given says that the dome skids make a meaningful impact to that take-off speed in certain situations, as do the beam wing flaps.

'It's going to make the job harder setting the car up at that safety aspect is something we have to deal with and we're just happy it is a little less of a knee-jerk reaction this time. At least on the Chevy side there's been a lot more CFD work and even some wind tunnel work that has gone into the development. So hopefully we won't have some of those surprises that we had at Indy last year.

'IndyCar certainly learned their lesson there, and I think they've done their homework this time,' Simmons continues. 'I think they also realised that the manufacturers weren't against them. Even though Honda is racing Chevrolet and we are competing against each other, in cases concerning safety and things like that they can trust what Chevy and Honda are telling them and they're not just having some ulterior motive. Everybody has pulled together on the aerodynamic side to do their best to make sure we don't have a repeat of last year. That is really important, and it is the way the sport is supposed to work.'


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Little wonder

For those looking for rear-wheel-drive thrills in the WRC, the R-GT class is just the ticket. Abarth's diminutive 124 Rallye is the category's first proper works-developed rally car

By SAM COLLINS

The Fiat road car on which the Rallye is based comes with a soft top so Abarth needed to make its own hard top to meet FIA regulations. This also helped increase the stiffness of the chassis

There is a third top level in the WRC that sits below World Rally Cars and R5, and for some years now it has largely been overlooked. It officially fits under the Group R regulations, but it is unlike anything else covered by those rules. It is R-GT. Until now only a tiny number of cars have been built to the rules, some privateer Porsches and an abortive Exige variant from Lotus. But then, at the Geneva Motor Show in early 2016, the Fiat 124 Abarth Rallye was revealed.

Most in the media believed that this 124 was a mere concept car, or a show car. Those who did think it was the real deal believed it was designed to the R3 regulations, where it would go toe-to-toe with the likes of the TMG built Toyota GT86. But Abarth is not doing things by half, and this is in fact the first serious manufacturer car built to the R-GT regulations.

Maurizio Consalvo, Abarth technical development manager, says: 'We want to use this car to go back to the roots of rallying, so that is our mission. We are launching a rear-wheel-drive car into an all-wheel-drive or front-wheel-drive world. But for the enthusiast an AWD or fwd car is not the ultimate in terms of spectacle, its all about rwd. Its an emotional engagement and we are emotionally engaged.'

The new Abarth 124 rally car is disarmingly small, especially when the potency of the engine is considered, and it's telling that Consalvo speaks of the engine first. 'The engine is the most important aspect of the car. We have installed the turbocharged DOHC 1.8 direct injection 4-cylinder, we call it the Bialbero. It produces around 300bhp depending on the settings chosen by the driver [via a steering wheel mounted control]. It is the same engine architecture used on the Alfa Romeo 4C, but we tuned it for the best output in competition.'

The production car has both the mild Fiat variant and a more highly tuned Abarth version, and in developing the new rally car the Italian engineers wanted to keep things close to home. 'What makes this car so different is that it is so close to the production car,' Consalvo says. 'If you look at the Polo WRC, it is beautiful engineering but it is a totally different machine to the car that is in the showroom. On our car we have a double wishbone front and a five-link rear, and that is what you will find on the road car. We also have a mechanical LSD, all in common with the production car.'

However, the mechanical components themselves have little to do with the road going machine. The transmission is an off the shelf longitudinal Sadev sequential unit and gearshifts are actuated pneumatically. Curiously, the road car and competition car transmissions have similar weights, according to Consalvo.

Hot Abarth

While the suspension has some general commonality with the production car, such as the inboard pickup points, it is also far from standard. 'The dampers are bespoke four-way adjustable units, we can make the travel longer or shorter depending on if you are on asphalt or gravel. We worked on the kinematics a bit but the pick up points are the same so that was a bit limited,' Consalvo explains. 'When you only have only two driven wheels you need to get the best traction you can, and that was the philosophy of the design.'

Ensuring the best traction possible was also the core aim of the chassis development, which is notable because the production car is a soft top. 'The hard top on the car is specifically designed for the rally car. It is a composite construction and bonded to the roll cage to further increase stiffness. In fact the cage is not only designed to meet the FIA regulations but it is also meant to improve the torsional stiffness, and as such it is linked to the front and rear suspension turrets. The result of the cage and the roof is an increase of 30 per cent in terms of torsional rigidity,' says Consalvo.

Working to improve the traction from the rear wheels has also impacted the layout of components in the car. 'The road car and rally car have almost identical weight distribution, because on the competition car we have increased the weight a bit, the big engine moves weight forward and the cage is heavy, but we save a lot of weight too in other areas,' Consalvo says. 'We have got the engine behind the front axle and also, because this car will do some very long stages and events on the WRC, we decided to find the extra space in the rear of the car to fit two full size spare wheels, rather than the usual one. This also helps us with the weight distribution a bit too, as it moves it rearwards a bit, which aids traction.'

The cockpit of the car is surprisingly large, with a lot of effort clearly placed on making the 124 as usable as possible, and this has resulted in the use of an advanced electronic system. Abarth has clearly outsourced this work but declined to declare who its partner is. 'The interior ergonomics were important, so every single detail was analysed and adapted so the steering wheel is more complex perhaps than some others, with controls for TC mapping,' Consalvo says. 'We have a TFT [flat screen]

The new Abarth 124 rally car is disarmingly small, especially when the potency of the engine is considered

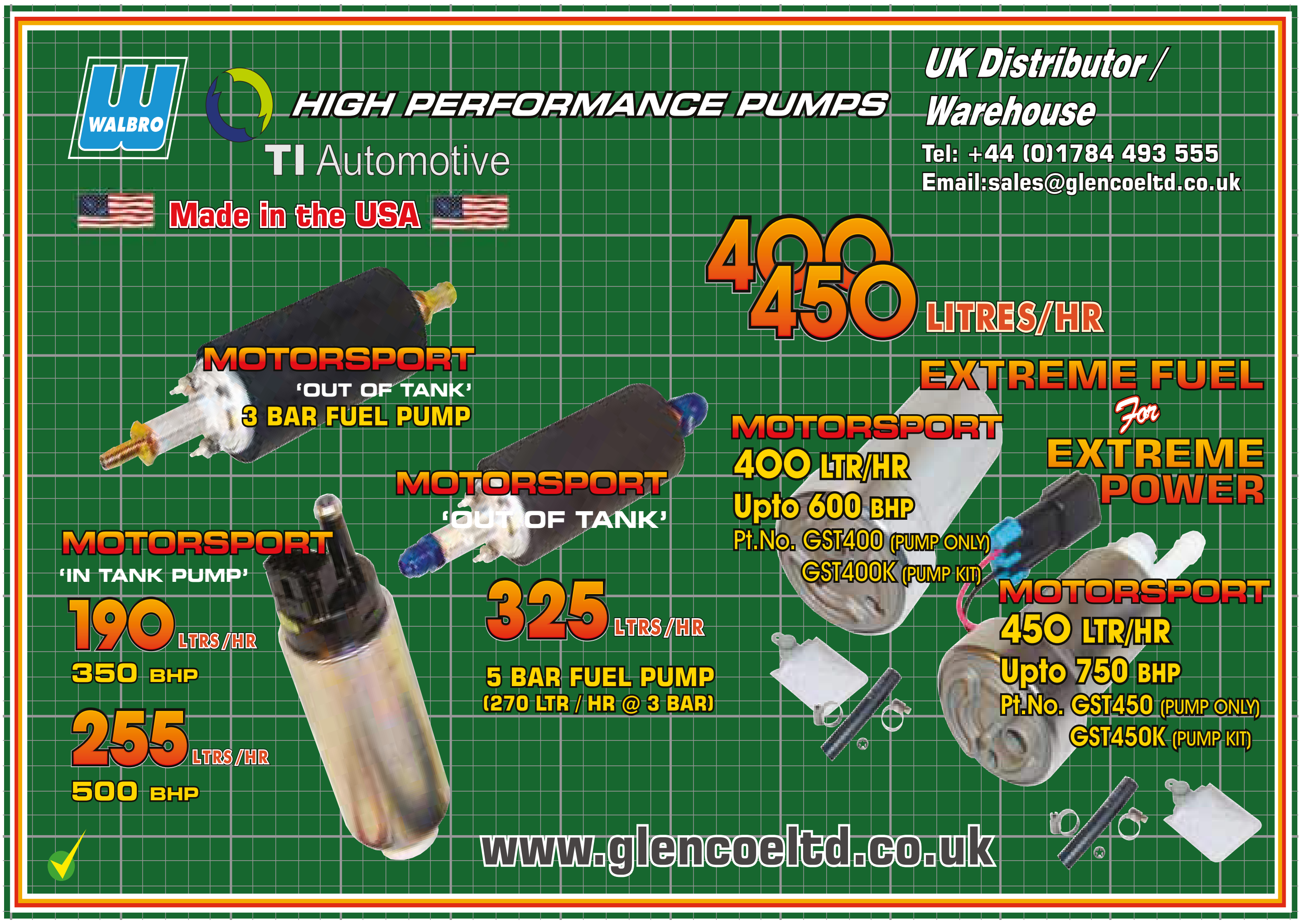
The turbocharged DOHC 1.8 direct injection 4-cylinder powerplant is called the Bialbero. It produces around 300bhp and it is actually the same engine architecture as used in the Alfa Romeo 4C. Abarth has tuned the unit for World Rally competition

display on the logger and dash. It's a next generation racing system, we used it not only to improve functionality but also to reduce weight. With this system you can make the adjustments on the car much faster.'

From the car's development, and especially the layout of the cockpit, it is clear that the new Abarth R-GT is not a car for a works assault of the World Rally Championship, but for privateers to use to try to upset the big boys. 'This is not a car for works teams, this is a car for normal people who want to go rallying at the top level. We will go testing with it in September, and we will be ready for the Monte Carlo Rally in 2017. Our aim is to challenge the R5 cars, but depending on the restrictor we have there is the potential to take on the WRC cars in some conditions,' Consalvo says.

Manufacturers using R-GT cars cannot score WRC points but the crews behind the wheel can, and they can compete for overall wins. The last serious R-GT effort, Francis Tuthill's privately developed Porsche 997, was hit with a very small restrictor shortly before its debut on Rally Germany in 2014. Many felt that this was because the car was not works endorsed and that it would be a bad thing for a privately built and run car to mix it up at the front.

However, there is still the belief that if a works-backed car arrived in R-GT then it would be given a more generous restrictor and would be allowed to compete for overall wins. There are rumours that the Fiat Abarth will not be alone in the R-GT class in 2017, and it may be joined by a new car from Alpine, which is due to be launched in the coming weeks. Whether this comes to be, and also whether this new, more exciting, breed of rally car will be allowed to be competitive, will only be clear on the Monte Carlo Rally early next year.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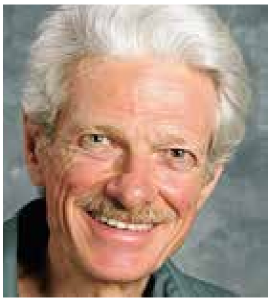

Lean machines: taking trikes to the next level

Some more thoughts on three-wheeled tilting technology

In past editions we have considered design issues in three-wheeled vehicles, and considered the possibility of letting a trike lean when cornering, like a two-wheeler (see October issue V25N10 for most recent of these). Well, Tilting Motors has now introduced a trike that leans. It was featured on Jay Leno's Garage just recently: go to www.youtube.com/watch?v=T3TumQ-ueMU if you want to see it in action.

It's really just an ordinary motorcycle with two front wheels. The front suspension has no roll resistance at all. Its springing only acts in ride. It has one coilover for each wheel, but these mount to a rocker that swivels freely about the *x* axis. There are control arms for each wheel that appear to be equal length and parallel, so all three wheels lean with the frame. When parked, the machine leans on the stock motorcycle kickstand. To stop when riding, you have to put a foot down. While in motion, it steers and stabilises gyroscopically, just like a regular motorcycle.

Trike it lucky

So if it acts like a regular motorcycle, what's the point? The main advantage claimed is that it provides better safety in the situation where the front wheel hits something slippery while cornering. With two front wheels, they both have to hit a slippery patch at once for the bike to go down, or at least that's true if you're far enough from the limit of adhesion so that one front tyre, carrying half the front normal force, on clean pavement, will not slide out. For most riding, that will be so, so it will be safer.

But it recently dawned on me that a leaning trike can also be given a gentle self-righting tendency, so that it will stay upright at rest by itself, without having any springing devices other than a single ride-only coilover bridging right and left rockers.

If those rockers provide rising-rate geometry, the vehicle will rise slightly when it rolls. This will provide an induced gravitational self-centring effect in the suspension. The effect would be similar to the induced gravitational self-centring effect in a steering system that results from front-view steering axis inclination combined with front-view steering offset (ISO)/scrub radius (SAE).

If an absence of ride compliance can be tolerated, and lightness is paramount, the system would do the same thing with a rigid link in place of the coilover. That would probably be of interest primarily for human-powered trikes intended for pavement use.

The main advantage claimed is that it provides better safety in the situation where the front wheel hits a slippery patch of asphalt while cornering

Tilting trikes have many of the attributes of ordinary motorcycles but could fitting an extra coilover to bridge the right and left suspension rockers improve these machines?

Examining the effects of widening a car's track

Going wide is a popular mod; but there are a number of things to look out for …

QUESTION

What effects should be expected from widening the track width on an existing vehicle, say by adding wider wheels with more offset? What changes to wheel alignment and other chassis settings are called for?

THE CONSULTANT

The effects will vary quite a bit from one vehicle to another. In many cases the biggest factors will be fender clearance and changes in compliance effects. In other cases a big change in wheel width or offset will be accompanied by changes to ride height. Sometimes these are to increase ground clearance. Sometimes they are to lower the car for competition or just for appearance. Sometimes they are simply necessary to get the wheels and tyres on the vehicle. Often, an increase in track is accompanied by other changes in settings, but the changes are not directly caused or necessitated by the wheel and tyre change; rather, both they and the wheel and tyre change are related to a change in what the vehicle is to be used for. If the objective is merely to get the look of the big wheels and if fender clearance is not an issue, most settings do not need to be changed.

If the vehicle has independent suspension with rubber bushings, we may see increased compliance toe-out in braking. This will show up as directional instability when braking hard. If this is encountered, it may be necessary to reduce bushing compliance, or maybe add toe-in to help ease the problem.

When we move the wheel planes outboard, there will be some effects on steering geometry. These generally cannot easily be adjusted out or compensated for, but it's useful to know about them.

Jack attack

Firstly, the front-view steering offset increases. This increases caster jacking and SAI jacking. Caster jacking rolls the car to the left when the wheels steer to the right and vice versa. It de-wedges the car; it adds load to the inside front and outside rear tyres while reducing load on the other two. SAI jacking creates an induced gravitational self-centring force in the steering.

Increasing the front-view steering offset also increases feedback through the steering from one-wheel bumps and brake pulsation.

Things get a bit more complex when we add more wheel offset and tyre size at just one end of the car. Most often, we see this at the rear on rear-wheel-drive cars. Typically, there is more room to increase track and tyre size at the rear, partly because the rear wheels don't have to steer and partly because manufacturers generally leave room for tyre chains, for when it snows, at the rear. Also, cars often look good with larger tyres at the rear.

If we stay with similar design and construction for the front and rear tyres, but make the rears bigger, as a rule that will add understeer. To counter this, we may want to add rear roll resistance and/or some negative camber in front. Alternatively, we may want to just deflate the rear tyres a bit. This will amount to throwing away lateral grip to balance the car, but within limits it will improve longitudinal grip at the rear. It will also make the car throttle steer more controllably, as rear breakaway will generally be gentler with lower tyre pressures.

What if we have a beam axle at the rear and we increase just the rear track, not the tyre size, and we don't change anything else? The car will roll the same amount. The rear suspension will have the same angular roll resistance. However, there will be less rear load transfer, since we are reacting the same moment over a wider base. This should increase understeer. If we have a limited slip differential, the understeer-inducing effect from that will also be increased a bit.

Now suppose we have the same situation, and independent front suspension, and we increase the front track, too, also without changing anything else? We have already discussed the effects on steering geometry. Front wheel rate in roll will not change a great deal, but with the increased track, the front angular roll stiffness will increase. Therefore, there should be less roll. The effect on understeer gradient is harder to predict. But in most cases, the understeer will be reduced somewhat.

When we move the wheel planes outboard there will be some effects on steering geometry

Wide rear wheels were a feature of 1970s racing saloons – as shown here on one of Ford's wonderful Cologne Capris

CONTACT

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

Utilising data for better shift work

The proper analysis of transmission data can sort out issues before they result in expensive gearbox damage. Here's what to look for

In the last issue, we looked at the channels available to monitor during gearshifts in a semi-automatic system. For the second part of this article we will explore how to characterise the common issues that can be diagnosed using the data as well as some more useful analysis techniques for assessing gearshift performance.

During a normal 'good' gearshift, there is a smooth transition between gear positions. By observing the barrel position throughout this period, poor shifts and abnormalities can help identify issues with both hardware and electronic set-up. Consider that with each gear change the dog rings will disengage the current gear and then move to and re-engage the next gear. At each stage of the shift it would be useful to consider the other channels available such as current draw, shaft position and strain on the actuator.

Consider that if, in an electric shift system, the barrel was stuck mechanically the current draw from the actuator would spike as it attempts to reach its target position. On the other hand, if the current drops off whilst the barrel has stopped rotating, the actuator may simply not be pushing enough to rotate the barrel.

Similarly, with a pneumatic or hydraulic system, the strain on the shaft would increase if the barrel was mechanically stuck. Obviously, this is dependent on the instrumentation and sensors available.

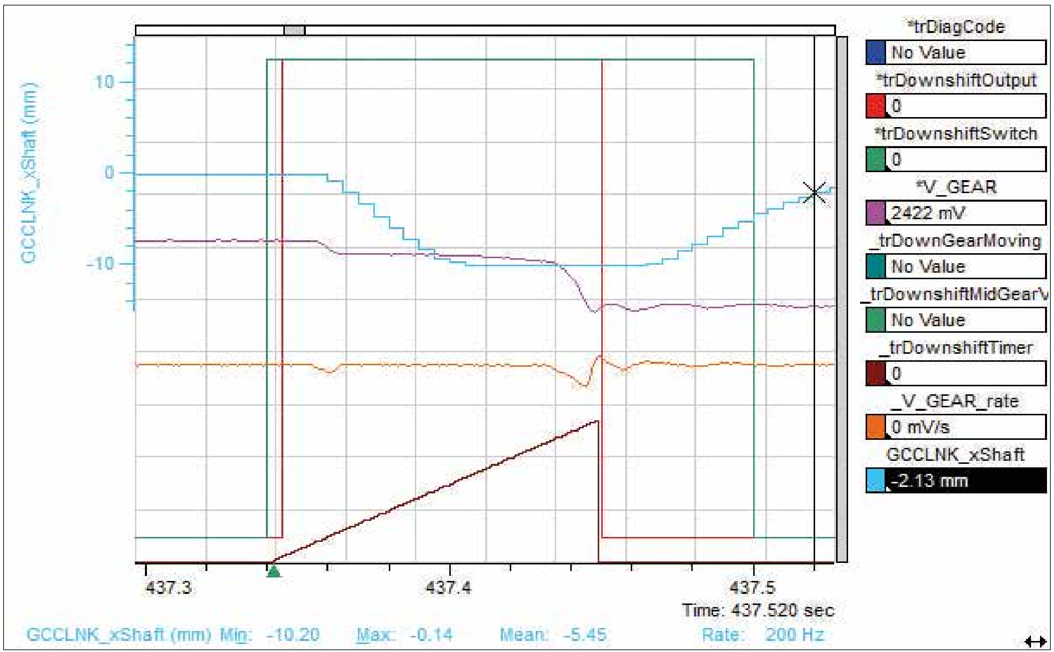

Fig 1: Ramp out stages and blip thresholds can be used to make sure barrel rotates smoothly when entering main cut phase

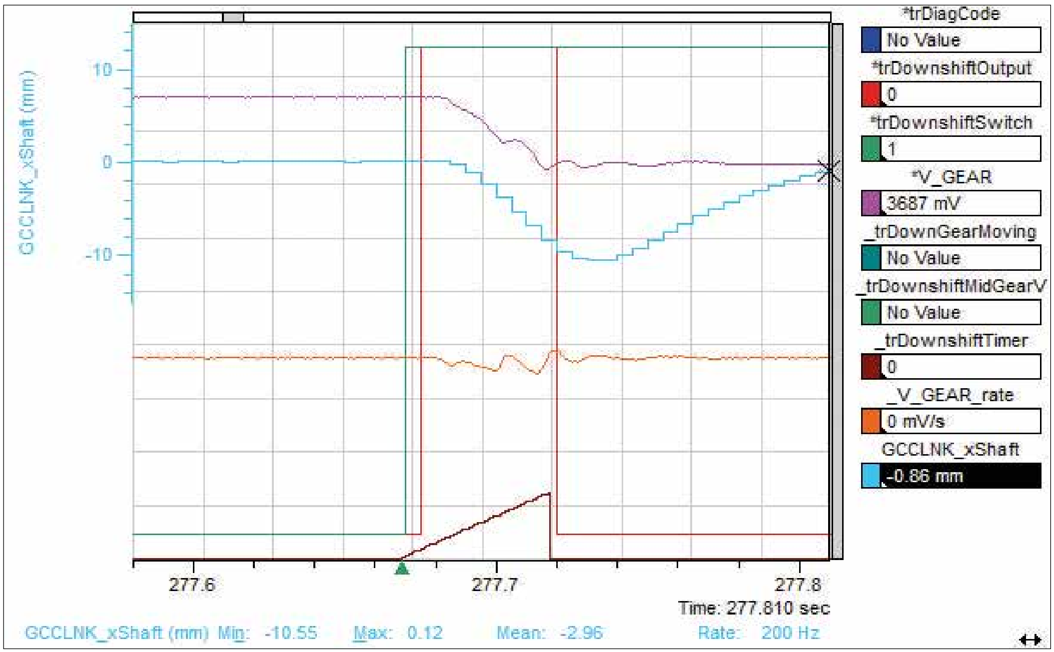

Fig 2: Here the barrel has rotated but at mid-travel the signal begins to oscillate, this shows there is a 'dog-dog' event

Struggling to disengage

In the early stage of the gearshift the barrel can appear to become stuck as it attempts to disengage the dogs of the current gear. Until the engine torque is reversed the barrel will be unable to rotate and select the next gear.

To correct this usually takes a lot of testing and analysis to determine how long and under what conditions the gearbox becomes unloaded. In addition to this, it's important that the time for the actuator to act upon the barrel is also taken into account.

