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Renault RS18

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2020 vision

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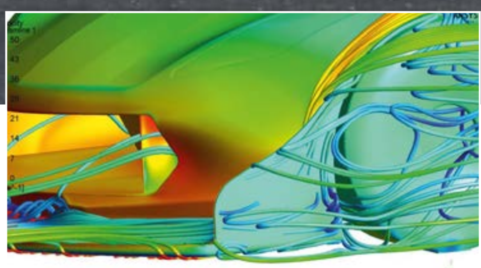

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Formula 1 returned to France, the birthplace of grand prix racing, for the first time in 10 years in June and to Paul Ricard for the first time in nearly three decades

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Ouest world

The good, the bad and the ugly from the 2020 top class prototype regulations

The next generation of Le Mans cars is something that is very close to my heart. Having raced there since 1983 and seen the successive generations of top class iterations, it seems that the all-out missiles that this century brought may have reached high tide. The fact that only Toyota (which had something to prove, after all these years as the bridesmaid) was left indicated that the cost had sobered even the wealthy manufacturers, although the fact that Audi and Porsche had nothing left to prove also no doubt played a part in their withdrawal.

The proposed top class for 2020-2024 (see page 80) tries to bring a closer connection to the look of the production car, to make the racecar similar to the road car. It's something for manufacturers to use when touting the marque.

Pretty quick

We did have that in 1995, when the production McLaren F1 that won Le Mans was practically indistinguishable visually from the road car; even the Mercedes CLK had visible relevance to the brand. This will either mean road cars are produced to morph into what we know is aerodynamically advantageous or, just maybe, make them look prettier; according to the ACO press release, 'aerodynamics cannot take precedence over aesthetics'.

But how is this going to be policed, and how relevant it is to the aesthetic tastes of car buyers is moot, after all, they seem more inclined to SUVs with a full *Mad Max* theme these days.

On the powerplant side we don't deviate too much from what we have at the moment, bumping max power to a possible 720bhp when the 520kW from the engine is coupled to the 200kW from the hybrid system, but demanding the power harvesting and release be from the front axle (so a 4WD layout) and that the single hybrid system be commercially available. As development continues on this there is hope prices will become viable.

Fixing a lap time close to 3m20s at Le Mans should bring the performance close to what we have at present at a proposed cost of 25 per cent of what is currently required for the premier class. Let us say it is feasible, barely, but one does have reservations about it happening, unless it's heavily policed. Meanwhile, the consumption limitations are expected to carry on with what has been a success, and should be trumpeted loud and wide, as this really is road relevance.

The time-line is to bring these online for the 2020-2024 period. How the transition will be handled without grand-fathering some of the existing cars is a bit of a mystery given the lead times, the September 2020 debut particularly short given the wide ranging changes due when the Sporting Commission rubber stamps the regulations come December this year.

I applaud the intention of matching OEM/privateers performance, but can tend to be a bit jaundiced in outlook. The rules so far have had bias built into them for decades towards OEMs and if we have strictly equivalent possibilities it would seem to take away the OEMs' main reason to want to race.

The Mercedes CLK of the 1990s sported plenty of brand styling cues and the new regs will also encourage road car-style Le Mans racers

Chassis design in LMP1 has actually been fairly stable for some years now. All the proposals since 2014 were pushed forwards due to the conflicting needs to alleviate chassis building costs when tied to the engine regulations that were proposed. They would have meant that there would be a new chassis every year in 2016, 2017 and 2018. That was not viable even for OEMs.

Safety drive

The needed safety changes for driver position and more head protection with a bigger green house has been apparent for some time, and will be implemented now, but the knock-on aero effects and space requirements for a real passenger place – and not the vestigial space usually filled with electronics now – will change the layout considerably, none of the current ones being remotely usable. How relevant it will be to a road car will depend on the tightness of the rules, but, once again, one does tend to be a bit dubious.

A fixed weight distribution is another example of the closing in of car design specs. So are fixed downforce and drag values, and we have seen the deleterious effects of the fixed stint length at Le Mans this year. The freedom of devising your own strategy and reaping the rewards cannot really be served by these limitations.

DRS sense

A single homologated bodykit imposes other restrictions, and will continue the tendency for teams to race in minimum downforce trim at all tracks to prepare for Le Mans, but the consideration of moveable aerodynamic devices could alleviate that, and introduce it to road cars with a vengeance. One has only been waiting for that for the last couple of decades.

The cryptic 'R&D split over five seasons' escapes me at the moment, let us see what the definitive rules bring here.

Meanwhile, EOT will be joined by BoP in the top class, another example of the homogenisation of racing.

But the really interesting bit is the lure of hydrogen power and fuel cells from 2024. This is a technology that had been pretty much in the background for some time, but finally it is making some progress and beginning to be more enticing in the route to zero-emission transport. I have always leaned towards it for use in goods transport and outside cities (which are ideal for electric-powered small runabouts) and this could be where we see some breakthroughs. After all, hydrogen is the single most common element in the universe, apart from human stupidity, and given we have a very big nuclear reactor close to us giving us power in all the spectrums, making the shift from sunlight to electricity to water to hydrogen and oxygen, or conversely hydrogen fuel cell to electricity, it seems to be the way to go. A few niggling problems having to handle it at 700bar (compressing hydrogen to this pressure is at 32 per cent of its cost) can be sorted out. If we look at petrol, which has quite a lot of handling problems itself, the years of use have tamed it to humdrum familiarity.

So, verdict? A curate's egg. Let's see where the final regs lead us; but endurance racing is done with its last cycle and needs to find a new goal.

How the transition will be handled without grand-fathering some of the existing racecars is a bit of a mystery to me, given the lead times

Who's the boss?

Watertight contracts mean it's not so easy for teams to dump drivers these days

WRC event-winning driver Kris Meeke made the news recently by being sacked from his works Citroen C3 seat following his major shunt in Portugal. Team principal Pierre Budar said Meeke's accidents meant he had decided to change the line-up on 'safety grounds and as a preventive measure'. He underlined that the driver was being dropped 'due to an excessively high number of crashes, some of which were particularly heavy and could have had serious consequences with regard to the crew's safety'.

The wording of the statement is interesting. I don't ever recall a driver being dropped before on safety grounds. Poor finishing record, failure to perform consistently and competitively, bad relationship with the team, wanting too much money – yes. Also, of course, there's lack of sponsorship versus another driver with more. But not safety. It can be argued in Meeke's case that his employer was acting upon a duty of care, so much a feature of creeping health and safety legislation these days. In addition, although not generally a factor in motorsport outside of rallying and sidecar bike racing, very much to consider is the risk to which the co-driver was equally being exposed.

Case notes

Now, I don't doubt that the safety issue was a genuine concern for Citroen, along with protection of its public image. However, the carefully-chosen emphasis of the statement, I suspect, was there to protect the corporation from possible legal action by Meeke. If he has a management company behind him, by this entity also, and maybe his personal sponsors as well. The driver was 'rested' temporarily by Citroen last year following an unproductive start to the season. Given the totting-up of crash damage since his reinstatement, which must total well into seven figures, and valuable points lost – let alone the pressures on the team in constantly rebuilding very heavily-damaged and expensive rally cars – it's possible that the team wanted to replace him anyway.

Unsurprisingly, I'm not privy to Meeke's contract with Citroen, but the nature of these documents involving top-line drivers tends towards complexities that a resourceful lawyer can manipulate in the client's favour. There has certainly been a lot of criticism following the decision – hence, probably in anticipation of this also, the safety matter on which Citroen has based its action, this being much more difficult to challenge.

Consider that Sebastian Vettel apparently threatened to sue Red Bull over the 'Multi-21' affair which erupted in the aftermath of the 2013 Malaysian Grand Prix. The team received a two-page letter from Vettel's lawyer after the race stating that they were in breach of his contract by giving him an 'unreasonable-instruction team order'. This order, as most will recall, was for Vettel to refrain from battling with his team-mate, Mark Webber, who was leading. 'Don't be silly, Seb!' was the memorable plea of team principal Chris Horner – a command that was promptly ignored.

XPB

Kris Meeke has a reputation for driving on the edge but the Citroen WRC team's patience finally ran out and it has sacked him on 'safety grounds'

Losing control

The point of the above is the question of 'who is the boss' in a motorsport team nowadays? Are contracts, especially in F1 and with the foremost drivers, such that the team management's ability to discipline or remove one is severely limited, even if the circumstances may warrant this? Are the superstars just too powerful? Think of Hamilton ignoring his Mercedes team in blatantly blocking team-mate and rival Nico Rosberg in attempting to win the championship at the deciding last race in Abu Dhabi, 2016. The frantic and points-losing scrapping between Force India's Sergio Perez and Esteban Ocon last year; currently, Max Verstappen's all or nothing (often nothing) approach to his racing. This has cost Red Bull dear. Verstappen may, at the time of writing, post Canadian GP, have redeemed himself somewhat. However, if I had been in Helmut Marko or Horner's position at Red Bull after Verstappen's early season antics, culminating in the Baku and Monaco GP humiliations, I would have wanted him to be sitting-out first practice at the next round. This is the only type of penalty that would really hurt, which is precisely why it can be effective. I recall the Toleman F1 team punishing Ayrton Senna early in his career for breaching his contract by negotiating with another team. The shock of him missing the next race altogether did the trick.

Max power

Unfortunately, apart from a storm of criticism in all aspects of the media from Max's fans (and the certain reduction in Red Bull energy drink sales in Holland) in reality the fallout from legal action on the driver's side would most likely be far too heavy a price to pay.

Further down the driver pecking order, however, the same organisation first demoted and then sacked Daniil Kvyat after the Russian lost his way. Indeed, there is a string of Red Bull supported drivers such as Sebastien Buemi and Jean-Eric Vergne who have gone a similar route, with Brendon Hartley currently under the cosh (for the second time). It seems that Red Bull's contracts are heavily one-sided regarding junior drivers. In truth, given the financial backing that the Austrian team has given them throughout their careers, this doesn't seem wholly unreasonable. No doubt a similar policy exists within other F1 teams engaged in bringing on young talent. In the case of the smaller outfits and their rocky financial positions, it is of course highly improbable for them to penalise a driver for misbehaviour or lack of results if the sponsorship he or she brings is keeping the whole shooting-match going. Williams must have this firmly in mind right now …

So I suppose that we have to accept that the tail wags the dog where team management is concerned at the top and bottom F1 teams. The opposite swing of the pendulum from when Enzo Ferrari in the 1950s would frequently decide, almost race-by-race, who would be favoured in being given a seat in one of his scarlet cars.

It is highly improbable a team will penalise a driver for lack of results if the sponsorship he or she brings is keeping the whole shooting-match going

Going fourth

Behind the top three teams the 'Class B' battle in Formula 1 this season has been furious but Renault now appears to be edging ahead. *Racecar* talked to its tech bosses to uncover the bold new design concept that's making the RS18 the best of the rest

By SAM COLLINS

It is unusual for an F1 team to embark on a major change of concept just one year into a set of rules, but this is exactly what Renault has done with its 2018 RS18 design. It's a bold move for a team which in 2015 (as Lotus) was on the verge of financial collapse, but the takeover by Renault and an injection of cash has seen the Enstone team get steadily more competitive, and at the same time increase its headcount while improving its facilities.

'At the end of 2015 we had about 450 people working at Enstone but since then we have been recruiting and building up the factory,' Nick Chester, Renault's chassis technical director says. 'There have been a lot of changes to infrastructure, we have got a much bigger drawing office. We have also updated the wind tunnel, we have a new chassis machining area with Breton machines, a dedicated paint shop now, too, so there is a lot of stuff we didn't have two years ago. The expansion of the floor area for sub assembly and the drawing office is going to make a big difference as this season goes on.'

While, as mentioned, the staffing level has also increased substantially, it's with an eye on the future and the likelihood of budget and staffing limitations being introduced. 'We are now at about 650 people, and we will likely get to 700 to the end of year and that should be enough to consolidate our best of the rest

‘I suppose I can justify the change in concept by saying that the car is now a lot quicker than it was last year’

The RS18 features a change in the cooling layout, tighter packaging throughout, and a switch from a titanium to a composite gearbox. At the time of writing Renault was fourth in the championship

position,’ chief technical officer Bob Bell says. ‘We have maybe about 125 on the aero side. We have half an eye on the future restrictions. If we believe the numbers that are being bandied around in terms of budget caps, then I think the top teams will have to come down, the smaller teams, if they can afford it, will come up.’

The RS18 is the first real evidence of what the upgraded Renault team can do, featuring as it does the team’s change of concept. ‘I suppose I can justify the change by saying that the car is a lot quicker than it was last year,’ Bell says. ‘We looked hard at what we had done in 2016 and the early part of 2017, we looked hard at what other people were doing, and we had a lot of new people on board with new ideas. As a design organisation I think we have matured as well. It was not exactly a light-bulb moment but I think many things combined which meant that we felt that we needed to do something reasonably progressive to move on. As a result of that the cooling arrangement is quite different now. We have also worked much harder on packaging, getting all the exhausts and ancillaries as compact as possible to get more space for aerodynamic development. We have also switched to a composite gearbox, too. But the fundamental aerodynamic architecture of the 2018 car is still a development of last year’s racecar, it is just a lot more refined.’

TECH SPEC

Renault RS18

Chassis: Moulded carbon fibre and aluminium honeycomb composite monocoque.

Power unit: Renault RE18 1.6-litre turbocharged V6 with direct injection. Energy recovery system with MGU-H and MGU-K in a compounded layout.

Transmission: Carbon fibre casing; 8-speed semi-automatic with reverse gear; quickshift system.

Suspension: Double wishbone with pushrod actuated torsion bars at front; pullrod at the rear; aluminium uprights.

Fuel cell: Kevlar-reinforced rubber fuel cell by ATL.

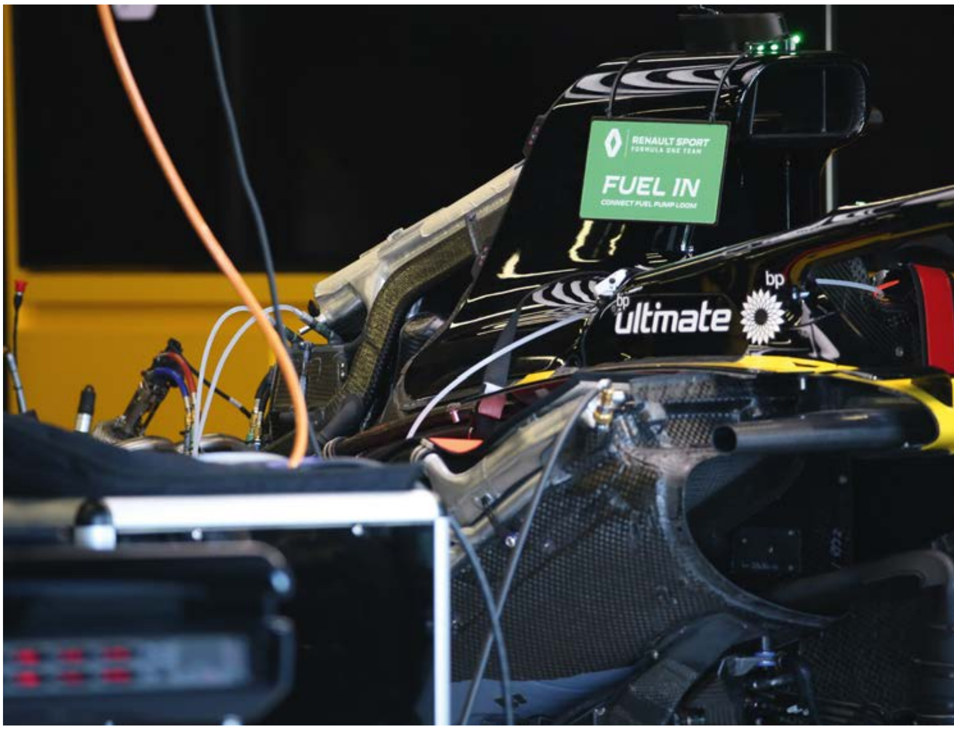
Electrical: MES-Microsoft standard electronic control unit.

Braking System: Carbon discs and pads; calipers by Brembo; master cylinders by AP Racing.

Wheels: OZ machined magnesium wheels.

Cockpit: Removable driver's seat made of anatomically formed carbon composite with 6-point harness seat belt. Steering wheel integrated gearchange paddles, clutch paddles, and rear wing adjuster.

Dimensions: Width, 2000mm; front track, 1600mm; rear track, 1550mm; length, 5480mm; height, 950mm.



Relocating the coolers to the centre of the car has helped to reduce the sidepod volume, which is all part of a concerted effort by the design team to force higher energy air to the rear of the car to work the diffuser harder

RS18 monocoque stripped down to its bare essentials. Weight reduction in the chassis was a major element of the car's design philosophy but Renault says this is still marginal and it has struggled to hit the weight limit

The RS18 is visually similar to the RS17, but there are many features that hint at those innovations under the skin. 'There is a lot that is different under the bodywork,' Chester says. 'We learnt a lot about the aerodynamics following the big regulation change last year, and we found that with a lot of the development areas we did not need to change the concept fundamentally, we just needed to carry on the way we were developing through 2017. But there are some things we have changed dramatically. The major things are the power unit installation, how we package things, the cooling package and how we package things around the engine, areas where we knew we could make some gains and shrink the car. We have also done some work on suspension geometries and suspension internals so we can work on our ride and ride height windows.'

Gram prix

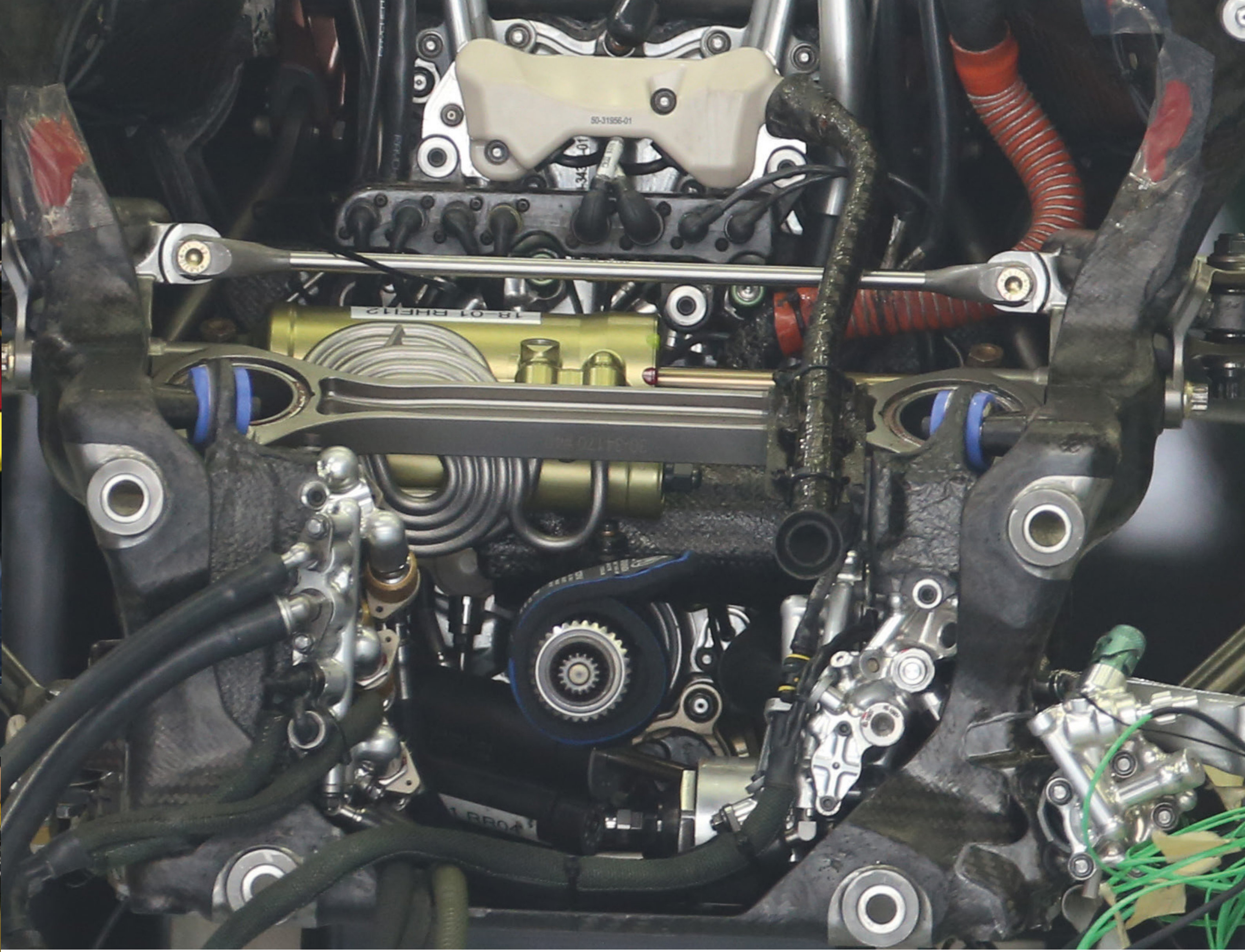
Weight was another major focus of the project, not least because one of Renault's drivers, Nico Hulkenberg, is the heaviest in the field at 70kg. 'We wanted to push a few weight savings as it was so tough with Halo, so we worked a lot with construction and materials for that,' Chester says. 'We knew a bit more about what we needed to do to fit Nico in the car, as he is pretty big, so we found a better way to package him in the car. It was an evolution, though I wouldn't say it was miles different to the 2017 chassis approach.'

A few years ago Force India had a heavy driver and it homologated a lightweight version of its monocoque for that driver, but Renault decided not to go to such extremes. 'To do two different tubs, one to suit the smaller driver, would be a massive overhead and would be a pretty marginal gain,' Chester says.

Load data

When the 2017 car was designed, nobody knew for certain what the requirements of the chassis would be as the tyres were an unknown, having never been fitted to a truly representative car. As such the monocoque was designed with some margin to allow for higher than expected loads, but for 2018 with a year's running under the new rules the engineers had much better data. 'We have done quite a good job on getting the weight out of the chassis, we have used some different construction techniques which have helped a lot,' Bell says. 'That is as much a result of us having a much stronger design team this time round as it is the improved data. They can work to try to get weight out of the laminate. But we do have more data and that allows us to be a bit more accurate in terms of load prediction, so it's a combination of things.'

The other major factor in the weight of the car is the introduction of the Halo, something



Rear torsion bars and other inboard suspension parts are located within the bellhousing; note transverse mounted dampers. Suspension system is smaller and lighter than in 2017

which was not fully accommodated for in an increase in the minimum weight of the cars. 'It was hard work getting the Halo so late in 2017, we had to change the chassis geometry and construction so there was quite a lot of work to do here,' Chester says. 'We did some sample tests and test pieces so that we knew we had a concept that was going to work and that meant we did not have to throw too much weight at it. The weight limit is still tough to meet, the Halo plus the chassis mods is perhaps 12 to 13kg.'

Even as the cars arrived for the Spanish and Monaco races in May the Renault team was still struggling with the weight of the RS18. 'We have had a weight reduction programme but things are still marginal, we can just about get the cars to the weight limit but it's been a push to do that, particularly for Nico who is a bit heavier than Carlos [Sainz]. I think we have lost about 2 to 3kg since the roll out, however,' Bell says.

Gear change

The attempts to lose weight and the increased capability at the factory were the major driving forces behind a switch to an all new transmission with composite casing, replacing the cast titanium gearboxes used by the team for many years. 'It was a combination of wanting to take weight out and lowering the centre of gravity,' Bell says. 'Actually, for us it was probably an easier gearbox case to manufacture than the cast titanium box we used before. It helped us by shortening the lead time too, so it was not just about the weight reduction, but about having a unit which was easier and faster to produce. You want to shed weight from all extremities of the car to give you more flexibility in terms of where you put the centre of gravity.'

Cool 'box

One thing which was less of an issue with the titanium gearbox was thermal management, with the Renault turbocharger mounted partially in the bellhousing the structure has to deal with some extremely high temperatures. 'Heat is a real issue, you have to be very careful and we are always squeezing this stuff closer and closer together to free up volume,' Bell says. 'We have to ensure that we don't cook the carbon, and that is one of the big disadvantages of having a composite 'box, that you have to be more careful in terms of the thermal load on the case. But on this car the thermal management under the bodywork is pretty good.'

Cooling was another area where the Renault team have made a major change for 2018, relocating a significant amount of the cooling package to the centre of the racecar, more than any other team on the F1 grid. Rather than feeding these coolers just from small ears on the roll hoop the RS18 has a very large duct situated directly behind the drivers head.

'I think one of the driving forces with the cars at the moment is to get volume out of the sidepods, generally speaking to get higher energy air to the back of the car to work the diffuser,' Bell says. 'So anything we can do to take radiator area out of the sidepods adds to that. When you do the sums, taking coolers out of the sidepod and putting them up high raises

'It was hard work getting the Halo so late in 2017, we had to change the chassis geometry and construction, so there was quite a lot of work to do'

Smoke and mirrors

The Renault approach to fitting mirrors to the Halo is thought to be wholly legal and it might well be raced later in the season

Ferrari's Halo mirrors were banned as the FIA deemed the upper element was primarily there for aerodynamic purposes

During the Spanish Grand Prix Ferrari introduced a new wing mirror layout with the unit mounted on a stalk extending from the Halo, something which the FIA has specifically said is allowed. The Ferrari solution was subsequently outlawed, though, as its upper 'support' was deemed to be purely for aerodynamic purposes. However, Renault also experimented with its own solution which is thought to be within the rules, as the support structure clearly has the primary function of actually being a support structure. It was only briefly fitted to the car in Barcelona in mock up form, but it's thought it is still likely to appear on the RS18 at some point during the season.

Renault has relocated a significant amount of the cooling package to the centre of the car, more than any other team on the F1 grid

A large portion of the cooling package is in the centre of the racecar but the introduction of the Halo was an unexpected complication as an additional cooling duct had by then been mounted behind the driver's head

the centre of gravity, but the gain is that you get better aerodynamic performance.'

Placing a major cooling inlet in such an unconventional location seemed a logical approach to the Renault team, but the introduction of Halo was an unexpected development, according to Bell. 'You have higher energy air up there as it has not had to pass through the front wing and front suspension so you can run a smaller cooler,' he says. 'Complicating it slightly is the driver's head is in front of it, and it's downstream of the Halo. Actually, the Halo was introduced after we had committed to doing it, and there was a little bit of scariness there, but the aero guys at Enstone did a great job of designing it and making it work, and it does work well now.'

Suspension tweaks

Another area of the RS18 which looks similar, at least externally, to the RS17 is the suspension. The car features pushrod actuated torsion bars at the front and pullrod actuated bars at the rear. The front bars are located in the front of the monocoque with the leading edge above, and slightly rearward of the front bulkhead, while the rear bars and other inboard suspension parts are entirely located in the bellhousing. 'We wanted to get a bit more corner entry stability into the car, which is something most drivers want anyway and we did make some good aero improvements,' Chester says. 'The ride quality last year was not as good as we would have liked so the drivers struggled a bit with kerbs and kerb riding so that is an area we have worked on.'

While neither Chester or Bell is willing to discuss the inboard component layout in detail, they are willing to discuss the general operation of the system. 'Because of the current regulations the functionality of the suspension is not actually an awful lot different to the way it used to be when we were constrained to simple springs and dampers,' Bell says. 'The bits today all serve the same basic functions but in the constant effort to take weight out and to reduce packaging volume we have squeezed everything down into smaller units. We have made them remote in some cases, and some people use air springs remotely, the principle is still the same, it just allows you to compress it all and package it a bit better.'

Aero platform

For some years in Formula 1 the suspension systems of the racecars were designed primarily to provide a good aerodynamic platform. Interconnected suspension and collapsible rear elements were all part of that, though almost all of these solutions have now been outlawed.

'We did have quite clever systems when we had the interconnected front and rear, but now we are not allowed to do that any more,' Bell says. 'The FIA would be very upset if they thought we were designing the suspension purely for aerodynamic benefit, which is why tuned mass dampers and things were banned. They really don't like us designing suspension things for aerodynamic advantage. Clearly though, anything that we can do that stabilises the car platform, the sprung mass so it is moving around less and what motion there is is more controlled, then we can expect better aerodynamic performance. A lot of thought goes into conceiving suspension set-ups and layouts that do help with that, and all that is completely legitimate.'

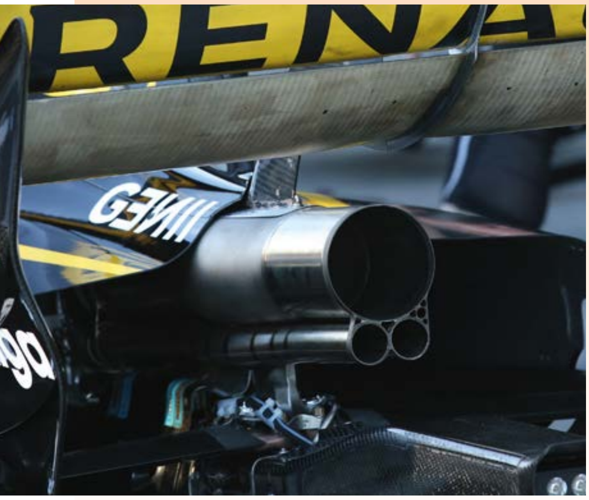
Flexible design

Tyre management is another major area where the suspension design can make a difference and it too was an area of focus for the Renault engineers. 'It does catch people

Pipe line

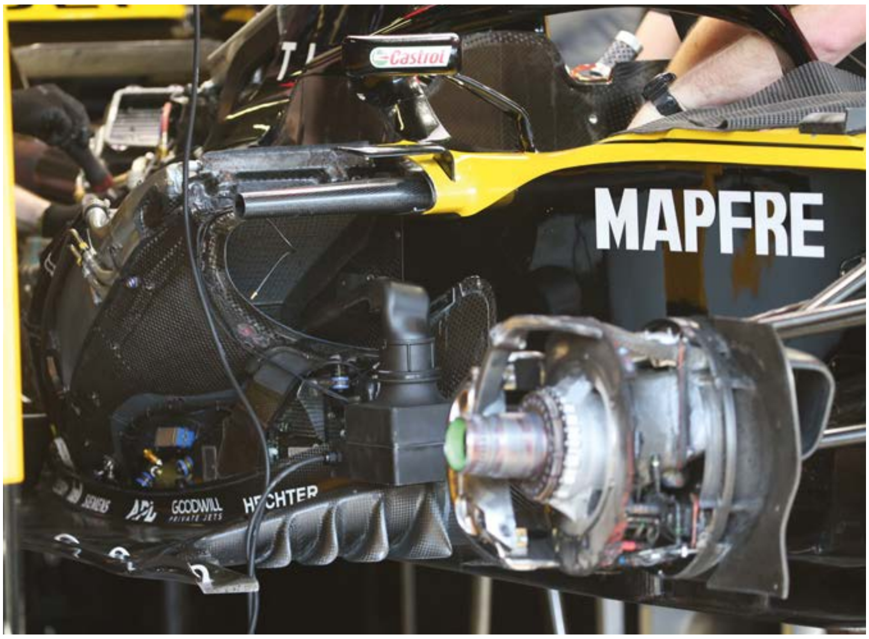
From the moment the RS18 rolled out in winter testing at Barcelona the relationship between its exhaust tail pipe and the underside of the rear wing raised eyebrows, and it is clear that the exhaust plume does have an influence on the wing because there is a ceramic thermal barrier applied to the underside of the main plane.

'To prevent blown diffusers the rules [say] the exhaust has to sit inside a regulatory box, and our exhaust is entirely within those limits, so it's completely legal,' Bell says. 'It is on the upper edge of the box but fully within it. Other people chose to put it lower, they didn't do that because they wanted to be even more honest, and even more in the spirit of the regulations, they chose it because they did the sums and it came out that it would be better lower. Our answer came out differently. Anything you can do to the under-surface of the wing to increase momentum will add downforce. This solution may also have the secondary effect of helping energise the flows over the lower surface of the wing which normally have to work a little harder to stay attached. Those two effects conspire to give you a bit more downforce, but it is not for free, the benefit is small, and you have to raise the exhaust and angle it upwards which means you lose a little bit of thrust, it's a bit heavier and the centre of gravity is a bit higher.'



Renault admits that the exhaust plume influences the rear wing but it says the benefit is small and it's within the rules

'It is a good all-round racecar, the integration between power unit and chassis is very good, as you might expect with us being a works team'



Sidepods with the bodywork removed. Renault has adopted the short sidepod style pioneered by Ferrari rather than opting for the lighter conventional layout. Brake calipers are by Brembo, master cylinders by AP Racing

out most years when the tyres change,' Bell says. 'We do the best we can to give the suspension characteristics which allow us to deal with differences in the tyres, but during the development you never really know until you get the real tyres. Hopefully you can design enough variability into the suspension set-up to deal with those issues that arise, so the design has to accommodate a degree of flexibility.'

The tyres also have a key impact on the aerodynamics of the racecars, too, and this has been an area of major effort for every team, including Renault. 'There are things like sidewall shape which are critical and that is very difficult to get right,' Bell says. 'Even if Pirelli were a lot more generous with the information that they give the teams it would still be a tricky thing to get right under all conditions.

The wind tunnel model is never as close as you would like and that is why you can end up with correlation issues,' Bell adds. 'Once we get the real tyres and start running them we can measure these things and try to improve the correlation with the tunnel, but it's an iterative process, we have to keep looping between tunnel and track. The major reason you have so many sensor arrays is to try and understand the aerodynamic flow structures and how they are influenced by the tyres. At the moment we get pretty good correlation between wind tunnel, CFD and the track. That is not our problem, I think our problem is just knowing what we need to do to change the car, rather than any mismatch between circuit and tunnel.'

Good package

Overall the Renault engineers seem fairly happy with the performance of the RS18, at the time of writing it's nosing ahead in a tight battle for fourth position in the constructors championship. The overall design appears to have met the objectives set out for it at the start of the project. 'It is a good all-round racecar, the integration between the power unit and the chassis is very good as you might expect, us being a works team,' Bell says. 'And as we have been able to squeeze that we have more scope for aerodynamic development. The aero team have more to play with. The cooling layout is a really good compromise, the suspension is smaller and lighter. Overall I think it has many medium sized strengths, rather than one overwhelming one, and that makes it a very good baseline to build on.'

Balance window

However, Bell also points to some areas where the car needs to be improved. 'It is basically about achieving a good balance with the racecar, between the high and the low speed corners and then during the corner between the entry, mid corner and the exit,' he says. 'If you imagine that as a two dimensional surface our area is too big, we need to close it down and reduce that balance window. I think that is the thing which is holding us back.

'The difficulty of achieving a good balance over a wide spectrum makes us more prone to other things like wind conditions or following in the wake of another car,' Bell adds. 'If our car was more tolerant of those things it would be a bit better in all conditions. That is something we just have to keep chipping away at.'

But as a works team representing a major manufacturer Renault's goal has to be to get back to fighting for wins and then adding to its pair of world championships (2005 and 2006). There's a step to make before it's up with the top three teams, but development is ongoing with the RS18 and it's expected to become more competitive as the season goes on, so Renault's certainly on the right path.

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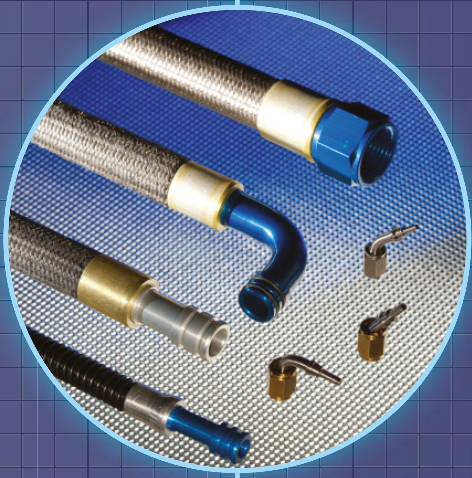

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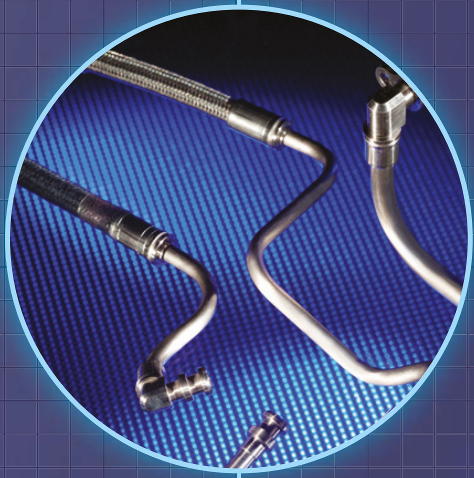

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Never too late

Faced with a very late switch to the much-maligned Honda power unit little was expected from Toro Rosso in 2018, yet its STR13 has shown flashes of real speed and the reputation of the RA618H PU has been enhanced as a result. Here's how both parties rose to the challenge

By SAM COLLINS

This year's Toro Rosso, the STR13, is propelled by the Honda power unit following the collapse of the Japanese manufacturer's relationship with McLaren

Toro Rosso directly translates from Italian to English as 'Red Bull', but the Austrian energy drink firm's junior F1 team is these days a very different organisation to Red Bull Racing. Gone are the days where it ran adapted versions of Red Bull's chassis fitted with different engines and transmissions. Today the team develops its own cars from scratch at the former Minardi factory in Faenza, Italy, and in its own technical centre in Bicester, England. On top of that, this year Toro Rosso is also the works Honda team!

But this year's car, the STR13, was not originally designed for a Honda PU, rather it was supposed to be a refinement of the 2017 car. 'It was a case of taking what we knew and either completely rehashing it or refining it, depending on whether it was a strength or weakness, while also applying the lessons learned from the first year of these new chassis regulations,' Toro Rosso technical director James Key says.

'The 2018 car is a bit of an evolution in some areas because of that, but in other areas we have changed things,' Key adds. 'As always there is a whole big slew of things that you want to account for when doing a new car, but I think the overriding point, of course, is pure performance level, which everyone is pushing as hard as they can to improve.

'To do that you have to understand what the strengths and weaknesses are and where you need to improve,' Key says. 'The big problem with that, of course, was that by the time we started serious work on the car for 2018 we were still quite early in 2017 and we didn't fully understand the impact of the regulations, that is, how the new wider tyres and aerodynamic changes would interact with each other. The second year is always an important time to try to pick up on the areas maybe you missed on in the previous year. But in many ways it was quite difficult to do that as there is such a diversity of ideas and approaches on the aerodynamic side in particular. So what we tried to do was identify the areas that we felt were developing well.'

Evolutionary theory

Comparing the STR13 to the STR12 of 2017 it is clear that indeed there are a lot of areas where the earlier concept has carried over to the new racecar, especially at the front of the car, the

‘We had to work pragmatically from both sides to get the relationship working quickly, and we did that’

ducted nose, upper-front wishbone and cooling layout around the roll hoop are all at least visually similar to the solutions seen in 2017.

