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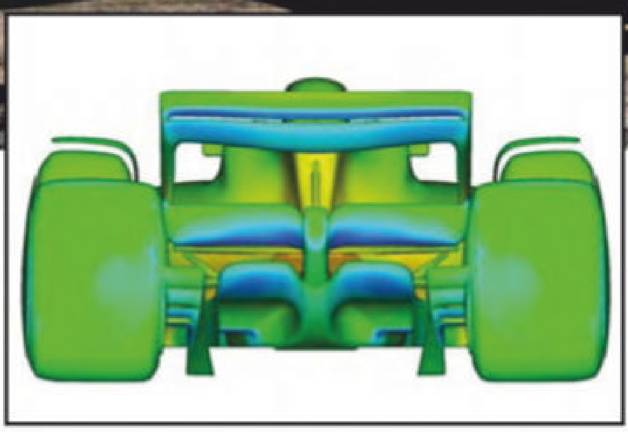

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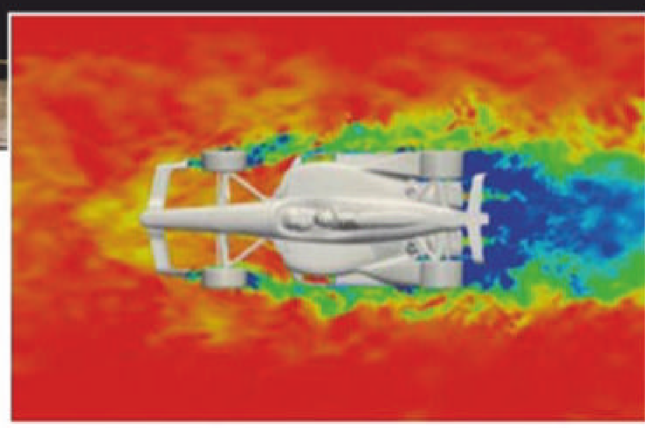

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The sun came up on another F1 season at Barcelona at the end of February. Turn to page 8 for our assessment of the challenges the teams face in 2019

Are we nearly there yet?

Sometimes the drama can start long before the racecars get to the track

A recent trip for a racing assignment was enlivened by a departure from the usual boring and annoying battle to get to the destination. This usually just demands a lot of forbearance, and a tight control on your urge to kill or at least painfully maim sundry fellow passengers, or the security agents trying to get hold of your footwear. Worst of all are the kids infesting the aisles, that is when they are not screaming at a pitch that makes you fear for the integrity of the portholes, or kicking the back of your seat, ignored by their parents.

But this time a medical emergency on board forced yours truly and 448 fellow passengers to spend 20 hours stranded in Sri Lanka, not at all our intention. Yet maybe it wasn't so bad, presumably Juan Manuel Fangio's experience of being kidnapped at gunpoint when in Havana while preparing to participate in the 1958 Cuban GP for sportscars would have been worse.

Fly drive

There has been quite a bit of drama on the way to or from a race, though. At one time I was aboard a Caravelle in the south of Brazil when the landing gear didn't come down, which was mildly alarming; if just for the grinding noise of the plane's belly rubbing the runway, and then the billowing clouds of foam laid down by the fire trucks which crashed in waves over the wings.

Another time a detour to Anchorage in Alaska on the over-the-Pole flight back from the Japanese Grand Prix, due to an engine failure, most definitely woke me up, despite accumulated jet-lag and lack of sleep from the race weekend – especially when I saw the line-up of ambulances and fire trucks by the side of the runway.

But as far as disruption to travel plans for a grand prix are concerned then nothing beats the 2010 eruptions of Eyjafjallajokull in Iceland, which, although relatively small for volcanic eruptions, caused enormous problems with air travel across western and northern Europe over six days in April of that year. Approximately 10 million travellers had their movement compromised when 20 countries closed their airspace over concerns about volcanic ash in the atmosphere.

Even Formula 1 was hit. Teams and drivers coming back from the Chinese Grand Prix, like Toro Rosso's driver Jaime Alguersuari, who travelled with Virgin test driver Andy Soucek, lost count of how many times they landed at airports to change plane and destination – travelling to Madrid via Shanghai, then Beijing and New York, is not a usual route. 'We feel like we've been around the whole world,' Alguersuari told the press after his odyssey. Well, nearly.

Meanwhile Mark Webber's return to his UK home took 44 hours. He flew from China to Dubai, and then to Rome, and finally woke up in Nice on the Tuesday morning after just five hours of sleep ready to return to Britain. Michael Schumacher's cunning ploy, of hitching a ride on Bernie Ecclestone's private aircraft, came a cropper as *even* private planes were affected by the closing of the airspace.

Arrive in style. Things have moved on a little since the 1950s, but one thing remains the same: getting to the races can still prove to be quite a challenge

Round the bend

My personal problems at this time were more of a survival nature, when the plan to drive down to the Hungaroring from Paris with the three drivers I was running in LMP2 turned out to emulate an endurance race in itself – it is never a good idea to be a participant in anything a gaggle of racing drivers will do. The ensuing mad dash across Europe confirmed my worst suspicions about them; pit stops for fuel were the only respite from the hair-raising antics on the roads and motorways. We survived, but it was not an experience I would repeat willingly. I have more respect for my sanity.

But 'the show must go on' mentality doesn't only apply to drivers and crew, it also concerns the coming and going of the racecars and the gear. Chaos seems to be particularly attracted to any endeavour concerning racing, especially travel, and sometimes in surprisingly unusual ways.

Haul of fame

The transporter breaking down was not an unusual occurrence when leaving UK shores, but to have the hydraulic lines to the ferry's bow doors flood the hold, thus making any attempt to drive up the ramp and on to the quay a futile exercise, certainly was unusual. The lack of traction was eventually solved by using tractors to winch us out, with our once pristine white Bedford Duple covered in a hydraulic fuel that was impossible to clean off.

An F2 race in Enna brought a different sort of problem when a trailer bearing a Porsche 911 for the supporting race disappeared from the hotel parking lot. Rumour had it that a group of Sicilian gentlemen who had an alleged connection with certain unwholesome goings on in gambling, receiving of funds from other businessmen to avoid unpleasant accidents, or running young ladies of easily rented virtue were, again allegedly, friends with the race organisers, and this resulted in the same trailer turning up overnight in front of the track entrance with a couple of cases of the local wine sitting beside it; just to make amends for any misunderstanding.

But surely the most surreal mishap for a racing team was the occasion the spare car at McLaren was being taken from Colnbrook to Brands Hatch on a trailer behind the team's new American big cubes V8 nine-seater van. The torque of the beast was being indulged in at every traffic light. The problem was that a fuel stop revealed that the car, supposedly strapped down on the trailer, was no longer there. The team members then backtracked to find the F1 car in an unharmed state sitting on the road at the traffic light, to the surprise of all the passing motorists, seemingly on pole position.

Never tell me that motor racing is a normal business. But whatever happens, the people, cars and the gear always seem to get to the race.

The Formula 1 car was found in an unharmed state sitting on the road at the traffic lights, to the surprise of all the passing motorists

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The human race

While the cars may all look the same the people involved still make Formula 1 special

I wonder if, like me, all the recent Formula 1 car launches have left you a bit underwhelmed and even glassy-eyed over their focus on the aerodynamic detail, some parts of which are no bigger than a cigarette packet?

To the aerodynamicists involved and probably to those who are aero nerds all this may be manna from heaven. However, as so much of it is variations on a similar theme it can even wash over the heads of those who are keenly technically-minded. To the more casual followers of Formula 1, it must appear rather 'same as, same as'; this year's designs look much like last year's and – apart from the bigger tyres and of course the front wing – not that much different really even from the season before that.

The cars are all equally angular, big, lacking line and proportion and, livery apart, it's difficult to distinguish one from another. Could this be a part of the reason why Formula 1 doesn't have as much appeal as it maybe should? Concepts of possible future F1 cars were published by Ferrari and Red Bull a year or so ago, and by McLaren more recently. How much more exciting to see racers like these on track?

XPB

The new Alfa Romeo sported a funky one-off colour scheme when it broke cover. These days liveries are often the only way you can tell cars apart

Send in the clones

A lack of individuality is of course what one must expect when all the designers have to work within such a constricting set of regulations, covering just about every aspect of the car and power unit. They use the same computational tools with similar aims, guided solely by functionality, with no place for artistry. Just as stealth jets, wondrous but far from beautiful, are a world away in appearance compared to more stylish aeroplanes of the past; both result from the same inevitable convergence of data-driven design.

Therefore, we look forward in hope to the promised 2021 regulations which, for a short time at least, just might produce greater daring in technical approach. Also promised is that the aesthetics will be improved – a little more along current IndyCar lines, at least in profile, would be a good starting point. Getting away from the long-standing Formula 1 standard of having an overhead airbox and the more recently adopted tail fin might get us back to the sleeker look of the previous era of turbocharged cars. It would also test the ingenuity of designers and engineers in arriving at more innovative cooling solutions, which could have applications outside of racing, something that the FIA is always banging on about.

The idea a few years back was to get rid of appendages such as the messy bargeboards and turning vanes. Apart from appearance, their unfathomable retention also helps to maintain the disparity between the rich and poorer teams, because spending a great deal of time and iteration on them clearly does pay off in performance.

People power

Because of the above it is then good that we still have the human element involved at all levels of a Formula 1 operation, with the effects that temperament and foibles can have in differentiating winners from losers. It's thankfully not – yet – all about artificial intelligence.

The capability of using mind management, as Sir Jackie Stewart so aptly describes it, in achieving results is seldom more obvious than with the Formula 1 drivers. Right now, Lewis Hamilton has finally attained this attribute, to a remarkable degree. Sebastian Vettel hasn't. Fernando Alonso comes close; his ability to succeed in several racing disciplines is totally impressive given that each has become such a speciality, his work ethic and personal preparation is up there with Hamilton's.

Unfortunately, Alonso is out of F1, at least for now. Max Verstappen is beginning to understand this aspect of the game and has succeeded, in addition, in making other drivers hesitant to duke it out with him. Even Hamilton gave him plenty of space on one occasion (at the US Grand Prix at Austin last year, although to be fair he had little to gain and much to lose if he had chosen not to do so). This is a powerful psychological advantage to have, but I doubt that the young contenders coming through, Charles Leclerc, George Russell, Lando Norris, Pierre Gasly *et al*, will let this deter them – in fact, they cannot afford to.

One might have thought that Valtteri Bottas, at least, would have twigged this by now. He needs to re-invent himself and to hell with the dutiful number two stuff. Away with the baby face now, Valtteri. Grow your hair, adopt a Keke Rosberg-style moustache, get a few tattoos, put Viking horns on your helmet, bang wheels, do whatever it takes to show that you're not prepared to be a patsy anymore.

The aura that a driver can project, in and out of the racecar, is so important in beating rivals that it can win a grand prix even before it starts. Ayrton Senna was a prime exponent of this.

Miracle workers

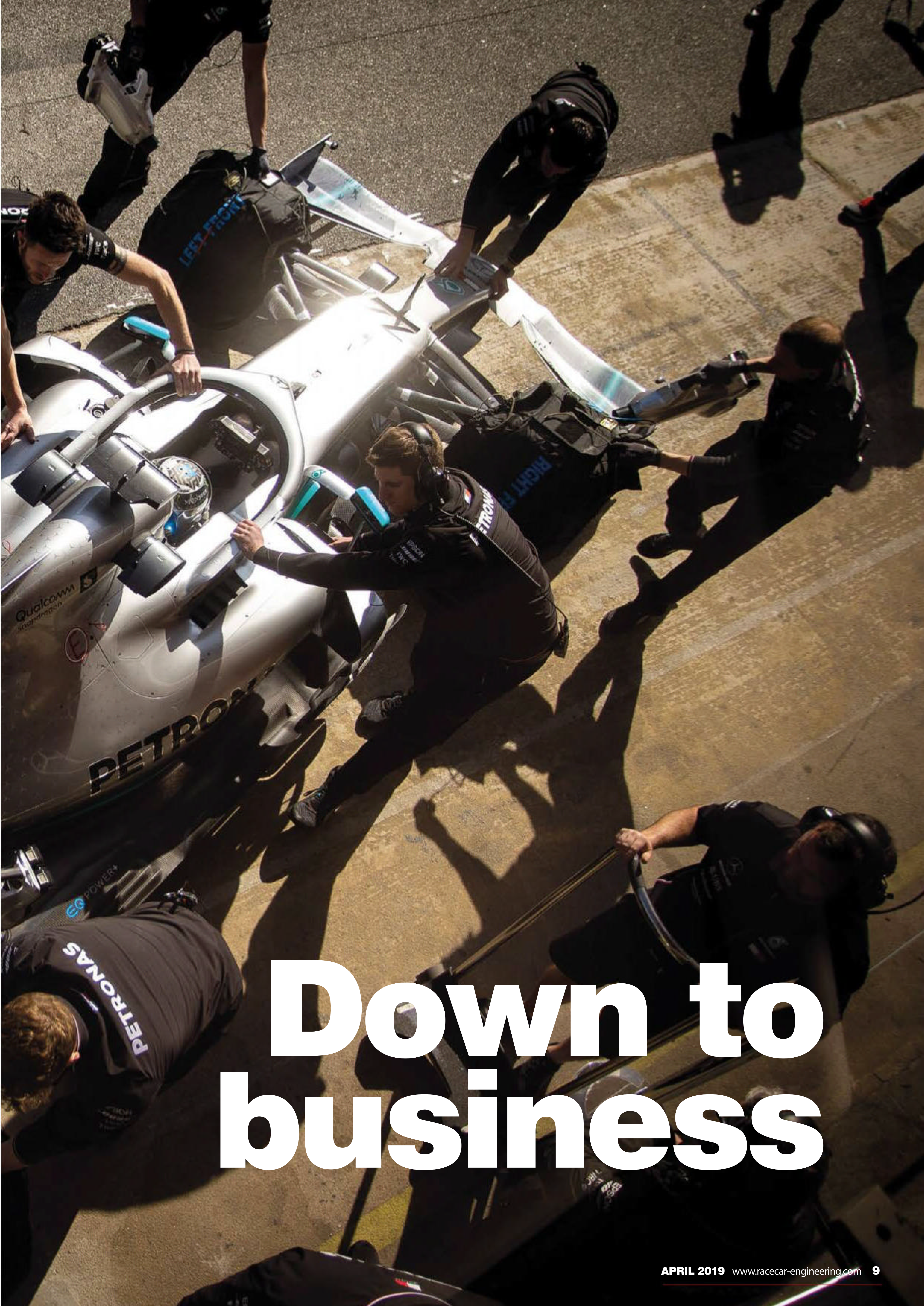
Despite some of my comments above and unnecessary 'dead-hand' regulations which frequently cause frustration, not least for fans, some aspects of Formula 1 (also applicable to other top forms of racing) always impress me. I cannot recall the last time that a car was rejected at post-race scrutineering. Given so many dimensional, deflection and weight tests and the like requiring to be checked post-race, it does testify to the professionalism of those involved, teams and scrutineers alike. Also, when grid places are decided by thousandths of a second, I cannot believe that tyres can be manufactured and prepared to perform equally within such infinitesimal fractions of lap time; some variance must exist.

Surely this serves only to emphasise just how good the engineers are, and the drivers, who consistently pull that ultra-fast qualifying lap out of the bag when it matters. Astonishing too is the reliability of the complex machinery, almost taken for granted nowadays. The processes, intelligence and sheer hard work inherent in achieving all this, plus so much more, puts to shame some of the dumber aspects of the sport to which we are all so drawn.

We look forward in hope to the promised 2021 regulations which, for a short time at least, might produce greater daring in technical approach

With differing approaches to the new aero rules the first Formula 1 test of 2019 was always going to throw up some interesting questions such as; who has clawed back the most downforce and where will the development battle be fought this season? *Racecar* trawled the paddock at Barcelona to find the answers

By SAM COLLINS



Down to business

The Formula 1 teams gathered together at the Circuit de Catalunya in mid February for the start of winter testing ahead of the 2019 season, as usual. What was less usual was the general lack of launches running up to the start of testing. Normally, before the hard work of testing begins almost every team shows off its car to the media in presentations of varying styles ranging from bacon rolls at Silverstone to glossy events more akin to a Hollywood premiere than an automotive engineering showcase.

But in 2019 only two teams opted to have formal launches; McLaren and Ferrari. A number of other teams held events to show off new liveries, while others still merely emailed out renderings of their new cars, which were only vaguely indicative of the real thing.

The reason for this slight change in procedure compared to previous years is not entirely clear but is likely to be, at least in part, due to the Australian Grand Prix being a week earlier than normal in order to avoid a clash with an Aussie Rules Football match, which meant an earlier date for testing, too. This change has put major pressure on the teams trying to get their cars ready. It particularly caught out Williams, which missed the first few days of testing as it was not able to get its car ready in time.

Renault also cut it fine. 'We were late with the build, that was pretty pushed,' its chief designer Nick Chester admits. 'As other teams have clearly had similar issues it has clearly been a factor, but I think it is probably a bit of a reaction to the lateness of the regulations as well. As the regulations were finalised so late the teams have pushed everything else quite late to get the most out of the new rules. Then it all got squeezed when the date of the first race moved forward, so its been a pretty tough winter.'

Wing working

The new rules, which have already been detailed in previous editions of *Racecar* (including January 2019, V29N1) aim to make overtaking easier by reducing the amount of aerodynamic outwash from the cars. To do this new wider, but far more simple front wings, are employed along with a higher, wider rear wing.

'One of the intended purposes of the 2019 regulation changes was to reduce the amount of outwash generated by the front wing and the end-plates in particular,' Toro Rosso's deputy technical director Jody Eggington explains. 'This leaves us with the challenge of reconstructing the required flow structures to recover the lost load within the scope of these new regulations. Although the front wing width has been increased, we have lost the winglets and the elements which were on the outboard portion of the main plane and the end-plate itself is simplified. Together with the simplification of the front brake ducts, the opportunities for generating the required flow structures and positioning them where you want are different, and this requires that you recover the size and trajectory of the front wheel wakes and flow structures by identifying key areas for aerodynamic development and exploiting these to the maximum.'

The front wing on the Alfa seems to be designed to encourage outwash, with flatter upper elements on the outer portions

To try to eliminate outwash very simple end-plates have been mandated for the front wing. Toro Rosso STR14 is pictured

The Alfa Romeo team (which was previously known as Sauber) utilises a very different looking front wing on its new car, the C38, and Ferrari has also experimented with a similar solution with its SF90. With this concept the upper wing elements do not extend all the way to the end-plate, leaving an open section. This seems to be an attempt to influence the front wheel wake into washing outward.

'It is a rolling development, everyone is looking to optimise all parts of the car and I am sure we will see front wings visually different and there will be strong developments there,' Eggington says. 'I think, depending on how you look at it there's two or three schools of thought on front wings visually at the moment. I can't speak for other teams, but for ourselves, we looked at an awful lot of

'One of the intentions of the 2019 rule changes was to reduce the outwash generated by the front wing, and the end-plates in particular'

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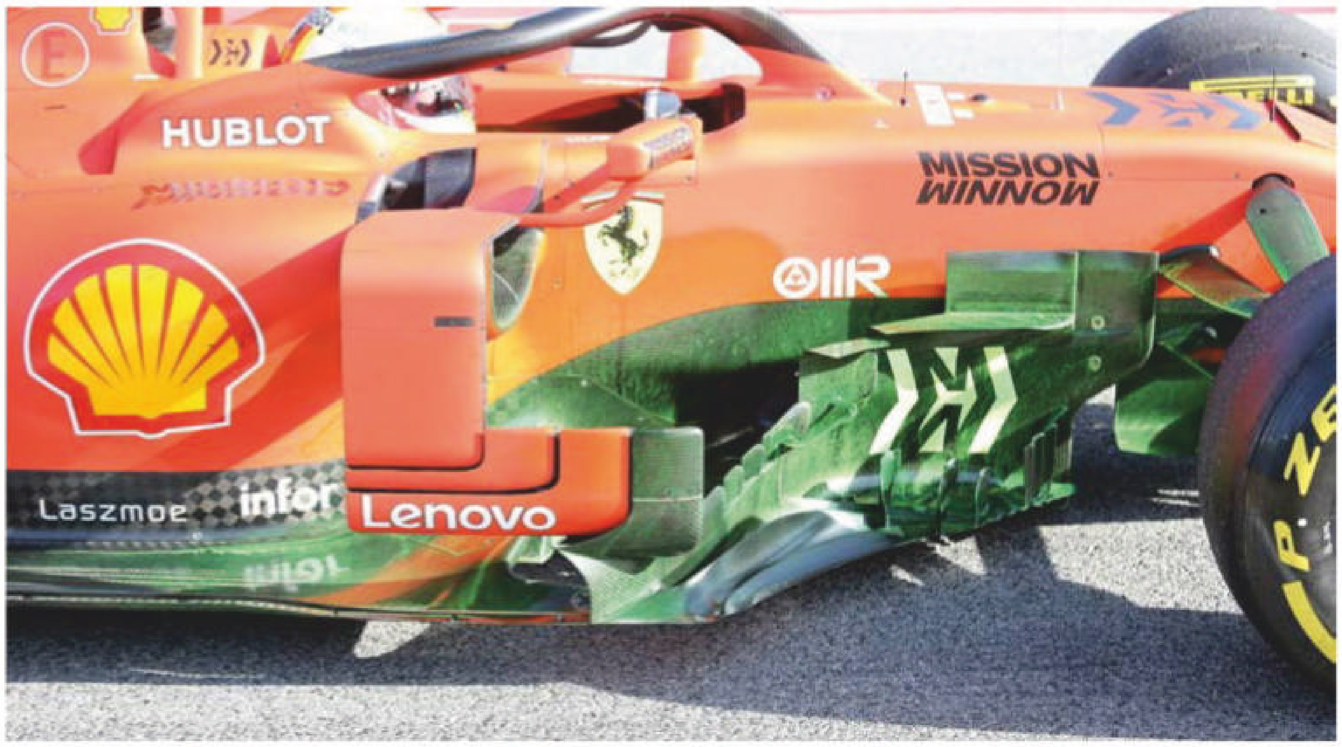
The front wings have a significant influence on many parts downstream of them and this means that changing a concept is no minor undertaking



Ferrari SF90's sidepod and bargeboard treatment is similar to 2018, although it is all a little lower, in line with the new rules

options on front wing, front wing end-plate, the bargeboard, and front wing brake duct, and at a certain point in the programme we decided to go one way or the other.'

In the paddock during the first test there was a widely held belief that most teams had yet to show all of their work, with many running what could best be described as interim front wings. 'There are a wide variety of solutions you will see but ultimately there is a choice between getting as much outboard loading as you can and trying to use the outwash to move the wheel wake out,' Chester says. 'There is a bit of a balance to be struck. Over the season we will see how that develops but I suspect everyone will end up moving in the same direction. On the other hand there are cars out there performing well with other solutions.'

Fixed wing

The front wings have a significant influence on many parts downstream of them and this means that changing concept is no minor undertaking. 'If you decided you were on the wrong tack and decided to go to a very different front wing concept, it would not be easy,' Chester says. 'You would probably put on the new wing and find that it was a long way down and you would have to develop with it for a couple of months to get it working. It would not be easy switching.'

Bearing in mind these comments, and comparing the front wing of the Alfa Romeo and a more conventional design such as that of the Haas, it might seem like the rules are wide open in terms of the front wings, but that is not the case. 'I think the front wing regulation was really well tied up, perhaps overly restrained as it is pretty difficult to design anything other than what you see on track,' Racing Point technical director Andy Green says. 'It's possible everyone will migrate to the Alfa and Ferrari, solution, it seems very promising to us. But teams like Mercedes have done their own thing for years in terms of design philosophy, they stand out for being quite different and they have won five championships. There is always room for another philosophy, we may end up with a mix of cars running one solution or the other and each may end up as competitive as the other.'

The 2019 rules severely restrict the design of the front brake ducts. Previously the teams had an area of technical freedom on the inner face of the front wheels and this saw many turning vanes and winglets utilised in this area. On initial

The bargeboards on the McLaren MCL34 feature a bridge section. This remains a prime area for development in Formula 1

Many cars, including the Red Bull RB15, ran basic front wings but much development is expected in this area

'The development work this year will be about trying to get outwash, and also trying to stop the wheel wakes coming back under the floor'

reading of the new rules, teams are limited to just a single brake cooling duct in this area and no other aerodynamic elements, but the teams have found many more creative ways of reading the rules and every single 2019 car features highly complex brake ducts, with some cars even featuring small aerodynamic elements.

'When we first looked at it we initially had a basic scoop there, but it was such a massive performance hit our incentive to claw it back was very high,' Green says. 'It is a huge development area in the short term, along with what we can do with the front wing.'

This seems to be the case up and down the pit lane, with most of the teams seemingly planning further development in this area. 'We found that it was quite a deficit in terms of overall performance as we lost all the turning vanes and a lot of the shaping we could do,' Chester says. 'But as you develop those brake drums and ducts under the new rules you start to find some big gains. It is an area where the teams will be working hard.'

The Mercedes W10 sports a highly developed front brake duct with a cluster of small aero elements sitting inside the wheel

Reigning champion Mercedes is notably the only team not to have relocated its side impact structures for this season

Bargeboard focus

Beyond the front wheels lies one of the most complex regions of the current generation of car. The bargeboard area is a position where there is almost complete technical freedom within a regulatory box, and every car has a different solution in this area. 'I think there will also be a lot of work on the bargeboards, with the sidepod vanes,' Chester says. 'I think predominantly the development work this year will be in the front half of the car. It will be about trying to get outwash and trying to stop wheel wakes coming back under the floor.'

Indeed, this development had already begun in pre-season testing with teams starting to experiment with new designs within 24 hours of the roll out of the new cars.

'People will move to a common design of front wing pretty quickly and then the development race will move to the middle of the car,' Green says. 'The bargeboard area, the front of floor area, that is the real playground, you have a huge amount of freedom, with that box you can put anything you like in. The outwash effect will just move to the bargeboard and I think by the time we get to the start of the European season that we will be very close to where we were in 2018.'

Rear wing end-plates are getting quite complex with some designs featuring distinct upper and lower sections

Carried over

Although the regulatory box defining the free area has been reduced in height slightly in 2019 the importance of the area remains. All but one team has opted to place the upper side impact structure below the main sidepod duct and take advantage of the potential aerodynamic gain that layout offers. But despite the rule changes and the increased importance of the centre part of the car most of the concepts seen in 2018 have been retained for 2019. 'Everyone has gone down the same routes as they did last year, there are no really new concepts out there,' Green says. 'It is an incredibly complex area but once you strip it back to basics there are essentially two concepts, then all the details are added. Basically the Red Bull camp and the Mercedes concept.'

Mercedes is notably the only team not to have relocated its side impact structures, continuing to believe this is probably more effort and risk than the potential reward justifies.

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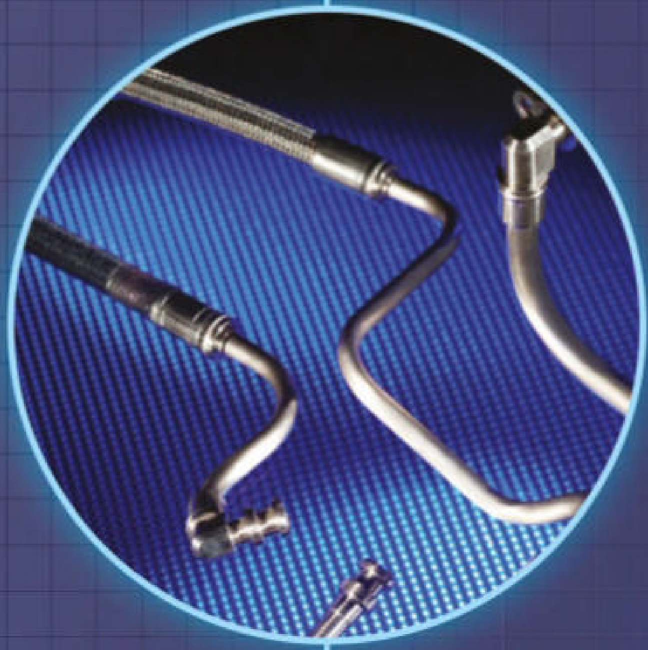

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'In terms of downforce levels, at this first test of 2019 we are not really very far off where we were at the end of the 2018 season'

Above the bargeboards and just ahead of the leading edge of the sidepods is another small area of technical freedom, and one which was meant to reduce the scope for development, but which has actually had the opposite effect: wing mirror design has reached a new level of complexity with attempts to reduce the drag of the housing while using the supports to gain an aerodynamic benefit.

'That is a real area of opportunity, it has become a little box of freedom, we will exploit it,' Green says. 'It only gives small gains but it is nice to have another area to look at. I don't think anyone has shown the race mirrors yet and I think there will be some really exotic solutions.'

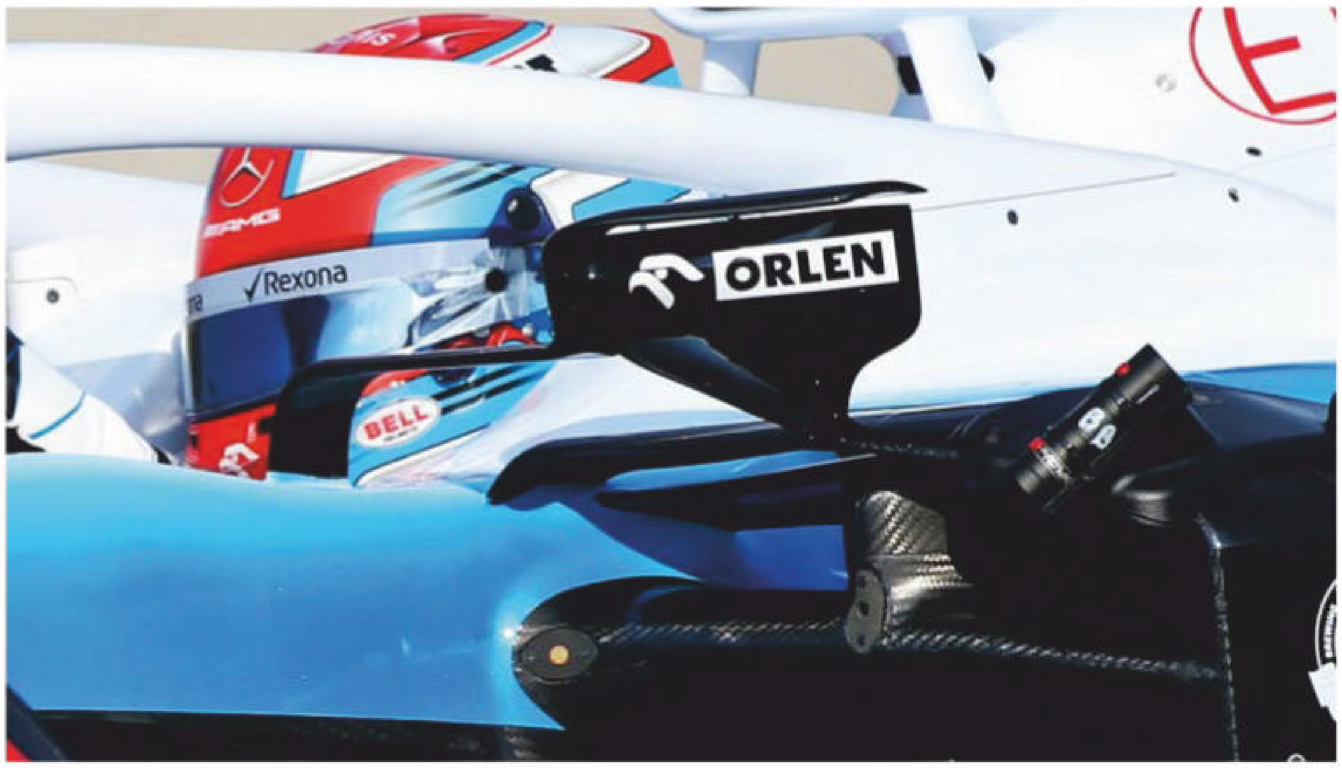
Rear view

Another area of change as a result of the new regulations is the rear wing. These are wider and taller and feature a more powerful DRS system, again in an attempt to increase the amount of overtaking. However, this caused issues for at least three teams in the first test, with Red Bull, Renault and Racing Point all suffering from unexpected failures. 'We had a problem with the DRS mechanism, we lost the link bar and it allowed the flap to rotate,' Chester says. 'Fortunately it was a fairly easy fix, we understood what the problem was and we fixed it. In a way it is related to the new regulations as it is a bigger wing, which is more loaded. There are new geometries, it has changed for DRS as we have a different line of action now, but it was just a detail change we needed to make.'