This is where the ramp out stages and blip thresholds can be used to account for these times such

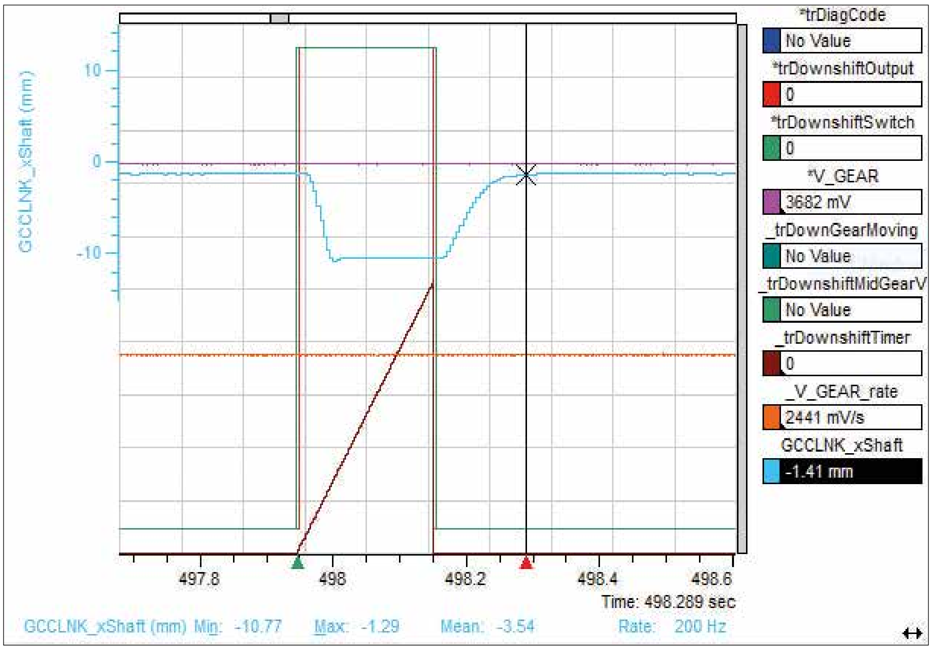

Figure 3: Here it can be seen that the driver has requested a downshift but no transition has taken place

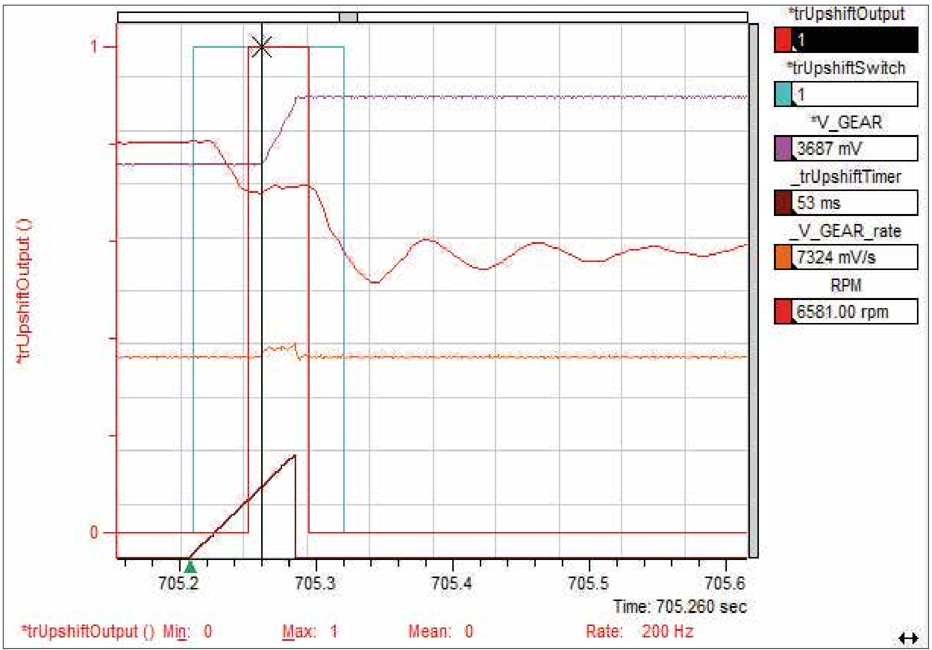

Fig 4: This shows ringing of the 'box after engaging the gear. This is characterised by oscillation of the RPM signal

The term dog-dog describes the dog rings in the gearbox clashing as the next gear is engaged. If this is a regular occurrence it can be a serious problem

that the barrel can rotate smoothly when entering the Main Cut phase (**Figure 1**).

Dog-dog events

The term dog-dog describes the dog rings in the gearbox clashing as the next gear is engaged. If this is a regular occurrence it can be a serious problem and very quickly destroy the gearbox. You can see in **Figure 2** that the barrel has rotated but at mid-travel the signal begins to oscillate. This a is dog-dog event. A dog-dog event will be seen in the later stage of the barrel's rotation.

A more accurate classification of a dog-dog can be achieved with a bench test by manually setting the gearbox up such that the dogs are aligned, then when the barrel is rotated the dogs will come together. By recording the measured gear position voltage this can be cross referenced with the voltage shown in the data to confirm a dog-dog event. The most common cause of a dog-dog event is where the shaft speeds have been poorly matched. Where there is a significant difference between the two shaft speeds the likelihood of such an event are increased. This can be combatted by proper tuning of the throttle blip or fuel/ignition cut for each gear.

Unresponsive transmission

Figure 3 shows us that the driver has requested a downshift but no transition has taken place. On first inspection the issue may be mistaken for a failed actuator. However, the data clearly shows the actuator moving to full extension whilst the barrel remains stationary in the current gear. Further investigation of the gearbox itself revealed that the spring loaded selector arm had become stuck out of position and was unable to rotate the barrel into the next gear.

Ringing

Figure 4 shows ringing of the gearbox after engaging the gear and this is characterised by oscillation of the RPM signal. This can sometimes be combatted by tuning of the reapplication of engine power; if done too early the system will clash as the gearbox is loaded. In some cases this phenomenon is inevitable due to mechanical compliance in the drivetrain.

An incorrectly calibrated shift system can result in catastrophic damage to the gearbox but careful analysis and fine tuning can save precious milliseconds over the course of a lap. Using some of the techniques discussed you will be able to quickly and effectively analyse your shift performance and identify problems early.

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Minding the gaps on an Aston Martin

Our Vantage GT3 aero study ends with a nod to Aerobytes of old

This month we conclude our examination of a British GT specification Aston Martin Vantage GT3 – kindly provided by Aston Martin Racing – by repeating some simple experiments performed in our very first wind tunnel session at MIRA 10 years ago. This particular Aston was being prepared for a private client but was to exactly the same specification as the one that Beechdean AMR used to collect first and second places in the 2015 British GT Drivers' Championship.

As regular readers will have seen in the two previous Aerobytes, the aerodynamics in the British GT series, as in all mainstream GT series, are tightly controlled by the technical regulations, and British GT regulations require homologation of the key components. The principal downforce-inducing parts then are the front splitter, which on the Aston Martin features a raised central leading edge and a gently curving profile across the central section of its underside to form a front diffuser; and the large and quite aggressively-angled single element rear wing, which on this car also features a subtle twist across its span-wise profile. Modest dive planes and the small standard rear spoiler are the only other obvious downforce-generating devices. Interestingly, the Aston Martin does not have a flat underside feeding a conventional rear diffuser, this apparently to lessen ride height sensitivity in the various worldwide race series with different ride height regulations that AMR supply.

We have looked in a previous instalment at the baseline aerodynamic performance of the Aston Martin, and found that it had respectable downforce compared to the previous GT cars we have tested for Aerobytes. The quite aggressive deployment of the rear wing gave a rear-bias to the aerodynamic balance, although this was apparently not an issue with the drivers. And last month we saw the effectiveness of the fully ducted cooling system and the front wheel arch exits.

Tape rewind

In our very first MIRA-based Aerobytes in June 2006 (V16N6) we looked at the effect of taping over some gaps on the front end of the Team Dynamics BTCC Honda Integra, and it was quite an eye-opening exercise (for this writer at least) to discover the scale of the aerodynamic benefits that could be found with a humble roll of race tape. So when Aston Martin asked to do something similar on the Vantage GT3 it presented a chance to explore the responses on a somewhat higher downforce production-based racecar. Gaps were sealed in three steps: first the gaps along the bonnet edges, between the wheel arches and airdam, and between the airdam and splitter were taped over, and the results are shown in **Table 1** with the responses of each aerodynamic parameter relative to the previous configuration given as percentage differences ('Δ or delta values').

Taping up the forward gaps *may* have reduced drag very slightly, and although this does not seem an unreasonable response to expect, the actual change was only just above the level of the repeatability of the duplicate results logged for each configuration, so the change must therefore be thought of as

Table 1 – The effects of taping up the forward shut lines and panel gaps

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Change	-0.5%	+1.7%	+8.9%	-1.1%	+2.04%	+2.2%

Table 2 – The effects of taping up the forward door shut line and front scuttle

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Change	0	+1.4%	+6.3%	-0.7%	+1.46%	+1.5%

Taping over the forward panel gaps on the Aston Martin GT3 at the MIRA wind tunnel

Blanking off the Aston's front scuttle and its forward door shut line was a useful exercise

Significant benefits may be obtained in the form of front end downforce

These were interesting results, and in fact the car responded to this increase in rear ride height in much the same generic way as one equipped with a conventional flat bottom and diffuser

Panel gaps between the rear wheel arches and bumper; the wheel arches and the boot cover; and between the roof and rear arches were taped over. This had minimal influence

A 10mm spacer can just be seen here under the rear wheel. This additional rake produced a typical response despite the absence of a flat bottom and rear diffuser

Table 3 – The effects of taping over the rear panel gaps

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	v-L/D
Change	-0.3%	-0.4%	-0.6%	-0.3%	-0.16%	-0.1%

Table 4 – The effects of a 10mm increase in rear ride height

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Change	+1.2%	+4.8%	+18.9%	-0.7%	+3.84%	+3.5%

almost negligible. However, total downforce and in particular front downforce showed a significant increase with almost nine per cent more obtained, just by sealing up the panel gaps at the front of the car.

The mechanism at work here is that of preventing unwanted air from entering the front compartment and creating lift under the front bodywork. The reduction in downforce at the rear of the car was almost certainly just the mechanical leverage effect of the gains at the front end.

Next, the forward door shut lines and the front scuttle between the rear edge of the bonnet and the bottom of the front screen were taped over, and the results compared to the configuration above with the forward shut lines already taped over are shown in **Table 2**.

This time there was no change in drag but there was a further increment of front downforce and, from trials we have done in the MIRA tunnel previously on the effects of taping up the front scuttle, it seems probable that most of this downforce increment came from here. The exact mechanism may be related to this being an area of raised pressure on any car (it is often used as the inlet for ventilation systems on road cars because of this), and taping it over may have caused this pressure to increase slightly.

Lastly, in this taping up exercise, the panel gaps between the rear wheel arches and bumper, between the wheel arches and the boot (trunk) cover, and between the roof and the rear arches were taped over. The results are given in **Table 3**. Within the limits of repeatability then, these rear end gaps made no discernible difference, or if they did then the effects were very small.

So we can conclude that it pays to mind the gaps at the front end of the car, and that surprisingly significant benefits may be obtained in the form of front end downforce, with perhaps a modicum of drag reduction too.

Rake change

We'll round off this mini-series with a quick look at how the car responded to a rake angle change. The rear end of the car was raised by 10mm, which is equivalent to just over 0.2 degrees, by inserting 10mm thick blocks under the rear tyres, and the delta values as percentages are shown in **Table 4.**

These were interesting results, and in fact the car responded to this increase in rear ride height in much the same generic way as one equipped with a conventional flat bottom and diffuser. The most obvious effect was a significant increase in front downforce, the dominant mechanism for which would probably have been the decreased ground clearance under the front splitter. It may also have been that raising the rear of the car also increased the mass flow of air under the car, despite the absence of a flat bottom and diffuser, which would also have boosted the front splitter's downforce gains.

Racecar's thanks to Aston Martin Racing.

CONTACT

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

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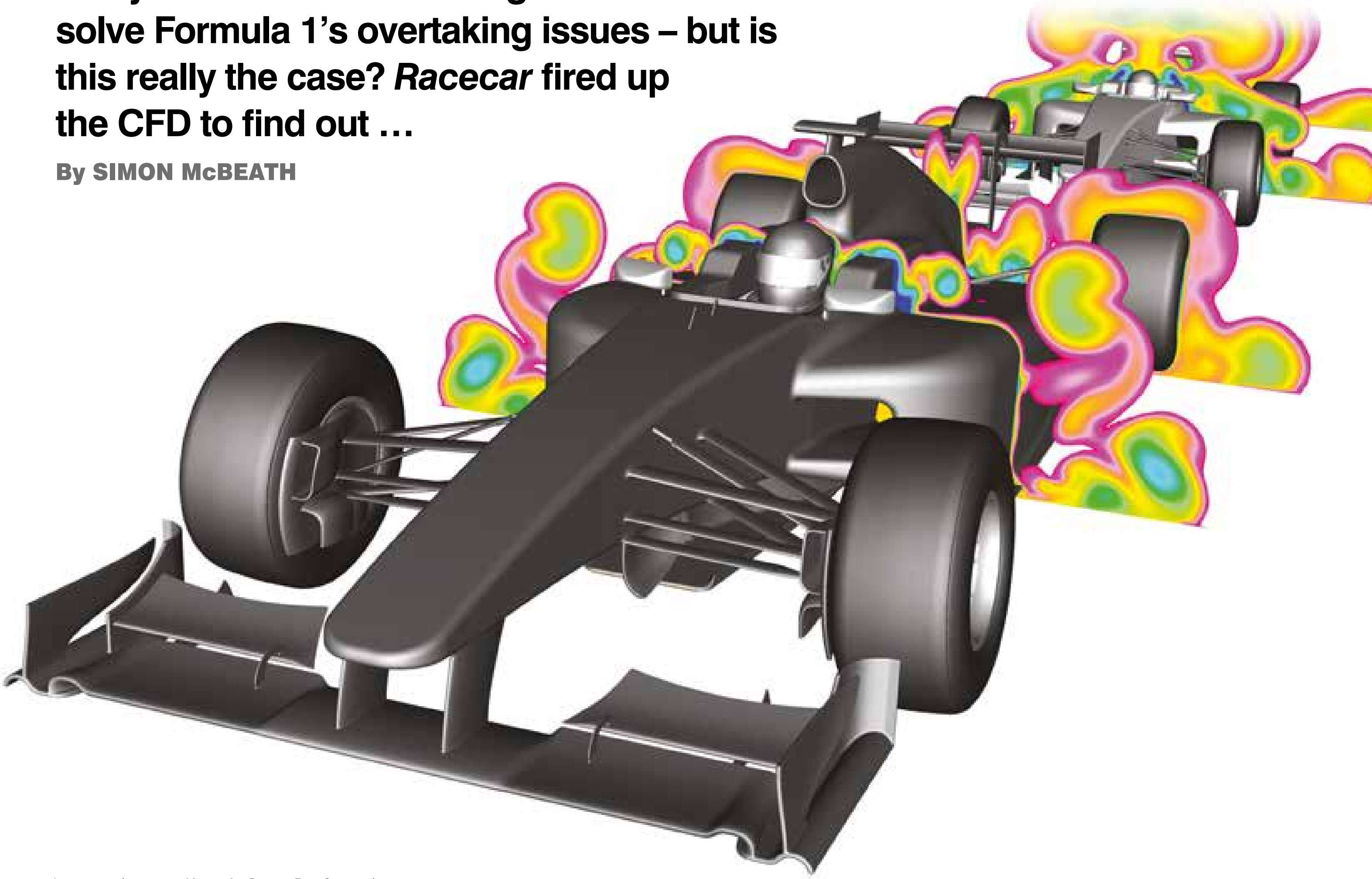
Ground control

Many insist that a return to ground effects will solve Formula 1's overtaking issues – but is this really the case? *Racecar* fired up the CFD to find out …

By SIMON McBEATH



Illustrations (courtesy of Miqdad Ali, Dynamic Flow Solutions)

At the time of writing, the 2017 Formula 1 regulations had yet to be published and indeed were delayed until April (see page 66). As this article is written mid-February 2016, it appeared that the 2017 proposals for modified aerodynamics that had been previously hinted at in the motorsport media had been watered down somewhat. But in any case those proposals seemed to be at odds with general thinking with earlier FIA proposals to create F1 cars in which drivers could more easily follow each other closely and, thus, potentially execute more frequent, genuine overtaking manoeuvres (as opposed to artificially aided position changes using DRS or during pit stops to replace rapidly worn out tyres).

Meanwhile, *Racecar* has been conducting its own studies into alternative aerodynamic configurations for an F1 car; to analyse the sources of the problems and to try to find some answers. Dynamic Flow Solutions and its director Miqdad Ali ('MA') has now, once more, been performing wonders on the CAD and CFD with some carefully considered changes to the car's aerodynamic configuration. But first let's briefly recap where we had got to in the previous instalment (February issue, V26N2), in which MA introduced us to his first design variant of the 2017 *Racecar Engineering* F1 car, which we will call the RE 2017 V1 (Version 1).

The principle aims of this were to put greater emphasis on underbody-generated downforce and, by using a modified rear wing, to produce less upwash in the car's wake, both of which were intended to improve the airflow onto a following car. CFD runs on the new model in isolation showed that the car had comparable total downforce and balance to the 2013 model previously tested (July and October 2015 issues, V25N7 and N10), with less drag and therefore a better –L/D. CFD simulations were then done across a range of two-car line astern formations with gaps between the cars of between eight car lengths down to half a car's length. And these two-car studies were repeated on MA's previous Formula 1 model, to the 2013 regulations, so that comparisons could be made.

Broadly, the lessons learned were that total downforce reductions on the RE 2017 V1 car when behind another were, not surprisingly, still in evidence. At some intermediate separations the RE 2017 V1 car lost less downforce than did the 2013 car,

The lessons learned were that downforce reductions on the RE 2017 V1 car when behind another were, not surprisingly, still in evidence

Figures 1 and 2: The RE 2017 V2 F1 car – with full ground effect tunnels

Figure 3: Surface pressure distributions

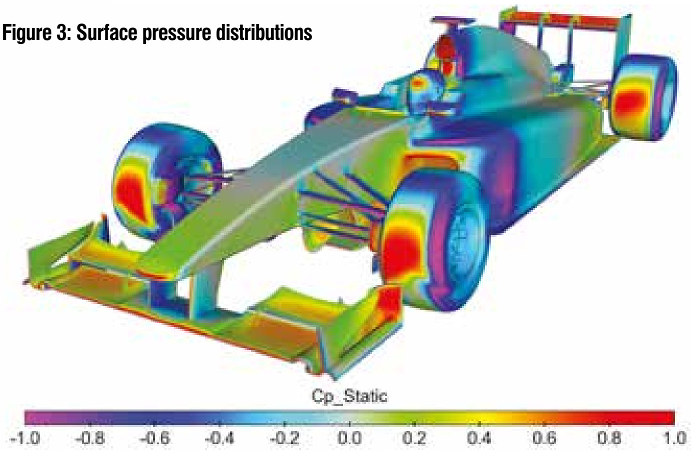


Figure 4: The underbody saw maximum suction at the tunnel throats, where the majority of the car's total downforce was generated

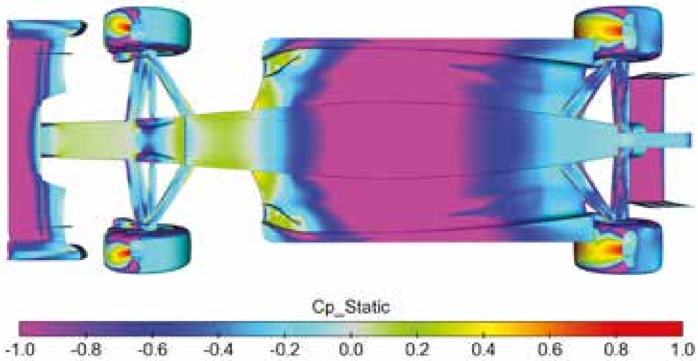


Table 1 – The aerodynamic data on the RE 2017 V2 compared to the RE 2017 V1 and 2013 models

	CD	-CL	%FRONT	-L/D
2017 V2	0.77	3.87	44.4%	5.04
2017 V1	0.96	3.95	45.0%	4.11
2013	1.173	3.89	45.0%	3.32

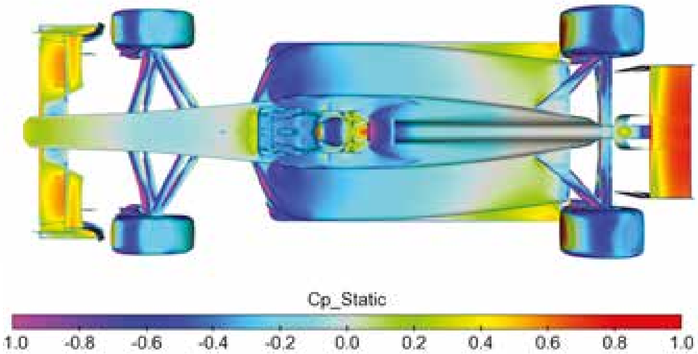


Figure 5: The upper surface pressure distribution shows where body lift occurred, but the net downforce was still on a par with our previous designs

while at just half a car's separation it lost slightly more downforce. However, a significant difference was that there was barely any change in the aerodynamic balance of the following car in RE 2017 V1 guise at any of the separations tested, whereas the 2013 following car suffered the well-documented rearward shift in balance which, in essence, worsened at each closer separation.

So, while the total grip of a following car would still reduce in 'aero corners' in RE 2017 V1 configuration, the aerodynamic handling balance would not alter and the driver would not have to contend with the pronounced understeer that occurs on the current (and on previous) Formula 1 cars in those situations. It seems reasonable to think that this would make it easier to closely follow another car.

Version two

Although RE 2017 V1 was therefore a very useful-looking step forward with the elimination of the aerodynamic balance shift on a following car, could the downforce losses be mitigated still further with a design that placed even greater emphasis on downforce generated by the underbody? To find out, MA set about designing the RE 2017 V2 with full ground effect tunnels. However, he expressed doubts, chiefly that the airflow's energy losses in the tunnels and the ensuing wake signature from the layout would mean answers many might want might not materialise.

Figures 1 and **2** show the RE F1 2017 V2. MA explained his design rationale: 'This car was two metres wide – to allow for more mechanical grip, in common with the FIA's expected 2017 regulation changes – and the central bodywork section was 1500mm wide instead of the previous 1400mm. The extra 50mm on both sides was for the footplate extensions along the bottom, outer edges of the sidepods. The sidepods were longer, the idea here being to design something which would have long underbody tunnels under the sidepods, and the underbody downforce contribution would be over 90 per cent of the total.