‘Some aero development is an obvious evolution of last year and some is completely new and that will be an ongoing process in 2018,’ Key says. ‘In some areas it is quite different to the 2017 car, in others it’s an improvement of what we had. Aero is an area where there is a great deal of work in progress at the moment. It’s something that was okay for us at the beginning of last season, but then we did not develop to the level that we really wanted to be at by the end of the year.

‘There’s still an awful lot to find within these chassis regulations,’ Key adds. ‘We will likely have a very different looking car come the middle of the season compared to where we started the year and aero development is very much a major focus for us at present.’

Under the bodywork there have been very substantial changes which were planned from the beginning of the STR13 project. ‘Conceptually we did look at some quite significant changes in the way the car behaves, and how to develop it in some areas on the aerodynamic side,’ Key says.

‘In terms of the mechanical side we made quite a lot of changes to try to simplify the car, that came from what we learned in the early part of 2017,’ Key adds. ‘There were actually quite a few fundamental changes we tried to get together at an early stage. We completely redesigned a lot of the areas at the back of the car and the way the suspension works, because that was something which was not a strength in 2017, but we identified those concerns and addressed them in the 2018 car.’

Change of heart

It was during this process that the Toro Rosso engineers encountered an unexpected change. When the Sauber team failed to secure a transmission from McLaren for its Honda powered 2018 car, it switched to a Ferrari power unit. A deal was then struck for Toro Rosso, which develops its own transmission, to use the 2018 Honda in place of the Renault power unit that the STR13 was originally designed around.

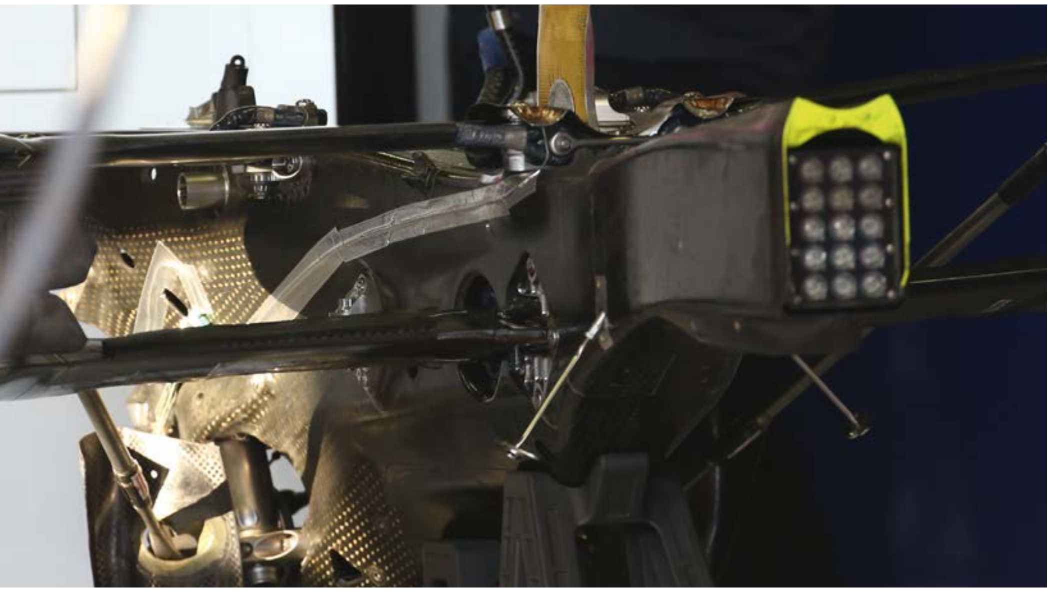
‘It was very late but we were confident that Honda had planned their way out of a

'Aero is an area where there is a great deal of work in progress'

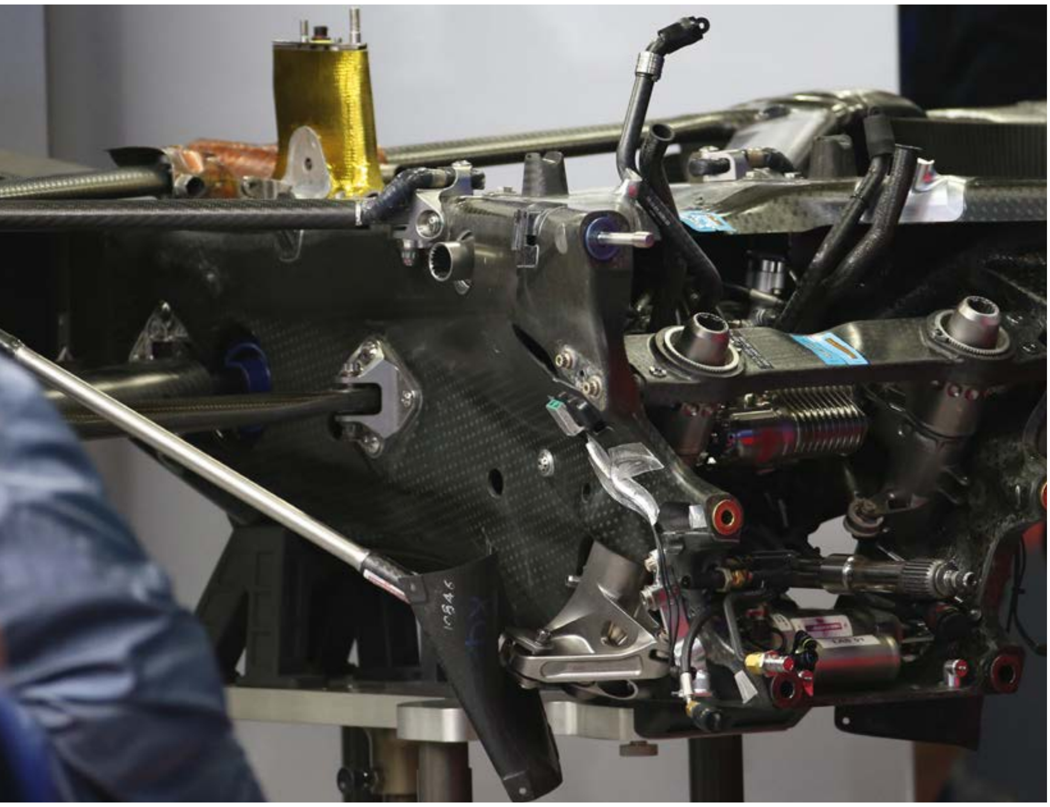
difficult 2017,' Key says. 'But the Honda has a fundamentally different architecture to the previous package we were using. That meant we had to redesign the gearbox, the rear suspension, and revise the cooling. We had to work pragmatically from both sides to get the relationship working quickly, and we did that.'

Toro Rosso has a recent history of having to deal with late engine changes, and that prepared the team well to cope with the switch from Renault to Honda power. 'Honda has produced a very compact, very easy to work with power unit,' Key says. 'That was a very welcome discovery when we first began to get the CAD data through and started to have technical discussions with them. It also meant we could redesign our gearbox in a way that allowed some of the rear suspension internals to be better installed, so there were several benefits to the installation itself.'

Honda's RA618H was originally destined for McLaren, then Sauber, and eventually found its way into the back of the STR13. As with all 2018 power units it has a 1.6-litre turbocharged V6 combustion engine featuring direct injection and a variable inlet system at its core. The ERS system consists of a 120kW kinetic energy recovery system (MGU-K) and a thermal energy recovery system (MGU-H) which also acts as anti-lag. On the Honda the turbo is split into two with the compressor mounted at the front of the engine block and the turbine at the rear, with the MGU-H sat between the cylinder banks.



The carbon fibre gearbox had to be specifically designed for the Honda PU, although it is similar in concept to last year



The internal rear suspension layout had to be changed due to the differences between the Honda and Renault power units

Honda's accord

From 2015, when Honda re-entered F1 as a PU supplier with McLaren, it has struggled with both performance and reliability, and ultimately that resulted in the somewhat acrimonious split between the two parties last year. Yet Toro Rosso has seemed more competitive with the Honda unit than McLaren had been, while reliability has also seemingly been quite good.

'From the beginning of this project our goal was clear, the concept would carry over from 2017 but we placed an emphasis on the reliability areas,' says Toyoharu Tanabe, Honda R&D Europe F1 technical director. 'Of course we did not ignore performance but the major focus was on reliability. We needed that for both the team, the drivers and ourselves at Honda.'

Increasing reliability was not only required due to the issues of 2017 but also due to a change in the power unit allowance for 2018, where only three combustion engines, turbos and MGU-Hs are allowed per driver along with two MGU-Ks, batteries and control electronics. This has resulted in the RA618H being slightly heavier than the RA617H of 2017.

'We managed to make it more reliable without increasing overall weight too much. In some areas, though, there was a trade off, we had to increase stiffness and strength and that can mean adding material, or you have to change the design concept,' Tanabe says. 'But it was difficult to change the design concept so we had to add material and that resulted in a slight overall weight increase. The exact details of this have to remain secret, I'm afraid.'

MGU-H focus

Much of the reliability work was focussed on the MGU-H as that had proven to be something of a weak point in 2017. 'One of the biggest issues which we had was with the MGU-H, so we did a lot of work there,' Tanabe says. 'It's a very complex part with a high level of technology, with the individual components and interaction between them it is a tricky thing. Due to its function and its role it is subjected to high temperatures and vibration.

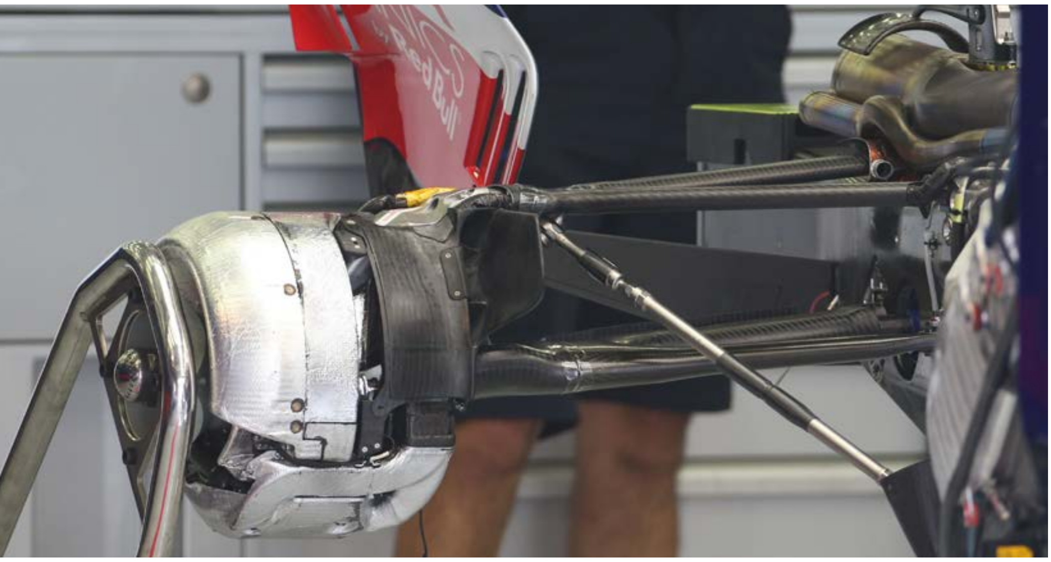
'It also has a very high RPM and that means that you have to look at things like the shape of the blades in the turbine and compressor, so it's far from easy,' Tanabe adds. 'We are constantly working on this area, but it takes time, then you have a new idea and change the concept then the design has to change as well. You know, it's

‘The Honda power unit has a fundamentally different architecture to the previous package we were using’

really a huge amount of work to get that right, and we are still working on it now.’

Despite its troubles with the MGU-H Honda has expressed its disappointment about the probable removal of the system under the proposed 2021 regulations, and feels that there are still gains to be had in terms of technical development. ‘I think you can still gain in these areas, we never stop in that area,’ Tanabe says. ‘You can improve the size and the weight. We achieved our targets but there are still things you can improve, like the C of G or the efficiency. We as Honda had a slightly late start on this so we still have space to catch up.’

Another late start was, of course, the relationship with Toro Rosso, with the deal only being confirmed in the Autumn of 2017. It created a heavy workload for both parties. ‘We started really a bit late, it was not enough time with a completely new team,’ Tanabe says. ‘That resulted in some difficult areas between us but we worked together really well to resolve them. It of course meant that things were compromised so in 2019 there will be a lot of gains to come. Our aim is always to make the chassis and power unit together in conjunction and we could not do that for 2018.’



The rear suspension on the car is pullrod with torsion bars. Note how the driveshaft runs right through the lower wishbone

The cooling layout is similar to last year’s STR12, despite the change of power unit. Note the cooler on the car’s centreline

Works team

For Toro Rosso the Honda supply deal is quite different to anything it has ever had before. As Red Bull’s driver-development squad it has always had customer engines, either from Ferrari or Renault (and for one season a Cosworth V10), but with Honda it is a pukka works deal.

‘It’s a really big difference in terms of the relationship with them compared to anything else we have had before, in that we are now a works team,’ Key says. ‘We had a larger input into their decision making process. That saw a great deal of rig and dyno testing, with the gearbox as well, to quickly establish a few fundamentals about the chassis and engine. That added quite a bit of additional workload late in the season, it was a challenge.

‘It is also a new experience when you have a new engine partner that’s not based in Europe, so you can’t just pop over and visit and have a chat around a CAD screen,’ Key adds. ‘It has to be a much more structured form of communication. We have a much bigger time difference to deal with, which can also be something that you need to carefully account for. For us, it wasn’t just a case of installing an engine and discussing all the plethora of details that go with that – the software, the electronics, even the garage layout, the operation of the engine itself, the cooling systems – it was also being able to be much closer to our engine partner and have some genuine influence over certain items. To sum it up, Honda have been a breath of fresh air to work with.’

Shape shifter

Once the deal was agreed and the initial power unit and chassis evaluations were done Toro Rosso embarked on a major rework of the STR13 with changes to the rear face of the monocoque, while a whole new carbon fibre transmission was required. This was largely because Renault’s engine is a fundamentally different shape to the Honda as it mounts the complete turbocharger at the rear of the engine block.

‘Our gearbox is specifically designed for the Honda engine and not an adaptation,’ Key says. ‘It has a fresh approach in terms of gearbox case

A great deal of the development effort is now focussed on design details in the diffuser area

Aerodynamic parts around the exhaust tail pipe are very much track dependent

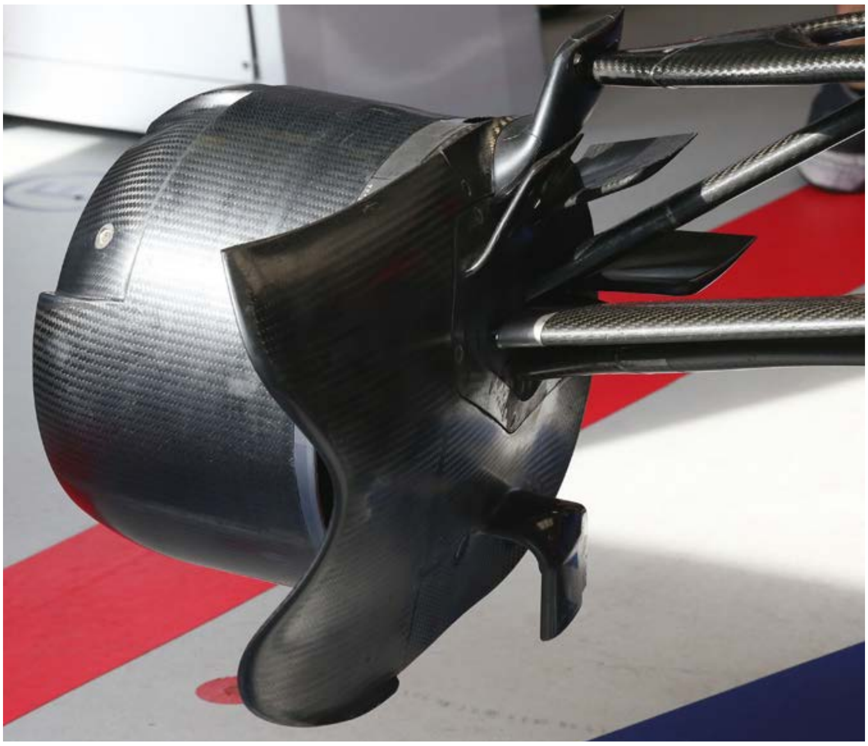
and packaging around the rear suspension. We did have to rush it through, but there were things we wanted to change anyway, the mechanical side of the rear suspension we knew we wanted to change quite substantially. While the gearbox casing is new the philosophy of design carried across quite nicely. In fact, the way we approach gearbox design allowed us to get it done, but it was a rush.

'If we had a different power unit in it there would be differences to the inboard suspension layout, so some of the positions of the elements wouldn't be the same,' Key adds. 'But the layout itself would be quite similar. In terms of packaging your rear suspension internals, you have to think about where the clutch is and any hydraulics you need to package as well as the turbocharger and pipes feeding it.

'There are many things that influence how you use the space that you have, so you have to use those units to optimise the space you have,' Key continues. 'The position of them is more a packaging exercise than a function of the suspension. But in the casing we have all the usual stuff; dampers, anti roll bars, and a few clever mechanical approaches to give linear or non-linear characteristics to certain elements.'

At full stretch

Other areas of the STR13 were influenced by the switch in power units, too. 'The wheelbase of the car was something that was changed by aspects of the power unit installation; STR13 has a slightly longer wheelbase than the 2017 car,' Key says. 'You have engine length in there which is essentially regulated anyway, but there are various bits of engine layout around it that vary, you can see that in the various compressor layouts used. There is an impact there on gearbox design which could be a different length if you wanted, but there are other areas affected too; there is the cooling layout, for example, which is influential.'



The STR13 retains the innovative upper wishbone mount that the Toro Rosso team introduced last season

Externally the cooling layout appears to be similar to that used on the STR12 and according to Key, despite the switch in engine supplier, it is the same story under the bodywork. 'Actually, the cooling layout ended up being pretty similar so it didn't have a big impact on the external parts of the car,' he says. 'We have had relatively large central inlets for several years now, it kind of came about with the change to the power units from the V8. Before the power units came in we just had to cool engine water and engine oil, gearbox oil and hydraulics. When they arrived in 2014 you then had to cool the MGUs, charge air cooling, it almost doubled the amount of cooling that was required. So we tried to find a balance by putting coolers on the centreline of the car.'

The Halo effect

The switch in power unit was not the only late change that Toro Rosso had to contend with. Like all F1 teams it also had to cope with the introduction of the Halo. 'That was a fresh challenge because there was no reference data from previous years to base anything on,' Key says. 'We therefore started from scratch on how to integrate it into the chassis. The very tough requirements for its structural integrity and

A major rework of the Toro Rosso STR13 was needed, including changes to the rear face of the monocoque and an entirely new carbon gearbox

'To sum it up, Honda have been a breath of fresh air to work with'

that of its mounting in the chassis were quite a challenge to ensure that we were on top of it. One of the reasons Halo looks like it does, which is one of the things that's been a bit of a topic of conversation, is that it has to be incredibly strong and to withstand the enormous loads it is intended to resist, you're not necessarily going to have this beautifully faired-in component. It's going to be something that's a bit raw.'

Tubular blockage

Like every team on the grid Toro Rosso has tried to reduce the negative aerodynamic impact of the tubular titanium Halo device, with the STR13 sporting an array of aerodynamic elements on the upper and lower edges of the Halo structure, taking advantage of a 20mm zone of regulatory freedom around it.

'The fairing does multiple things really, you have a tubular blockage so you want to reduce that, a tube is not a very good thing aerodynamically, it is very "lossy",' Key says. 'You have got that to deal with, and you can do it in a straightforward manner with a fairing and reduce that shape. After that the parts become quite car specific as you have got the flow around the cockpit and around the driver's helmet. There is the air intake, the cooling around the roll hoop and stuff downstream like the rear wing, those are all effected by the Halo. So depending on the shape of your car, the top lip of the chassis, for example, and the flow around it, you create parts to deal with that.'

Aerodynamics at the rear of the car were also a key feature of the STR13's design, and remain an ongoing development area, with a lot of attention paid to the diffuser. 'There is a lot of stuff going on in that area of the car,' Key says. 'As an aerodynamic part on the car it is of course very powerful, the diffusers in their own right, with some kind of ground effect. But there is only so far you can push that. Where it gets complicated are some of the details, and the approach that you take with them. Every car has a lot of details on the outboard sections and in the centre around the rear crash structure, there are a lot of little subtleties in there especially with the interaction with the rear tyres, and they tend to be the development areas. This is why there are a lot of details in those areas.

'There is also a lot of difference in that area which shows nobody has got it 100 per cent right yet,' Key adds. 'Overall, though, the diffuser itself is relatively straightforward. I think everyone can get 90 per cent of the performance, it's the last 10 per cent that comes from all those fine details around it, and that is the main performance development area.'

Slick work

Improving the aerodynamic performance and indeed the power unit has a major influence on what is widely considered one of the toughest areas to master with a current-era Formula 1 racecar. 'Tyres is another one of those major topics,' Key says. 'From an aerodynamic point of view you have some fairly bluff rotating surfaces, so they are very complex and chaotic shapes to have in very high speed airflow. So that profile shape and the bulge are surprisingly influential on the aerodynamics of the car.

'The combined effect of continued development on the aero side and on the power unit, along with more grip from softer tyres, means the speeds are going to be greater,' Key adds. 'Therefore, you have got to ensure that is a part of your prediction for loading conditions for the car. You also have to consider that it might bias the way in which you need to set up the car and the way in which your suspension geometry might need to adapt a little bit to a range of tyre compounds that are, on average, softer than last year.'

Best and worst

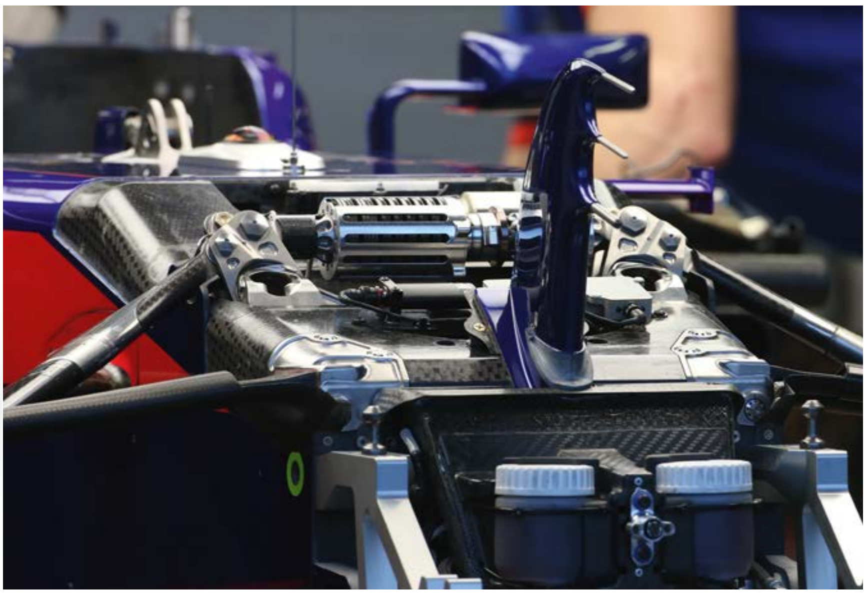
Indeed, when discussing the whole of the STR13 it is the way it works with the current Pirelli tyres that Key highlights as not only the best aspect of the car, but also the worst. 'This year the tyres have quite a narrow working range and the softer compounds in particular take quite a bit of understanding,' he says. 'But when you get it right there is a big benefit. We have had quite a difficult year so far, and a lot of analysis work has been done to ensure we are just on the right side of the tyre working ranges. When we get it right the car goes really well, but when it's not we struggle. The biggest challenge we have faced is making sure we are in the right window for the tyre and more often than not we have learned the hard way as it is very track dependent and very condition dependent.'

Significant development is expected on the Toro Rosso STR13 as the 2018 season continues and the team remains optimistic about securing the best constructors' championship result for a Honda-powered team since the manufacturer's factory operation finished fourth in 2006. To achieve that both the chassis and the power unit will need to improve, and that is exactly what the engineers in Faenza, Bicester and Sakura City are working on right now.

TECH SPEC

Toro Rosso STR13

Chassis:	Scuderia Toro Rosso Composite monocoque.
Power unit:	Honda RA618H.
Transmission:	Gearbox maincase, Scuderia Toro Rosso one-piece carbon fibre; 8-speed sequential; active hydraulic operation.
Suspension:	Front – upper and lower carbon wishbones; pushrods; torsion bar springs; anti roll bars. Rear – upper and lower carbon wishbones; pullrods; torsion bar springs; anti roll bars.
Steering:	Toro Rosso assisted steering rack.
Exhaust:	Honda.
Calipers:	Brembo.
Brake by Wire:	Toro Rosso.
Steering wheel:	Toro Rosso.
Tyres:	Pirelli.
Fuel system:	ATL tank with Toro Rosso internals.
Overall weight:	733kg.



Front suspension showing the third element damper. The front of the car is very similar to last year's STR12

Laps of honour

It might not have had much in the way of competition but Toyota allowed its two cars to race and thoroughly deserved its long-awaited Le Mans triumph – as *Racecar*'s in-depth race analysis clearly shows

By ANDREW COTTON and PAUL TRUSWELL

Toyota's much-needed victory at the 2018 Le Mans 24 hours came at the end of a very carefully executed race. Yet while the 12-lap margin over the nearest non-hybrid was substantial, this wasn't a slow cruise to the flag. The two Toyota team cars, prepared at TMG in Cologne, were allowed to race each other, and only late race penalties and a driver error confirmed the result.

Kazuki Nakajima overcame his nightmare of 2016, when he stopped on the last lap having done all but take the chequered flag, Sebastien Buemi scored the biggest victory of his career, while Fernando Alonso took a step towards his dream of winning the triple crown; with wins in the Monaco Grand Prix and Le Mans he now has only the Indy 500 left for this.

But the biggest winner was Toyota Itself. For the Japanese manufacturer this was the culmination of more than eight years of investment – which included developing two engines, one normally aspirated and one turbo, and two hybrid systems, one super capacitor the other battery. With no competition from old rivals Audi and Porsche, who withdrew from the WEC in 2016 and 2017 respectively, Toyota concentrated on improving reliability and systems for this year's Le Mans, and has long since abandoned plans to develop an exhaust energy recovery system for this season.

After eight

The winning No.8 Toyota finished the race two laps ahead of the sister car of Kamui Kobayashi, Mike Conway and Jose Maria Lopez, which had its turn in the lead during the night but did not have a good balance in the cooler night temperatures. Third placed, and 12 laps down, was the Rebellion of Thomas Laurent, Matthias Beche and Gustavo Menezes. But the winning margin was as much about a combination of rules that favoured the hybrid and reliability as it was about the private teams not having enough race mileage with their new racecars.

For those who say that this was an easy win for Toyota, the winning TS050 completed 5286km, the furthest since Porsche's first win in 2015 (5383km). This was only nine laps shorter than the overall race winning distance set in 2010 by Audi with 5410km **(Table 1)**. Yet by regulation the TS050 had to stop more often and spent more time in the pits, eight minutes longer than the winning Porsche in 2016 in fact.

It's clear then that this was not a race that Toyota treated as a show, even though everything was stacked in its favour and the race could never be described as exciting – the two TS050s were never headed throughout the race. They were able to go further during every stint than their non-hybrid rivals, were

For those who say that this was an easy win, the winning TS050 completed 5286km, the furthest since Porsche's first win in 2015

Main picture: The No.8 Toyota took the initiative during the cooler conditions of the night, when its sister No.7 car was unable to find a good balance **Left:** Toyota was able to stage a formation finish for the cameras thanks to the two-lap gap between its cars at the end, but it had let them race throughout

Table 1: Winning car data since 2010

Year	Race average lap	Best stint average lap	Best lap	Average of best 100 laps
2010	3m32.5s	3m21.5s	3m19.074s	3m21.160s
2011	3m58.8s	3m28.8s	3m25.289s	3m28.086s
2012	3m42.3s	3m27.1s	3m24.189s	3m26.538s
2013	4m00.4s	3m25.8s	3m22.746s	3m25.310s
2014	3m29.1s	3m24.9s	3m22.567s	3m24.912s
2015	3m33.6s	3m20.2s	3m17.475s	3m19.154s
2016	3m39.1s	3m24.3s	3m21.445s	3m23.015s
2017	3m39.6s	3m20.4s	3m18.604s	3m19.848s
2018	3m35.7s	3m20.3s	3m17.658s	3m19.680s

Note: Race average laps are affected by safety cars, since 2014 by slow zones, and by the weather

able to refuel faster and had a pace advantage, all built into the regulations. Yet the regulations were not designed to artificially give Toyota an advantage, rather they were designed to reduce the advantages that the car had after years of development, while not eliminating them altogether. The hybrids were restricted from executing the performance shown last year; they were limited to 11 laps when in 2017 the car could do 14 laps, and could refuel even faster.

New non-hybrids

The non-hybrid cars run by SMP, Dragonspeed, Rebellion and Ginetta were all new this year, and did not have the test miles that Toyota had racked up since it started its hybrid programme in 2012. And they did not have the reliability to even test the Equivalence of Technology (EoT).

The average 20 per cent of the laps completed by the winning No.8 Toyota was

The non-hybrid cars did not have the test miles that Toyota had racked up since it started its hybrid programme in 2012

Rebellion finished third and fourth and headed the non-hybrid LMP1s but it will be disappointed with a lack of pace and its slow refuelling stops

3m19.895s; the No.17 SMP BR1 was 3m22.137s, 1.3 per cent slower than the hybrids and therefore 0.8 per cent more than the EoT allowed. The Rebellions were even slower by the same comparison, the No.3 setting 3m22.425s as its fastest 20 per cent of laps **(Table 2)**.

All week the No.8 Toyota had a pace advantage over the No.7. Nakajima was on pole comfortably, setting a time that was close enough to Kobayashi's extraordinary lap in 2017 to be credible. They undoubtedly could have gone faster, but that would have served no purpose as the two cars comfortably filled the front row of the grid. The non-hybrid cars could reach the mid 3m17s, but stood no chance of challenging for pole at 3m15s. The race for the non-hybrids was for the final spot on the podium, unless a Toyota broke down, so there was no point in them attacking for pole, either.

The turning point of the race was during the night following an extraordinary stint by Alonso against first Conway, and then Lopez. The Spaniard closed more than two minutes on the leading car following a penalty for speeding in a slow zone. 'It was the set-up of the car, it was better in the cold temperatures, and I am used to stress the tyres,' said Alonso after the race. 'When it is hot I overstress the tyres but when it is cold conditions I switch on the tyres very quickly. I like driving in cold temperatures and damp temperatures and the night is closest to damp.'

Race data

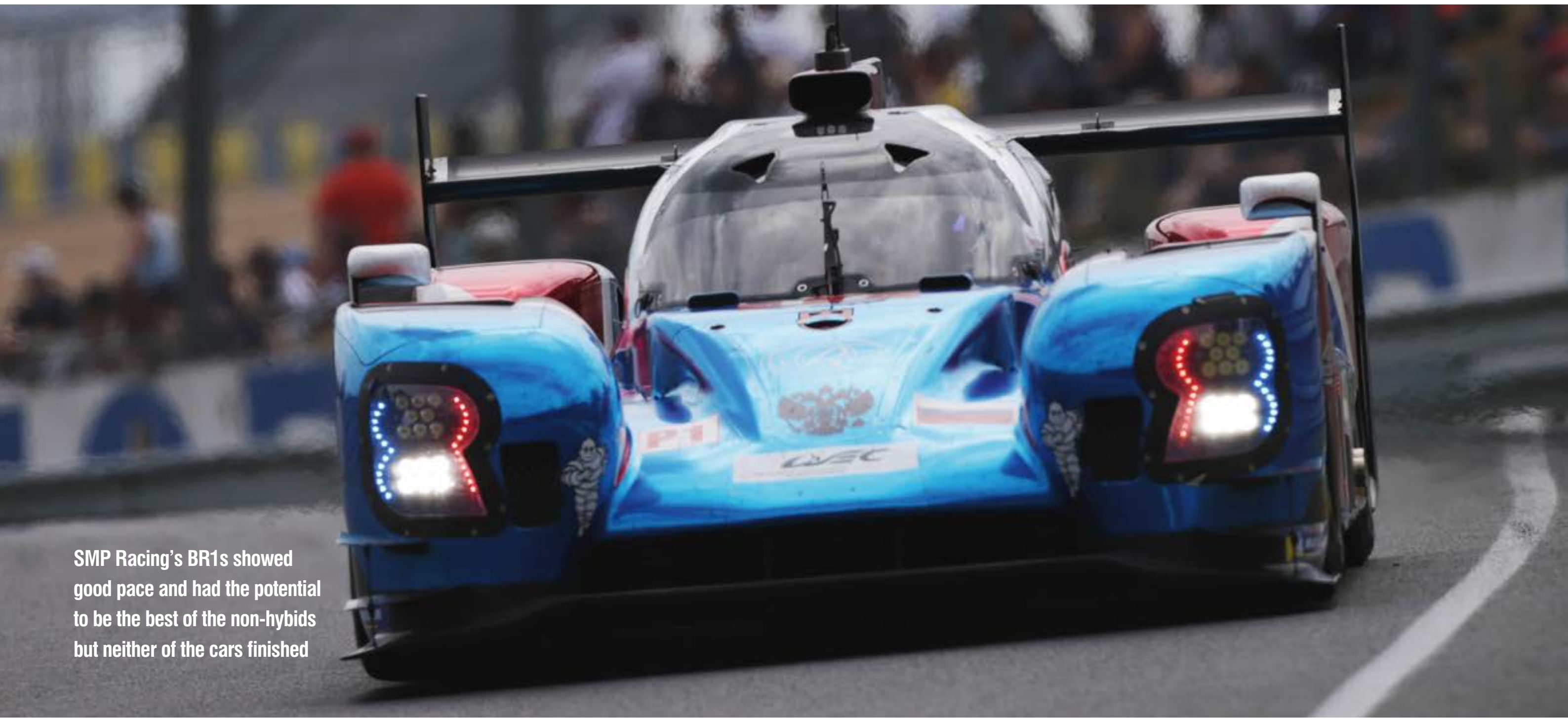
The data shows that only when Alonso got in the car with ten and-a-half hours of the race gone, did the No.8 suddenly start going a lot quicker than the No.7. Up until that point average lap times were around 3m23s, then suddenly Alonso was in the 3m21s bracket. Kobayashi was quicker in No.7 when he got in with nearly 14 hours on the clock (4:40am), and started closing in on Nakajima again, but when Buemi got back in No.8 again he was quicker **(Table 4)**.

Alonso's laps were on average two seconds faster than Conway on the first stint of what was a quadruple stint, and almost a second per lap faster than Lopez. The Spaniard was also requesting to go for a fifth stint on the same set of tyres, but the team instructed him to stick to the schedule and he had to get out of the car.

His stint brought the car right back into contention, and as the temperatures dropped the balance of the No.7 car started to worsen, and the drivers were struggling with the handling. 'There were no reliability issues at all,

Table 2: Average of 20 per cent of laps completed
Toyota No.7 average of fastest 77 laps (20% of 386): 3m20.236s
Toyota No.8 average of fastest 77 laps (20% of 386): 3m19.895s
Rebellion No.1 average of fastest 77 laps (20% of 386): 3m22.820s
Rebellion No.3 average of fastest 77 laps (20% of 386): 3m22.425s
SMP BR1 No.17 average of fastest 24 laps (20% of 123): 3m22.137s
Note: In terms of a percentage this means that the SMP BR1 was 1.3 per cent slower than the slower of the two Toyotas, rather than the ACO recommended 0.5 per cent

Table 3: Average of fastest 100 laps
Toyota No.7 average of fastest 100 laps: 3m20.511s
Toyota No.8 average of fastest 100 laps: 3m20.134s
Rebellion No.1 average of fastest 100 laps: 3m23.153s
Rebellion No.3 average of fastest 100 laps: 3m22.719s
SMP BR1 No.17 average of fastest 100 laps: 3m46.577s
Note: This is a somewhat skewed comparison, since the SMP only covered 123 laps, compared to the Toyota's 388 and 386 and the Rebellion's 376 and 375



SMP Racing's BR1s showed good pace and had the potential to be the best of the non-hybids but neither of the cars finished

Dallara redesigned the front wheel arch on its BR1 following a spectacular Spa flip. The larger hole added a little drag but it also reduced the impact of rubber build-up on the downforce

The non-hybrid cars could reach the mid 3m17s, but stood no chance of challenging for the pole, which was in the 3m15s

Table 4: The fastest (average) 50 laps of the Toyota drivers and the drivers of the non-hybrid cars from Rebellion and SMP

Toyota No.8
Buemi: 3m20.802s
Alonso: 3m20.260s
Nakajima: 3m20.892s
Toyota No.7
Lopez: 3m20.838s
Conway: 3m20.965s
Kobayashi: 3m21.202s
Non-hybrids
No.1 Jani: 3m23.329s
No.3 Menezes: 3m22.665s
No.17 Orudzhev: 3m21.942s
No.11 Petrov: 3m23.704s

and everything went smoothly,' said Conway. 'It moved around in terms of gaps, and penalties really weren't ideal and when you have high competition you can't afford those things. They [the No.8] seemed stronger in the night in the cooler conditions and we lacked [grip at] the front end, so they were strong all night and we dropped pace. That was the turning point of the race, really. We lost our buffer, but they have been strong all week.'

Rebel yell

During the race Toyota was able to lap in the 3m19s, as it had during the test day, while the Rebellion team was in the region of 3m22 to 3m25s on its way to third and fourth places. Both of the team's cars had clutch pressure sensor failures. One of them had the rear of the plank come off and needed repair, while the team's refuelling was also far from perfect **(Table 5)**. Rebellion estimated that it was losing eight seconds each stop compared to Toyota and knows it has work to do on its new car.

Reliability was key to the result, and the two Rebellion ORECAs simply reached the finish of the race. The first of the two Rebellion cars finished third, one place ahead of the sister ORECA Gibson driven by Andre Lotterer, Neel Jani and Bruno Senna. Jani had a long final stint as his driver's door was coming open, and the team's repair meant that once opened, it was unlikely ever to close again.

One flaw in the EoT is the ability to deliver the power where required; a trait of the hybrids that have a push to pass system, while the non-hybrids do not. Jani, who drove for Porsche previously and has now has switched back to Rebellion, estimated that the non-hybrid cars would lose an average of three seconds per lap compared to the Toyota, only through the lack of this system. Also, tyre selection weeks ahead of the race meant that Toyota had an advantage having run Michelin tyres for many years, while for the privateers it was all new.