The Renault man's opposite number at Racing Point offered a little more clarity. 'It looks like we made a bit of an assumption in the loading on the flap while the DRS was functioning, with it fully open or closed there was no issue, the problem came when the actuator went to push the flap closed and it was the force required that was the one we missed. It was the actuation force, not the general loading on the flap,' Green says.

Mishaps aside, the increased loads on the rear wings have seen a number of teams switch to twin wing supports in order to cope with the increased stress. 'For us it was mainly structural; a single pylon already had to work pretty hard last year,' Chester says. 'The extra loads from the bigger wider rear wing we have this year mean that we need the two supports.'

The rear wing end-plates where another area where the regulations suggested the designs would be simplified. But the reality is that the end-plates have, if anything, become more complex, with some teams designs featuring distinct upper and lower sections linked by thin strips of carbon fibre.



The mirrors on the Williams FW42 perhaps give a hint of the direction in which the aero development in this area will go

'I don't think anyone has shown their real race mirrors yet and I believe there will be some really exotic solutions'

'It's an area of freedom and everyone has gone to town on it,' Green enthuses. 'It does bring performance, but not as much as the centre of the racecar. The end-plates need to be optimised with the rear end and rear wing, but I think it is one of those areas that will be developed quite a lot initially, until a solution is settled, and after that the developments will be more infrequent.'

Quick step

Despite an initial loss in downforce as a result of the 2019 regulations the new cars were already setting extremely fast lap times during the opening test, leading to suggestions that any benefit that the new regulations may have brought about will probably be negated by racecar developments relatively early in the coming season. 'I think you will see that the cars are a chunk quicker than they were last year; by the end of 2019 they are going to be quite quick,' Green says. 'In terms of downforce levels at the moment we are not very far off where we were at the end of 2018.'

Even after the first test had concluded it remained unclear if the new regulations had achieved what they set out to achieve then, and certainly there is real doubt about the effectiveness of the aerodynamic changes in terms of encouraging more overtaking. 'The new regulations were created to promote car following, but it will be a few races until we know if it has really worked,' Chester says. 'In Melbourne it won't be clear really as it is so hard to overtake there anyway. Once we get to Barcelona for the Spanish Grand Prix we will know a bit better. My feeling is that it might improve a little bit but probably not hugely, but in the right direction.'

It could be that to see really effective changes in terms of encouraging overtaking Formula 1 will have to wait until the 2021 season, then, when a fundamentally new set of aerodynamic and chassis regulations (see page 22) are set to be introduced.

Fuel rule

Shortly before the opening test the Formula 1 teams were all sent a technical directive which aimed at cracking down on what could amount to cheating using the fuel system. 'The rules say that there are supposed to be no additional areas where fuel can be stored, either in the low pressure side or the high pressure side,' Renault's Nick Chester explains. 'We are now limited to 0.25 litres of fuel maximum in the high pressure side, outside of the safety cell, and we used to be allowed two litres. Also you are not allowed any little volumes or restrictors which might allow you store and recharge. Its made it clear what is allowed.'

The suggestion here is that teams were building up excess fuel beyond the fuel flow meter and using it to get an extra on-demand performance boost, uninhibited by the fuel flow limit. Additionally the FIA has tightened up testing on how much fuel is used during a race.

Taking the heat

Why solving the problems associated with measuring tyre temperatures when the car is on track is now the Holy Grail for sensor suppliers working within Formula 1

By SAM COLLINS

With the launch of the 2019 Formula 1 cars a huge amount of attention was paid to the designs of the new front wings. But there was one small but hugely important detail that featured on a number of these that was almost entirely overlooked. And yet this could quite soon be a key factor in determining the outcome of world championships.

From the moment that Pirelli was appointed as Formula 1's sole tyre supplier in 2011, F1 teams have struggled to get the best out of the Italian rubber. At times it has made the difference between finishing on the podium or getting lost in the midfield. As a result of this F1 teams have spent a lot of time trying to get a clearer idea of how the tyres actually work on track, working with sensor manufacturers to create new products to give a better insight into what is really going on during a run. These projects have had mixed results.

'Teams were mounting sensors on the leading edge of the sidepods or in the mirror housings, but positioned there they suffered from loads of dirt and grit being thrown at them so the lenses were killed pretty quickly,' Stephen James, CEO of sensor manufacturer the Texense Renvale Group, says. 'Also, the distance from those mountings is quite far away from the point of interest. Generally speaking they were 800mm to a metre from the surface of the tyre in either of those locations. This had an impact on accuracy as you had to amplify the signal quite a bit, but that also meant that there was quite a wide spread for the data points. The overall results were okay but from an eight-channel sensor you were only seeing three or four spots of data as the others had missed the edge of the tyre. Additionally we found that it wasn't really possible to run a narrower sensor and get the level of accuracy needed.'

Common sensor

Engineers at a number of suppliers worked on solutions to resolve this issue and variety of products hit the market, but the most popular was introduced in 2014. It is a wireless eight-channel infrared sensor developed by Texsense, specifically designed for mounting on the front wing, a position which in many ways is better than the sidepod or mirror housings, but also comes with its own challenges.

'Mounting it on the front wing means that it is much closer to the tyre,' James says. 'This gives

‘From an eight-channel sensor you were only seeing three or four spots of data, as the others had missed the edge of the tyre’

great accuracy, but having it there really meant it has to be wireless as you don’t really want wire going through the nose when you might have to change it during the race. One or two teams do take wire through to the front wing but its quite a complicated system of connectors with locating dows and everything else to make sure you can still change the nose really quickly, we wanted to avoid that complexity.’

That style of sensor is still in use with a number of the F1 teams, the tear drop housings visible on the front wings of the new cars, but is now absent from others, with those teams moving toward alternative methods of monitoring tyre temperature.

‘It is difficult at the moment,’ James says. ‘Right now, generally what the teams do is run a thermal camera in Free Practice 1 or 2 on the Friday of the race weekend along with the eight-channel IR sensor. The problem is that the thermal cameras are generally quite bulky, smaller ones are available but broadly speaking the smaller and lighter they are then the less accurate they are. At the moment the Formula 1 teams have to take the thermal imagers off after Free Practice 2, so they don’t have it in FP3 or qualifying. In the race they probably would not use it anyway as the thermal image would be a huge data packet.’

According to James, while the thermal imagers do give valuable data, they are not as accurate as they really need to be, hence their use in conjunction with the IR sensors. ‘The ideal scenario is for the teams to be able to have the thermal image but also be able to extract accurate data points from it,’ he says. ‘While you can already do this to some extent with the thermal imagers on the market, the teams have fed back to us that while the data is alright, it is not great. Accuracy is really important to the teams now as the operational window of the tyres is very tight, it can be a matter of two or three degrees and it is crazy how much of a knife edge the teams are running on to get the tyres in the window. So the temperature spots are essential, they need those individual data points and they need to be accurate.’

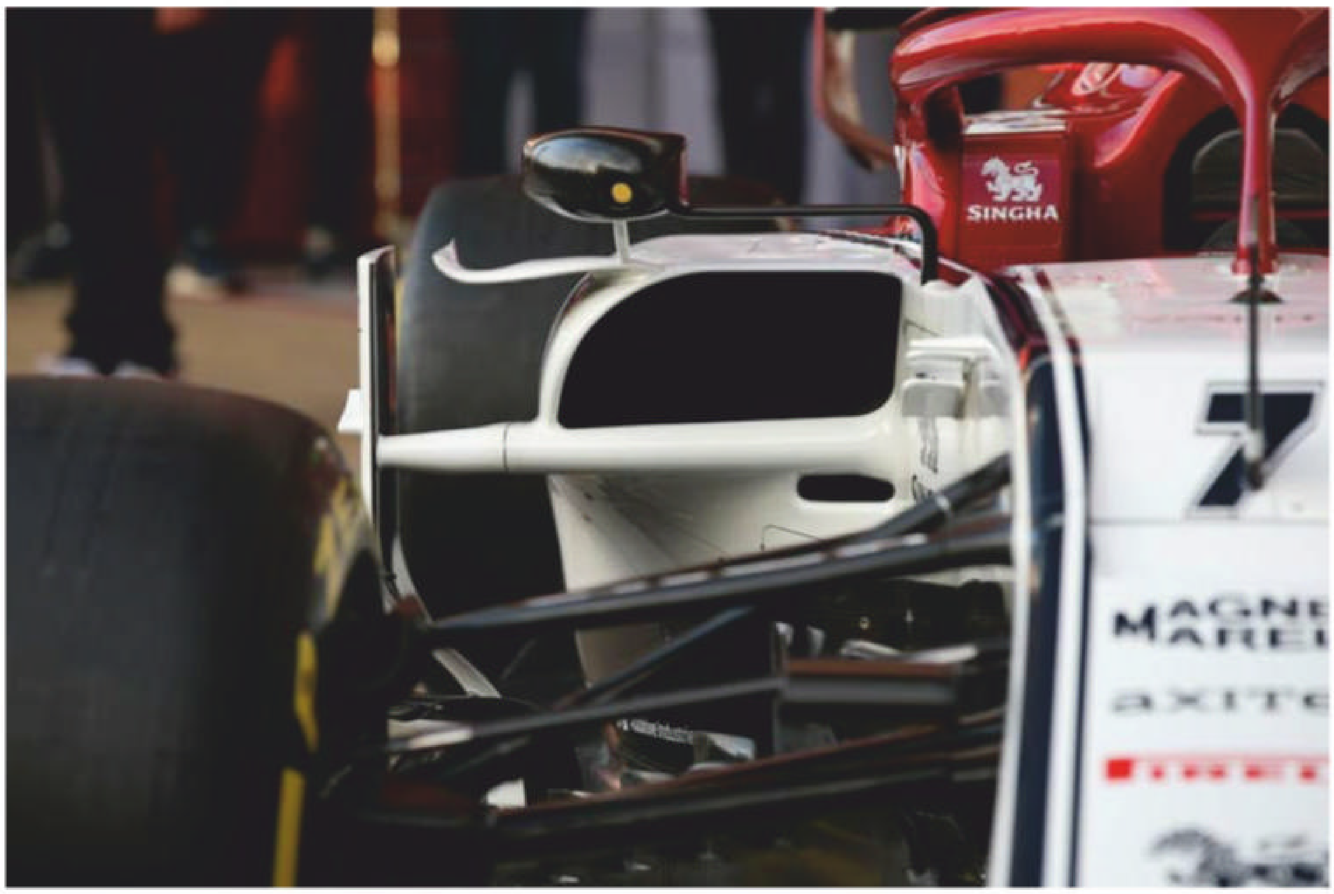
Heat and light

With both the IR sensors and the thermal imagers having their shortcomings, the F1 teams have approached the sensor suppliers to ask them to create something which has the advantages of the thermal imagers with the data spot accuracy of the IR sensors, all of this made as small and light as possible.

‘They told us that the real golden ticket would be a unit which could give you close to the same level of accuracy as the larger thermal imagers but in a small package so that you can run it all the time,’ James says. ‘That is the next step. Being brutally honest, we as a company have probably missed one stage in the development, namely people doing FLIR [forward-looking infrared] based cameras.

‘We are now working with a thermal imaging supplier that we know nobody else uses, and we are creating that new sensor which will fit in a small housing, which can be retained right through the weekend, and offer both a thermal image and eight or sixteen spots of data,’ James adds. ‘This will give the teams the advantage of getting that extra data in FP3 and in qualifying, which is likely to be quite useful. The mechanics will like it too as they will no

Mercedes has a multi-channel IR sensor mounted on the front wing end-plate, as close as possible to the tyre



The Alfa Romeo has its tyre sensor mounted in the mirror housing, but this location has caused issues for teams in the past

‘The Formula 1 teams are putting crazy temperatures into the rims and it can kill the sensors’

longer have to take it off the racecar at the end of the sessions on a Friday.'

Formula 1 teams are not only taking temperature measurements on the surface of the tyre, they are also utilising sensors inside the tyre, mounted to the rim and directed at its inner surface. This is another crucial area in developing a clear understanding of how the tyres work and it is an increasing challenge for the sensor manufacturers.

'It is so difficult as the internal temperature sensor itself is part of the tyre pressure monitoring system [TPMS], and that gets seriously hot as the teams are putting so much energy through the brake drums into the wheels to do bulk heating of the tyres,' James say. 'You already see issues with TPMS units struggling to survive. That is not an issue with the sensors it is just that the teams are putting crazy temperatures through the rims, and it is killing the sensors. There comes a point where the battery technology and electronics cannot cope and right now the units are on the very edge of survivability. You have to consider that it is a location which is spinning around at 300km/h, at 150degC, while being subjected to substantial *g*-forces. It could not be a lot worse.'

The heat is on

The harsh environment inside the tyre is not only a challenge in terms of reliability of the sensors, it is also a major factor in terms of their accuracy. 'If you have a thermopile which has not been thoroughly calibrated and point it at a black body target, it might show you a reading of 100degC, for instance,' James says. 'But if you then heat the thermopile up you will see the result for the same target start to drift and change. If you heat up the sensor its output changes, even though the target is the same. So with that in mind consider the fact that the temperature of the tyre is constantly varying, as is the temperature of the sensor. If the high temperature was a constant you could compensate for it quite easily, but with these units inside the tyre everything is varying all the time. It is really very difficult; I have no doubt whatsoever that getting good accuracy of the internal sensor mounted on the TPMS unit is a very difficult challenge indeed.'

Inside the TPMS unit there is only the IR tyre temperature sensor and the pressure monitoring system, but in some instances it also contains a third tier of sensor.

'The teams like to know the temperature of the rim, and a lot of the systems on the market at the moment give you that,' James says. 'Generally they are not a true temperature sensor stuck on the rim, instead they are usually a thermistor stuck on the PCB of the TPMS, so it is inside the housing, and that means that it can be influenced by the temperature of the electronics. So we don't think that it is truly accurate, the same goes for the gas temperature sensors mounted in the same way.'

Rear tyre sensors are generally mounted in a blister on the floor. Thermal imagers will often be found in this location too

Could it be that the F1 teams are basing their simulations and calculations on flawed data?

The Texys IRN8-WS4 is an eight-channel Infrared sensor designed to be mounted on the front wing

This point about accuracy also raises question marks about the teams' understanding of the way the current Pirelli tyres work. Could it be that they are basing their simulations and calculations on flawed data?

'The external tyre temperatures we think are pretty accurate, but the harsh environment of the internal sensors does bring into question their accuracy,' James says. 'That all brings into question the accuracy of tyre core temp models being used. It is super important to understand and accurately model the temperature of the core of the tyre, the surface temperature is important as is the liner temperature but it is the temperature of the rubber in the middle which is key. You cannot measure that easily, you could put thermocouples into the tyre but that is not really a race-able solution and it is not an option available to the teams.

'Right now the models are made from the temperature of the liner and the surface temperature of the tyres,' James adds. 'From that the teams have to make an assumption about the core temperature, so I think there is scope for more accurate data to help the teams do a better job of modelling the core temperature. I really think there is a lot of benefit to be had from getting better correlation between the external and the internal temperature of the tyre. For a team this is key information, the more accurate the model the more accurately they can work on keeping the tyres in the window and preventing them from dropping off. I don't think we are at the point where this is as accurate as it could be.'

Size matters

While the sensor manufacturers and the teams try to find a way to better understand the core temperature of the tyres the goalposts will move in 2021 when F1 switches to 18in wheels and lower profile tyres. 'For the external sensors the new wheel and tyre sizes will not make much difference but for those inside it will be a bit of a reset as there is a different gas volume, the distance between the sensor and the liner will be smaller, you also have a not insignificant increase in the inertial forces on the sensor too,' James says. 'In fact, the bigger the wheel and the smaller the tyre the bigger the challenge is for measuring the temperatures, as you will need to get a spread of IR points across the tyre but with the liner so much closer that will be a challenge.'

This development process my seem minor, but if a team or a sensor manufacturer manages to solve the problems then this alone could be a big enough advance to change the result of a future world championship.

A glimpse of the future

The shape of Formula 1's 2021 regulation package is beginning to emerge with all parties currently working on a base model codenamed 'India', a conventional open wheeler that will feature ground effect aerodynamics and a number of control parts. *Racecar* investigates

By SAM COLLINS

Formula 1 is to adopt a completely new technical rulebook in 2021, but until now all that has officially been revealed are some vague concept sketches and the announcement that 18in wheels fitted with low profile tyres will be used. But there has been progress, and behind the scenes the FIA, the F1 Group and the teams have been collaboratively working to thrash out the details of the new technical regulations. At the time of writing that work is ongoing, but recent documentation has provided a lot more clarity on the overall shape of things to come.

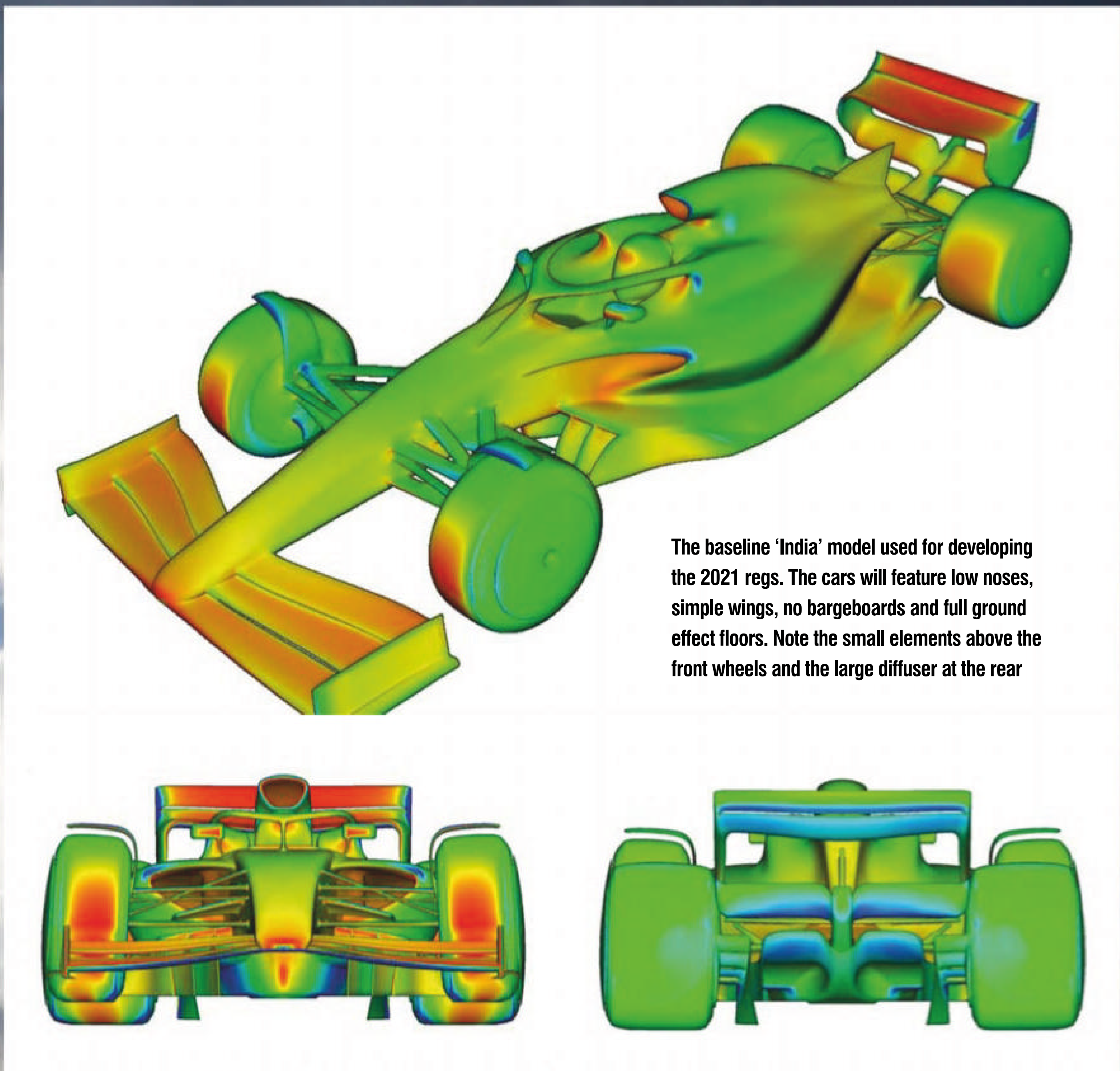
Despite rumours of fighter jet style canopies and Le Mans Prototype inspired bodywork, Formula 1 will remain an open cockpit, open wheel, single seater category, with most of the main elements of the current cars retained, albeit in modified form. We know this because a base model of a generic 2021 car has been created and supplied to the teams, and the latest iteration of it, called 'India,' offers a clear insight into the direction of the new rules.

Passage to India

The biggest change in terms of the aerodynamic package is the introduction of a fully ground effect floor complete with substantial tunnels and a number of underbody aerodynamic elements, while the cars will feature far more basic front wings (even compared to the 2019 package), low noses and an interesting double element rear wing with no end-plates. Outer wheel covers will also feature front and rear, reducing the drag but perhaps also creating a major challenge in terms of brake cooling.

In terms of the sidepods, the current trend of complex bargeboards and lowering the side impact structure for aerodynamic gain is unlikely to continue beyond 2020, with the India model not featuring bargeboards at all, and the low side impact structure approach seemingly ruled out with new, more sculpted, sidepod ducts.

Each team, if it wishes to, can get involved in the CFD development project using the India



The baseline 'India' model used for developing the 2021 regs. The cars will feature low noses, simple wings, no bargeboards and full ground effect floors. Note the small elements above the front wheels and the large diffuser at the rear

Formula 1 will remain an open cockpit, open wheel, single seater formula, with most of the main elements of the current cars retained

The India concept aims to keep the front wheel wake as narrow as possible and inboard of the car

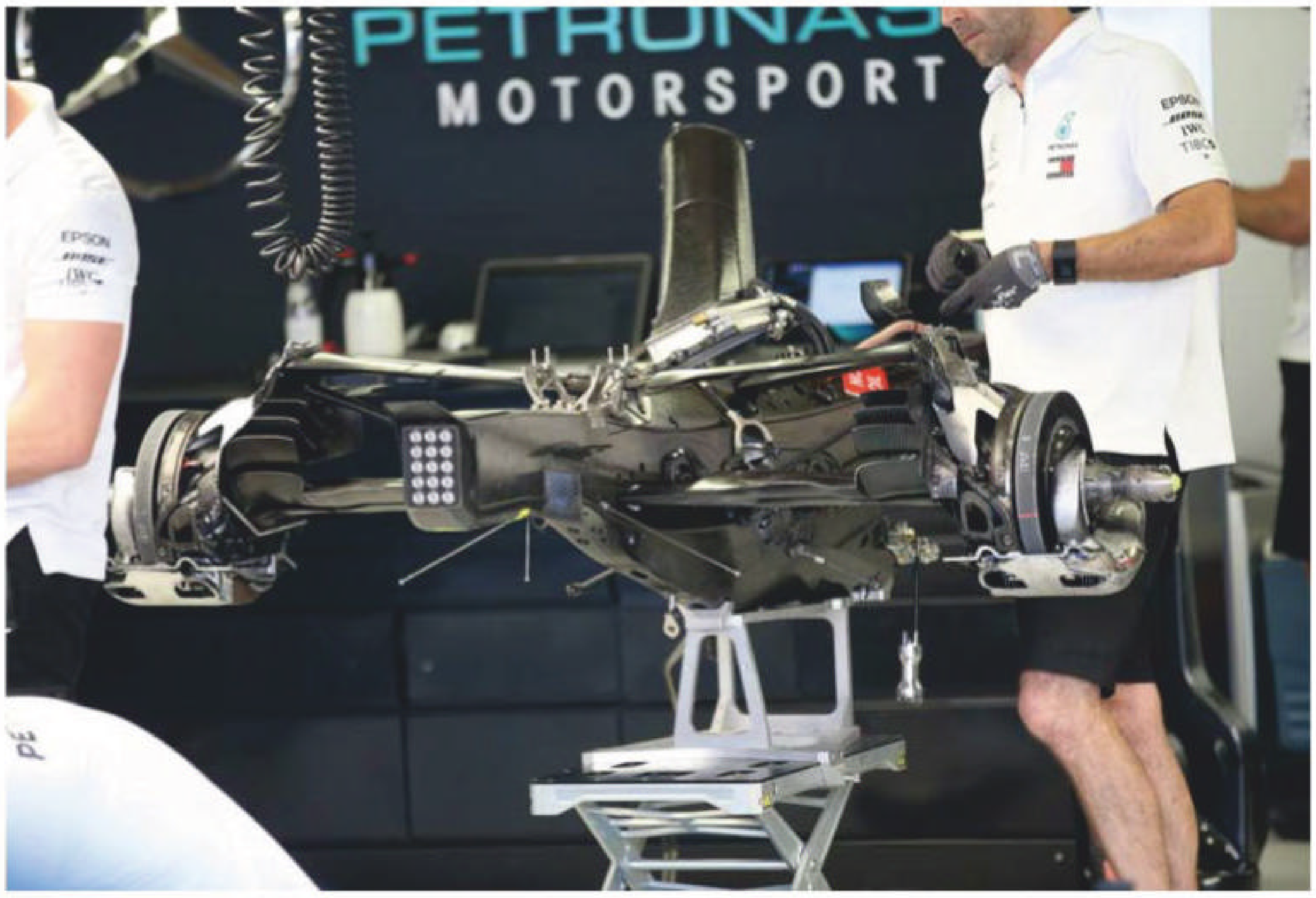
model and many have also already done work on the previous version codenamed 'Hotel'. The teams can nominate a project to work on and a list of projects is circulated to all the teams, so that the work is spread and not repeated. Once the results have been processed they are shared with the FIA. CFD work on these projects is not covered by the current aerodynamic testing restrictions during two six week periods, the first of which concludes at the end of March 2019, and the second in May 2019.

Wake up call

The India concept aims to keep the front wheel wake as narrow as possible and inboard of the car, achieving this by relying on a balance of vorticity either side of the contact patch. However, reliance on this is not ideal as some conditions or minor design changes can result in a imbalance between the vortices and moving the wakes outboard, something that is known to be detrimental for any following car. In documents circulated to the teams just before pre-season testing got underway in Barcelona, they were challenged to look at changing the front wing concept, in terms of width, height and end-plate design, to ensure that the front wheel wake will be properly managed. Front wheel arches and wheel pods are also being considered and could be retained 'as long as the car maintains an open wheeled appearance'.

In the centre part of the car the India concept has a fully tunnelled floor with a single, large, locally generated vortex to provide downforce, but documents show that this is far from a completed concept and the teams have been asked to investigate this area further, and to get a better understanding of what influence it has on the wake of the car. Ideas like underfloor turning vanes and adjustable canard wings have all been suggested.

Meanwhile, at the rear of the India concept model the Formula 1 R&D group, headed by Nikolas Tombazis, Dominic Harlow and Jason Somerville, has developed a rear end system which could make it easier for Formula 1 cars to follow each other more closely. It is designed to ensure that the rear tyre wake is kept as narrow as possible and is drawn into the so-called 'mushroom' wake structure. This mushroom structure is created by the



Gearbox casings will remain the responsibility of the individual F1 teams but the transmission cassette will be a spec part

Drag reducing wheel covers, as seen here fitted to the 2006 Ferrari, could be a feature of Formula 1 cars from 2021

In an attempt to reduce costs there is a plan to introduce an increasing number of control parts

upwashing cascade of the diffuser, low beam wing and a number of other small elements.

The diffuser is protected from undesirable flows entering from the side by end-plates on the rear brake duct winglets and other components creating a downwash between the diffuser wall and the rear brake duct. However, the vortex coming off the rear wheel can still enter the diffuser and reduce its performance. This is something that the blown diffusers of a few years ago, in both Formula 1 and LMP1, were designed to prevent. Here the teams have been asked to counter this effect, and it potentially could see the return of the blown diffusers. Another task set for the teams to work on is to raise the mushroom higher to allow the cars to follow even more closely.

Transmission revamp

Details about the mechanical elements of the 2021 cars are also beginning to emerge, including the transmission. In an attempt to reduce costs there is a plan to introduce an increasing number of control parts, which will be used by all cars. The latest of these is the gear cluster. Currently teams work with a

The tender calls for a single spec cassette containing seven forward gears and one reverse, down one ratio from the current transmissions

range of companies such as Ricardo, Xtrac and others on their clusters, but the FIA has now issued a tender for a single supplier for the 2021 season. The tender calls for a single spec cassette containing seven forward gears and one reverse, down one ratio from the current transmissions. Gear ratios will be fixed across the field, while the differential will be a multi-plate, hydraulically controlled unit.

'It is anticipated that the layout will be similar to current Formula 1 gearbox/final drive assemblies,' the tender documentation states. 'The exact layout definition will be part of the selected provider's responsibility but it should be as close as practical to something all teams are happy with. It is believed that both single barrel and dual barrel arrangements are currently in use but it will be for the selected provider to select the layout they believe is best.' In the tender it is recognised that the teams are likely to push the rear end packaging of their cars as hard as possible, and it calls for applicants to apply 'significant effort' to making the cassette as small as they can and as light as possible while meeting the required demands.

Those demands are not all that clearly defined, as in some areas the regulations are still a work in progress, but the new gearbox would be expected to last around 5000km (roughly the distance covered in the Le Mans 24 Hours by an LMP1 car). While the power unit regulations remain unclear (see box out) the tender states that the input shaft speed is expected to be around 14 per cent higher than at present and that there will be a power increase over the current power units due to natural development, but also an upgraded MGU-K (with around 30kW more power).

With cost reduction a major aim of the 2021 rulebook the tender makes it clear that the new transmission internals will not need to utilise as much advanced machining as is common now. 'Saving the last few grams can be replaced with more cost effective machining as this is a common part. As a guide, it is anticipated that the gearbox cassette will be around 1.5kg heavier than an equivalent cassette-style F1 gearbox today,' the tender explains.

On the case

The perimeter of the spec transmission includes the complete oil system for the unit comprising tanks, pumps and scavenging systems in a self contained unit, with an outlet and inlet to and from an oil cooler. However, the tender does not cover the transmission casing and this will remain the domain of the teams. Currently McLaren, Red Bull, Mercedes, Ferrari, Renault and Williams all design and utilise bespoke casings while the other four teams buy them in.