'The tyres were of a similar width and diameter to our 2013 and 2017 V1 car. The nose was raised slightly, to halfway between our 2013 and 2017 V1 car. The front wing was simplified further and now used two elements instead of three, and the rear wing had a single element profile with the same overall chord as the previous dual-element upper wing on 2017 V1 but no lower 'beam' wing. This would reduce the rear upwash further and, hopefully, improve flow directionality further for the following car. The resulting car did not meet the current

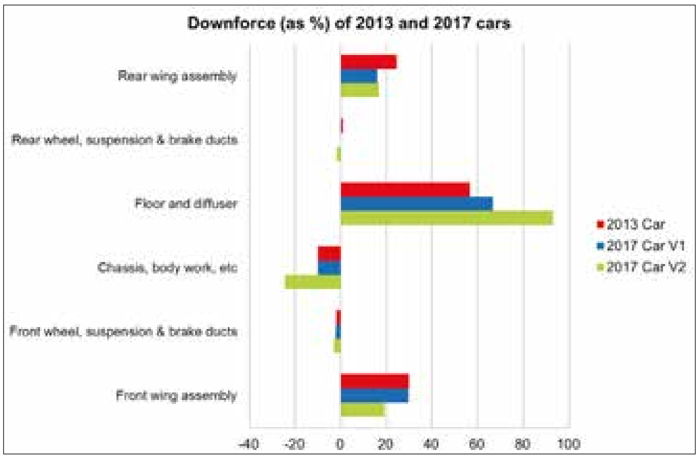


Figure 6: Downforce contributions from the major component groups on our three cars show that the 2017 V2 car's underbody ('floor and diffuser' here) dominated

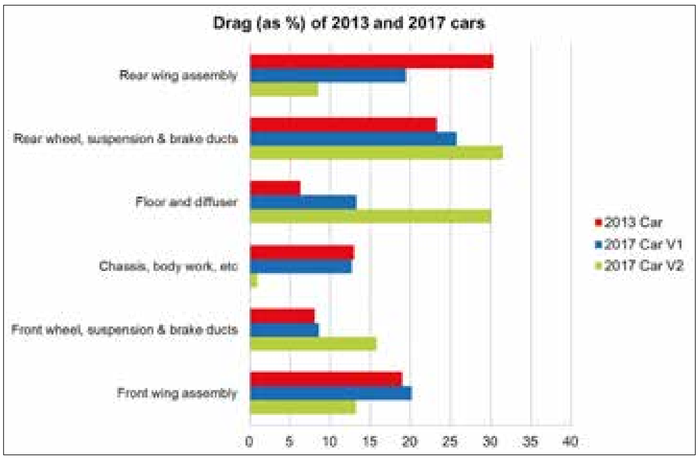


Figure 7: Total drag reduced from the 2013 racecar to 2017 V1 car and again to the 2017 V2 racecar – but the distribution of where drag was generated also changed

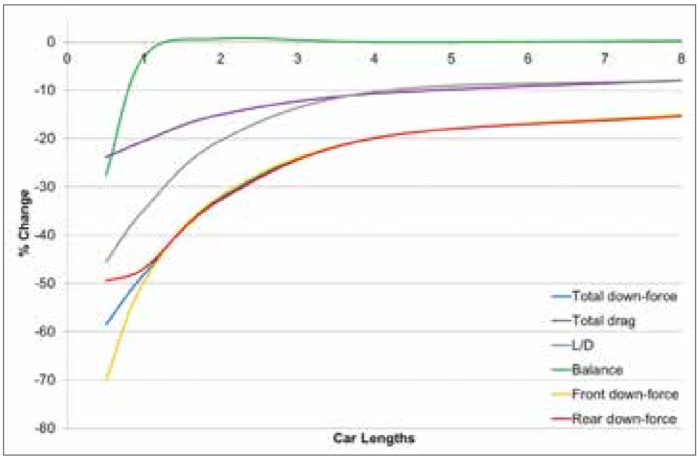


Figure 8: The principal aerodynamic parameters on the 2017 V2 car (see Fig 9 for key) when it was following showed different trends to those exhibited by the previous cars

Figure 9: The 2017 V2 following car's balance shift matched that of the 2017 V1 except at the closest separation, when it saw the biggest balance shift of all our racecars so far

rules, obviously, but the aim was to design a modern ground effect car which used underbody tunnels as its main concept,' MA explained.

The basic aerodynamic numbers are shown in **Table 1** and for comparison the data on the two previous design iterations are also given. Surface pressure distributions are shown in **Figures 3** to **5.**

From **Table 1** we can see that at a comparable total downforce level, and with the same nominal aerodynamic balance, the 2017 V2 model generated significantly less drag than the others and achieved an –L/D value over 5.0. Thus, the latest configuration was considerably more efficient than the previous designs, which relied more heavily on their wing-generated downforce.

Figure 6 compares the downforce contributions of the major component groups on the three cars. The most obvious difference was in the contribution of the underbody, shown as 'floor and diffuser' here, with the latest car generating over 90 per cent of its downforce from this area. The front wing's contribution reduced on the 2017 V2, but its rear wing contribution was roughly the same as that of the 2017 V1, despite the single element configuration. This was largely thanks to the increase in track width that put the front wheels and, crucially, their wakes further outboard, allowing a cleaner feed of air to the rear wing. So in terms of placing the emphasis on the underbody to generate in excess of 90 per cent of the car's total downforce the target for the 2017 V2 car had been achieved.

In comparing the drag contributions of the major component groups we have to keep in mind that the three cars generated very different total drag levels. **Figure 7** shows the contributions of the major components on the three cars but these proportions are on total drag levels that reduced from the 2013 car to the 2017 V1 and reduced again on the 2017 V2 car. Nevertheless, we can see that the extra downforce production by the underbody ('floor and diffuser') on the 2017 V2 car also saw it generate a greater proportion of the car's total drag than on the other two cars. Conversely the rear wing's drag contribution reduced thanks the above mentioned cleaner onset airflow and a more efficient profile configuration.

Line astern

So how would the more efficient RE 2017 V2 full ground effects car measure up in the two-car line astern scenarios? **Figure 8** shows the changes to the usual aero parameters across the same range of separations. Once again the least surprising aspect is that the following car saw downforce and drag reductions, which became more pronounced as the gap to the car in front reduced.

Looking at the balance plot in **Figure 9**, the 2017 V2 car, like the V1 (but unlike the 2013 car, which saw balance move rearwards even at eight lengths separation), also saw virtually no balance change across the range of separations, until the gap closed to the minimum separations tested, that is. And this is where V2 behaved very differently to V1, for V2 saw a rapid and marked rearwards shift in balance at the closest separation, whereas V1 maintained balance right across the full range. The front and rear downforce lines in **Figure 8** at half a car's separation hinted at where the problem lay, and **Figure**

The front wing's contribution reduced on the 2017 V2, but its rear wing contribution was roughly the same as that of the 2017 V1

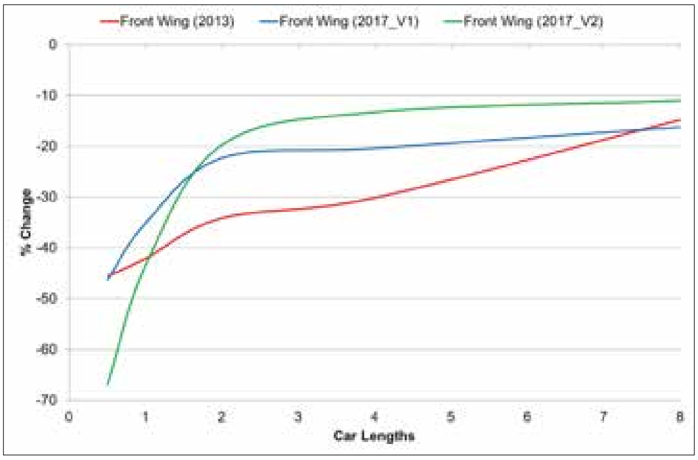


Fig 10: Front wing downforce loss was a cause of balance shift at closest separations

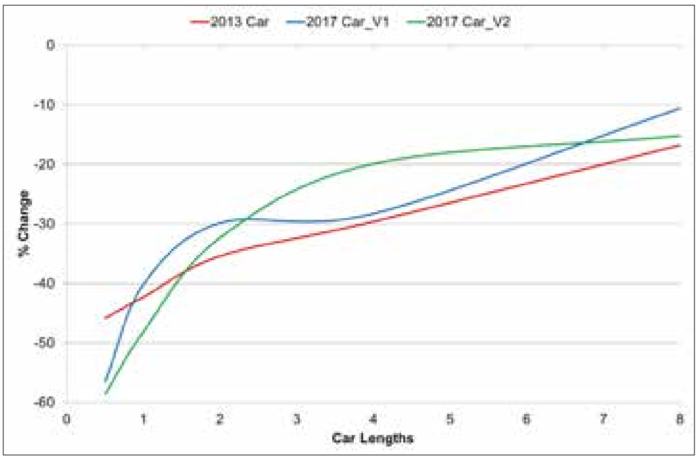


Figure 11: Following ground effects car lost less downforce at intermediate separations

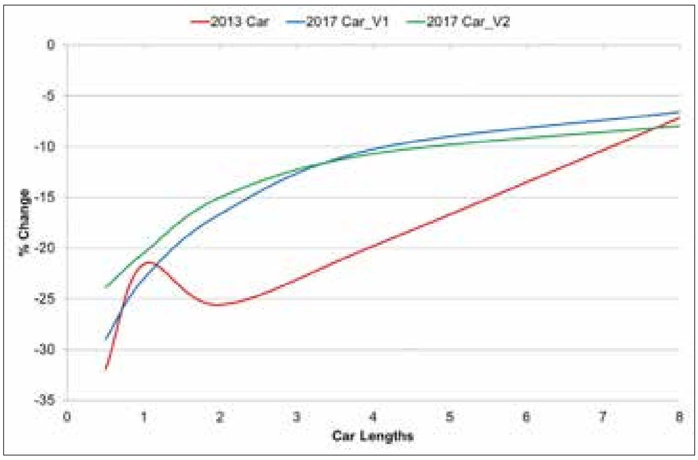


Figure 12: The drag reductions on the following racecar were similar for the two RE 2017 configurations, while they were both less than the 2013 following racecar

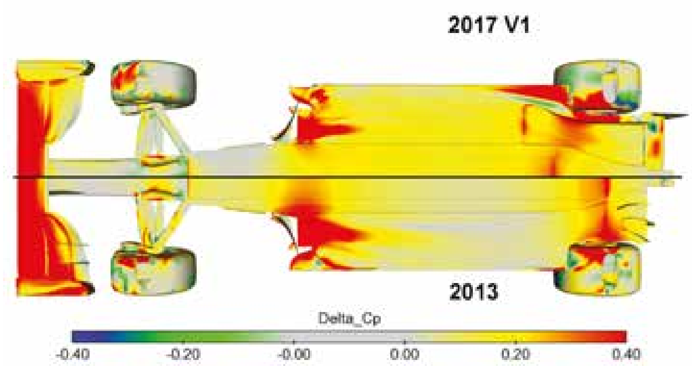


Figure 13: The underside surface pressure changes on the following racecar at four car lengths separation on the 2013 car and also on the 2017 V1 car

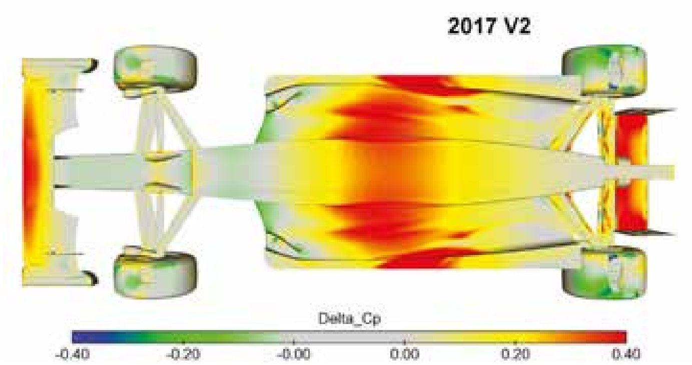


Figure 14: This shows the underside surface pressure changes on the following racecar at four car lengths separation on the 2017 V2 ground effects racecar

10, showing how the front wing's downforce on the V2 car declined very rapidly at separations of two cars and less, provides further clarity. So even though the front wing's contribution to overall downforce was less than on the previous two cars as **Figure 6** showed, the effect of this reduction was enough to cause the significant change in balance when the gap to the car in front closed right up.

Aero comparison

Looking now at **Figure 11** we can compare and contrast the changes in overall downforce at the different separations for all three cars studied so far in the two-car setting. It is apparent that the 2017 V2 lost less downforce than both previous cars between about six lengths to just over two car lengths separation, with the biggest difference between the V2 and the others at four car lengths. However, at less than two car lengths the V2 car had lost more downforce than either of the other two.

Figure 12 shows how total drag changes on the three cars across the separation range. When following, all three cars saw similar drag reductions at eight car lengths, but both 2017 concept cars saw much smaller reductions at four and two lengths separation. Then as the cars closed right up the reductions once more became comparable. Would these lesser reductions (of lower drag in the first place, don't forget) at the intermediate separations make it more difficult to slipstream either of our 2017 variants?

Close up trouble

So, frustratingly perhaps for its advocates, the ground effect concept as implemented here at least, provided the following car with improvements (less downforce loss with no balance shift) at intermediate separations but appeared to make things somewhat worse as the cars closed right up. So it's important to analyse why the concept performed the way it did in order to create further potential improvements.

Going back to the comparisons of how balance was affected at different following car separations, we saw in **Figure 9** that, when following, the 2013 car suffered a balance shift whereas the two 2017 variants did not. **Figure 13** shows how the surface pressures on the underside of the 2013 and 2017 V1 cars altered on the following car at four car lengths separation, relative to the surface pressures on the car in isolation, and **Figure 14** shows the 2017 V2 car in the same situation. The reds and yellows indicate where there were increases in the negative pressure under the following cars' undersides and therefore where losses of downforce occurred. It's clear that the 2013 car saw bigger losses from

It is apparent that the 2017 V2 lost less downforce than both previous cars between about six car lengths to just over two lengths separation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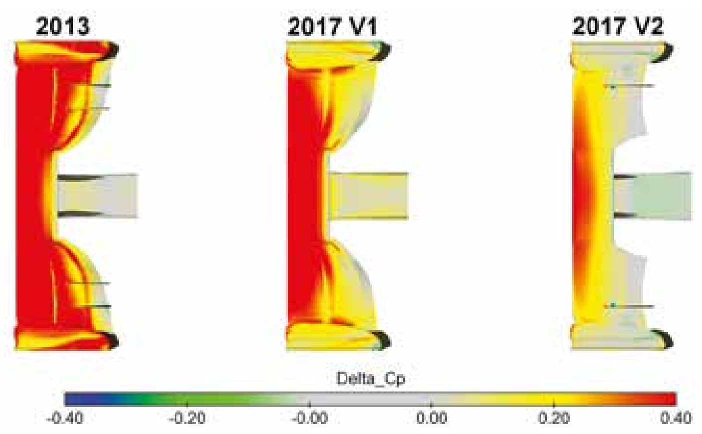

Figure 15: Here the front wing underside pressure changes on the following racecar at four car lengths separation for all three models is shown in much closer detail

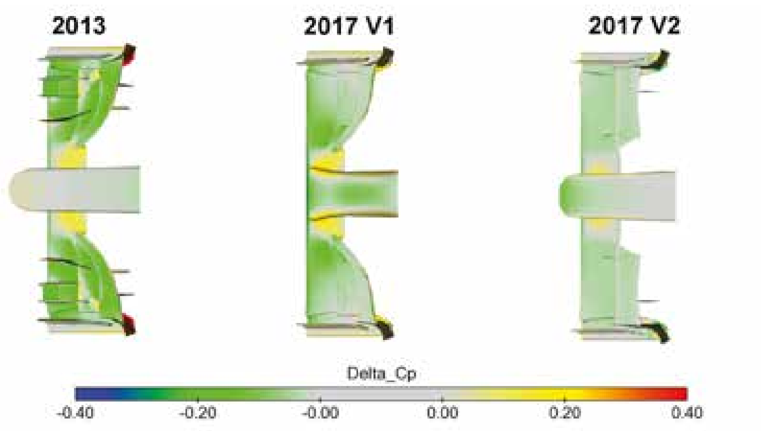

Figure 16: This shows the front wing upper surface pressure changes on the following car at four lengths separation on all three racecars

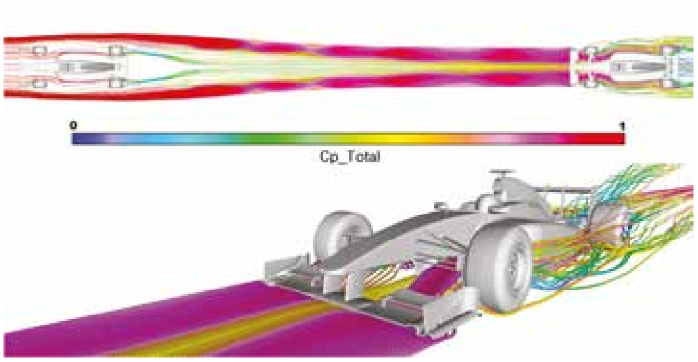

Figure 17: Streamlines coloured by total pressure show how inwash transported energetic 'tidy' air to the following car's front wing at four car lengths separation

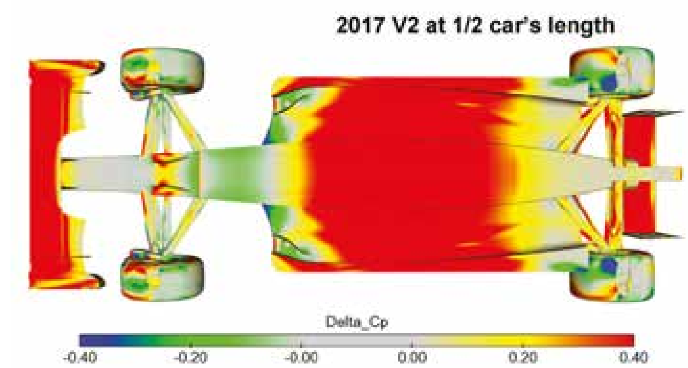

Figure 18: The results here are telling, clearly showing that at a half a racecar's length separation our 2017 V2 car lost a great deal of downforce and balance

its front wing and forward underbody, leading to the rearwards balance shift, whereas the 2017 V1 car saw much more evenly spread losses along the length of the car. The 2017 V2 car, however, saw much smaller losses under the front wing, concentrated at the centre of the span, and the losses in the underbody were concentrated around the throats of the tunnels.

We can focus on the front wing comparisons in more detail, as shown in **Figure 15**, again on the following car at four lengths separation, and the location and extent of the downforce losses under the front wings is even clearer in this image. The 2017 V1 wing lost less downforce from its outer portions than did the 2013 wing, and as discussed in our February 2016 feature this was because the air encountering the outer portions in the 2017 V1 car case had greater total pressure (energy) than it did in the 2013 car's case at this and other intermediate separations. Looking at the 2017 V2 car's front wing underside we can see that the losses were generally less extensive and were concentrated more towards the wing's centre. The view in **Figure 16** of the surface pressure changes on the front wing upper surfaces tells much the same story. Here the green colours show where reductions in positive pressure occurred on the following car's front wing at four car lengths separation, which again equates to downforce losses.

These observations lead us to the consideration of an important effect in this context. We have already mentioned the role of upwash at the rear of the leading car, and its potential to influence the following car. Indeed, part of the reasoning behind MA's concepts for the two RE 2017 F1 variants was that a reduction in upwash at the rear would give the following car, and especially its front wing, an easier time. This was also central to the 'CDG' or 'Centreline Downwash Generating' concept announced by the FIA back in late 2005 and discussed with MA's CFD input in this magazine in June 2007, V17N6. But consideration of upwash alone does not provide all the answers, nor explain how the performance of the following cars' front wings varies so much from concept to concept in our current CFD studies. We need also to look at 'inwash'. This is the inwards movement of streamlines to fill in behind a car when viewed from above, and in our context it is largely driven by the rear wing tip vortices. And because our 2017 V2 racecar had a less potent rear wing, with less potent tip vortices as a result, the inwash behind the car was different.

Looking at inwash

Take a look at **Figure 17;** the upper image is a view from above that shows the total pressure (energy) in the streamlines passing around the outside of the leading 2017 V2 car and how the inwash saw them encounter the following car four lengths behind. Evidently the energy in the flow reaching most of the front wing of the following car was quite high except for the centre section, which is where we saw that the losses were concentrated on this car. And in the lower image in **Figure 17** it is clear that the direction of the streamlines encountering the front wing on the following car is comparable to a freestream situation. It is also apparent that the front wing would still see a feed of energetic air at half this car separation. So it is fair to say that the 2017 V2 concept not only created less upwash but the modified inwash also led to improved energy and flow directionality onto the following car's front wing (and all downstream components too), the combination of which enabled better aerodynamic performance from the following car at these intermediate separations.

Balance shift

However, as we saw in **Figures 8** and **9**, when the 2017 V2 car closed to half a car's length behind the car in front, it lost considerable downforce and balance, and **Figure 18** can be contrasted with **Figure 14.** In **18** it

We need also to look at inwash. This is the inwards movement of streamlines to fill in behind a car when viewed from above


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The airflow emerging from the underfloor tunnels proved to be the cause of some problems rather than a total solution

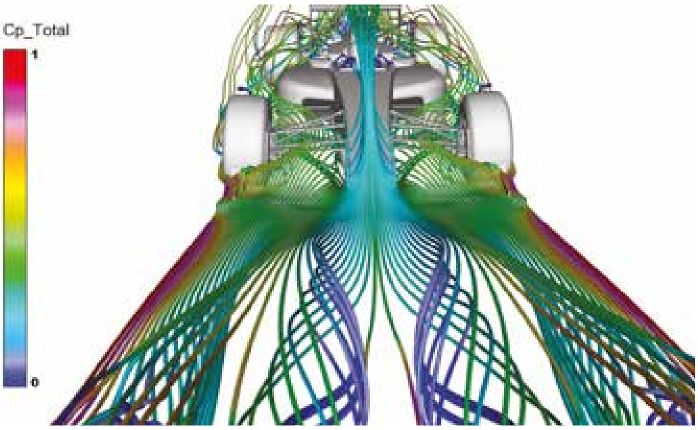

Figure 19: Large, potent vortices from the leading racecar's tunnels and the wide wake had an adverse effect on the following car's front wing at half a car's separation

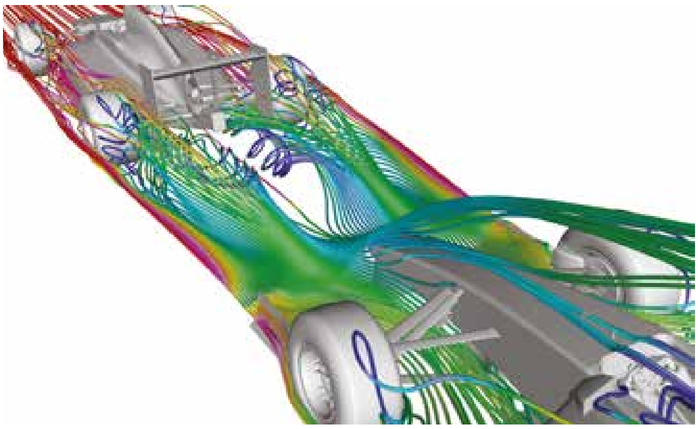

Figure 20: Rear view shows how the tunnel vortices draw in the rear wheel wakes towards the following car's front wing at half a car's separation; airflow directionality onto the following car is also highly disrupted

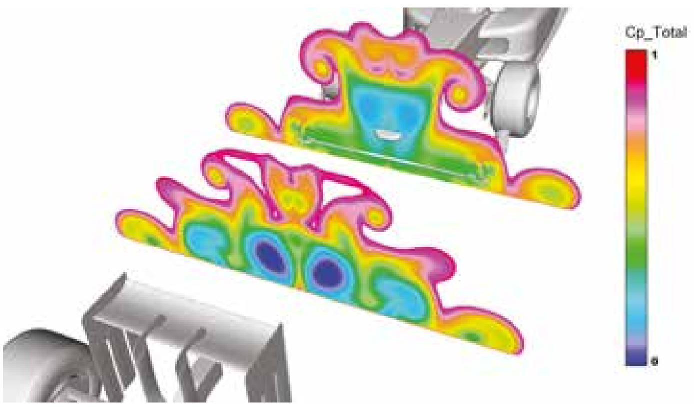

Figure 21: This total pressure slice shows how the low energy in the airflow from the leading racecar's tunnels and rear wheel wakes encountered the whole front wing span on the following racecar at half a car's separation

This car was wider than the previous cars, so the wake was, accordingly, also wider

is apparent that downforce losses under the front wing at half a car's length separation were now greater and more widespread across the wing's span; the underfloor too, and the rear wing, lost much more downforce, but the front wing losses were significant enough for a marked rearward shift in balance to occur.

So why was the situation at half a car's length, which is probably always going to see the following car in turbulent airflow, worse with the 2017 V2 design than with the previous designs? The answers are provided in our last three images, which back up the assertion made by MA at the outset of this phase of our project that the airflow emerging from the underfloor tunnels would be the cause of some problems rather than a total solution to them.