Fast but fragile

However, even among the privateers, the ORECA was not the fastest of them. The SMP team had the potential having tested its Dallara-designed BR1 extensively pre-season, enough for Toyota to complain about the EoT based on the rumoured top speeds seen in testing, and lobby to have the non-hybrid cars slowed. The BR1 ran well in the early stages but a series of unfortunate events put paid to the team's race.

Vitaly Petrov was the first to hit trouble early on when a suspected throttle body sensor caused a long stop. 'We changed a lot of things, but think that it was the throttle body,' said team principal Dmitry Belousov. The team managed to get the car back out, but had lost

The turning point of the race was during the night following an extraordinary stint by Alonso against first Conway and then Lopez

Table 5: Pit stop times

No.	Car	Number of stops	Total time in pits	Average stop time (excluding penalties and SC stops; also non-standard stops)
No.8	Toyota	37 (incl 2 penalties)	46m10.637s	1m05.8s
No.7	Toyota	38 (incl 3 penalties)	44m37.873s	1m06.3s
No.3	Rebellion	39	1h09m08.093s	1m14.6s
No.1	Rebellion	42	1h07m16.778s	1m12.4s

Note: Obviously, the Toyotas had more 'standard' stops than the Rebellions, but Rebellion was losing at least six seconds per stop, and often more. An extra 23 minutes in the pits is between four and five laps

Porsche in the pink

Porsche won a disappointing GTE-Pro category after opening out a comfortable lead in the fourth hour due to luck with a safety car. It then held on to it until the end of the race. The No.92 Porsche took the lead on lap 54 of the 344 it completed, as its closest competitors pitted under the safety car and were held until a second of three safety cars had passed by.

Under GTE regulations, the stint lengths were limited to 14 laps, under all conditions, refuelling was limited to 35 seconds per stop, although Porsche's stops seemed faster, and refuelling and tyre changes could take place at the same time, so there was nothing to be gained from stretching the tyre allocation.

There was nothing that the No.92 Porsche's rivals could do other than hope for luck with a slow zone, safety car, or a reliability issue for the leading Porsche. Nothing happened, and so the procession to the chequered flag was dull. Performance-wise, Aston Martin was the only car far outside the lap time window, closely followed by BMW and Ferrari. Ford, Porsche and Corvette were relatively well balanced, which conversely meant that no one had the on-track pace to close the gap to the Porsche either.

With 17 cars, 51 pro drivers and no weak links, this could and should have been the battle of this year's race. Unfortunately, luck with a safety car for Porsche and over-regulation in the pit lane turned it into a procession.

GTE-Pro race data

No.	Team	Laps completed	Best lap	Average best 20%	Percentage difference
92	Porsche GT Team	344	03:50.406	03:51.582	0.21%
91	Porsche GT Team	343	03:50.201	03:51.222	0.05%
68	Ford Chip Ganassi Team USA	343	03:50.108	03:51.099	0.00%
67	Ford Chip Ganassi Team UK	343	03:50.180	03:51.339	0.10%
63	Corvette Racing	342	03:49.448	03:51.278	0.08%
52	AF Corse	341	03:50.569	03:52.025	0.40%
95	Aston Martin Racing	339	03:52.318	03:54.007	1.26%
81	BMW Team MTEK	332	03:50.917	03:51.920	0.36%

Good fortune with a safety car did play its part in the 'Pink Pig' Porsche RSR's win but it also ran faultlessly to the finish

almost 50 laps, and eventually it pulled off and retired in the final hour with an engine issue.

His team-mate Matevos Isaakyan, the driver who crashed heavily at Spa in May, had another high-speed accident in the Porsche Curves during the night. The Russian slid sideways across a new run-off area, and eventually hit the barriers with the rear wing, ending a strong run for the car shared with Stephane Sarrazin and Egor Orudzhev. Belousov was disappointed with the EoT, claiming that his cars could not get within four seconds of Toyota's race pace over the course of the race, and that any development would be penalised by regulation.

Enter the dragon

The Dragonspeed version of the BR1, fitted with the Gibson engine, had an off on Saturday afternoon when Renger van der Zande suffered a broken floor, although whether that was cause or effect had yet to be determined by the team at the time of writing. The race was ended for them on Sunday morning when the team's other professional driver, Ben Hanley, crashed in the Porsche Curves and broke the gearbox, bellhousing and left rear suspension.

The Ginettas, that had effectively missed the Spa race, had a Le Mans baptism of fire. The two cars lost much of Wednesday's running with electrical problems brought about by new software it had brought to the race. The same issue hit both cars and it was eventually fixed, along with a new engine on one of the cars.

However, in the race more electrical gremlins struck one of the Ginettas, while the other suffered the majority of mechanical dramas around the suspension, steering and bodywork. The team was pleased that the No.5 of Charles Robertson, Michael Simpson and Leo Roussel finished and was classified fifth, although this was 99 laps behind the leader.

The only other starter in the LMP1 category was the Enso CLM P1/01 NISMO of the ByKolles team. While that was the slowest of the non-hybrids, it had potential to be reliable and pick up some useful points before Dominik Kraihamer crashed in the Porsche Curves after contact with another competitor. The car briefly caught fire and was retired in the fifth hour.

EoT phone home

It could be claimed that the EoT was wrong, but this calculates the potential best lap time according to simulation, not according to the ability of the team to execute this performance. Nevertheless, with Rebellion, SMP and Ginetta all failing to get what they needed out of their cars, the ACO and FIA must make a change for future races along with the private teams needing to step up their preparation.

The 2018 24 hours will not be remembered as a classic. It was, however, an old-style Le Mans race, one of reliability rather than outright speed. And it has been a long time since that was the deciding factor.

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Mega Megane

While most WRX racers are based on WRC cars the new GCK Renault Megane RS, built by Prodrive in collaboration with GC Kompetition, is a radical and bespoke machine conceived with just one goal in mind – winning World Rallycross races

By GEMMA HATTON

World Rallycross is one of the fastest growing forms of motorsport around. But with growth comes cost, and in order to try and protect the financial stability of the privateers, this year's regulations have restricted the number and type of components teams can use to develop their cars. These have included limiting teams to two engines per season instead of three whilst reducing the number of turbochargers from two per event to four per year. Also, only two sets of gear ratios are allowed for the entire season, and rear aerodynamic development is forbidden.

No compromises

Yet despite these restrictions, WRX still remains a very open formula. In fact, the main limitations come from the fact that most rallycross racers have evolved from R5 or WRC rally cars and so come with some of the engineering compromises required to compete in a 15 mile rally stage, instead of a five lap rallycross race. But does that mean there's something to be gained from building a bespoke WRX car?

World-renowned engineering company Prodrive and French rallycross team GC Kompetition certainly believed so, which is why they got together to produce the brand new GCK Renault Megane RS. 'Most of the cars have been developed from R5 or WRC and although these are highly developed, there are several limitations because you bring a lot of baggage that you don't really want,' explains Paul Doe, chief designer at Prodrive. 'One thing that was clear on both our sides [it and GCK] was that we didn't want to carry anything over from our back catalogue of previous rally projects. We wanted to design the car from the ground up, starting from the cleanest sheet of paper possible.'

There are three main limitations with rally cars that Prodrive wanted to avoid. Firstly, the engine position, which is regulated to be within 25mm of the production crankshaft and therefore forces rally teams to adopt a transverse engine layout. Secondly, the rules stipulate that rally cars in the WRC have to run with MacPherson suspension, which has now filtered through to the majority of today's rallycross contenders. Finally, there's the subframe, which for World Rallying has to be interchangeable with the production car, despite not actually coming from the production car itself.

'Luckily, World Rallycross is free in many respects,' says Doe. 'Engine position is much freer, so you can have the engine transverse or longitudinal and the crankshaft height can be wherever you like. There is also only slight control on the longitudinal position of the engine. You can have any kind of suspension

TECH SPEC

GCK Renault Megane RS

Chassis: Renault Megane RS five-door bodyshell with composite panels; roof and driver's door from standard production car; carbon composite rear wing.

Engine: 2-litre 4-cylinder direct injection engine; Garrett turbocharger with 45mm restrictor as per the WRX regulations; Prodrive anti-lag system; Grainger & Worrall cast engine block; Mahle pistons.
Power, approximately 600bhp.

Electronics: Li-ion battery; Cosworth engine management system.

Transmission: Four-wheel drive; bespoke Xtrac 5-speed sequential gearbox with floor mounted manual gearshift; Xtrac plated limited slip differential (front and rear).

Clutch: Alcon carbon/carbon triple plate.

Fuel: ATL fuel tank and system.

Suspension: Prodrive Ohlins double wishbones front and rear with adjustable 4-way dampers.

Steering: Sportech electro/hydraulic power assisted steering rack.

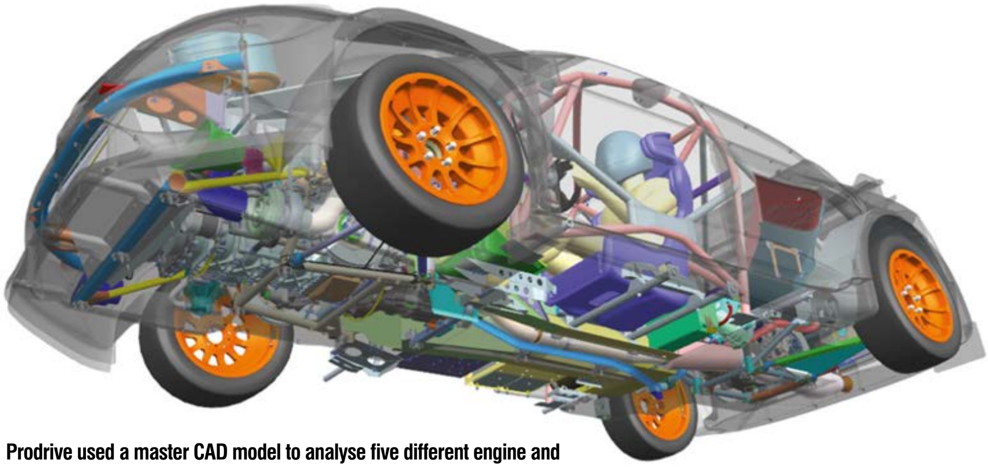
Brakes: Inboard Alcon 4-pot calipers front and rear with 300mm vented discs.

Wheels: 17in x 8in, Prodrive and OZ Racing.

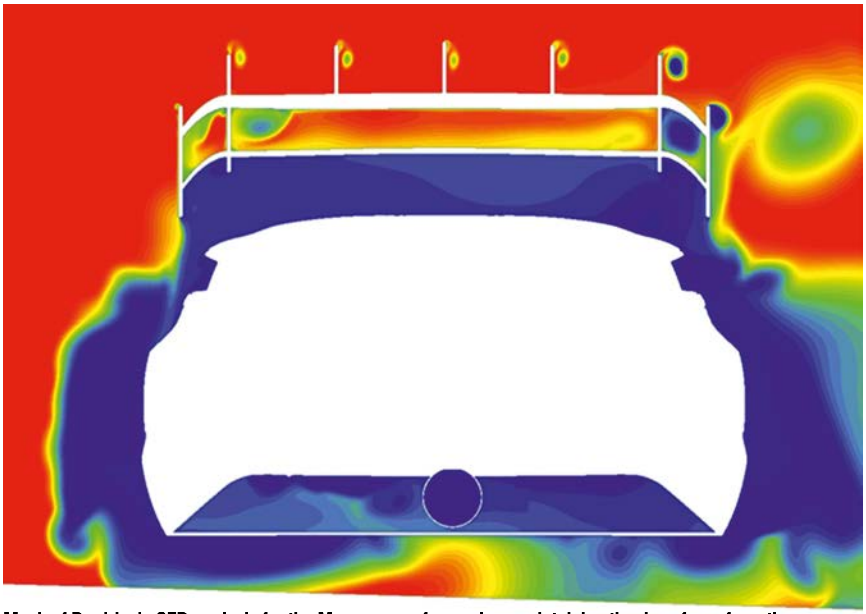
Tyres: Dry 225/640-17 Wet 201/635R17 by Cooper Tyres.

By designing and building the Renault Megane rallycross car from scratch Prodrive was able to incorporate a number of technical innovations

'We didn't want to carry anything over from our back catalogue of previous rally projects'



Prodrive used a master CAD model to analyse five different engine and drivetrain layout concepts. It decided on a longitudinal layout as opposed to transverse as this allowed the CoG to be as low as possible as well as giving the desired mass distribution



Much of Prodrive's CFD analysis for the Megane was focused on maintaining the downforce from the rear wing during the high yaw angles experienced during a rallycross race, when the cars are very often sliding

you like and the subframe doesn't have to have any relationship whatsoever to the production car, which has enabled us to come up with some interesting ideas for this car'

Gripping stuff

Generating and maintaining grip was a key area for Prodrive and the effect of parameters such as centre of gravity (CoG) height, unsprung mass, driveability, power and aerodynamics on the lap time sensitivity was analysed and then optimised. 'Defining these sensitivities is extremely important and almost forms the DNA of the project,' says Doe. 'We derive these from a combination of methods, and once we have our sensitivities, we can then start to define the important numerical parameters which we set as the targets to develop a competitive car. A lot of our decisions on the architecture of the car were driven by these sensitivities.'

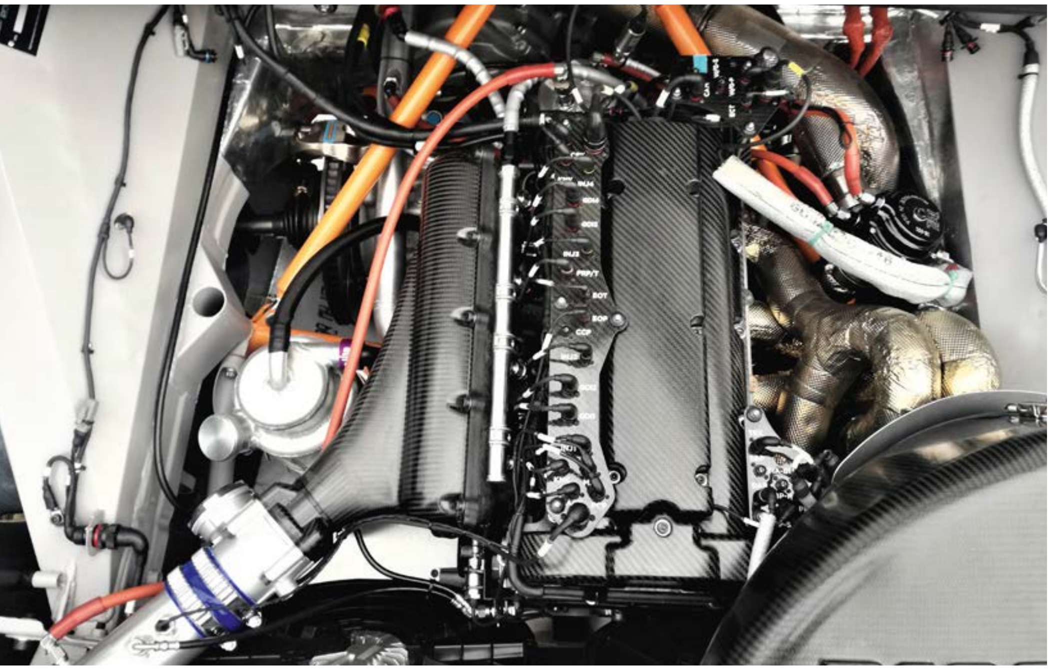
To help explore the various engine and drivetrain layout configurations, a fully integrated, master CAD model was created, along with several Excel spreadsheets that calculated the associated mass distribution, CoG and yaw inertia for each iteration. This virtual model allowed the engineers to explore the different layout concepts, whilst modelling the effect on the overall car package so that the optimised architecture could be chosen.

'We must have analysed more than five different engine and drivetrain layouts,' Doe says. 'But one of the good things about World Rallycross is the minimum weight of the cars is actually quite high. So if the car is designed properly from the ground up then you have a lot of ballast to play with, which means you can play more games with the architecture. In my view, this is what makes the biggest difference. I have worked on projects where, despite the updates you bring, you can never come back from the fact that the car wasn't conceived in the right way.

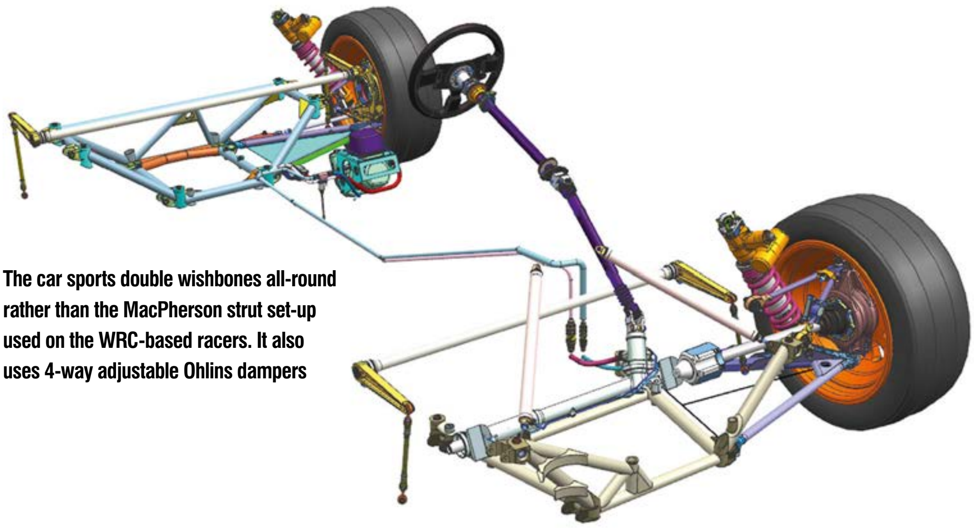
'We ended up going with a longitudinal engine layout which is different from a lot of the rally car-based rallycross cars in the championship,' Doe adds. 'This configuration enabled us to keep the CoG as low as possible while optimising our mass distribution.'

Bespoke engine

Despite several in-depth studies into the available power units on the market, it was clear that this radical concept demanded a bespoke engine, which Prodrive decided to develop itself. 'Although this meant a great deal more work for us, it gave us the flexibility to position and mount the engine where we wanted,' explains Arthur Shaw, chief engine engineer at Prodrive. 'Obviously the number



The Megane RS packs a 2-litre direct injection 600bhp turbocharged powerplant which has been developed by Prodrive



The car sports double wishbones all-round rather than the MacPherson strut set-up used on the WRC-based racers. It also uses 4-way adjustable Ohlins dampers

Prodrive decided on an inboard braking system to reduce unsprung mass while also allowing a degree of freedom with the suspension geometry. The brake calipers are fixed to the gearbox on the front axle and to the differential on the rear axle

one requirement is excellent power output and to achieve that with a 45mm air restrictor, you need good combustion, low engine friction and efficient turbo systems. There is no point making power and then throwing it away through heat and friction. It's all about getting good tumble and mixing so that the burn is efficient to minimise any heat rejection. Once you do get heat into the chamber, then you need to manage it in the cylinder head to keep it as uniform as possible and avoid any hot spots that could lead to knock.'

A further factor that helps to sustain effective knock control as well as reliability is the internal cooling system. The 2-litre unit makes over 550bhp and this high specific output requires the heat to be managed efficiently.

'Our water jacket layout is like nothing we have really seen before,' says Shaw. 'In past projects, where we have inherited water jackets, we have found a lot of compromises so we made the key decision to incorporate a cross-flow water system.' This is where the engine coolant enters the inlet side of the engine, flows around the rest of the block and then exits via the exhaust side. Therefore, heat generated on the hot side of the head never actually goes into the head and is immediately exited, improving the thermal efficiency. Although simple in concept, the optimisation of such a system required extensive CFD work.

Science friction

The threat of friction, however, was arguably the most important consideration that drove the design. 'Every little bit counts, so we really focused on the details of each component to minimise friction,' Shaw says. 'We looked at the power output of the valve train to minimise the losses in there. The details of the pistons were quite tricky because with such a high power output you need quite a robust piston with large skirts, so we spent time minimising the friction on the piston assembly, but at the same time it was such a short project that we didn't want to do anything radical. If you've got a fixed potential with a restrictor and you combust it well and don't throw a lot of it away in friction then the [engine] output is going to be correct.'

Once the engine has generated all that power, it then needs to get to the wheels via the transmission. The high torque outputs of a rallycross engine are often too much for existing gearboxes and to avoid the rallycross gearboxes that have been adapted from rally cars Prodrive decided to design a bespoke transmission with the help of Xtrac. 'The front section of the gearbox, literally the box with the ratios in, is an off the shelf unit used in some American truck racing series,' explains Doe. 'The interesting bit of how it is distributed to the wheels is all bespoke. You look at any other longitudinal layout cars out there and the engine is normally sat on top of the transmission and the driveshafts go under the engine. In this case we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Despite several in-depth studies into the available power units on the market, it was clear that this radical concept demanded a bespoke engine

The wheel hubs do not need to accommodate brake calipers, discs or pads because of the Megane's clever inboard braking system

sat everything on the floor and got the engine position as low as it could go [to achieve a lower CoG]. I would say this is the most nicely packaged racecar I have worked on for a while.'

In terms of suspension, Prodrive has gone for double wishbones all-round to allow for much more freedom with the geometry compared to the standard MacPherson suspension used in World Rally cars. 'One of the problems with MacPherson cars, aside from the unsprung mass and friction issues, is you tend to lose camber,' says Doe. 'Therefore, in high speed corners the car takes more load and rolls more, so you lose control of the tyres. Whereas with double wishbones you can tune the suspension and it enables us to reduce the unsprung mass. I don't think there will be anyone else that has a lower unsprung mass than us.'

The dynamics of the suspension, along with the anti-roll bars and roll centre height have been optimised using Prodrive's extensive rally experience. Ohlins supply the dampers, although again these were designed specifically for this car and they feature new technologies.

Brake from the norm

However, the most innovative part of the car has to be the brakes, which are inboard. This means that the brake calipers are fixed to the gearbox on the front axle and to the differential on the rear axle, rather than the uprights. 'It is not a new idea and it has been done before but it does not feature on many modern racing cars,' says David Lapworth, technical director at Prodrive. 'It's something we've had on the radar for a long time, but there are a couple of challenges. The packaging to physically make it work is particularly difficult at the front where you've got the engine and gearbox to accommodate, the rear is not so bad because you've only got the rear differential. Cooling is the next concern, but then rallycross makes that relatively easy because they are short races and the driver is not very hard on the brakes, so that made us think that rallycross was asking for it.'

The wheel deal

One of the consequences of this radical braking system design is seen with the wheel hubs, which are completely different when they don't have to incorporate space for the discs, calipers and pads. Of course, with the majority of suppliers manufacturing traditional wheels, nobody had the tooling to make a wheel that suits inboard brakes. Therefore Prodrive, together with OZ, designed bespoke wheels.

'The cross section of the wheel is very peculiar, it's more like an aircraft wheel because normally the brakes create a huge packaging constraint,' says Doe. 'We have a wheel that really is on the minimum weight, if you try to do that with a conventional wheel then you would have life issues. We can also get a bigger air volume in there and so can remove the heat input from the wheels. In terms of tyre pressure control we have got a completely different regime to what you normally have.'

Often rallycross drivers complain that the tyres are over-pressurised by the end of the race, which is a consequence of the increase in tyre temperatures as the compound is loaded through the corners. When tyre pressures are too high, the tyres effectively start to 'balloon', reducing the contact patch size and therefore grip. By not having the heat from the brakes dissipating into the wheels and tyres, Prodrive is expecting much less temperature and therefore pressure rise over the course of a race.

Inboard brakes have also allowed greater freedom for the suspension geometry. 'The effect of removing the brakes from the suspension package is more than you expect until you do it,' says Lapworth. 'You quickly remember when you come to lay out your suspension uprights and wishbones how much the brakes normally get in the way and dictate it. It is only when you come to do it with a clean sheet of paper you realise there's a lot more freedom on the geometry, so you can design the uprights more effectively.'

Megane marvel?

Overall, GCK's Renault Megane RS represents the first time that a car has been specifically designed, built and optimised for World Rallycross, as opposed to simply adapting a successful rally car. Therefore, the design features entirely different and bespoke concepts when compared to the rest of the grid. However, despite being a fascinating car to write about, after five rounds of the championship, GCK are sitting in last place. So has Prodrive gone too radical? Or will 2018 provide the team with enough experience to come back and win the championship, as targeted, next year?

Inboard brakes allowed for a completely different wheel design, but manufacturers didn't have the tools to make it so Prodrive partnered with OZ to develop a bespoke wheel that's said to be light and also good for tyre pressure control

Street cred

How the maker of the BAC Mono, said to be the world's only single-seat road going car, has made use of the very best of motorsport technology to produce its stunning machine

By DR CHARLES CLARKE

It's always possible to increase horsepower, but weight saving is a more difficult trick

TECH SPEC

BAC Mono

Chassis and body: Inconel tubular spaceframe; high-strength carbon fibre composite around a steel safety cell; FIA-compliant steel roll over structure; side impact structure and a front carbon crashbox; prepreg carbon fibre bodywork.

Engine: Longitudinally-mounted Mountune-built 2.5-litre, 4-cylinder inline Ford Duratec. Power 305bhp; torque 308Nm.

Transmission: Formula 3 spec Hewland 6-speed sequential gearbox.

Suspension: Fully-adjustable pushrod system; Sachs Racing dampers.

Brakes: 295mm ventilated discs with AP Racing calipers.

Wheels: Dymag carbon fibre/aluminium hybrid wheels.

Dimensions: Length, 3952mm; width, 1836mm; wheelbase 2565mm.

Weight: Dry weight 580kg.

Performance: Top speed 170mph; acceleration 0-60mph 2.7s.

The BAC Mono may be road legal but it's more at home on the race track and the company leant heavily on motorsport technology when designing and building this very rapid machine

From time to time we've all dreamt of building our own car. But the Briggs brothers, Neill and Ian, went a step further when they founded Briggs Automotive Company (BAC) in 2009. This was no pipedream, though, for they had the advantage of a background in an automotive design consultancy which meant they had worked for several automotive A-listers for over a decade, notably Porsche, Mercedes, Smart, AMG, Maybach, Ford and Bentley. They used this experience as a platform to design and build their own car, taking cues from both niche projects and mass-production items to find the perfect formula. Then in 2011 they then launched the world's only single-seat road legal supercar – the BAC Mono.

Mono-poly

The objective was to create a very specialised vehicle that essentially had no competition, with an aim of putting the focus back on driving. It's no surprise then that the Mono is essentially a road-legal racecar. There is currently no competitive category that it fits into, so it is actually a road legal track day car. But perhaps more interestingly the Mono also provides a vehicle for the transfer of technology that first appeared in Formula 1 and other elite racing formulae into the road car arena.

The product strategy is usable power with minimum weight, so anything that saves weight is appropriate. It's always possible to increase horsepower, but weight saving is a more difficult trick. There have been hi-tech materials in racing since the early 1980s and yet very few have made the technology transfer leap into series automotive production. But this kind of technology transfer is a major focus at BAC, both in terms of prototype production and general manufacturing. Critical attention has been paid to the implementation of technology adoption. With its software partners BAC has developed programs to do financial implication 'what ifs' of utilising specific technology, so before anything goes into production there is a detailed breakdown of the costs of the component or development.

Material benefits

The materials in the Mono vary from the use of wood in the plank, much like in Formula 1, to prepreg carbon, inconel, stainless steel and titanium. BAC is also looking to use magnesium and other materials that are outside of the Formula 1 regulations. Carbon fibre wheels are banned in F1, for example, but the BAC uses a carbon fibre/aluminium hybrid wheel to save even more weight. The BAC team, led by its co-founder and design director Ian Briggs, designed the carbon-composite wheels in collaboration with British performance wheel manufacturer Dymag. As well as revolutionising the look of the BAC Mono, the new wheels bring weight and performance improvements – lowering the unsprung mass and rotational inertia of the wheel.

BAC scooped a world first when it became the first manufacturer to develop a car featuring panels incorporating grapheme, an innovative and lightweight material. In a collaboration with Haydale Composite Solutions, BAC created graphene-enhanced carbon fibre composite rear wheel arches. It is significantly lighter and stronger than standard carbon. The use of graphene brings weight reductions of around 20 per cent while producing panels that are 200 times stronger than steel.

The Mono is constructed using high-strength carbon fibre composite around a steel safety cell. The cell is designed for maximum safety and includes an FIA-compliant steel roll over structure, a sophisticated side impact structure and a front carbon crashbox. The chassis is an inconel tubular spaceframe and the bodywork, which is non-structural but has to withstand and transfer the aerodynamic loads, is made from prepreg carbon fibre and graphene and is bolted on to the chassis.

The use of graphene brings weight reductions of around 20 per cent while producing panels that are 200 times stronger than steel

BAC made a conscious decision in the early stages of development to use a spaceframe chassis, because it provided the maximum flexibility for development at reasonable cost. If BAC had elected to go full carbon from the outset it would have been much more difficult to change or modify the chassis once tooling had been produced. The spaceframe is only 48kg and an equivalent carbon chassis would only be about five per cent lighter. It made a far bigger weight saving switching from fibreglass to carbon fibre for the bodywork.

The spaceframe also allows BAC to ring the changes as the vehicle evolves. Having this flexibility is important as it will enable it to accommodate new engines or modify the body or the cockpit width as customers require – it is an essential part of the project that it provides a fully customised vehicle tailored exactly to each driver. In addition to all this, the spaceframe chassis is not as fragile as carbon and is much easier to repair. The chassis structure is said to be very robust for its light weight and torsional stiffness is exactly where it needs to be.

The Mono uses a carbon fibre/aluminium hybrid wheel to help save weight. The tyres have been specially developed by Kumho

Looking BAC

A distinct philosophy has been at the heart of the project since the start. 'We started to have ideas about our own car in 1999,' says Neill Briggs, director of product development. 'We had conversations with racecar makers with regards to how we could do it – we weren't that experienced at the time and learned a lot on this project. For us there was clearly a market made up of high net-worth individuals who had a focus on performance driving. These people were attracted to a low-volume, differentiated product and stimulated by its collectability, desirability and high residual values.'

It was also an opportunity for BAC to take the concept one or two steps further, in terms of its absolute focus. 'Rather than strip out a supercar to save weight on something designed to hold two people and luggage to go to the south of France,' says Neil Briggs, 'we started with a single seat and a blank sheet of paper and designed up from there. The vehicle architecture of only having one seat was the easiest decision we ever made. Formula cars have developed a characteristic layout over the last 40 to 50 years, we've taken that layout and racing design and manufacturing technologies and brought it to the mainstream.'

As well as the single seat the Mono has a longitudinal semi stressed engine. 'We never looked at any other config as that would compromise the ultimate performance goal,' says Neil Briggs. 'The whole concept is about performance and ultra-light weight; another person offset to one side has a bigger impact on a car that only weighs 600kg than it would on a car that weighs one and a half tonne.'

The single-seat philosophy is central to the Mono's design. Airflow traces in a CFD simulation are depicted on this 'Art Car'

Race bred

The Mono is powered by a longitudinally mounted 2.5-litre, 305bhp 4-cylinder engine built by Mountune. This unit is bespoke to the Mono, but it comes from the same family of Ford Duratec engines that Mountune prepares for the World Rallycross Championship, with a special dry sump developed for BAC. This is coupled to an F3 spec 6-speed sequential gearbox from Hewland. The suspension is a fully-adjustable pushrod system with dampers made by Sachs Racing. It is fitted with 295mm ventilated discs with AP Racing calipers.

The Mono weighs just 580kg, which gives it a very healthy power-to-weight ratio of 525bhp per tonne, which is better than hypercars like the Porsche 918 Spyder and the Bugatti Veyron. This propels it to 60mph in just 2.7 seconds and gives it a top speed of 170mph.

Tyre manufacturer Kumho used its motorsport and road car experience to develop a special rubber compound for the Mono, which is designed to work with the low weight and the optimised pushrod suspension set-up.

There isn't much of an interior to the Mono, but what little there is has been immaculately executed. This is certainly not a typical British lightweight special where parts are borrowed from all sorts of vehicles. Rather, this is an immaculate piece of automotive design, every component, weld and join is finished with meticulous attention to detail. The suede-style cabin lining is weather resistant, there's actually room in the footwell for both feet, and enough space in the front boot for a helmet (for track days) and a few travelling essentials.

Brand hatched

With the architecture defined as a single seater racecar for the road, the next challenge was to create the brand aesthetic to establish its position in the 'racecar for the road' market. This is where the brothers' design consultancy background came to the fore. The basic premise was to establish a unique identity and try to avoid 'it's a bit like X' comments.

Surprisingly, the main inspiration for the branding came from the robot in the Bjork *All is Full of Love* music video, which is now in the Guggenheim Museum. The mixture of exposed mechanicals and essential cladding, much like a superbike or MotoGP bike, is the essence of

The car uses a spaceframe rather than a carbon monocoque. BAC says this provides good torsional rigidity at a lower cost

A Mountune-built Ford Duratec sits in the back of the Mono. Rear arches are made of graphene-enhanced carbon composite

The brakes are race specification, featuring 295mm ventilated discs clamped by AP Racing calipers. Hi-tech ceramic brakes for the BAC Mono have been developed by Surface Transforms

The suspension is a fully adjustable pushrod system with Sachs dampers. Such adjustability is crucial on a car that can be used both on the road and on the race track

Low-volume, high-quality racing suppliers have a significant place in BAC's supply chain

the brand. The exposed front forks of the bike correspond to the exposed dampers on the BAC Mono, for example, and as you move backwards more of the mechanicals are on show.

The objective here is to strive for engineering perfection and put it on show rather than cover it up, and so to only put bodywork where it's needed from an aerodynamic point of view, in a classic form following function kind of way. If the ultimate goal is to save weight, why wrap up the engineering when you don't have to?

Art and soul

This branding exercise was so successful that BAC created the 'Art Car' with Autodesk – its technical software partner – where the car is adorned with artwork that reflects the Mono's airflow simulation. The Art Car is painted black with hints of blue and green CFD streamline tracers at the front and with combinations of red and yellow tracers at the back.

BAC's business goal is to take hi-tech concepts, materials and processes from racing and productise them in such a way that they are affordable in the mainstream. The second and probably more important goal is to have an all British and local supply chain. This is fairly easy to achieve given the prominence of British companies in the motorsport industry. Currently 50 per cent of BAC's bill of materials is regionally based, with 98 per cent coming from the UK as a whole. With the BAC Mono being a low-volume, fairly high-ticket price car, it's no surprise that low-volume, high-quality racing suppliers have a significant place in the supply chain.

Pound for pound

But this kind of outright performance and engineering quality doesn't come cheap and the base price of the BAC Mono is £165,000. Some might argue that its natural stable mates are the Ariel Atom and Caterham Super Light – which do cost significantly less. But their performance is not at the same level and, in truth, Mono has no direct competition.

The Mono is a handcrafted custom vehicle that does not share the parts bin of any other car. It has hypercar performance for a fraction of the cost. The engine and gearbox are tried and tested, and its fuel economy is reasonable. Once you have taken it around a race circuit a few times the smile it brings to your face, every time you press the loud pedal, will erase any financial considerations for ever.

Mono is the fastest accelerating rear-wheel drive road car in the world and it demolishes supercar and hypercar opposition on track. Yet it is friendly enough to be driven by enthusiastic, well-schooled weekend warriors. And such is the rate of development and the efforts to 'add lightness' that it is only going to get quicker.

So why isn't it raced? You might be interested to know that a one-make race series is currently under consideration.


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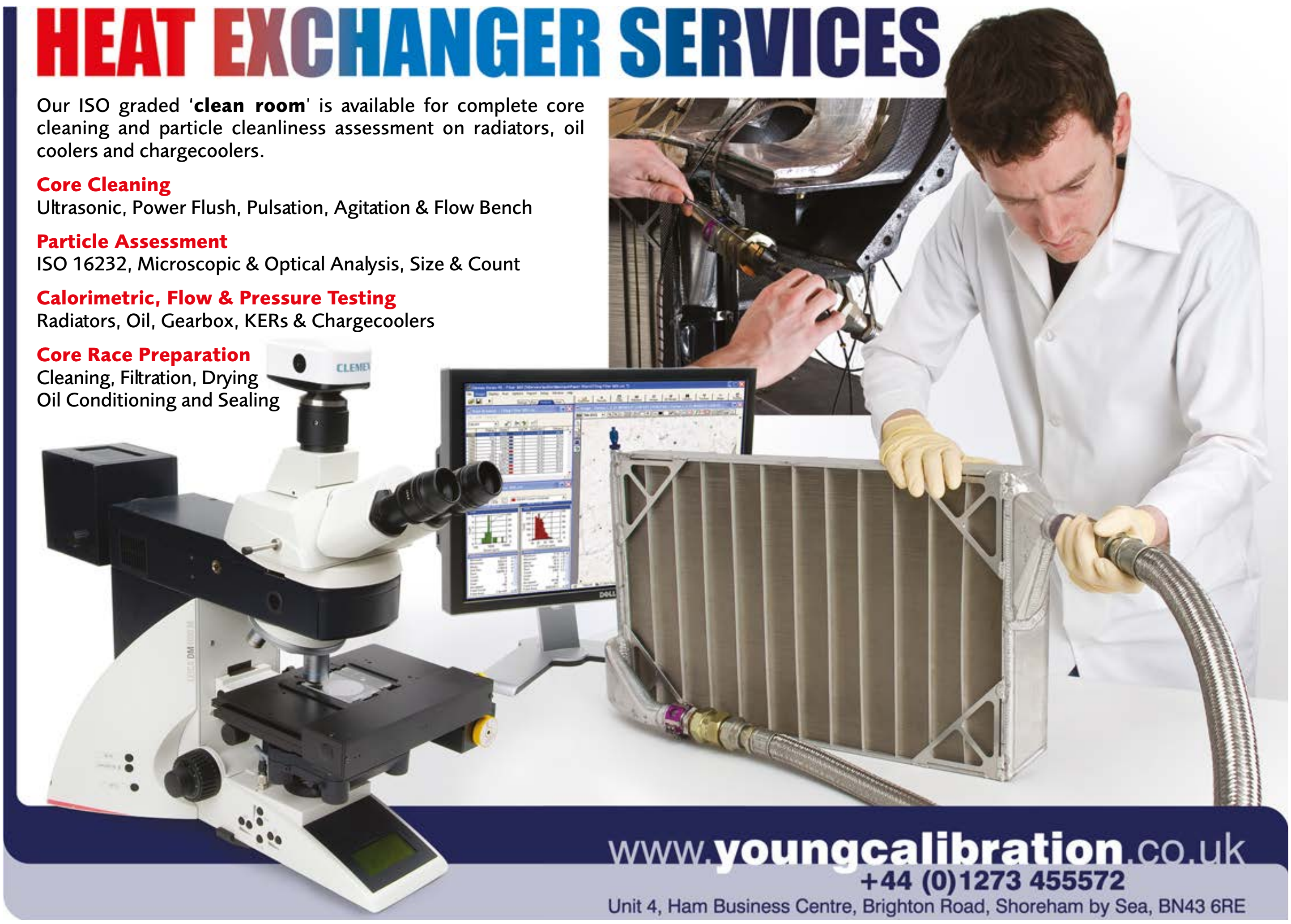
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Cooling versus drag on a BTCC racecar

Could blanking air inlets improve the aero on Team Hard's VW CC?