The input and output set-ups of the 2021 transmission are defined in the tender documents; 'a team-specific input shaft will connect the engine-mounted clutch to the input of the gearbox cassette, which will provide the team with the ability to tune the torsional behaviour of their complete transmission system. The gearbox cassette end of the shaft will be defined by the selected provider and will include an appropriate spline drive and a short portion of shaft used for the FIA-defined torque sensor. Forward of the torque sensor portion, the design of the input shaft will be free,' states the document. In terms of output the driveshafts will remain free though it is thought that the design of the inner end will be prescribed in the technical regulations. The new transmissions will be used from 2021 through to the end of the 2024 season.

Further details of the 2021 cars are expected to be revealed in the summer, after the second phase of the India concept CFD studies are completed in May, and the regs are likely to be approved towards the end of 2019.

Formula 1's future power unit

For some time in Formula 1 a substantially new power unit rule book was expected to be introduced for the 2021 season. However, it now appears that this will now not happen after all, and that if there are any changes to be made then it seems likely they will be fairly minor.

'I think Formula 1 has a role to play in powertrain development, but I think 2030 is where we should be looking,' says F1's chief technical officer Pat Symonds. 'The current engine, may or may not have a mid-life facelift in 2021, and that will be with us until 2025. So the new engine will be mid-life by 2030.'

So 2025 is now the expected date for the introduction of the new power units, and it looks like these will be fundamentally different to what is in use today. 'We will be looking at novel mechanical and chemical solutions,' Symonds says. 'We might be looking at two stroke cycles, split cycles, variable valve phasing, variable valve timing and lift, and variable compression ratio as well. We need to improve gas exchange, that means better turbochargers with a lot of extension of the maps, perhaps two stage turbocharging, variable geometry, things like that. More waste heat recovery is likely to feature, we are obviously using turbo compounding at the moment, but perhaps we could look at fuel reforming or organic Rankine cycle. There are reports that say the latter could improve fuel consumption by about 4.2 per cent.'

Formula 1 restricted combustion development somewhat when it limited component weights and compression ratios in order to close up the field, but in this area it is clear that substantial change can be expected in 2025. 'In terms of combustion we are already using pre-chamber ignition and perhaps things like simultaneous ignition could come in,' Symonds says. 'We will also be looking at high peak firing pressures, though they are already very high at the moment, [and] gasoline compression ignition is very much on the horizon. [Also], model based combustion control and multi mode control where we can use machine learning and AI to improve the timing.'

It seems certain that, with the wider automotive industry moving towards all new passenger cars becoming either fully or partially electrified within the next 10 to 15 years, Formula 1 will remain a hybrid formula. But the detail of that hybrid system is likely to change with the rest of the power unit.

'On the hybrid side, we are probably going to quad voltage systems, where we are using 400 volt, with 600 volt for traction, a 48 volt system for ancillaries, a legacy 12 volt system and a 5 volt instrumentation system,' Symonds says. 'The 48 volt system will allow the auxiliaries to be used on demand, and I think anything with a load of over about 500 watts is certainly better running on the 48 volt system; an electric valve train, for example, you need about 800 watts per cylinder to run it.'

Small changes to the PUs are expected in 2021, and possibly a more powerful MGU-K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The thunder down under

With 635bhp 5-litre V8 powerplants and no driver aids Aussie Supercars are big on spectacle, but beyond the engine noise and tyre smoke there's a well-thought out set of technical regulations that underpin this championship's success – as *Racecar* discovered on a visit to Holden works team Triple Eight Race Engineering

By GEMMA HATTON

‘The cars are very physical machines to drive, which is fun to watch and also generates exciting racing’

The Triple Eight Holden ZB Commodore burns some rubber. Supercars is primarily about entertainment, which is probably why the series is so successful

Triple Eight's Holden ZB Commodore in the raw. Although it's a control chassis the frames from the road car are integrated to ensure that each manufacturer's car retains its DNA

There are few categories of motorsport that embody national pride quite like the Australian Supercar Championship, and with its television audiences growing by approximately 12 per cent year on year and a healthy 24-strong car grid lining up for the 2019 season, it's fair to say that it is extremely popular, too.

But how has this championship, which is so far away from any other major form of motorsport in terms of both geography and approach, become so successful? Answer: it has focused on pure, hardcore touring car racing.

'Obviously I'm biased, but for me, Supercars is the best type of touring car racing in the world,' says David Cauchi, race engineer and head designer at Holden factory team Triple Eight Race Engineering, an outfit which ran the first hatchback in the series last year, the Holden ZB Commodore. 'The cars are very raw, there are no driver aids so they move around a lot and lock-up under braking and the tyres are relatively small for the amount of horsepower and the weight that these racecars have. This makes Supercars very physical machines to drive which is fun to watch, while this also generates exciting racing.'

This is all the result of cleverly defined regulations that balance the need for equal competition through the use of spec parts while also allowing just enough technical freedom to keep things interesting for the teams and for the spectators.

Aussie rules

Prior to 2013, the teams were allowed to design their own chassis/roll cages and would therefore invest a lot of resource into optimising the stiffness and weight of their chassis. However, the governing body, together with Pace Innovations, then developed and introduced the Car of the Future (COTF) concept for the 2013 season. This was a control chassis that each racecar had to adopt, regardless of the manufacturer, and it effectively halved the costs of building a Supercars chassis.

The aim of COTF was to make it easier for new manufacturers to enter the championship and be immediately competitive, whilst retaining each manufacturer's individual DNA. Therefore, to make a Holden look like a Holden, parts of the road car frame such as the side presses were incorporated into the control chassis, along with customised fixings to allow the exterior road car panels of each manufacturer to be fitted. These panels are now mostly composite, with carbon fibre and E-glass construction, while the door skins also contain some ballistic Kevlar to improve driver protection. Today, aside from the engine, these road car frames and the associated bodywork panels are still the major difference between each manufacturer in terms of car design.

Unlike the BTCC, where each team receives its spec roll cage from RML, Supercar teams (if they have the capability) can actually manufacture their own chassis, but it has to be built to a set specification and then later homologated. 'Although the cars are a lot more controlled nowadays, we are still allowed to manufacture many of the components ourselves, but we manufacture them to a set spec,' Cauchi says. 'Here at Triple Eight, we probably manufacture in-house around 85 to 90 per cent of our car, including suspension arms, exhaust systems, crash structures, front uprights and radiators – essentially any CNC machined or fabricated component on the car is made in-house. We can therefore sell complete cars and supply a lot of the other teams on the grid with components. For example, we have the rights to

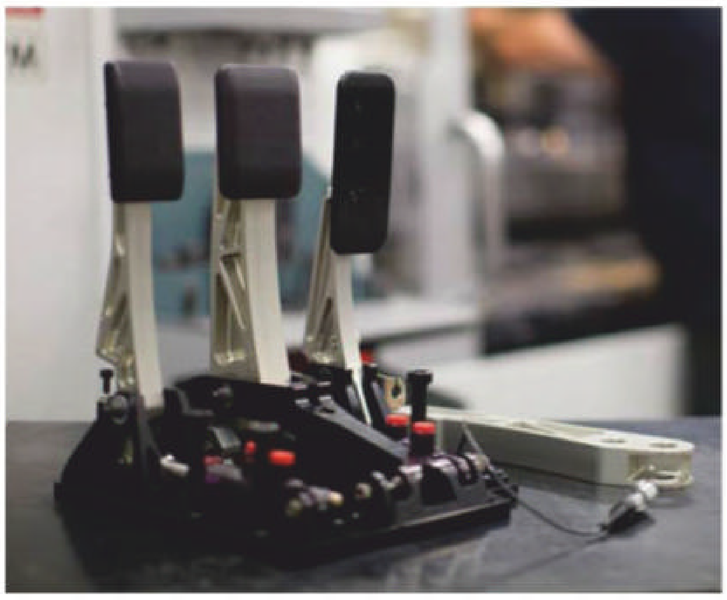
'Sometimes we only have three days from when the racecar gets back to when it has to leave again for the next event'

Being sponsored by Red Bull really does give you wings. Changing the rear wing angle is one of the very few things the teams can do to tune aero performance after homologation

'There is a good balance between spec parts and tech freedom – there are still plenty of ways for engineers to confuse themselves!'

supply the pedalbox, which is a controlled part, and we also sell front uprights and suspension arms. So, every team on the grid is running with parts that we have manufactured at our factory.'

Another fundamental change that the COTF brought with it was the shift to independent rear suspension and although this is controlled, there are still certain freedoms. 'We have freedom in terms of adjusting the chassis pickup point locations, so we have plenty of adjustments from a race engineering perspective. But the biggest freedoms we have is with the front suspension,' Cauchi says. 'There are some restrictions such as a minimum weight, but otherwise it is almost completely free. We can also design our own front and rear anti roll bar systems and their adjustments. In terms of dampers, there are three homologated dampers that we can choose from; Ohlins, Sachs and Supashock. But we can valve these dampers any way we want as long as the parts within them are from the supplier catalogue, so they are not a spec component as such. There is a good balance between spec parts and technical freedom – there are still plenty of ways for engineers and mechanics to confuse themselves!'



Triple Eight manufactures nearly 90 per cent of its car while it also supplies other components, such as the pedalbox, to rival teams

Shock tactics

But as the drive to contain costs continues, so does the need to reduce these technical freedoms, as demonstrated by the 2019 rules, which now ban twin-spring dampers. Previously, most teams would run these dual springs as part of the rear suspension package, but some teams, such as Triple Eight, also used them at the front. By having two springs, each exhibiting a different spring rate, engineers could precisely tune the behaviour to help set up the attitude of the car for corner entry and exits. Now, only a single linear spring is permitted.

'This has been the area that we have focused most on during the off-season,' says Cauchi. 'Looking at what the effect of the linear springs is going to be on our set-up and simulating what mechanical things we need to design as well as what new tools we need to have in our toolbox to make sure we have the necessary tune-ability once we hit the track.'

Another change for the 2019 season has been the switch from an Albins gearbox to the Xtrac P1293 unit. This transmission is a 6-speed transaxle unit, utilising a gear cluster, with input drop gears and a full form ground final drive bevel gear set, to suit the particular requirements of Supercars and the tracks they race at. This is all mounted in a brand new casing assembly designed to allow easy access and mounting into the chassis. Last year, to help Xtrac with its development programme, the P1293 unit was run by Nissan Motorsport, Brad

Air for cooling the brakes can be provided via a controlled opening in the front of the racecar. This can only be adjusted, to tune for tracks and the conditions, with blanking plates

Jones Racing and Tickford Racing during several races in the latter half of the season.

'Xtrac have a multi-disciplined approach to gearbox design and an array of simulation tools which can validate designs to the technical specification with a high degree of confidence,' says Xtrac's principal engineer, Mark Brogden, who led the project. 'The experience we have gained through the various motorsport sectors that we support has allowed us to correlate our analysis tools closely to real world running. With an engineering team of over 85 staff, spread through design, analysis, R&D, production engineering, metallurgy and various support roles there is a wealth of experience which can be relied upon.'

The crown wheel and pinion set is one of the higher value parts in a gearbox and to help longevity and ensure adequate load capacity, taper bearings were specified in place of lower capacity ball bearings used in the previous gearbox. Many of Xtrac's gearboxes use a cassette type cluster, which comes out as one assembly on a cluster plate, for quick and simple inspections, thereby reducing the workload for the teams during test and race sessions.

'Alongside GT3 racers, the Supercars are probably the hardest application that we have to design for in terms of braking'

'The service life of the old 'box was not where we needed it to be and changing boxes during a race meeting happened more often than we would like,' Cauchi says. 'It has served us well but the category decided to try something different. We are hoping that the new Xtrac box will give us a longer service life so we can leave them in the car for longer. We have some tight turnarounds, so sometimes we only have three days from when the car gets back to when it has to leave again for the next race and a lot of servicing needs to happen within that time. It's another attempt by the regulations to reduce the amount of time teams spend on key components which will again reduce costs.'

Another tactic for minimising costs is ensuring that teams run the same set of fixed ratios for every circuit. As specified by the regulations, only the final drive changes for each track via a drop-gear change.

Hard drive

Although Xtrac has designed its gearbox to accept a plate type differential, the Supercar regulations specify a spool, so it is a solid locked rear axle where both rear tyres rotate at the exact same rate. 'This makes Supercars quite unique to drive relative to most other GT or touring cars and it is also a bit different to set up,' Cauchi says. 'That is why you sometimes see that some international drivers come and drive our cars and they are not instantly quick, because it

'Even though we have quite low downforce numbers, drivers still experience understeer during high speed corners when following'

takes time to get used to the driving style. It also simplifies the gearbox design; there are fewer elements for engineers and mechanics to deal with, which is the main reason why it's used.'

The brake calipers and discs are a controlled part, supplied by AP Racing. 'Alongside GT3, Supercars are probably the hardest motorsport application that we have to design for in terms of braking, particularly with the cars using iron brake discs,' says Ian Nash, business development manager at AP Racing. 'They are fast and heavy touring cars with 70 per cent front braking, and the series has developed the cars to have more traction and grip which has certainly presented its challenges.'

Tough brakes

Adding to the braking challenge in Supercars is the fact that the pads are also a controlled part and there are three front compounds from three suppliers to choose from. But the front upright and cooling strategy is not controlled so there is significant variation down the pit lane, therefore the friction interface between disc and pad is not controlled, which makes designing a brake disc for this application all the more challenging.

'The most challenging race for the brakes is Bathurst,' Nash says. 'Not only because it is one of the endurance races, but also because it is generally a light braking circuit, with one big stop from 300km/h at The Chase. Therefore, the brakes run cool for the majority of the time and then experience a sudden increase in temperature, which can induce thermal shock, particularly difficult for cast iron discs. Furthermore, with such restricted testing, circuits like Bathurst are closed for most of the year. So, you have a set of circumstances that you can replicate on the dyno, but you can't actually go there and test before the next event.'

At the heart of these racecars remains an exciting 635bhp 5-litre V8 engine

Air for cooling can be taken from a controlled opening in the front splitter which is then guided through to the brakes via a carbon fibre shroud on the back of the upright. These ducts are unique to each team, but only blanking plates can be used to restrict the amount of airflow to the brakes, from the front bar opening, no other modifications can be made during the season.

To homologate the aerodynamic package the cars complete straight-line testing at an airfield and the downforce and drag for each car from each manufacturer is matched. Once homologated, there is very little the engineers can do to tune the aero. 'The only freedoms you really have is to change the rear wing angle, the front and rear ride height or blank your brake ducts and your radiators to tune the amount of downforce and drag you want for each track,' Cauchi says. 'The aero features are quite simplistic, to avoid cars being effected when following one another. However, even though we have quite low downforce numbers, drivers still experience understeer during high speed corners when following.'

In terms of tyres, teams get between six or seven sets per car per race weekend, which totals 436 new slicks for the season. This number

Mustang sallies forth

The sixth generation Ford Mustang has been homologated for the 2019 Supercars Championship. The Mustang will replace the Ford Falcon FG X, which was used between 2015 and 2018. Tickford Racing and DJR Team Penske will oversee the development of the car, with Ford Performance providing additional technical support.

Ford Australia will provide financial support in developing the car, but no team will officially be recognised as a factory team. The homologation process has required some modifications to the bodywork to fit the series' control chassis, but the car will continue to pack the V8 engine used by the FG X Falcon.

The decision to return the Mustang to the series was made because Australia's domestic production of the Ford Falcon ceased in 2016. The Mustang's return marks the first time since 1990 that a Mustang has contested the premier class of Australian motorsport. The car completed the homologation process in December 2018 and was subsequently approved for competition by the Supercars Commission.

In many ways the new Mustang is basically a Ford FG X Falcon in different clothes and with a different aero package. Of the six Mustangs at the Phillip Island test in February, five were 're-purposed' Falcons from last year and there was only one truly new example at this first test.

There was talk in the media at the end of last season that the control chassis was too high at the rear to accommodate the Mustang bodywork and the chassis itself would have to be modified. In the end this turned out not to be true and all the racecars running in 2019 are running the same control chassis.

It's possible that the Chevrolet Camaro will be tried next with the existing Supercars control chassis, if the Mustang proves successful this season.

Dr Charles Clarke

The Ford Mustang testing at Phillip Island. This year it replaces the Falcon as the Blue Oval's Supercars challenger

‘We have to be quite careful that all the cost cutting we are going through in the Supercars series does not damage the racing’

is carried over from 2018, despite the calendar dropping from 16 to 15 events, as additional sets have been assigned to five rounds. Also for 2019, the rule requiring one set to be handed back after Friday practice has been scrapped, allowing the teams to take that set through to qualifying and the race. Dunlop supply two compounds: Soft and Super-soft, which have been carried over from last season and are based on their 2016 construction.

‘Generally, you only get one lap of maximum performance out of the tyres, so qualifying is critical, but in the race it varies,’ says Cauchi. ‘There are some circuits that have high degradation and other circuits where it is less critical, but most of the time the tyres have to be managed. The surface is sensitive to following, so if you catch someone up you then need to pass them within roughly two laps or else the front tyre gets too hot and passing then becomes too difficult.’

V8 power

At the heart of these racecars remains a 635bhp 5-litre V8 powerplant, despite the Gen2 rules allowing turbocharged V6s to enter from the 2017 season onwards. The Triple Eight team was one of the first to experiment with a twin-turbo V6, but it announced last year that it had decided to stick with the V8 and its ZB Commodore for the foreseeable future.

‘The V8 unit is well established and everyone has large stocks of it here, so moving to a new engine architecture can be costly,’ explains Cauchi. ‘Performance-wise, the V6 engine was certainly there, although we still had plenty of testing and development to carry out to get it completely race-ready.’

The term ‘manufacturer-backed’ in Supercars doesn’t necessarily mean that the manufacturer is heavily involved in the engineering side of things. Often, they are investing in Supercars to have their brand of car on the podium, so that fans associate the winning racecar with the road car, rather than developing the latest technology under the bonnet. Add to this the general decline of the Australian automotive industry, along with the Aussie culture of V8s, and it’s clear why modern turbocharged engines as well as hybrid and electric cars are difficult projects to get off the ground in Supercars.

The next five years is going to be a fascinating transitional period for motorsport categories across the world. With the desire for advanced hybrid and electric technologies, the introduction of hydrogen and the realisation that the internal combustion engine still has a long life to live, which route should championships take? No-one seems to have the answer, but for now the Supercar formula seems to be working, down under, at least.

‘Currently, I think the rules are well balanced and the end product, which is the racing, is of a very high standard and more often than not very entertaining, Cauchi says, but he adds: ‘We have to be careful that the cost cutting we are going through does not damage the racing. It’s important to have differences in car, team and driver performance because this leads to overtaking and ultimately a good race. If everything is spec, then the racecars are all the same and you can end up with boring racing which you then have to artificially manipulate to put on a good show. Our championship is so successful because it is arguably one of the purist forms of racing around – but the balance between cost, technology and good racing is a difficult one to strike.’

Three CNC mills and two CNC lathes allow Triple Eight to manufacture everything from uprights to engine components in-house

For this season Supercars has switched to a new Xtrac 6-speed gearbox which has been specifically designed for the category

Lambda chops

There is a new Supercars ECU for 2019, which now has a lambda controller built in. This seeks to control fuel usage by checking exhaust gas quality, instead of mandating in-line fuel consumption devices or sensors, as is the case in Formula 1.

‘We are trying to help the teams protect themselves from themselves by introducing lambda control,’ says Adrian Burgess, head of motorsport at Supercars. ‘All the teams try and run the engines as lean as they can in order to maximise the distance between fuel stops while still maintaining as much power as possible. They make all sorts of expensive remedial kit in order to cope with the consequences of running a large V8 engine as lean as possible.’

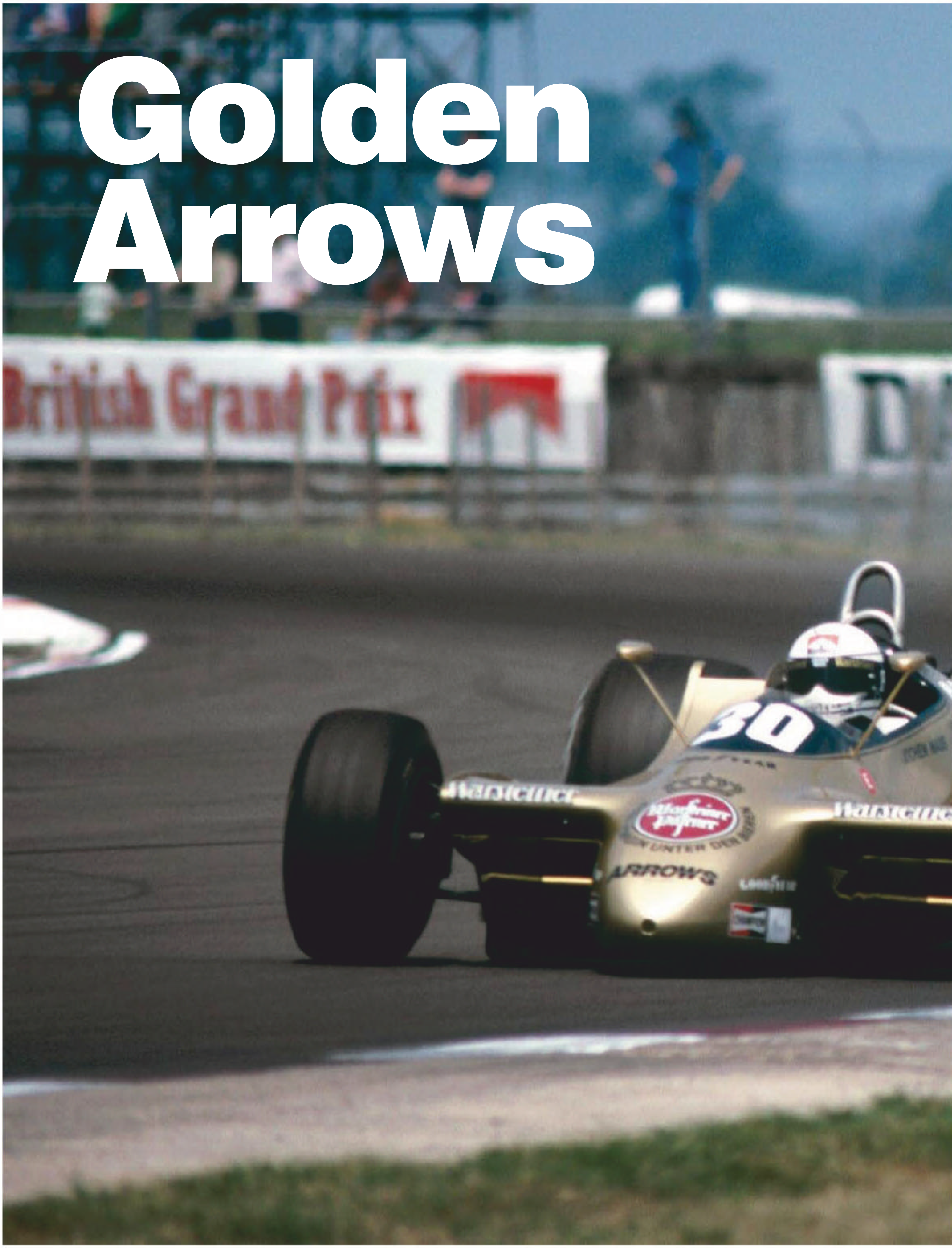
When the engine runs lean it runs hot, so the teams are spending a lot of time redesigning radiator cores and developing oil spray systems to cool the pistons down. They are spending heaps of cash trying to stop the pistons and cylinder heads going soft at these higher temperatures. Engine parts get replaced on a far more regular basis when the engines are running lean and the extra 3 to 4bhp gain from these kinds of expensive add-ons isn’t really noticeable for the racing fan. ‘If we can cut down the frequency that the teams are rebuilding their engines we’re saving them money,’ says Burgess.

‘We try to keep the sport sustainable without detracting from the show, so we’re trying to save themselves from themselves, although doubtless they don’t all see it that way,’ Burgess adds. ‘Currently the big teams can afford to spend money gaining these minute competitive advantages, what we’re doing is helping the smaller teams keep up.’

Burgess adds that the lambda control ‘is in the new version of the Motec ECU, but it probably won’t go live at the first race, but it will be introduced this season’.

Dr Charles Clarke

Golden Arrows



Pictures by Motorsport Images

With ground effect aero creating huge downforce Arrows took the brave decision to design its 1979 F1 entry without front and rear wings. Forty years on *Racecar* spoke to the car's designer, Tony Southgate, to get his take on the still radical-looking A2

By ALAN LIS

The A2 was designed to run without a rear wing yet one was fitted by the time of its second race; but this was more to do with driver confidence than producing downforce

The striking Arrows A2 Formula 1 car was intended to take the ground effect aerodynamic concept to a new level in 1979. Its designer, Tony Southgate, had been the chief engineer at Team Lotus in 1976 and 1977, a period in which Colin Chapman's men were developing the revolutionary Lotus 78 wing car. Having designed the relatively conventional Arrows FA1 and A1 wing cars for 1978, Southgate pushed the envelope with his A2 design which, like its contemporary the Lotus 80, was intended to generate sufficient downforce from its underbody, which would then make the use of conventional front and rear wings unnecessary.

The Arrows A2 made its race debut at the 1979 French GP at Dijon, the race famous for the frantic duel for second place in its closing laps between Gilles Villeneuve in the Ferrari 312T4 and Rene Arnoux in the Renault RS10. The performance of the Arrows A2s was rather less spectacular. The cars qualified 19th and 21st in a field of 24 starters and Riccardo Patrese finished 14th with Jochen Mass 15th, three and five laps behind Jean-Pierre Jabouille's winning Renault.

In six subsequent F1 races the best results by an A2 were a pair of sixth place finishes at the German and Dutch grands prix, both with Mass at the wheel, and before the end of the year the Arrows team was already working on a more conventional successor. And yet the A2 project had seemed to have so much promise when it was started. So what went wrong?

Slings and Arrows

The first two Arrows Formula 1 cars, the FA1 and the A1 had been built very quickly, both featuring Southgate's unique take on ground effect sidepod design. In fact, the A1 had to be produced in super quick time to enable the team to continue its 1978 programme when the FA1 was adjudged to have been a copy of the 1978 Shadow DN9, the design of which Southgate had completed in a brief period at that team before leaving to join the newly formed Arrows outfit in late 1977.

An FA1 driven by Patrese came close to winning the 1978 South African Grand Prix until an engine failure stopped it 15 laps from the finish and, later in the season the Italian finished second in the Swedish Grand Prix, won by the Brabham BT46B Fan Car. The hastily produced A1 proved less successful, a fourth place by Patrese in Canada being its best result.

For the Arrows A2 Southgate's aim was to come up with a 'proper car' and spend a lot more time working on the aerodynamics in the wind tunnel. 'Knowing what I did of the Lotus 78, the Arrows FA1 was obviously going to be a full ground effect car but I was amazed that, apart from Harvey Postlethwaite at Wolf, no one else had twigged what was happening and they were all building conventional F1 racecars for 1978,' Southgate says.

'By the end of 1978 it was absolutely clear that ground effect was the way to go and it was felt that if you were to do a ground effect car properly it would be so efficient that it wouldn't need front and rear wings,' Southgate adds. 'The downforce generated underneath the car would be enough. Lotus was also working in that direction so a little race developed between us to see who would be the first to build a car that really could run without wings. Of course, there were wing sections on the A2, but they were not conventional front and rear wings.'

Southgate modelled the A2 at 25 per cent scale, ran it in the wind tunnel at Imperial College in London, and the figures suggested that the full-scale car would produce 1500 to 1600 lbs of downforce at 150mph road speed.

'A little race developed between us and Lotus to see who would be the first to build a Formula 1 car that really could run without wings'

'It was quite heavy because I was going for good torsional stiffness to withstand the expected high aerodynamic and chassis loads'

'The Arrows FA1 and the Lotus 78 had made 1100 lbs at best and the Lotus 79 made 1500 lbs, twice as much as any of the conventional 1978 cars,' says Southgate. 'The thing about the A2 was that it was producing these figures quite easily so there was scope for more with further development. When I showed the figures, Jackie Oliver [team boss] and the others at Arrows were really enthusiastic. To them that meant instant winning, but I remember saying at the time that there was more to it than wind tunnel figures, although I felt that they pointed the way to go and that it was a very interesting project.'

Tony Southgate in late 1979, pointing to the flap at the rear of the 'wing section' that was used to adjust aero balance

Weight and see

When the decision was taken to go ahead and build the racecar, Dave Wass was assigned much of the mechanical design while Southgate himself took care of the layout, aerodynamics, body, suspension and other systems. 'The chassis was a fairly conventional sheet aluminium monocoque but it was quite heavy because I was going for high torsional stiffness to withstand the expected high aerodynamic and chassis loads,' he says.

In contrast to the FA1 and A1, there were conventional Lotus-style sidepod wings with the water radiators mounted inside. The exits from the radiators were out at the edge of the sidepods and the air from the underside was extracted through the flip ups ahead of the rear wheels. There were full length sliding skirts on the lower edges of the sidepods between the front and rear wheels and there were secondary skirts that ran down the inside of the rear wheels and through to the back of the wing section under the engine and gearbox.

At the front of the car was a rocker suspension system and the top links of this were completely enclosed in a large wing section. At the back of this wing section were large flaps that were used to adjust the balance of

The Arrows A2: an aerodynamicist's view

Dr Mark Handford, who has worked on racecar aerodynamics for more than 25 years, including spells with Benetton, Jaguar and Tyrrell in Formula 1, and Lola Cars, Swift and Newman-Haas Racing in IndyCar, gave *Racecar* his assessment of the Arrows A2.

'For many, many years Formula 1 teams have gone to great lengths to get their cars as far under the minimum weight limit as possible and then put the weight back in as ballast positioned as low on the chassis as possible. Unfortunately, the Arrows A2 was heavier than the minimum limit so that approach wasn't an option for the team. If you have a racecar that is overweight and has a high cg, then it's an uphill battle.

'Porpoising is usually the result of the underbody stalling. If you run the car on soft springs it could happen with the front wing but usually it's a problem resulting from a lack of attitude control. It occurs due to the stalling and un-stalling of the underwing. The usual reaction is to run the racecar higher off the ground. In the porpoising that the first-generation ground effect cars suffered from there would be a huge loss of downforce – large enough for the chassis to rise back up on its springs – before the underwing un-stalled and yanked the chassis back down again. Under those circumstances the peak grip would be huge, but the average was awful.

'Porpoising is nearly always an inlet-outlet issue. If you take the flow in through a 4in high slot and expand it into a 12in high tunnel you might well get a stall. If you lift the car to give a 5in inlet and 13in outlet, you have significantly less expansion of the flow but a large reduction in the tendency to porpoise.

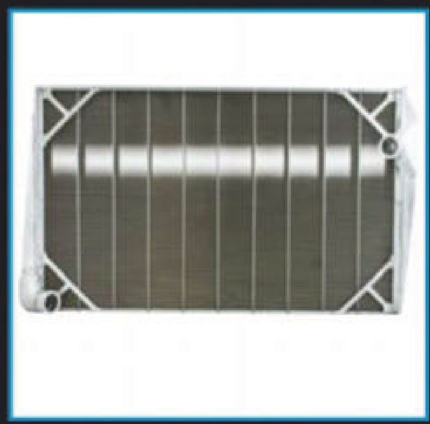
'It sounds like the A2 had the unholy trinity of being overweight, having a high cg and needing to be run at a higher ride height than desirable to avoid porpoising. That combination would pretty well kill the chances of any car.'