Figure 19 shows the streamlines coloured by total pressure (energy) emanating from the rear of the lead car at half a car length's separation and show very clearly how the flow encountering the following car's front wing was at reduced total pressure, which reduced the wing's downforce generating potential. Two large, potent vortices which emerged from the lead car's tunnels can be seen to draw in the rear wheel wakes, which further ensured that the airflow encountering the following car's front wing was at much reduced total pressure. **Figure 20** is a different view of the same scenario giving a clearer idea of where the flows emerged from on the leading car, and also that the flow directionality at the following car's front wing was, to coin a phrase, all over the place across its span, and rising steeply upwards in the centre. This would also compromise the mass flow into the following car's underbody, leading to greater downforce losses there too.

Figure 21 shows the leading car's wake signature in transverse total pressure slices, and the slice at the leading edge of the following car's front wing shows how the entire front wing span received airflow with reduced total pressure, as well as with widely variant onset flow direction. Remember too that this car was wider than the previous cars, so the wake was, accordingly, also wider.

In summary

Thus, with our 2017 V2 design we have seen a much improved situation for a following car at intermediate separations, changing to a worse situation at the closest separation, demonstrating that ground effect tunnels *per se* bring some very useful advantages, but not the entire answer to the problem Formula 1 is currently experiencing, and seeking to mitigate.

But what of RE 2017 V3? MA is currently contemplating, among other things, tunnels with shallower outlets and rear wheel fairings as potential mitigating solutions. We will look at this in detail in a future issue.

Dynamic Flow Solutions

Dynamic Flow Solutions Ltd is an aerodynamics consultancy led by director Miqdad Ali, an ex-MIRA aerodynamicist who has performed design, development, simulation and test work at all levels of professional motorsport, from junior formula cars to World and British touring cars, Le Mans prototypes, up through to F1 and Land Speed Record cars.

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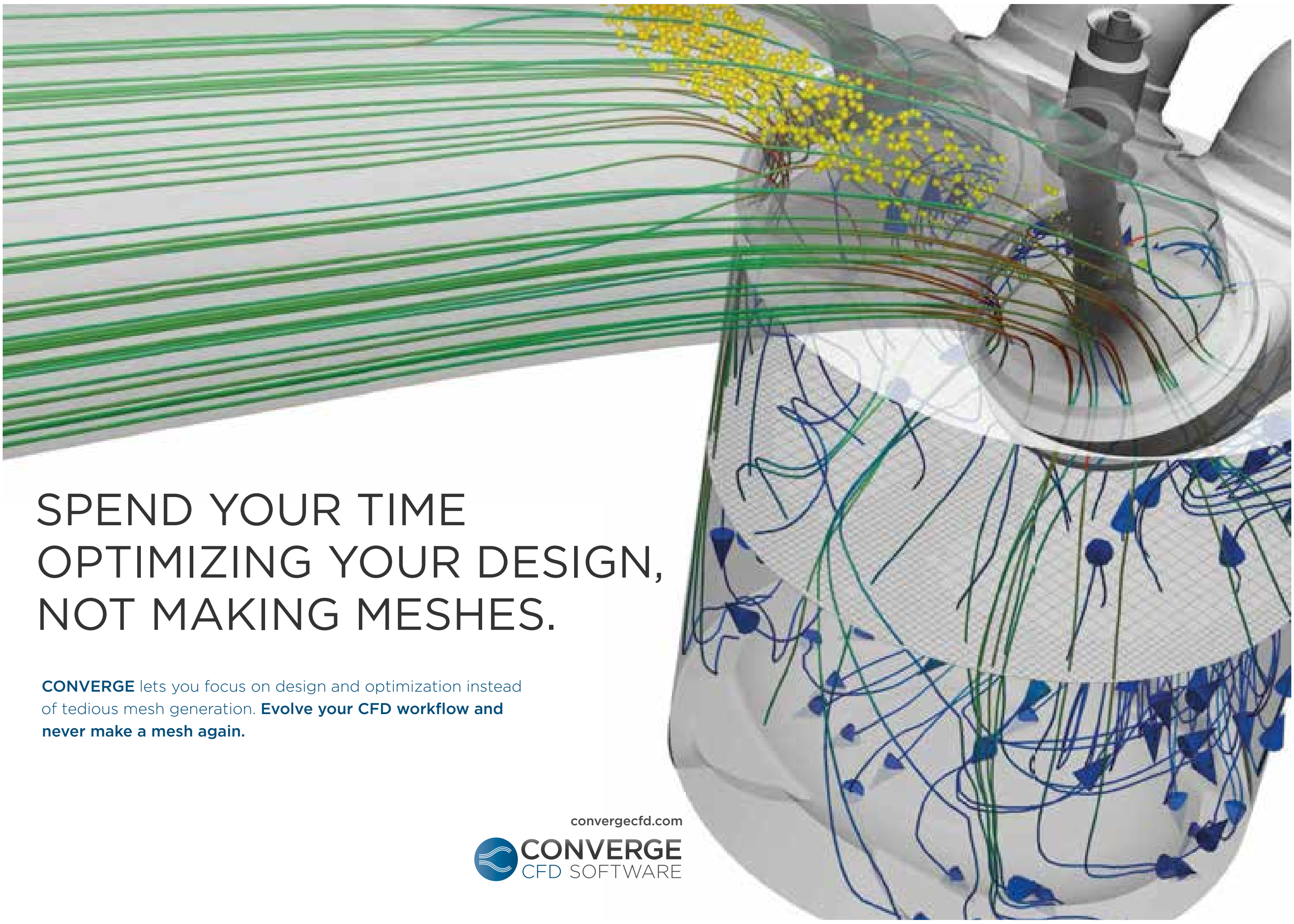
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Maximum wait

We're just nine months from 2017 and yet next year's F1 regulations have yet to be set in stone. *Racecar* investigates

By SAM COLLINS

Faster, more spectacular, more exciting, with better racing … This is what Formula 1 should be in 2017, according to plans announced by the FIA. These plans have actually been announced a few times now, but detail remains lacking and with 10 months to go before the cars are due to run on track, there are still no finalised technical regulations.

The aerodynamic regulations were a set of bullet points until the end of the first pre-season test at Barcelona. A crunch meeting in Geneva (bafflingly scheduled during the opening test) failed to deliver much more detail. However, a few days later a set of regulations was published, though not even the teams noticed until halfway through the second test. But on a quick inspection of those rules it was clear that they were far from final, and indeed the rules can be changed right up to the end of April 2016. Even after that point changes could still be made, but only with the agreement of all teams.

However, some areas appear to have now been finalised. The cars will be wider overall with a maximum track of 2000mm (200mm wider than in 2016) and a lot of that width will come from much wider tyres. The front tyres will have treads which are 305mm wide (60mm bigger than '16) and the rears up to 405mm (an increase of 80mm). The front wing will be slightly wider and will have a delta wing shape, while the rear wing will be wider and lower and will have a rearward swept endplate when looked at from the side. The floor of the car is wider with a notably larger diffuser, while the general bodywork width is to be increased by 200mm. (The full proposed aerodynamic changes can be seen in **Fig 1**).

'We have been working on the aerodynamic regulation for a while, but we still don't have final rules,' Williams technical director Pat Symonds complained openly following the meeting in Geneva. 'I was surprised that they still could not make a decision. There used to be quite a clear procedure with the TWG [Technical Working Group] but since that has been disbanded we only have an advisory group. We have seen three distinct sets of regulations since December, and if we don't have anything finalised until May that is very difficult for the small teams. Delays like that have a much bigger impact on the smaller teams like ours, it is much harder for us to react than it is for Ferrari or Mercedes.'

The new rules as they are have some interesting implications, not least a notable increase in drag, from the increased frontal area of the cars (wider wheels, wider bodywork), and with the power units remaining largely untouched, peak straightline speed looks likely to be lower than it is in 2016. However, the increased contact patch and more substantial bodywork will see apex speeds rise significantly, and that is something that has some in the paddock concerned. 'I don't think all the implications have been considered,' a senior engineer at one team said. 'There are corners that would become very marginal with that kind of increase. But that is the way of it in F1, we come up with these plans then discover the reality and have to dilute things a bit.'

Another consequence of the increased amount of bodywork and larger wheels and tyres is that the cars will get heavier, with the minimum weight creeping up to 722kg. In the document issued following

Another day dawns and still F1 is no closer to knowing what the full regulations for 2017 will look like – though there have at least been some decisions on the size and the aero of the cars

the Geneva meeting (**Fig 1**) the 722kg weight would not include the tyres; but in the regulations published just a few days later that weight does include the tyres, so it may be that the weight increases again.

'The big change came from hybrids, and hybrid racing cars are just like hybrid road cars, heavier. It's a fact of life,' Symonds adds. 'But the cars are getting quite chunky now and it will be worse in 2017; you think about the wider wings with the same deflection requirements, it's schoolboy physics to work out that it is going to be heavier.'

Fuel consumption

One issue that has seemingly yet to be addressed is that with the cars having more drag and more weight one might reasonably assume that the fuel consumption would increase, but in the published regulations the maximum fuel allowed to be used by a car in a grand prix remains at 100kg.

Beyond that, in general there does seem to be concern in some quarters that the chassis and aerodynamic rules have not been adequately thought through. 'The '17 chassis regulations were proposed some time ago and the teams have been allowed a window to do initial CFD studies and feed back to the FIA on those studies,' says Red Bull's Adrian Newey. 'If you look at the current regulations, while you may criticise them there was a decent amount of research behind them with the overtaking working group and Jean Claude Migeot's work. But these new regs have come about in a different way. The problem is that after the initial CFD amnesty period stopped there have been all sorts of attempts at diluting the new rules in the period to now, and in that time no further work has been done on it. That is a wasted opportunity.'

There is another major factor which could influence the weight, the weight distribution and the aerodynamic performance of the car: the possible introduction of enhanced cockpit head protection. This comes in the wake of the accidents which killed Jules Bianchi, Maria De Villota, Justin Wilson and Henry Surtees, and nearly claimed the life of Felipe Massa.

The FIA has tested a range of head protection solutions in recent years including an F-16 fighter aircraft type of perspex windscreen, and a titanium forward roll hoop. More recent designs include fins ahead of the cockpit designed to deflect objects away from the driver's head, a set of three thin tubes running over the driver's head and the most publicised of all, the so called 'halo'.

Ferrari trialled a mock up of the halo during the second test at Barcelona. Officially this was a visibility test (which it passed according to the Ferrari drivers), but it also served as an aesthetic test, which it failed. Drivers, fans and engineers all criticised its looks.

Halo effect

What the Ferrari test did was to bring the implications of introducing such a system into sharp focus. The part used by the team was a non structural mock-up, the final design is likely to be made from CDS tubing; it is not clear if it could be shrouded or not. Mounting such a device on to the monocoque will not be straightforward, with hard points and interference with other components to be considered. There seem to be more questions than answers: will the protection be an FIA supplied part? If so what will its dimensions be and what will the mounting requirements be? It seems likely that the structure will have to undergo some sort of impact testing, too, but again what will the standards be?

'We have got as much idea about that as we have on the aerodynamic side,' Symonds

There seems to be concern in some quarters that the chassis and aerodynamic rules have not been adequately thought through

Summary of proposed bodywork changes for 2017 FIA Formula 1

		2016	2017
Tyres	Front tyres	245mm wide thread	305mm wide thread
	Rear tyres	325mm wide thread	405mm wide thread
Suspension	Track	1800mm	2000mm
	Legs	+/-5° profile incidence	+/-10° profile incidence
Front wing	Wing	1650mm span	1800mm span, swept plan view shape
	Endplates		simplified endplate legality
Rear wing	Top wing	750mm wide, 950mm high	950mm wide, 800mm high
	Endplates	rectangular endplate	swept endplate in side view and tucked in front view
Floor	Step plane	1400mm max width	1600mm max width
		1300mm min width	1400mm min width
		Edge radii <50mm constant	Edge radii <100mm variable
	Reference plane	starts 330mm behind front axle	starts 430mm behind front axle
	Plank	homogeneous plank	pocketed plank for weight saving
	Diffuser	125mm high, 1000mm wide, starts at rear axle	175mm high,1050mm wide, starts 175mm ahead of rear axle
Bodywork	Width	1400mm max width	1600mm max width
	Sidepods	no constraint	swept leading edge in top view
	Bardgeboards	big exclusion zone behing front wheels	reduced exclusion zone allowing for larger bargeboards
Weight		702kg max weight	722kg max weight + tyres (est 5kg)

Bigger 405mm rear Pirellis (80mm wider than the current tyres) are to be a feature of the new Formula 1 regulations in 2017, as well as a wider rear wing. Pictured here is an A1GP racecar

One thing that looks certain to happen for the 2017 season is the dumping of the engine token system and a return to free engine development in Formula 1

says. 'We have had drawings of the suggested cockpit protection, and drafts of the overall aerodynamic rules. We are assuming we know where we are so we can start in the wind tunnel.'

There is much uncertainty about it. Some teams are testing '17 designs with halo fitted in the wind tunnel, others are not. Indeed, the FIA has made it clear that while halo is the current preferred option it is not the only option.

Red Bull has proposed its own solution, which some have referred to as the 'batmobile'. This sees the cockpit surrounded by a curved transparent screen with a supporting structure. At the time *RE* went to press the team has yet to release full details of the design but it is not clear what impact it would have on the airflow around the car, though it looks likely to be significant, while the issues of driver egress and visual distortion have also yet to be addressed.

'The real deadline is the teams' timing to modify their cars accordingly and our capability to assess all the connected issues,' says Laurent Mekies of the FIA. 'Design is done very much in advance in F1. Therefore, if we want to make 2017, it needs to be decided in the next few months. Nobody wants to rush these things but we are all trying to go as fast as possible.'

Deadlines are becoming something of an issue with the new rules as teams are fast running out of time to define long lead-time items such as the tub and transmission, and are starting to have to work around the lack of rules. Even the aero work being done is a bit finger in the air, as Pirelli has yet to fully define the shape of its new bigger tyres, let alone supply the teams with model tyres for wind tunnel use.

'I think you have to develop in parallel, though the bias is a bit stronger towards 2017 than it normally would be,' James Key of Toro Rosso says. 'Most people have started their 2017 projects, we certainly have, but although the regs are still a bit uncertain we seem to have a direction confirmed now. The upfront work we can do is surprisingly high even without the final rules there is still a lot you can do, the talk of a wider track and tyres has carried through these regs. And that has mechanical implications, there are also strong aerodynamic implications. Those things can be looked at in isolation of the other areas. The driver protection side of it is more of a structural challenge than aerodynamic, depending on the final solution, so there is a bit more time to get it right.'

The power units are also a topic of discussion, while the technical regulations appear to be remaining unchanged there may be some related things that could be altered. During the meetings in Geneva 'significant progress' was made on the problem of power unit supply. A cost cap on power units supplied to customer teams seems to be on the table, as is an obligation to supply. Perhaps the biggest area of discussion is performance convergence.

Halo is the FIA's current preferred option but it is not the only option


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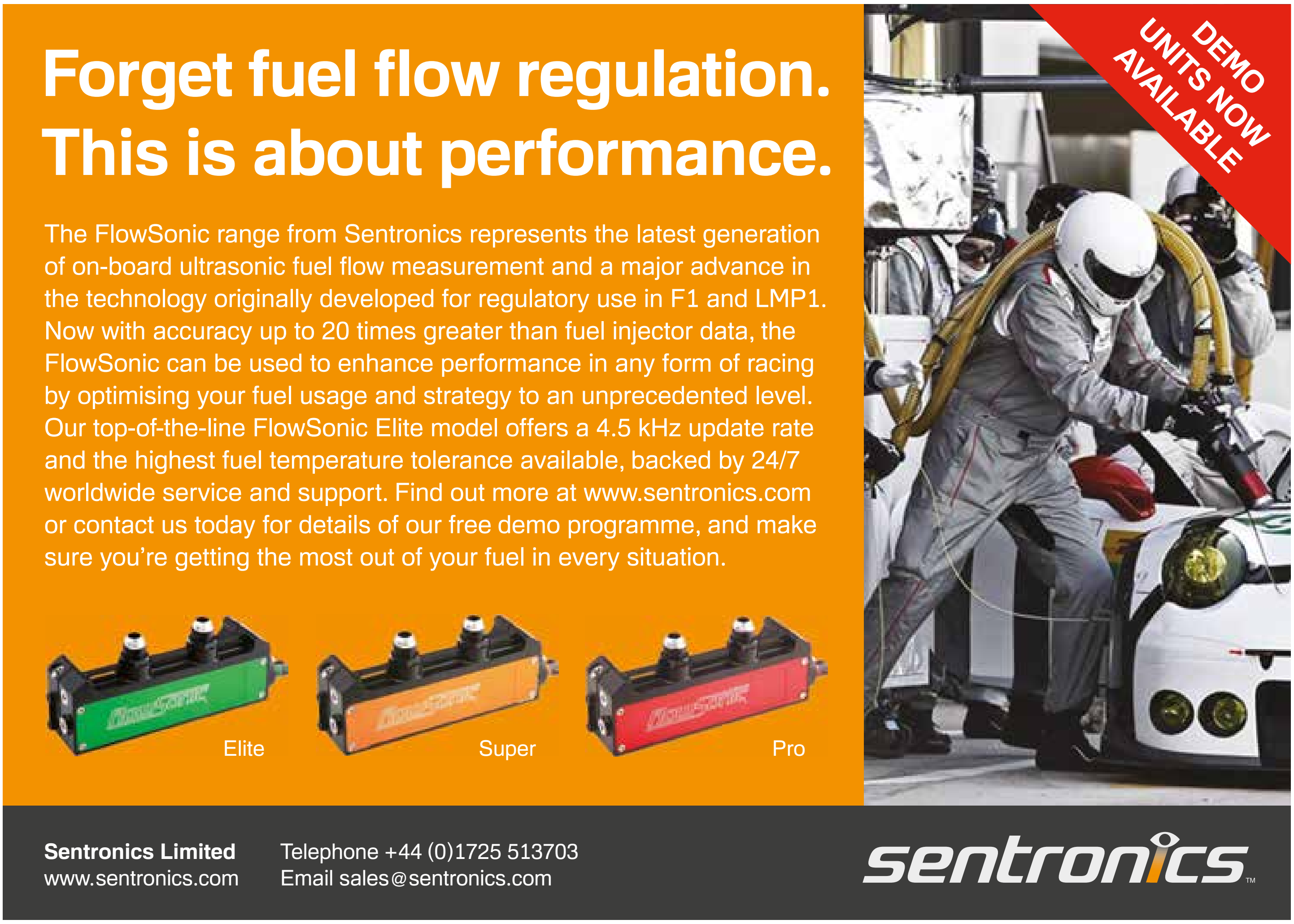
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Red Bull has released its own take on a driver protection solution which, while it possibly looks nicer than the halo (see below), might not be perfect for driver egress and could cause problems with impaired visibility

The Ferrari drivers had no problems with the view with the halo in place; but those watching them did

The halo is the FIA's preferred driver protection option at present but there are few details on how this would impact on car design

One suggestion that seems certain to happen is the abandoning of the development token system, while it still appears in the regulations most in the paddock are confident that open engine development will return next year. The idea of this is to make it easier for struggling power unit suppliers to catch up, though it could be argued that it also makes it just as easy for the manufacturers of the strongest units to maintain their advantage.

But there are those who think these power unit proposals do not go far enough, including Red Bull designer Rob Marshall: 'What we have had so far is inadequate. A few trifling regulations about bearing size and the weight of an MGU is not going to see the power units converge. Engine spend has been left wide open as is all of the development spend on fuels. There is a huge hidden cost there and Joe Public does not see. It makes it very difficult for a power unit manufacturer who has fallen behind, probably not because they are underspending, just that they are not spending silly money. We should have regulations that see chassis and driver become the predominant factors not power units. I think there are changes that could be made in time for 2017 or even this year which could bring power unit convergence. While it's not the case for us, other customer teams of other manufacturers are given sub-standard service and seem happy with it. Some manufacturers are making a big thing of all of their customers getting equal equipment this year, but it's not the equipment it's the software that makes the difference, you just tweak a few knobs and it makes a huge difference. Having the same hardware is not the trick, you need the same hardware, software, fluids and operational parameters to allow the customers to compete with the works teams.'

There are many who agree with Marshall and others who go further and suggest that perhaps F1 has lost sight of where it is going.

'There has been a lot of politics outside of the show recently and it would be nice if everyone would just settle down,' says Newey. 'There is a lot of competition on TV, more every year, over what to watch, we have to be careful that Formula 1 does not get left behind in that. It's all complicated and intertwined. I think the danger is the tendency for the teams to vote for self interest rather than the sport, and we need a strong governing body.'

The final technical regulations are now expected to be published on 1 May. Quite what they will contain is unclear and what is even more unclear is if this is the right thing for the sport at all.

Most in the paddock are confident that open engine development will return to F1 next year

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Reality check

In part two of our simulation series *Racecar* examines how simulators evolved to become crucial car and driver development tools that are now at the very heart of motorsport engineering

By SAM COLLINS and PHIL MORSE

Creating artificial worlds has been part of the history of humanity from the very beginning, probably. Valhalla, Olympus and other realms of the gods were all dreamt up by someone, somewhere. But the creation of useful artificial reality has been a relatively recent development, first proposed in science fiction with some wonderful machines such as Pygmalion's Spectacles. But later the machines and the virtual reality started to become very real.

Simulation, in its many guises, has now been a part of the vehicle design and development process for more than a century, though for most of the 20th century it consisted entirely of slide rule-driven, on-paper design work coupled with physical testing. This required real hardware in the hands of test drivers on real roads and tracks in advance of introducing new cars ahead of the racing season.

Later, with the onset of the post-World War Two rise in computer technology, simulation in an off-line software-based environment became increasingly popular because it enabled vehicle performance calculations to take place in advance of, or concurrently with, the testing of actual prototypes. One of the first instances

The human factor – that inescapable and mysterious combination of physiological and psychological elements that defines the usage and operation of the end product

of this was the development of the anti-dive and anti-squat characteristics of a suspension system developed in 1958 jointly by Ford, Klaus Arning, and Chuck Carrig. The latter was a recent graduate with bright ideas who wrote a Fortran computer programme for the vacuum-tube driven IBM 704 to simulate the suspension movement based on the pickup points. This early simulation gave the engineers a predicted camber change, caster change, toe steer, and anti effects, just from adjusting those pickup points – on the room-size machine.

In the 21st century simulation has become all-powerful in the engineering industry, and this in turn has increased the complexity of the end product. Indeed, the design, development and even operation of a modern racing car would be impossible without simulation. Such technologies have developed to the point where at times many engineers trust them more than their own instincts and experience, and this has often lead to an over-reliance on the computer and its outputs.

When the Virgin F1 team was launched in 2010 there was much fanfare about all of its aerodynamic development being done in the 'virtual wind tunnel,' but by 2012 it had reverted to convention and started scale model testing in the real wind tunnel. The team had found that doing everything in the virtual world did not entirely work, but that is not to say that simulated data is no good, indeed the opposite is true. It is more a question of how that data is obtained and used.

Reality bytes

While off-line simulation has contributed to the state of the art and moved the game forward, it has also, at times, raised more questions than it has answered. After all, is it a simulation or a measurement that is closer to the truth? Is it better to trust objective representations of 'reality,' or subjective feelings and perceptions about 'reality?' Weeks of valuable testing time can be lost chasing that at times seemingly mythical thing, 'correlation'. Sometimes teams can find good correlation but then conditions change or a different driver gets behind the wheel and it vanishes. It is the classic riddle for vehicle engineers and is especially pronounced in the motorsport industry. Which do you trust more: simulation results or test results? It is far from unknown for the two to conflict.

Strong cases can be made for either answer in various situations, but we can perhaps agree that both are honest attempts to capture some sort of objective 'truth'. Perhaps the best we can do in our quest for answers, in an engineering sense, is maintain a consistent approach, and carefully document all our assumptions.