Having demonstrated inherently low drag by topping the speed trap table in the pre-2018 season test at the UK's fastest circuit, Thruxton, back in the Spring, Team Hard's VW CC came to the MIRA full-scale wind tunnel in the configuration from that test. The baseline numbers showed the drag to be 13 to 14 per cent lower than the two most recent BTCC cars we had tested, the Mercedes A Class and the Subaru Levorg, at similar overall downforce levels. This figure was derived from a comparison of the three cars' CD.A and –CL.A values, the products of the drag and lift coefficients multiplied by the respective frontal areas, in order to be able to make direct comparisons, as shown in **Table 1**. In a category where it is said that low drag is the dominant aerodynamic influence on lap time, given that downforce levels are controlled and very modest, this is obviously useful.

This month we look at how much drag the main cooling system contributes, and also at the effects of changes to rake angle and roll angle on the aerodynamic numbers.

This VW CC BTCC car has proved to be quick on the faster circuits, but is there scope to reduce the car's drag even further?

Table 1: Baseline data from three different BTCC cars derived in the MIRA full-scale wind tunnel in Aerobytes sessions

	CD.A	-CL.A
VW CC	0.763	0.398
Subaru Levorg	0.882	0.400
Mercedes A Class	0.891	0.385

This illustrates that a well-ducted system doesn't impose a large drag penalty

Table 2: The effects of blanking off the cooling system inlet aperture

	CD	-CL	-CLfront	-CLrear	%front	-L/D
No blanking	0.343	0.189	0.151	0.039	79.8%	0.550
Partly blanked	0.336	0.208	0.176	0.032	84.8%	0.618
Totally blanked	0.320	0.230	0.238	+0.008*	103.3%	0.720

**Positive value indicates positive lift, not downforce*

Cooling drag

Cooling is necessary but, done properly, adverse effects on the overall aero can be minimised, while simultaneously cooling efficiency can be maximised. To this end our test car had a well-engineered inlet duct connecting the lower aperture in the front panel to the radiator and the intercooler, with a horizontal vane in the duct splitting the cooling air between the two coolers. The rest of the front panel, except for the brake cooling ducts and engine inlet, was blocked so that air could not bypass the coolers and enter the engine compartment (bonnet shut lines were tight too).

Two trials saw, first, partial blanks taped over the inlet aperture; and second, the inlet was completely blanked off to demonstrate the overall aerodynamic effects of the cooling system. The data are shown in **Table 2** and compared to the previous configuration (which was not the same as our baseline).

The first conclusion is that the effects on the aerodynamic coefficients depended on how much of the cooling inlet was blocked off. Second, drag was reduced and total downforce was increased as the aperture was blocked. And third, front downforce increased but rear downforce decreased, leading to significant forward shifts in downforce balance (%front) as the cooling aperture was blocked.

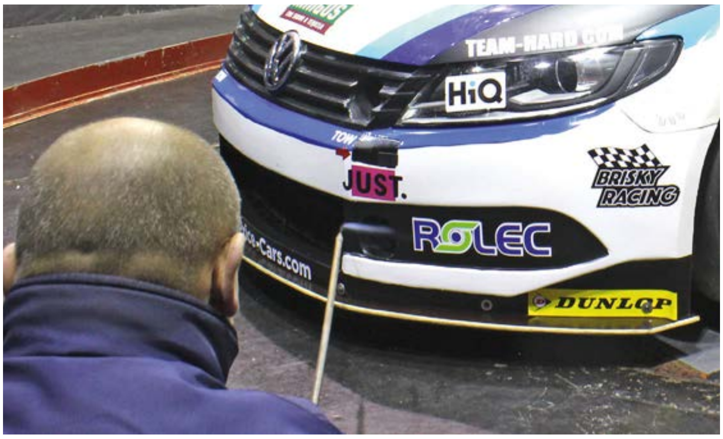
Looking more closely at some of the numbers, partial blocking, as done here, reduced drag by around two per cent and added over 16 per cent front downforce. The team's technical leader, renowned race engineer and designer Geoff Kingston, agreed that this principal might be something to exploit in short qualifying runs where avoiding overheating would be possible, but added that the rules require such modifications to be properly fitted parts rather than just blanking panels.

In overall terms, blanking off the whole aperture saw a relatively modest 6.7 per cent reduction in drag, illustrating that a well-ducted system doesn't impose a large drag penalty. The increase to the front downforce was very significant though, and most likely the result of increased static pressure on the splitter's upper surface plus increased mass flow under the splitter's lower surface generating greater suction there. It's highly unlikely that this configuration would be run at the track, but it serves to illustrate the importance of balancing just the right amount of flow through the cooling system to fulfil the cooling function.

The front brake cooling inlets were located either side of the main cooling aperture in the front bumper. Again, if there was aerodynamic

The front cooling duct was partly blocked; this reduced drag and gained some downforce

Blanking of the front ducts completely resulted in a modest decrease in the car's drag



Brake duct blocking was evaluated but this proved to have little effect on the aero numbers

The rake and roll angle (pictured) effects were also examined, with interesting results

benefit to be had, these could perhaps be blanked off for short qualifying runs. But how much effect would this have? **Table 3** illustrates this, and the short answer was 'very little'. In common with blanking off the main cooling aperture, the biggest effect was on front downforce rather than drag, but the relative magnitude was quite small.

Rake and roll

As delivered to the wind tunnel the car featured 20mm rake over the length of the floor. Two successive adjustments were made to gauge their effect; the rear ride height was lowered by adjusting the suspension pushrods by 20mm to give zero rake; it was then raised 20mm from the baseline position. The results are in **Table 4**.

The responses to these quite coarse changes were thus similar but opposite, relative to the baseline. Levelling the car by dropping rear ride height 20mm reduced the drag by six counts or 1.7 per cent, but front downforce decreased by 53 counts, or 35.1 per cent. Conversely, increasing the ride height by 20mm over baseline added eight counts or 2.3 per cent drag but also added 52 counts or 34.4 per cent front downforce. While drag is said to be the dominant aerodynamic factor in performance, would a 1.7 per cent reduction from running the car flat be noticeable? Maybe it would on faster tracks. Conversely, would 2.3 per cent extra downforce from increased rake be noticeable on slower tracks and would the 34.4 per cent extra front downforce be exploitable?

These are questions that need to be answered through simulation and track testing.

But not before we have examined a 'normal' roll angle to see what the effects were on the numbers. Pushrods and tyre pressures were adjusted on the high rake set-up mentioned above to give a sideways lean of roughly 1.7 degrees, resulting in a 42mm difference in the ground clearance across the splitter. No yaw angle was applied. **Table 5** shows the results. Thus, drag reduced by 6.7 per cent, overall downforce by 32.9 and front downforce by 36.9; rear downforce barely changed.

These significant changes could result from a combination of factors, including reduced ground effect on the high side of the car, and suppression on the low side as it hit the boundary layer above MIRA's fixed floor.

Table 3: The effects of taping over the front brake duct inlets

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.320	0.230	0.235	+0.008	103.3%	0.720
Blanked	0.319	0.232	0.242	-0.012	104.5%	0.726

Table 4: The effects of rear ride height changes

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.343	0.189	0.151	0.039	79.8%	0.550
RRH -20mm	0.337	0.142	0.098	0.044	69.3%	0.421
RRH +20mm	0.351	0.234	0.203	0.031	86.5%	0.668

Table 5: The effects of roll angle

	CD	-CL	-CLfront	-CLrear	%front	-L/D
No roll	0.351	0.234	0.203	0.031	86.5%	0.668
With roll	0.329	0.157	0.128	0.029	81.8%	0.476

CONTACT

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

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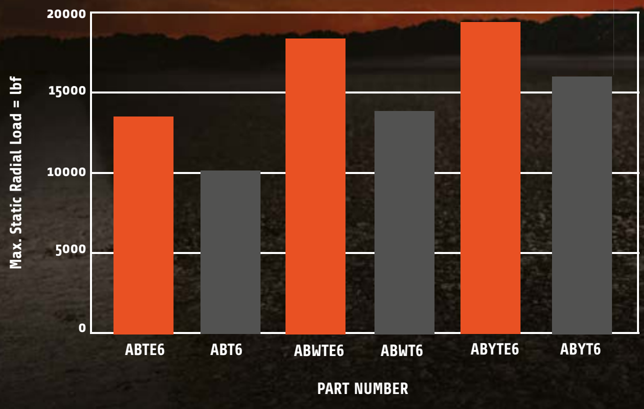

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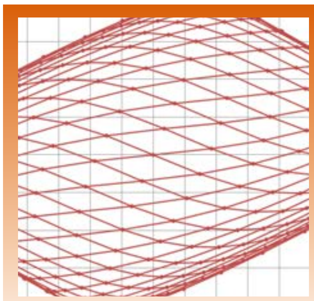

Slip Angle provides a summary of OptimumG's seminars

How to calculate a corner's importance

In Part 2 of OptimumG's explanation of track asymmetry Claude Rouelle looks at the impact of individual corners on lap time

In last month's article we explained how to make use of a GG diagram as a way to understand the race track. By calculating the percentage of distance the car spends in a given area of the GG diagram, we were able to objectively quantify the asymmetry of a track. Based on the amount of time the car spends in each sector of the diagram, we can get a very good estimate of how much distance the car spends in braking, accelerating, cornering and combined situations.

Even though the GG diagram can give us an idea of the asymmetry of the track, it is not able to show us the relative importance of each corner. A slow corner exit followed by a long straight, for example, could have more influence than a high speed corner. When our goal is to quantify the importance of each corner on lap time, we need to make use of simulation. We can, for example, artificially increase the mechanical grip of the tyres by five per cent only in a specific corner of the track. Once we do that for all the corners and check the gains in lap time, we are able to rank them in importance.

Figure 1 shows the lap time gain for each corner at Monza. The y-axis represents the percentage of lap time gain. We can observe, by looking at **Figure 1**, the influence of each corner in the overall lap time. Turn 3 and Turn 5 are the least sensitive to an increment in grip, while Turn 4 and Turn 11 are the most sensitive.

Now if we sum all the lap time gains for left and right turns, we will have, respectively, a total lap time gain of 0.38 per cent and 0.53 per cent, which indicates that we may benefit from having an asymmetric set-up in our racecar here.

Since the GG diagram only considers the resultant vehicle acceleration, it doesn't give us an indication of how much each tyre is being used. However, if we make use of a reliable tyre model and a good simulation tool, we can calculate the sliding energy that is being applied on each tyre, giving us an estimation of tyre usage.

When our goal is to quantify the influence of each corner at the track on the car's lap time we need to make use of simulation

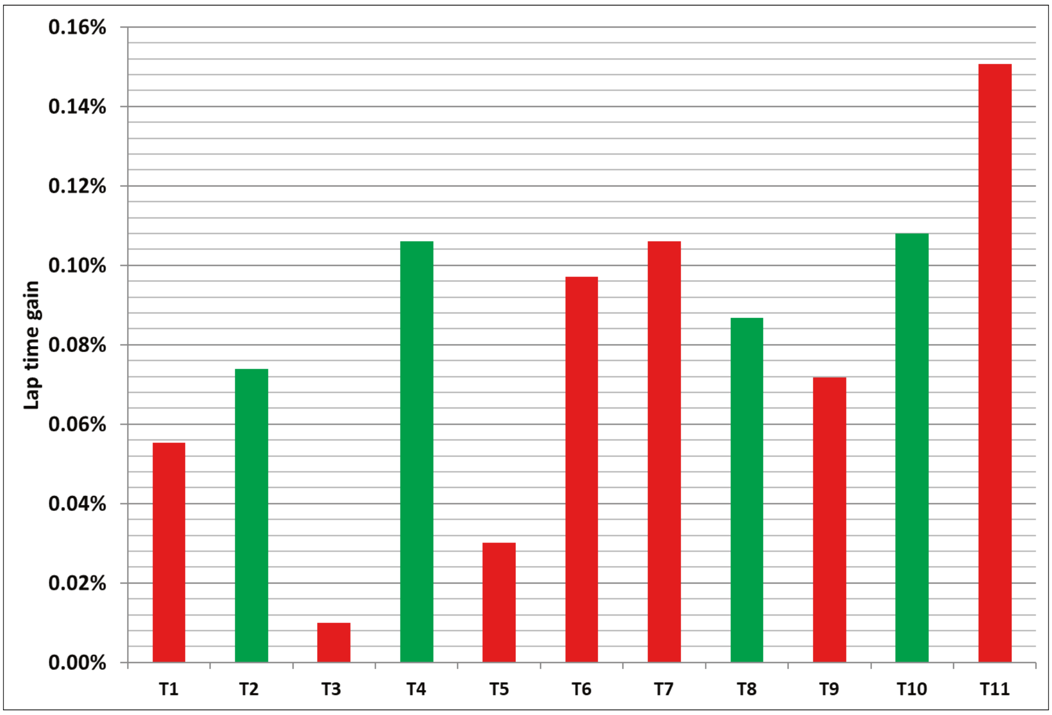

Figure 1: Simulation of a five per cent grip increase *vs* the lap time gain. Red columns are right turns and green are left

Sliding tyre energy

To calculate the sliding power on the tyre, we first need to compute the slip speeds, both in the longitudinal and lateral directions, as described in **Equations 1** and **2** in **Table 1**.

The resultant slip speed is then defined as the vector sum of the longitudinal and lateral slip speeds **(Equation 3)**. The second step is to calculate the resultant tyre force, which is the vector sum of the lateral and longitudinal forces **(Equation 4)**. Finally, the combined sliding power is calculated as the product between the combined tyre forces and the combined slip speed **(Equation 7)**.

If we then integrate the combined tyre sliding power over a full lap, we then end up with the sliding energy of that tyre **(Equation 10)**.

In the equations **V** is the translational speed of the centre of the wheel, **α** is slip angle, **Ω** is angular speed, **SR** is the tyre slip ratio, F_x and F_y are, respectively, the longitudinal and lateral forces in the tyre coordinate system. Linear speeds are given in metres per second, angular speeds in radians per second, angles in radians, forces in Newton, power (**P**) in Watt and energy (**E**) in Joules.

By using the same approach used in the previous article we can divide sliding energy into nine sections: pure acceleration; combined acceleration out of a right turn; pure right cornering; trail braking going into a right corner; pure braking; trail braking going into a left corner; pure left cornering; combined acceleration out of a left turn; and centre of the GG diagram. We can then plot all sections and compare for each track how the tyre energy is distributed.

Figure 2 shows an example of this type of analysis, made for different race tracks.

We can see here how the energy of the rear right tyre varies from track to track. At Spa, tyre energy is concentrated in pure left cornering and combined acceleration out of a right turn condition, while at Silverstone it is distributed between pure right cornering, pure left cornering and at centre. We can also see that at Imola, the only counter-clockwise circuit, tyres spend more energy in right combined acceleration. The different energy distributions shown here can help us make decisions about the amount of damping (compression damping has a huge influence on tyre temperature), toe, camber, cross weight, aerodynamic balance, brake balance, traction control, and differential settings that we will use for each of the circuits.

Total tyre energy

Another effective way of evaluating race track asymmetry is by looking at the difference between left and right tyre energy at both front and rear axles. Left-to-right asymmetry tends to be larger at more asymmetric race tracks. **Figure 3** shows the total energy spent on each tyre, for different race circuits.

We can clearly see that, at Le Mans, front and rear left wheels use more energy than front and rear right wheels. At Imola, the front and rear right tyres are being used more.

Total tyre energy, however, doesn't give you a fair comparison between tracks with different lengths. For example, comparing the total energy at Le Mans, which is 14km long, with Imola, which is 5km long. Therefore, when comparing different race tracks, we need to divide the total tyre energy by the track length, and analyse the tyre energy per kilometre, as shown in **Figure 4**.

We can see that, although, Le Mans is the longest circuit it is the one which uses less tyre energy per kilometre when compared with the other tracks. Paul Ricard and Silverstone have a big difference in the energy used in the front tyres.

Table 1: Tyre energy equations

Equation 1 – Lateral slip speed	$v_{lateral} = V * sin(\square)$
Equation 2 – Longitudinal slip speed	$v_{longitudinal} = V * cos(\square) * SR$
Equation 3 – Resultant slip speed	$v_{resultant} = \sqrt{v_{lateral}^2 + v_{longitudinal}^2}$
Equation 4 – Resultant tire force	$F_{resultant} = \sqrt{F_X^2 + F_Y^2}$
Equation 5 – Longitudinal sliding power	$P_x = F_X * v_{longitudinal}$
Equation 6 – Lateral sliding power	$P_y = F_Y * v_{lateral}$
Equation 7 – Combined tire sliding power	$P = F_{combined} * v_{combined}$
Equation 8 – Longitudinal sliding energy	$E_x = \int P_x$
Equation 9 – Lateral sliding energy	$E_y = \int P_y$
Equation 10 – Resultant sliding energy	$E = \int P$

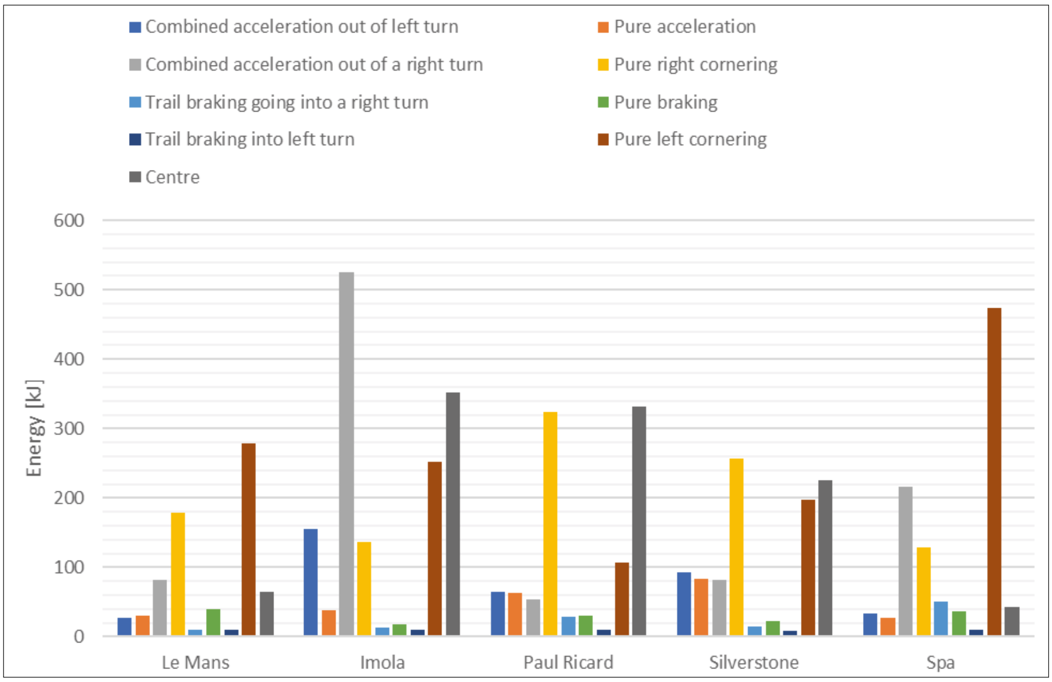

Figure 2: Total energy distribution of rear right tyre during a lap at different tracks. Note pure left cornering at Spa

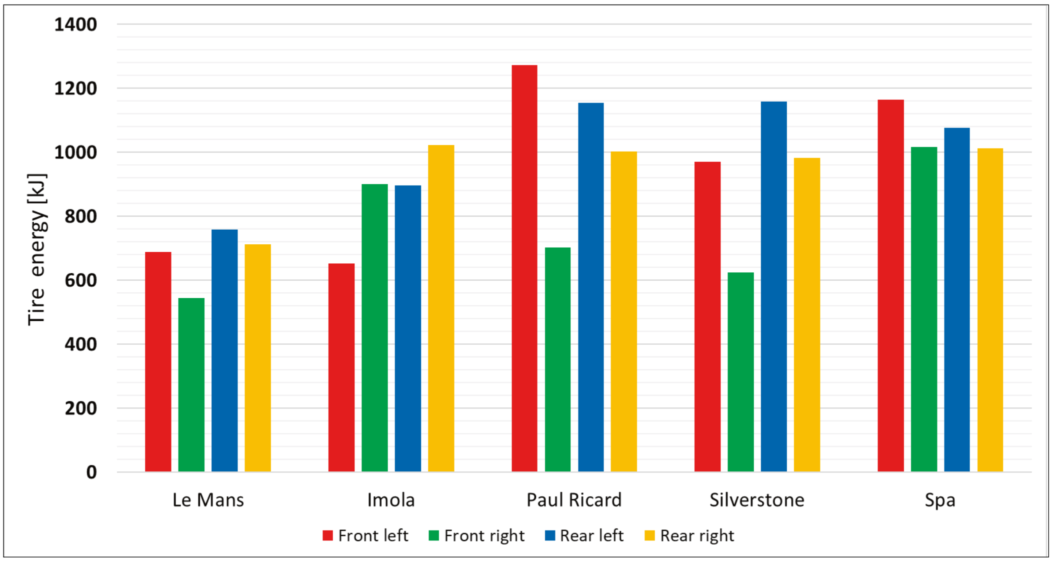

Figure 3: Total tyre energy in each wheel at different tracks. Note that at Imola front and rear right tyres are used more

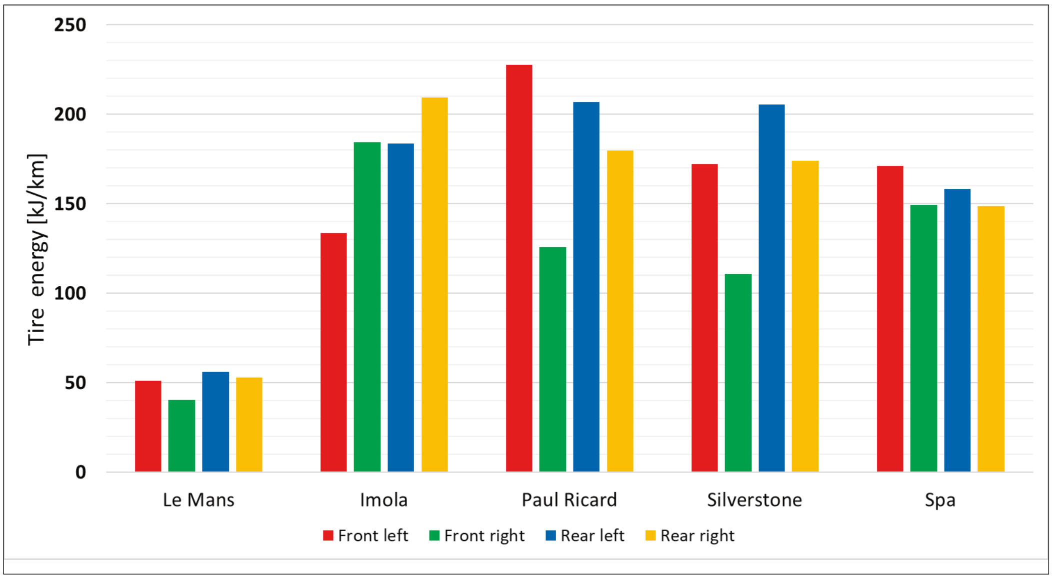

Figure 4: The tyre energy per km at different tracks – this is required as these race circuits are all of different lengths

Table 2: Front/rear and left/right energy calculation

$$Front/rear\ Energy\ Distribution = \frac{(FL\ Energy + FR\ Energy)}{(FL\ Energy + FR\ Energy + RL\ Energy + RR\ Energy)}$$

$$Left/right\ Energy\ Distribution = \frac{(FL\ Energy + RL\ Energy)}{(FL\ Energy + FR\ Energy + RL\ Energy + RR\ Energy)}$$

FL = front left, etc.

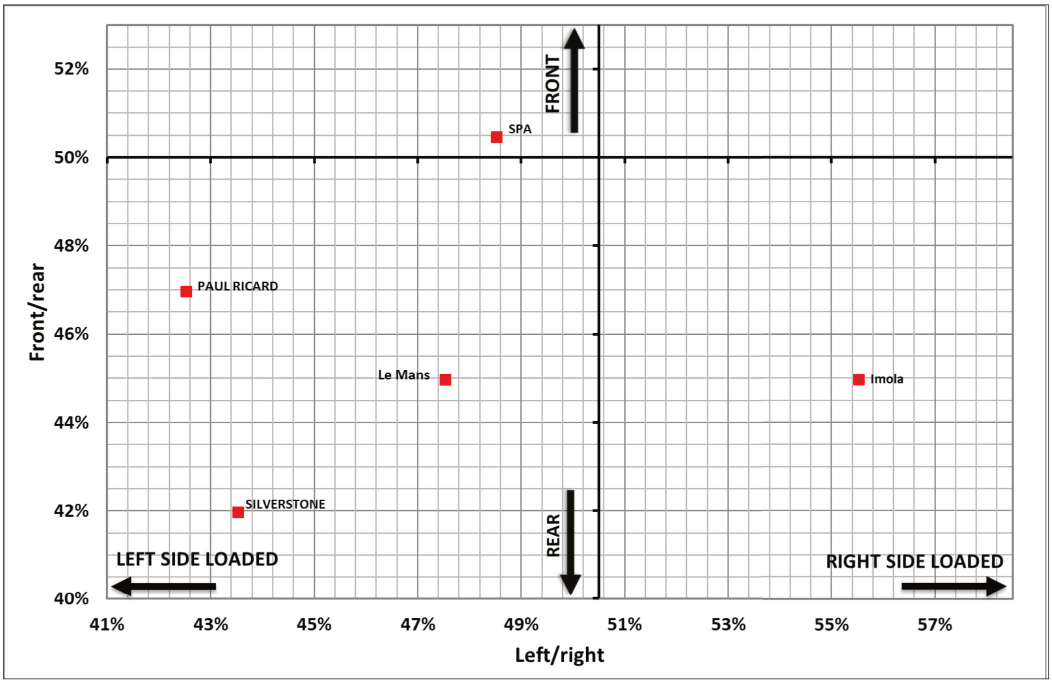

Figure 5: This gives us a visual reference as to how the sliding energy is distributed between tyres at different tracks

Although Le Mans is the longest circuit, it is the one which uses less tyre energy per kilometre when compared with the other race tracks

Spa actually has an even energy distribution between all the tyres, suggesting a symmetrical track.

Another method of comparing different race tracks is by calculating the front-to-rear and left-to-right tyre energy distributions, as shown in **Table 2**. Once we calculate these values for different circuits, we can plot them in a chart, as shown in **Figure 5**. This chart gives us a visual reference of how the sliding energy is being distributed between the tyres at different race tracks.

Conclusion

Even though the GG diagram we explored last month is useful, we can only draw a few conclusions on the characteristics of the race track, since all corners are assumed to have the same importance on the lap time. That's why it is necessary to make a second analysis using simulation.

Running simulations with varying grip factors allows us to understand the relative importance of each corner. By increasing the grip by five per cent in one corner at a time, we can understand which corners have the biggest influence on the lap time on a given race track.

Finally, we should also look at the energy spent by each tyre to better understand the work in each tyre. The goal is to make the tyre work in its ideal ranges of pressure, camber and temperature for its operation conditions. These conditions are defined by both the track layout (turn direction, cornering speed) and vehicle design/set-up parameters.

In this article we described another method to characterise a race track, and why you might want to run your car with an asymmetrical set-up. This and other methods are discussed in depth at the OptimumG Data Driven Performance Engineer Seminar. We explain, step by step, how to process the data, make interpretations, and draw valuable conclusions. To find out more about the seminars' content and dates, visit us at optimumg.com

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Peak performance

There's much more to aero development for the Pikes Peak Hillclimb than merely bolting on a massive wing, as the first part in our new Chevrolet Corvette CFD study clearly shows

By SIMON McBEATH

The Rotek Racing Chevrolet Corvette Z06 takes the flag at the top of the Pikes Peak Hillclimb course last year. It finished in 17th overall and was fourth in its class (*Larry Chen*)

Rotek Racing's managing partner Robb Holland took his Chevrolet Corvette Z06 to Pikes Peak in 2017 and, according to the official results, netted 17th place overall for cars with a very creditable fourth in the Time Attack 1 class. Holland says: 'We did a last minute build of the car for the 2017 event with a wing and splitter thrown on to give it whatever downforce we could get. This year we are looking to do a chassis-up build that is more of a racecar than a street car with some aero thrown at it.'

The objective for 2018, then, was to improve in all areas, including aerodynamics. And so *Racecar Engineering* took on the task of developing the aerodynamics of the Rotek Racing Chevrolet Corvette Z06 for the world-famous Pikes Peak International Hillclimb (PPIHC).

The project came about following a conversation between owner/driver Holland and *Racecar's* editor at PRI late in 2017, with the original idea being simply to apply some lessons learned from CFD projects on our generic digital GT project car, as showcased in previous issues.

However, your writer had been working with occasional wind tunnel test colleague James Kmieciak ('JK') of Black Art Customs, a specialist in the application of contemporary 3D processes including CAD and CFD, on the creation of improved CAD models for CFD projects for this journal. JK's ability to produce CAD models with a representative level of accuracy and fidelity – yet which did not contain superfluous detail that would needlessly consume computing resources and which would mesh with minimal issues – was going to be invaluable. Such models are incredibly useful for analysing and developing aerodynamic packages at what might be called the macro and meso levels, and the micro level was neither attainable on the available

Table 1: The aerodynamic coefficients on our Corvette Z06 road model, derived in ANSYS CFD-Flo

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Road model	0.372	0.010	-0.026	0.035	-263.8%*	0.026

**The value for %front seems anomalous because it is large and negative*

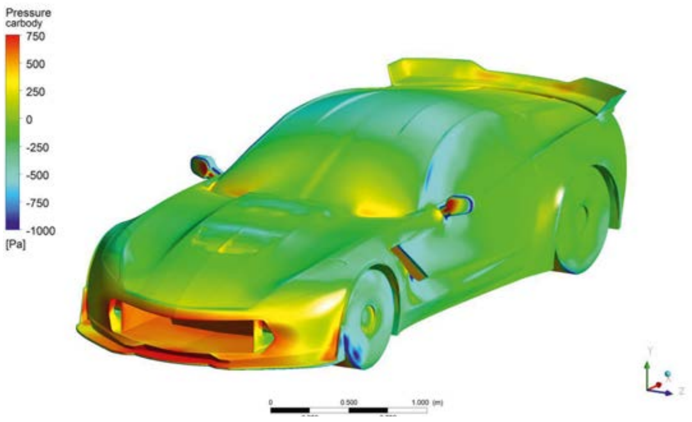
computational resources, nor essential in this, the early stages of development. In short, aerodynamics can be driven into the right ballpark using this approach.

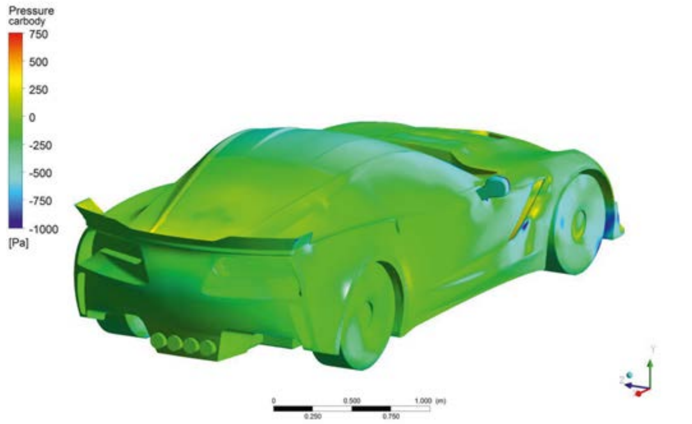
Project strategy

The first stage, then, was for JK to generate a model of the Corvette Z06 body using (validated) online resources plus measurements and photographs supplied by the team, to which your writer subsequently added simple wheel and tyre models using the sizes specified for the road car, along with simplified suspension. This was then used to ascertain satisfactory CFD conditions and to produce comparison data on the road version of the model using ANSYS CFD-Flo. Given that our models were necessarily simplified compared to reality, the actual forces and coefficients we obtained were of less interest than the delta values, that is, the changes brought about by modifications, and these are what drove the development through its various stages. Nevertheless, the comparison between our road model and real data was irresistible, as we shall see shortly.

One further simplification is that with no apparent facility to alter the density of the air in CFD-Flo simulations to reflect the reduced density found at PPIHC altitudes, all runs were carried out at mean

Aerodynamics can be driven into the right ballpark using this approach





Figures 1 and 2: The pressure highs and lows on the road model of the Corvette go some way to revealing the sources of drag, lift and downforce in the car

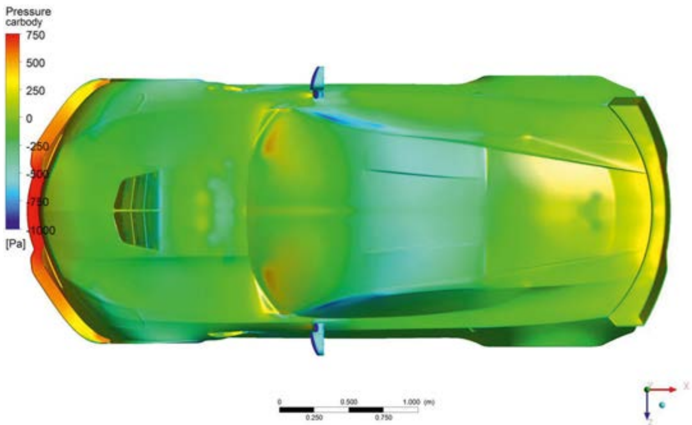


Figure 3: Suction over bonnet and roof is offset by pressure on splitter and rear deck

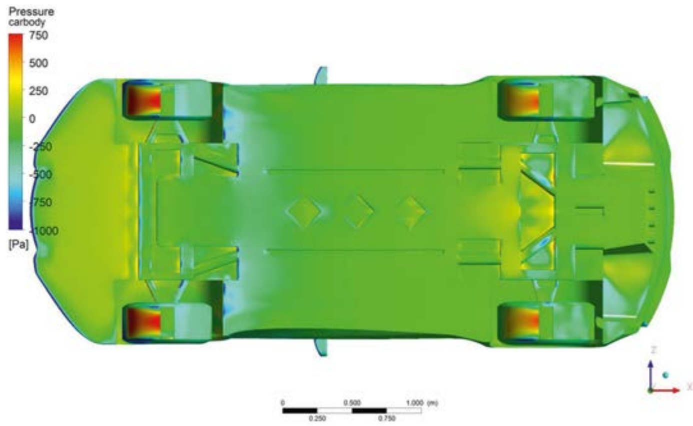


Figure 4: Pressure was actually raised under most of the road model's splitter

Figure 5: Pressure readings on the symmetry plane show pockets of high pressure

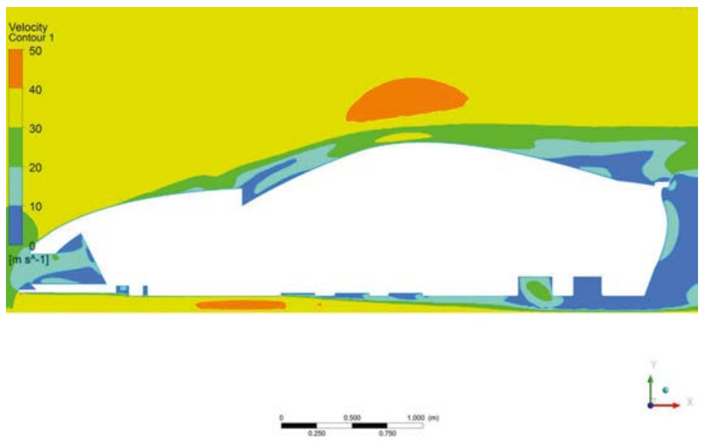


Figure 6: Rough underside created a thickening boundary layer under the rear of car

sea level pressure and 25degC. This was not felt to be an issue, having no appreciable effect on the proportionate delta values and trends observed. However, the simulated air speed was reduced from our usual 100mph to 80mph, so that the Reynolds Number was akin to that at 100mph at the average altitude (and reduced air density) of Pikes Peak International Hillclimb, giving flow similarity.

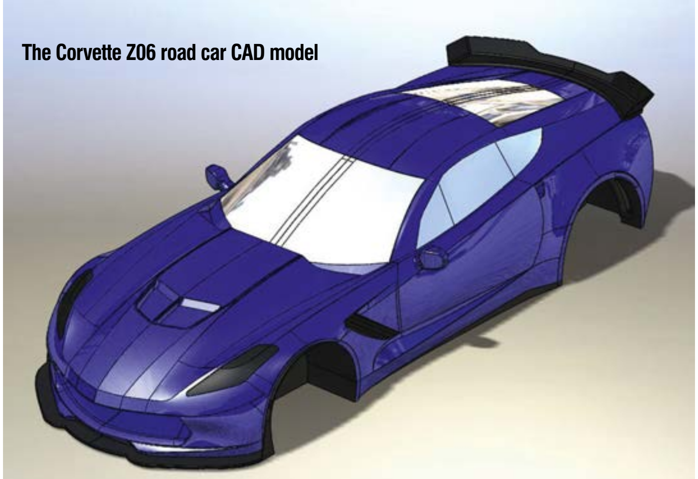
Once satisfactory CFD parameters had been derived on the road model, including rotating wheels and moving ground, and baseline data had been obtained, the model was then modified in line with the 2017 racecar, the starting point for the subsequent incremental development approach.

Front first

The focus was initially directed at the front end of the car, for two reasons. First, it was going to be straightforward obtaining enough rear downforce by either increasing the rear wing angle above the shallow angles used in 2017, or by fitting a more aggressive rear wing; and second, consideration had to be given to the manufacturing times on the front end components, and with the project not starting until Spring 2018 the schedule was tight.

The data obtained on the road model are given in **Table 1** as coefficients for easy run-to-run comparisons. In short, the model showed modest drag and a very small amount of total downforce, amounting to some 19N (2kg or 4.4lb) at test speed. The aerodynamic balance actually showed a small amount of front lift (a negative –CLfront value) and a not quite so small amount of rear downforce. Brief internet research revealed quoted values of 0.34 to 0.37 for the drag coefficient of the Z06, so the value of 0.372 on our simplified model was of the right order. No published values were found for the vertical coefficient of the real car, but our first run showed an essentially neutral car that would not change its vertical forces, aerodynamically anyway, across its speed range, which would seem like a reasonable premise for a road car.