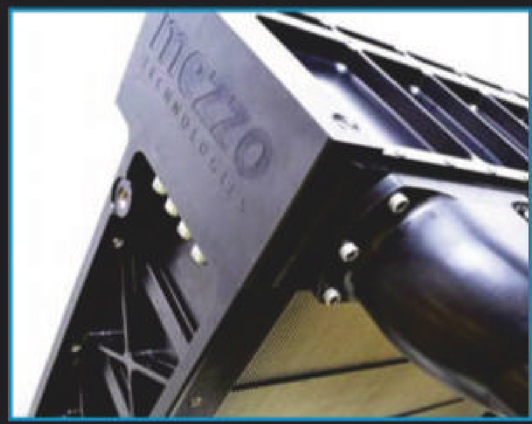
But was it really feasible to attempt to run the car without a rear wing? 'Wings are actually very efficient,' Handford says. 'The downforce you get from a rear wing is a volume that derives from the plan area x the frontal area x the span. In the late 1970s the cars could run with relatively big wings. In that era, I would have thought that, the wings would have had an l/d [lift/drag] of 5:1 or 6:1, which was close to that of the underwing, but in their favour these wings were enormously adjustable. Therefore, I'm surprised that there was a move towards running without a rear wing.

Underbodies can be as efficient as having a 10:1 l/d and, up to a point, that is almost drag free downforce. That's all well and good but you don't have any real facility to tune that downforce. If your centre of pressure isn't in the right place there's not much you can do about it with just the underwing. For a relatively modest drag penalty a rear wing is a tremendous tuning aid.

'The Arrows A2's aerodynamic structure around the front suspension doesn't appear to be very adjustable. Being able to move the centre of pressure backwards or forwards if it's not where you need it to be is an important consideration. To some extent you can do that by changing the shape of the tunnel itself. The point at which the tunnel starts is a powerful area of the underwing and is therefore crucial. Usually anything you put upstream of that is a problem. You pretty much get one stab at the air. If you have a front wing on a Formula 1 car then that's fine because there isn't much downstream of it and a huge chunk of downforce is made by the front wing itself. On the ground effect cars of the late 1970s, getting a slug of air to go under the car with minimum disruption was key.

'If you start fiddling with how much goes under the car you're making life unnecessarily hard for yourself. You'd want as much downforce as the air would give you and it's doubtful that you would save any drag by diverting the flow somewhere other than under the car. If you needed more downforce on the front structure you might fiddle with the flaps, but in doing so you might end up losing overall downforce because you've disturbed the flow downstream.'

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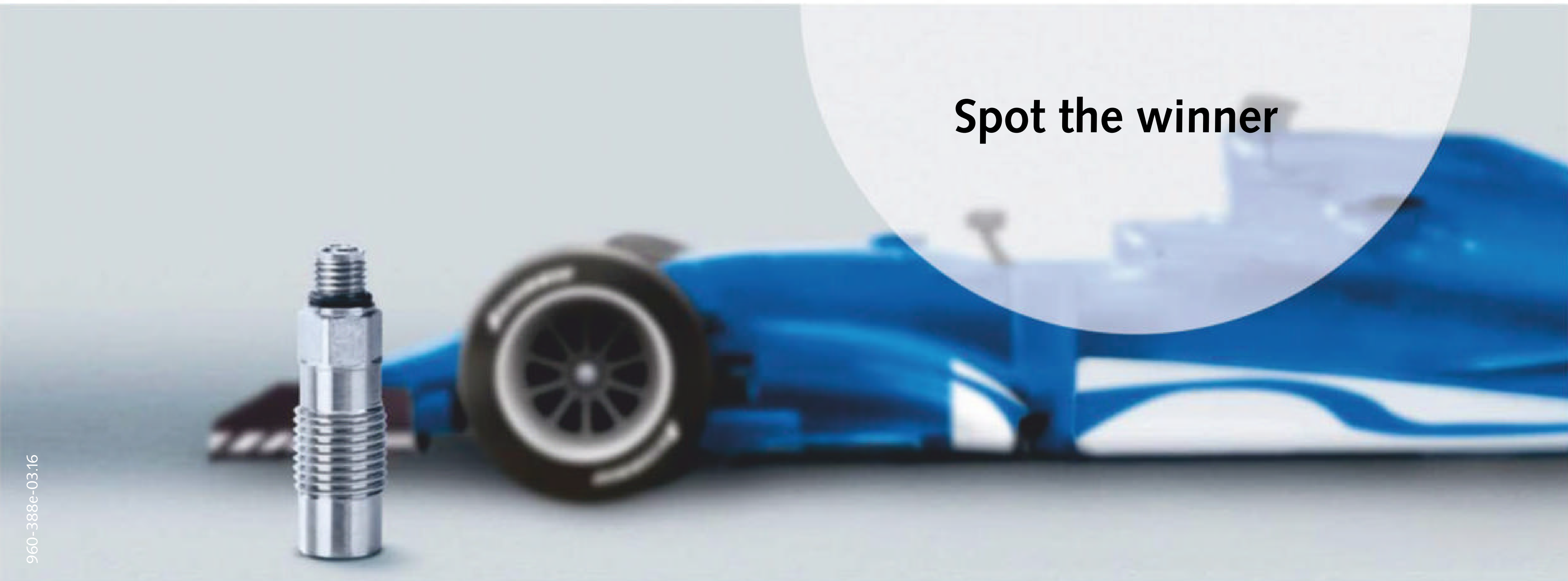
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'With a normal wing on a racecar you raised the flap to increase downforce, with the flaps on the Arrows A2 you lowered them'

the car. 'Curiously they worked in the opposite way you would have expected them to,' says Southgate. 'With a normal wing you raised the flap to increase downforce, with these flaps if you wanted more downforce you lowered them. When you did that they deflected the airflow below the car into the under wing and increased the ground effect.'

Blown cover

The Arrows A2 was originally designed so that other than the air inlet trumpets for the Cosworth DFV engine the rear end was fully enclosed by a swooping engine cover and tail section which cleaned up the flow ahead of a large flap of about six inches chord that went the full width of the gap formed by the end-plates between the rear wheels. 'This flap was how overall downforce was adjusted,' says Southgate. 'Unfortunately, there were overheating issues the first time the car ran due to the transmission and engine being fully enclosed so the tail section was removed.'

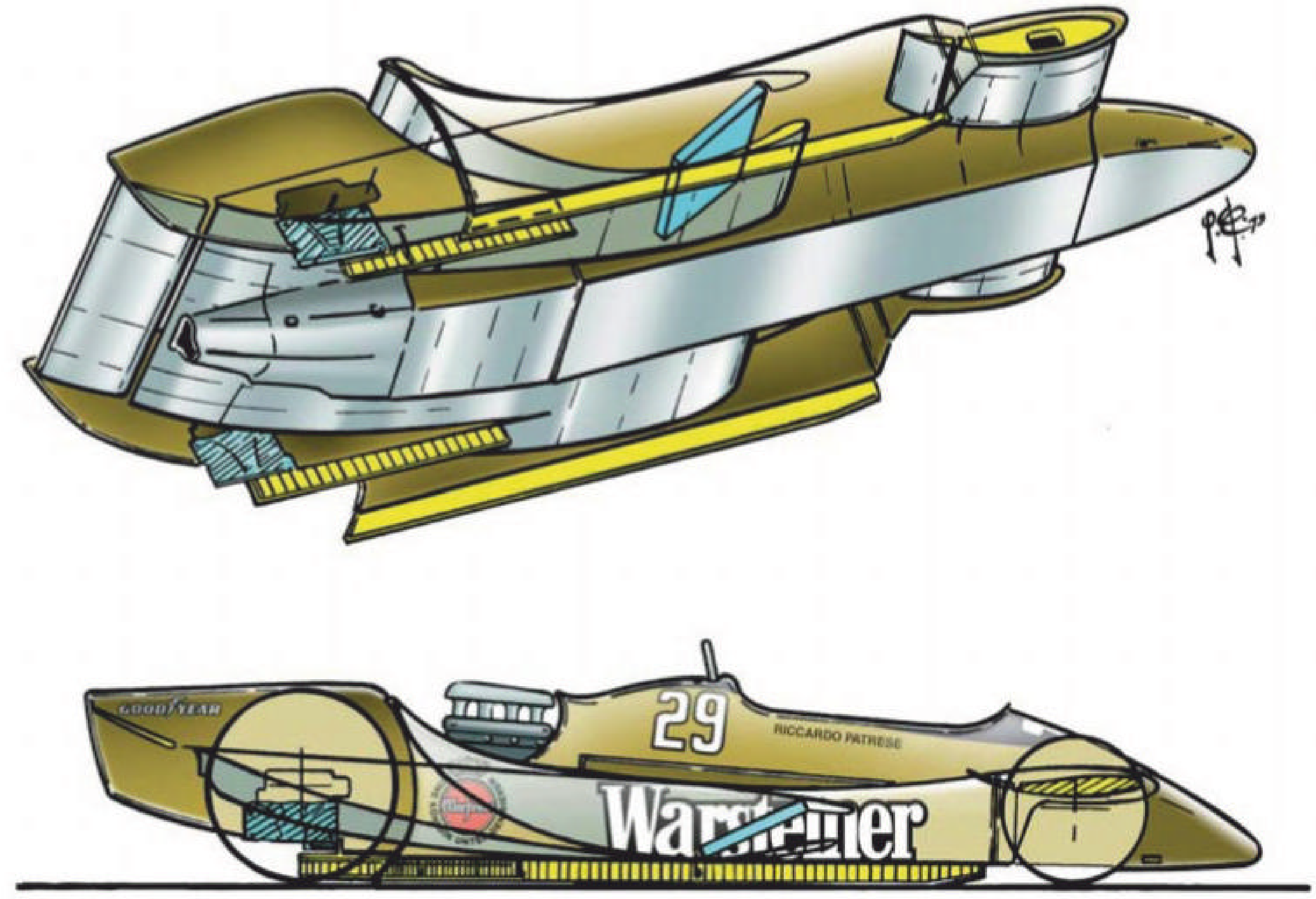
But, Southgate says, the secret of the A2 was on the underside. 'If you had turned the car upside down it would have looked like the hull of a boat. There was no engine or gearbox visible and to achieve that the underside of the car was tilted upwards with the result that the underside was very clean and the only things that intruded into that area were the lower rear wishbones. Everything else was covered. I was looking for what would be the ultimate shape if there was no restriction.

'I have never really cared for wide-track cars but, interestingly, although the A2 was designed to the maximum track width limit in the rules it was quick in a straight line,' Southgate adds. 'It had a very clean shape and the driving position was quite reclined – almost Jim Clark style – with arms outstretched. I don't think the drivers were too keen on that but it meant that the airflow over the top of the car was good.'

Poison Arrows

But the big problem for the A2 was when it had to go around corners. 'It didn't like that,' says Southgate. 'There was a 2.5-degree uplift on the underside of the car that started under the driver's backside and this meant that by the time you got to the engine it was well above the zero line and of course the gearbox was even higher. That meant that the centre of gravity was far higher than it should have been – about 2.5 inches higher than a Williams or a Lotus – and when the car went into a corner it effectively wanted to fall over. That was a big mistake.

'When I look at the A2 now I can't help thinking that if I had mounted the engine level and had a bulge in the underwing it would have



One of the A2's problems was a high centre of gravity, due to the chassis being designed with the rear bulkhead at an angle

knocked off 100 lbs of downforce but at least it would have been able to take corners properly,' Southgate adds. 'Instead we had to fit big anti roll bars to stop the damn thing from wanting to topple over in corners and that mucked up the handling and traction. In the wind tunnel the A2 was great but when I was doing straight line tests on a 25 per cent model I wasn't thinking

The big issues for the A2 came when it had to go around corners

about centres of gravity and stuff like that, I was a bit blinded by the high downforce numbers that were being produced.'

Another aspect that had an impact on handling was the weight of the car. Its wide track stance, sturdy construction and large body surface area resulted in a race ready weight of around 600kg, 25kg over the minimum weight limit then in force. 'Cars always put on weight as they are developed so we were fighting an uphill battle from the start,' says Southgate. 'With a heavy car you are giving away lap time before you even start the engine.'

The A2 was the only ground effect car that ever raced without a rear wing when it ran for the first time at the French Grand Prix in 1979, even Lotus boss Colin Chapman had admitted defeat and put a rear wing on the Lotus 80 for the Spanish Grand Prix. 'That was purely to keep the drivers happy,' says Southgate, but by the A2's second race at the British Grand Prix wings had been added for the same reason. 'They made no difference at all to the downforce; the car had more than enough, to the degree that we occasionally ran into porpoising problems [see box out]. If you look closely at photos of the wings we used on the A2 you can see that they were single element wings run at almost no angle of attack. They were psychological devices for the drivers. There was no measurable performance improvement, the cars qualified in more or less the same grid positions but the drivers said that they felt better, which I accepted.'

Broken Arrows

The Arrows A2 only ran for half a season and pretty quickly it became clear that there was no way of engineering a way out of its problems. Before the end of 1979 it was decided to start work on the subsequent A3 model and give up on the A2, because there was simply no way to improve or change it.

'You couldn't lighten it or lower the engine because the basic structure of the chassis was designed with the rear bulkhead at an angle,' explains Southgate. 'It wasn't just that the engine was angled up, the whole underside from beneath the driver was angled upwards. To change the rear end so the engine was not at an angle would have meant us having to build completely new racecars.'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The Arrows A2 weighed in at around 600kg, which was 25kg over the minimum weight limit in 1979. This might explain why it took four mechanics to push it

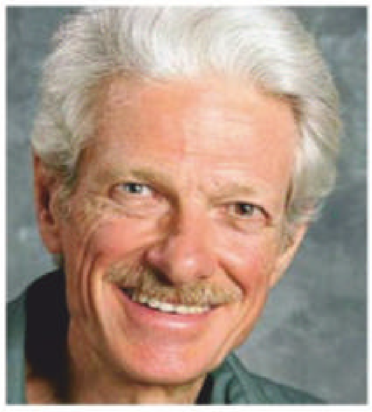
'I deliberately put a hole in the nose, which was actually an air intake for the driver, but it looked like a machine gun!'

Reflecting on the Arrow A2 project now, Southgate observes: 'The Arrows A2 was one of the last racecars built in an era when a Formula 1 designer was in a position where he could pretty much do what he liked. If you were confident enough to try a new idea and the management were happy enough to take a risk, that might be an advantage.

'For its day the A2 was super efficient aerodynamically, but it's the old story, the aerodynamics are only part of the job, the rest of the car has to be right too,' Southgate adds. 'Having said that the A2 was a striking design, at Arrows we called it the Heinkel Bomber because of it's rounded-off nose. I rather liked that shape and I deliberately put a hole in the nose, which was actually an air intake for the driver, but it looked like a machine gun!'

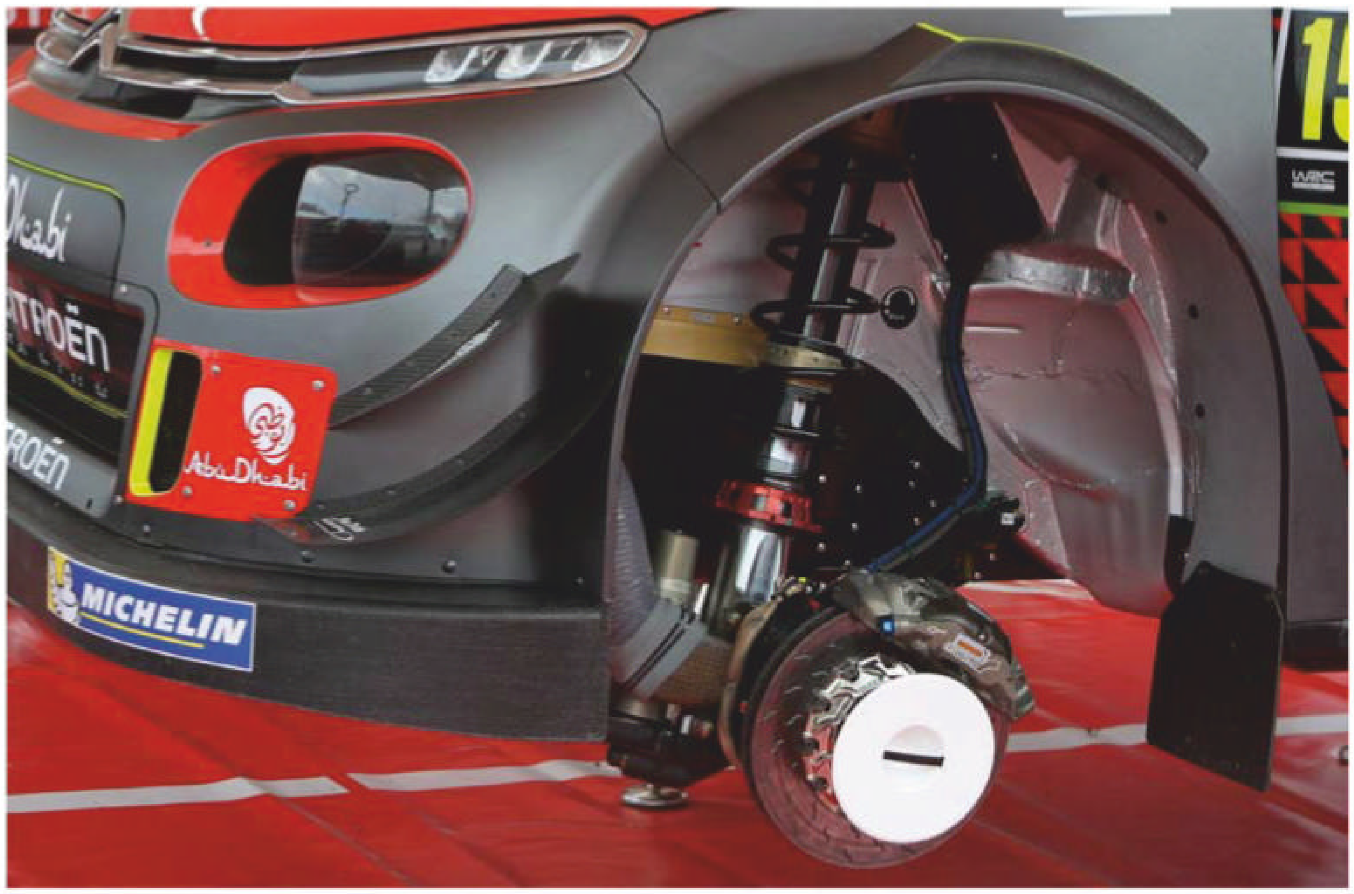
But Southgate concludes: 'Really the A2 was a wind tunnel exercise that should have remained just that. I should have taken the best bits of the tunnel testing and built them around a more conventional chassis, and that's what I did with the next car, the A3.'

The A2 was originally going to have an almost fully enclosed engine, but overheating issues scuppered that plan



Under the arches: tilted struts on World Rally cars

Why the current WRC cars are fitted with inclined MacPherson set-ups



XPB

MacPherson struts on WRC cars slope back within the wheel arch, giving both suspension travel and anti-dive benefits

Q On the current WRC cars, I see the MacPherson strut is tilted very much back at the top and forward at the bottom. I think this must be bad for anti-dive. Is it to get longer suspension travel? But then again, that should have been possible to obtain with a more upright strut, correct?

THE CONSULTANT

A I think this is about increasing travel, along with some related considerations. One might think these suspensions have a huge amount of caster and trail. However, that's not the case. Both the upper strut pivot and the ball joint are required to be in stock location, per the rules. Generally, the control arm will incorporate some provision to move the ball joint fore and aft for caster adjustment, and we can use that, but we will be limited to the range of settings the stock vehicle would have.

Ordinarily we expect the ball joint to be in line with the strut, at least in side view. But under WRC rules, strut or damper design is free, except that no inter-connection is permitted, and remote reservoirs are allowed. Consequently, for a driven wheel, we can make the unit longer if we offset the bottom end of the tube so it passes ahead of the hub carrier, or behind. It could even hang below the hub carrier, except that we have to keep it clear of the control arm at full steer and full droop.

Strut your stuff

It is advantageous to get the bottom end of the strut as low as possible, for a number of reasons, even if we are not bound by rules that fix the location of the top pivot. The strut inevitably takes large bending loads when the tyre generates ground plane forces. It also usually takes some bending loads in gentle driving, where the main loads at the contact patches are normal to the ground plane. To resist bending loads, the strut experiences side loads at the shaft bushing and at the piston. The farther apart we can position these two points, and the lower we can position them, the lower the side loads become. This reduces both wear and friction in the unit.

Unfortunately, to get the piston and the bushing further apart, either the unit has to get longer, or the available travel has to get shorter. We can also raise the top of the strut, but there are packaging limitations constraining that, even if we don't have rules prohibiting it.

For the least friction and wear in gentle driving, we'd like the strut axis to pass through the centre of the contact patch. However, if other considerations prevent this, we may be able to offset the spring a bit to reduce side loads on the piston and bushing. This has become quite common, and it can work when offsetting the strut longitudinally as well as laterally. But this trick is not very helpful for dealing with the large ground plane forces we get when the car corners and brakes hard.

Geometry set

To understand the dynamics of a strut front suspension with the bottom of the strut offset, you have to realise that the offset affects the suspension geometry, but not steering geometry. The steering axis is a line through the centres of rotation of the ball joint and the top pivot, regardless of whether this coincides with the strut axis. However, the virtual upper control arm plane is the plane perpendicular to the strut axis at the upper pivot centre of rotation, regardless of whether this is perpendicular to the steering axis. So, when we move the bottom of the strut forward and tilt the strut back, the effect is similar to tilting the upper control arm of a short and long arm suspension up at the front and down at rear: anti-dive increases. Assuming that the side view projected lower control arm is horizontal, the side view instant centre (SVIC) stays at the same height and moves forward. The force line for braking (contact patch centre to SVIC) then slopes up to the rear more steeply.

The SVIC is still below hub height, however, so a line from wheel centre to SVIC slopes *down* to the rear more steeply. The hub moves back more as the suspension compresses. This portion of the effect does diminish anti-dive. However, the hub carrier also rotates rearward more as the suspension compresses, and that increases anti-dive. We may say that the system has thrust pro-dive but has greater torque anti-dive. If the brakes were inboard, the anti-dive actually would decrease, or more properly, the pro-dive would increase.

CONTACT

Mark Ortiz Automotive is a chassis consultancy service primarily serving oval track and road racers. Here Mark answers your chassis set-up and handling queries. If you have a question for him, please don't hesitate to get in touch:

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Slip Angle is a summary of Claude Rouelle's OptimumG seminars

Hitting the brakes: is your driver aggressive enough?

The way they apply the brake is what separates the good drivers from the average, but just how do you measure their level of braking aggression? OptimumG's Claude Rouelle explains all

XPB

Top drivers brake aggressively when they need to, but the balance between getting it right and locking up is a fine one

In the last two Slip Angles we defined what key performance indicators (KPI) are, and how using the steering wheel angle signal to create KPI such as steering smoothness and steering integral will help you better understand driving style and vehicle balance.

OptimumG engineers usefully use these data analysis techniques on a day-to-day basis in racing series such as WEC and ELMS, Supercars in Australia, Brazilian Stock Car, and the Blancpain GT Series. And you can too. If you haven't read the previous articles, try to check them out (January and March issues), as they will help you get the most from this month's piece, as some of the important definitions and calculations were included in these.

Braking good

The goal of this series of articles is to highlight the benefits of a data-driven approach and provide some examples on how it can be used for getting the most performance from the car and driver. Here we will be looking at the brake signal. The brake KPI can be calculated using a range of signals including brake pressure in the master cylinders, brake pedal displacement or brake pedal force.

First, we will define what we call a braking zone. This is the zone where brake pressure is applied before a corner. It can be split into two major phases. The first phase, commonly called brake application, is defined from the point where the driver starts to brake until the point of maximum brake pressure, and the second one, brake release, from the point of maximum brake pressure until the release of the brake pedal.

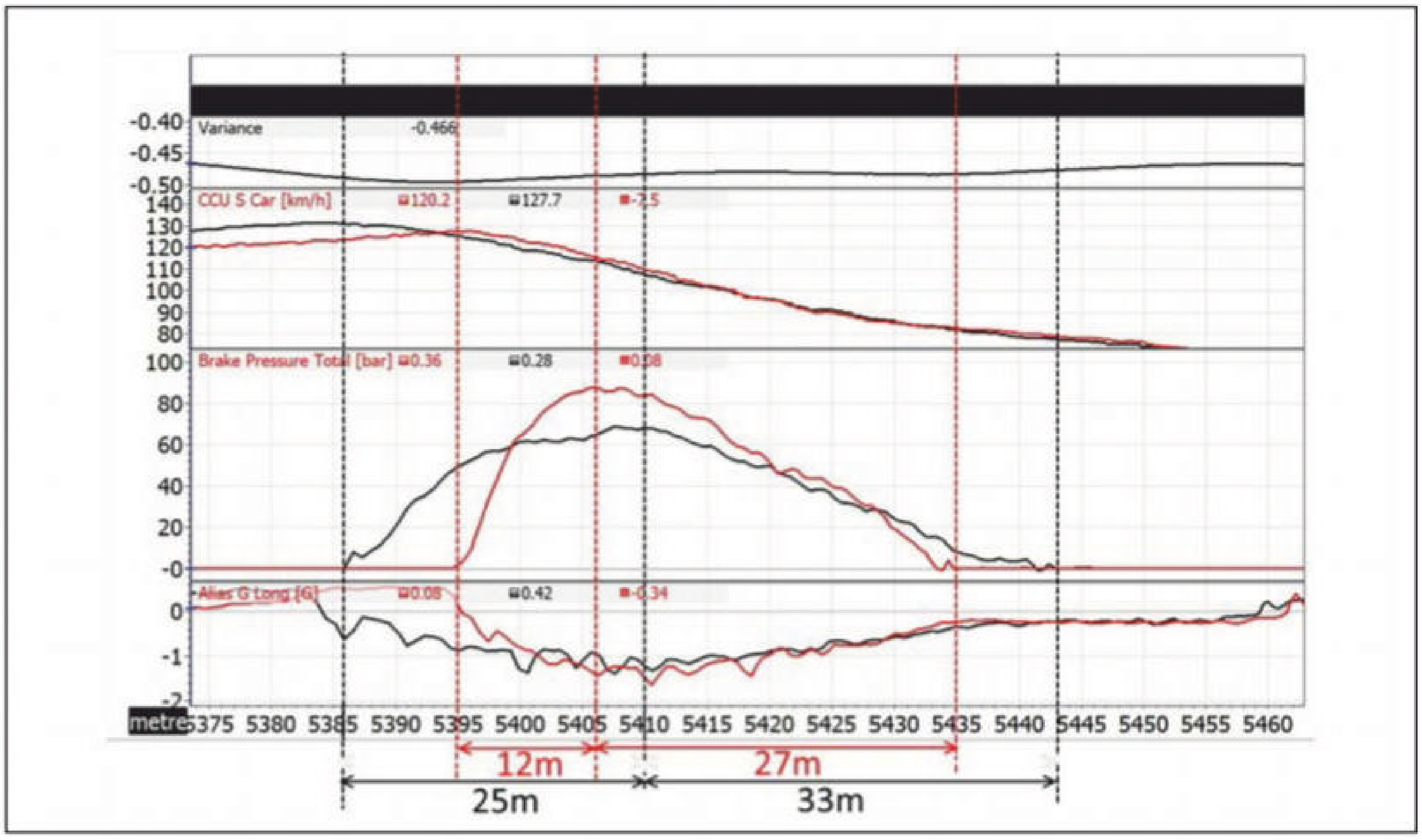

Figure 1: Analysis of the braking zone for two different race drivers heading in to Turn 10 at the Paul Ricard circuit

Both phases are highly dependent on the type of corner (speed as well as early, normal, or late apex), on the driver's driving style (aggressive/smooth at braking), vehicle type (aero car versus a non-aero car), the overall grip of the tyre, and the vehicle balance.

An overlay of the data of two drivers braking for Turn 10 at the Paul Ricard circuit is shown in **Figure 1**. The chart is composed

Most driver inputs really should be smooth, except in the hard braking zones such as the end of the long straight at Le Mans

of four traces: variance, vehicle speed, total brake pressure (defined as the sum of the front and rear brake pressure, see **Table 1**), and longitudinal acceleration.

Large differences can be seen in the braking application and brake release of the two drivers. The driver with the red trace applies force on the pedal later, more rapidly and ultimately with a higher force. This will cause the car to decelerate quicker and allow the driver to release the brake sooner.

If we look at the variance, which is the difference in lap time between both drivers (a positive value means that the red trace is faster than the black one and a negative means the opposite), the red driver was able to gain 0.016s in this corner.

Hard and fast

Brake aggression is the ability of the driver to apply a braking force rapidly. The higher the brake force speed (the slope of the brake force during the brake application phase) the more aggressive the driver is.

Most driver inputs to the car should be smooth, except in hard braking zones, such as the end of the long straight at Le Mans, where speeds can reach well above 300km/h and where braking aggression will make a massive difference in braking distance, which translates into faster lap times, or the ability to defend a position or make a pass. This is especially important in aerodynamic cars, the higher speeds mean more downforce and more load on the tyres. This means that at higher speeds, the car is capable of larger braking accelerations. In order to make use of this, a driver needs to achieve the peak braking pressure very quickly, but then release the pressure as the car slows and the downforce decreases.

The process

Here we will firstly show you how to calculate the brake pressure speed during the brake application and create a KPI to characterise brake aggression. Secondly, we will give you a few examples on how you can analyse brake aggression with other variables such as wheel locking, brake wear, vehicle balance, etc.