Such questions often bring into focus the human factor – that inescapable and mysterious combination of physiological and psychological elements that defines the usage and operation of the end product. A British university lecturer, now long retired, would tell his students the following about the use of modern simulation techniques in competition car design: 'If you gave a computer the technical regulations and asked it to come up with the perfect design, it would do just that, but the car you had would be simply undriveable because an imperfect user needs a machine which itself is imperfect, and thus able to deal with the deficiencies of the human in the loop.'

A variety of advanced simulation tools have evolved to study this interaction – most prominently driving simulators or driver-in-the-loop (DIL) simulators. These allow drivers to interact in real time with vehicle simulations, and to perform 'virtual test drives' in a laboratory setting. As with any engineering tool, it is important to delineate R&D activities from

'An imperfect user needs a machine which itself is imperfect and thus able to deal with the deficiencies of the human in the loop'

defined and stable procedures. In addition, DIL simulations, by definition, always include the human element, since a real driver participates in the simulations. Sometimes, seemingly complex engineering mysteries can be solved by recognising that drivers are, in fact, unable to discern the causes of their virtual experiences, so subjective feedback must always be correctly interpreted in light of the technology in play.

All the modelled tuning parameters are adjustable, and all the measurement details are readily obtained. But adding a real driver into the mix is the key, since it elevates simulations to function as subjective feedback tools – and this is not just practical, it is necessary. It makes the simulation more 'real'.

Stepping back for a bigger view beyond just the motion machinery, the following assertion can be made. If an engineer wishes to use a DIL simulator as a tool for vehicle engineering and product development work, then it must make the driver drive like he does in reality. In order to do this a DIL simulator must operate in real time, with minimised latencies in all interactions and feedbacks such that the driver is cued into realistic operation behaviour. He must drive as though he is doing it for real.

Once that is achieved, then the inputs from the driver, how he drives around the track, can be fed into other environments to evaluate how other things perform. The most straightforward of these is software-in-the-loop (SIL) simulation which uses software models to describe vehicle subsystem and/or environment details. These models might reside externally, but are nonetheless expected to function with real-time connectivity to the primary DIL simulator system. It means that real drivers are put into direct contact with experimental systems *in situ* much earlier in the design cycle.

When brake-by-wire systems and hybrids became standard equipment in LMP1 and F1 much work was done using SIL to not only get drivers used to driving cars fitted with the technologies but also to allow teams to develop the ways they are used. 'When we first tried them on the sim in 2013 the BBW was really steppy,' one driver says. 'But after a few days on the simulator we got that mostly dialled out so it was a lot smoother and more predictable.'

Hardware-in-the-loop (HIL) means DIL simulators are linked to test rigs in real time and this can theoretically be used in both directions; but in reality there is at present a bit too much lag with HIL to driver connections

Chuck Carrig wrote a computer programme for this vacuum-tube driven IBM 704 to simulate suspension movement in 1958

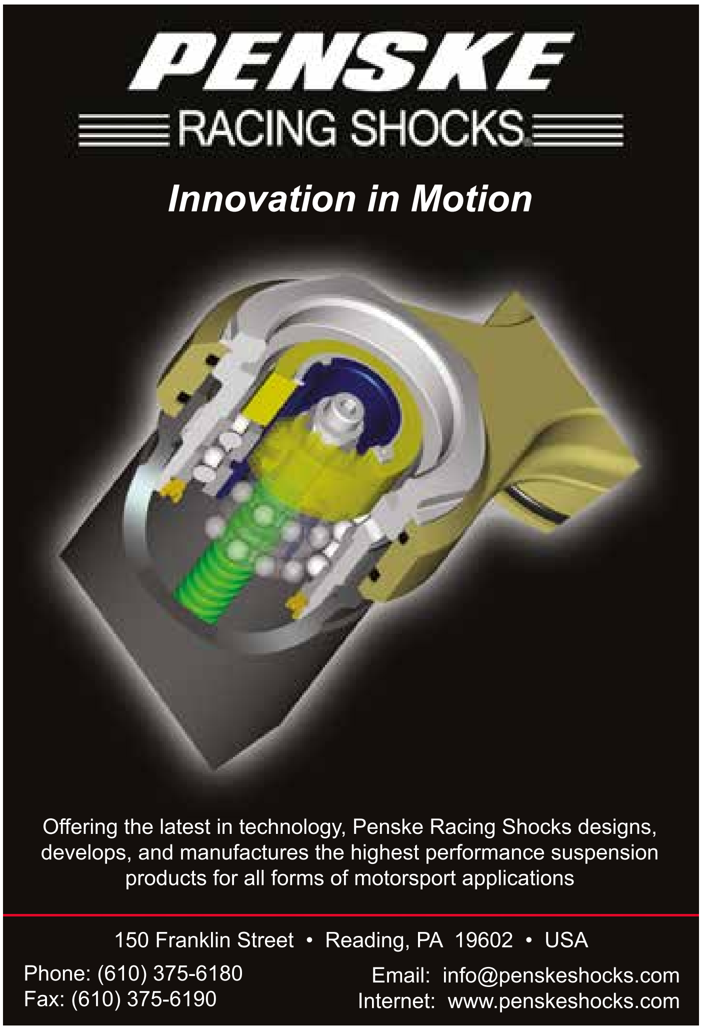
Simmers world

Where this has been applied with notable effect recently is in Formula 1, where harsh restrictions on pit-to-car radio have been introduced. Drivers had to not only practice dealing with errors and alarms while at the wheel with no assistance, but teams also had to make menu systems and displays clear and easy to use. For some teams this also meant a change of the steering wheel design itself, to make it more intuitive – an example of how simulation can be used to rapidly change hardware.

Hardware-in-the-loop (HIL) adds physical components to the virtual testing environment. Historically, HIL was associated exclusively with attaching physical ECUs and electronic controllers to real-time vehicle simulation models, a sort of enhanced SIL. Now, however, the definition of HIL has expanded to include mechanical-HIL, in which physical hardware systems such as drivetrain or chassis/ suspension test benches are attached to real-time vehicle simulation models. These HIL and/or mechanical-HIL 'models' typically reside externally, attached via real-time computing systems that are expected to have communication connectivity to the primary driver-in-the-loop simulator system.

In other words, it is now possible to hook up a hardware test rig directly to the simulator, something which in times of severe testing restrictions can become very valuable indeed. Theoretically it is possible to have the communication working in both directions, the driver inputs on the simulator and the simulated track feeding to the hardware on the rig which responds and feeds back to the simulator so the driver can 'feel' the hardware.

The reality here is that this can cause unacceptable lag, and communication from the hardware-in-the-loop to the driver is less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The steering rack on the Haas F1 car. One of the biggest challenges for car development with simulators has been to replicate steering feel and this has also been one of the great advances

F1 steering wheel displays have been made clearer to read and more intuitive thanks to work in the simulator in response to recent pit-to-car radio restrictions

The 2010 Virgin Formula 1 car's aero was created in virtual reality, but the team later had to revert to more traditional methods

important than the signal from the driver to the hardware-in-the-loop.

But in some instances the feedback and feel of the hardware is crucial, indeed can be the whole point of the simulation. As the primary control device for the car and a major contributor to a car's overall character, the steering system, more than any other, requires accurate and reliable subjective evaluation. If such subjective evaluation can occur via DIL simulation, vehicle manufacturers have a powerful tool for exploring more variations in less time, safely, and also at earlier stages in the car's development process.

In the past testing a steering system, for example, has required that a prototype is manufactured and fitted to a running test car on a real circuit. The reason for this is that steering feel is a crucial, subjective and not an easily measurable thing. Indeed, even for simulator development and gaming development the simulation of steering feeling has been one of the most challenging performance tasks.

Steering system performance evaluations (objective and subjective) are typically focused on the broad categories of steering effort, response, and linearity. Each category has its own nuances and it is no small task to command an electric motor (in a driving simulator) to deliver representative hand/wheel torque from vehicle, tyre, and road surface models in order to convey such nuances.

Until recently DIL simulators have lacked the computational and motor control capabilities that would enable drivers to receive informative, realistic hand/wheel feedback from complex real time models. But that has now changed and it is now possible using some techniques to model complex subsystems such as steering systems in the simulator. This approach immerses drivers into compelling environments that can capture the key characteristics of the vehicle, road surface, suspension, tyres and on-board electronic control systems. In so doing, it brings real people back into direct contact with the complex modelling which has been relegated to off-line simulation in recent years.

The architectures which allow this to happen provide real-time sensory feedback that is free from the latencies and motor cogging issues that can inhibit the subjective perceptions of an expert driver. With sufficiently descriptive vehicle and environment models, the driver's brain can accept the illusion of controlling a real car using a real steering system due to the fidelity of the sensory feedback.

Getting real

This next-generation technology features several key elements that enable vehicle steering systems to be accurately modelled and evaluated using the simulator, but if a manufacturer wants to test the hardware itself rather than the design concept then it has to look to HIL simulation. To do this creates some serious challenges, the vehicle physics models must be executed in real time, and must be of sufficient fidelity to provide appropriate demand signals to motion and feedback systems. Within the steering sub-system model alone there are mechanical and electrical system modelling challenges to overcome.

Driving simulators, by definition, combine what would traditionally be classified as 'simulation' and 'test,' and they also purposefully introduce a potentially corrupting influence into the otherwise purely objective pool – a human driver. Indeed, adding any system to a simulator loop, human, software or hardware, can and probably will introduce other imperfections; as technology develops so does the accuracy of each sub system, and this can lead to increasingly complex systems (and thus more imperfections). So how is it possible to extract 'objective' data from such a combined scenario?

Well, there is no simple answer to that. Right now it is a developing science, with multiple approaches. Emerging driving simulator technology is reinventing how things are being done. Utilising such technologies as stratiform motion machinery, powerful synchronous computing techniques, and low-latency driver feedback cues, modern dynamics-capable driving simulators deliver objective measurements in the form of real-time calculated vehicle physics channels, driver measurements, and environment information, which can all be viewed via telemetry or saved for later review. Practically speaking, there is so much information available, that it is only a matter of selecting the data subset that is of particular interest for any given set of experiments, and that is where the skill of the engineer comes to the fore.

Next month we will take a look at the rise of the simulator test pilot in motor racing.

When brake-by-wire systems and hybrids became standard equipment in LMP1 and Formula 1 much work was done using software-in-the-loop

Slide rules

Add dirt and ice to the equation and the race maths gets a whole lot trickier – *Racecar's* numbers man grapples with the slippery subject of rally simulation

By DANNY NOWLAN

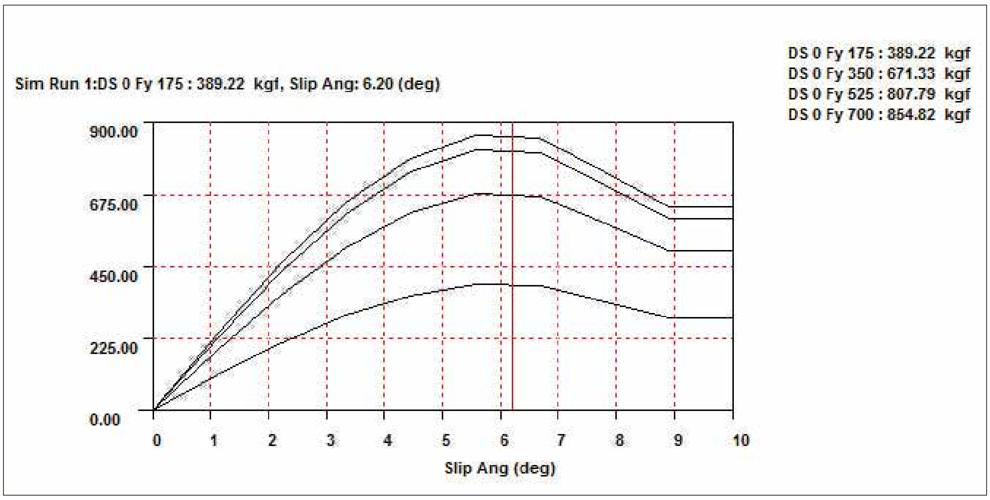


Figure 1: Lateral force *vs* slip angle characteristic for road tyre. Note how curve drops away once peak slip angle is exceeded

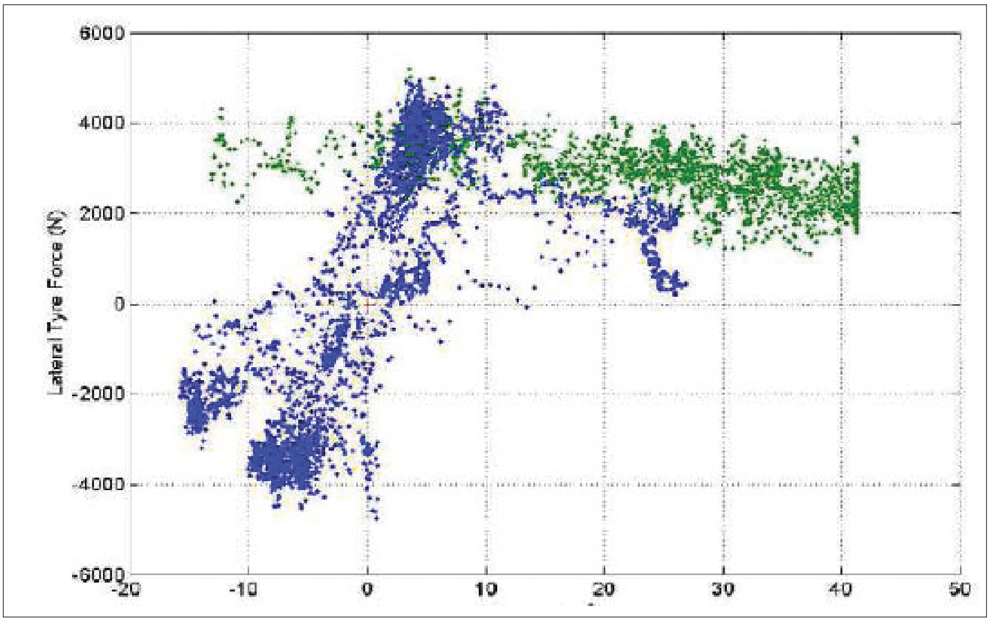


Figure 2: The force *vs* slip angle characteristics of a rally tyre – this shows there is grip to be had in the post-stalled region

If you want to go fast on a road racing tyre there is no point in being sideways, because the grip isn't there

For the last few months my work has been dominated by a project to adapt ChassisSim for WRC. The tarmac bit was easy, but the tough bit has been adapting it to run on dirt and ice. It has been challenging, yet also incredibly informative at the same time. The challenging aspect has been resolving why you have to run well into the post-stalled region of the tyre, and then resolving how to stay there. But let me state from off; I am not pretending to be an expert on this. If truth be told, I'm actually writing this more for me than you at this point, so I can start to get some things straight in my head. That being said I've learnt a lot so far, so if you are involved with rallying or have any interest as to what happens when a car goes sideways, then please read on.

So here is the question: why do you want to go sideways in a rally car? For all of us that have been involved in circuit racing this is a cardinal sin. It looks impressive, but when it comes to tarmac racing we all know it's a guaranteed way to kill your speed. The answer to this question lies in what the tyre is doing.

Slip angles

Specifically, the answer as to why we want to go sideways on dirt and ice comes down to the slip characteristics of the tyres. To really hammer home the point let's illustrate this graphically – a typical force *vs* slip angle characteristic for a road racing tyre is shown in **Figure 1**.

The thing to note in this curve is how significantly the grip drops away after you have exceeded the peak slip angle. In the post stalled region this is in the order of 10 to 20 per cent. Consequently, if you want to go fast on a road racing tyre there is no point being sideways, because the grip simply isn't there.

When you are on dirt and ice the tyre characteristics are a totally different ball game. When I was doing my research I came across two excellent thesis. These were Michael Croft-White's thesis from Cranfield University, *Measurement and Analysis of Rally Car Dynamics at High Attitude Angles,* and a thesis from Stanford University entitled *Dynamics and Control of Drifting in Automobiles* by Rami Yusef Hindiyeh. The upshot from both of these is that when you are post-stalled the grip doesn't drop off that much. White did some basic tyre modelling from a beta sensor he had developed. This is presented in **Figure 2**. The key thing to note is what is happening in the post-stalled region. Looking at slip angles well in excess of 20-degrees the grip has only dropped of by 10 per cent. This is significant, because it shows there is grip to be had in the post-stalled region.

If the drop in post-slip grip is mild the reason there is grip is because of what happens with the longitudinal forces of the tyre at large slip angles. This is illustrated in **Figure 3** along with the equations of motion with the car.

The symbols in **Figure 3** are:

F_{y1} to F_{y4} – Lateral forces of tyres 1 to 4 respectively.
F_{x1} to F_{x4} – Longitudinal forces of tyres 1 to 4 respectively
α_1 to α_4 – Slip angles of tyres 1 to 4 respectively.
δ –Steer angle of the front wheels (equal steer angles are used on both sides to keep the representation simple).
F_{YF} – Lateral force applied at the front axle.
F_{YR} – Lateral force applied at the rear axle.

The tyre loads are applied vertically downwards for each tyre.

All tyre forces are applied along the slip angle line. *FXF* and *FXR* are the sum of all the longitudinal forces at the front and rear respectively. Longitudinally this will not have a huge impact. But as we'll see shortly it has big ramifications laterally. This is particularly apparent at large slip angles.

Sine language

But a note about small angle assumptions here. Strictly speaking they only apply to about +/- 10 degrees. However for practical calculation purposes we can stretch this to about 20 degrees. Let me illustrate what I mean. In radians 20-degree is 0.349. The sine of 20-degree is 0.342. The cosine of 20-degree is 0.94. Yes, we sacrifice a little bit of accuracy longitudinally but the sine of the angles are still very close. Consequently, the equations we are about to present still work out. The other option is to include the sine and cosine terms. While it is fully accurate, the problem is you start to lose any perspective on what the maths is telling you. Also, in rallying, it is rare to see a side slip greater than 30 degrees. While this is not ideal we are certainly not in fantasy land.

Also, to simplify things we have lumped in the lateral forces here as well. Using small angle assumptions **Equations 1** and **2** may be concluded. From the derivation presented in Wong[3] (see references) the slip angles are **Equations 3** to **6**. Resolving forces and moments from **Figure 1**, the differential equations of the racecar become **Equations 7,8** and **9.**

Equations 3 to **9** describe everything about how the racecar will behave. The thing to note here is the longitudinal forces. To reiterate they are applied on the slip angle line of the tyre. At this point you might be thinking, so what? But

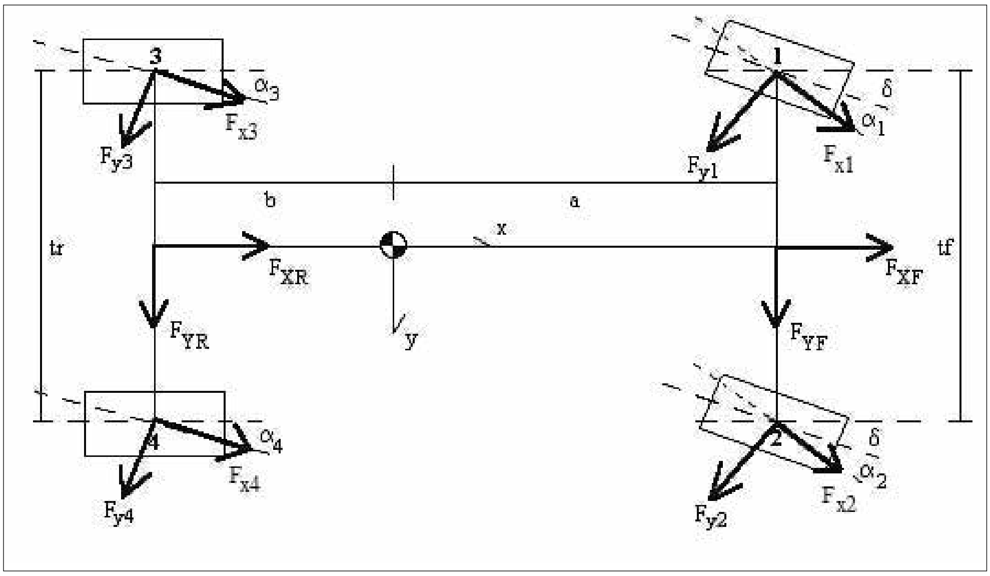


Figure 3: Free body diagram of the forces acting on the racecar showing longitudinal forces of tyre at large slip angles

EQUATIONS

EQUATION 1

$$F_{YF} = F_{y1} + F_{y2}$$

EQUATION 2

$$F_{YR} = F_{y3} + F_{y4}$$

EQUATION 3

$$\alpha_1 = \delta - \frac{a \cdot r + V_y}{V_x + tr \cdot r}$$

EQUATION 4

$$\alpha_2 = \delta - \frac{a \cdot r + V_y}{V_x - tr \cdot r}$$

EQUATION 5

$$\alpha_3 = \frac{b \cdot r - V_y}{V_x + tr \cdot r}$$

EQUATION 6

$$\alpha_4 = \frac{b \cdot r - V_y}{V_x - tr \cdot r}$$

where;
V_y sideways velocity.
V_x forward velocity.
r yaw rate.