Pausing briefly to examine the pressure plots on the road model reveals some pointers to where developments needed to be focussed **(Figures 1-6)**. As ever, yellows and reds indicate where surface pressure was raised, greens and blues where it was reduced, and the sources of



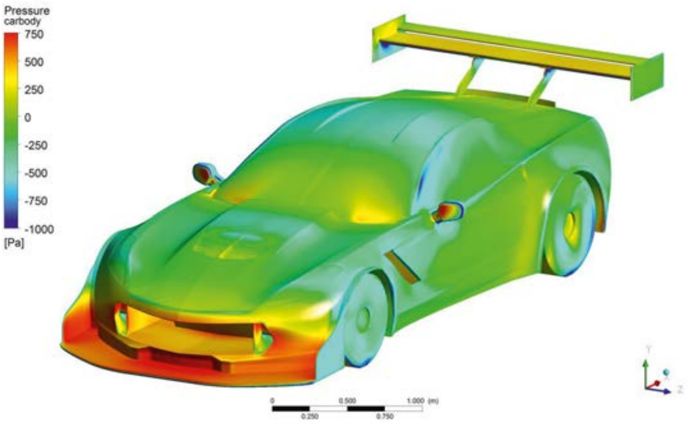


Figure 7: The 2017 racecar's more effective splitter produced some useful downforce

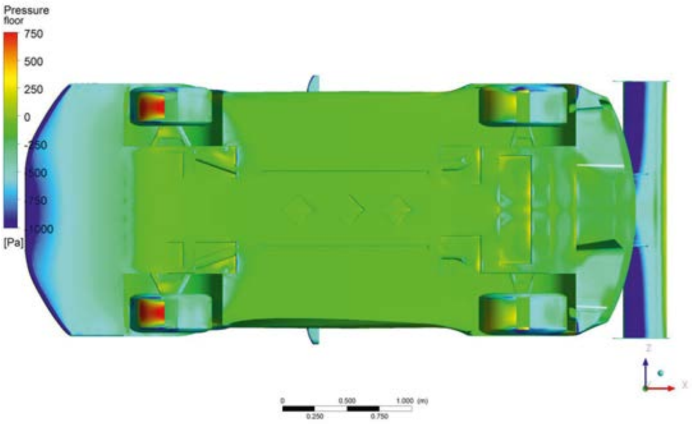


Figure 8: The pressure was negative under the 2017 baseline racecar's splitter

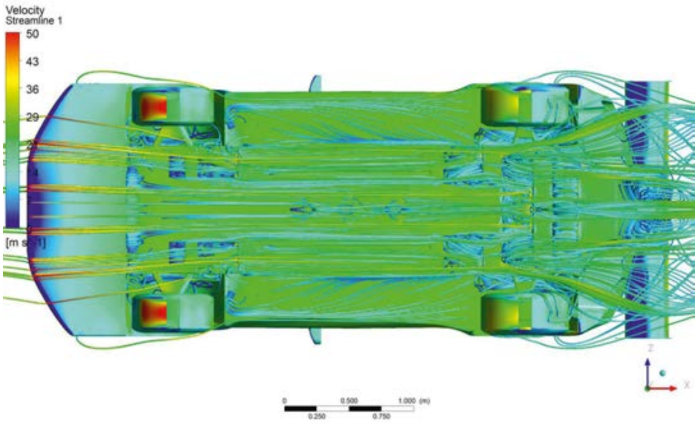


Figure 9: It was evident that the rough underside of the racecar disrupted the flow

Table 2: The 2017 baseline racecar aerodynamic data

	CD	-CL	-CLfront	-CLrear	%front	-L/D
2017 car	0.457	0.650	0.370	0.280	56.9%	1.421

drag and lift/downforce, become evident. The road model was given a rough underside to make it more representative of the real car which, although relatively tidy for a production car, still featured bumps and cavities. And these can be seen to create pockets of raised pressure on the underside as well as contributing to the thickening of the boundary layer of slow-moving air under the rear of the car, as shown in **Figure 6**.

Another key aspect is that most of the underside of the splitter was at slightly raised pressure, and this was because it was slightly higher than the main floor of the car. This reflected that on the real car the cross members carrying the bottom suspension arms, and the rest of the underside, were lower than the splitter's underside. This created blockage, leading to the raised pressure under the splitter.

On the other hand there was reduced pressure under much of the floor, especially just behind and inboard of the car's front wheels. And there was raised pressure on top of the splitter and ahead of the rear spoiler, which collectively just about redressed the reduced pressure over the roof and the forward regions of the car's upper surface.

Racecar 2017

Next, the road model was modified to represent the car as it was run at PPIHC in 2017. This included slightly altering the wheel and tyre sizes, along with the ride height and rake to dimensions supplied by the team.

The primary downforce inducing devices, comprising a simple but quite substantial, inclined, flat splitter with large end fences and a modestly cambered, shallow angle dual-element rear wing, were also added, again based on CAD data and information from the team.

The rough floor of the road car was retained, as it was on the 2017 racecar. The splitter was now lower than the main floor, even at its trailing edge, so there was no forward facing blockage, as seen on the road car. The set-up of the splitter, tilted 25mm overall with the leading edge down at 50mm ground clearance, and shallow rear wing angle, had been derived at the 2017 event and produced a balance with which the driver was happy: 'We were aiming for a somewhat front biased aero balance last year as with the steepness of the hill we tended towards understeer,' Holland tells us. So it was going to be interesting to see what the first CFD run on the racecar specification produced. The data are shown in **Table 2**.

These results were not unreasonable for a car with no aerodynamic development, and the %front figure tallied nicely with the driver's view that the car's aerodynamic balance had been slightly forward biased. However, total downforce could undoubtedly be increased from this starting level.

Analysis

Pausing briefly to study three visualisations, **Figure 7** shows how the bigger splitter produced a larger area of raised pressure on its upper surface, aided by the end fences; and the rear wing and part-width body Gurney that replaced the rear spoiler of the road car. **Figure 8** shows much reduced pressure under the 2017 racecar's splitter, and the low pressure on the wing underside. The rear underside of the car was also at lower pressure than the road car's, as shown in **Figure 4**. And **Figure 9** shows streamlines projected upstream and downstream from the floor, and

'We were aiming for a somewhat front biased aerodynamic balance last year as with the steepness of the hill we tended towards understeer'

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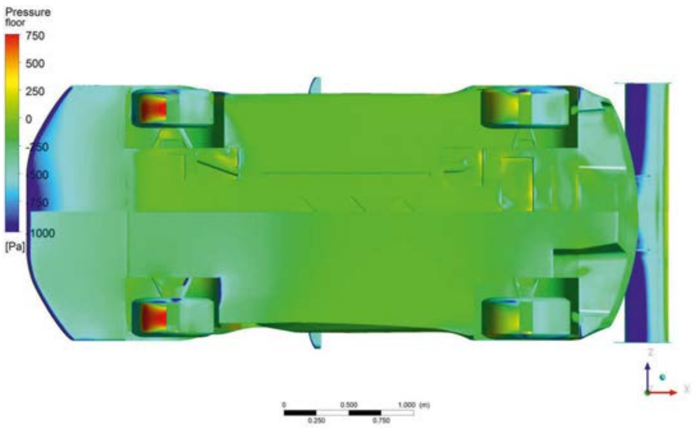


Figure 10: Underside pressures changed to those shown in the lower half of this image

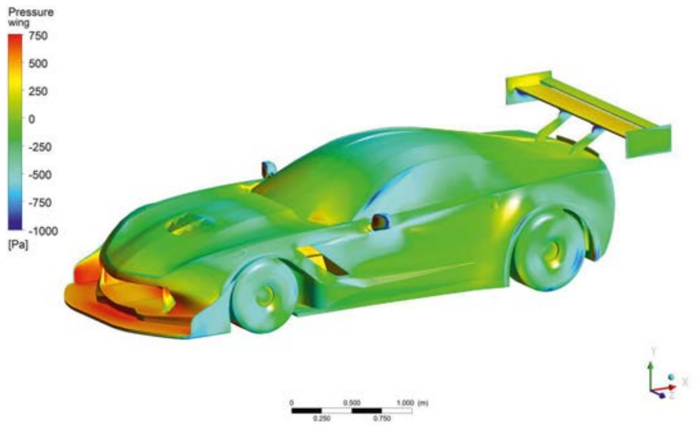


Figure 11: Here the wheel arch extractor can be seen aft of the front wheel

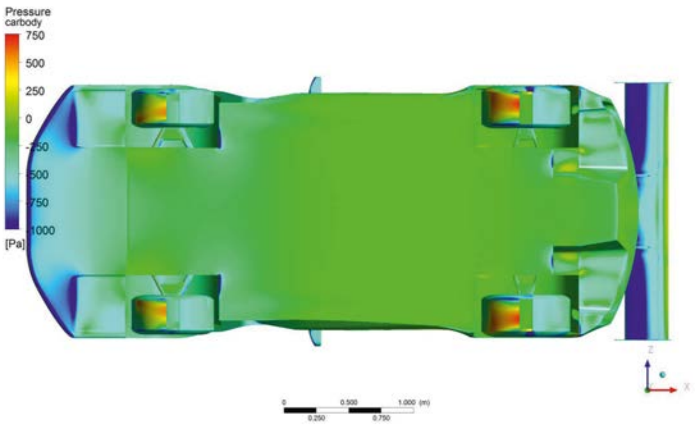


Figure 12. The first front diffuser increased splitter downforce but needed optimising

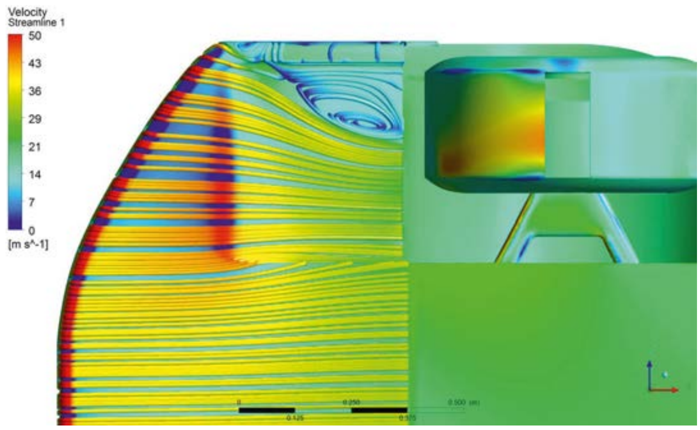


Figure 13: Stall could be seen in the outer section of the first front diffusers we tried

Removing the tilt in the splitter enabled overall downforce to increase by over five per cent

illustrates well the disruption caused by the roughness here.

In keeping with the strategy, the first part of the project focussed on essentially front end modifications, and this included integrating the front underside with the rest of the racecar's floor. The rationale behind these first steps was to improve the overall performance of the floor with a view to then adding front diffusers on the way to maximising front end downforce.

The first step involved removing the tilt from the splitter by raising its leading edge, mainly because it was already grounding too frequently, causing damage as well as restricting mass flow under the car. Thus the splitter underside was now parallel to the floor but 25mm lower.

Removing the tilt enabled overall downforce to increase by over five per cent and the main beneficiary was the floor thanks to that increased mass flow. Balance shifted rearwards to just under 51 per cent front, the splitter obviously losing some downforce at this stage simply because of its increased ground clearance.

Next, the simulated roughness in the floor was removed to create an entirely smooth floor (at the same height as the original floor); rake was 20mm, as run in 2017, measured at the front and rear of the side sill. This added nine per cent more total downforce for no change in drag, and once again the floor was the principle contributor here, with the pockets of raised pressure having been eradicated. Aero balance again migrated rearwards to just under 48 per cent front.

False bottom

Wheel sizes and geometry meant that it wasn't going to be possible to lower the car on its suspension, yet the floor of the car was well clear of the ground. So a 25mm lower false flat floor was incorporated, such as might be achieved with 25mm thick honeycomb panel, and the splitter underside was aligned with this lower floor plane with the same 20mm rake along the side sill. This boosted floor downforce by a further five per cent, but splitter downforce reduced so that overall downforce was the same as the previous run, and balance shifted slightly further rearwards.

The car runs in the Time Attack 1 class which has refreshingly open regs (*Larry Chen*)

Lastly in this initial phase the lower part of the wheel arch and forward sill behind the front wheels was sculpted away (hopefully compatibly with the chassis structure within) to provide improved egress for air flowing from under the splitter and within the wheel arch. A floor panel extension was also inserted behind the front wheel.

This wheel arch modification was really in preparation for the next phase. However, even at this stage it produced a 3.8 per cent increase in total downforce, with both the splitter and floor seeing downforce increases. The predominant gain was once more from the flat floor, so balance again shifted slightly rearwards to finish this first stage at 45.5 per cent front, ordinarily an acceptable figure but our target figure was in the mid-50s.

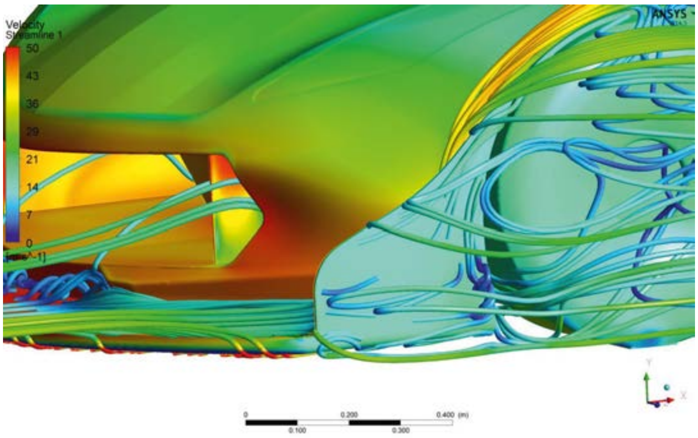


Figure 14: Flow separation on outer faces adversely affected the flow under outer ends

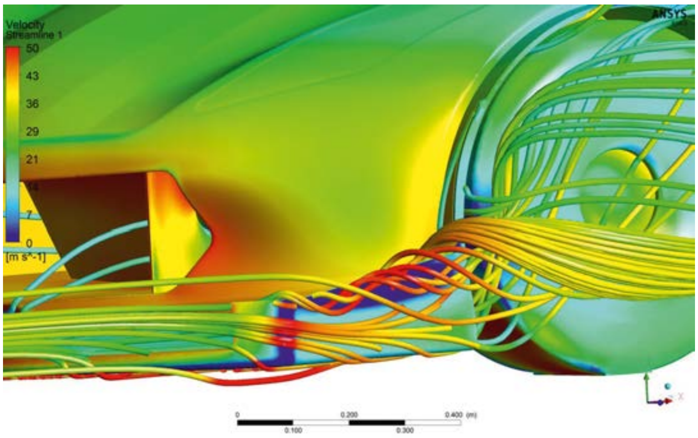


Figure 15: Longer and not so high fence allowed energetic air under the splitter ends

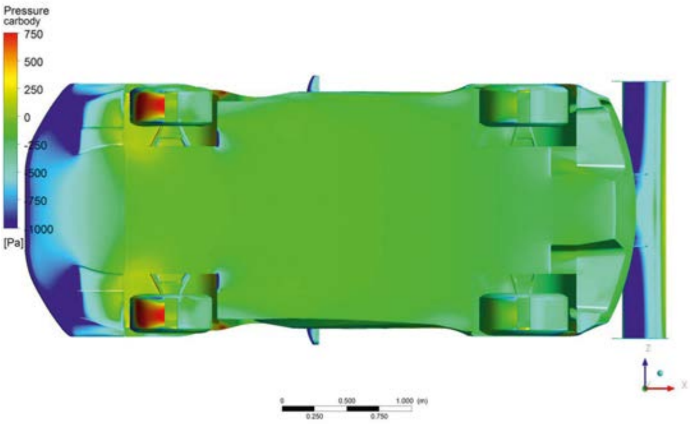


Figure 16: The modified end fences and angled walls improved the dual-height diffuser

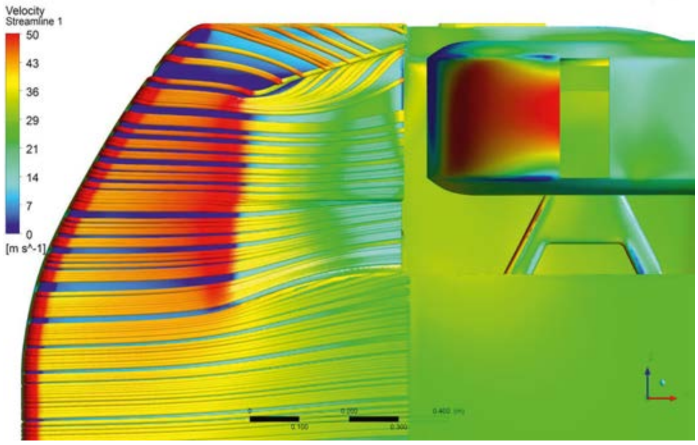


Figure 17: Instead of stall there was an energetic vortex that helped increase suction

Last year the aero package on the Rotek Racing Corvette was rudimentary (*Larry Chen*)

Nevertheless, so far we had reduced drag by 4.4 per cent and increased downforce by 18.8 per cent.

Figure 10 compares underside pressures between the start and end of this first phase, **Figure 11** shows the front wheel arch extractor.

Front diffusers

The first steps had usefully improved the performance of the floor, so next some front diffuser options were evaluated in order to shift the balance forwards while adding more total downforce. A simple parallel sided diffuser **(Figure 12)** increased splitter downforce by over 21 per cent compared to the previous run, with balance shifting forwards to exactly the same value as the 2017 baseline at 56.9 per cent, total downforce now being 24 per cent more than that first run. JK then implemented a dual-angle front diffuser he had applied to the RCM Gobstopper 2 Time Attack Subaru we featured in Aerobytes in 2013. The angle of the diffuser ahead of the front tyre was shallower than the angle ahead of the chassis-tyre gap (where greater mass flow can be channelled). This added another 7.5 per cent splitter downforce and 1.7 per cent total downforce, with the balance now at 60.2 per cent.

However, inspection of the pressures and streamlines in both front diffusers showed that stall was occurring **(Figure 13)** in the outer sections, so the angle of the outer wall was changed from parallel to the car's centreline to divergent, a feature that had helped on previous projects by creating a vortex inside the outer wall that increased suction and helped maintain flow attachment.

Unexpectedly this did not help, and attention switched to the flow separation on the outside faces of the tall splitter end fences that appeared to be related to the flow passing under the outer ends of the splitter **(Figure 14)**. So a further measure known to be beneficial from previous projects (and shown to work in Aerobytes sessions) was to cut down the height of the end fences and also to extend them forwards and around the splitter's curved corner for a short distance **(Figure 15)**. Satisfyingly, this enabled a significant increase in the performance of the single height front diffuser and the dual height diffuser, which now also incorporated the divergent outer wall **(Figures 16** and **17)**. At this stage we had achieved 35.5 per cent more total downforce with a 4.2 per cent drag reduction, and balance was close to target at 55.2 per cent front.

Ducting

As configured in 2017 there was no ducting leading to the coolers in the front aperture of the car, and our starting CAD model was configured in a similar way. This meant that air was able to bypass the coolers and enter the front compartment, which would have contributed to reduced cooling efficiency as well as reduced aerodynamic efficiency. There were 'gill' exits on either side of the front wheel arches to vent some air from the engine bay. So the next phase of the CAD/CFD project looked at adding a duct on the inlet side of the radiator (just one in our simulations), a full exhaust duct (a partial one was installed from the outset), and also at blanking off the apertures either side of the radiator duct, previously open into the engine bay.

Finally louvred apertures were installed in the bonnet, but constraints on the CAD model in this area meant that only a part of

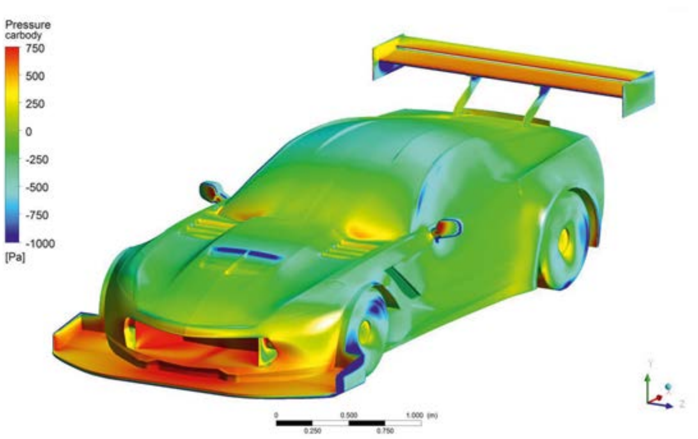


Figure 18: With wide splitter a near maximum wing angle was needed for aero balance

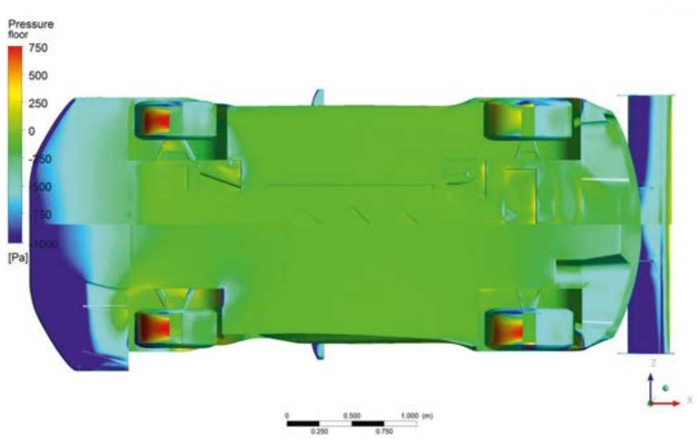
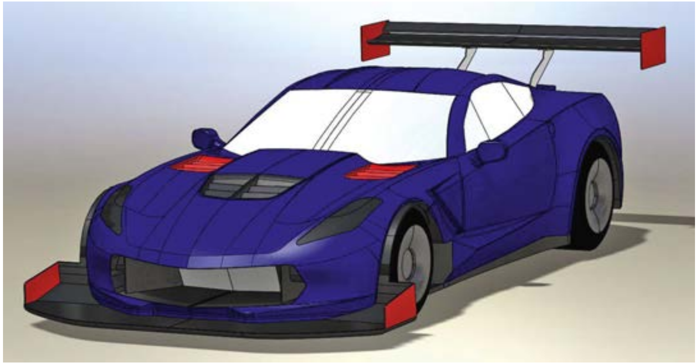


Figure 19: Baseline car's underside (upper half) is compared to the final variant



The phase 1 2018 aero CAD model. We will be developing this further in a future issue

Rotek Corvette in the Top Paddock at the Pikes Peak Hillclimb last year (*Robb Holland*)

Table 3: Data following the balancing wing adjustment, with changes shown in percentages

	CD	-CL	-CLfront	-CLrear	%front	-L/D
2017 PPIHC	0.457	0.650	0.370	0.280	56.9%	1.421
Run 21	0.588	1.335	0.758	0.577	56.8%	2.272
Change, %	+28.7%	+105.4%	+104.9%	+79.6%	-0.01%*	+59.9%

** Absolute rather than relative difference in percentage front*

the desired region could be opened up on the model. With the most successful combination of ducting and blanking panels employed, plus the bonnet louvres, drag reduced by 9.4 per cent, total downforce increased by 1.2 per cent, leading to an 11.7 per cent increase in –L/D, and balance moved forwards to 58 per cent front. In terms of the effects on component groups, body lift and splitter downforce both increased, these responses probably the result of more mass flow going over and under the racecar, the latter outweighing the former and being responsible for the overall downforce increase and forwards balance shift.

With the rules essentially open in the Time Attack 1 category, the owner/driver was asked if a sideways splitter extension could be used in this class. The response was 'yes, but by a maximum of 150mm each side, mainly for aesthetic reasons.'

So JK extended the splitter and the front diffuser on the CAD model by 150mm sideways. The ensuing increase in total and front downforce was much bigger than expected, although there was also a drag penalty, probably much of this from the detail of this first iteration. Drag increased by over 23 per cent and total downforce by about 15 per cent, so the efficiency of the modification was not good. However, thanks largely to a 47 per cent increase in splitter downforce the balance changed to 82.6 per cent front.

Now, this level of front end downforce raised the question of whether the current rear wing was going to be capable of balancing the front. For the next run, which happened to be Run 21, the wing was set at what was expected to be close to the maximum possible main element and flap angles. Perhaps fortuitously with this first wing angle adjustment, balance was almost exactly the same as the Run 1 target value at 56.8 per cent front. The full set of coefficients is shown in **Table 3**, with the Run 1 data for comparison. **Figures 18** and **19** illustrate.

Double downforce

Over this whole sequence of modifications drag increased by less than a third while total downforce more than doubled, efficiency increased by nearly 60 per cent and balance remained exactly the same.

In force terms at the 80mph test speed (at sea level), downforce went from around 2kg (4.4lb) on the road model, to 132kg (290.4lb) on the 2017 baseline model, to 272kg (598.4lb) in this last reported run. That force would scale up by the square law to around 425kg (935lb) at 100mph, and 612kg (1346.4lb) at 120mph.

The next step

Further modifications have been done on rear diffusers along with some rear wing and rake mapping, but at this point a line was drawn, partly because of available space in these pages, but also to enable the major body parts that were defined in this short project to be manufactured (hopefully) in time for the 2018 event, which will have just taken place by the time this issue is published.

At the time of writing in early June, ECU issues may have precluded the car running at all. But if it does not make PPIHC in 2018, it certainly will in 2019. Meanwhile, the next challenge in 2018 could be tackling the Nurburgring Nordschleife, which will surely require a re-think on the car's aero balance. *Racecar* will return to this project in a future issue.

Over this whole sequence of modifications to the Corvette model, drag increased by less than a third while total downforce more than doubled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The Victoria line

A hi-tech race motor needs a hi-tech build approach, so you can be sure that the Ricardo production line on which McLaren's GT units are assembled is every bit as impressive as the engines themselves. *Racecar* visited 'Victoria' to find out more

By GEMMA HATTON

There are over 250 main parts that make up a McLaren Automotive race engine. Which begs the question, how on earth do you go about piecing them all together? Well, you would have to go to Victoria to get an answer to that.

Victoria is the codename for the Ricardo High Performance Assembly Facility in Shoreham, and this is where the company has built and assembled every McLaren road and GT race engine since 2011. These have included the one-make series 570S GT4, the McLaren 12C GT3 which has claimed four championships and 60 race wins; and the latest 650S GT3 currently competing in this year's Blancpain GT series.

'We now have the capacity to assemble over 20 engines per day across two shifts,' says Steve Milton, the head of operations at Ricardo. 'Originally we produced around 600 engines a year but our capability has developed significantly and we can now produce around 4500 engines a year. With the GT3 engine build now finished, we predominantly assemble the GT4 variants, which this year will probably account for two to three per cent of the total volume we produce on the line.'

The beauty of this facility is the innovative lean manufacturing strategy which allows both the automotive and race engines to be assembled on the same line. This is achieved through the 'any engine, any order' concept which is essentially where each engine is loaded on to the line as a totally unique build.

The process consists of 10 stations, each with a 40 minute cycle time. The engines move through each stage along the horizontal indexing line

'The great thing about "any engine, any order" is that you can pick the complexity of the part that needs to be assembled and the equipment is capable of coping with all the different variants,' says Daniel Hall, head of new product introduction at Ricardo. 'This means we can do anything from a continuous build of road car engines to support a new vehicle launch to a totally bespoke one-off for a racecar engine. The hi-tech, flexible engine line gives you the best of both worlds; the skilled assembly area of a road car facility, but the flexibility on the line required to cope with the fluctuating demands of motorsport.'

Power stations

So how has this alliance between the infinite regulatory standards of automotive and the extreme performance of motorsport been achieved? The assembly of the engine has been divided up into 10 main areas, which forms the 10 stations that make up the production

Each of the stations on the production line is equipped with an HMI screen which walks the Ricardo technician through the required tasks; from the tool that they should be using for the job to how much torque should be applied to each of the bolts

line. These stations are situated alongside a horizontal indexing line and each engine gradually moves through the different stages of assembly, with each stage limited to a 40 minute cycle time to ensure the continuous flow of the workpieces. Each station is equipped with a highly developed human-machine interface (HMI) and a technician. The assembly starts off at Station 0 where the 3D barcode of the engine block is first scanned, along with the build book. This automatically sets up the stations so that when that specific engine variant arrives at each station the HMI screen directs each technician through the required sequence of processes, guiding them on what to build, which tool to use and how to build it.

Step by step

'The HMI screens essentially step the technicians through each process,' explains Milton. 'A digital work instruction will be displayed and it might instruct the technician to pick a particular tool or part. Behind each station we have the necessary parts stored next to a 'light curtain' which communicates to the HMI via WiFi and lights up to tell the technician which part to pick for assembly depending on what engine variant they have at their station. It is the same for the tools. There are lights located next to each socket wrench for example, so the technician knows which size to use. Once each process is completed, the technician signals to the HMI that the stage has been completed.'

This HMI method not only improves the reliability of each process, but it is a two way system, which means that every action is logged, analysed and then checked for quality. For instance, when a technician is tightening a head bolt, the HMI is continuously communicating with the tool to specify the exact amount of torque and angle the tool should apply to each bolt. That data is recorded and the technician can be notified of any fault. Of course, the same tool can be used for several different processes, but the system is capable of automatically adjusting the instructions for each particular element of that job.

On the line

Once the block has been scanned at Station 0, it is attached to a ladder-frame and swung round to Station 1 where its journey through the assembly line begins. Here, the pistons are fitted along with the crankshafts and essentially all the other components located in the bottom end of an engine.

'We also have another line for assembling the cylinder heads,' Milton says. 'We use exactly the same process; we take the cylinder head, scan it and again it steps the technicians at each station through the required processes of installing the intake and exhaust valves and so on. Once the components are assembled into the head, we do a comprehensive leak test at specific pressures to check that everything has been assembled correctly.'

Another process separate to the main production line is the shimming of the camshafts. The head assembly is a complex

'It might sound ridiculous, but it is actually much harder to produce 4000 engines as opposed to 400,000 engines'

The cylinder head assembly line. This uses the same controlled manufacturing process as is used with the engines. The cylinder head is scanned at the beginning and the system then tells the technician exactly what to do and when to do it

The inspection regime includes using vision sensors. These are used to check the quality of the components, specifically the surface finish and fitting, both essential to engine performance

group of precision sub-components, each manufactured to their own tolerance and as such the final stage of the head assembly is setting the clearances between the camshafts and the inlet and exhaust valves with the use of shims. A CMM (Coordinate Measuring Machine) is used to measure the elements of both the camshaft and the cylinder head and this data is used to select the correct level of shims, which are graduated in increments of 15 microns.

Checkpoint

The cylinder heads are fitted at Station 2, while Station 3 is the first of three quality stations, where the assembly quality achieved over the previous stations is measured. Again, the technician will step through a series of checks and if there are any faults then they will demerit the previous stations for that piece of work. For example, feeler gauges are used to over-check the measurements recorded by the CMM when the valve gaps were set.

'There are around 32 different types of shims for each engine and usually we might end up changing one out of each engine when double checked with a feeler gauge,' says Milton. 'If the shim does require changing then we raise a demerit, these demerits drive a continuous improvement culture in the facility, constantly looking at where our people and processes don't meet our expectations and ensuring we continue to develop them further. For instance, at one point in the process we attach a rubber hose to the engine, the clip has to be between 4mm and 10mm from the end of the hose. Even if it is only 1mm out, we demerit ourselves by one point thus ensuring we understand what causes build variability. I truly believe that our current engine build demerits are world class and we are constantly analysing and improving our build processes.'

Stop signs

Another tactic to ensuring ultimate quality is through the implementation of the 'no faults forward' system. If something fails – for example, a bolt doesn't achieve the required torque – the system will automatically stop and flag an error. This in turn triggers the need for an engineer to investigate the fault further. They then have to make the decision on whether the engine steps back a task or whether the entire process needs to be redone. Only these engineers have the ability to override the system once it has detected an issue and this data is logged, which allows any decisions to be questioned if there are any problems further down the line. If the problem can't be rectified at the station, then it is quarantined for further investigation. In this way, any faults are either fixed immediately, or removed from the line completely, ensuring that no mistake is carried forward, whilst the details of any corrections are recorded.

Station 4 is where all the components associated with the variable valve timing (VVT), gearing chains and chain guides are fitted. By Station 5, the engine is starting to take shape as the water pumps, cam covers, injectors, coils and spark plugs are assembled, along with some of the wiring.

The first time the integrity of the whole engine is checked is at Station 6, where it is subjected to rigorous pressure and flow tests. Station 7 is the second quality control station where the technician will check things such as the integrity of the clips, the routing of the pipes and the wiring harness.

End product

The turbochargers are sub assembled in another room and are integrated into the exhaust manifold ready for fitment at Station 9. The same goes for the fuel rail system. The final stage, Station 10, consists of fitting the engine transportation bars and the quality of the assembly is checked once again.

It has taken exactly 400 minutes to reach the end of the assembly line. However, the engine still has to go through a final set of checks before it can be shipped to customer. This starts off with each engine getting 'dressed' once it has come off the line and this is essentially where the engine and its related piping is connected so it is ready to go through the testing phase.

The facility is a fantastic example of how the demands of the automotive and motorsport worlds can align and benefit the outputs of each industry

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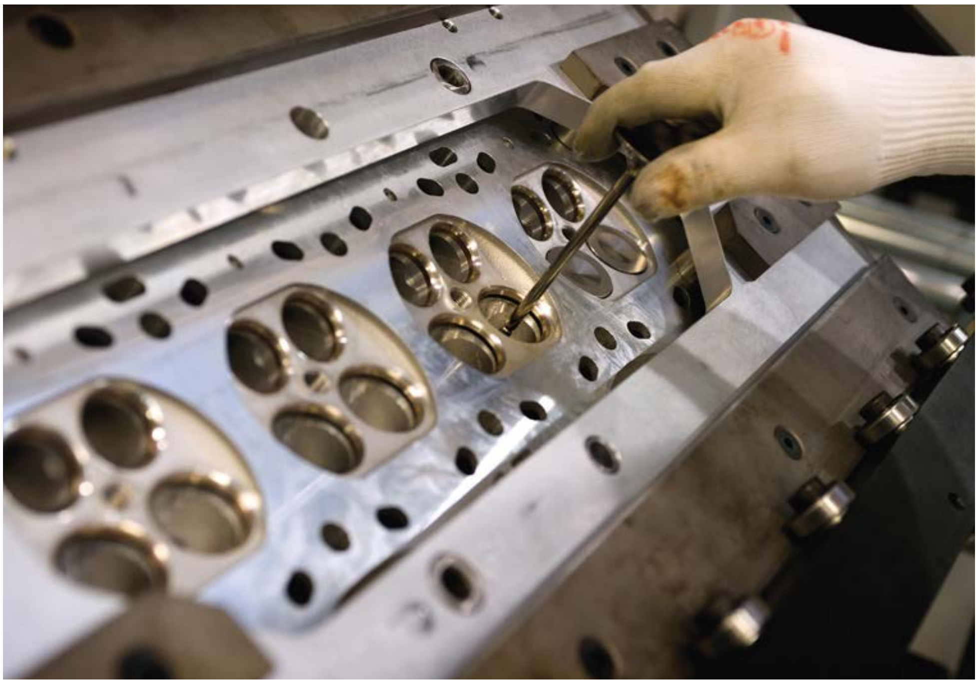
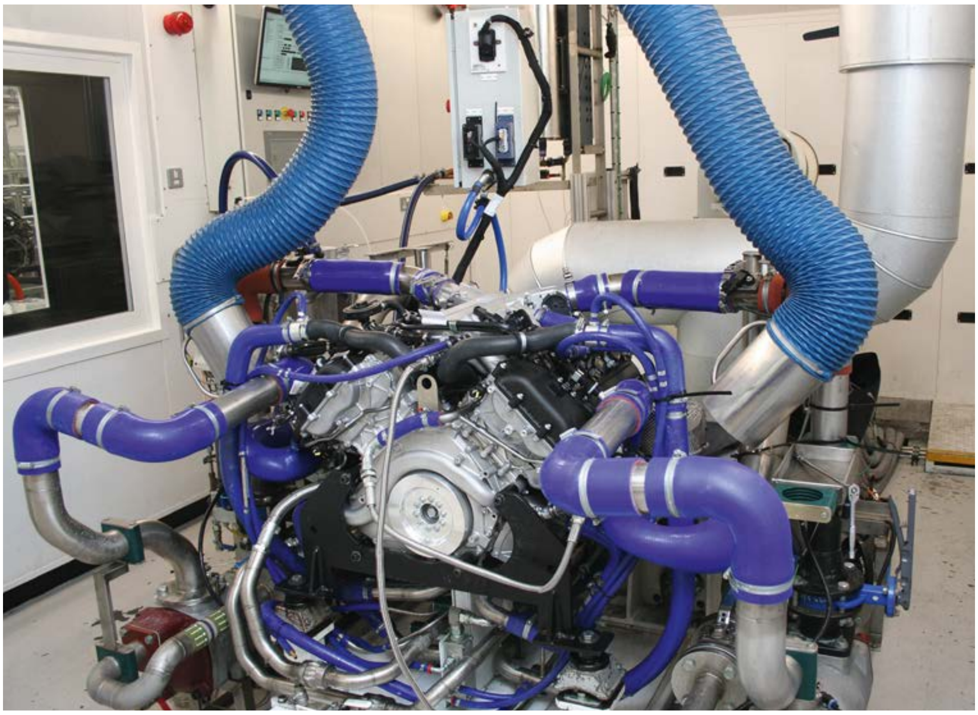
‘The line gives you the best of both worlds; the skilled assembly area of a road car facility, but with the flexibility required for motorsport’

‘Basically, we secure the engines into a palletised engine subframe,’ says Milton. ‘This allows us to securely run the engine just as it would do in a vehicle while still being able to easily transport it around the factory. The engine on this subframe is docked with the test cell and all the necessary fluids are automatically fed to the engine ready for its first fire. We have two test cells, allowing us to test the engines across their full power and torque capabilities. Unlike high volume engine assembly we run a comprehensive hot test on 100 per cent of our engines, regardless of whether they are a road or race variant. We can dress an engine, hot test it through a full 20 minute run-in cycle, and undress it again in under 40 minutes.’

Once tested, the engine then goes through pre-delivery inspection (PDI) which is a final 140 point check – this procedure has been continuously evolved utilising the knowledge gained over the last seven years. The engines are then packaged in custom transport containers before being sent to McLaren.



Ricardo’s quality control is stringent. Here CMM probes are used to measure the geometries of the inlet and exhaust ports



Once the McLaren engines come off the production line they are secured into moveable palletised engine subframes where the necessary piping is connected so that the finished powerplants can be run on the dyno. Every single engine is hot tested

‘Even though we have some of the world’s most skilled technicians, it’s important that they follow the process governed by the HMI,’ says Milton. ‘It’s all about achieving a repeatable process to ensure a reliable build regardless of what engine variant we are assembling. This means we can produce 4500 engines per year, each achieving the same levels of outstanding quality. So far, we have assembled over 15,000 engines since the start of this project and we are able to instantly access every unique piece of build information relating to any of those.’