In this first example we will be using the brake pressure signal, but the same calculations can be

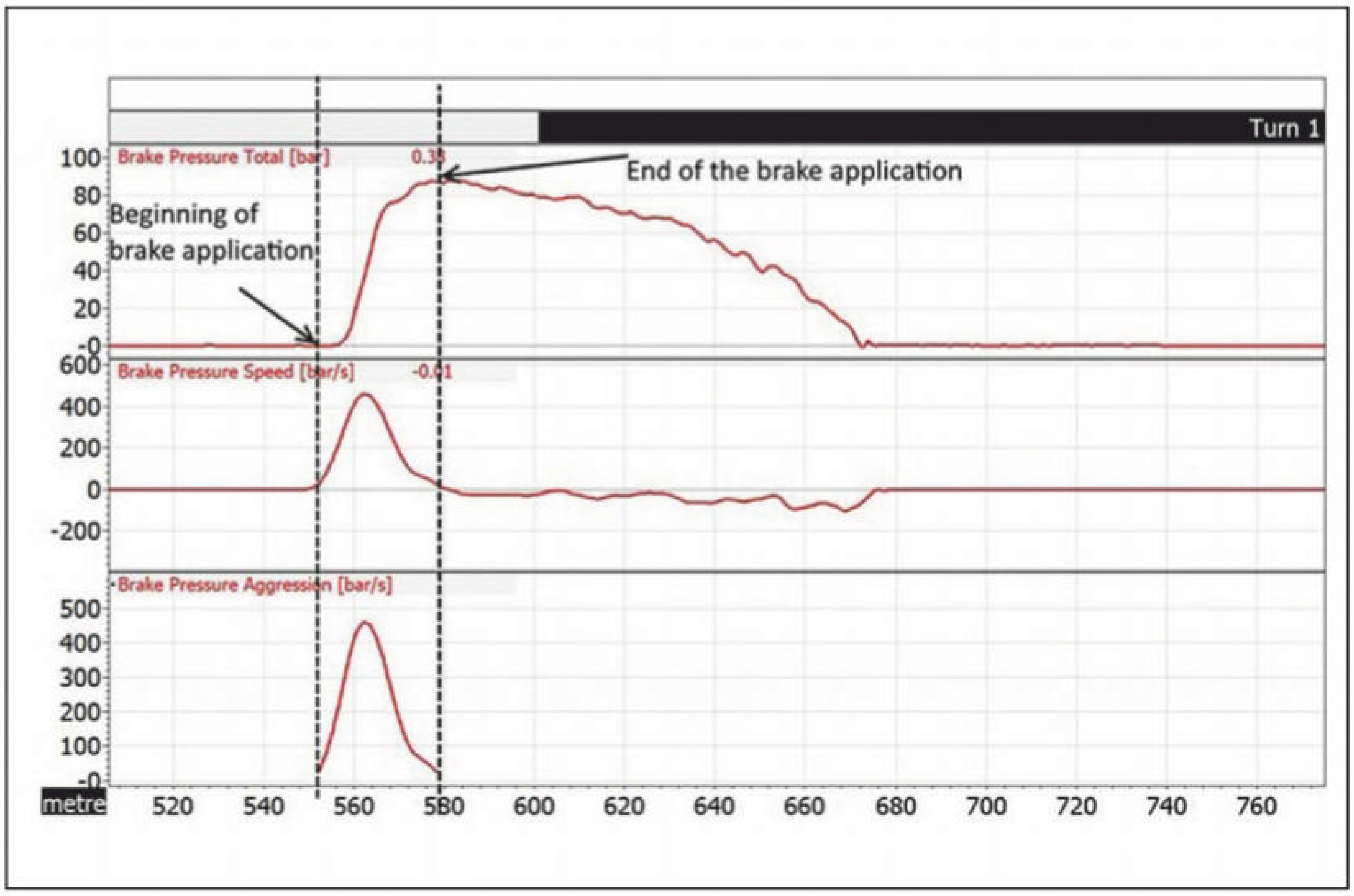

Figure 2: The results of the Table 1 math channels are applied. Calculating brake pressure speed correctly is key

Table 1: Math channel equations in MoTeC i2 to create the brake pressure aggression KPI

Math channel name	Math channel equation
Total brake pressure	'Brake Front' [bar] + 'Brake Rear' [bar]
Brake pressure speed	derivative('Brake Pressure Total' [bar], 0.2)
Brake pressure aggression	choose('Brake Pressure Speed' [bar/s] > 20, 'Brake Pressure Speed', 1/0)
Brake pressure aggression KPI	state_mean('Brake Pressure Aggression' [bar],1,range_change("Outings:Laps")

'Brake aggression' refers to the ability of the racing driver to apply a braking force rapidly

performed using the brake pedal displacement or force. First, we create a math channel called 'Total Brake Pressure'. To obtain this math channel, the first thing we need to create is the total brake pressure sum of the front and rear brake pressure. Note that this is optional and the KPI can be calculated either with the front or rear brake pressure.

Then we create the math channel for the 'Brake Pressure Speed', which is the differentiation of the previous created math channel 'Total Brake Pressure'. The derivative function is simply called *derivative* in MoTeC. This function measures the rate of change for a given number of points or a time frame. Thus we want to calculate the variation of the total brake pressure in a time frame of 0.2s. The chosen value of 0.2s is based on the delta time from brake application until reaching the maximum brake pressure. By selecting this value, we are naturally filtering the signal by not taking into account the small variations from, for example, small vibrations that occur when the brakes are applied. We only calculate the variation from initial to the maximum braking pressure.

Brake away

The next step is to extract the braking speed only of the brake application phase, which we achieve by using the MoTeC *choose* function. What characterises the braking application phase is a positive braking speed, all values below a certain threshold are ignored. In our case we used 20 bar/s but this is a reference value and it will have to be adapted depending on the racecar concerned: typical values are normally between 20-40 bar/s. We use this value in order to remove any small braking that could occur during the trail braking phase, by the driver modulating the brake.

Finally, we then calculate the 'Brake Pressure Aggression KPI' by calculating the average of the brake pressure aggression during the braking phase for each lap. The total brake pressure, brake pressure speed and brake aggression are shown in **Figure 2**.

For a more detailed explanation of how to use the *choose* or the *'state_mean'* function please refer to our March edition (V29N3).

Figure 3 shows the braking aggression over a stint. Plotting the KPI over a stint or the duration of a race gives a good overview of what is actually happening and allows you to detect any variation/deviation from a nominal value rapidly. It also enables you to see the progression of the brake aggression during the stint. This can be very useful, to see the evolution over the weekend during practice, qualification, or during the whole race.

By looking at the data we can see that Driver A is the most aggressive compared with their peers, but after lap 10 we can see that the braking aggression decreased significantly.


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The goal of the race driver is to apply the maximum braking pressure at the fastest rate possible without locking up

To better understand why Driver A started to brake less aggressively we could look at the amount of time that the driver is locking the wheels (**Figure 4**). Wheel locking is the total amount of time that the racecar spent with its wheels locked, a high value means that the driver locks the wheels a lot, and a low value means that the driver doesn't lock-up that much. The wheel locking can be calculated based on comparing the speed of the car with the speed of each wheel, if the difference between the car's speed and wheel speed is higher than a predefined threshold then it's considered wheel locking.

Table 2 summarises the creation of this math channel for the front left wheel, the same methodology can be applied to calculate for the remaining wheels. To simplify the creation of the wheel locking math channel we use an intermediate step. The *'IsFLWheelLock'* returns 1 if the front left wheel is locking and 0 if not. We then create the math channel '*WheelLockFL*', which will integrate (sum) every time that the *'isFLWheelLock'* returned a 1, giving the total amount that the wheel locked per lap.

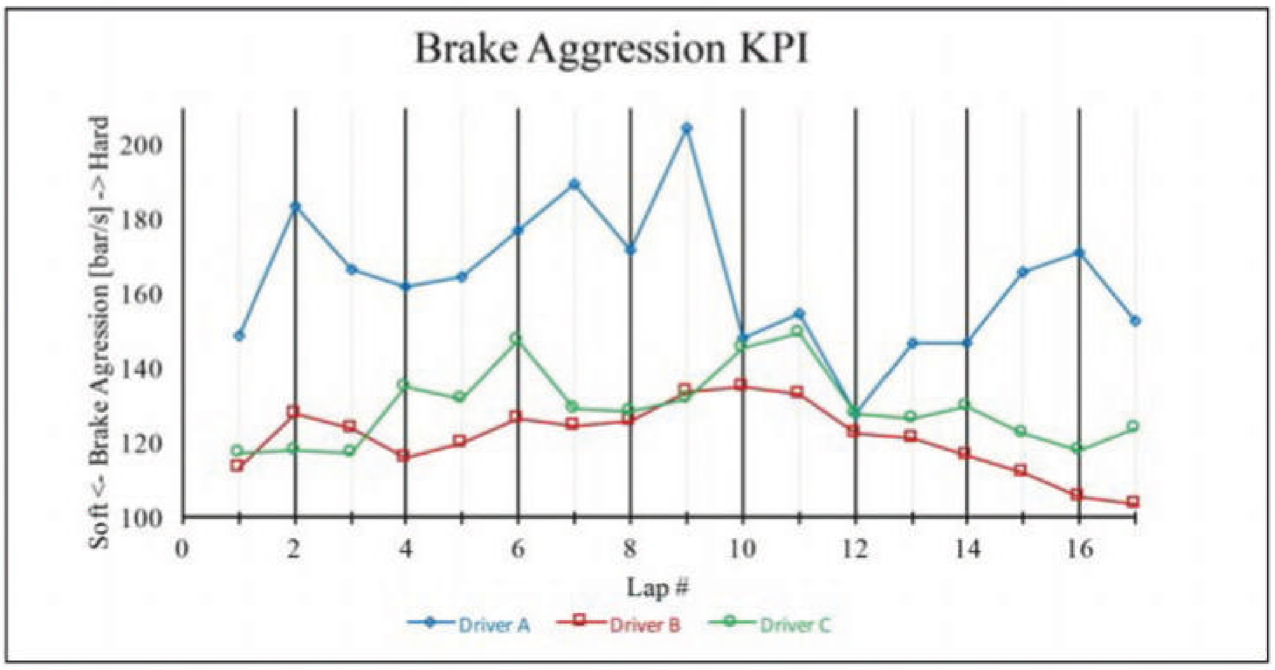

Figure 3: Braking aggression evolution during a stint. Driver A is the most aggressive of the three racers

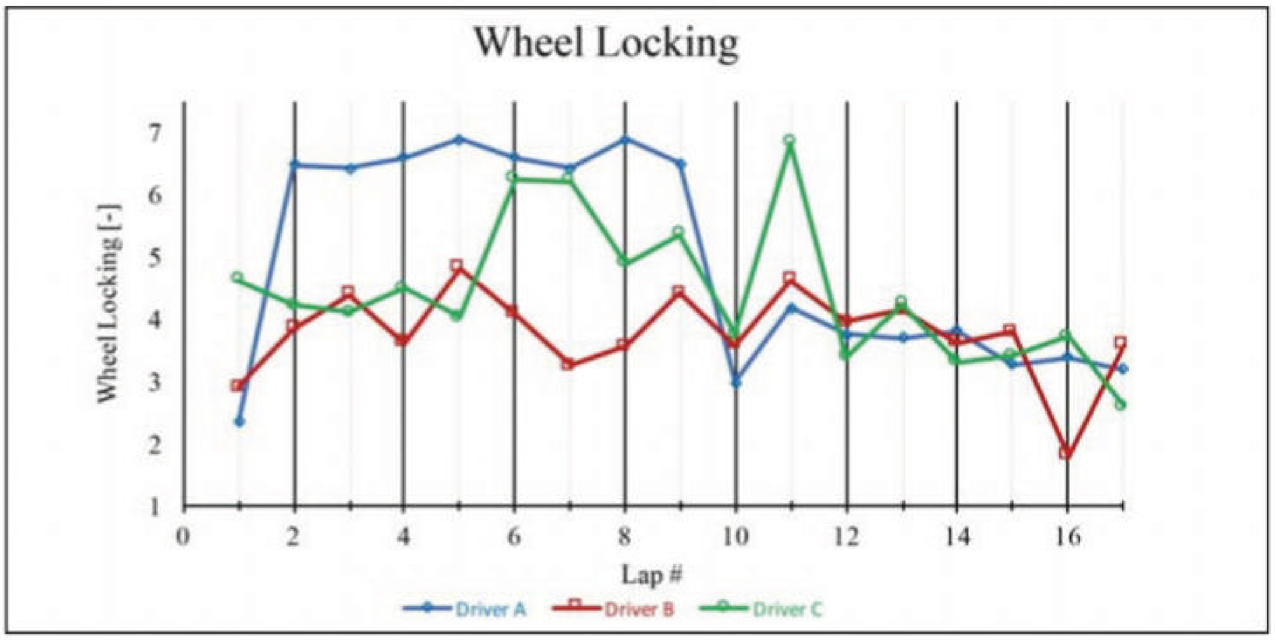

Figure 4: Wheel locking over the same stint. It's no surprise that Driver A locks up more than the others

Wholly smoke

What we can expect is if a driver locks their wheels a great deal then maybe they are being too aggressive on the brakes. This can cause overheating of the tyres/brakes which can led to premature tyre wear. This is most likely what happened to Driver A; being too aggressive and therefore then needing to ease off to avoid continuing to lock up too much, in order to manage the tyres.

Another way to look at the data is to correlate brake aggression and brake stability. Braking stability is defined as how stable the car is under braking. This is estimated by studying the amount of steering wheel angle correction applied during the braking. With both Driver B and Driver C the braking aggression decreased towards the end of the stint. The reason why both drivers become less aggressive under braking was to react to the lack of rear stability that became more significant with rear tyre wear. With the rear tyre wear greater than the front tyre wear, the grip balance shifted forwards, meaning the car was more likely to spin under braking if the rear wheels locked.

Table 2: Equations in MoTeC i2 to create the wheel locking math channel

Math channel name	Math channel equation
IsFLWheelLock	choose(('Car Velocity' [km/h] - 'Wheel Speed FL' [km/h])>5,1,0)
WheelLockFL	integrate('isFLWheelLock',1,range_change("Outings:Laps"))

Braking good

Braking technique is one of the most important of race driver skills, as often braking is what conditions how quickly you can go around a corner. Simply put, being able to brake later while accelerating sooner will result in faster lap times.

Braking data can be looked at in many ways: brake application point, maximum braking pressure, brake lock-up, brake aggression, brake release smoothness, and braking stability, to name but a few. But more important, understanding how they relate to each other can help extract the most performance from the racecar and the driver.

Applying the correct amount and pressure of braking is necessary to provide good retardation. The goal of a driver is to apply the maximum braking pressure at the fastest rate possible without locking the wheels.

By braking too hard and fast, there is a risk of locking the wheels, creating flat spots which could compromise vehicle handling and performance, forcing the car to pit, and thus losing more time.

OptimumG offers a complete solution for testing, simulating, and improving the dynamic performance of your vehicle. All consulting services can be sub-contracted or we can simply guide your race team through our methodology.

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Charge of the light brigade: Time Attack's new breed

In the first of a new series we evaluate the aero on a brace of UK Time Attack weapons: a Caterham R400 and a Noble M12

Front and rear single element wings plus wheel arch Gurneys adorn the Caterham R400

The rear wing proved to be effective even though it was mounted behind the roll cage

While the fastest cars in UK Time Attack's top Pro Extreme class continue to be the potent Mitsubishi Evos and Subaru Imprezas, there appears to be a slow and possibly inexorable shift towards smaller, lighter cars across the other top classes. So how long will it be before the Pro Extreme class is won by one of the nimbler machines?

In anticipation of this possibility, in this and the next two issues we look at two smaller, lighter but successful competitors on the UK Time Attack scene; a Caterham R400 that won the 2018 Super Lap Scotland Pro class championship, and a Noble M12 RSR that won the 2017 Club Pro 2wd class in UK Time Attack and came second in 2018.

In our previous examination of UK Time Attack cars in 2013 we examined the rapid Lotus Exige of Jamie Willson and the impressive Roger Clark Motorsport 'Gobstopper 2' Subaru Impreza. These cars also reflected the alternative small and nimble versus classic Time Attack approaches. The question now was: how would our latest candidates fare in the MIRA full-scale wind tunnel, and how did they compare to those we had previously tested?

Table 1: The aerodynamic coefficients on the Caterham R400

	CD	CL	CLfront	CLrear	%front	L/D
Baseline	0.700	-0.271	+0.074	-0.345	-27.1%	-0.387
Best	0.661	-0.243	-0.063	-0.179	25.9%	-0.368

Opening salvo

David Long's Caterham R400 arrived at the wind tunnel with a new wide, single element front wing that had not yet been set up – he had run the car with a narrow dual-element front wing of his own making during his 2018 campaign. Among the objectives for the Caterham then was to try and find the best possible aerodynamic balance.

Simon Roberts' Noble arrived at the wind tunnel as it had been run in 2018. The driver was happy with the car's balance although your writer, having devised the fundamental package, was convinced that the car, as set up, would have a too rear-biased aero balance.

Let's look at those revealing baseline test numbers, the Caterham first, as shown in **Table 1** – along with the best in-session numbers to illustrate the progress made during the less than two hours we had to work on each car during our half-day session.

Leaving aside for now the drag coefficient and the customary aerodynamic comparisons with a brick that Caterham owners punish themselves with (it's not that bad, and we'll come back to this in our next issue), the initial downforce distribution was rather surprising. As mentioned, the car had not actually run with the new front wing but clearly the initial wing angle was too low. As delivered, the Caterham

The Noble M12 RSR sports a full-width dual-element rear wing and a large front splitter

The Noble's wing, spoiler and diffuser all interacted to help generate high downforce


The Lotus Exige tested in 2013 didn't quite match the Noble's level of downforce or balance


The Impreza also fell short of the Noble's downforce levels, even with those big wings

generated a small amount of positive front lift and a moderate amount of rear downforce. By the end of the all too short stint on this car, adjustments had enabled some tangible front downforce that produced a downforce distribution of around 26 per cent front. With a static weight distribution of 48 per cent front, more front downforce would be very desirable.

We will examine this in more detail in the next issue because intrinsic front lift was surprisingly high. For now, this was the best we could achieve, and total downforce at 100mph in this configuration amounted to 6.4 per cent of all up weight including driver. The car's owner and driver, David Long, considers that although adding downforce certainly increased his confidence, especially in the wet, the car's soft, compliant suspension helps to generate excellent mechanical grip, and supporting high levels of downforce would likely compromise this aspect. This is an omnipresent compromise with production-based racecars.

Noble endeavour

Moving onto the Noble M12, **Table 2** shows the as raced in 2018 aerodynamic data along with the best in-session figures.

Initially, then, the Noble had a very similar drag coefficient to the Caterham but generated considerably more downforce. Furthermore, the aerodynamic balance was around 35 per cent, very much on target for a car with a static weight distribution of 38 per cent front.

The Caterham's success is largely down to mechanical grip and low weight

This confirmed that the driver's impression that the car possessed high speed balance while out on track was accurate and that the aerodynamic package was working well in balance terms. Photographs that showed the rear suspension more compressed than the front at speed were apparently more to do with suspension wheel rates than your writer's postulated downforce imbalance.

Adjustments through the session enabled 18.8 per cent more total downforce to be found with virtually no change in balance, and drag increased by around 11.9 per cent. So the gains were at the decreasingly efficient end of the scale but nevertheless overall efficiency, as given by the L/D (downforce divided by drag) figure, still increased by 6.8 per cent. Total downforce amounted to about 30 per cent of all up weight at 100mph.

Table 2: The aerodynamic coefficients on the Noble M12 RSR

	CD	CL	CLfront	CLrear	%front	L/D
Baseline	0.695	-1.157	-0.404	-0.754	34.9%	-1.665
Best	0.773	-1.375	-0.489	-0.886	35.6%	-1.779

Table 3: Time Attack aerodynamic coefficient comparisons

	CD.A	CL.A	CLfront.A	CLrear.A	%front	L/D
Caterham	0.866	-0.318	-0.083	-0.234	25.9%	-0.368
Noble	1.446	-2.571	-0.914	-1.657	35.6%	-1.779
Lotus Exige	0.952	-1.748	-0.499	-1.250	28.5%	-1.836
Subaru Impreza	1.443	-1.845	-0.535	-1.310	29.0%	-1.278

Time travel

By way of comparison with the pair of Time Attack cars we tested back in 2013, **Table 3** gives all four cars' best in-session figures, with coefficients multiplied by frontal area (which is directly proportional to forces) to enable direct comparison.

The Caterham was clearly a low downforce car in this comparison, and its success probably owes more to mechanical grip, low weight and nimbleness; its modest downforce did bring some driver confidence to the party, though. The stand-out figures in **Table 3** are the downforce and balance of the Noble. It had more than 39 per cent greater total downforce and more than 70 per cent greater front downforce than the Subaru Impreza. The latter deliberately had a rear-biased balance, but the Noble had more rear downforce too, despite running a less potent wing. The Impreza had a minimal rear diffuser at the time of our wind tunnel test and the hatch shape probably generated more intrinsic positive lift.

Table 4: Downforce as a percentage of the vehicle weight at 100mph

Caterham	6.4%
Noble	29.6%
Lotus Exige	27.8%
Subaru Impreza	20.9%

Table 4 shows total downforce at 100mph of each car in best in-session configurations as a percentage of vehicle weight, which in simplistic terms illustrates how much extra grip was added by the downforce. The Noble and the Exige stand out here, and despite the Exige developing 32 per cent less total downforce than the Noble, being nearly 26 per cent lighter meant that its downforce at 100mph was almost the same proportion of its total weight. Notably the Impreza trailed somewhat in this comparison.

CONTACT

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

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Close encounters

As part of an ongoing quest to improve overtaking, IndyCar and ARC are now using a range of technologies to better understand the behaviour of cars running close together on high speed ovals. Here's the inside story

By ANDREW MOSEDALE

With technology advancing so quickly, the challenge for many industries is not how to gather enough data, but rather how to manage the wealth of information becoming available. For IndyCar, this means reviewing the telemetry data of hundreds of cars from the past few years of racing and testing. Developing a single car in isolation has been challenging enough, but looking in detail at the effect of traffic, the second-by-second GPS updates as cars jockey for position around each corner, increases the task exponentially, and it's a fascinating challenge to keep on track of all this.

Close combat

While longer-term work is ongoing to upgrade driver-in-loop (DIL) simulators to model the effects of racing scenarios (see January issue, V29N1), IndyCar is also pressing ahead with updates on a race-by-race basis using track testing, wind tunnel and computational methods (CFD) to improve the close-combat handling performance. In partnership with the Indianapolis-based Auto Research Center LLC (ARC) and high performance computer (HPC) resource provider R Systems NA, Inc, a programme has been set up to investigate the behaviour of multiple racecars in close proximity through a series of stages that promises to deliver deeper understanding – and a better experience for fans.

One path for development has been to map the impact on performance as a function of position relative to another car. This has helped guide the transition from the individual manufacturer aerokits to the universal aerokit introduced in 2018. Using the extensive computational resources provided by R-Systems, and the expertise of ARC with its Elements software suite, simulations are

Like many race series IndyCar has been grappling with the problem of cars losing downforce when running in traffic, and how this affects overtaking and thus the quality of the show

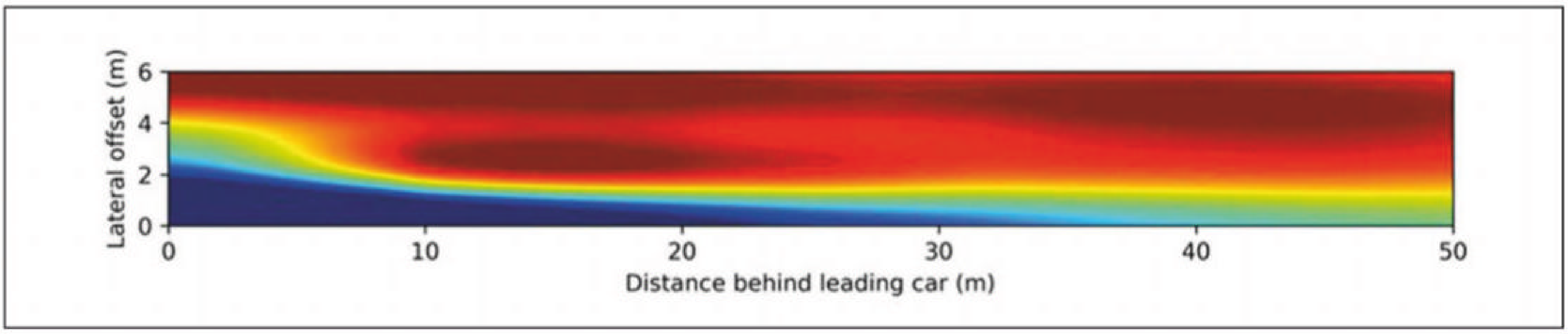

Figure 1: Surrogate model of the percentage loss in drag due to following another car. This drafting aeromap has helped identify several key factors affecting performance when running in wake

being run with cars in a range of statistically-determined positions to create a model with machine learning that can help visualise the task in new ways, such as shown in **Figure 1**. This 'drafting aeromap' has helped identify several key factors affecting a car's performance when in the wake of another racecar.

In the balance

It has long been understood that entering the tow of another car reduces the drag (and downforce) experienced by the following driver, allowing them to close up on the straights so long as they can hang on in the corners. A critical factor in this is the balance of downforce between front and rear tyres. Typically, the front wing sees more disruption than the rear wing, and so disproportionately more front downforce is lost, causing the following car to understeer.

The front wing sees more disruption than the rear wing and so disproportionately more front downforce is lost

But this is complicated by the influence of the floor (underwing). Being so close to the ground, the air is less disturbed so the balance of the components in ground effect is an important consideration in predicting the response when entering the wake of another car.

Understanding the effects of this 'low-energy' wake flow can help with getting into a position to attempt an overtake, but as the distance between the cars comes down clear zones of influence appear to upset the handling of the car further. As the cars jink from side-to-side, the relative position of the front wing and wheels of the following car to the rear diffuser and wheels of the leading car can cause it to switch from understeer to oversteer in a matter of inches. And even with the simplified front wing and end-plate configurations that were seen last year, there is still a lot of sensitivity and variation across the span of the wing that can lead to some unanticipated consequences.

Improving any one of these flow behaviours is manageable using traditional approaches, but because of the knock-on effect on the handling in another position, not to mention the one-lap speed in free air, care needs to be taken to improve performance as a whole. To this end, ARC and IndyCar have identified a typical overtaking trajectory using real race data that shows a car passing through all these critical zones and is using this path to evaluate changes to see where the car is weaker or stronger.

Figure 2 shows the GPS trace of all the cars on the circuit. By combining the on-board data with video footage, several simple overtakes

Figure 2: GPS tracking of all the cars during the 2018 Indy 500. This was used to help identify a typical overtaking trajectory

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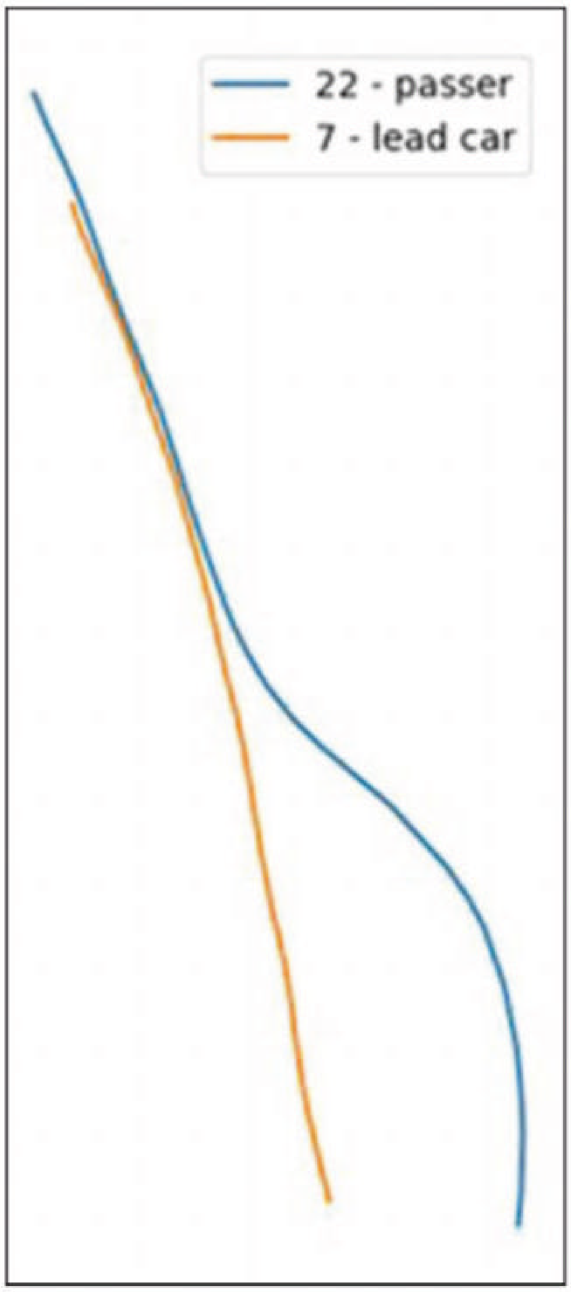


Figure 3: GPS track of a representative overtaking trajectory; in this case it's a pass on the inside

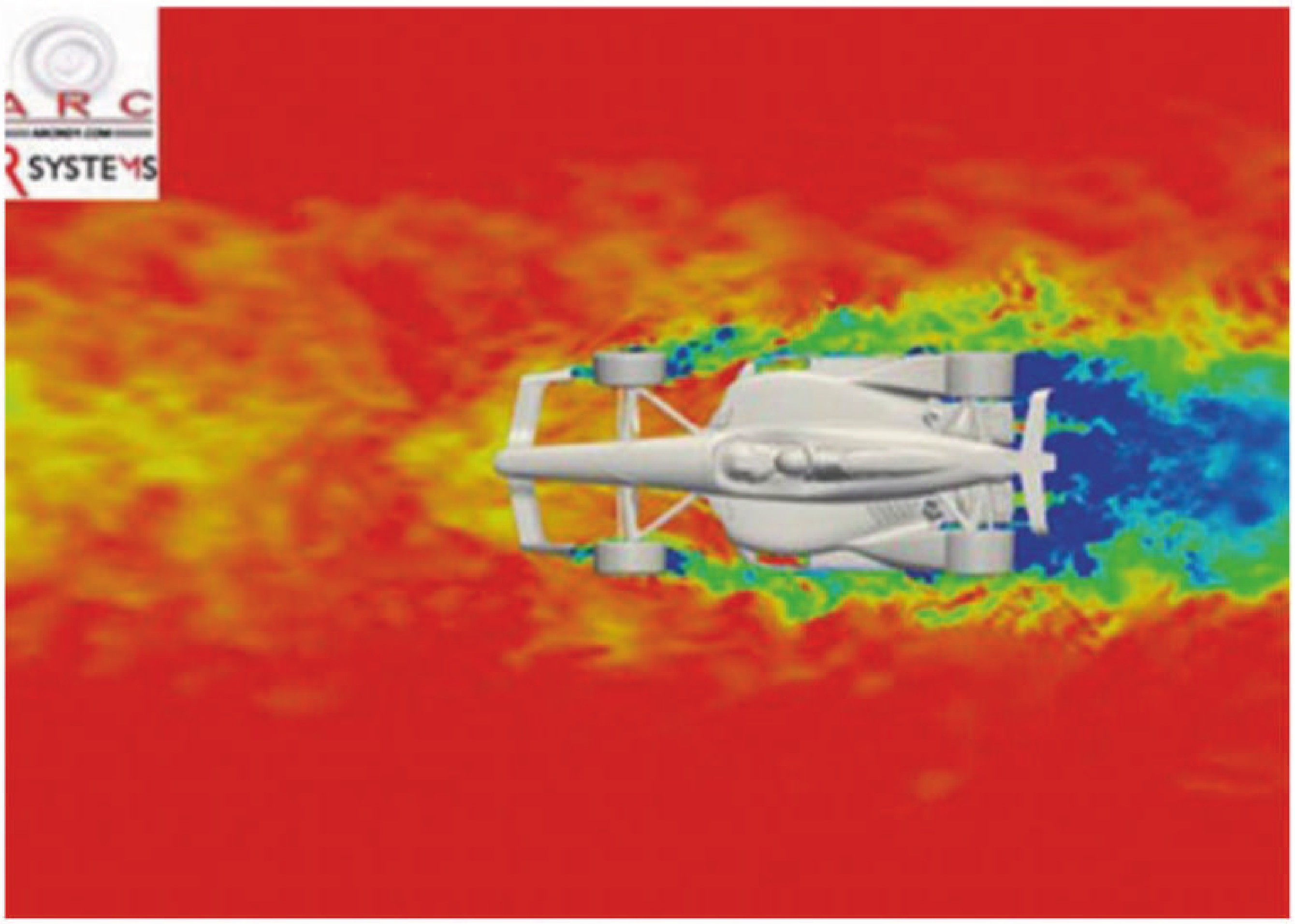


Figure 4: Turbulent wake 50m downstream of leading car, coloured by total pressure. This is a gap of about half a second

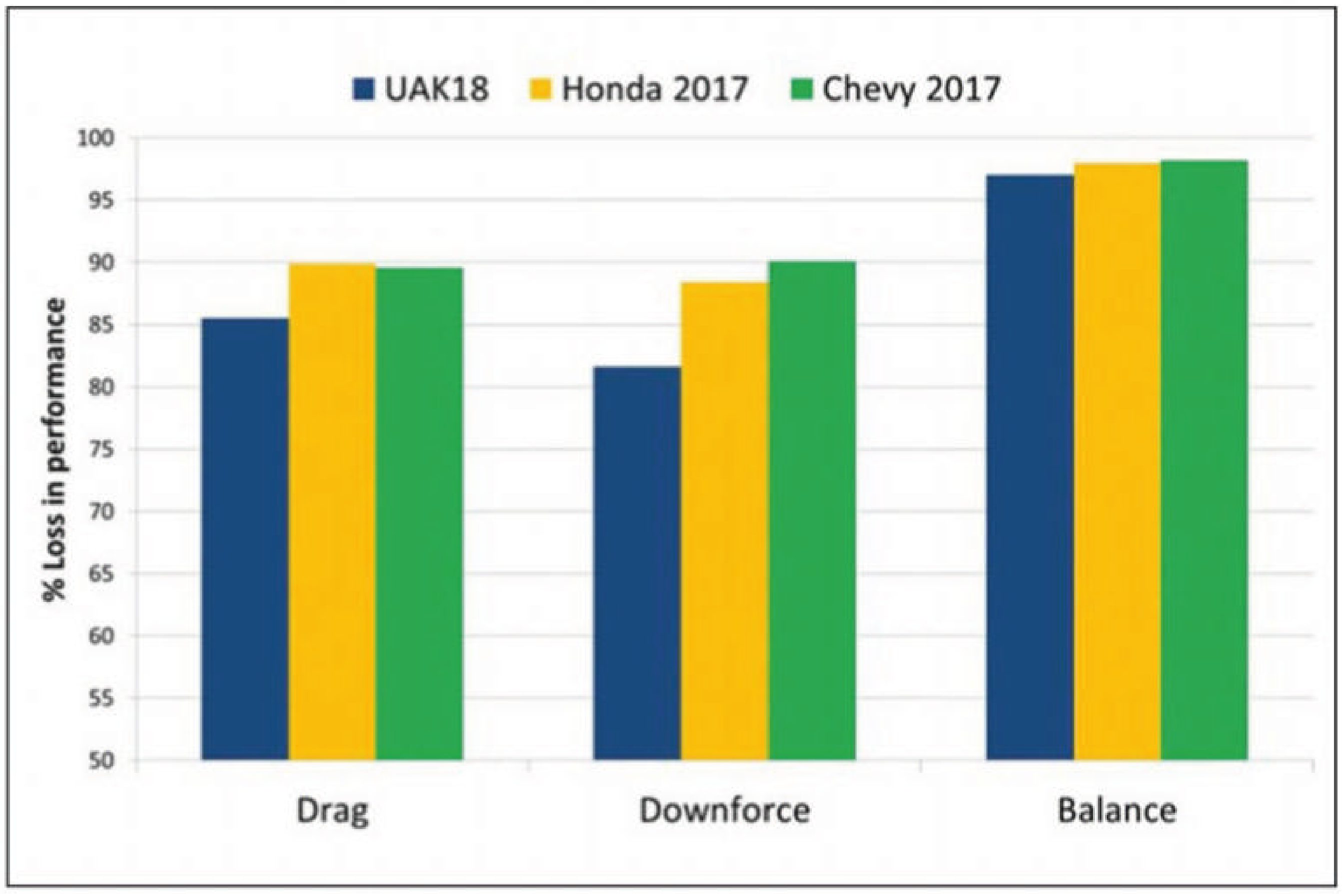


Figure 5: Loss in performance from following 50m behind another car with the 2018 kit and both of the 2017 aerokits

were selected to characterise the manoeuvre. The criteria were for the following racecar to close on the straight without the leading racecar trying to break the tow, and to pull out and get alongside before the corner. Selecting these criteria reduces the number of variables that need to be accounted for when setting up the analytical models to understand the car performance and effect on any proposed developments to the bodywork.