EQUATION 7

$$m_t(V_x' + V_y r) = F_{XR} + F_{XF} - \sum_{i=1}^{2}(\delta + \alpha_i) \cdot F_{yi} - \sum_{i=3}^{4} \alpha_i \cdot F_{yi} - 0.5\rho V^2 C_D A$$

EQUATION 8

$$m_t(V_y' + V_x r) = F_{YF} + F_{YR} + (\delta + \frac{\alpha_1 + \alpha_2}{2}) \cdot F_{XF} + \left(\frac{\alpha_3 + \alpha_4}{2}\right) \cdot F_{XR}$$

EQUATION 9

$$I_z \cdot r' = a \cdot (F_{YF} + \left(\delta + \frac{\alpha_1 + \alpha_2}{2}\right) \cdot F_{XF}) - b \cdot (F_{YF} + \left(\frac{\alpha_3 + \alpha_4}{2}\right) \cdot F_{XR})$$

Here,
m_t = Total mass of the car.
I_z = the rotational inertia of the car

Table 1– Rally car parameters

Parameter	Value
Car mass	1300kg
Cornering *g*	1
Peak slip angle: tarmac	60
Peak slip angle: dirt	160
CdA	1.1
Cornering speed	108km/h

Table 2 - Numbers for the balanced longitudinal forces in tarmac and dirt mode

Mode	FXT (kgf)	Lateral component (kgf)
Tarmac	198kgf	20.7
Dirt	424kgf	118.7

EQUATIONS

EQUATION 10

$$F_{YF\_FXF} = (\delta + \frac{\alpha_1 + \alpha_2}{2}) \cdot F_{XF}$$

$$F_{YR\_FXR} = \left(\frac{\alpha_3 + \alpha_4}{2}\right) \cdot F_{XR}$$

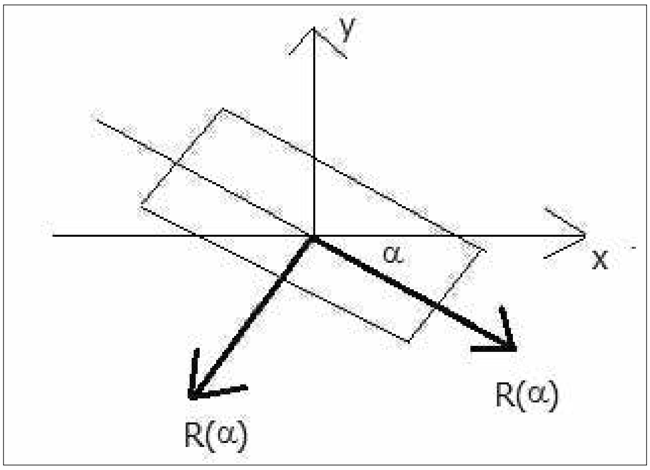
EQUATION 11

$$F_{XT} = \frac{1}{2}\rho \cdot V^2 \cdot C_D A + \alpha_p \cdot m_t \cdot a_y$$

Here we have,

F_{xt} = Total longitudinal force applied (N)
p = air density (kg/m³)
V = Car speed (m/s)
a_p = Peak slip angle in radians
m_t = total car mass
a_y = Lateral acceleration in m/s²

Figure 4: Here two tyre forces are acting both laterally and longitudinally



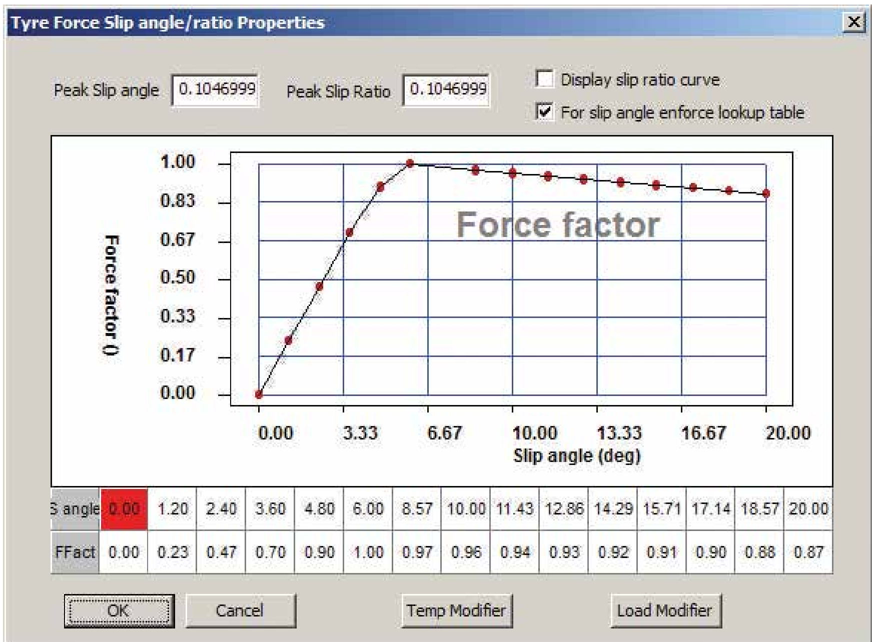


Figure 5a: Road course tyre. Equation 14 shows us that this tyre has an optimum slip angle of 6.2 degrees

the key lies in the lateral components of the longitudinal forces – see **Equation 10**. Here *FYF_FXF* is the lateral force at the front induced by the front longitudinal forces and *FYR_FXR* is the lateral force induced by the rear longitudinal forces.

Where things get really interesting is with what happens when the slip angles go up. Let's illustrate this with some numbers. Let's consider a typical all-wheel-drive rally car that weighs in at 1300kg. Some performance numbers are illustrated in **Table 1**. I realise the cornering *g* on dirt will be less than tarmac, but let's keep these the same for the time being. I want you to get a feel for the magnitude of the numbers.

So, balancing the speeds and assuming front and rear slip angles to be the same we have **Equation 11**. I know this is not strictly accurate but it is in the ballpark and, as I've said, I'm doing this so you get a feel for it. Crunching the numbers for the tarmac and dirt modes you get the results presented in **Table 2**.

Engine force

So, in tarmac mode we have about 20.7kgf of lateral force produced by the applied longitudinal force. In dirt mode this jumps to 118.7 kgf. While the analysis is incredibly over-simplified it rams home the rally observation that on dirt the engine force is a significant part of your corner grip.

But how do we determine that this is viable or not? We will enter what I will term the *drift feasibility equation*. Let's illustrate this situation graphically – this is shown in **Figure 4**. As can be seen here we have two equal forces acting laterally and longitudinally. I will term this force *R(a)*. Both of these components will have lateral components. Let me set *R(a)* out in **Equation 12**. Here *C(a)* is the normalised slip curve and *FmOUT* and *FmIN* are the outer and inner traction circle radius values. Our goal here is to find the best compromise of slip angle that produces the optimum lateral grip. Our total lateral forces will be given in **Equation 13**.

Just to be clear, I am slaving the force *R(a)* to the force *vs* slip angle equation that we all know and love. However, I'm still keeping it in traction circle limits so that we don't enter fantasy land. So the optimum slip angle will be given by deriving **Equation 14** as a function of slip angle; using the product differential rule it is found that the optimum slip angle that will produce the most lateral grip will be given by this equation.

Equation 14 is the drift feasibility equation. This won't necessarily tell you the optimum slip angle you need to be at for drifting. However, it will tell you if your tyre can actually do it. As a case in point consider **Figure 5a** which is a road course tyre and **Figure 5b** which is a rally tyre. Evaluating **Equation 14** for both of these curves show that **figure 5a** has an optimum slip angle of 6.2 degrees and **figure 5b** has an optimum slip angle of 16 degrees. Try doing this numerically. List out R(α) and the subsequent

Now we need to nail down at what angle we have to go sideways at

derivatives. If you try and do it analytically you'll drive yourself nuts. This is the first step in seeing if it is worth your while to go sideways or not.

So now that we have established if it's viable or not to go sideways we know need to nail down at what angle we have to go sideways. Remember we are drifting on dirt and ice not just because it looks impressive but we are doing this to get grip. The answer lies in the lateral grip front and rear.

Front to rear

Let's put some maths to this. To simplify things a little bit let's use the bicycle equations of motion for the front and rear slip angles. This is presented in **Equation 15**. Here *af* and *aR* are the front and rear slip angles. The front and rear lateral forces taking into account both the forces due to slip angle of the tyre and the longitudinal forces are shown in **Equation 16.**

Let's nail down the nomenclature here:

CF(a) – Normalised force slip angle curve at the front

CR(a) – Normalised force slip angle curve at the Rear

Fm1 – Traction circle radius at the Left front tyre for a given load.

Fm2 – Traction circle radius at the Left front tyre for a given load.

Fm3 – Traction circle radius at the Left front tyre for a given load.

Fm4 – Traction circle radius at the Left front tyre for a given load.

Where things get really interesting is taking the derivative with respect to slip angle of **Equation16**. Then we see **Equation 17**.

In order to be worth your while to drift, the differential of the front and rear force curves must be greater than zero. This is where the grip is and the reason the grip is there is as the slip angle increases you will actually be producing force you can use. It's the reason that you see Sprint cars on an oval hanging the tail out because that is where the grip is. If your car is rear-wheel-drive, the last bit of **Equation 17** applies. If your car is front-wheel-drive the first bit of it applies. If you are all-wheel-drive then both come into play. For rallying, **Equation 17** outlines the appeal of all-wheel-drive cars.

So what is the procedure to determine the slip angle that you should be drifting to satisfy **Equation 17**? You start by choosing a corner speed and looking at the peak curvature you want to corner at. You then nominate the factor of grip you want to maintain at the rear. The crux of this is that we want to maintain equilibrium both laterally and longitudinally.

Keeping the slip angles the same front and rear we have **Equations 18** and **19**. Here *tspR* is the torque split at the rear and *FXFR* is the factor of rear longitudinal tyre force we want to contribute to the lateral grip. Putting **18** into **19** yields the relation for the rear slip angle we are after, as seen in **Equation 20**.

The solution of **Equation 20** will give you a reference check. You are then going to go through an iterative process to see if this makes sense. In particular, if it is achievable through the slip angle curves you have.

The other thing to check is the load transfer, so that you have the traction. The limitation will be the inside rear tyre loads. You will then check **Equation 17** and if all this adds up you have equilibrium. When this all checks out you have determined the rear slip angle and side slip angle you should be drifting at. What all these equations tell you is that drifting to improve vehicle grip is only viable in low grip situations.

Let's re-inspect equation **Equation 17**, but this time let's do it through the lens of load transfer. As a rough rule of thumb your tyre loads

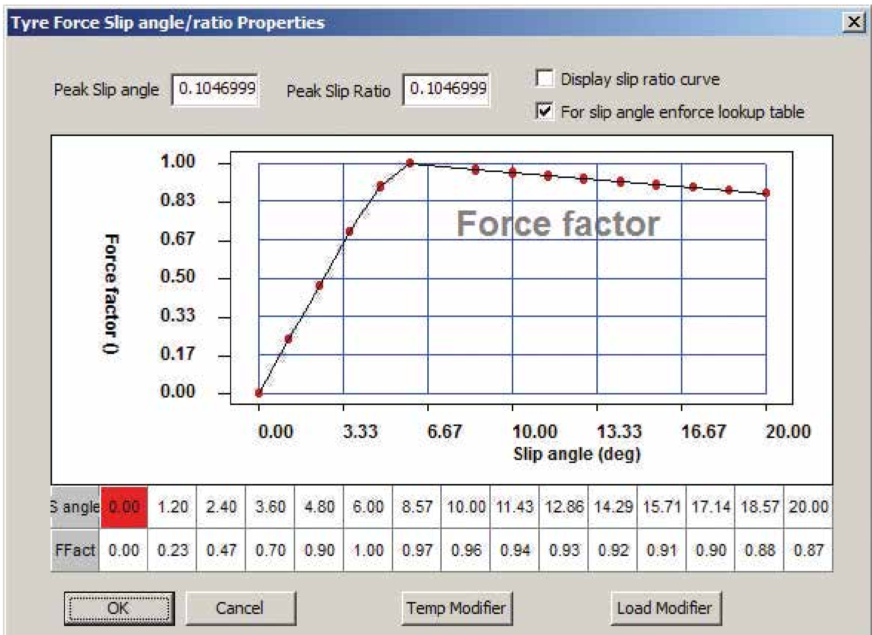


Figure 5b: This time it's a rally tyre. With Equation 14 we can see this has an optimum slip angle of 16 degrees

EQUATIONS

EQUATION 12

$$R(\alpha) = C(\alpha)\cdot(Fm_{OUT} + Fm_{IN})$$

EQUATION 13

$$F_{YT} = 0.707\cdot R(\alpha)\cdot(\cos(\alpha)+\sin(\alpha))$$

EQUATION 14

$$\frac{\partial F_y}{\partial \alpha} = 0 = R(\alpha)\cdot(\cos(\alpha)-\sin(\alpha)) + \frac{\partial R}{\partial \alpha}\cdot(\cos(\alpha)+\sin(\alpha))$$

EQUATION 15

$$\alpha_F = \delta - \frac{a\cdot r + V_y}{V_x}$$

$$\delta = \alpha_F + \frac{a\cdot r + V_y}{V_x}$$

$$\alpha_R = \frac{b\cdot r - V_y}{V_x}$$

EQUATION 16

$$F_{YF} = C_F(\alpha)\cdot(Fm_1 + Fm_2) + (\delta + \alpha_F)\cdot F_{XF}$$

$$= C_F(\alpha)\cdot(Fm_1 + Fm_2) + \left(2\cdot\alpha_F + \frac{a\cdot r + V_y}{V_x}\right)\cdot F_{XF}$$

$$F_{YR} = C_R(\alpha)\cdot(Fm_3 + Fm_4) + (\alpha_R)\cdot F_{XR}$$

EQUATION 17

$$\frac{\partial(F_{YF})}{\partial \alpha_F} = \frac{\partial(C_F(\alpha_F))}{\partial \alpha}\cdot(Fm_1 + Fm_2) + 2\cdot F_{XF}$$

$$\frac{\partial(F_{YR})}{\partial \alpha_R} = C_R(\alpha_R)\cdot(Fm_3 + Fm_4) + F_{XR}$$

EQUATIONS

EQUATION 18

$$\alpha_R \cdot F_{XR} = F_{XFR} \cdot wdr \cdot m_t \cdot V_X{}^2 \cdot iR$$

EQUATION 19

$$F_{XR} = tsp_R \cdot \left(\frac{1}{2} \cdot \rho \cdot V^2 \cdot C_D A + \alpha_R m_t \cdot V_X{}^2 \cdot iR\right)$$

EQUATION 20

$$\alpha_R{}^2 + \frac{0.5 \cdot \rho \cdot C_D A}{m_t \cdot iR} \cdot \alpha_R - \frac{F_{XFR}}{tsp_R} = 0$$

EQUATION 21

$$TL_1 = \frac{wdf \cdot m_t \cdot g}{2} + \frac{awf \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} + \frac{prr \cdot m_t \cdot a_y \cdot h}{tm}$$

$$TL_2 = \frac{wdf \cdot m_t \cdot g}{2} + \frac{awf \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} - \frac{prr \cdot m_t \cdot a_y \cdot h}{tm}$$

$$TL_3 = \frac{wdr \cdot m_t \cdot g}{2} + \frac{awr \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} + \frac{(1 - prr) \cdot m_t \cdot a_y \cdot h}{tm}$$

$$TL_4 = \frac{wdr \cdot m_t \cdot g}{2} + \frac{awr \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} - \frac{(1 - prr) \cdot m_t \cdot a_y \cdot h}{tm}$$

EQUATION 22

$$SI = \frac{a \cdot \frac{\partial F_{YF}}{\partial \alpha} - b \cdot \frac{\partial F_{YR}}{\partial \alpha} - \left(a^2 \cdot \frac{\partial F_{YF}}{\partial \alpha} + b^2 \cdot \frac{\partial F_{YR}}{\partial \alpha}\right) \cdot \frac{r}{V_X}}{\left(\frac{\partial F_{YF}}{\partial \alpha} + \frac{\partial F_{YR}}{\partial \alpha}\right) \cdot wb}$$

Figure 6: Some predictive rally action from ChassisSim which shows the car being controlled in the post-stalled drift zone

If you're sliding in a rear-wheel-drive car here, you have no option but to keep the power applied

for a given aero load and load transfer are given in **Equation 21**. Where the downforce is not significant what will limit you will be the inside front and rear tyres unloading. Consequently your ability to apply the longitudinal forces you need, to ensure **Equation 17** is greater than or equal to zero, will be limited. Strictly speaking you could channel all the longitudinal force to the outside rear wheel, but you will have a destabilising moment due to the tractive force trying to destabilise the car.

The drift zone

The last topic to touch upon is; what does the racecar stability look like in the post-stalled drift zone? As discussed in some of my previous articles, there is an excellent tool to look at this, which is the stability index. This can be written as **Equation 22**.

Inspecting **Equation 17** and putting it into **Equation 22** we will still have some measure of stability. However, it will be much more marginal. This is because the slope of the force *vs* slip angle curves are much smaller. The applied longitudinal forces are the dominant terms. The combination of **Equations 17** and **22** mean that if you are sliding in a rear-wheel-drive car you have no option but to keep the power applied. This was also confirmed in Hindiyeh[2], where the engine force is used as an integral part of his drift controller.

Lastly, to show this isn't just theory, the beginnings of it have now been incorporated into ChassisSim, as you can see in the example of a predictive rally simulation done in real time controlling the car in the post-stalled zone of the tyre, shown in **Figure 6.**

The first trace is speed, the second is steered angle, and the third trace is throttle. However, the real traces are the fourth and fifth traces that show front and rear slip angles. The stall angle for this tyre is six degrees. The front slip angles are in the order of four to five degrees. However, you can see the rear slip angles are in the order of 10 degrees and they are being controlled. I should add that the car model needs work.

In closing, the vehicle dynamics of drifting are an exceptionally interesting field. The thing that dictates why you want to drift is what happens to the tyres on dirt and ice. Here the slip angle curves drop of moderately in the post-stalled region of the tyre. This makes it viable to slide and we can readily calculate where we need to be drifting.

While this is certainly not the last word on the vehicle dynamics of rallying, I trust what I have given you is the mathematical framework to put some numbers to it.

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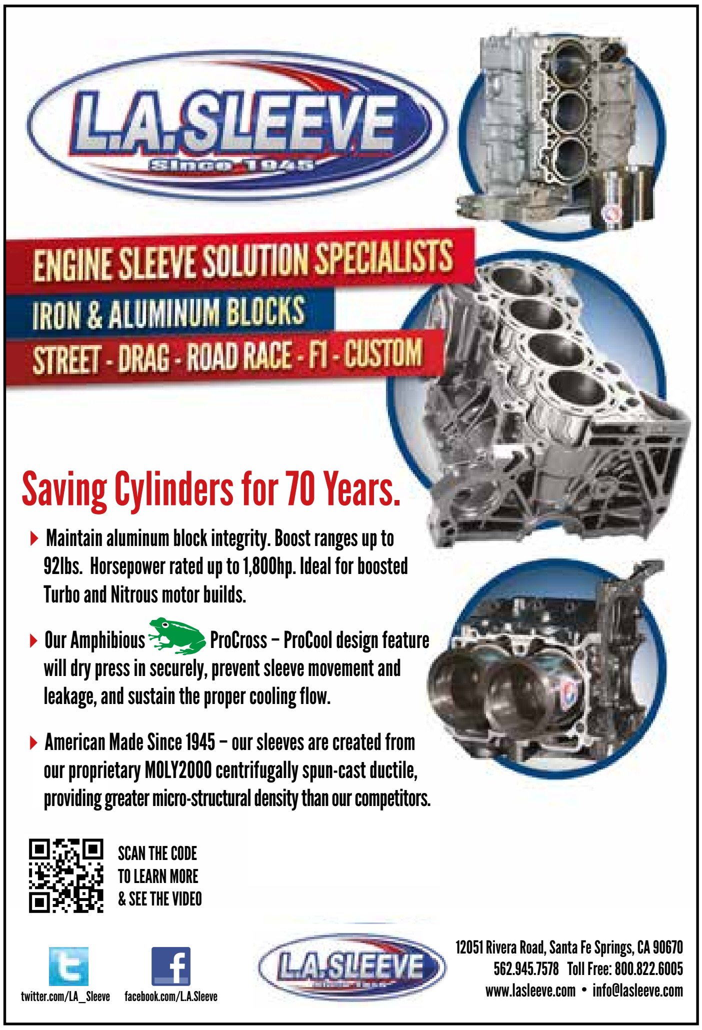
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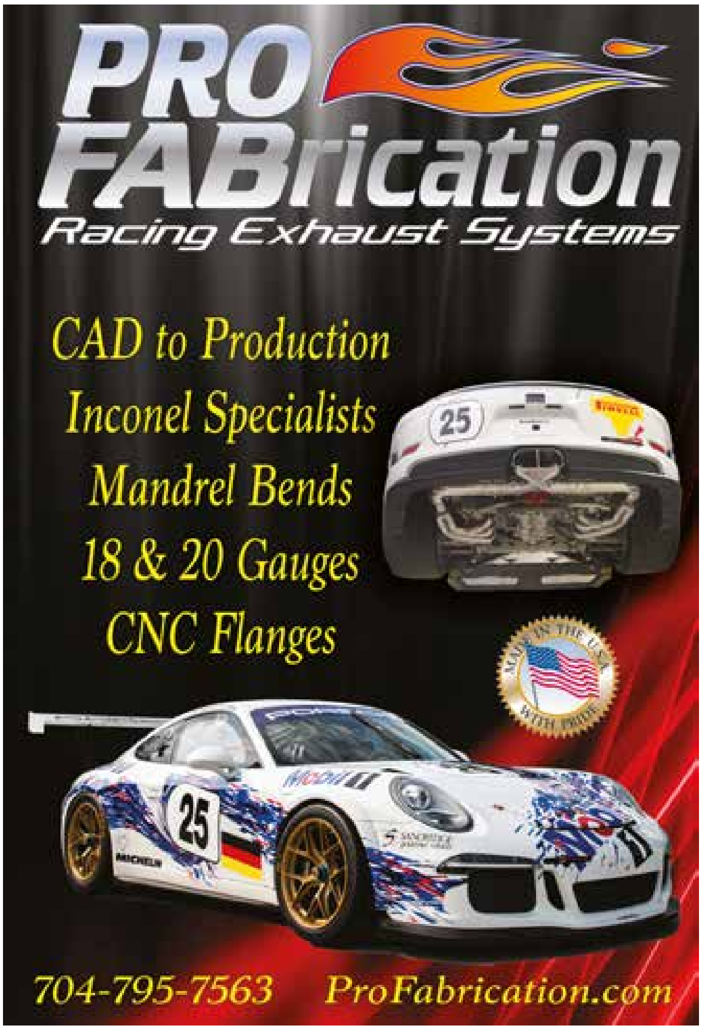
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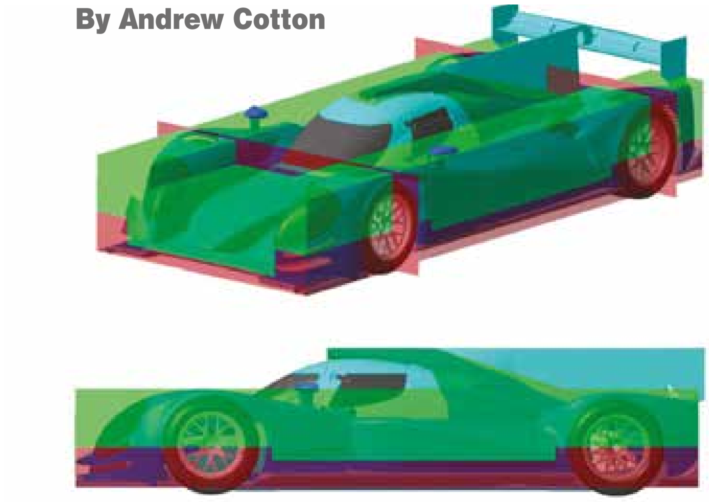
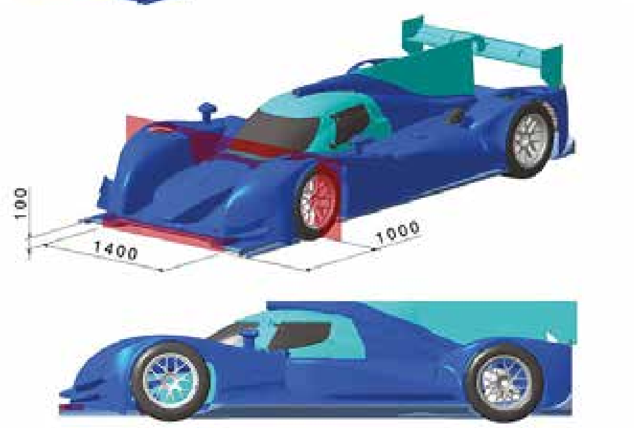
Culture **clash**

The new-for-2017 LMP2 and its American DPI cousin are to use the same four base cars from next year – but dig a little deeper and there's a whole world of difference between the two

By Andrew Cotton





The aero kit for the IMSA DPI car will be based around the European LMP2 but a manufacturer will be allowed to develop the front, the sidepods and the rear deck to fit with its own design cues (above right)

Plans for a global prototype category, using P2 chassis regulations, are reaching fruition with the FIA posting draft regulations on its website early in March, while in the United States IMSA is now putting the finishing touches to its final specification. What has become clear is that, while the two have taken the same four chassis as specified by the FIA and ACO, the concepts have proven to be wildly different.

The idea was for teams to be able to race in the World Endurance Championship, IMSA and the Asian Le Mans Series with the same car, and that is still possible with the European-specification LMP2. That will be fitted with a standard Gibson engine and will be the reference car against which all the others will be performance balanced in Europe.

However, one of the main issues to overcome was that in the WEC, the LMP2 category was designed for the privateers competing in the second-tier of prototype racing, while in the US, the DPI category would be competing for overall wins at races such as the Daytona 24 hours, the Sebring 12 hours and the 1000-mile Petit Le Mans.

The four chassis manufacturers, three from Europe and one from the US, were selected last year and all are pushing ahead with developing partnerships with interested manufacturers to develop both the IMSA car, and the European-specification bodywork should any of them choose to race at Le Mans.