Supplier demands

Despite the countless quality control checks conducted throughout the assembly of these engines, the quality performance is ultimately down to the manufacture of the parts themselves. Therefore, Ricardo has its own team of supplier quality engineers whose job is to travel the globe, auditing and reviewing the performance of the suppliers and the quality of their manufacturing to ensure they meet Ricardo’s high standards.

‘Repeatable assembly is actually relatively straightforward assuming you receive repeatable parts,’ Milton says. ‘As long as you have the right parts coming in, and at a good level of quality, then you can build an engine. Our process proves that as long as the parts are good, then the ultimate assembly will be good. Issues arise when there is a variation in the quality of components.’

Volume control

‘The more common problems we face are supply chain-based because of the smaller volumes we produce,’ Milton adds. ‘It might sound ridiculous, but it is actually much harder to produce 4000 engines as opposed to 400,000 engines because we are operating with the very specialised and niche volumes. We often ask for components to be supplied in a one-off order of 100 units when other customers they are supplying are requesting continuous supply of 80,000 units for a high volume application. But overall we have a good supply base and they are very effective at dealing with our required niche volumes.’

Ricardo’s Victoria facility is a fantastic example of how the demands of the automotive and motorsport worlds can align and benefit the outputs of each industry. However, ultimately it is the quality and fitment of all those internal components that allow engines to either race round a track at top speed or drive on the motorway for six hours.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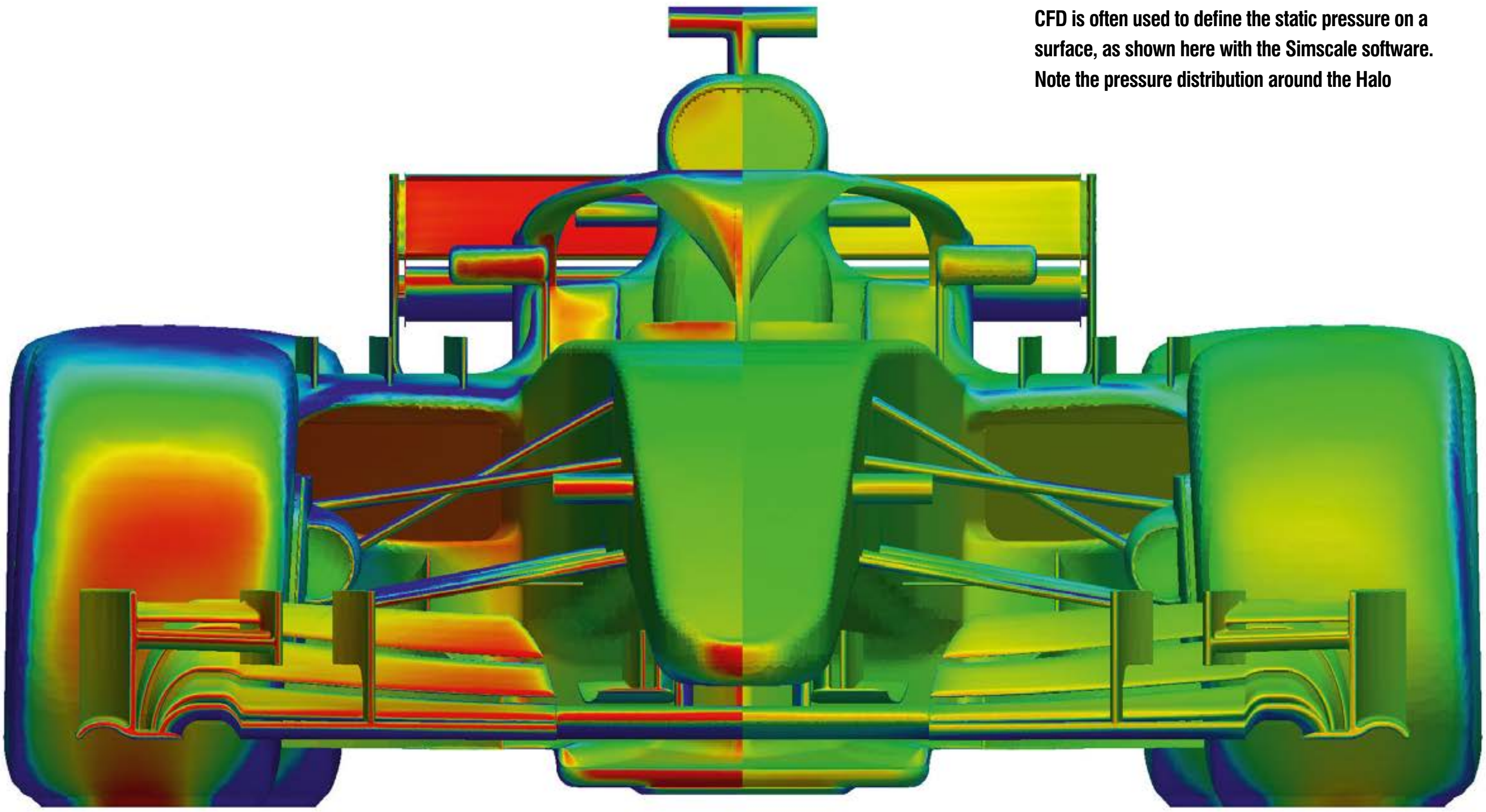
Gone with the wind?

Could CFD ever be developed to the point where it completely replaces the wind tunnel and becomes the dominant tool for the aerodynamic development of racecars? This and other questions were addressed at the Internect Advanced Automotive Aerodynamics Forum

By GEMMA HATTON



CFD is often used to define the static pressure on a surface, as shown here with the Simscale software. Note the pressure distribution around the Halo

In recent years we have constantly been told computational fluid dynamics (CFD) would revolutionise the aerodynamic development of racecars. This has indeed been the case, supported by the relentless development in computational technology and modelling techniques. However, CFD has not yet advanced enough to replace wind tunnels entirely, as was at one time forecasted.

'I think there will come a day when we will stop using wind tunnels all on our own, because new technology becomes superior, but I think the timing of that is a long way off; many years,' Paddy Lowe said back in 2015. 'At the moment CFD is a great complement to the wind tunnel process, but only when it has the ability to be calibrated against the tunnel on a regular basis.'

Wind tunnels, therefore, are still an essential validation tool, as well as an experimental one. But the questions remain; will CFD ever replace wind tunnels? What does the future hold for wind tunnel tech? And will we ever be able to fully simulate reality? *Racecar* attended the Internect Advanced Automotive Aerodynamics Forum at the end of last year to find out.

The right tool

The first thing to understand is that despite the persistence of the CFD *vs* wind tunnel debate the two tools actually measure very different aerodynamic performance parameters. This was highlighted by Professor Jochen Wiedemann, from FKFS, who suggested that the primary strength of wind tunnel testing is to establish the integral values such as drag coefficients and lift coefficients. Whereas CFD is more focused on understanding the local and internal flow field properties, which would be almost impossible to define in a full-scale wind tunnel, due to the practical constraints.

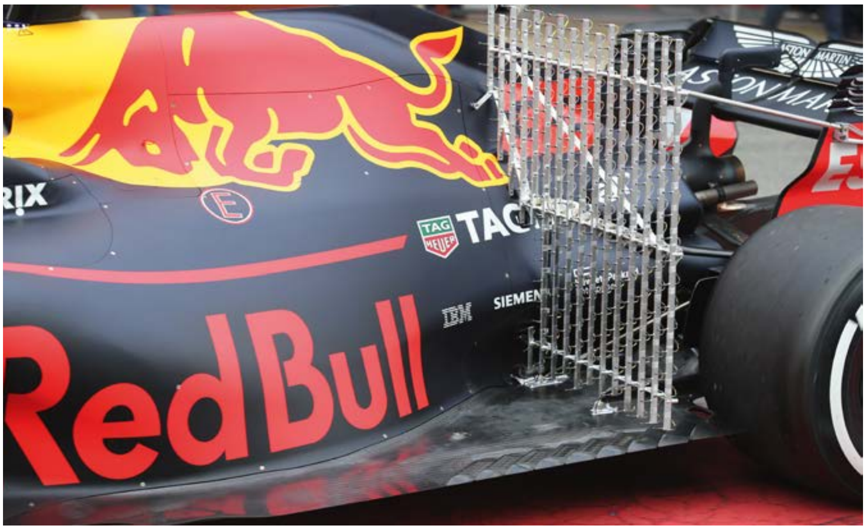
For example, areas such as brake cooling are best investigated through the use of CFD. The detailed behaviour in this specific area would be extremely difficult to obtain reliably during a wind tunnel test, unless the test went on for months, which no company, motorsport or automotive, has the time or budget for.

However, in areas which are not yet fully understood, such as the complex downstream effects of tyre wake, this cannot be accurately measured in the wind tunnel or precisely simulated by CFD. Atsuchi Ogawa, head of aerodynamics at Honda R&D suggested that only in 2044 will computing power be fast enough to fully predict such airflows.

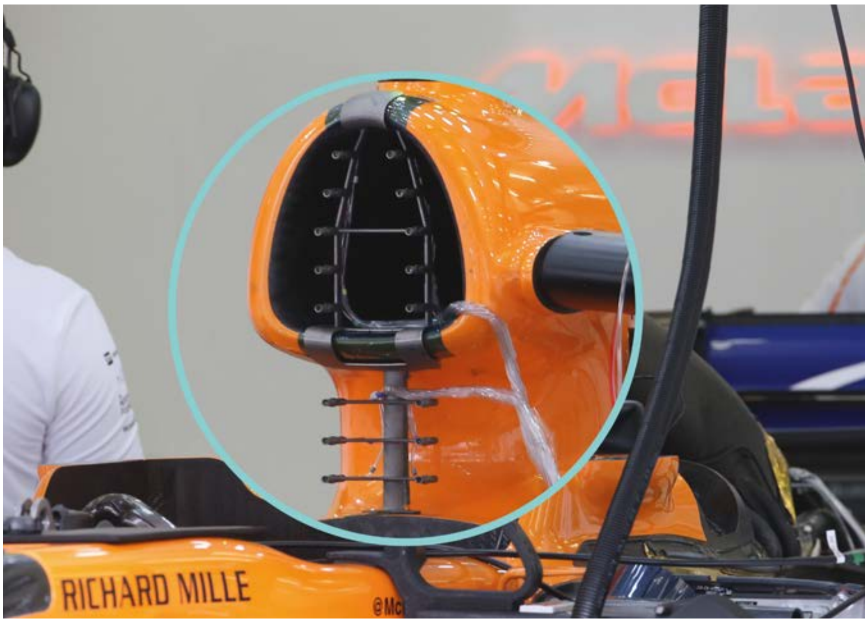
Waking up to wake

Quantifying the effects of tyre wake has been one of the major recent concerns for European automotive manufacturers. In 2017, the EU developed a new testing cycle called the WLTP (Worldwide Harmonised Light Vehicle Test Procedure) to which new models from

Wind tunnels provide an excellent validation tool for CFD and are still very widely used. Even Formula Student teams might test their cars in a wind tunnel – here the Stuttgart FS team's car is shown in the FKFS facility



Though heavily restricted in F1 track testing is also an essential tool for optimising aero performance. Often Formula 1 teams will use pressure rakes to measure the static pressure of airflow coming on to the rear wing



Pressure rakes are often made up of a series of Kiel probes which are designed to measure the total pressure of the flow at non-zero angles of attack. F1 teams tend to use FP1 for aerodynamic testing at the race circuit

Wind tunnels and CFD actually measure very different aerodynamic performance parameters

automotive OEMs have to abide. The aim of this test is to become a global standard for road cars, where manufacturers have to develop their vehicles to meet the specified CO_2 emissions and fuel consumption targets.

Of course, one of the major contributors to fuel consumption is aerodynamics, because if you can design a car to travel through the oncoming air more efficiently, then you need less energy and therefore less fuel to travel the same distance. Therefore, not only are automotive companies focusing on improving their aerodynamic efficiencies, but as part of the WLTP they have to accurately quantify the drag and lift coefficients of their models, and this is difficult to achieve if areas such as tyre wake cannot be precisely measured.

Drag net

With CFD currently unable to cope with these complex flows to the required accuracy of the OEMs, utilising wind tunnels is the only option. As well as actually measuring the drag of areas such as the tyre wake, different configurations and parts are also tested to try and meet the WLTP standards. In fact, the WLTP actually demands automotive companies to declare exactly how many counts of drag each exterior trim option will add to the overall drag of the vehicle and therefore how much the fuel consumption will increase by. These figures then have to be released to the customer before they purchase the part. However, how accurate are these figures if these tests are only validated in the wind tunnel? With each road car company using different wind tunnels, does this mean the accuracy of each tunnel is the same? The answer, unsurprisingly, is 'no'.

Wind gauge

Dr Moni Islam, head of aerodynamics at Audi AG highlighted that a typical exterior trim option can increase the drag by approximately six counts. Yet, a study was done recently by another manufacturer which tested 10 identical vehicles in 10 different wind tunnels and found that the overall drag of the vehicles varied by six counts. Therefore, companies are being forced to quantify the drag of additional components, but the differences in wind tunnel accuracy can actually be as much as the drag of the component they are trying to quantify.

This reveals a major flaw in the global aim of the WLTP testing procedure, but it also highlights the fact that no two wind tunnels are

A manufacturer tested 10 identical vehicles in 10 different wind tunnels and found that the overall drag of the vehicles varied by six counts

the same, and their different designs do result in a wide array of inaccuracies.

Whenever you measure something, whether it's by software algorithms or with a physical instrument, there is always some degree of error. For wind tunnels that error can be due to either the effects of blockage, the interference between the freestream air with the walls, or the boundary layer strategy. None of these are present in CFD. With each wind tunnel differing in design, these inaccuracies vary for each individual wind tunnel, making any direct comparisons unreliable and inaccurate, or as Professor Wiedemann said: 'comparing apples with bananas, rather than apples with apples.'

Therefore, not only do you need to correlate the CFD results with those obtained from the wind tunnel, but you also need to establish a correlation factor between wind tunnels.

The third way

CFD is accurate in some of the areas that wind tunnels are not, and tunnels allow investigation into areas that cannot be done in CFD; and both are unreliable in some areas. 'This is why wind tunnels have to be used hand-in-hand with CFD', Islam says. 'You also need to look at the real drag of the vehicle in the real world, not just from simulation.' Therefore, there is a third test platform to add into the equation; track testing.

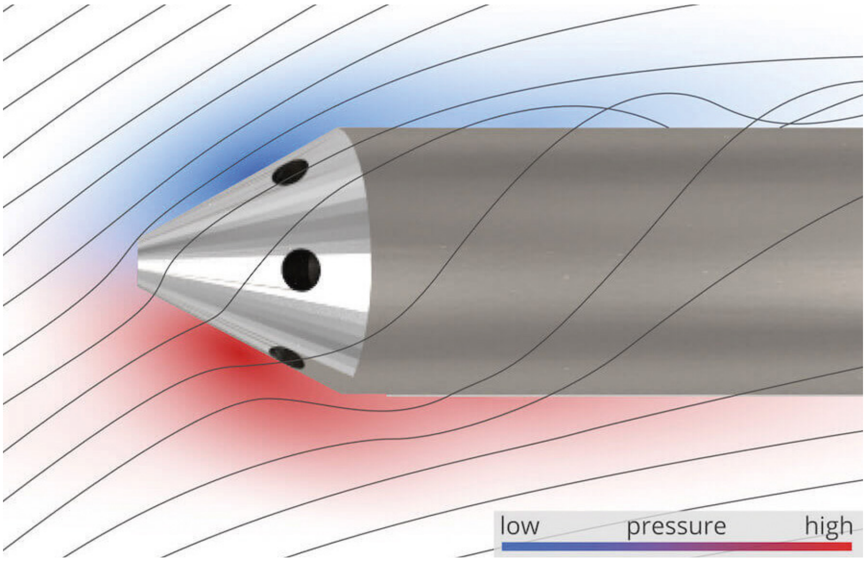


Diagram showing the air pressure differences around the point of a Pitot tube. These have multiple holes so that the total and static pressure can be measured as well as the angle of attack and the flow velocity

Flow-viz paint can be used at a track test to not only help understand the behaviour of the flow physics, but also validate results from CFD and wind tunnels. It also adds a welcome splash of colour to drab Friday morning practice sessions

In motorsport, track testing used to play a huge role in aerodynamic development. However, cost-driven cuts have reduced the number of tests days for categories such as Formula 1. This is why F1 teams essentially use the practice sessions for testing work, particularly FP1, when the track is often very green, and track temperatures are relatively low, which makes it impossible to get a good understanding of tyre performance. This is why you will often find teams experimenting with flow-viz paint or pressure rakes as they complete constant speed laps (CSLs) in FP1. Interestingly, the majority of these pressure rakes are located behind the wheels, collecting data on the tyre wake, which will then no doubt be compared to CFD and wind tunnels results.

Similar to wind tunnel testing, on track testing also has its practical constraints, and the real world environment is a very difficult one to control. That said, Nikolas Tombazis, previously chief designer at Ferrari F1, former head of aerodynamics at the Manor F1 team and now working at the FIA, claims that the achievable accuracy of full scale track testing is now less than one per cent. Considering the amount of potential noise that can often be found in track data due to the brutal and uncontrollable environment of a racecar, this is impressive.

Wages of sim

Another tool to add to the mix is the simulator. This year Honda had an interesting issue with its simulator in relation to its Super GT car. The driver complained that the downforce level on the simulator was different to what he experienced on track, despite the tyre and vehicle dynamics models being the same.

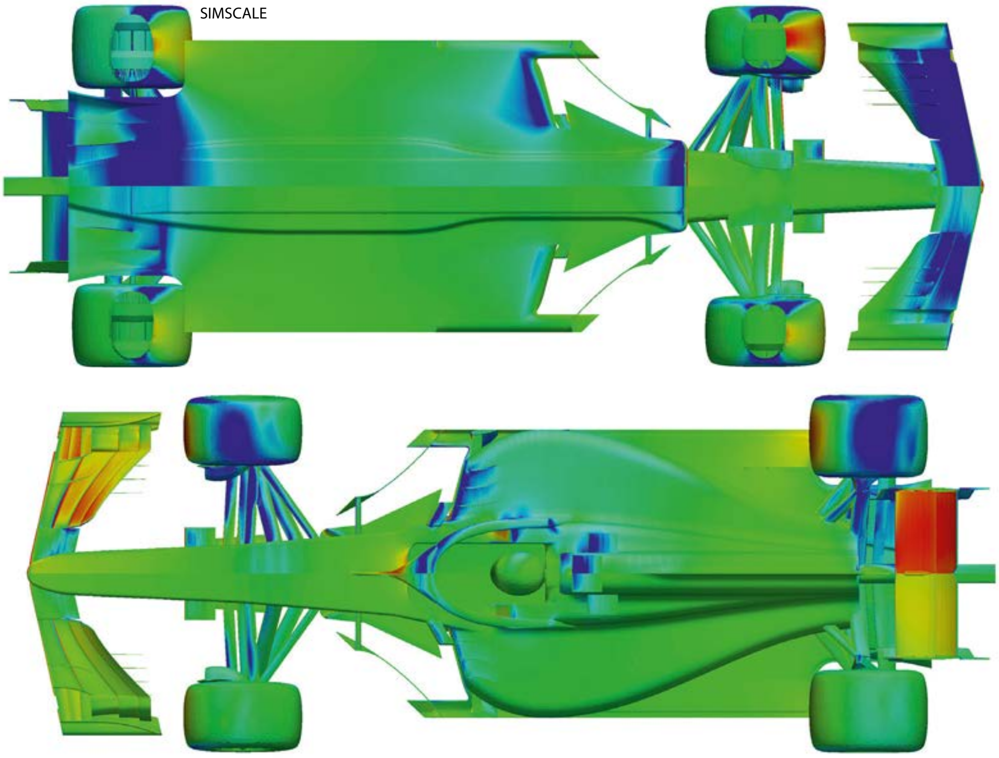
Honda investigated by putting the car in a wind tunnel and it measured more than 100 pressure taps on the underfloor. The driver was right, and at the same ride height the downforce level differed by as much as 30 per cent between what was programmed in the simulator and on the real car. The cause was found to be separation hysteresis, where the vibrations on track actually caused the airflow along the underfloor to separate, and it never re-attached. This effect was fed back into the simulator, proving how valuable all these complementary testing tools are in achieving an overall understanding of the aerodynamic performance, despite their associated errors.

Another strand to the CFD *vs* wind tunnel debate is the number of configurations that can be tested. F1 teams are now running hundreds of simulations per week, which is a much cheaper option than hiring out a wind tunnel. But these simulations don't necessarily mean

F1 teams are now running hundreds of simulations per week, which is a much cheaper option than hiring out a wind tunnel

testing different configurations. According to Islam, in a well-planned 10-hour wind tunnel test day, you can test approximately 50 different vehicle configurations, which could take between 50 to 100 days in CFD. Of course, F1 teams are restricted in the number of hours they can use the wind tunnel, again in an attempt to try and control costs. Therefore, the F1 strategy is to use CFD to test new concepts and refine parts, whilst utilising the wind tunnel together with track testing for final validation.

The general consensus seems to be that wind tunnels will be around for a long time, despite the advances in CFD. Therefore, the two tools are complementary and have to be utilised in parallel along with track testing and simulators to try and gather as much information as possible, to improve the reliability of the final results. However, Tombazis argues that even if the algorithms behind CFD do become accurate enough, wind tunnels will never be abandoned. Instead, they should be developed into a much more sophisticated and high calibre correlation tool, using PIV (particle image velocimetry) and continuous motion systems. The idea being that these tunnels could be shared between automotive manufacturers and race teams, providing periodic confirmation of each operation's CFD results.



CFD is predominantly used to understand the internal and local flow field properties and is ideal for detailed aero work

Wind power

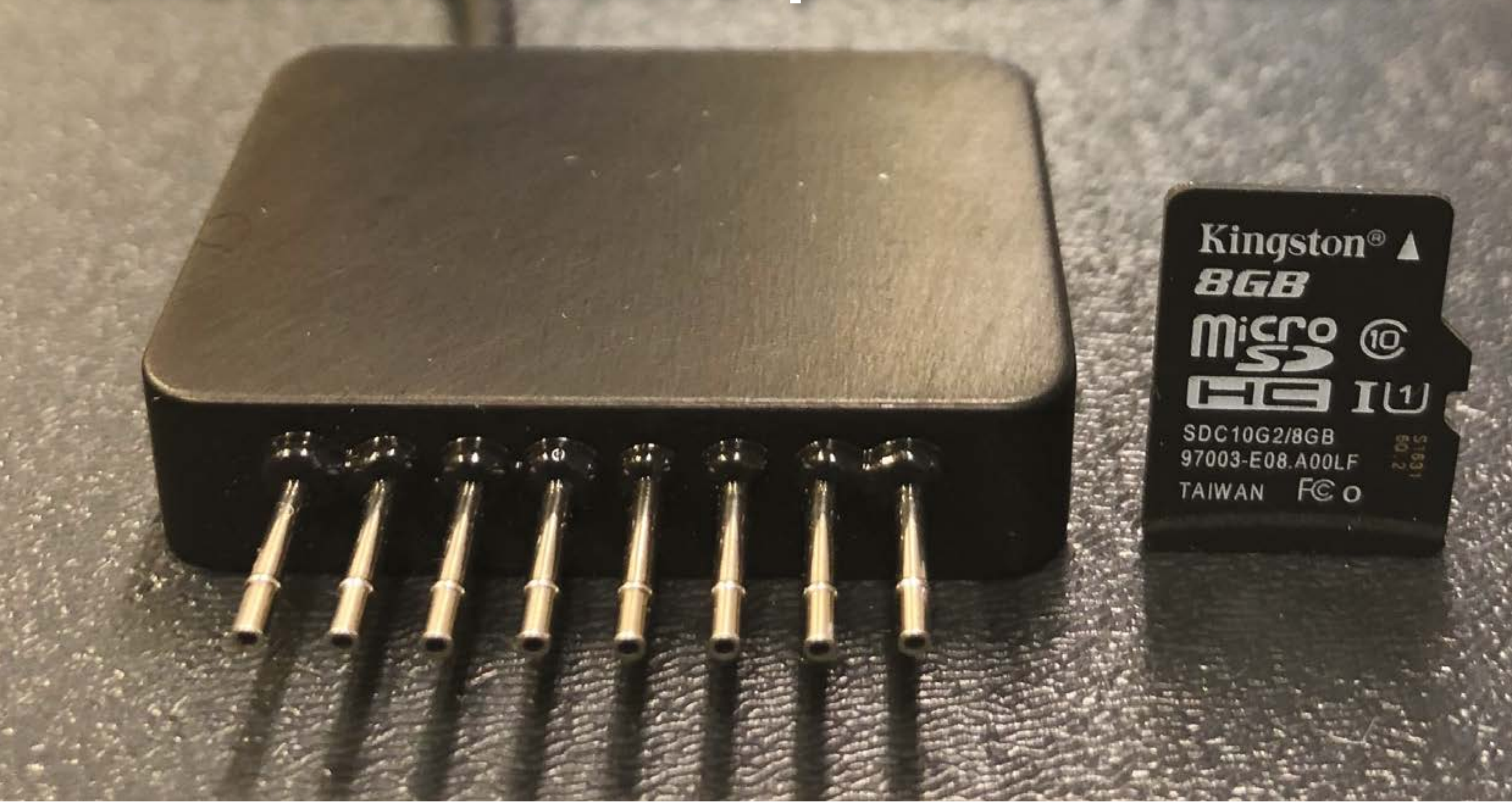
An interesting point made by Wiedemann was that 20 to 30 years ago, when CFD was invented, wind tunnels initially suffered from a lack of clients. However, when companies realised that they needed to validate their CFD results, the only viable option was testing in wind tunnels, so tunnels became busier than ever. This is unlikely to change, especially if wind tunnels do evolve into specialised validation tools in the future. This in itself answers the question of whether CFD will ever be able to fully simulate reality, because even if and when it can, engineers are notorious for scrutinising the reliability of results and so will always turn to wind tunnels or track testing for that final validation of their findings.

Regulation issues

But motorsport development is driven by regulations so it will be interesting to see how the new 2021 F1 regulations will approach the costs associated with wind tunnels and CFD. No doubt the teams' allowance for both will be tightly controlled. But whichever platform the FIA restricts more, teams will then invest and exploit the alternative; consequently advancing that technology further. So perhaps the future of CFD and wind tunnel development will actually depend on regulation alone?

Each wind tunnel features a different design of boundary layer control, test space geometry and moving belt, which can lead to inaccuracies between them, so teams have to establish the correlation between the different tunnels (*Lola Wind Tunnel*)

Introducing the PR8, motorsports smallest 8 channel pressure scanner



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Front-wheel thrive

Getting to grips with the peculiar challenges of a high-power front-wheel drive car can be a headache. Luckily *Racecar's* maths guru has crunched the numbers to help you solve this engineering conundrum

By DANNY NOWLAN

XPB

There's a fine art to tuning fwd racecars and a delicate balance between the suspension set-up and the differential is at the heart of it

Table 1: Some typical front-wheel drive numbers

Parameter	Value
Weight	1200 to 1400kg
C.G height	0.5-0.6m
Front weight distribution	60 to 70%

Unless you have been living under a rock for the last 30 years it would be impossible not to notice the emergence of front-wheel drive, not just on the road but in racing too. In many respects front-wheel drive is a very different proposition to rear-wheel drive. Consequently, the focus here will be on discussing the dynamics of a front-wheel drive racecar and exploring through simulation the tuning tools you will need to deliver the maximum benefit.

Front loading

To start this discussion off we need to get back to basics about the challenge that front-wheel drive racing imposes. Let's consider the FBD (free body diagram) of a front-wheel drive car that is shown in **Figure 1**.

At low power values and low grip values a front-wheel drive road car offers some elegant solutions. Firstly, it is impossible for your Aunt Maude to kill herself by being silly on the throttle. Also, for low grip values the thrust vectoring you will get from the front wheels will add to turn in performance. It offers a lot of benefits in packaging and layout, too.

But to frame this discussion, we need to quantify some front-wheel drive numbers. These are presented in **Table 1**.

Road worthy

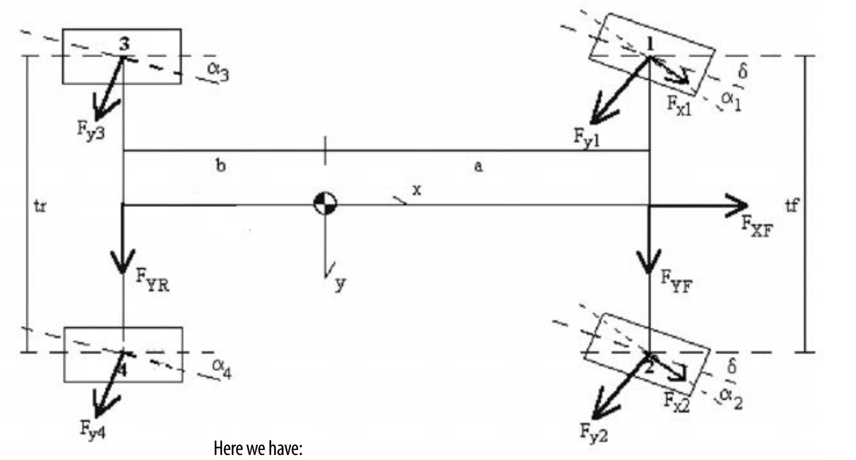
To re-iterate what we have just discussed, as can be seen, for a road-going car where you are typically pulling 0.4 to 0.5*g* and only have 100kW to play with front-wheel drive is perfectly fit for purpose. Where we get into trouble is when the grip levels start to head north of 1*g* and the power levels start to hit somewhere in the order of 220kW/300bhp.

The reason we get into trouble comes down to the properties of your typical touring car tyre. An example of this is presented in **Figure 2**.

As can be seen, once the load heads over 680kgf the tyre becomes saturated. As we'll soon see, this presents a significant problem.

The reason this is a problem is to do with what the load transfers look like when we pull

Figure 1: A FBD of a front-wheel drive car



Here we have:

$F_{y1} - F_{y4}$ = Lateral tyre forces of tyres 1 through to 4

$\alpha_1 - \alpha_4$ = Slip angles of tyres 1 through to 4

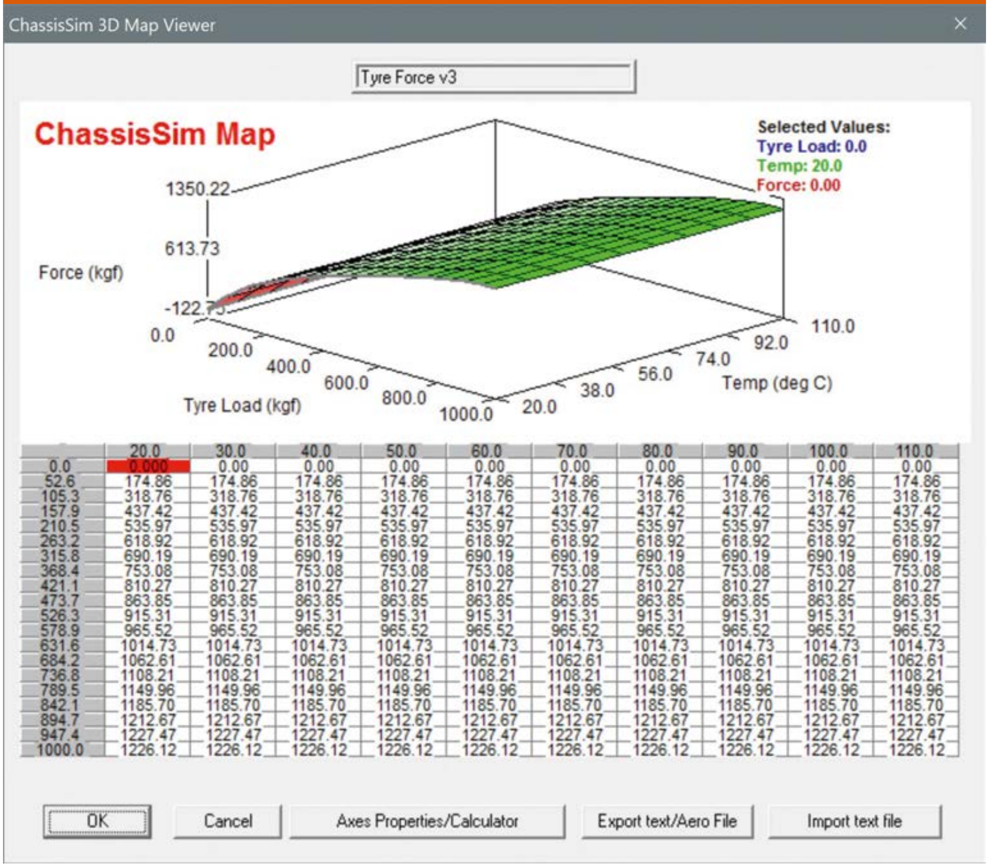
$F_{x1} - F_{x2}$ = Longitudinal forces of tyres 1 through to 2

F_{xf} = Combined front longitudinal forces

F_{YF} = Combined front lateral forces

F_{YR} = Combined rear lateral forces

Figure 2: Typical touring car traction circle radius *vs* load characteristic



	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0
0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52.6	174.86	174.86	174.86	174.86	174.86	174.86	174.86	174.86	174.86	174.86
105.3	318.76	318.76	318.76	318.76	318.76	318.76	318.76	318.76	318.76	318.76
157.9	437.42	437.42	437.42	437.42	437.42	437.42	437.42	437.42	437.42	437.42
210.5	535.97	535.97	535.97	535.97	535.97	535.97	535.97	535.97	535.97	535.97
263.2	618.92	618.92	618.92	618.92	618.92	618.92	618.92	618.92	618.92	618.92
315.8	690.19	690.19	690.19	690.19	690.19	690.19	690.19	690.19	690.19	690.19
368.4	753.08	753.08	753.08	753.08	753.08	753.08	753.08	753.08	753.08	753.08
421.1	810.27	810.27	810.27	810.27	810.27	810.27	810.27	810.27	810.27	810.27
473.7	863.85	863.85	863.85	863.85	863.85	863.85	863.85	863.85	863.85	863.85
526.3	915.31	915.31	915.31	915.31	915.31	915.31	915.31	915.31	915.31	915.31
578.9	965.52	965.52	965.52	965.52	965.52	965.52	965.52	965.52	965.52	965.52
631.6	1014.73	1014.73	1014.73	1014.73	1014.73	1014.73	1014.73	1014.73	1014.73	1014.73
684.2	1062.61	1062.61	1062.61	1062.61	1062.61	1062.61	1062.61	1062.61	1062.61	1062.61
736.8	1108.21	1108.21	1108.21	1108.21	1108.21	1108.21	1108.21	1108.21	1108.21	1108.21
789.5	1149.96	1149.96	1149.96	1149.96	1149.96	1149.96	1149.96	1149.96	1149.96	1149.96
842.1	1185.70	1185.70	1185.70	1185.70	1185.70	1185.70	1185.70	1185.70	1185.70	1185.70
894.7	1212.67	1212.67	1212.67	1212.67	1212.67	1212.67	1212.67	1212.67	1212.67	1212.67
947.4	1227.47	1227.47	1227.47	1227.47	1227.47	1227.47	1227.47	1227.47	1227.47	1227.47
1000.0	1226.12	1226.12	1226.12	1226.12	1226.12	1226.12	1226.12	1226.12	1226.12	1226.12

Since all your drive is coming from the front the effects of load transfer mean you start to reduce longitudinal grip exactly when you need it

Figure 3: Load transfer on a front-wheel drive car pulling 1*g*

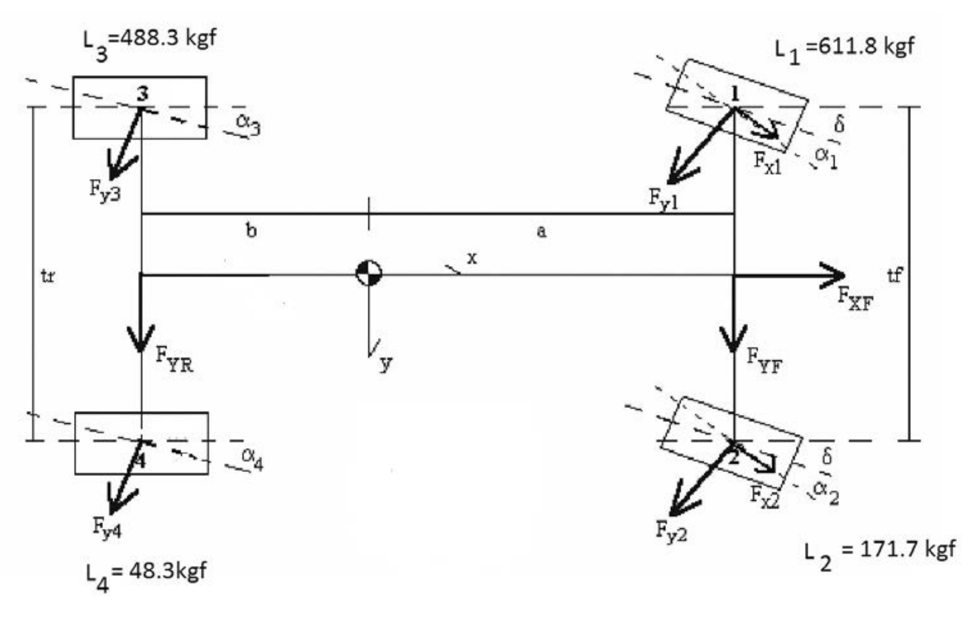
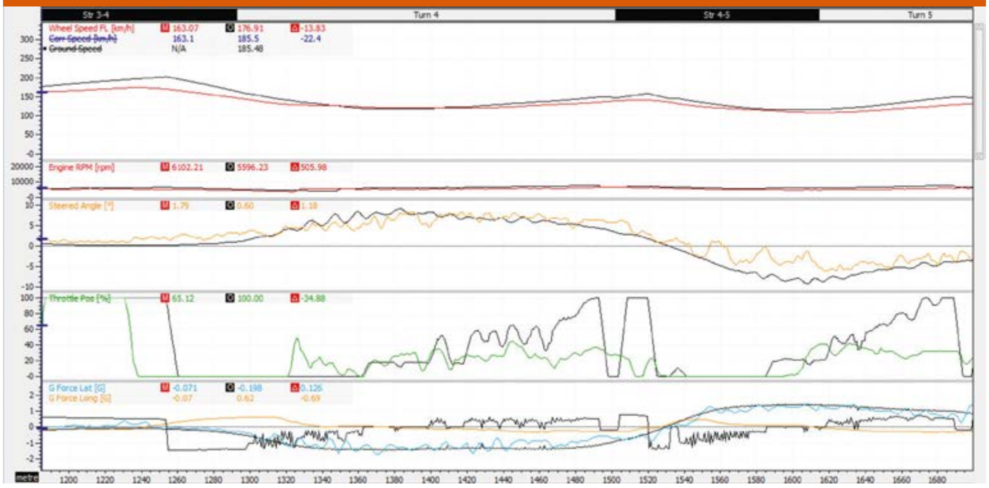


Figure 4: Actual *vs* simulated data for a front-wheel drive racecar



For a front-wheel drive racecar your mechanical set-up and differential will be the dominant terms to play with

Table 2: Sample front-wheel drive car parameters

Parameter	Value
Weight	1320kg
C.G height	0.5m
Front weight distribution	60%
Wheelbase	2.53m

Table 3: Order of magnitude effects for a front-wheel drive car

Parameter	Turning moment (Nm)
1 deg of steer	1330
Max diff potential	315
1mm toe adjustment	253

1*g* in a corner. If we take a car weight of 1320kg with a forward weight distribution of 60 per cent the loads will look like **Figure 3**.