The chosen trajectory, shown in **Figure 3**, is for an inside pass, although data showed that overtaking in the 2018 Indianapolis 500 was evenly split between the inside and outside lines. Based on previous work to understand the effects of the wake on a following car, this trajectory was further broken down into five points, so that CFD could be run for each case with two cars in the respective positions.

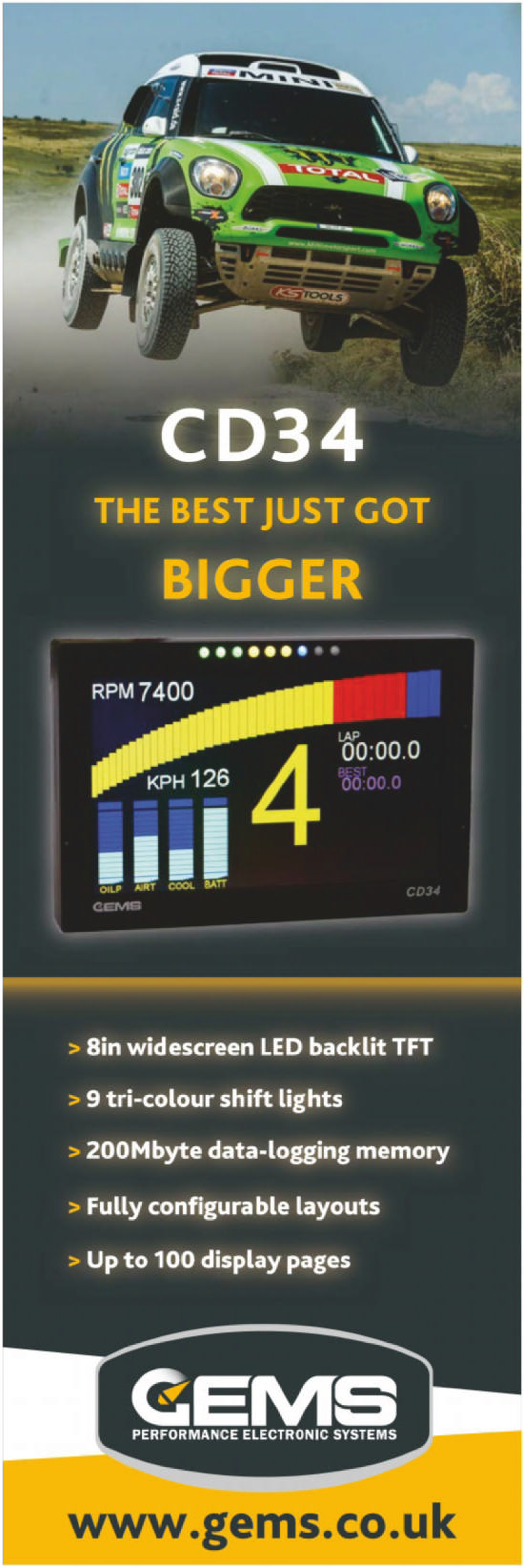
By comparing the effect on drag, downforce and balance for the following car from the UAK18 bodykit development proposals, as well as referencing the 2017 aerokits, a better picture of the respective strengths and weaknesses of each set-up in traffic could be identified – and the detailed flow field available from the CFD provides further aerodynamic understanding to continually improve the ability of the drivers to race.

Close to the wind

The first critical position for setting up an overtake is also the most familiar. Perhaps one of the fundamental things – and one that is common to all forms of racing – is whether a racecar gets closer or further away once it is within the turbulent air of another car. This is represented by the 50m following condition in the passing trajectory, a gap of about half a second. The focus on this position is understandable. Improve performance here, and the cars will follow closer and have more opportunities for overtaking. As is often the case, there are several competing elements in play for maximising performance.

The turbulent wake of the leading car at this distance is shown in **Figure 4**. As can be seen, the flow unstructured and the mean wake can be considered to be a uniform low energy zone where the following car will experience reduced

Teams reported that the cars were seeing a greater than one per cent shift in downforce from front to rear, which was an issue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The wings can be considered to be a single system that is biased towards the front, while the floor is biased towards the rear

air velocity. The most obvious consequence of this is a reduction in drag, the key to slipstreaming. Set against this is a reduction in downforce, as reduced air velocities mean all forces are proportionally less. In simple terms, the following car gains on the straights but loses in the corners as it struggles for grip.

The effect for a typical UAK18 set-up compared to the manufacturer aerokits of the previous year is shown in **Figure 5**. The results here show that the UAK18 experienced a bigger reduction in both drag and downforce than previous years, implying a bigger wake effect. Comparing the wakes from these different vehicles confirms that the wake area from the UAK18 is larger, mostly due to the removal of the rear wheel guards (**Figure 6**). It punches a bigger hole in the air, so the tow was greater, but still it was difficult for racecars to close that gap. The answer is in the downforce, and more specifically how the change in balance affected the handling.

Teams reported, and the simulations confirmed, that the cars were seeing a greater than one per cent shift in downforce from front to rear in this position – which was an issue compared to previous years.

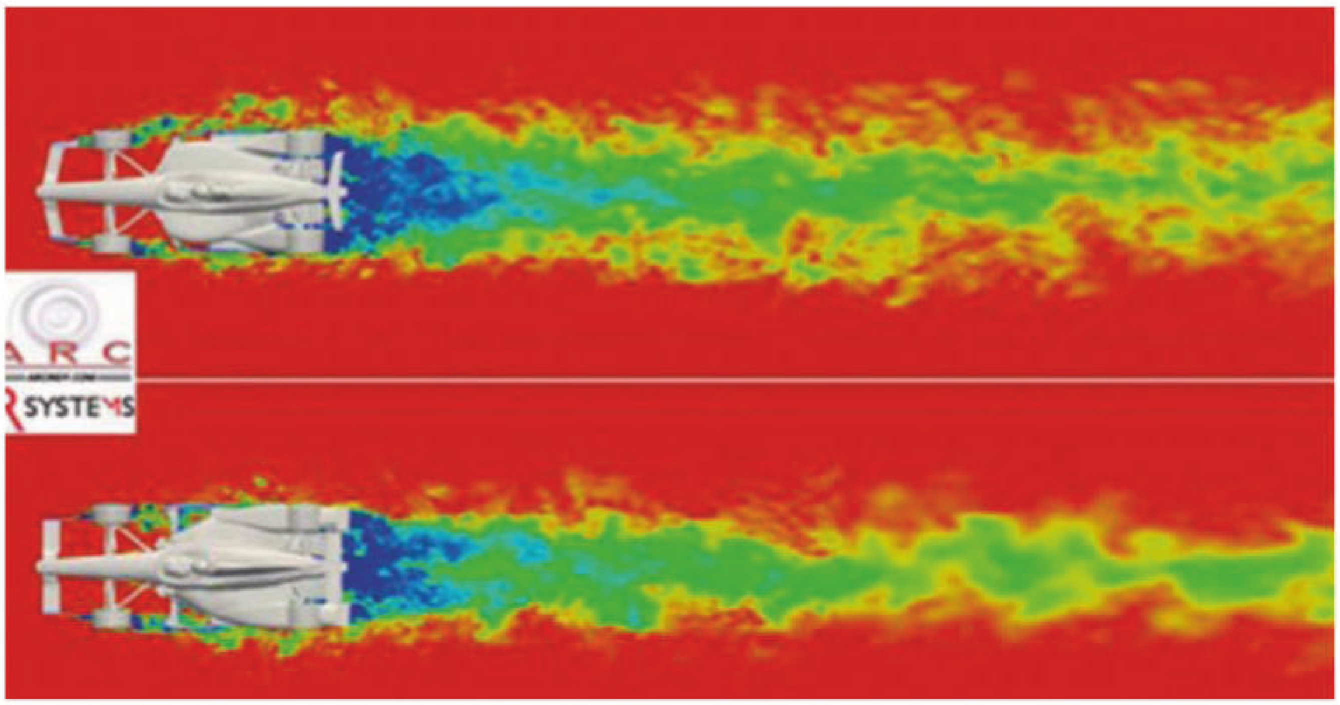

Figure 6: Larger wake with UAK18 (top) compared to previous cars (bottom) shows how wheel guards narrowed the effect

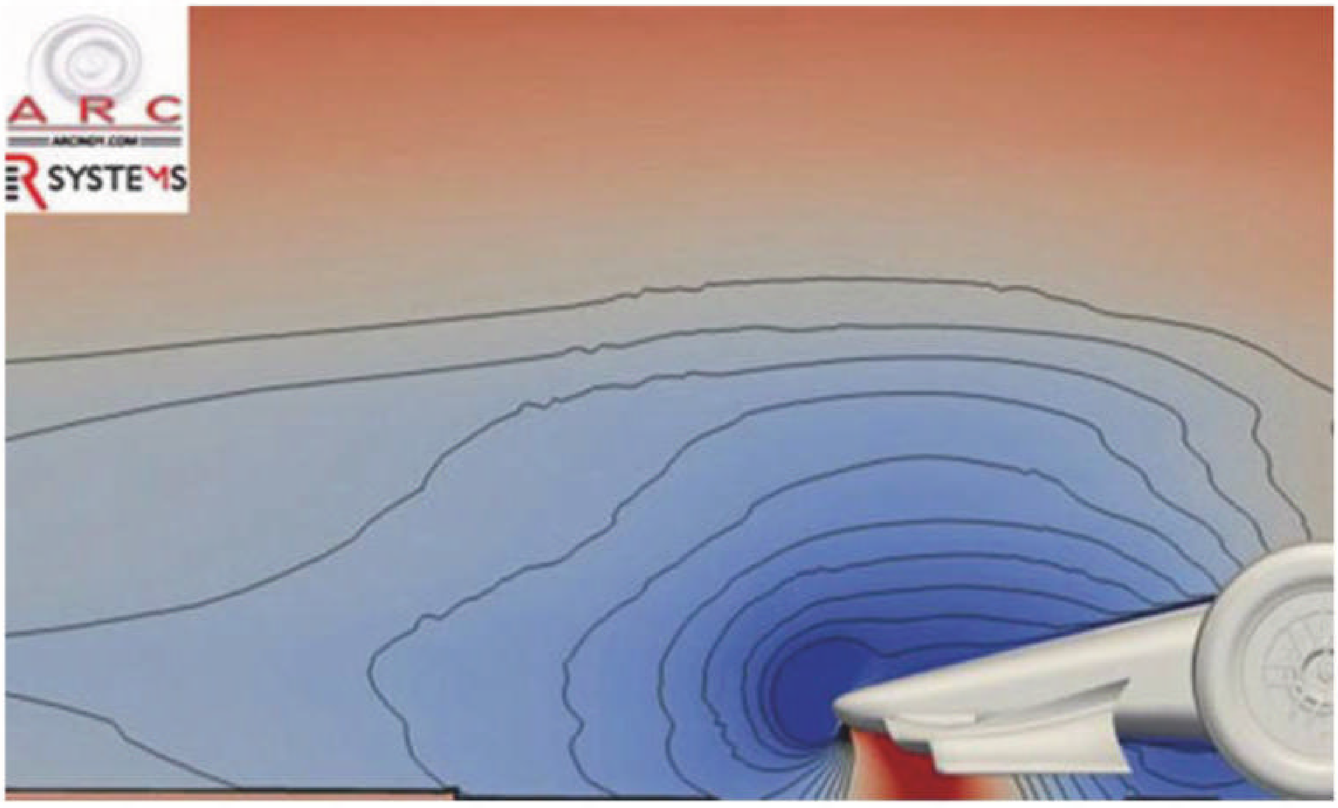

Figure 7: The velocity gradient boundary layer on the ground results in higher velocities for the underfloor than the wing

Frontal assault

While we have seen how the design of the rear of the leading car can have a big impact on the size of the wake in general, there is a lot more to examine in the front end of the following car, and again CFD can help where intuition fails.

Looking in detail at the velocity distribution of the wake, some general conclusions can be drawn. As expected, the wake effect is strongest in the centre. A simple rule of thumb for designing for good traffic performance is to put the large, bluff components that create a lot of drag in this region, and move your downforce generation as far to the sides as possible. Of course, the biggest drag components in open-wheel racing are the wheels themselves which are always going to be exposed. Using front wing end-plate design to partially shield the wheels means sacrificing the best location for making downforce. Similarly, the underfloor is a strong downforce-generating component, but is not in the best location.

However, the lowest parts of the underfloor are close enough to the ground to benefit from higher air velocities than might be expected due to the wake boundary layer (**Figure 7**). In fact, this higher energy layer of air is crucial to understanding how the different kits perform within this gap. In typical configurations, wings suffer more than the underfloor in the wake.

The main components determining the balance of downforce are the front and rear wings, and the underfloor. Looking at the UAK18 car compared to previous years, one of the objectives was to reduce the complexity of the wings. This resulted in less downforce being generated by them, and so more work was done by the floor. When taking the wake effects into account, this effect is magnified and the floor begins to dominate the overall balance.

The UAK18 bodykit experienced a bigger reduction in both drag and downforce than previous years, implying a bigger wake effect

Wing system

Although it is tempting to think that a loss in front balance is due to the front wing being more exposed to the wake than the rear wing, calculation of the wing forces show that both wings lose proportionally the same amount of downforce (18 per cent) – the overall ratio of front to rear is unchanged. The rearwards shift in balance was due to the increased prominence of the underfloor which only loses 13 per cent of its downforce. The wings can be considered to be a single system that is biased towards the front, while the floor is biased towards the rear.

Since the wake weakens the wings more than the floor, the overall balance shifts rearwards. This was a big challenge at last year's Indy 500 as many teams were already at the limit of front wing adjustability and struggled to compensate for this loss in front downforce.

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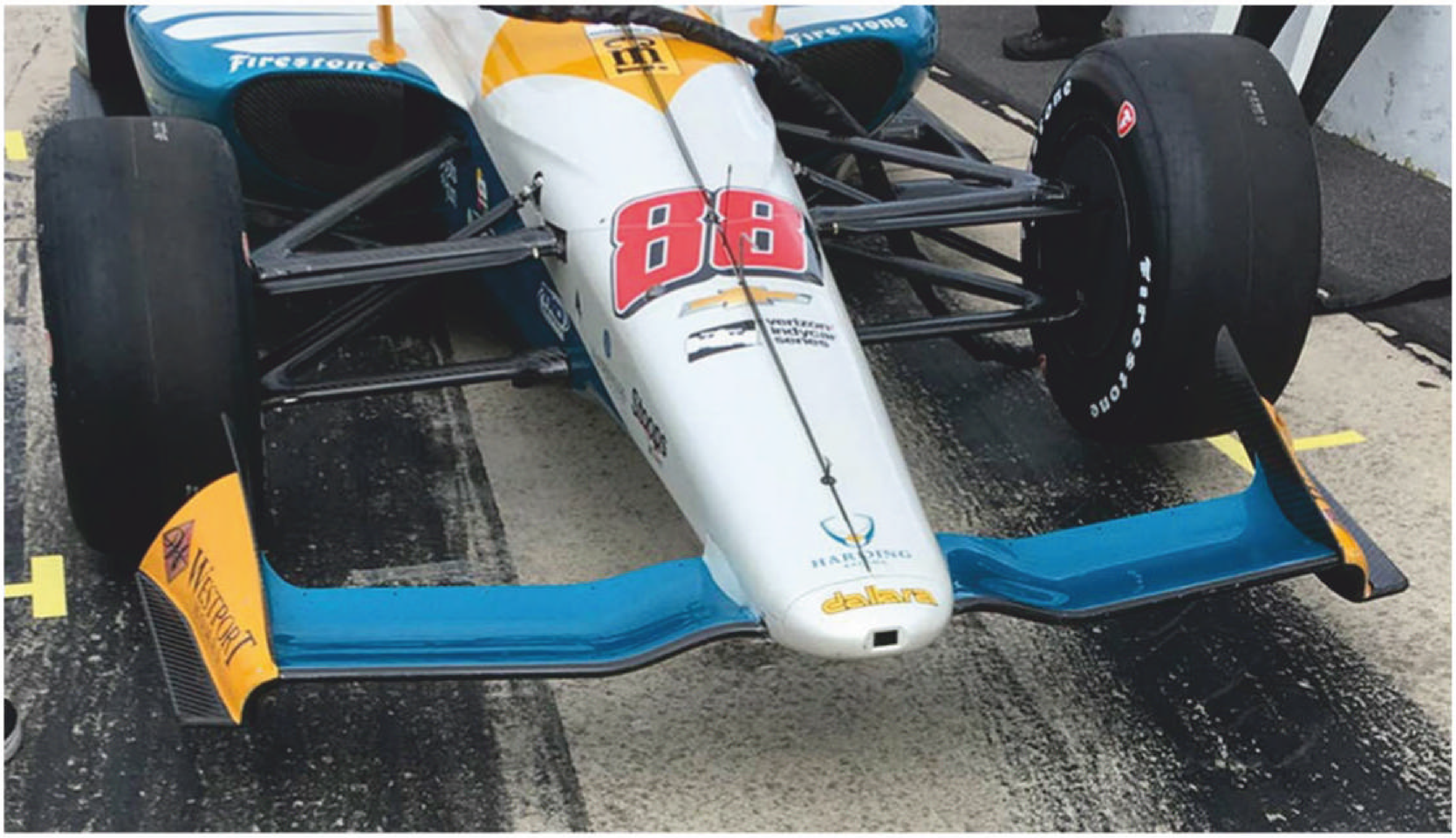

The UAK18 wing was less complex than those on the 2017 aerokits. One effect was that more air reached the floor, which was biased towards the rear, and this led to an imbalance

Some of the changes being considered are intended to tackle this very issue. One option being explored is to increase the surface of the floor at the front end to make the underfloor balance neutral. Other possibilities involve changes to the front wing to increase the downforce generated at the outer ends so that the wing suffers less of a wake effect.

Caution is required when implementing these changes, though, as they themselves will change the shape of the wake when implemented on the leading car so many iterations are needed to find a solution that actually delivers the targeted improvement. But with a good understanding of what is needed, and with the tools to evaluate the changes in detail, progress is being made.

Passing comments

Of course, allowing the cars to follow closely is only one part of the puzzle. Actually passing another car is a different matter, and it is not uncommon to see cars pulling alongside before having to drop back. Often the cars are alongside in the corner, where handling is even more important to avoid understeering right into the other car or off track.

Any change to the design to get the cars racing closer together has to also allow them to overtake and to evaluate this the remaining points of the passing trajectory are also run (**Figure 8**). Again, the effect on performance of the following car in these positions can be understood through examining both the wake structure from the back of the leading car and the front end design of the chaser.

Looking at the wake in Figure 8, when the cars are only 5m apart some of the same conclusions can be made as before, but there is much more structure to the flow that creates additional effects. In general, the flow in the centre is rising in the upwash of the diffuser, while to each side the air is pulled down as it passes over the rear wheels. This variation in flow angle not only has a dramatic effect on the following car as it closes within 20m, but has a different effect every fraction of a second

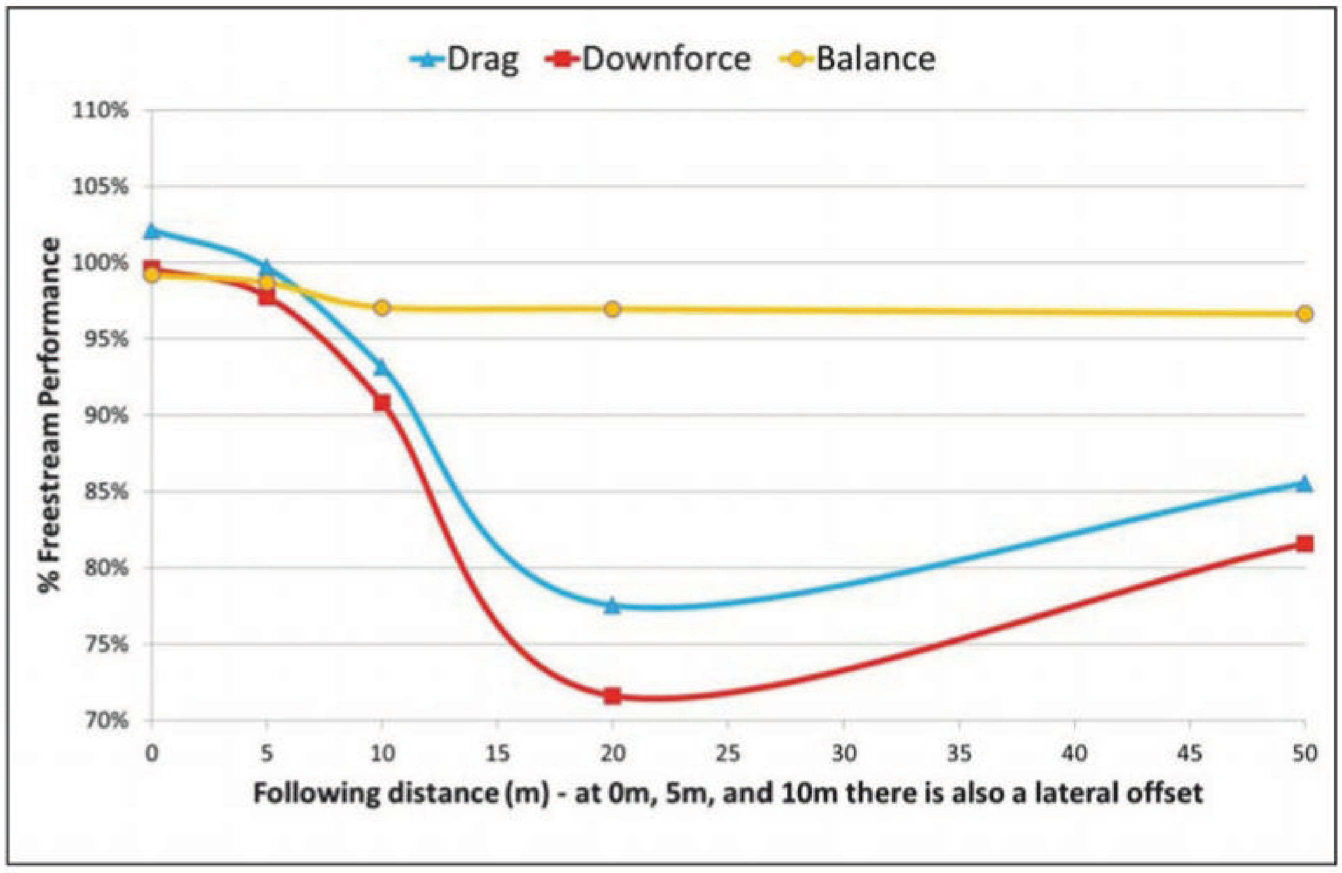

Figure 8: This shows relative performance at different points during an overtaking manoeuvre with the UAK18 IndyCar

Each section of the wing may respond differently, creating more or less downforce and influencing flow over the car in an unpredictable manner

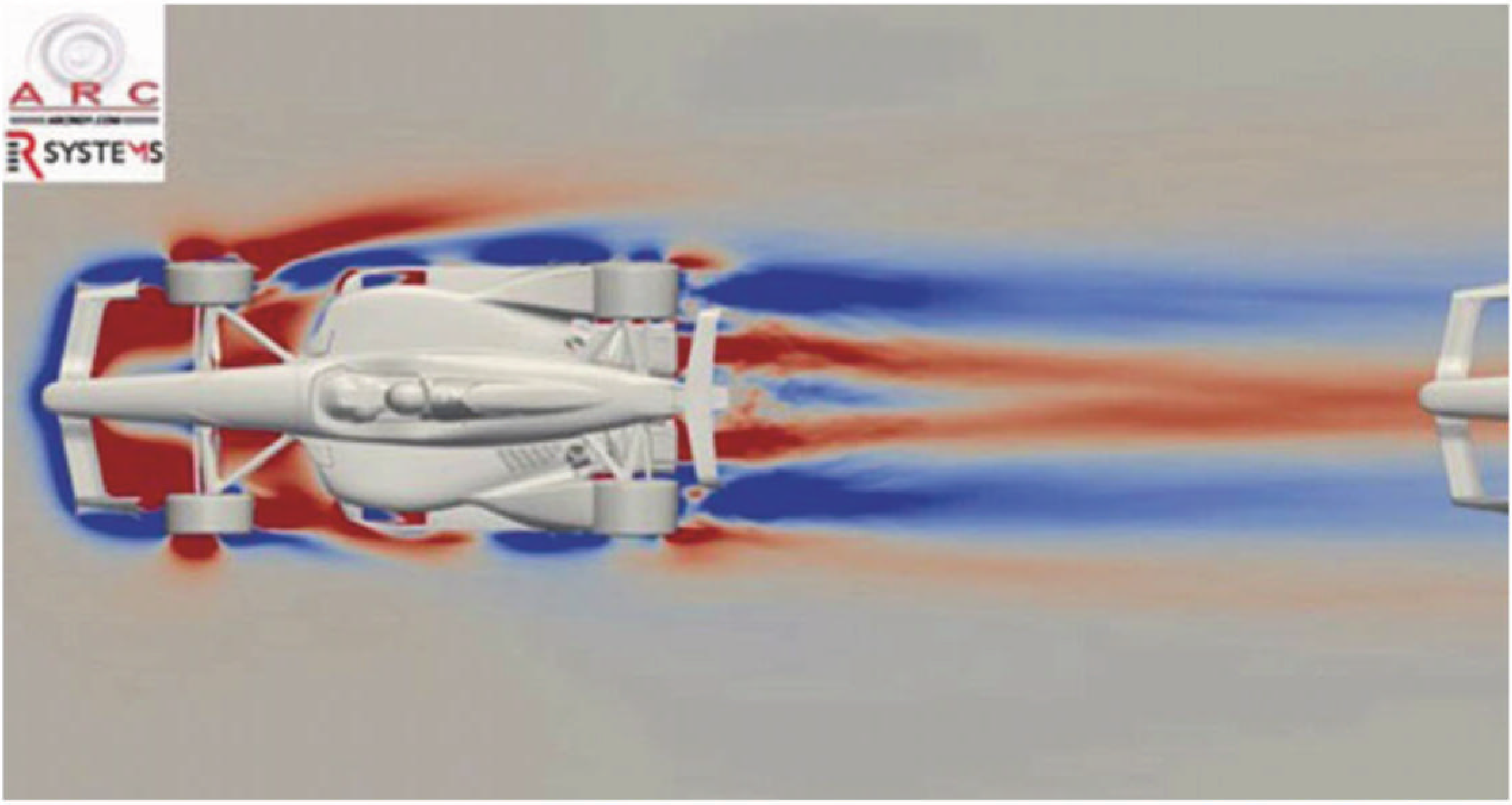

Figure 9: Wake behind the UAK18. Red is upwash, blue downwash. The centre of the following car's wing sees less angle due to the wake, but outboard sections see a higher angle

as the racecar starts to pull out. To understand this requires both a basic and detailed understanding of the front wing loading.

The downforce generated by wing elements depends on the angle of attack – the angle of the air flow relative to the wing. Downforce grows as this angle increases up to the point where the wing stalls. As seen in **Figure 9**, the centre of the wing sees less angle due to the wake but the outboard sections see a higher angle – so long as the racecar remains directly behind. So part of the wing will create less downforce while other parts create more – unless those parts are set up at a critical angle and the additional downwash off the tyres causes them to stall instead.

Figure 10: The centre of the front wing may be partially stalled, and here the flow beneath it does show regions of near stall

Stalling tactics

Similarly, the centre of the wing may already be partially stalled in normal running (see **Figure 10**) and the reduced flow angle from the upwash of the diffuser may actually improve performance. Each section of the wing may respond differently, creating more or less downforce and influencing the flow over the rest of the racecar in an unpredictable manner. Trying to account for this during set up with the typical tools available to the teams would be extremely challenging. Managing it correctly with a split-second change in a pit stop is almost impossible. And then the car has to move.

All of the above considerations of the effect of flow angle on different parts of the wing, whether it is better or worse than its normal operating point, and the knock-on effects in feeding the floor and directing flow past the wheels, need to be re-evaluated as the driver moves sideways. The centre section of the wing passes quickly from the diffuser upwash into the downwash of the wheel. One end of the wing starts to move from the downwash into clear air, while the other moves into the central upwash, before going into the downwash of the second wheel but this time with no counter-balancing effect on the rest of the wing.