IMSA's Mark Raffauf is confident that the LMP2 constructors and the OEMs can work with DPI regs

In IMSA, the engine regulations are far more open, with, for example, Honda claiming that they would run a turbocharged engine in their chosen chassis, which would then have to be performance balanced against the Gibson should it race at Le Mans. The bodywork would also need to be changed for the French sojourn, with a European specification developed to take the cooling system required for the turbos.

'There are two things going on, the IMSA DPI and the ACO/FIA process,' says IMSA's director of series platforms, Mark Raffauf. 'Their process requires stamping by the World Council. We are working through details of points in this process that started in July last year. There is another meeting scheduled in May where there may be the final stamped FIA rules. Our constructors manual, which is the same process as the original Daytona Prototypes, gives the constructors and OE manufacturers what they need to do and how it is going to be done and what the process for certification and balance will be is sitting right here.

'It is not new, it has been in process since August of last year, being slowly refined as the LMP2 regs have been defined, the key stuff that people need. We are comfortable that the four world-wide constructors and the OE manufacturers know what they need to do to build an IMSA car. We are ready to go with that. There are still some details on the car, where electrical circuits plug in that the constructors will continue to work with the ACO and FIA, the


OAK markets the Ligier LMP2 car and is one of the four racecar manufacturers chosen to build the new generation of P2s, set to hit the track next year

type of air conditioning unit, the type of clutch, but nothing that changes the material needed to build an IMSA car or a P2 car. They still have to go through crash testing certification and all that, but all the major stuff for now is in place.'

The chassis manufacturer will select the gearbox that must be mated to the manufacturer's engine but the majority have chosen to use the Xtrac gearbox. The aero kit will be based around the European kit, but a manufacturer will be allowed to develop the front, the sidepods and the rear deck according to its own design cues. 'It is a replacement body,' confirms Raffauf. 'The car is the splitter, floor, diffuser, wing, cockpit, tub and fin. The sidepods the nose and the tail are what make a DPI in conjunction with the same branding of the engine. You will have different cooling needs and exhaust, so there will be deviations from the standard LMP2 car.'

Le Mans costs

Opinions are split as to the cost of taking an IMSA car to Le Mans. If a manufacturer wants to go to Le Mans, they can spec-up their IMSA car with that in mind, including selecting the European-specification Cosworth ECU.

'The only way that you can go to Le Mans with our kind of car is with a hybridised car, which is essentially an LMP2 Le Mans kit car, with our engine in it, operated per the ACO's rules for operating that engine,' says Raffauf.

> 'The only way that you can go to Le Mans with our kind of car is with a hybridised car, an LMP2 Le Mans kit car'

The IMSA-developed balance of performance system, introduced to the GT classes this year, will be used to balance the different engine and bodywork concepts against each other in the US series, and against the Gibson should anyone select this engine to race in the US. 'The data logger that the FIA uses is Magneti Marelli, we use Bosch,' says IMSA's vice president of competition, Simon Hodgson. 'Our system has dedicated sensors around the engine, and we are looking at selected data. We have developed our own data analysis in terms of timing and scoring, and have our own process for evaluating the car data that is supplied in scrutineering so the two work in collaboration with each other. The manufacturers always want trigger points to see when the BoP changes might occur, but we have every manufacturer's information. Of course, there was this insinuation that things were going on behind a curtain, but we have developed a process of sharing the data with each manufacturer. We have group calls with the manufacturers, they preview the BoP tables, and have the opportunity to speak on that call where their performance is and what adjustment they feel that they need. A manufacturer may defend their information, but we will not expose their proprietary information.

'The World car is the LMP2, that can compete anywhere and is welcomed in our series as a competitive option. For 30 years the philosophies of what we do here has been different. It's not universal in that regard. We have to create our own niche and grow it.'

For the chassis builders, OAK Racing, ORECA, Dallara and Riley-Multimatic, selecting an engine partner to work with is a priority. 'Of course it will be easier [in Europe with a single engine manufacturer], but we know that we are not doing an easy job,' says OAK's Jacques Nicolet. 'The more interesting thing is to compete. For me, I think that to have a different car for the global competition, it is a good thing.

'We are completely focussed on the new car and when we know exactly what we need to do for the DPI we can start, but we have also to know with which manufacturer we are working because the design is linked with the manufacturer, not only with the rules. The basic car has to be the same in Europe and America … for the moment!' Nicolet adds.

Time constraints

'We have to work together with the manufacturer to design what they want to be close to a sportscar, a road car, and to adapt this design with the aero we need to be very efficient,' Nicolet continues. 'But, if they do what they said, we will have afterwards a complete BoP between the engines, and the aero. It is a lot of work in a short space of time. If you consider that we have to be ready for middle of November, to run in Daytona, it is a short time.'

And will the cars be able to race at Le Mans? 'If they choose this way, it is impossible. The car will be too different because with the DPI, you can have turbocharged engines, and in LMP2 you have only a unique engine, normally aspirated, the bodywork will be completely different,' Nicolet says.

Max Angelelli, who is co-ordinating relations between Wayne Taylor Racing and Dallara, says that the global concept is alive and well. 'The WEC car can come over and race in Daytona,' says the Italian. 'There is a process to go through, and once they are eligible and once they have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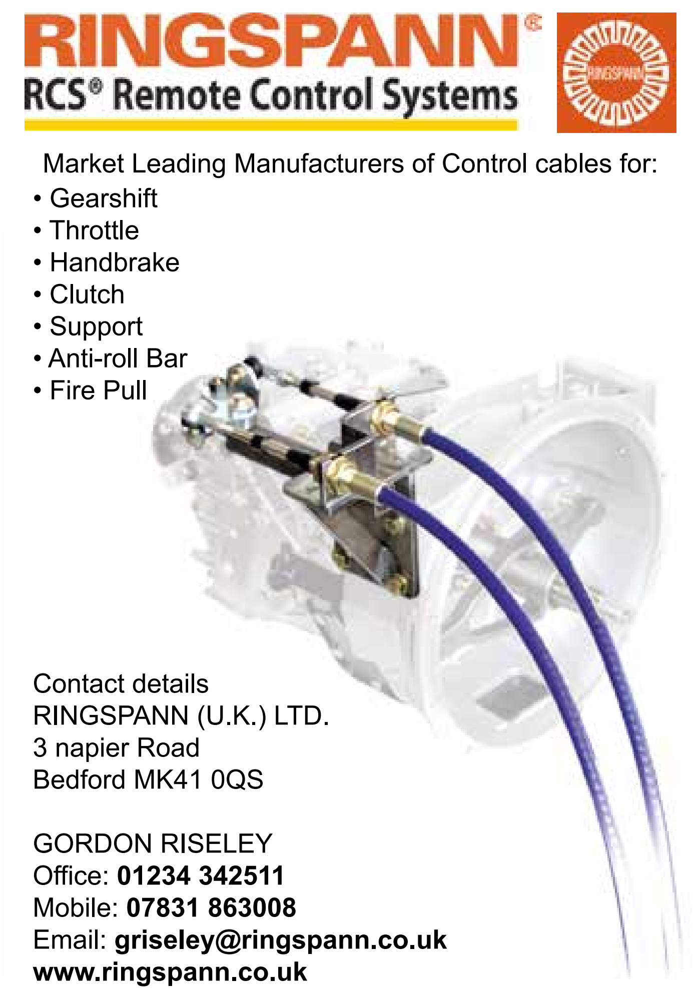
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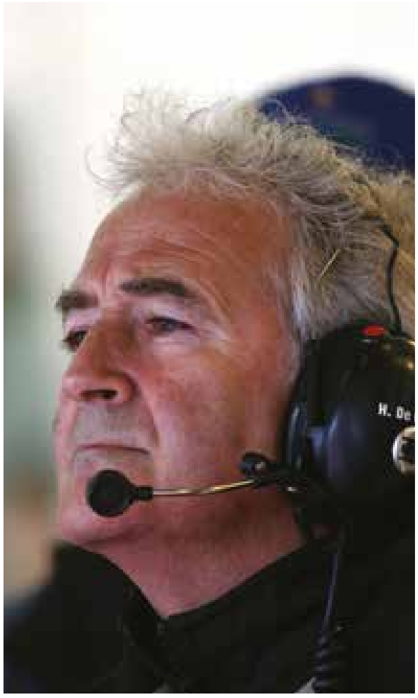


While LMP2 is a secondary class in the WEC and at Le Mans, DPI will be the top class in IMSA, with its teams aiming for big wins at races such as Daytona. ORECA boss Hugues de Chaunac (above right) believes this will mean that manufacturer teams in the United States will not want to compete at Le Mans. ORECA is one of the four new LMP2 manufacturers

been through the process they can race. The Gibson has to be balanced against the IMSA cars with regard to aero and so on. The Gibson will be very powerful, but I don't think that we will be as powerful as people believe. There are a lot of unknowns, but you have the WEC car, and you can race in IMSA. You have an IMSA car, and you can race in Le Mans, with changes.

'The exercise is; a chassis manufacturer has to design a WEC body that will fit a turbocharged engine. IMSA will have turbo so they have to consider while tooling and engineering the body, the intercoolers, plumbing and so on. If the chassis manufacturer doesn't want to do that, because their WEC will be penalised, that is their problem.'

Will the costs be a prohibitive factor? 'The point is that you are going to, say, Ligier, you buy a WEC body. That WEC body must fit your IMSA car. They have to consider the requirements when they design the WEC body. They need to be linked with an OEM, and consider that everyone knew by April last year, more or less, the path that people were going. They have had plenty of time to arrange themselves. ORECA already did it. I think they are right there. Dallara is right there I believe, and Riley is right there, too.

'They want to be first in the USA, and don't want to be in category two at Le Mans. Nobody wants to do it'

'Let's assume Mazda want to go to Le Mans, and assume they want to go with Riley, they can. Riley will fit the IMSA Mazda car with the WEC body, with 20 gear ratios, with the Le Mans electronics package, which is a Cosworth, and go to Le Mans. The choice of electronics is open, and you can use Cosworth. You can do what you want,' Angelelli says.

Second best?

For ORECA, the issue of an American manufacturer racing a P2 chassis at Le Mans is academic. 'I think that if Honda wants to run their engine at Le Mans, at that moment, they will see with the constructor that they have chosen how they can do the body side; everything now is fixed,' says ORECA boss, Hugues de Chaunac. 'For me, I always say that there is a one per cent chance that a car manufacturer wants to come to Le Mans. No one wants to come to Le Mans. They want to be first in the USA, and don't want to be in category two at Le Mans. I think there is no problem on that side because nobody wants to do it. I don't see a difficulty on that side because I don't see anybody who wants to come.'

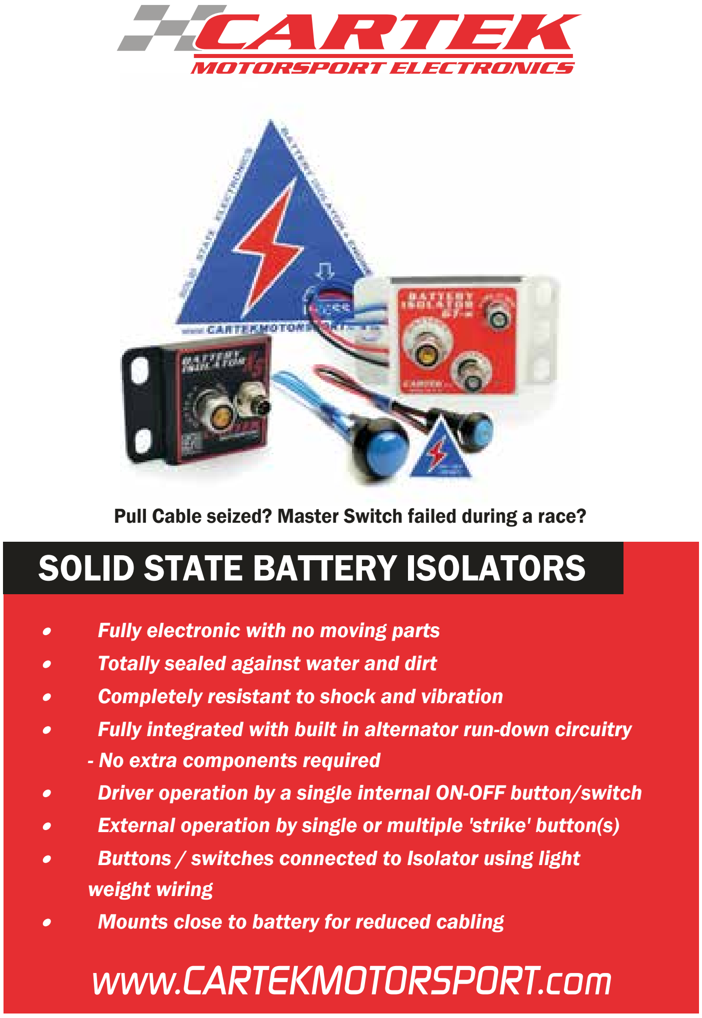
So the global prototype category that they envisaged is the only link? 'The teams that are competing in the US are only teams, they are not works teams from the manufacturer. If one of these teams, like Action Express, for example, wants to compete in Le Mans, it is much easier for them to rent a European car to do Le Mans. That is all. I think it is a good compromise to have the same car in Europe and USA and the targets are not the same. In Europe it is category two and not category one. We keep the same base of car, and only four chassis manufacturers, so they try [to be different] and they improve, but it is impossible to do a unique car. I think that the actual situation is reasonable.'

Bill Riley, one part of the American consortium building a P2 chassis, says that the link between IMSA and the ACO is as strong as ever. 'We do have to do a lot, and have to think about what you are designing for as the car does have to have multiple uses. You have to think about the engine mounts, what potential turbo intercoolers will look like, the turbo mounting, air intakes to the turbos; so there is a lot to think about way up ahead.

'I don't think it will be too far away [from a global car]. You have to change parts, but it is closer than it has been for a long time,' Riley adds. 'You will have boxes to do the stylised body and if you want to go to Le Mans, you have to put the WEC body back on. It is not a nightmare, but it is a lot of work, without a doubt. The work comes in stages. You have to do the WEC car, and then stylise the body after that, and the homologation is staggered. In our case, with the Multimatic Riley, you have two companies that can do it. If Multimatic can take one OEM, and we take another, and then do the LMP2 together.

'I would say that the aero will not be as good as a WEC car as they have to BoP the bodies to the lowest common denominator and that probably won't be a WEC car, so they will have to bring the WEC cars down a little bit.'

One twist in the tail came at the WEC Prologue at Paul Ricard. There, the ACO came up with another solution; to allow the IMSA cars to run in the LMP1 non-hybrid category, a solution that would fit with the US philosophy of campaigning for overall wins with professional driver line ups. In that case, is the argument for the 'global prototype' still valid?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lister

Formula 1 team bosses deny that top constructors operating as a 'cartel'

Formula 1 bosses have hit back at suggestions by the sport's own head Bernie Ecclestone that F1 is now run by a cartel of the leading manufacturers.

Ecclestone made the comments in relation to Mercedes and Ferrari, in particular, who he has accused of forming a duopoly to try to hold on to their current dominance, but he has also criticised the other teams on the Strategy Group, who have voted to stop some new regulations he was in favour of, chiefly the alternative low cost engine supply.

The F1 chief has said the top teams are operating as a 'cartel', and added that F1 is now so bad 'he wouldn't spend money to take his family to watch'.

Ferrari team principal Maurizio Arrivabene reacted angrily to this, saying: 'I think [saying there is] a cartel is simply ridiculous because everybody is doing their job and they try to do their best and we are talking here about brands that have a long story. They are not going to throw out of the window their story, their reputation.

'They [the comments] don't deserve even one word,' Arrivabene added. 'I have to say it is strange because with this word you have to be careful sometimes, because if you are talking a bit more with somebody and you are going to dinner with Toto [Wolff] or Cyril [Abiteboul] are you a cartel? It is simply a dinner and no one wants to talk about having a cartel. It is simply ridiculous.'

Mercedes boss Toto Wolff agreed, though he also put Ecclestone's comments down to headline grabbing. 'I don't think there is any cartel around here. Bernie is always good for controversy … if it were run like a cartel, we wouldn't be sitting here. Some of us are part of multi-national global companies and we take compliance very seriously. It just causes headlines, but nothing else.'

However, Red Bull team principal Christian Horner did have some sympathy with Ecclestone's views: 'I think you can understand that Bernie is frustrated. I think his comments are born out of frustration of being unable to influence change and you have got a dynamic in Formula 1 at the moment where the manufacturers collectively have a lot of strength and that is primarily through the technical regulations and the current situation regarding the power unit. I think Bernie's frustration as a promoter is that he can't influence that at this point in time,' Horner said.

XPB

Ferrari and Mercedes at the front once again in Melbourne. Ecclestone thinks top teams are running F1 like a cartel

Ferrari biggest power unit token spender over off-season

Ferrari has spent 23 of its 32 engine development tokens over the winter and now has only nine left for in-season development.

This year each of the power unit manufacturers, Mercedes, Ferrari, Renault and Honda, is allowed 32 tokens, up from an original 15, while development is to be allowed on areas of the PU that were to be restricted – namely the crankshaft, upper and lower crank case, valve drive and the air-valve system.

The FIA confirmed in the run-up to the season opening Australian Grand Prix that Ferrari had, at that point, spent 23 tokens, with only nine remaining to use for the remainder of the season.

Mercedes was not too far behind, with 19 spent (13 left), Honda had used 18 and had 14 left in the bank, while Renault had spent by far the fewest with just seven used, leaving 25 tokens for in-season development.

But Renault managing director Cyril Abiteboul believes this does not mean the team had made little progress over the winter. 'This is a demonstration that we have used little tokens but I hope the fact we have made a substantial step in terms of performance will be actual evidence that there is no connection between token use and performance,' he said.

'You can use a lot of tokens and bring absolutely nothing in terms of lap time, which is maybe something we did last year. There is a plan to use more tokens during the course of the season. Hopefully it will happen, both for the benefit of the Renault works team and also Red Bull,' Abiteboul added.

Renault sported its new retro livery at Melbourne – the manufacturer has spent the fewest engine tokens over the winter

BRDC F4 becomes new British F3 regional championship

MSV's BRDC Formula 4 Championship received a last-minute name change just days before its opening race and is now to be known as the BRDC British Formula 3 Championship.

This move came in the wake of a request for expressions of interest from the Single Seater Commission of the FIA aimed at promoters wishing to fill the wide gap between national Formula 4 and the F3 European Championship, by running new regional Formula 3 championships.

With budgets of up to €750,000 in European Formula 3, drivers have been finding it a huge step up from many of the Formula 4 series around the world, which cost about a third of that on average, and the FIA has now decided it needs new rungs on its single seater ladder.

Motor Sport Vision (MSV), the company run by former F1 driver and multiple circuit owner Jonathan Palmer, has now agreed that its BRDC F4 Championship will now be known as BRDC F3 and will thus fill this 'regional F3' position in the UK.

The MSV car has received a big performance upgrade this year, with more power and a carbon Tatuus tub, and in a test at Snetterton pre-season the fastest BRDC F4 set a time just 0.369seconds off the pole position time from the last British F3 Championship round run there in 2014 – though newer F3 cars are a little bit quicker thanks to different engine regulations.

Palmer said: 'I am delighted that we have successfully worked with the FIA and MSA to streamline British single-seater motorsport and establish a clear and logical hierarchy for both drivers and teams. Our much-advanced 2016 BRDC F4 Tatuus Cosworth car has proved an outstanding success, being very close to the performance of British F3 in its heyday – but at less than half the budget. Cost-effectiveness and value for money is critical to any championship's health, and having set standards with our BRDC F4 Championship we are now doing the same at F3 level with the BRDC British F3 Championship.'

The MSV-run BRDC F4 Championship has had a name change and will now be known as the BRDC Formula 3 Championship

The FIA has also called for expressions of interest from those wishing to stage a World Final for Formula 4, which presumably would be along the lines of the Formula Ford Festival when it was at its height in the 1970s and 1980s.

McLaren to invest £1bn in burgeoning road car arm

McLaren Automotive intends to invest £1bn on R&D over the next six years

McLaren Automotive has announced it's to invest £1bn in to research and development over the next six years.

The investment is part of the company's Track22 Business Plan, which also includes a commitment that Automotive – part of the wider McLaren group which includes the Formula 1 team – will continue to focus purely on the development of two-seater sports and supercars.

At the heart of the business plan is a commitment to 20 to 25 per cent of turnover invested in research and development for future products and technology over the six-year business plan period, which represents an investment of £1bn, and will lead to the launch of 15 all-new cars or derivatives.

In the wake of its success with the petrol-electric hybrid-powered McLaren P1, McLaren Automotive has also now confirmed that at least 50 per cent of its cars will feature hybrid technology by the end of the six-year business plan period.

Research engineers at the McLaren Technology Centre in Woking are now also in the early prototype stages of the development of a fully-electric powertrain to evaluate its possible use in a future generation of an 'Ultimate Series' car, McLaren tells us.

Mike Flewitt, chief executive officer at McLaren Automotive, said: 'The launch of our new six-year business plan, named Track22 because I believe that we are on track to a very exciting and successful future, scopes our future investments and development strategy up until 2022. This will see us launch 15 all-new cars or derivatives within our existing Sports Series, Super Series and Ultimate Series families. We will also develop an all-new engine architecture that will debut towards the end of the business plan period.'

SEEN: Acura NSX GT3

A GT3 version of the new Acura NSX supercar has been unveiled ahead of a full works race campaign in North America next year. The NSX could see action in either Pirelli World Challenge or the GTD class of the IMSA SportsCar Championship, or perhaps both. The Acura NSX racecar has been jointly developed by Honda R&D in Japan and the Italian JAS organisation, which is well-known for campaigning Hondas in the World Touring Car Championship. JAS built the first of the NSX GT3s, and also ran the car at its debut test in Italy.

The Acura NSX GT3 racecar features custom bodywork and aero components, including a large deck wing spoiler and underbody. It will be powered by a 3.5-litre, 75-degree, twin turbocharged DOHC V6 engine using the same design specifications as the engine in the production 2017 Acura NSX, including the block, heads, valve-train, crankshaft, pistons and dry sump lubrication system. This engine will be mated to a 6-speed, sequential-shift racing gearbox, delivering power to the rear wheels.

The second-generation NSX road car has been developed in the USA and will be built at Acura's Ohio production facility. It is a four-wheel-drive hybrid, but GT3 regulations prohibit the car's hybrid system, while it must also be raced in two-wheel-drive configuration.

Ford to enter World Rallycross this season with Focus RS

XPB

Ken Block's Hoonigan organisation will spearhead Ford's rallycross assault

Ford Performance has confirmed that it will be entering the World Rallycross Championship this year in a tie-up with Ken Block's Hoonigan Racing Division organisation.

The works-backed team will use the blue oval's new Focus RS as the base for its rallycross car and Ford has said that the campaign is aimed at publicising its RS brand.

Dave Pericak, global director, Ford Performance, said: 'RS is a worldwide brand with a rich heritage that motorsports enthusiasts know and love. Our RS badge has a natural connection to racing, and we have a passionate, dedicated team on the project. We're excited to honour the history of Rallye Sport by pushing every aspect of performance and design to the limit.'

The Focus RS build project is a collaboration between Ford Performance, Block's Hoonigan Racing and M-Sport. The car is to feature all-wheel-drive, a new EcoBoost engine producing 600bhp, and a 0-60mph launch time of less than two seconds.

Mark Rushbrook, motorsports engineering manager, at Ford Performance, said: 'We have dedicated the same level of cutting-edge tools, technical resources and engineering know-how from our Le Mans GT and NASCAR programmes, and working with M-Sport brings renowned expertise in rallycross and stage rally vehicle development.'