As can be seen we have the worst of all possible worlds coming together here. First of all, the outside front tyre at a load of 611.8kgf is pretty much close to load saturation and the inside rear tyre is virtually a passenger.

Also, to add insult to injury, since all your drive is coming from the front the effects of load transfer mean you start to reduce longitudinal grip exactly when you need it. On top of this, this is just at 1*g*. As can be seen front-wheel drive tuning is actually disaster management.

Trace engineering

To illustrate how parlous this situation is it would be wise to compare actual *vs* simulated data. The racecar that is discussed here was a front-wheel drive time attack car running a C_LA greater than four and with engine power greater then 300kW. The actual data *vs* simulated data is shown in **Figure 4**.

As always the actual data is coloured and the simulated is black. The important thing to note here is the throttle trace. Even with the simulated trace note the long delay in getting back on the throttle. You are not really getting on to full throttle until the corner is virtually over. This illustrates what you have to contend with in a front-wheel drive racecar.

So, now that we know the challenge that faces us, what can we do about it?

The first thing is to do a moment analysis of the magnitude effects of what we are looking at. Again, taking our sample car we'll articulate what we are dealing with in **Table 2**.

So taking a 1*g* balanced turn our order of magnitude effects are shown in **Table 3**.

What **Table 3** shows very clearly is that the dominant terms are your mechanical set-up, as shown through the delta moment due to the steer and the differential. While you certainly don't ignore toe it is the cherry on top. Consequently, for a front-wheel drive car your mechanical set-up (suspension geometry/springs/bars/dampers) and differential will be the dominant terms to play with.

Load analysis

However, before we get into looking at this with the simulation results one key point to stress is that you should thoroughly explore a potential set-up using a static transfer load analysis. That is an Excel sheet where you can plot lateral load transfer at the front *vs* total grip and stability index. A screen shot of a static transfer load analysis I often use is shown in **Figure 5**.

If you can combine this with a representative tyre model it forms a great feedback loop to ensure you can make informed decisions. It will also give you a good feel for the numbers involved. Also, given everything we have discussed about front-wheel drive, I actually consider this to be an essential step.

Figure 5: Excel lateral load transfer sheet

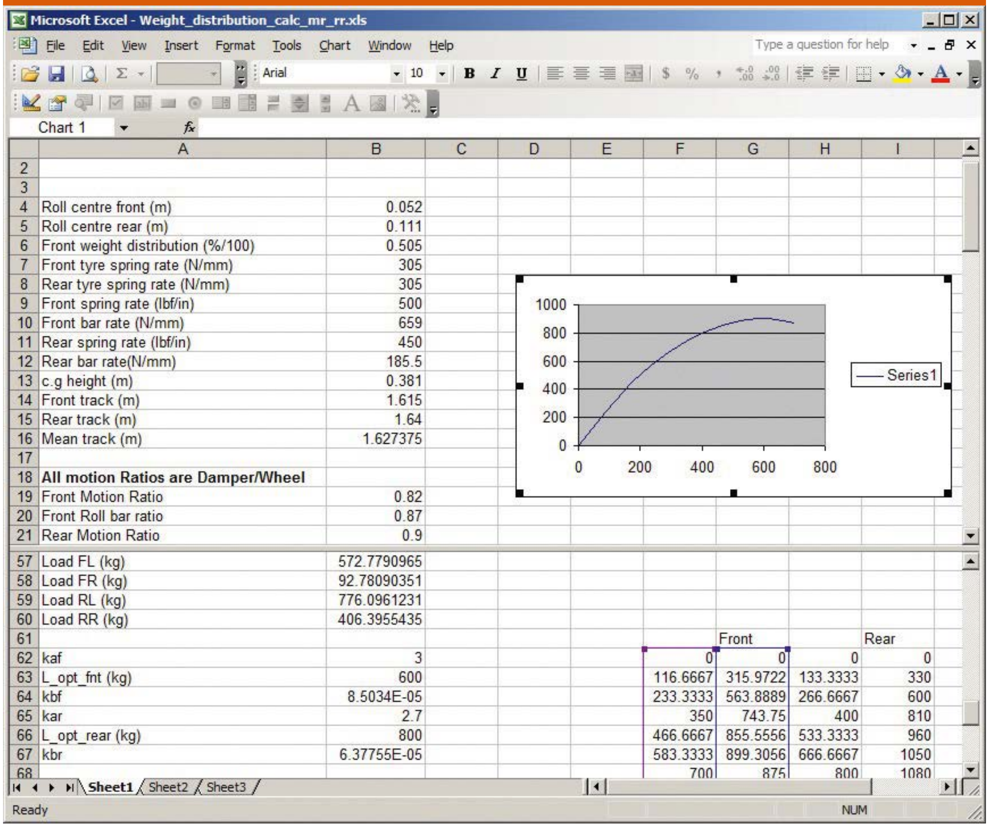
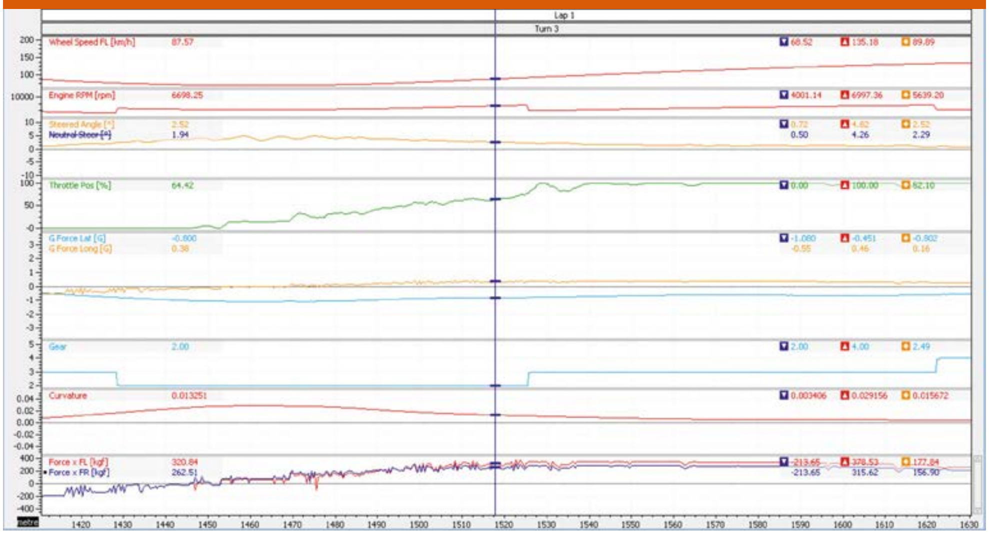


Table 4: Sensitivity analysis for a front-wheel drive racecar at Queensland Raceway	
Set-up	**Lap time**
Open diff baseline	83.76s
LSD locking ratio 10%	83.6s
Super diff	82.4s
Rear bar 100N/mm	83.5s
Rear roll centre -30mm	83.52s

Figure 6: Applied longitudinal forces



You would balance this to more oversteer, since when you apply the throttle you will be taking away grip at the front of the car

To nail the sensitivities down even further some simulation sensitivity studies where run. The results are summarised in **Table 4**.

For the mechanical changes the baseline set-up was the car with limited slip diff at 10 per cent. What is abundantly clear from the simulation results and a little surprising given what we discussed in **Table 3** is the impact the differential had. I fully realise you would be insane to run an open diff on a front-wheel drive racecar. However, I included it as a point of reference so you know the effect the differential has. The LSD drops 0.16s, which for a simulation change is quite significant. However, when we put on the super diff, that distributes the longitudinal forces in the same ratio as the max forces of the tyres and the lap time drops by a whopping 1.36s. Consequently, the diff plays a huge part in the set-up of a front-wheel drive car. Also, as can be seen, the roll bar and rear roll centre also play a significant part in this.

Frontal attack

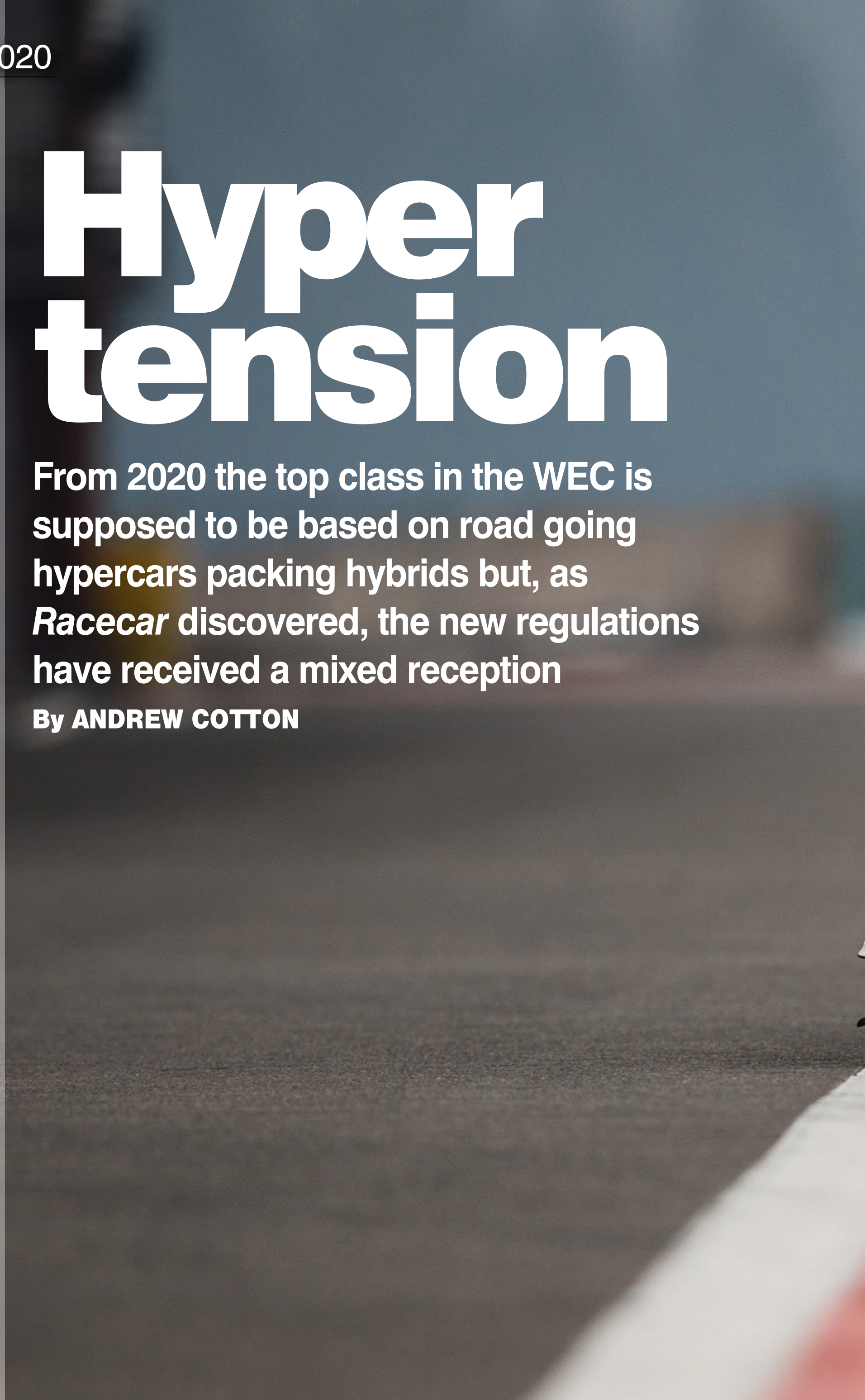
So what is the plan of attack for navigating through this vehicle dynamics minefield? Well our first port of call will be to get the mechanical balance right. That is, choosing the appropriate balance of springs, bars and roll centres. If anything, you would balance this on paper to more oversteer, since when you apply the throttle you will be taking away grip at the front. You then move on to the differential. Here is where something like ChassisSim is about to become your very best friend. What you can do here is play with the different locking ratios and keep a track of the applied longitudinal forces. This is illustrated in **Figure 6**.

In particular here, if you keep your eye on the variables Force Fx_FL and Force Fx_FR that will allow you to tune the turning moment you need. So, as a case in point, if you are turning right the greater the differential between Force Fx_FL and Force Fx_FR is, the greater the turning moment will be. This, of course, presumes Force Fx_FL is greater than Force Fx_FR. Once you are done with that you then fine tune with toe and axle steer.

Tooled up

In closing, while front-wheel drive has its significant challenges there is a way to get through the jungle. The challenge posed by racing a front-wheel drive car is that the combination of the car's weight, the weight distribution and load transfer in racing conditions places the car in a difficult spot. But as I've said, there is a way out of this mess. By using simple Excel tools and simulation packages such as ChassisSim you will have the tools to navigate through this jungle.

In particular, these tools will be crucial for sorting out the car's mechanical and differential set-up. If you can get your head around this you are well placed to deal with everything a front-wheel drive car will throw your way.



Hyper tension

From 2020 the top class in the WEC is supposed to be based on road going hypercars packing hybrids but, as *Racecar* discovered, the new regulations have received a mixed reception

By ANDREW COTTON

On the Friday before the race at Le Mans, the ACO laid out its roadmap for the future of its technical regulations. As revealed in *Racecar,* V28N1, all top class prototype cars on the grid will be hybrid, will be measured aerodynamically both in CFD and in the wind tunnel with minimum drag and maximum downforce levels, and will resemble road cars.

That latter point pleases the likes of Aston Martin and Ford, who are both looking at the new global top class of prototypes and also want to highlight their technology in racing. Aston Martin, for example, will be able to design a car that resembles its Valkyrie.

By introducing a front KERS, the current breed of LMP1 non-hybrid cars will become obsolete in the new regulations, although there were rumours that the IMSA series may consider taking on these chassis when its DPi regulations come to an end in 2021.

Safe seat

There will be no standard monocoque for LMP1, but manufacturers will have to be able to provide a tub, engine, gearbox and hybrid system to customer teams. The cockpit will be significantly different to today's design, with the driver sat more upright, feet lower, and that will have an effect on the aero through the car, probably with less flowing under the cockpit.

'The cars will be slightly higher because they will match more or less the dimension of a hypercar sports car,' said FIA technical director Gilles Simon at the launch of the 2020 regulations. 'We will define the safety box in which the driver will sit, and it will be designed so that the driver will sit properly and will not have their feet as high as they do today.'

Headlining the regulations was a budget limitation, which will reduce spending to a quarter of what was spent by the hybrid manufacturers

Headlining the regulations was a budget limitation, which will reduce spending to a quarter of what was spent by the hybrid manufacturers (the target is €25m to €30m according to the press release from the ACO). Meanwhile, the weight limit will be 980kg (with weight distribution capped as it is in Formula 1) and the engine design will accommodate different sizes and number of cylinders, but will be weight restricted.

The engines will have their minimum size, weight and centre of gravity defined, which will effectively dictate the architecture that will be optimal for them anyway. There will be controlled efficiency, also, with the BSFC fixed – and paddock rumour is that this will be artificially high. Even the gearbox will be limited to centre of gravity height (it will have eight speeds with one set of ratios) while electric and/or hydraulic differentials will be banned.

Hyper drive

The target power from the engine will be 520kW and from the hybrid system a further 200kW, amounting to 720kW in total, and lap times will be targeted around Le Mans at 3m20s, with the help of moveable aerodynamic devices. This may not be just DRS but could also include blocking off the front aero to reduce cooling to the brakes and thus reduce drag.

Only one bodykit will be homologated for the season, which indicates high downforce that will be mitigated by moveable aero, although when and where this can be deployed is not yet defined. The hybrid system will be entirely homologated by the FIA/ACO, and must be made available for any competitor entering the WEC. An ERS manufacturer, such as Gibson and Bosch, must be able to supply a defined minimum number of cars, must lease its system, and there will be clear extensive technical definitions to prevent expensive development. The ERS consists of the motor, inverter, battery or energy storage device and electronics.

However, as always, the devil is in the detail. For instance, the hybrid system can be developed by a manufacturer or a supplier and must be made available for lease to a privateer,

Porsche's upgraded LMP1 car, the 919 Hybrid Evo, features the sort of moveable aero devices that are to be a major facet of the new for 2020 regulations

although what constitutes the hybrid system was not completely defined. Does it include trackside support staff, for example? Also, what is in it for Toyota? If there is a standard ECU as was proposed, what is left for a manufacturer to develop in terms of strategy? If they open up the ECU to development, what else will they allow to be developed?

Mystery machines

Another big cost driver is how big the hybrid system and energy storage will be. How many times per lap will the hybrid be able to boost? Will there be a chance to go back to super capacitors, which were fast to discharge and recharge? Toyota abandoned that technology when it leaped to an 8MJ battery storage, but with reduced capacity, what's better? According to one leading engineer, the increase in hybrid cars at Le Mans will require more systems engineers, and there's already a shortage of those as they're sucked into other industries.

'There will be more need for system engineers, but this is a general request of the industry because this is what you have on all hybrid cars, even taxis,' admits Simon. 'There are more engineering schools and training for that.'

The reception in the paddock was mixed; some thought that it was the right way to go in terms of concept, but everyone, without exception, feared that the technology could not be attained within the target cost. 'It is the same old story really. They go so far, but don't get the whole story,' said Bill Gibson of Gibson Technologies. 'We need a lot more information. It is the same old thing that they want to keep the costs down, but then why have hybrid systems? And if you made one, and had to sell it, what's inside the box? You open so many cans of worms you can't believe. For us, we might need to make a bigger engine. We haven't had any detail, there is no weight yet, no centre of gravity yet, any number of cylinders. Why can they not define it? They don't make the difficult decisions. Next week there will be something else that will be changed.'

Factory outlet

Gibson was also concerned that the manufacturers were driving the regulations, and said he felt that his company, and others, weren't being adequately consulted. 'We have no voice, we go to the meetings, but they are only listening to the big manufacturers,' said

JOHN BROOKS

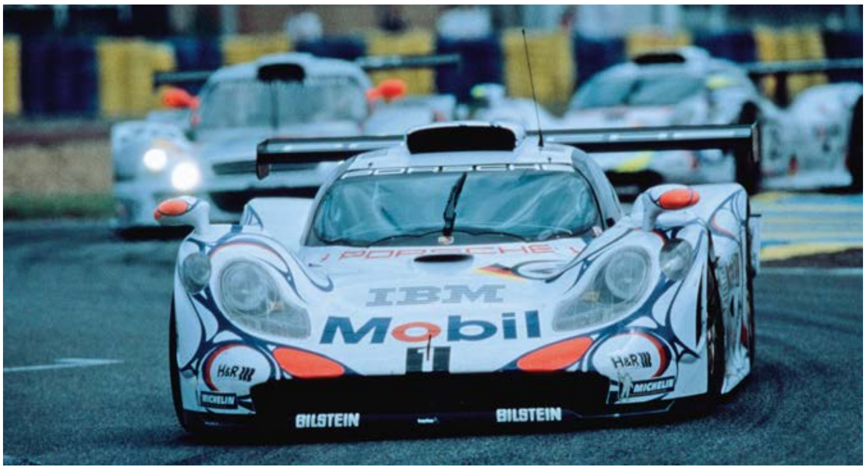
The last time a road car-based machine won Le Mans outright was when this McLaren F1 GTR was victorious in 1995. The 2020 regulations will allow prototypes based on hypercars

Gibson. 'Without us, Toyota would not have bothered, so without us providing engines for three cars, it would all be a nonsense.'

The budgets are to be spread over five years, including 2024, and at the end of the presentation there was a hint that the ACO believes the future to be hydrogen, and that its next set of LMP1 regulations will reflect this. How this can be incorporated into a €30m budget was also not discussed.

Hyper inflation

Privateers were also confused as to what would happen to their budgets. A reasonable privateer cost is between €5m to €8m per car in the FIA WEC and even that is hard to justify for a smaller team. If it goes much higher, it will be even harder to justify, even with a Le Mans win at stake. 'I won't be able to afford a new car, and I don't think that anyone else will be able to either,' says Dragonspeed's Elton Julian, who has entered a Gibson-engined BR1 in the WEC this season, alongside an LMP2 entry. But he adds: 'I see it as an opportunity. We need to show what we can do, now, in LMP1, and do our own development away from SMP, and show that we have the ability to do it. The goal is to be an operating team for a factory. When they bring new manufacturers, you hope that if someone has to pick somebody that we are on their list. So we have to learn how to run hybrids, the certifications and all of that.'



When the FIA previously tried to make room for production-based prototypes Porsche produced its GT1-98, which won Le Mans in 1998. The costs of competing in the FIA GT Championship soon spiralled out of control

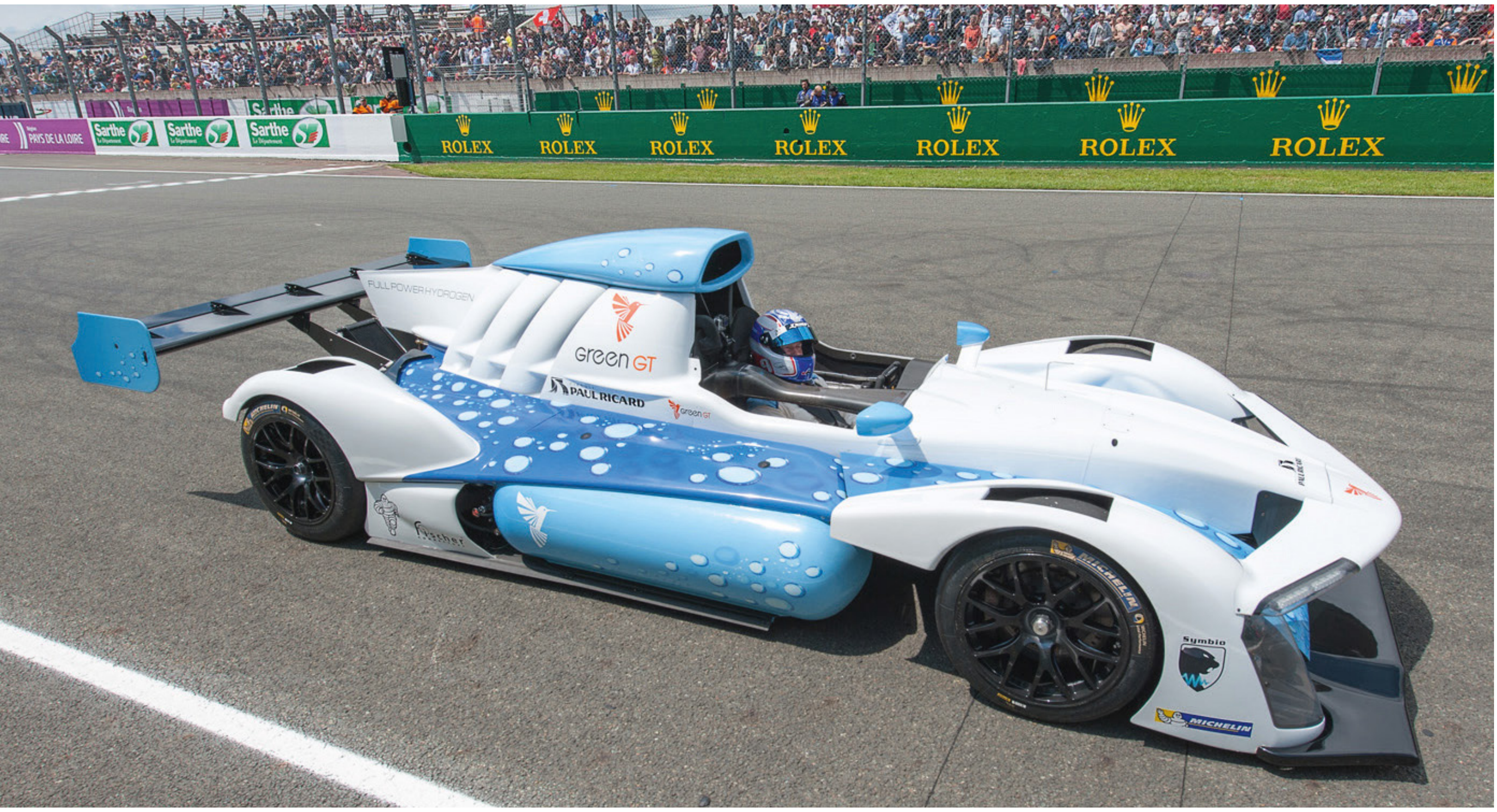
Experts needed

But will a privateer be able to run a hybrid and, crucially, afford the wage bill for the expertise needed? 'They are going to have to make the system more user-friendly, because they have to make it available to everyone,' says Julian.

Another leading privateer is Rebellion Racing, which runs the Gibson-engined ORECAs in the WEC. The team enjoys exclusive access to the ORECA chassis, which apparently are not for sale, and so the commercial aspect of obsoleting their cars is not that relevant.

'What we saw in the press conferences was quite exciting,' said Rebellion team manager Bart Hayden. 'What can Rebellion do to fit into that is too early to say. Traditionally we have been steady in making our minds up. We give ourselves a bit of a challenge. The announcement on Friday before Le Mans is great for getting lots of media, but the focus from the teams will only come after the race. A privateer is not spending €30m, it is spending half of that. You have a period of stability in the regulations which allows you to spread your costs, but you will need a serious backer to make that happen. There are not many of them around. [The €30m budget] has to be a manufacturer development budget. For privateers we have to find a way to halve that. There is an engineering challenge, and a new

'It is the same old thing, that they want to keep the costs down, but then why have hybrid systems?'



The ACO's hinted that the 2024 regs will include hydrogen. It's been demonstrated at Le Mans in the Green GT, but the technology is still too young to be considered viable right now

skill set to be taken on board, but the hybrid systems are further advanced than they were five years ago, so there is more awareness of the pitfalls and a wider knowledge base.'

For ORECA, the budget limitation was the important first step as it provides a barrier against which everyone can push without it yielding. 'I think that it's a good regulation because the first step, which was necessary, was the budget side, even if the number has to be defined,' says its boss, Hugues de Chaunac. 'To put that as target number one is important, to get in small manufacturers with very little budget, and for private teams that are very competitive as everyone will have the same hybrid system. The budget is focussed on the car manufacturer, and the car manufacturer doesn't have to spend a lot of money. I think the budget for the privateer is around €15m to €18m, and you could do it for €12m.'

Works interest

There are manufacturers looking to join the discussion. In November the FIA revealed that there were six that were serious, and that's believed to include Toyota, Aston Martin, Ford and McLaren. They have been the driving force behind finalising the bullet-points that were announced at Le Mans, and will continue the discussions to December. Only after that process will any of them have the ability to say whether or not they have a case to take to their boards.

'They are headed in the right direction, exactly where we want to see them going,' said Aston Martin chairman David Richards. 'They are based upon a car that resembles our production cars. I fear the devil is in the detail and we have a lot of work before we get to a real solution. The good news is that we are going in the right direction, and we might see a production-based car winning again. I think that if the development costs are covered by a manufacturer, the run-on costs for operating a car are significantly less for privateers. If we build a car, run it as a manufacturer and have privateer cars running, that would be ideal for us.'

Business case

For suppliers, the story was already clear; they will be in business. Tyre suppliers have been told that the sizes will not change, and with shy of 800bhp including front-wheel drive, they will have a good place to start their development. Gearbox suppliers are also relatively comfortable, with the power needing to be transferred to driving wheels whatever the power storage or delivery.

Technical working groups will be set up and working overtime in order to deliver the final set of regulations by the World Council in December. The first meeting is July 2, and will be attended by interested parties, including IMSA.

The American organisation pledged to work with the FIA in finalising the regulations, but has not set a time-line for when it will make its decision whether or not to follow them. 'This is a work in progress,' read a statement from IMSA. 'And, while a lot of progress has been made there is still much to be done. We look forward to continuing to work closely in the coming months, collaborating with the ACO and FIA and our existing prototype manufacturers, to confirm a viable cost structure for competing in the Prototype class. We remain committed to our strategic partnership with the ACO and for the future growth and success of professional sportscar racing worldwide,' it added. Its manufacturers were slow to commit to the new regulations, pointing to a lack of detail.

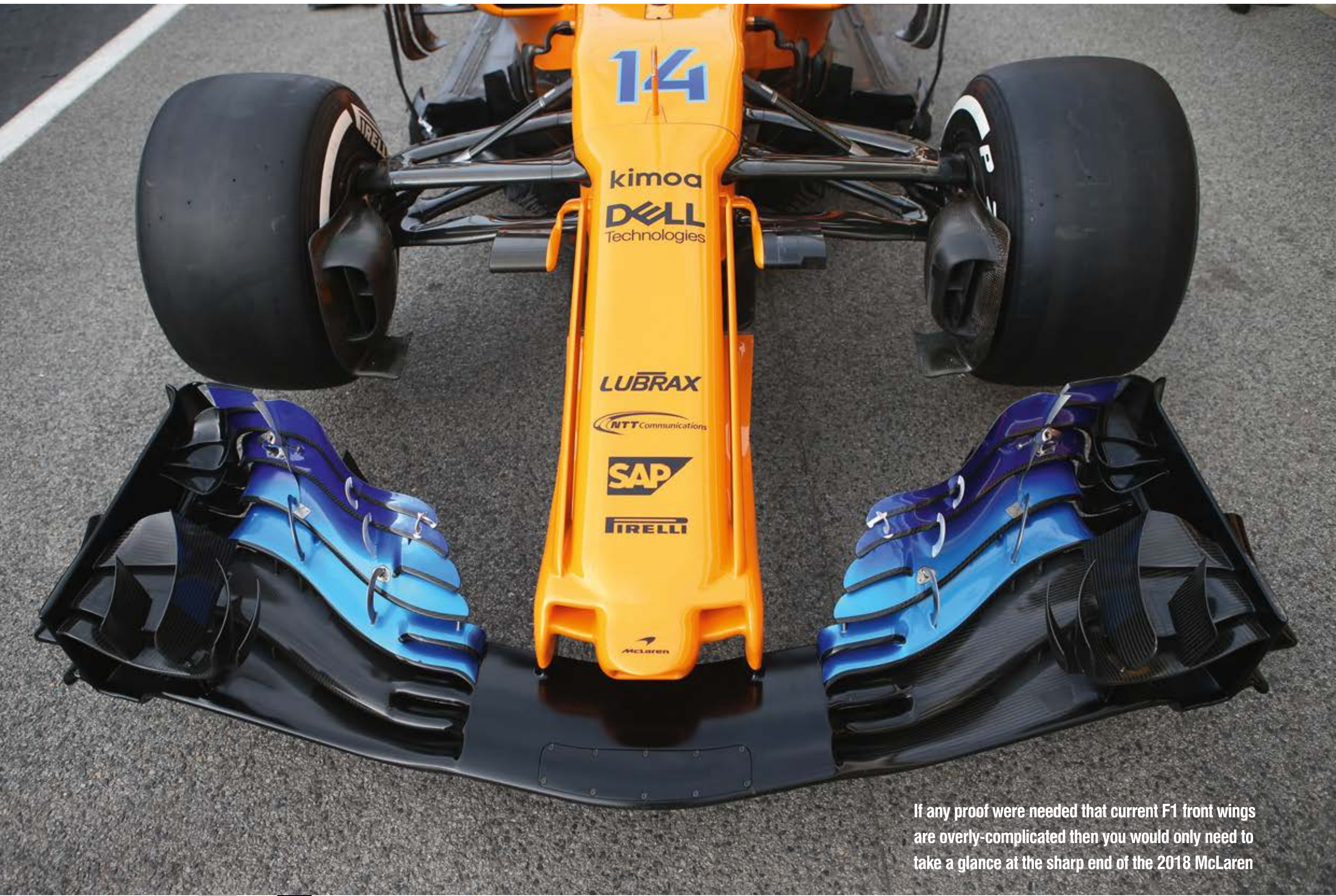
All this gives just under two years for the manufacturers to build, develop, perfect and sell their customer-based and pro programmes before the rules are introduced in the second half of the 2020 season.

Hydrogen future?

As for hydrogen, which could be introduced in 2024, the FIA and ACO readily admit that there is work to be done on the idea.

'We are far from it, [but] we are working on it, and we believe that it is possible,' says Simon. 'We are too far from the goal [to reveal details]. We know what to do to be able to introduce it, [but] there are some safety issues, cost issues and also weight issues. We have a working group, but we are too far from the target to comment on that. It's a long term plan.'

'The good news is that we are going in the right direction, and we might see a production-based car winning again'



If any proof were needed that current F1 front wings are overly-complicated then you would only need to take a glance at the sharp end of the 2018 McLaren

Air rage

The new aero regulations for 2019 have ruffled a few feathers in the Formula 1 paddock but might they actually solve the perennial problem of a lack of overtaking? *Racecar* weighs up the pros and cons

By SAM COLLINS

'Trying to get everything working when you have yaw and steer is going to be really tough'

When the current set of Formula 1 aerodynamic regulations were announced partway through the 2016 season (ahead of a 2017 introduction), their stated aim was to 'improve the show,' but almost immediately concerns were raised that the new rules would actually reduce overtaking opportunities and result in rather dull, processional racing.

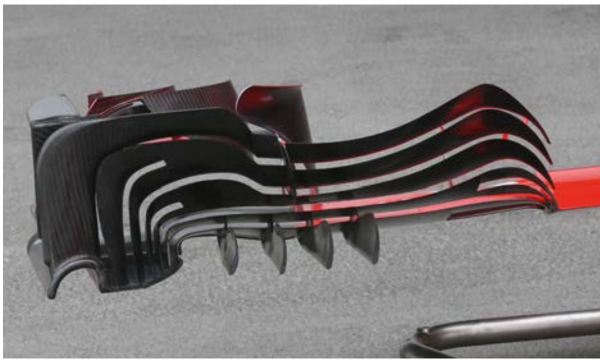
These concerns proved to be valid. In 2017 there were just 435 on track passes, compared with 866 in 2016. Recognising the issue the F1's technical department, headed by Ross Brawn, and the FIA's technical department started work on a new package of aerodynamic regulations aimed at improving the racing for the 2019 season. This new rules package was created using the 2017 Manor F1 wind tunnel model adapted to the proposed regulations and tested in an undisclosed wind tunnel. Work in the tunnel was augmented by additional work conducted by a number of teams using both CFD and their own wind tunnels. During this research phase a key trend in the design of the current cars was identified as being detrimental to overtaking, and this is something which has been present in Formula 1 for some time.

'Some really fascinating work has been done by the FIA and Formula 1 to research the effect of front wheel wake and particularly the impact of front wing endplates on that,' Williams technical director Paddy Lowe says. 'A decade

Out-washing front wing endplates first appeared in 2009 (seen here on Toyota's TF109) and quickly proved to be detrimental to the quality of the racing. Many believe the problem should have been addressed back then

Arrays of additional front wing elements, as seen here on the Haas at the leading edge of the wing, have been used by all of the Formula 1 teams in 2018. These have now been banned in the new 2019 aero regulations

At the heart of the new regulations is a desire to do away with the vastly complex front wing arrangements that are a part and parcel of F1 (as seen here on the Ferrari) and the out-wash they are designed to create



Only two strakes on each part of the underside of the front wing will be permitted when the new rules come into force. This year some teams have been using as many as four (Ferrari pictured)

ago we had the Overtaking Working Group [OWG] which delivered the 2009 regulations. I was part of that process and I thought that it would deliver a reasonably good outcome. But at the time 'out-washing' endplates as they became known had not been invented. However, as a direct result of the 2009 rules they were invented. It is interesting to see now that those out-washing endplates undermined significantly the work of the OWG programme and reduced the benefits it found.'

Indeed, Lowe believes that had the original OWG project continued once the 2009 cars took to the track the problem could have been identified much earlier and acted upon. 'The original OWG project was funded by the teams, each who paid about £50,000 for the research, and it would have been interesting to have done it again a year later and we could have understood what the teams had done,' he says. 'Had we done that at the time we might have landed at this correction much more quickly. Now Formula 1 has funded centralised research we are able to get onto these things in a centralised way. I'm optimistic that it will make a reasonable impact on the ability to follow.'

Clearing the air

Former Haas and Ferrari aerodynamicist Nicholas Tombazis had played a key part in creating the 2019 regulations as the FIA's head of single seater technical matters. He echoes Lowe's sentiments, warning that if nothing had changed the racing would have got worse. 'The way development is going in current racing, one of the key tasks of aerodynamicists in an F1 team is to move the wheel wake further outboard for the benefit of their own car,' he says. 'The more outboard it is the less it affects the diffuser or the rear wing and they gain performance. That key objective is also bad for the following car. So our expectation is that if we didn't do a rule change, in 2019 and 2020 it would be gradually getting worse.'

It is then no surprise that the rules around front wings have been substantially changed for 2019. The delta shape introduced in 2017 remains, however, the overall width of the wing is 200mm wider (100mm each side) with the

‘Sometimes Formula 1 has a real ability to shoot itself in the foot’

With a view to restricting out-washing devices, as seen on the Red Bull, front endplate design has been drastically restricted

The rear wing endplates will increase in size but the vented sections (as seen here on this year’s Red Bull) are to be banned

The canted back shape of the rear wing endplates will remain but the wing itself will be bigger to allow for a larger DRS slot

leading edge of the centre section sitting 25mm further forward than at present. The reason for the increase in the width of the wing is to partly offset the loss of downforce resulting from other rule changes made to the front wing.

Wings clipped

On the wing the so-called ‘cascade’ outer section of wing elements has been far more tightly restricted, with only five elements allowed, each stacked in size order. This is a major reduction from the current wings which can feature a large number of elements. In terms of the shape of these elements there are again tight regulations, with none of them having a local concave radius of curvature smaller than 50mm. According to documentation supplied to the teams this is to prevent them attempting to create strong longitudinal vortices by rapidly changing the local lift of the wing along the span.