Even in this simplified passing scenario, the variables keep mounting up, and trying to predict the effect of set-up changes or new designs on the handling for each of these cars really does require the kind of intensive effort and resources being put to the task.

While this study cannot cover every eventuality, it can help avoid some unintended consequences and provide insight to drive future development in the right direction. The next steps involve considering more complex passing scenarios, the effect of cornering and dynamic car behaviour, as well as extending it to short oval and road course configurations. Every new discovery opens up a world of exploration, with terabytes of more data to process. It is a constantly moving target, but IndyCar is getting in position to close the gap.

Allowing the racecars to follow closely is only one part of the puzzle, actually passing another car is a different matter entirely


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Stratospheric strategy for 3D firm Stratasys

How a 3D printer company is making its mark at the highest levels of the sport

By RACECAR STAFF

Reflecting 3D printing technology's increasing ability to enable top level race teams to accelerate design iterations, workflows and final part production, Andretti Autosport has just announced a new collaboration agreement with global 3D printing leader, Stratasys – one of a number of top-line motorsport partnerships the company has now entered in to.

A recognised performer in IndyCar, Indy Lights, rallycross and Formula E, Andretti Autosport expects to leverage Stratasys' advanced FDM technology and materials to accelerate design and development of its diverse racing platforms. One of the most established types of 3D printing technologies available, Stratasys FDM is recognised as being particularly suitable for use with production-grade thermoplastic materials to build strong, durable and dimensionally stable parts.

'We have been looking for the right partner to add 3D capability to our design and development activities for a while now,' Andretti Autosport COO Rob Edwards says. 'We couldn't be more thrilled to establish a relationship with the industry leader, Stratasys. Since the machines were commissioned, they have been operating at capacity and we look forward to seeing the benefits of our expanded capability on the race track throughout 2019.'

IndyCar team owner Michael Andretti (centre) has entered into a technical collaboration with Stratasys

Cutting edge

Leveraging the technology with the objective to become significantly more competitive on the track, Andretti will advance both design and production cycles using both the Stratasys F370 and Fortus 450mc 3D printers.

Pat Carey, senior vice president at Stratasys, says of the partnership: 'We are excited to join the Andretti Autosport family and look forward to working together in the coming years.'

In recognising that Stratasys' FDM solutions are being increasingly adopted by the world's top teams and manufacturers, Carey explained that the company's engineering grade printers and wide choice of high-performance materials are the perfect fit for the extreme challenges faced by its customers in this sector.

The agreement with Andretti Autosport follows similar partnerships that Stratasys has already established with other leading race teams. For example, in the UK, the company is the official supplier of 3D printing solutions to the McLaren Formula 1 team. To support McLaren Racing's goal of accelerating design modifications and reducing weight to increase performance, the team uses FDM and PolyJet-based 3D printing solutions and materials for visual and functional prototyping, production tooling and customised race-ready final parts.

'By expanding the use of Stratasys 3D printing in our manufacturing processes, including producing final car components, composite lay-up and sacrificial tools, cutting jigs, and more, we are decreasing our lead times while increasing part complexity,' says Neil Oatley, who is the design and development director at McLaren Racing.

Print on demand

To further accelerate design and manufacturing cycles, McLaren Racing now intends to takes Stratasys 3D printing technology trackside, enabling its Formula 1 race team to produce parts and tooling on demand.

Similarly, US motorsport powerhouse, Team Penske has also selected Stratasys as its official 3D Printing solutions partner. Under this agreement, Stratasys provides equipment and support services to assist Penske in its manufacturing efforts across its NASCAR and IndyCar racing platforms.

Busy season

As for Andretti Autosport, which is led by former race driver Michael Andretti, the operation expects to make significant strides in converting parts via in-house 3D printing.

Under the banners of Andretti Autosport, Andretti Rallycross and Andretti Formula E, the Indianapolis-based team fields multiple entries across the IndyCar Series, Indy Lights, the FIA Formula E Championship, the GT4 America Series and Americas Rallycross. Additionally, the team competes as Walkinshaw Andretti United in the Australian Supercars category through a partnership with Walkinshaw Racing and United Autosports.


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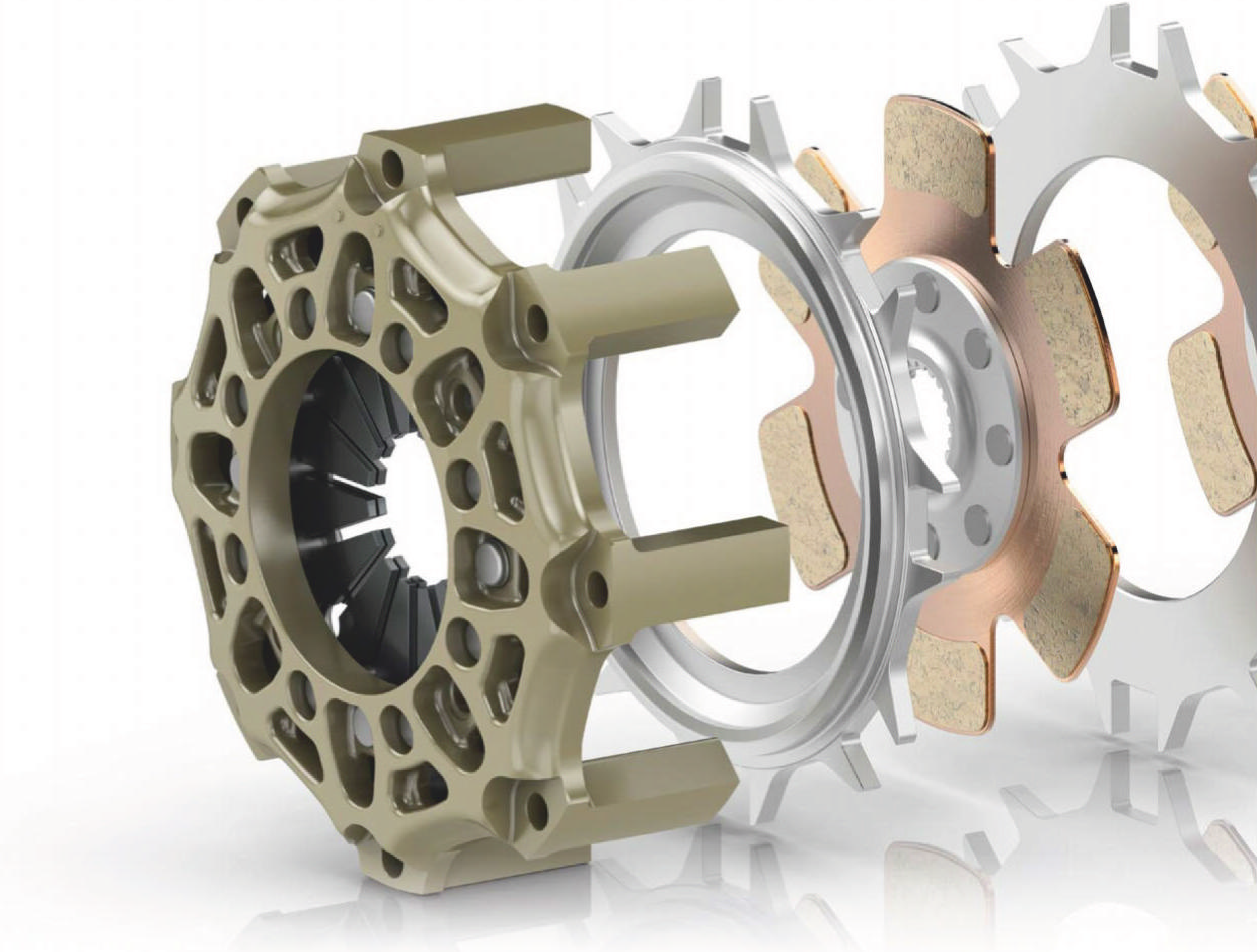
Biting points



Race clutch design and manufacture remains one of the most challenging fields in motorsport engineering, as *Racecar* discovered when we engaged with some of the leading companies in the sector

By GEMMA HATTON

Whenever we sit in our road cars we are faced with two large dials displaying the vehicle's speed and the engine speed (or the revs). Usually, unless you are trying to prove a point to the car next to you, or are on a race track, we very rarely accelerate the needle into the red zone near the rev limiter. This is because, despite internal combustion engines having a large range of operating speeds, there is only a very narrow window in which the engine can operate at its highest efficiency, where is it achieving the maximum output power for the minimum amount of fuel (brake specific fuel consumption, BSFC).

Therefore, a transmission is used to effectively vary the speed of the driven wheels, to ensure that the engine is always operating within that efficiency band as the vehicle accelerates or decelerates. So when you accelerate, you are demanding more torque from the engine so the revs increase up to a point where you change to a higher gear and the revs drop back down before gradually increasing up through the rev range once again.

In a manual transmission, to enable a smooth transition between the gear changes, the flow of torque from the engine to the transmission has to be disconnected. Of course, it is not practical to turn the engine off every time you want to make a gear change. Therefore, a clutch is used to transfer the torque from the powerplant to the gearbox, and this can also be used to disconnect the engine from the gearbox during gear changes without having to turn off the engine.

The make-up of a modern clutch. From left to right: clutch housing or clutch cover, diaphragm spring, pressure plate, driven (or friction) plate, intermediate pressure plate, followed by a series of driven and intermediate pressure plates, all combining to form a four-plate clutch

'When the friction surfaces are working they create extremely high temperatures, around 800degC with carbon clutches'

A clutch is also necessary to get a car in motion. When you turn your keys in the ignition, the engine starts to tick over and after an initial increase in revs it will settle down at idle. The engine is providing a small amount of torque, but the transmission is stationary. The torque of the engine can't be stopped or decreased below idle otherwise it will stall, so to increase the torque of the transmission up to that of the engine, the clutch needs to slip. This is essentially a balancing act between the clutch pedal and the throttle pedal where the clutch starts to engage, or bite, up until when the clutch is fully engaged and the speeds of the engine and the transmission are matched.

To achieve this, a clutch is made of several parts. Firstly, there is a clutch disc, also known as a driven plate (friction plate) which, as the name suggests, is coated with a high friction material. This disc sits on a flywheel and when an external force is applied, the friction between the two results in the friction plate rotating at the same speed as the flywheel. To apply this external force, a diaphragm spring is used which exerts the necessary force on to the driven plate via a pressure plate. The input shaft of the transmission is splined to the driven plate, and so this is how the clutch transmits the torque from the engine to the transmission, and under this condition the clutch is engaged.

Spring time

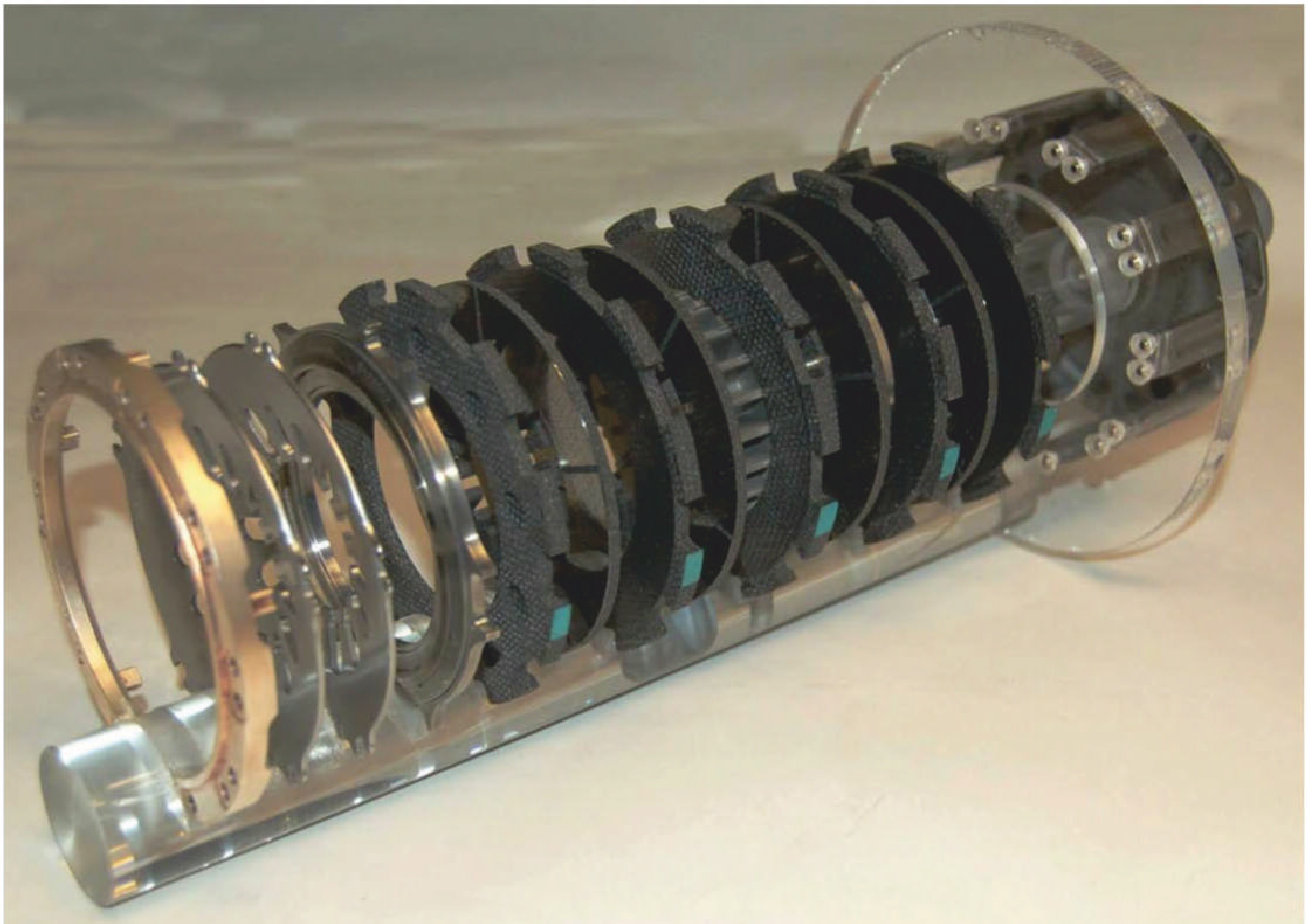
However, to enable the clutch to disengage, a diaphragm spring is incorporated between the clutch cover and the pressure plate. Diaphragm springs are circular steel discs that have a hole in the centre. The inner portion of the disc consists of a series of radial slots, which essentially creates a set of actuating fingers. When a force is applied to these fingers, the outer section of the spring moves in the opposite direction. This spring lies between the pressure plate and the clutch cover and as the cover is fastened, the diaphragm spring is slightly flattened, and therefore loaded, exerting a force onto the pressure plate, which is then transmitted to the friction disc. When the fingers of the inner portion of the spring are pushed inwards, the outer portion of the spring reacts in the opposite direction, moving the pressure plate away from the friction disc, removing the external force and disengaging the clutch.

This is exactly what happens when the clutch pedal is pressed. A hydraulic system is used to translate the movement of the clutch pedal to the centre of the diaphragm spring. So when you press the clutch pedal, the centre of the diaphragm spring moves inwards, the outside of the diaphragm spring moves outwards, removing the load from the pressure plate, which disconnects the drive from the flywheel. When you release the pedal, the centre of the diaphragm spring moves back outwards, the outside of the diaphragm spring moves inwards, re-applying load via the pressure plate and thereby connecting the driven plate back to the flywheel, resuming drive.

Science friction

'A clutch is actually very simple to explain in principle, the complications come in the details,' says Marco Trautmann, at ZF Race Engineering. 'On one side you have a diaphragm spring within the pressure plate which basically creates the clamp load. The work is done by the friction stack which is in the middle and on the other side you have the flywheel. If the car is standing still the flywheel on the engine side is rotating and the clutch discs on the gearbox input shaft are static so as you engage the clutch, the surface of the pressure plate which is in the clutch cover, contacts the friction stack and this is pushed towards the flywheel and the friction between the three transmits torque from the engine to the gearbox.'

In F1 the switch to V6 turbos in 2014 increased engine torque, so to cope with this higher torque capacity clutches went from three-plate to four- or five-plate. The four-plate F1 clutch is shown above and in exploded view below



'There is a new group of materials in town when it comes to clutches, and these are the sintered ceramic materials'

So those are the basic working principles of a clutch, but as ever in engineering it is not quite as simple as that, because there is a wide array of options for each of the clutch components. Furthermore, a clutch can consist of more than just one friction plate.

'In the 1960s and 1970s the more powerful the engine, the larger the clutch diameter, which is defined as the diameter of the friction plate,' explains Jon Grant, who is chief engineer in the race department of AP Racing. 'But where do you go from there? To cope with the increased power of the engines, you would end up with a massive clutch. So instead, you can go for a twin plate clutch, and drop the diameter size down. Essentially, for a given plate diameter and a given applied load you just multiply to get the torque capacity. So, if you have a single plate that transmits 200Nm of torque, then a twin plate will be capable of transmitting 400Nm before it starts to slip.

'In Formula 1, teams ran triple plate clutches for many years and the evolution of these clutches was relatively stable until the V6 turbocharged engines were introduced in 2014,' Grant adds. 'As max rpm decreased, torque increased and so did the vibrations. Therefore, the clutch needed more torque capacity but the previous issues relating to high engine speeds were gone because the regulations now limit the engines to 15,000rpm and, in reality, teams don't usually go above 12,000rpm. Whereas prior to 2014, the engines were running at over 20,000rpm, overall, this triggered the switch from three-plate to five-plate clutches.'

Hot plates

In a single plate clutch, the diaphragm spring presses on a pressure plate which clamps the driven plate to the flywheel. Whereas, in a five-plate carbon clutch there are five driven plates with six intermediate pressure plates that sit in between and at either end. These driven plates can either be circular or paddle-type and be made of a variety of materials such as organic, carbon, Kevlar, ceramic and iron.

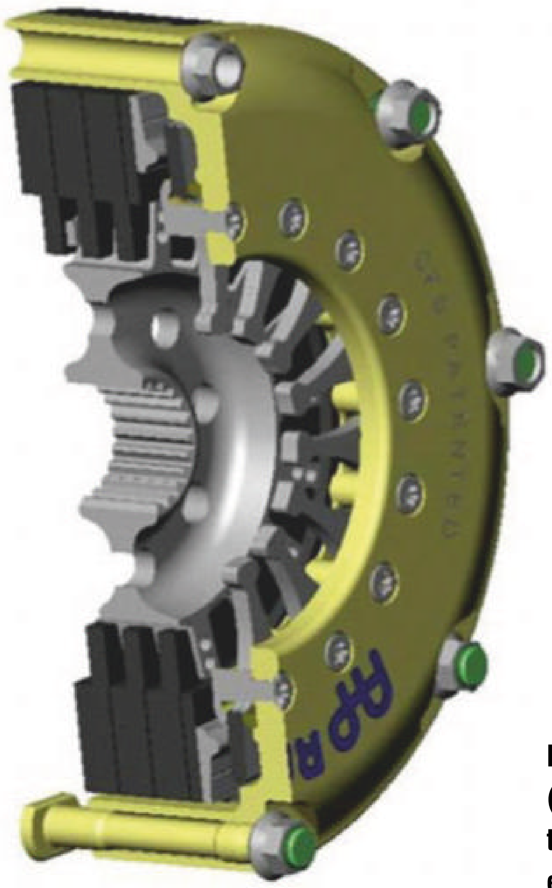
'Carbon materials were introduced in the late 1980s, because they can withstand higher energies and temperatures without distorting, unlike steel. They are also very lightweight, but expensive,' Grant says. 'So they became the choice for pretty much all the categories, as long as the regulations allowed them and the teams had the necessary budgets for them. But there is a new group of materials in town which are the sintered ceramic materials. This is a hybrid of ceramic friction plates interposed with more conventional sintered bronze materials on a steel plate. The advantage of this is the wear rate is much lower.'

Interestingly, carbon clutches were first introduced into the world of rallying due to the high energies, but then to control costs were later banned by the regulations. Consequently, AP has had to develop the technology of the older, more conventional type clutches to cope with the high performance of modern rally cars.

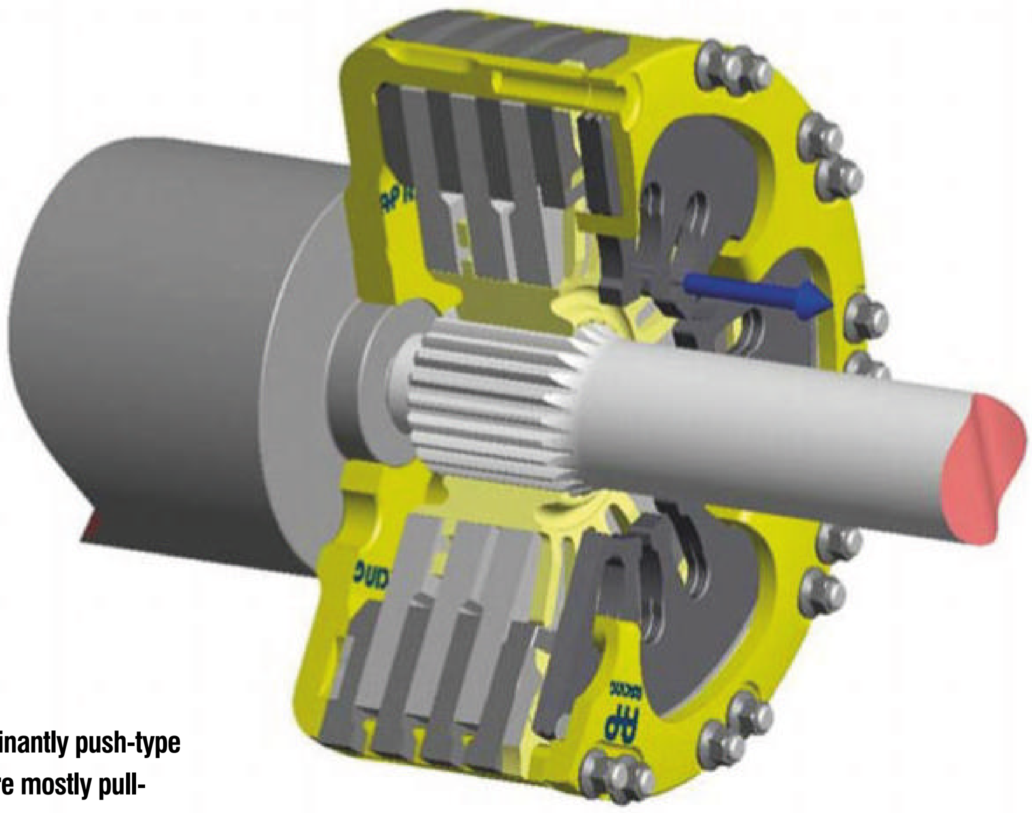
Another differentiator between clutches is whether the driven plates are sprung or unsprung. The former utilises coil springs that are radially positioned around the centre of the friction plate. Also, the friction plates can either be solid or constructed from two friction plates that are combined together, with leaf springs in between them. Both the coil and leaf spring arrangements combine to help minimise torsional vibrations and shocks as well as enable smooth engagement, and these are therefore heavily utilised in road car clutches.

While driver comfort is not such a factor in racing the engagement of the clutch does needs to be precisely controlled during race starts and pit exits. Therefore, having spring elements integrated into race clutches, just like

The coil springs can be seen clearly on both the driven and pressure plates of this clutch. These springs help to minimise torsional vibrations as the plates start to engage



Road car clutches are predominantly push-type (left) whereas race clutches are mostly pull-type (right). The latter are 20 per cent more efficient, but fitting them into a car can be tricky



AP Racing has supplied clutches to the entire F1 grid, and each one utilises cushioning technology tuned to specific requirements

they are in road clutches, is necessary. However, AP racing developed this a step further with its patented cushioning technology.

'Essentially, what we did was take a standard clutch with a diaphragm spring and the drive driven plate which has a spring element in, and moved that spring element into the clutch exactly where we wanted it. This has given us the controllability in a race clutch that you would normally only ever see in a road car clutch,' explains Ian Nash, technical sales manager at AP Racing. 'When you engage, the spring elements give you another level of finite control with lower rate of load rise compared to what the diaphragm spring can provide alone. In this way, we can carefully control the low torque area of the engagement to avoid wheelspin and ensure that the car gets away with the most efficient start possible.'

This cushioning design was originally developed for a touring car in 1995, but was dramatically downsized and re-engineered to be integrated into the smaller diameter multi-plate clutches of F1. Over recent years, AP Racing has supplied clutches to the entire F1 grid, and each one utilises this cushioning technology tuned to specific requirements.

'The other thing that really helps the engagement controllability is the friction material,' says Grant. 'In terms of priority, what the customer generally wants first is a repeatable material. So however the material behaves with increasing temperature, it does the same thing every time. Then ideally you would like that friction behaviour to be at a linear rate of friction rise or decay. Unfortunately, not all materials are linear and therefore certainly not repeatable because the level of friction is very dependent on surface temperature. Measuring this surface temperature is extremely difficult, but F1 teams will have infrared sensors measuring the outside diameter of the plates, which gives a general bulk temperature measurement. Some materials work much better at higher temperatures so often on the formation lap you will see the Formula 1 cars completing practice launches, or clutch scrubs, to try and get the temperatures up into that range.'

Heat and dust

With temperature such a persistent by-product of friction a clutch needs to be designed to allow heat to escape. This can be done using vents or active fans. However, in categories such as rallying or on the Dakar leaving the clutch open to the elements can cause far worse issues than overheating. 'You need to protect the clutch from all the dirt coming in because that can affect the friction surfaces and therefore the coefficient of friction in an unpredictable manner, which can lead the clutch to slip,' says Trautmann. 'At the same time if you put too much protection around the clutch, it won't be able to get rid of the heat. The moment the clutch is engaged, the friction surfaces are working, creating extremely high temperatures, around 800degC on carbon clutches. If that heat cannot escape then it could damage other components within the clutch.

'You also need to consider wear,' Trautmann continues. 'Every clutch has a specific wear range and after that the torque cannot be transmitted because it is out of the range of the diaphragm spring. This leads to microslip, which can be a few degrees of rotation or a complete rotation depending on how high the torque peaks are during engagement. This increases the wear further, generating more heat which in turn increases wear. You can end up with an exponential destruction of the clutch.'

Conventional clutches are called 'push-type'. This is where the release bearing pushes against the inner portion of the diaphragm spring towards the flywheel which then results in the outer section of the spring reacting and pulling the driven plates away from the flywheel and releasing clutch pressure, as explained earlier. However, 'pull-type' clutches are much more efficient, allowing benefits in terms of clamping and release loads or wear capacity, which can amount to, approximately, a 20 per cent improvement. A pull-type is where the release bearing fulcrum is actually inside the clutch and pulls the diaphragm spring fingers to disengage the clutch.

'In a pull-type, the diaphragm springs are inverted, hence the requirement to pull the fingers to disengage. In this case the outer diameter of the diaphragm spring reacts against the fulcrum inside the clutch cover, with the pressure plate fulcrum inboard of this,'

Clutch control: Each and every carbon clutch that AP Racing has manufactured for motorsport applications has been tested on a rig to gather data on its particular characteristics

explains Grant. 'This is more efficient for three reasons; firstly because the fulcrum ratio [which determines the mechanical advantage achieved by the fingers of the diaphragms spring] is greater with a pull-type configuration, hence the load required to disengage a given clutch spec is lower. Secondly, the frictional losses within the clutch are lower, as the load is always reacted against the clutch cover in the same direction, unlike a push-type configuration where the direction of the load reacted to the clutch cover reverses during disengagement, requiring two fulcrums [one either side of the spring]. The gap between those fulcrums is only correct when the spring is flat; when the spring is at a conical attitude, it forces the fulcrums apart, which results in an increase in hysteresis. On a conventional car you are unlikely to ever notice this hysteresis, but because of the servo-hydraulic fly-by-wire control system used in the Formula 1 cars, when the closed loop control wants to adjust the clamp load, any hysteresis will result in the control system struggling to know what to do because it is trying to find the right load, but it can't.'

'Thirdly, with the cover fulcrum near the outside diameter of the spring and near the cover fixing there is very little cover deflection from the clamp load of the clutch and when the clutch is released and no load reversal,' Grant adds. 'In contrast a push-type has significant deflection with the fulcrum positioned further inboard and load reversal from clamp load to release load is a significant inefficiency.'

Tight fit

The disadvantage of pull-type clutches is the fact that to actuate them the slave cylinder needs to be connected to a release fulcrum, which is inside the clutch spring fingers, which can be difficult to achieve in categories of racing where the installations are designed for a push-type. Therefore, AP Racing had to design a way of connecting up to the clutch whilst getting behind the spring to be able to put it all within a conventional gearbox and engine set-up.

'Because you are not just applying load to the diaphragm spring as you would in a push-type, you have to be able to hook up and pull the diaphragm spring in a pull-type,' Grant says. 'So our solution was to have the release mechanism not in the gearbox, but bolted on to the back of an engine in a three or four legged arrangement. So you put the clutch on, then the gearbox over the top, and it is only the spline that needs to connect up.'

As with most aspects of motor racing, the future of clutches is uncertain. With electrification on the horizon, clutches may no longer be needed in the future. 'It is a very interesting time, at the moment we need to focus on R&D,' Trautmann says. 'We believe that electrification will not take over everything, and next to electric vehicles will be the introduction of alternative fuels such as hydrogen and gas, which will power engines and therefore require a clutch. We may also discover areas in the future that may need a clutch that we haven't thought of yet. Also, if you electrify everything then race starts will simply be computer controlled, so every car will start the same and the magic of a race start will disappear. If racing is going to be predictable then no one is going to watch it, and if no one is watching then what is the point of going racing?'

Electric avenue

Could the key to the motorsport industry's future be found in the consumer electronics sector? The MIA's US (west) development director visited the CES trade show in Las Vegas to find out

By DON TAYLOR

There's one question that's asked ever more frequently in motorsport circles these days: 'What is the future of racing?' Many regular readers of *Racecar Engineering* may wonder where racing technology is going in order to entertain their armchair intellectual curiosity, but it's a more critical question for those readers with current, or future, careers in motorsport.

We have all seen that TV and live audience numbers are declining internationally for a number of the major racing series. We are told that the inevitable age of the autonomous vehicle (AV) as an appliance for transportation lies just around the corner, and that the younger generation has little interest in car ownership and driving. Are we simply at the twilight of the glorious golden age of the automobile, and auto racing? Or are we headed for the most exciting time ever in motorsport, boosted by a Hogwarts-full of magical technologies?

Current thinking

Faced with these concerns, many have been offering opinions. But when predicting the future in times of upheaval the road ahead is never clear. There are bits and pieces of what might be in store, but chances are that this time the answer won't be 'more of the same'. With that in mind, I thought I'd look for hints of motor racing's future behind a different curtain. And so I roamed the floors of the 2019 CES (formerly known as the Consumer Electronics Show) in Las Vegas for some signs of our possible future.

Why would I look there? The trade-only CES is an annual celebration of the newest tech in TVs, cameras, domestic robots, and automatic pet feeders, dating back to 1967. Most recently the show has included digital assistants (robots), IOT (internet of things) devices, and passenger drones. In its last several iterations CES has also become such an important motor show that at least 10 car manufacturers plus numerous automobile supplier companies felt compelled to be there with a major presence.