Ken Block said: 'To have official factory support for my race season in 2016 and beyond as I enter the FIA World Rallycross Championship full-time is absolutely incredible. It opens up a ton of powerful resources that myself and my team will be able to benefit from in terms of engineering prowess, research, development and racing experience from different fields.'

Malcolm Wilson, managing director at M-Sport, added: 'Working closely with our colleagues at Ford Performance and Hoonigan Racing Division, a huge amount of work has gone into this project. It's been an extremely exciting, rewarding venture – one we hope yields considerable success. I am confident we have a winning formula for the season ahead.'

Nissan and BMW evaluating Formula E race campaigns

It's been reported that Nissan and BMW are both looking at racing in the FIA Formula E Championship and could be on the grid, in commercial partnerships with existing teams, as early as season three.

Nissan, which pulled out of its disastrous LMP1 programme with the GT-R LM at the end of last year, has confirmed it is conducting a 'fact-finding' mission as part of its long-term motorsport strategy, while both it and BMW are said to be already in talks with existing FE operations.

One possible barrier to Nissan's involvement is the presence of sister Renault-Nissan Alliance company Renault, which is currently in the series as a partner to the e.dams operation. If Nissan was to join FE it would be the championship's first Japanese manufacturer.

BMW has actually been involved with FE from the very start, supplying its i8 and i3 electric models as course cars, but it has previously said the mid-race car changes, which are currently a part of Formula E, have put it off racing in the championship. Now, however, FE has said that it aims to move to one car per driver by the time of its 2018/19 season.

If Nissan and BMW were to join the series it would mean nine of its 10 teams could boast links with a manufacturer of some kind. Currently, Renault has the highest profile involvement, while Jaguar will be joining FE in season three. Indian car maker Mahindra, Citroen luxury brand DS, EV-makers Venturi and NEXTEV are the other manufacturers. Audi is affiliated with Abt, while outgoing VW motorsport boss Jost Capito recently told *Racecar* that it is also considering an involvement.

Meanwhile, Formula E has now made it clear it will never be an open chassis formula, and the FIA has put out to tender a 'three- or four-year' supply deal for a new spec chassis. Dallara, in conjunction with Spark Racing Technologies, is the series' current chassis supplier, and is likely to apply for the new deal, too.

The FIA will make its decision on June 24 and has asked for at least one 'futuristic' bodywork design to be lodged, while there also needs to be a 40kg weight saving to accommodate a heavier battery. The full kit cost cap is €270,000 and the car needs to be homologated by June 2018.

Nissan and BMW are said to be considering joining Renault on the Formula E grid – pictured is Renault-supported e.dams car

Ford once again scoops top NASCAR business award

A Ford Sprint Cup car leads the pack at Las Vegas this year – last year the Blue Oval also led the way when it came to business-to-business deals within NASCAR

Ford has won the prestigious NASCAR Driving Business Award, becoming the first organisation to pick up the prize three times.

The Driving Business Award is awarded to the company that achieves the best results in the NASCAR Fuel for Business (NFFB) Council – an organisation that brings together an exclusive group of nearly 60 Official NASCAR Partners. Within the Council, members bring key personnel from across their organisation to construct customised deals that help address specific business needs.

Ford has been competing in NASCAR since 1949 and has been a member of the NFFB Council since 2007.

Highlights from Ford's success in generating business in 2015 include: selling more than 3500 vehicles through its Partner Recognition Programme; co-marketing programmes with MillerCoors, Goodyear and SiriusXM which resulted in nearly 900 vehicles sold; and executing multiple deals that eclipsed $5m in value. Ford also says that more than two-thirds of Council members participated in business-to-business deals with it throughout 2015.

Tim Duerr, Ford Performance motorsports marketing manager, said: 'As a proud member of the Council, winning the Driving Business Award for the third time is proof, yet again, of how effective the platform is at generating a positive return on investment for partners … this tool maximizes our B2B strategy in motorsports.'

Steve Phelps, NASCAR executive vice president and chief marketing officer, said: 'Committed to winning both on and off the track, Ford's ability to execute business-to-business deals delivered results worthy of being a three-time recipient of the award.'

INTERVIEW – Pascal Couasnon

Compound interest

Michelin may well have missed out on the F1 tyre deal but LMP, FE and WRC are bringing their own rich rewards, says its motorsport director

By MIKE BRESLIN

'We use motorsport as a lab. For me it's a wonderful accelerator of innovation'

When Michelin's motorsport director Pascal Couasnon walks the short way from his office in Clermont Ferrand to the firm's headquarters to ask his boss for an increase in budget he knows the question that will be fired back at him: 'How will this help tyres on the street?' It is this question that encapsulates the French firm's attitude to motorsport, and also explains why, while it was disappointed not to clinch an F1 tyre supply deal last year, it is more than happy with its major presences in World Endurance (WEC) Word Rally (WRC) and Formula E.

It also shows why Couasnon is the right man for the job, which he has held for the past four years, for during 29 years at Michelin he has worked in R&D, sales and marketing and communications – all this on the back of a degree in physics and chemistry – and that's a background that fits the firm's attitude to the sport perfectly. 'The philosophy at Michelin really is to use motorsport as a lab,' he says. 'For me that's the wonderful accelerator of innovation. It is also a great amplifier of communications, and both are important.'

It's surely that second point, the PR value, that lured Michelin into its failed attempt to take the Formula 1 tyre deal from Pirelli last year, but just how much did that hurt? 'We were not happy [not to clinch the deal], but we are realistic, and most importantly we want to be true to our values,' Couasnon says. 'Coming back to Formula 1 was important to us, but even more important was to be able to bring something different. We believe today that the drivers cannot drive to their own limits, and also the tyre is not really shown as the very technical object that it is. And bringing new sizes [it was pushing for 18in wheels with low profile rubber], and a different philosophy, was what Michelin was bringing to the table. But at the end of the day the people managing the sport said it was to go another way; and we respect that.'

LMP1 challenge

Part of the reason why Pirelli might have been chosen over Michelin was that the former was the incumbent manufacturer, while Michelin had been out of F1 for almost 10 years. But it was through its involvement in other categories, LMP1 in particular, that it argued its case, says Couasnon: 'When we visited the F1 teams last year, showing why we wanted to go 18in, they were saying: "You've been out of Formula 1 for a little bit of time now, so are you capable of making the tyre?" We were expecting that question, so we came with data from LMP1, because I can tell you that today the challenge with the tyre is more difficult with LMP1 than it is with Formula 1.'

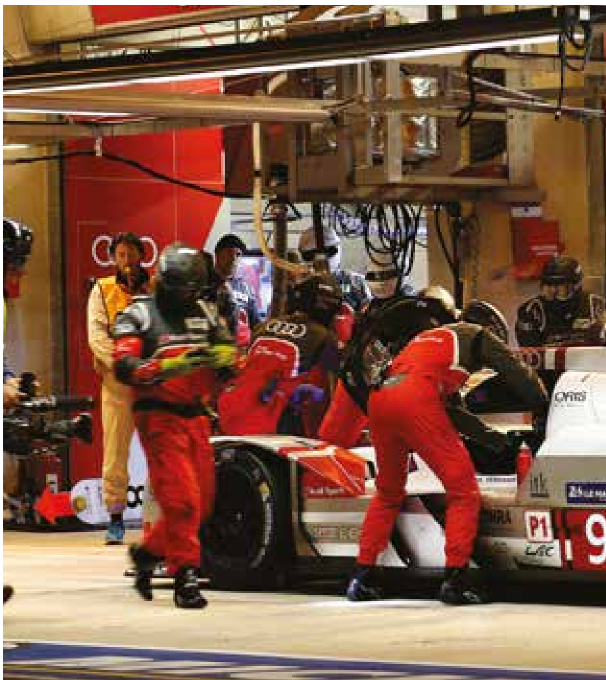
And that LMP1 challenge is one he clearly relishes: 'We are pretty proud of what has been done over the last few years in LMP1; with the tremendous power that you have to handle with the hybrid, with the rules which means you cannot change tyres and refuel the car at the same time; and on top of that a while ago the ACO were asking us to go two inches narrower with the tyres, to use less materials for the same performance, or even more performance. But that's the kind of challenge that we love, because that's really pushing us to extend to the limit. When you think about it; [LMP1 is about] stable performance; longevity, less materials; that is something that is really helping for the [road] mobility of tomorrow.'

For this Couasnon gives the ACO some credit: 'What's very interesting with Le Mans and endurance racing, not just LMP but GT racing also, is that the ACO has been very clever, in giving some rules which are pushing us to make progress in the direction that makes sense for the everyday tyre. That is perfect for us,' he says.

Formula E success

Meanwhile, Formula E, for which Michelin is the sole supplier, has also been a big success for the company, both in terms of exposure and – crucially – development for the road. 'The various studies we have done shows that Formula E is already on the radar, so that's quite an achievement, I would say, for the communications part. In terms of technology, it has been also very interesting. First of all, we were passionate about the idea of bringing an 18in tyre to the open wheel car. Formula 1 was the goal, we have not been able to fully convince everybody, or at least some of the decision makers, but we have been able to do it with Formula E. In terms of style, it's pretty nice.

'But also we are able to learn something based on a tyre that is much closer to what you see on the street. In



Couasnon believes that making tyres for LMP1 is a bigger challenge than producing the race rubber for Formula 1

Formula E what is great is that the tyre, which is obviously very fast, is also very good with [decreasing] the energy consumption [of the car]. And that is something that's being asked for by the OE manufacturers more and more,' Couasnon says.

The FE tyre is also for use in both wet and dry conditions, which again suits Michelin's philosophy – indeed Couasnon tells us much of the technology in its new Pilot Sport 4 road tyre comes from Formula E, including its tread.

Another category in which Michelin has thrived is WRC, which like the WEC is also an open formula for tyres. This is, says Couasnon, the company's preferred way of competing, and he would certainly welcome a tyre war in F1. 'That is something that we enjoy. We would love to do that. People say, "Well it's going to cost money". And I tend to not fully agree with that. Because, yes there will be some testing, but you can limit the cost. WRC is open; WEC is open, and you can limit cost by having a limit on testing and so on and so forth; or on the number of specs that you can change for the races,' he says.

Risky business

Even if Michelin were to return to F1 – and at present it's still keen to take Pirelli's place when the latter's contract is up in 2020 – there is a rather large downside to an involvement in such a high profile sport, as it found to its cost at the US Grand Prix at Indianapolis in 2005, when it pulled all the cars running on its rubber from the race due to safety concerns, leaving just six cars – and a number of empty beer cans from disgruntled punters – on the track. But Couasnon has an interesting take on that. 'Everything we were hearing, especially from the tyre dealers, but also from the consumers – not necessarily from the fan of motorsport – they said: if Michelin was able to take such a tough decision, not even thinking about the short term image, but thinking about what was going on on the spot, then it gives me a lot of trust in what they are doing.'

As for the risk of PR flak in general – after all, when an F1 tyre fails it's often big news – Couasnon says: 'Formula 1 is very visible; so obviously there is a risk, but Michelin is a leader, and you are a leader by also taking risks. If you don't take risks you don't move. By working at the high level, that's where you are pushed.' But all that will mean nothing if F1 does not allow its tyres to be more road relevant, you sense.

XPB

RACE MOVES

XPB

Alex Hitzinger (see page 16) has left Porsche, where he had been technical director on its LMP1 programme for the last four years. He is now to take on a new challenge outside of motorsport. At the time of writing there was no word on who would replace him at Porsche.

Alan Henry, one of the doyens of Formula 1 journalism, has died. Henry covered his first grand prix at Silverstone in 1973, and went on to report on close to 650 F1 races in all. Among many tributes was one from **Ron Dennis**, which said: 'As a journalist he was knowledgeable, accurate, intrepid yet fair-minded, and as a man he was warm, kind loyal and always funny'.

The Mercedes Formula 1 team has swapped mechanics between the **Lewis Hamilton** and **Nico Rosberg** cars, with some members from Rosberg's 2015 crew moving on to Hamilton's car for 2016 and vice versa. There are five crew changes on each car for this season, which the team says is partially made up of swaps, and partly new personnel coming in as the result of normal staff turnover.

Robey Clark is the new SCCA (Sports Car Club of America) Enterprises president and CEO, replacing **Erik Skirmants**, who announced his resignation in February. SCCA Enterprises is the racecar construction arm of the SCCA, and is responsible for making the Spec Racer Ford, Enterprise Sports Racer, and the Formula Enterprises racecars. Since the debut of the very first Spec Racer in 1984, over 940 racecars have been built and delivered by the company.

Frank Christian Jr is now the chief executive officer at NOLA Motorsports Park, the New Orleans-based race track and events facility. Christian has more than 20 years of experience in the catering and special event industries. Prior to joining NOLA Motorsports Park, he spent the majority of his career at Hospitality Events in San Diego.

NASCAR has announced the nominees for its 2017 Hall of Fame Class, and as always the technical and business side of the sport is well represented. Among those listed are team owners (past and present) **Richard Childress, Rick Hendrick, Jack Roush, Raymond Parks**; crew chief **Ray Evernham**, former crew chief **Harry Hyde**, and engine builder, crew chief and car owner **Ray Fox**; engine builder **Waddell Wilson**, and engine builder and car owner **Robert Yates**.

NASCAR has also announced the nominees for its Landmark Award, which is for 'Outstanding Contributions to NASCAR'. These include: **H Clay Earles**, founder of Martinsville Speedway; **Raymond Parks**, NASCAR's first champion car owner; **Ralph Seagraves**, who formed the ground-breaking Winston-NASCAR partnership as an executive at RJ Reynolds Tobacco, and broadcaster the late Ken Squier

Graham Macbeth, a former motoring journalist who was known in the sport for his time at the British Automobile Racing Club as press officer, and then general secretary and competitions manager in the '50s and '60s, has died at the age of 88. Between 1967 and 1979 he was also press officer at Brands Hatch.

Long-time motorsport executive **Dan Davis** is to join forces with two-time Indianapolis winner **Arie Luyendyk** and fellow former IndyCar driver **Max Papis** to form the stewards' panel for this year's IndyCar Series. They will report to Jay Frye, IndyCar's president of competition and operations. Davis has 40 years of experience in the auto industry with General Motors and Ford. He spent 14 years as the latter's director of Ford Racing Technology.

Mike Castro, the jack-man on the **Kevin Harvick**-driven Stewart-Haas Racing Chevrolet in the NASCAR Sprint Cup, returned to action at the Phoenix round of the series after suffering a shoulder injury back in November of last year.

Wolff ends connection with Williams with share sell-off

Toto Wolff has finally cut all his financial ties with Williams by selling the last five per cent of his shares in the British-based Formula 1 team.

The current Mercedes motorsport boss first invested in Williams Grand Prix Holdings back in 2009, and was said to be instrumental in helping the team to float on the Frankfurt Stock Exchange in 2011.

However, when Wolff joined Mercedes in 2013 it was on condition that he sold the shares he held in Williams, which then accounted for 15 per cent of the company.

Five per cent of his shares were sold to US healthcare entrepreneur Brad Hollinger in 2014, with a further five per cent going the same way last year. Now the remaining five per cent of the shares have also been sold in to the American.

Wolff said of the sale: 'I am surprised how emotional I am about this day, to be cutting my final business ties to Sir Frank [Williams] and to the team at Williams. Having entered the team from a pure investment perspective, I soon found myself in a much more active role, helping to restructure this great independent Formula 1 team.

'I am proud to have joined the sport with a team of true passionate racers, where we had to make spot-on decisions for the future of the business and its employees. I learned some lessons the hard way, but they were all valuable for understanding the industry,' Wolff added.

Wolff also said that Hollinger, who now owns 15 per cent of Williams Grand Prix Holdings, was the right man to take on the shares: 'The plan to sell my stake was a long-term one agreed with Daimler in 2013, but it was always important to find the right investor, who was doing it for the right reasons. Brad is that guy; he's a serious businessman with the right long-term perspective about Williams and Formula 1, and a true passion for racing.'

Frank Williams said: 'In Brad Hollinger, Toto has sold his full shareholding to a highly successful businessman with an immense passion for Formula 1 and our team – he is a great asset.'


XPB

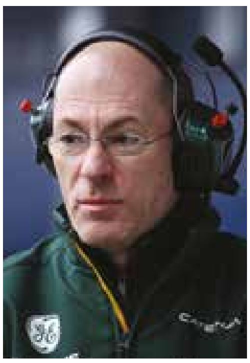
Wolff has now sold all of his Williams shares

Smith jumps ship at Sauber

Sauber technical director Mark Smith left his post at the Swiss team just days before the F1 season opener in Melbourne.

Smith, who only joined the team in July of last year, is said to have left for personal reasons. Sauber said of his decision: 'The technical director of the Sauber F1 Team, Mark Smith, has decided to go back to the UK for family reasons. He has already left the company. We would like to thank Mark for his efforts and we wish him all the best for his future.'

Before joining Sauber Smith was at Caterham, where he was also technical director, while he has also worked at Lotus, Force India, Red Bull and Jordan.


XPB

Mark Smith, shown here during his time at Caterham, has now stepped down from the technical director role at the Sauber Formula 1 team

Smith's departure came on the back of some high profile money problems for Sauber, which admitted that it had been unable to pay some of its staff the wages owed to them in February. This was due to the late arrival of some sponsorship payments, the team said at the time.

Sauber was one of three teams that had asked Formula 1 boss Bernie Ecclestone for an advance on their championship payments last year.

RACE MOVES – continued

Yasuhisa Arai has now left his role as motorsport boss for Honda's Formula 1 programme. **Yusuke Hasegawa** has replaced Arai as head of development, manufacturing and management at the F1 operation, while Arai has now moved into the role of senior managing officer of Honda R&D. Honda had a torrid time during its return to F1 last year, the sole user of its power unit, McLaren, finishing a lowly ninth in the constructors' standings.

Bill Pappas is now vice president of competition, race engineering, at IndyCar. He replaces **Will Phillips**, who left the series in March. Pappas has more than 30 years' experience in motorsport, and has worked with some of the most respected teams in the IndyCar paddock.

NASCAR has reinstated **Frank W Earnhardt**, a former crew member in the NASCAR Xfinity Series, upon his successful completion of its Road to Recovery Program. He was suspended from all NASCAR competition in May of last year, having broken NASCAR's strict substance abuse policy.

The pit crew for **Adrien Tambay** at DTM outfit Audi Sport Team Abt scooped the award for the best 2015 stop from series tyre supplier Hankook, which has been presenting its prize for the fastest pit stop since 2011.

Former Furniture Row Racing crew chief **Todd Berrier** made a one-off return to the NASCAR Sprint Cup outfit for the Phoenix round of the Series, where he stood in for suspended FRR crew chief **Cole Pearn**. Berrier is currently the director of fabrication at Joe Gibbs Racing, with which FRR has a technical alliance.

Les Needham has been presented with the Motor Sport Council of the MSA (Motor Sports Association) Award of Merit by **HRH Prince Michael of Kent**. Needham first became involved in motorsport back in 1937 and since then he has spent decades as an organiser and administrator, from club level right up to the British Grand Prix and the RAC Rally.

Former IndyCar team owner and driver **Sarah Fisher** will serve as a pace car driver for the series during the 2016 season. Fisher will share duties with three-time Indianapolis 500 winner Johnny Rutherford, who has been the series pace car driver since 1996, but has scaled down his schedule in recent seasons.

Well-known motorsport PR man and former British Rally Championship manager **Jon Horton** has died at the age of 68 after suffering a heart attack. Horton's motorsport career began back in 1972 at the Dunlop tyres rallying department and he went on to head up PR at the British Grand Prix and at Rally GB.

Andretti Smith, a crew member with NASCAR Sprint Cup outfit Wood Brothers Racing, was forced to miss the Phoenix round of the series after tearing biceps at the top of the shoulder and the elbow while handling a fuel can at the Las Vegas race. Amazingly, this was the first Sprint Cup race Smith had missed since joining Wood Brother back October 1990.

◆ 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**

Top of the BoPs

The topic of Balance of Performance once again raised its head at the Sebring 12 hours in March. Ferrari believes that it is unduly hampered by the IMSA system that has rendered its 488 GTB slower in a straight line than the old 458. Its representatives point towards the FIA BoP as justification – there the conditions are far more favourable. Predictably, Porsche is in favour of the IMSA BoP and is concerned that the FIA BoP is not as accurate.

Of course, this is all verbal jousting ahead of the Le Mans 24 hours in June, and this sort of thing will continue in racing until there is a time that there is no more balance of performance. When that will be I have no idea, because IMSA will use its system to also balance the DPI category, its own version of LMP2 – which is featured on page 85 of this edition.

I don't take to Twitter often but I did on the occasion of Ferrari's protestations and the response to my twittering was pretty instantaneous. What is BoP doing in a professional racing series, they said? The answer is pretty obvious; without it, a front engine car would not be able to race against a mid- or rear-engine car, a V6 would not be able to race against a V8 or a V12, and cars of different architecture, such as the BMW M6, would not be there at all. It goes back to the original argument; the balance of performance was designed to get different concepts into the same ballpark, and then allow them to race. Now teams demand that it is so accurate that it has almost become a performance development tool.

If the general public really don't like prototypes and cars they can't relate to, then where does that leave Formula 1 and IndyCar?

However, into the fray then steps Stefan Johansson, who asks why, if a manufacturer wants to compete at Le Mans, it doesn't just build a car to do so. He points towards Ford as a justification; it wants to celebrate the anniversary of its first Le Mans win in 1966 with a four-car effort this year. So, it built the new version of the Ford GT, and is developing the road car alongside the racecar. If BMW wants to race in the GTLM or GTE category, it should build a car that is suitable for the job. Get rid of prototypes, because no one relates to them anyway, and just have GT racing, he says.

However, there are a few things that I would take issue with regarding this argument. Firstly, the return on endurance racing is simply not there to justify such an investment for the majority of manufacturers. Sure, Ford can produce a limited number of cars and probably the project will be entirely justified as I am sure that sales will justify the expense, but BMW would have to design and produce thousands of cars to achieve the same goal. If it did follow Ford's route, and produce a limited edition, we are in danger of going straight back into the GT1 days of 1997 and 1998, where a limited number of production cars were required (that is, just one) to produce the racing car. In 2001 BMW itself produced a 4-litre V8 version of the M3 to satisfy the criteria, neatly finding its way around the regulations and competing against the Porsche that was produced in mass numbers.

Secondly, to get rid of prototype racing is not going to solve the problem. Fans turn out to watch some great racing, be it in prototype or GT, and at Sebring were treated to a fantastic show as the P2s and Daytona Prototypes fought for overall wins, while the GTE cars waged their own war. The balance of performance may have played its part in the outcome in both categories, but then so did the yellow flag procedure in the US, and the weather. BoP played just one part in deciding the result, and arguably was more valuable in bringing together different concepts to provide a race.

Getting rid of factory prototypes in LMP1 means to do away with the costly development programmes. But to say that the manufacturers are doing this for fun and burning cash for the sake of it is not correct. There is a return on investment; if there wasn't, none of them would have signed up to their programmes. Besides, if the general public really and truly do not like prototypes and cars that they cannot relate to, then just where does that leave Formula 1 and IndyCar?

The argument for balance of performance is, I am afraid, one born of necessity. To have cars of completely different concept racing together, to reduce the development costs (or at least, to withdraw the incentive for huge development programmes), and in IMSA's case, to create a suitable gap in performance between the GT Daytona cars (GT3) and the Prototype Challenge cars (PC) so that the GTLMs, and the manufacturers, have a safe place to race.

There are problems with the system, but there is nothing that is perfect in this world. Should someone come up with a better, cheaper and more reliable option, everyone would sit up and take notice. Until then, we just have to accept that BoP is part of today's racing scene.

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