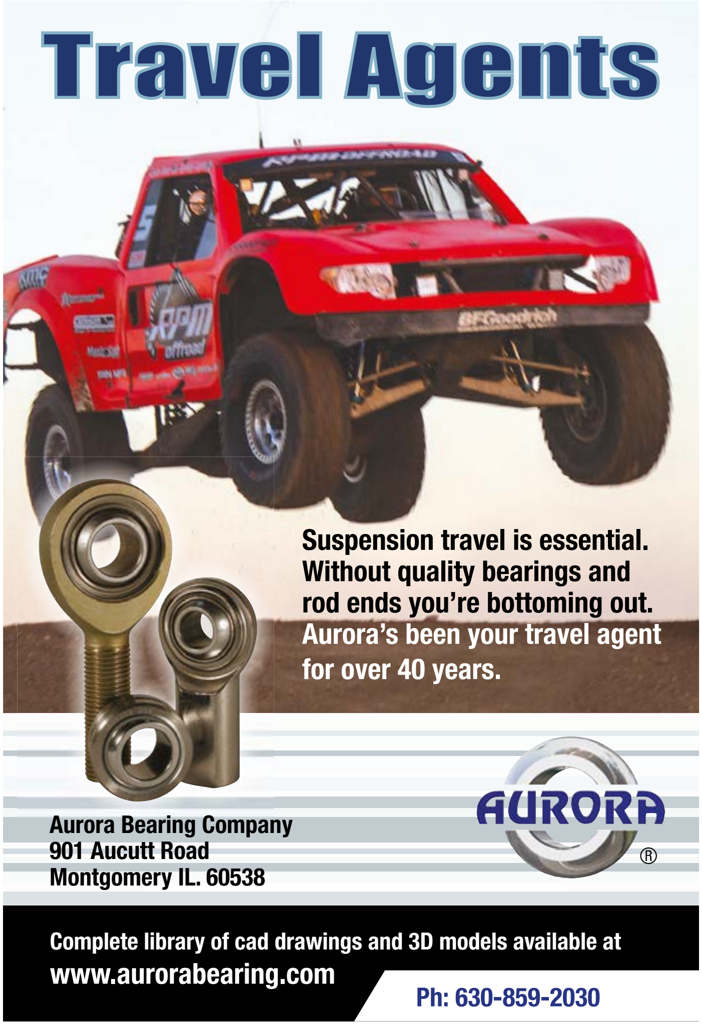
Additionally, the small winglets mounted on every car in 2018 forward of the main cascade have been banned entirely. On the underside of the wing only two strakes either side will be allowed in 2019, with at least 50mm between them, the size and shape of these strakes will also be more tightly restricted.

As endplate design was found to have a major influence on overtaking the rules regarding their design have been completely re-written resulting in (at least in theory) far simpler shapes with no opportunity to create the out-wash effect introduced in 2009. Indeed, vents and slots in the endplates, along with additional external elements have been banned entirely, meaning that the plates are meant to be really that, single shapes. To help prevent over-eager drivers cutting the rear tyres of other cars in close on-track battles the thickness of outer parts can be no less than 10mm with a 5mm radius applied to all extremities.

Tall tail

With such major changes to the front wing, it’s no surprise that the rear wing regulations have also been changed significantly, with the wings now being 20mm taller, 100mm wider and with stricter regulations on endplate design. As is the case with the front wing, vented endplates have been outlawed, though at the rear the endplate size has been increased to accommodate the height increase of the wing. The reason for this height increase is to allow the DRS to be more potent (and in turn further encourage more on track passing). To do this the gap in the wing will be increased to 85mm (20mm bigger than in 2018), giving around a 30 per cent larger reduction in drag than the 2018 cars get.

‘I think the main advantage to us will be that we will be able to make the DRS more effective on shorter straights,’ the head of the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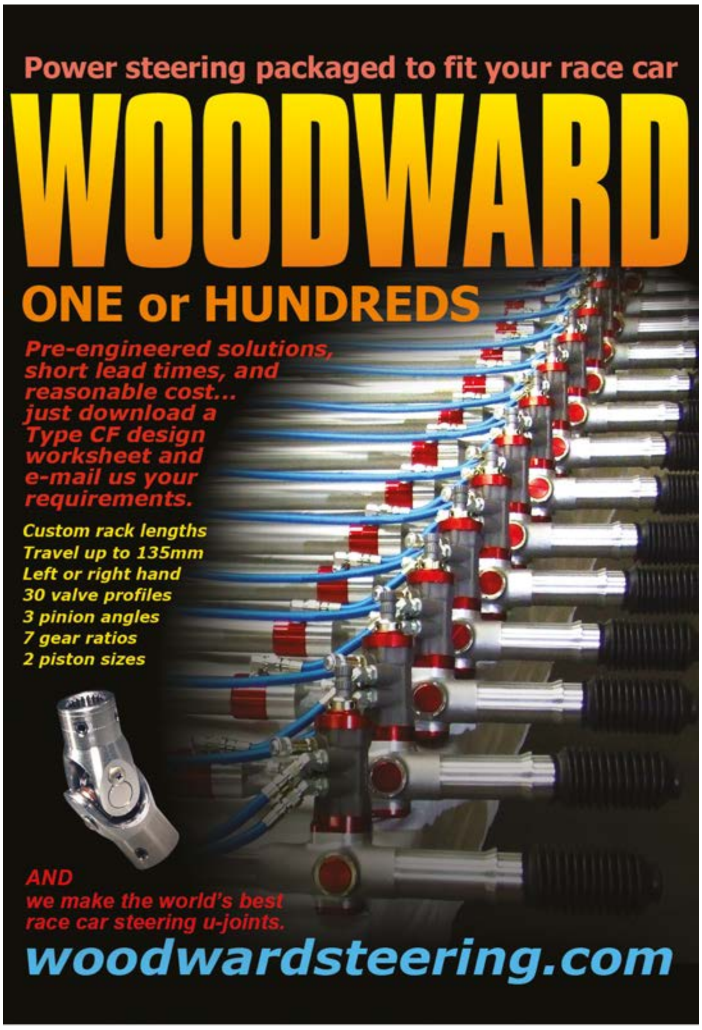
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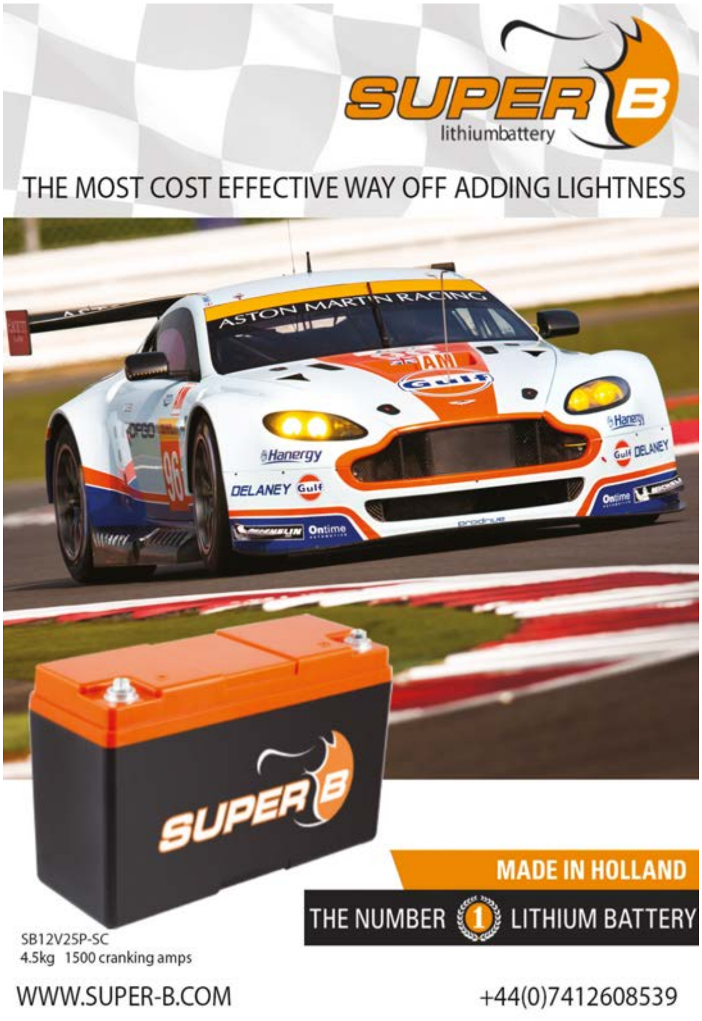
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'Out-washing endplates undermined significantly the benefits derived from the Overtaking Working Group's programme'

FIA Technical Department, Charlie Whiting, says. 'At the moment we're trying to lengthen zones where we can, in places like Melbourne, for example, and with an extra DRS zone in Canada. Those are the sorts of circuits that with the extra power from the DRS we should be able to make them work a bit better.'

As well as the changes to the front and rear wing the regulations relating to aero parts around the front wheels have also been changed substantially. Currently there is a regulatory box around the inner face of the front wheels where aero parts are essentially free, and teams have taken full advantage by mounting complex arrays of winglets and turning vanes. Some of these parts are designed to generate load acting directly on the wheel while others are used to manage airflow in the wheel wake. For 2019 the teams will be limited to a simple plate on the inner face of the wheel which is fitted with a single air scoop, which can protrude no more than 120mm from the inner face of the wheel rim, and can be no more than 140mm in height. The size of the cooling aperture will also be defined in the regulations (these had not been published at the time of writing and the aperture size had not been decided). This could lead to some interesting external shapes on these scoops as teams try to recapture some of the losses in this area. Additionally, the practice of allowing air to escape via ducts in the centre of the front axle ('blown-nuts') has been banned for 2019.

Currently there is a regulatory box around the inside of the front wheels where aero parts are essentially free but in 2019 the plate on the inner face of these wheels is to be simplified; so winglets such as these on the Mercedes will be outlawed

The size and position of brake ducts has been more tightly defined in the 2019 regulations and solutions such as this on the McLaren will not be allowed. Teams are highly likely to try to exploit the shape of the scoop to recapture losses in this area

Air force blues

All in all then, it seems that the 2019 rule changes are in fact far more substantial than when they were first mooted and this has caused some consternation in the design offices of various teams. 'It is a very late change,' Renault chief designer Nick Chester says. 'The front wing with the much wider span, and the fact we are very limited on what we can do with the profiles, furniture and endplates changes a lot. I think teams will be able to generate wing load in a straight line but trying to get everything working when you have yaw and steer on there is going to be really tough. It's going to take quite a lot of work to get things working the way you want them to and get the right flow structures down the side of the car. That means that the front wing area is going to be crucial, and with the air ducts changing too we can't turn the flow as much as we used to in that area.

'There may be a few little things we can do and we are looking at those,' Chester adds. 'Ultimately it could all put more reliance on the bargeboard system because if you can't turn the flow with the front wing you might be trying to get a good deal of out-wash with the sidepod vane system. All that whole area, including the front wing and brake ducts, will be crucial in making the rear of the car work properly.'

Tank battle

The aero regulations are not the only thing to be changed for 2019, an increase in the total fuel allowance for the race has also been announced, up from 105kg to 110kg, something the rule makers claim 'will allow drivers to use full engine power at all times.' While a 5kg increase to the total fuel allowance may seem like a minor change this has actually seen at least one team significantly change its car development plans.

'It is going to have an impact on the car design as the changes were much bigger than we anticipated even a month ago,' Force India technical director Andy Green says. 'We had not done too much about 2019 because it was going to be a continuation of the current regulations, then one or two teams decided that they wanted more fuel, that extra 5kg really scuppered our plans for next year as it

From 2019 the practice of allowing air to escape via ducts in the centre of the front axle (known as 'blown nuts') is banned

meant that we would require a whole new chassis, and we had not planned to do one. We have had to start to allocate resource to that already, and that has an impact on this year as we are not a big enough team to do both at once. It has meant we have had to build a new wind tunnel model, and that has a cost too.'

The arrival of the new rules has gone down badly with other teams, too, most notably at Red Bull. 'Sometimes this sport has the ability to shoot itself in the foot,' its team boss Christian Horner says. 'The work that has been done for 2021 is all good stuff, the problem is a snapshot of that has been taken and hasn't been fully analysed and there are no proven conclusions from it. It has then been rushed into a set of regulations that completely conflict with existing regulations. It completely changes the philosophy of the car because the front wing will be wider and different. The point that the car meets the air is the front wing and that then changes everything behind it: the suspension, the bodywork, absolutely every single component. We talk about costs and being responsible but what has just been introduced is a completely new concept which will cost millions and millions of pounds.'

Cost *vs* benefit

However, the FIA feels that predictions of vastly increased costs are wide of the mark, and that the cost increase of the new rules will be outweighed by their benefit in terms of the on track action. 'We've had stable rules in the past but teams have always had new cars each year. I think the likelihood of a team wishing to carry a complete car over from one year to the next is very, very low indeed,' Whiting says. 'Occasionally a team might carry a survival cell over, but that's really the extent of it. I think the teams honestly are going to be doing the aero research anyway. So I think the contention that it's going to cost a fortune to make these changes is a little over-exaggerated.'

Will it work?

With all the changes combined the cars are expected to be around 1.5 seconds a lap slower than they are now. But the question remains; will these new rules actually improve the racing? 'We'll only really know how well we've achieved that aim next March or April,' Tombazis admits. 'We'll be able to follow teams' development before that but we won't really have any proper results. Any rule change has a degree of risk and these are no exceptions in that regard. We cannot be completely certain of every single thing teams will do in developing the new cars. What we have tried to do for these rules is to have a much more careful wording on some areas of the car to try to avoid any particular loopholes or any completely different directions that teams could take. And I think the probability that we will make it better is very good. The possibility that we will make it better but not by a huge amount is also there. I think the probability that it actually makes it worse is, close to zero, if not zero, in my view. But clearly people who maybe haven't seen the data as much as we have can express their doubts and worries, that is understandable.'

The 2019 regulations were signed off by the FIA World Council and were due for publication as *Racecar* closed for press.

'I think the contention that this is going to cost the teams a fortune is a little over-exaggerated'

Interview – Sylvain Filippi

Bright spark

The new boss of the DS Virgin Formula E operation talks about the growth and the future of both the team and the electric race series

By MIKE BRESLIN

'I still remember the scepticism from the media and other motorsport paddocks, some of them saying that Formula E would never happen'

Formula E is full of familiar names, refugees from other arenas on both sides of the pit wall. Drivers, team bosses and engineers have come from F1, LMP1 and just about every other major series you might care to mention. But the peculiar nature of FE means there's another type of person involved, too, those that were initially motivated by the motivation, if you like, rather than the competition.

Sylvain Filippi, who has recently been hoisted from the position of chief technology officer at DS Virgin Racing to chief operations officer with the departure of former team principal Alex Tai (see Race moves), is a good example. 'I started my career working for several of the major car manufacturers and then in 2007 moved to working with electric vehicles and simply fell in love with them,' he says. 'After this I co-founded an electric car racing series called the EV Cup – I guess a kind of small scale Formula E for saloons – and then was approached by Alex Tai to join the team.'

Filippi, who will be in charge at DS Virgin until at least the end of the current campaign in mid-July, has been in FE since the early days, then, and it's fair to say he's pleased with its progress since it hit the streets in September 2014. 'I guess in many ways it has exceeded my expectation, but the reality is that I have always been very optimistic about the future of Formula E,' he says. 'As a passionate supporter of EVs, to have been involved with Formula E from the very beginning and to watch it evolve to where it is today has been fascinating. I still remember the scepticism from the media and other motorsport paddocks, that Formula E would never happen. Now it has attracted almost all of the top manufacturers, 20 of some of the world's best drivers, and raced in cities many thought not possible. It's also very satisfying to see how the car industry, and now the public, are starting to accept EVs and realise their true potential – and all this in just four seasons.'

Charged up

The fifth season, which gets underway in the autumn, represents a further step for FE with the introduction of the Gen2 car. Filippi says his first impressions of the new racer have been positive. 'Firstly, it's a very futuristic-looking car and, with FE always striving to be innovative, it was important for the series to keep the look fresh and not to remain static,' he says. 'But more importantly, it was crucial to showcase how far the technology has come and, after just four seasons, to release a car that has almost double the energy storage capacity and double the range. FE's come in for criticism about the mid-race car swaps, but this is clear proof of the advancements in battery and electric motor tech. What I like the most is that we have been able to increase the power as well, from 180kW to 200kW during the race and from 200kW to 250kW in qualifying, while covering the race distance with one car. This is such a powerful way to show how quickly we are improving EV technology.

'At this stage, having not taken delivery of ours yet, it's hard to say what will be the most challenging thing about running it, but like any new racecar it will be about getting to grips with it as quickly as possible,' Filippi adds. 'Extracting the maximum performance, learning how to be as efficient as possible and isolating any weaknesses are always key. From a more practical point of view I know there are some concerns around the amount of bodywork and therefore repair times, which could make things harder for the mechanics.'

And this will be on top of what is already a tight schedule over an FE event. 'I suppose it is not that different from any other motorsport category, apart from the fact that all the action, free practice, qualifying and race, happens over one day,' Filippi says. 'This means that there is even less room for error than in any other motorsport series, and preparation is absolutely key. This is the most difficult thing, as if something goes wrong in FP1, the entire team spends the rest of the day on the back foot and it is very difficult to recover from it.'

Electric works

Most FE teams do, of course, have the resources of the many manufacturers involved behind them – at the time of writing DS (PSA) with the Virgin team, though it's expected to become a customer team with another manufacturer next year. Some have seen this large manufacturer involvement as a possible double-edged sword, should the car makers ever pull out, but Filippi insists the brand is strong enough to stand on its own two feet. 'I think the Formula E platform is so strong and

its potential so great that it could probably survive without manufacturers, but I don't think this is a scenario that will ever happen, given the strong relevance between the FIA FE roadmap and electric road car development, making Formula E a very appealing project for OEMs,' he says.

Yet however much FE and the manufacturers involved in it talk about technical innovation, there's no getting away from the fact that, on the chassis side, this is essentially a spec series. 'Running as a spec series was never the intention,' Filippi says. 'FE's goal is, and always should be, about advancing and promoting EV tech and to do that you need competition and manufacturer influence. It's the manufacturers and the teams, not the series, that will take on the engineering baton and run with it and it's this tech that will filter down into everyday cars.

'Technical innovation remains the foundation of the series and the FIA have worked very hard on producing a clear roadmap that sees the teams and manufacturers focus on developing the right areas in the right time-frame,' Filippi adds. 'Besides, we are not concerned with aerodynamics, other series have pretty much exhausted what is possible already, so having a spec chassis is immaterial. What we want to focus on, and have been, is the powertrain and the software and then slowly opening this out to eventually allow for battery development, but not in the short term. Ultimately, it is this technology that will have the greatest benefits – and is the most relevant – for the electric vehicle industry.'

Bright future

As for the future of the series, Filippi remains positive. 'It looks very promising with more manufacturers joining and new cities being added,' he says. 'Everyone in the paddock is ultimately working towards the same goal – making the series a success. I haven't changed my view on Formula E since four years ago, I think it's destined to become one of the largest and greatest motorsport championships in the world.'

The DS Virgin team itself was recently bought out by renewable energy and technology company Envision, but Filippi says that will not affect the way it goes about its business, nor its aims. 'Our goal has never changed from the off,' he says. 'We want to win, and be a fantastic platform to accelerate innovation and promote the benefits of EVs.'

The DS Virgin Formula E team has been involved in the championship since the beginning. This season is the last with the current FE racecar

RACE MOVES

XPB

Alex Tai is no longer the team principal and CEO of the DS Virgin Racing Formula E team. Tai, who has headed the operation since the inaugural FE season in 2014/15, is leaving to 'focus on his other business activities', the team has said. **Sylvain Filippi** has been promoted to chief operations officer as a result and will now oversee both the racing activities and day-to-day operations of the business (see Interview, left).

Dirk de Beer, the head of aerodynamics at Williams, has now left the team. The former chief aerodynamicist at Ferrari and head of aerodynamics at Renault had only been with the Grove-based outfit since February of last year.

The Williams Formula 1 team has announced that newly appointed chief engineer **Doug McKiernan** has now taken over control of future car design at Grove, following the recent departures of **Ed Wood** and **Dirk de Beer** (see above). Meanwhile **Dave Wheater** has been promoted and is now the head of aerodynamics.

Matthew Harman, head of powertrain integration at Mercedes, has now been hired by rival Formula 1 team Renault. Harman joined Mercedes' engine division in 2001, as engineering team leader, before moving into a role with the F1 team in 2011. He will start work at the Enstone operation in September.

Le Mans-winning former Audi race engineer **Leena Gade** is no longer with IndyCar outfit Schmidt Peterson Motorsport, having left the team after just five races. The split was announced after the team's lead driver, **James Hinchcliffe**, dramatically failed to qualify for the Indianapolis 500 in May.

IndyCar team Schmidt Peterson Motorsports has promoted **Will Anderson** to fill the role of race engineer on **James Hinchcliffe's** car, after re-organisation following the departure of **Leena Gade** (see previous story). It's a return to the Hinchcliffe car for Anderson, as he has worked as an assistant engineer on this entry in the past.

The 52nd Schwitzer Award, which recognises individuals for innovation and engineering excellence in motor racing technology, has been presented to Dallara engineers **Andrea Toso** and **Antonio Montanari**, IndyCar's **Tino Belli** and London-based product designer **Chris Beatty**, for their joint effort in designing the new-for-2018 universal IndyCar aero kit.

Canadian **Michael Latifi**, the father of Formula 2 racer Nicholas, has become the McLaren Group's first new shareholder since the departure of **Ron Dennis**. An investment of over £200m will be made over the next year by British Virgin Island-based Nidala (BVI) Limited, which is controlled by Latifi. He joins **Mansour Ojjeh** and Mumtalakat, the Bahrain sovereign wealth fund, as the only shareholders in the group.

Harry Stiller, a double Formula 3 champion of the 1960s who went on to run a team for a short spell in Formula 1 in 1975 – fielding a Hesketh 308 driven by **Alan Jones** – has died at the age of 79.

Gil de Ferran, the two-time IndyCar champion and former Indianapolis 500 winner who was the sporting boss at BAR-Honda in F1 for a short time, has now been taken on as a consultant at McLaren in what's been described as an advisory role which will cover both Formula 1 and a potential IndyCar project. The Brazilian advised **Fernando Alonso** during his Indy 500 outing last season.

Team owners **Roger Penske** and **Jack Roush** are amongst the five inductees for the NASCAR Hall of Fame Class of 2019. Penske owns squads in many motorsport categories and in 2016 his team chalked up its 100th win in the top level NASCAR series. Roush came from a drag racing background but switched to NASCAR in 1988. Roush Racing (now called Roush Fenway Racing) has won a record 325 races across all three NASCAR national series.

Ferrari man takes on the Sauber technical boss role

Simone Resta has left the Ferrari F1 team to take on the technical director post at Sauber.

Resta had been chief designer at Ferrari since 2014, albeit with the job title of head of vehicle project coordination, and had worked at the Scuderia since 2001. He started his F1 career at Minardi in 1998.

Sauber recently parted ways with its technical director Jorg Zander and its team principal Frederic Vasseur had said it was looking at a high profile replacement. The Swiss team has close ties to Ferrari, it uses the Scuderia's powerplant and carries branding from Ferrari sister-organisation Alfa Romeo.

Vasseur said of Resta's hiring: 'Simone Resta has the best profile to take on the role of technical director. His arrival at Alfa Romeo Sauber F1 Team marks a significant step ahead of a long term project that aims at strengthening the team in order to achieve ambitious results.'

XPB

After 17 years at Ferrari Resta has now moved to Sauber to take on the lead technical role at the team

Ferrari has said it will not replace Resta directly and will instead share his responsibilities between current technical personnel, with his deputy Fabio Montecchi taking on most of his responsibilities. Chief aerodynamicist David Sanchez and Enrico Cardile, a Ferrari GT aerodynamics expert who moved into the Formula 1 team in 2016, will take on wider roles within the Scuderia.

Former FIA safety chief Laurent Mekies is also set to take on an as yet unspecified senior technical role at Ferrari in September, at the conclusion of his gardening leave.

OBITUARY – Martin Birrane

As the boss of Lola, the owner of Irish race circuit Mondello Park, a team chief and a successful sportscar racer, Martin Birrane – who died suddenly at the age of 82 in June – had been a central figure in motor racing for over 50 years.

Birrane's involvement in the sport started behind the wheel of a Ford Anglia in 1967 and he went on to drive in Formula 5000 and top class sportscars – including 10 appearances at Le Mans, winning the Group B class in 1985 at the wheel of a BMW M1. He continued to compete as a driver in historics until he was well into his 70s.

He also owned a Cup-level NASCAR team in the early 1990s and in 1986 he bought Mondello Park, which under his ownership went on to host BTCC races and major sportscar events.

Martin Birrane, the former owner of Lola Cars and a Le Mans class winner as a driver, died suddenly in June

But it was as the rescuer and then boss of Lola that he will likely be best remembered. Birrane, who had made a fortune in property development and was rated among Ireland's most successful business people having built up the London-based Peer Group property portfolio to its current worth of £190m, bought Lola out of administration in 1997, renaming it Lola Cars International. Under his stewardship Lola diversified into new areas of business including aerospace and automotive. During his time at the helm it produced the first-generation A1 Grand Prix car and a succession of successful LMP prototypes.

Birrane was busy with arrangements for events to celebrate the 50th anniversary of Mondello Park, the 60th anniversary of Lola cars at the Goodwood Festival of Speed in July, and also his diamond wedding anniversary, when he died so unexpectedly.

Martin Birrane 1935-2018

RACE MOVES – continued

XPB

Vijay Mallya is no longer a director of Force India, having handed his seat on the board to his son Siddarth, although Mallya senior remains in place as team principal. Mallya has said he wants to concentrate on his legal issues and does not want these to affect the team. **Siddarth Mallya** is a well-known actor in India while he also has some business experience.

NASCAR has announced that **Jim Hunter** has been awarded with the Landmark Award for Outstanding Contributions to NASCAR, for his work helping to guide the organisation's growth during six decades working as a company executive, track president, public relations professional and journalist.

SRO Motorsports Group has announced that the incorporation of WC Vision LLC and the Pirelli World Challenge into its organisation will not mean a change in leadership for the US sports and touring car series with **Greg Gill** staying on as president and CEO, while **Bob Woodhouse, Peter Cunningham, Jim Haughey** and Gill will remain in place as members of the board.

Dr Henry Bock, for a long time the medical director at the Indianapolis Motor Speedway and a man who helped to develop the SAFER barrier, has died at the age of 81. Known as 'Hank' Bock served as IMS medical director from 1982 to 2006 and also as a consultant for IndyCar and the Speedway following his retirement.

There's been a flurry of promotions within NASCAR's management where **Gene Stefanyshyn** will now lead its international efforts as senior vice president and chief international officer, while **John Probst** has been promoted to vice president, innovation and racing development, **John Bobo** has been promoted to vice president, racing operations, and **Scott Prime** has been promoted to vice president, strategic development.

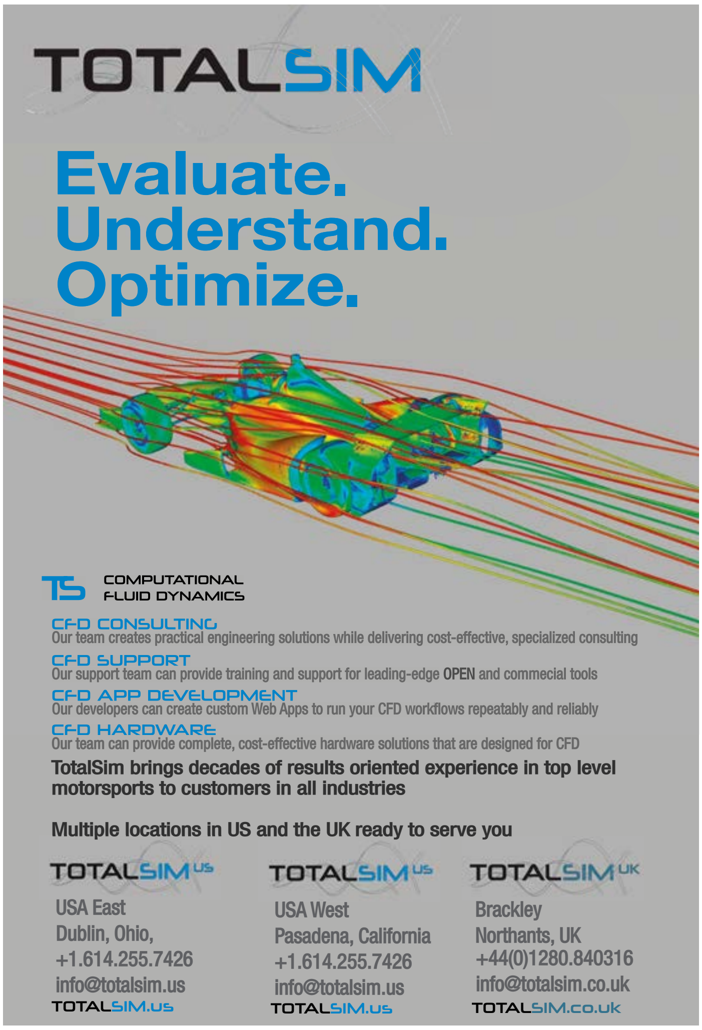
Jean-Marc Gales, until recently the CEO at Lotus Cars, is now CEO of JD Classics, known for its work restoring and selling classic cars and also for running many historic racecars in events across the globe. Gales has around three decades of executive experience within the automotive industry, including senior executive roles in sales, marketing and operations at Mercedes, Volkswagen, Fiat and General Motors.

Grahame White is to retire from his role as chief executive of the Historic Sports Car Club (HSCC) in the UK – a position he has held for the past 20 years – at the end of this year. He will, however, remain involved with the club, acting as a consultant.

John Leonard is now the interim crew chief on **Kasey Kahne**'s No.95 car in the NASCAR Cup Series. He was previously the lead engineer but has moved up following the departure of former crew chief **Travis Mack**. The latter left for an as yet unknown reason.

All three crew chiefs for NASCAR Cup operation Joe Gibbs Racing – **Adam Stevens, Chris Gayle** and **Mike Wheeler** – have been fined $25,000 each and were suspended from one round of the series after all their cars were found to be fitted with unapproved splitters at pre-event inspection at the Michigan race.

◆ 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**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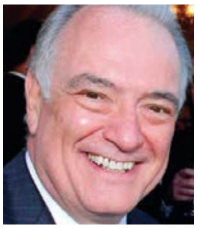

Growing pains

Business growth was under the spotlight at the recent MIA conference

Wherever I look across the motorsport and high-performance engineering landscape, I see many changes afoot – some really positive, some highly dangerous. Achieving business growth during these fast-changing times was the theme of the MIA Business Growth Conference on 5 July, in partnership with *Racecar Engineering*, at Sahara Force India F1 HQ.

There was much to ponder. How many job losses will occur when the F1 teams react to cost reduction; will this boost the supply chain; how will new FIA Endurance Racing plans and those of Formula E create new opportunities – the list is endless.

All these issues affect growth and they will need the attention of business owners so they aren't caught napping. But let's get possible negatives out of the way first.

Vnuck's sake

The UK Department of Transport clearly laid out the genuine, imminent threat to all EU-based motorsport from the latest proposals on the Vnuk issue from the EU Commission. These are even more damaging for the future of motorsport than the previous ones, in spite of 3500 responses which exposed the substantial job losses which the plans would create. This is really bad news.

Let's be clear, Brexit makes no difference to the EU's plans for Vnuk, as no insurance will be available it will close down all motorsport across the whole of the EU, an area upon which the future of the UK motorsport industry depends. Co-ordinated action is needed by everyone in the sport and industry right now. The MIA will again do all possible to help, but must call on the FIA and its ASNs to be proactive too.

We must also take a different and positive view on Brexit. We should cut through the waffle and political babble of the negotiations and develop plans to handle the next three years.

The UK leaves the EU in March 2019 – that's just nine months away. So clear, sound plans are needed to take advantage of the extended implementation period. Our industry prides itself on being 'solution providers' so let's use our innovative talents to find a solution to see us through this first Brexit period. Having heard the expert advice at the MIA Business Growth Conference, I'm confident, if we get our focus right, we will do just fine.

Good markets are opening up where we should direct our efforts. Asia, including China, is set for rapid expansion over the next five years. Never forget South East Asia, including Malaysia, which invested heavily in F1 and which has increased its interest in motorsport, and needs suppliers. Good, motorsport-experienced contacts in the region are vital and the MIA has these linked through our liaison offices in Shanghai and Hong Kong.

Racecar Engineering has reported on potential changes to technical regulations in Formula 1 in 2021 which will call on suppliers to help prepare and develop solutions during 2019 and 2020. There will be no time to waste discussing details once these become clear very soon. This is also true of the latest announcement from Le Mans by the FIA and ACO (see page 80). Their technical plans and new cars are needed even earlier, once confirmed by the FIA, so new suppliers have to be ready for this.

An idea to refer to historic racing as 'pre-owned motorsport' was discussed at the MIA's conference. Pictured above are some Jaguar C-Types in a 'pre-owned' race at Goodwood

Cross wired

World Rallycross is another growth opportunity, rapidly gaining popularity. Plans for its electric series have been announced and some suppliers contracted already. So many suppliers which have experience in supplying electric solutions to Formula E can now sell to WRX. I expect BTCC to embrace elements of electric power very soon too.

The UK government recently committed £250m to the Faraday Challenge to make Britain a world leader in battery technology. This investment, and the need it is creating for prototype and R&D work by small, agile companies, is already underway. Motorsport suppliers need to engage with this programme and secure government funds to benefit. Just as the Faraday Challenge is aimed at the global automotive industry, be sure close behind will be increasing demand in the sport for high performance electric powertrain suppliers.

'Pre' historic?

Another significant growth opportunity is staring us in the face. It's been hidden for many years under the easily misconstrued banner of 'historic, classic, and vintage' sport. The conference discussed the idea that this vital sector should embrace common practice from the automotive world and be renamed 'pre-owned motorsport vehicles', as this is undoubtedly the largest car park of motorsport vehicles in the world and grows every week.

An ugly title, yes, but one that has gained acceptance over many years in the mainstream automotive world, to no ill-effect. Every major brand offers pre-owned vehicles and the same now applies across motorsport. How can a Le Mans or Formula 1 car from 2010 be considered 'historic'? It's FIA regulations which categorise cars as being 'historic', 'classic' or 'vintage', but all of them are 'pre-owned'.

This vast car park will guarantee a healthy future for ICE powered vehicles, on two or four wheels, for decades to come. The pleasure from these racecars will last for generations and provide good income for all involved. The wider (modern) motorsport supply chain must get more actively involved in the pre-owned motorsport vehicle market and share in its bright future.

I started this piece by outlining some challenges that lie ahead, but I hope I have caught your imagination with some of these outstanding opportunities for business growth in the next two or three years, too. Make sure you prosper whilst others complain. I'm very positive about the future and full of confidence that our innovative industry, populated by business people who know how to win, will continue to enjoy great success.

The motorsport industry must take a different and positive view on Brexit

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Racing rethink required

This year's Le Mans 24 hours was not the procession that everyone says it was. The distance covered by the winning Toyota would have delivered the Japanese team victory in both 2016 and 2017. And despite the lack of manufacturer opposition, this was still a real race between the two Toyotas, and it resulted in a respectable performance, without team orders.

However, there was still a feeling of ill-will throughout the paddock. Not towards Toyota at all, but towards the organising body, and that was because of the over-regulation of the pit stop times and stint lengths in all categories bar one; LMP2. For the first time, each of the classes was performance balanced in various ways. In LMP2, however, a conservative strategy could see the fuel limits stretched to an extra lap, and that was made use of as it is a fundamental part of endurance racing. Yet in other categories, over-regulation killed the competition and was one of the reasons why the GTE-Pro category promised so much and delivered so little.

The GTE-Pro cars are all performance balanced throughout the season. Le Mans is not counted in the automatic BoP that governs every other race because it is such a different circuit; where other tracks are downforce related, Le Mans is all about top speed. Teams produce special low-drag kits for the event, and even the tyre usage is different. The BoP is therefore a little more tricky to sort out and the easiest racecars to balance are those that have raced before. Race and qualifying data is then used to balance the cars, but the problem comes when new cars arrive; BMW and Aston Martin this year.

The arguments raged, the arms waved about, the accusations of sand falling out of particularly the Aston Martins was actually topped when one rival team said that the Astons were given a slow target lap time and competed under threat of penalty if they exceeded it. 'We are not that clever,' was Aston's response, having been given even more power on the Friday before the race, yet still lapped seconds off the pace.

However, the class had another problem, and that was an arrangement that all the action would take place out on track, and not in the pit lane. Stint lengths were therefore limited to no more than 14 laps, whether there were slow zones or safety car periods. Refuelling was restricted to 35s minimum time, whether the car needed a full fill after its 14-lap stint or not (i.e if it was under the safety car). The number of non-confidential Michelin tyres were limited, but with 17 cars, 51 all-pro drivers, it could have been good.

It wasn't. One lucky roll of the dice behind a safety car was all it took for Porsche to gain a minute over the rest of the field, and with such restrictions in place there was strategically nothing anyone could do to catch it. Lap times were balanced, and all Porsche had to do was execute its race. That task is not to be underestimated, but was still a relatively straightforward thing to do. Suspension worries due to kerb hopping were pretty much all that may have slowed the number 92 pink pig.

It was the same in GTE-Am, and LMP1 under the Equivalence of Technology formula. It led to calls up and down the pit lane for the regulators to take their finger off the jugular and return the sport to exactly what it is supposed to be; a sport. Managing fuel mileage, tyre strategy and performance is ultimately what racing is all about, yet thanks to over-regulation, one mistake early in the race can be a decider.

What the sport needs, I think, is to separate back out the refuelling and tyre changes as a matter of urgency. Not only is the practice unsafe in my opinion, with driver changes rushed, it is also unnecessary. Return to the teams that opportunity to make a difference in the pits, and don't give them the chance to change set-up (through bodywork changes for example) without a penalty, or change brakes, while the car is refuelling.

Motor racing needs unpredictability and at this year's Le Mans 24 hours there was none

Rethink the safety car procedure, too, because no matter what you do, a stoppage will favour one car over another. You cannot introduce such a system without having an impact on the race, and we have to accept that fact. Then, it all becomes easier. In 2017, the race director did not release a slow zone if there was a hybrid in it, as not to affect the outcome of the race. In 2018, there was no such luxury. Slow zones came and went as fast as was possible. It was the only lottery in the race, apart from the bad weather which frustratingly didn't arrive to spice up the show.

Motor racing needs unpredictability and at Le Mans this year there was none. Toyota ran cleanly, and won. G-Drive Racing was only the third leader in the LMP2 class, taking over on lap 10, and it held on to its lead until the end. It was later excluded for refuelling infractions, but on track it was a non-event. In GTE-Pro, on Saturday night Porsche finished up behind a different safety car to the rest of the GTE field in hour four, and held that advantage for the remainder of the race.

Le Mans 2018 was not a classic race, but there are simple things that can be changed to liven things up. They need to be, as another year like this one will be very hard to bear.

ANDREW COTTON Editor


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