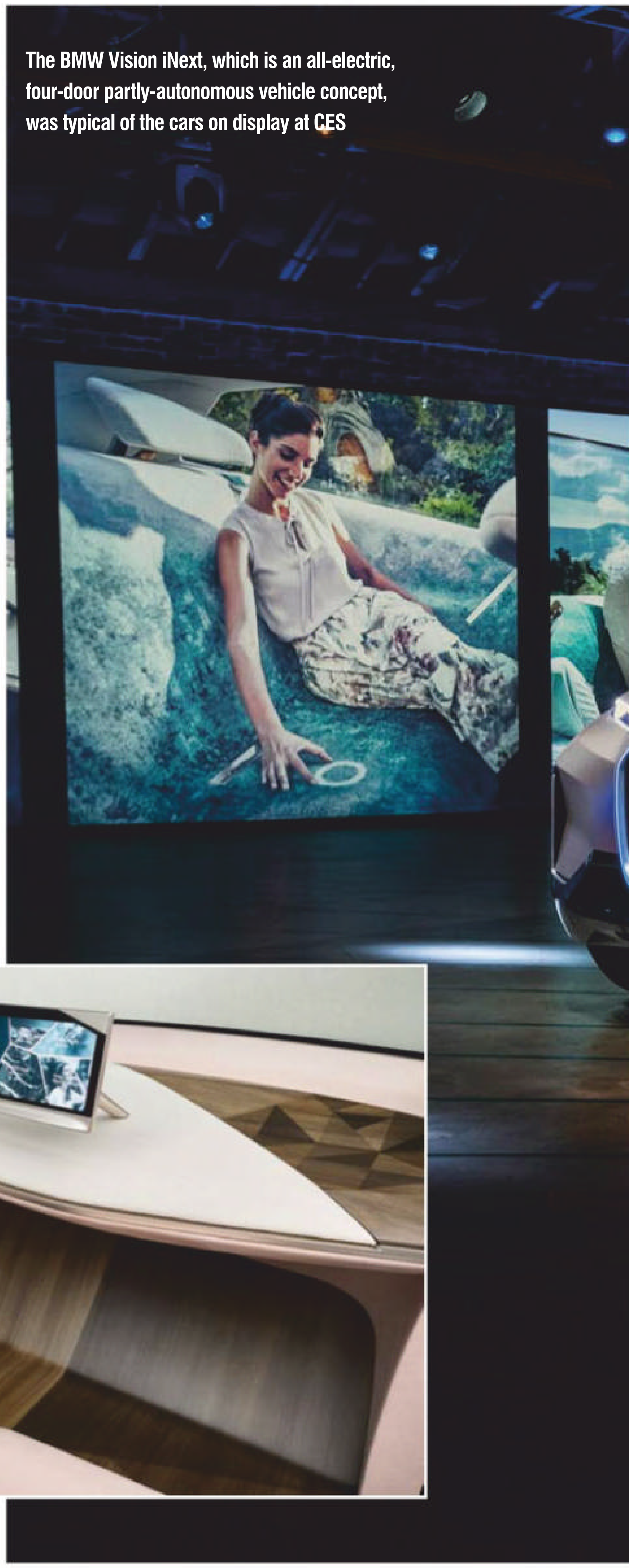
Unlike public motor shows, where the focus is on the current iron the car makers need to sell, here they show what they are developing in order to survive in the next decade or two. They are there to reassure the world, and to make deals with digital tech partners to help achieve their vision. Audi, BMW, and Mercedes see CES as more important for them than the concurrently timed North American Auto Show in Detroit. All three bypass the latter entirely.

I suspected that what these brands showed at CES as their future direction might also give us some inkling of their future engagement with racing. Also, keep in mind that the auto manufacturers have traditionally brought big marketing dollars and engineering resources to the sport in order to demonstrate their technical prowess and to reinforce their marketing position. Think of the mighty F1 and Le Mans conquering exercises by Mercedes, Porsche, BMW, Audi, Jaguar, Aston Martin, Renault, Toyota, Ford, and so many others.

So no doubt the future direction of car makers will be critical to the sport. But the fact that many are now calling themselves 'mobility companies' rather than car companies should get your attention. If all they plan to make are autonomous passenger-carrying capsules in the future, why would they go to Le Mans?

Show business

So, what exactly did I see and hear at the CES Show? Being a huge show with around 2.9 million square feet of exhibit space and more than 4500 exhibiting companies that touch



The BMW Vision iNext, which is an all-electric, four-door partly-autonomous vehicle concept, was typical of the cars on display at CES

The interior of BMW's INext features bamboo flooring and a minimalistic steering wheel every industry, there are fascinating diversions wherever you turn. However, I was there to stay on track, and focus on the automotive sector, and so first I headed for the BMW building.

The inside of the German manufacturer's structure was not decorated with reminders of the open roads where BMW's driving machines rule, but like a peaceful, green rain forest; a tranquil setting in the midst of which was its concept car, the Vision iNext, an all-electric, four door cross-over following on the heels of the i3, and i8. The first thing that caught my attention was the purple velour engulfed rear seats, with matching fuzzy door panels, intended for cosy passenger comfort. Okay, not what I expected, but what about the front seats and driver controls? I was pleased to at least see a steering wheel. Thank goodness. It can still be driven by humans. At least sometimes.

The iNext concept promises the choice of a driver-take-charge, 'Boost' mode, or an autonomous 'Ease' mode. BMW tells us: 'The windshield becomes an augmented-reality screen with information about the drive and surroundings' and as soon as the vehicle reaches a regulated autonomous vehicle highway, 'the BMW Intelligent Personal Assistant suggests that the vehicle take over driving from here and the journey continues autonomously.' In going to the Ease mode, we're told: 'The steering wheel and pedals disappear, creating an open and spacious feeling'. How relaxing, with that pesky steering wheel out of the way! But just how quickly is car control returned to the human in an emergency? Hmmm…

When it was visible, the meek looking, designer steering wheel, with no paddles, hardly looked like it was designed for take-charge driving. It made me ask whether BMW still uses the tagline, 'The Ultimate Driving Machine'. Well, guess what, they do, although with this vehicle, featuring bamboo floorboards,

it looks like they may be tilting more toward being 'the ultimate self-driving machine'. This may well indicate an internal debate about the future direction of the company.

Game theory

Moving on to Audi, I found that it had a similar concept car. Shown previously in Frankfurt, the Audi Aicon also features lots of get-comfortable and be-entertained features, with the car on the ready to take over the onerous chore of driving.

Getting more specific about that entertainment part of Audi's vision was their separate 'Immersive Experience' demonstrator vehicle. Audi's interior concept not only gives you a movie type experience with screens and audio, but the car can also move on its active suspension, vibrate the seats, and blow hot or cold wind in your face via the HVAC system. Peter Kunsch, head of advanced engineering, chassis, says: 'When all those systems are in perfect alignment, this package really delivers a complete new way to enjoy tech.'

The whole car becomes a racing game simulator. You control the steering, pedals, and shifting, as you 'feel any kerb you hit on the Nurburgring while racing, or hear and feel the specific rattle sound when you're driving rally routes,' Kunsch adds. I want to believe that the Audi race programme engineers' legwork in simulation and vehicle dynamics trickled down and was applied to help create this high-fidelity entertainment experience.

Just to be clear, all of this racing game action happens in the front seat only while the car is parked up, and not while it is travelling down the roads, where it would frighten other motorists as it leaps around like a kangaroo.

Next I took a look inside the big box black structures that housed sister-companies

Atelier Brueckner/Michael Jungblut

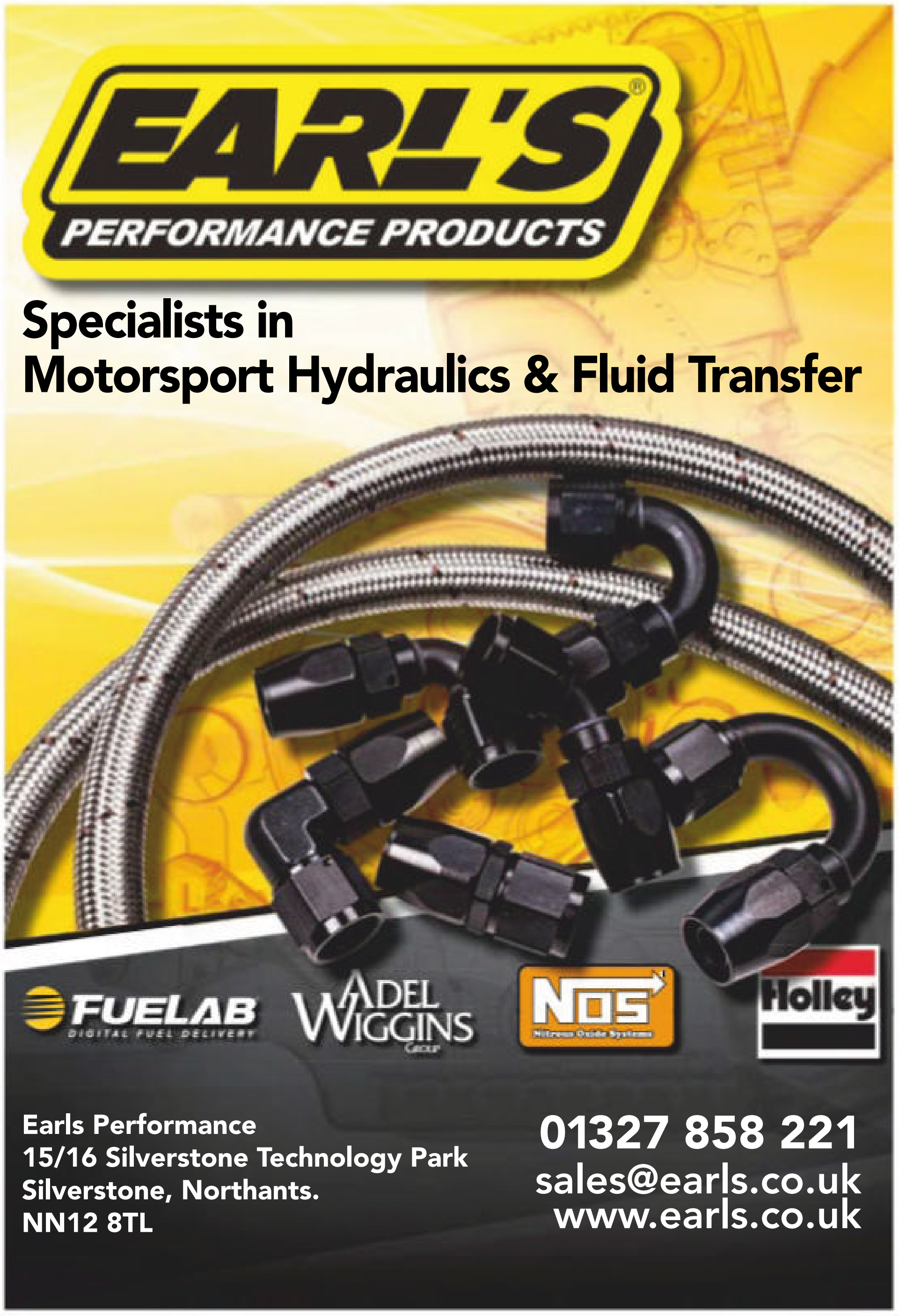
Hyundai's offering was entirely focussed on the interior of future vehicles, displayed in an array of transparent bubbles

CES has now become such an important motor show in its own right that at least 10 car manufacturers felt compelled to be there

Hyundai and KIA, and stepped into a total dream world. I had expected that with its commitment to WRC and the signing of Sebastien Loeb, plus the entertainment value of WRC video games to reach younger customers, you would think that would be an obvious thing to display. Well no, it wasn't. Instead, Hyundai featured the interior entertainment features of their future vision, and only the interiors, with the distracting 'car part' not shown at all (the 'car part' in this case being the body, wheels, or anything else you couldn't see from the interior anyway). That left you with a floating control panel, featuring 180 degrees of screens within a clear bubble hemisphere, and seats. Picture the Star Ship Enterprise Captain's station.

There were a half dozen of these glass orbs, all floating in a sea of glowing light, reminding one of *The Matrix*, the objective, apparently, being to give the passengers a virtual world

Kia showcased what it calls V-Touch technology, where your car 'reads your mind' via your gaze or a small movement of your finger tips. Could this tech ever be used in racing?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experience detached from the outside real world as they are whisked from place to place.

The display design was fantastic in setting a tone of this make-believe world to which we were supposed to escape. Sadly, there were no motor racing or human driving activities featured in this future scenario.

Kia aura

Hyundai's next-door neighbour, KIA, was ready to deliver the second blow of their one-two punch. It invited you to 'amplify your joy with emotive driving'. Basically, it is proposing to read your bio-signals while in transit, and adjust the interior environment to reduce your stress, increase your comfort, and numb your mind, taking it off that boring reality outside while being in transit from A to B. The sensors within their toaster-shaped, transport module are designed to automatically read your temperature, heart rate, blood pressure, track eye movement, and know what's good for you.

Even in this relaxed mental state, you'll still be in control because with their V-Touch technology, 'KIA is building a new era where your car reads your mind with just your gaze or a small movement of your finger tips'.

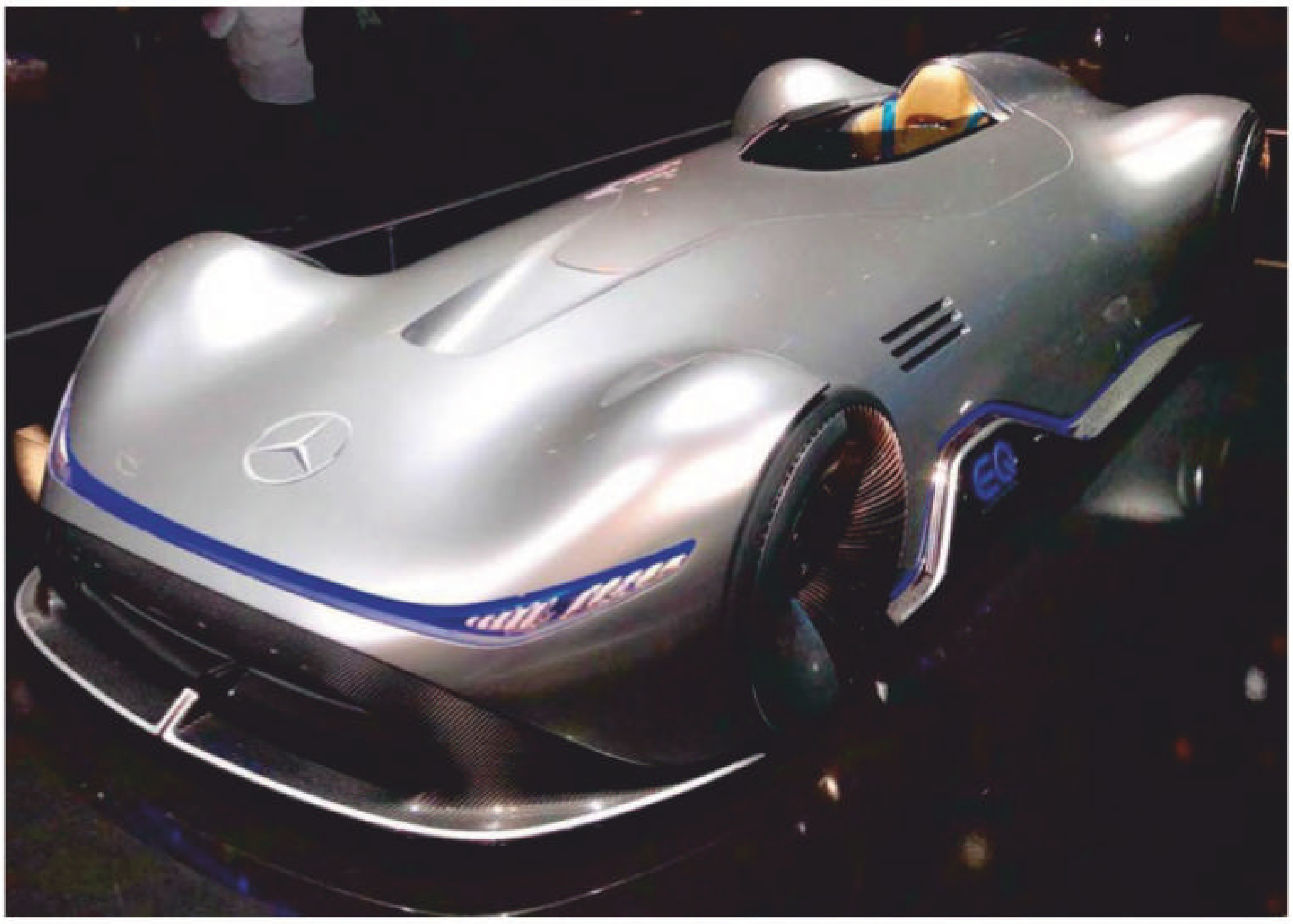
We should not be quick to dismiss this as hocus-pocus. The use of haptic technologies to control functions and the monitoring of bio-data is here. I'd ask, could such technology be adapted to a racing application? Is there a possibility of the F1 driver controlling the many steering wheel knob settings he has without touching them? Remember when taking one hand off of the wheel to grab the shift lever was the norm? Now it's not, except in historic racing.

Could pit crews be made more efficient, reliable, and predictable in their execution of tasks by reading and acting on their bio-data? At one time, having physical training for pit crew personnel was a radical new idea, as was videoing the pit stops to improve performance. Is the use of bio-data the next advancement in the pit lane? It sounds like another area for motorsport engineers to explore.

Silver lining

Moving further down the hall, Mercedes was to provide a well-needed uplift of my spirits. Although missing was any mention of its five-time world championship-winning F1 car, what was there was cool and provided me with my most visceral experience of the trip. And it didn't involve any virtual or augmented reality either.

This was its Vision EQ Silver Arrow concept car. It's a single seat streamliner, which is a modern tribute to the Mercedes 1937 record setting W125. To me this looked to be the ultimate track day car, and this thought was confirmed by David Wilfinger, one of the engineers behind the concept who told me: 'It's you, and the car, and the race track. We believe you could use it in the street, but that's not its environment … it's definitely not for commuting'. He also emphasized that it is strictly electric powered, but *not* autonomous.



That's more like it! Mercedes showed off its striking Vision EQ Silver Arrow, an electric-powered single-seat track day car

The Nissan display, like others, had as its focus of attention a part-time-autonomous, built-for-digital-entertainment car. However, my eyes were immediately drawn to the nearby Nissan Leaf NISMO RC. This is the company's second generation of an all-out, electric racecar, under a Leaf-looking body. It's built as a demonstrator to go on tour with Nissan's Formula E programme, and beyond, as it is building six of them to deploy around the world.

'The all-new Leaf NISMO RC shows how we're setting our sights even higher when it comes to raw power and performance, making electric vehicles even more exciting for customers,' says Nissan executive vice president Daniele Schillaci. 'It's our most thrilling expression yet of the philosophy of Nissan intelligent mobility.' Nissan was indeed another high point of the show for me.

Meanwhile, many automotive suppliers, primarily those with entertainment or autonomous vehicle technologies to sell, were also exhibiting at CES, and snuggling up next to the OEMs in the Automotive Technology Hall. Take note that automotive technology supplier companies have traditionally supported racing as well, and can provide great opportunities for vehicle-performance oriented engineers.

And what were the racing references in the supplier's booths? Nvidia pointed out that its Drive PX 2 AI supercomputer is being used in the Roborace Championship, the first global autonomous motorsports competition. Meanwhile, Magna International showed off the Andretti/BMW Formula E Championship car, which it proudly helps support.

Fever Las Vegas

Staying with Formula E, I also checked out the Schaeffler exhibit. Schaeffler is a motor supplier in the series, and is making great efforts to stay in the new-tech game by developing steering, suspension, and chassis gear for the next generation of production vehicles.

The 2016 Formula 1 Champion Nico Rosberg was present on media day, speaking as a partner with Schaeffler, as the Rosbergs' TRE Vehicle Dynamics company built the chassis for Schaeffler's Moverurban vehicle concept. What makes this conveyor uniquely manoeuvrable is the electric motors being mounted directly in the wheels. This allows for 180 degrees of steering angle range on all four wheels, which Rosberg willingly demonstrated in test rides, and by doing some doughnuts.

Sadly, there were no racing or human driving activities featured in Hyundai's future scenario

In an interesting example of transferring racecar engineering to street car development, Schaeffler also showed its in-house vehicle development car, a BMW saloon car modified for handling simulation correlation work. To ensure it had enough power, it installed four of the Formula E motors. Schaeffler's motorsport engineer Benedikt Locker said: 'We had a technical relationship first with ABT and now Audi, and I was project leader for building up this car … we needed a drivable test rig to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Nissan displayed the latest incarnation of its NISMO Leaf RC, an electric racecar concept which will be demonstrated at Formula E rounds. Six of these rapid cars are to be made

develop four-wheel drive vectoring, giving every wheel its own gearbox and its own motor.' Working back and forth, the real car will now behave like the simulation model, to duplicate extreme handling manoeuvres, as it learns how to remain in control.

Racing ahead

So, after four days of hoofing around CES, and putting it all together, what are my takeaways? To engineers in the automotive performance arena I would say passenger vehicle transportation is in for a big change, but performance and racing are not going away.

I'm not convinced that all the gloom and doom talk about self-driving vehicles is warranted. Like the switchover to electric vehicles, this is not going to happen overnight, nor will it ever attain one hundred per cent penetration. In reality, these things generally take longer, and are less cataclysmic than initially predicted by exaggerated news stories.

But racing needs to be looking into the technologies being developed for autonomous driving cars. Could it be possible, for example, to assist the driver's vision on a foggy, rainy night at Le Mans for improved safety, without hurting the sporting challenge of the event?

Another positive thing I came away with is that car makers clearly see themselves staying in the business of building vehicles for individuals, and not automatically caving in to the notion that all human transportation will be handled by fleets of public, hop-in hop-out anonymous pods, where the maker's brand doesn't matter.

Surely, high population density areas like London and New York will head toward full autonomy vehicle requirements. But not everyone is willing to ride-share. And that's where the part-time autonomous, hybrid vehicles will come in. In highly trafficked areas, like cities and intra-city highways, their drivers will be required to surrender control to the system, and join the grid of marching-ants, driving alongside those shared-passenger AVs, moving no faster or slower than they are.

Sometimes that break from driving will be most welcome, with no need to worry about finding a parking spot. But if you are like us, after you get fed up by being helplessly shuttled around, and have experienced all the diversionary virtual world entertainment you can stand, you'll be ready to head out to wherever you can still grab the wheel and take control again. Will it be in the country? Or just on approved 'vehicle recreation areas' (race tracks)? Either way, you'll be ready for it, and want a car that's up to your pent up demands.

Racing and performance driving will survive in part because of basic human nature, which I very much doubt will be changing for a long, long time. It is hardwired into us to be competitive, to get a thrill from motion and speed, and to have freedom of choice.

Furthermore, people will always enjoy seeing other humans perform with extreme skill or daring, whether it is in the Olympics, on a playing field, or at a race track.

Unless mankind goes totally numb and becomes totally 'rational', avoiding any risk or danger whatsoever, as we all get sucked into the singularity, the above will still hold true, and so 'mobility companies' will also continue to use racing as a marketing tool.

A sporting chance

Sporting enthusiast cars will survive, as a new kind of part-time autonomous hybrid. Sure they'll have to totally behave in some settings, but they can instantly turn back into brutish hypercars, not unlike Dr Jekyll and Mr Hyde.

I believe we will find a ton of interesting engineering challenges, if we can stay flexible and keep learning the new technologies.

In conclusion, there is no denying that the autonomous, self-driving, electric vehicles are headed our way, my visit to Las Vegas pretty much confirmed that, but in spite of this, some of mankind will still have the desire to travel down the road less automated.

Passenger vehicle transportation is in for a big change, but I very much doubt that performance driving and motor racing are going away

Strength in numbers

Racecar's maths guru shows how you can evaluate a car's stability index at turn-in, through mid-corner and at the exit using a handful of potent equations

By DANNY NOWLAN

XPB

When a racecar is turning in the forces on the tyres are both longitudinal and lateral, which is why a whole new level of stability index maths needs to be employed

One of the matters that I have written about at length over the last couple of years has been quantifying dynamic race car stability. This is termed the stability index. However, previously I've only discussed the calculation of this when the forces on the tyre are applied laterally. So how do we calculate stability index for when longitudinal and lateral forces are being applied to the tyre at the same time?

It might be tempting for readers to skim over this article, but it's actually quite important. One of my constant gripes with this business is the aversion that most people have to proper mathematical analysis. Yet when things go wrong, you do really need the mathematical tools to quantify what has happened. If you're serious about going fast and working in this game then you simply have to know why things happen; this article provides some very good analysis tools to help you with this.

But firstly, it would be wise to review what the stability index actually is and how we can quantify it. Basically, the stability index is a non-dimensional measure of the moment arm between the centre of gravity and the lateral forces. This is illustrated in **Figure 1**.

Here we have:

a = distance of the front axle centreline to the centre of gravity

b = distance of the rear axle centreline to the centre of gravity

Fy_f = front lateral force.

Fy_r = rear lateral force

α_f = front slip angle

α_r = rear slip angle

A simplified formula to work out the stability index is shown in **Equation 1**.

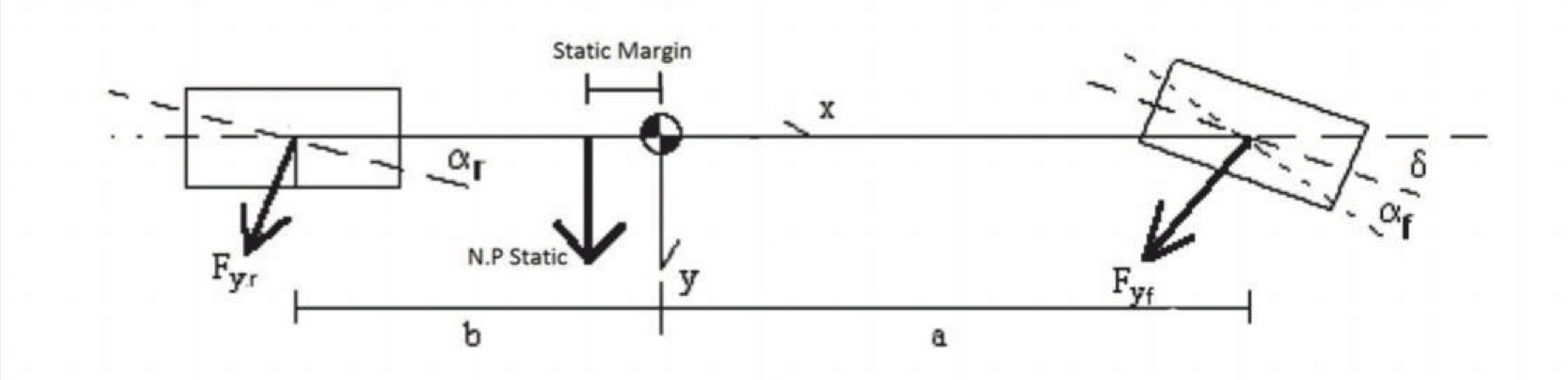
The problem we face is that while in pure slip angle the calculation is straightforward, in combined slip angle and slip ratio conditions these calculations become messy. Where it breaks down is with the calculation of $dC_F/da(\alpha_f)$ and $dC_R/da(\alpha_f)$, as this is no longer simple. Also, if you just use the pure slip angle terms it can lead to erroneous results. The good news is, if you know where to look, the process does actually become straightforward.

Angles and ratios

The solution lies in the combined slip angle and slip ratio tyre model postulated in Bill and Doug Millikens' book, *Race Car Vehicle Dynamics*, and adapted for the ChassisSim tyre model. This has been battle tested with the ChassisSim driver in the loop toolbox. The centrepiece of this technique is to normalise the current slip angle and slip ratio. This is presented in **Equations 2**, **3** and **4**. What we have presented in these

When things go wrong in the race engineering business you really do need to use mathematical tools to quantify what has happened

Figure 1: The stability index



EQUATIONS

EQUATION 1

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

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

$$C_T = C_f + C_r$$

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

Where:

$dC_f/da(\partial C_f)$ = slope of normalised slip angle function for the front tyre
$dC_r/da(\partial \alpha_f)$ = slope of normalised slip angle function for the rear tyre
$F_m(L1)$ = traction circle radius for the left front (N)
$F_m(L2)$ = traction circle radius for the right front (N)
$F_m(L3)$ = traction circle radius for the left rear (N)
$F_m(L4)$ = traction circle radius for the right rear (N)
wb = wheelbase
a = distance of front axle to the centre of gravity
b = distance of the rear axle to the centre of gravity
C_T = slope of total tyre force front and rear vs slip angle
C_f = slope of total front tyre force vs slip angle
C_r = slope of total rear tyre force vs slip angle

EQUATION 2

$$\bar{\alpha} = \frac{\alpha}{\alpha_{max}}$$

EQUATION 3

$$\overline{SR} = \frac{SR}{SR_{max}}$$

EQUATION 4

$$k = \sqrt{\bar{\alpha}^2 + \overline{SR}^2}$$

Where:

$\bar{\alpha}$ = normalised slip angle
α = slip angle.
α_{max} = peak slip angle
$\overline{SR}$ = normalised slip ratio
SR = slip ratio
SR_{max} = peak slip ratio
k = normalised combined slip

EQUATION 5

$$\frac{\partial F}{\partial \alpha} = \partial \frac{\left(f(k) \cdot \frac{\bar{\alpha}}{k}\right)}{\partial \alpha}$$

Where:

Fy = lateral force (N)
$f(k)$ = normalised slip function
Fm = lateral traction circle radius at that load and temperature condition of the tyre

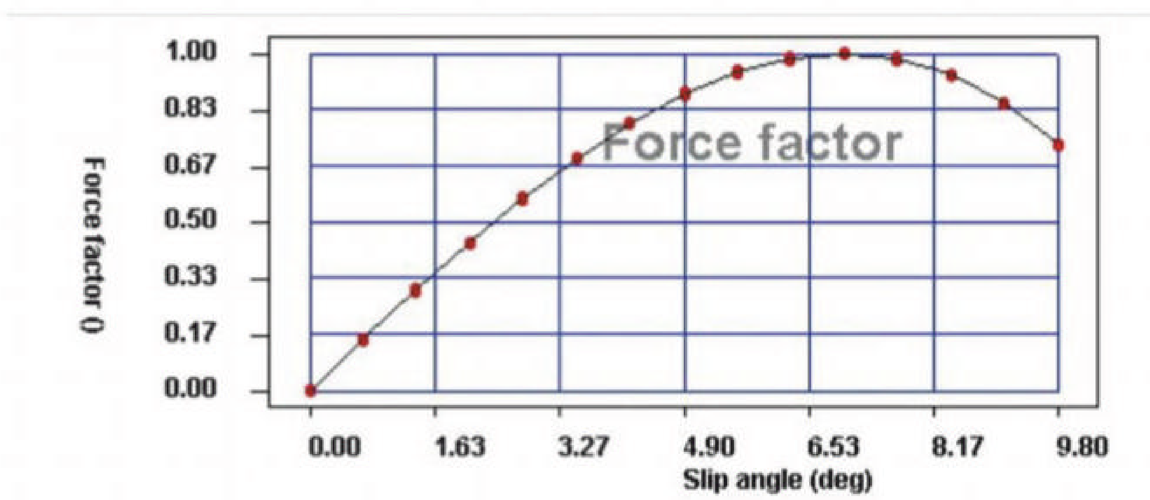
equations is simplified, compared to what you'll see in Milliken, but it gives you the idea.

The next step in this process is constructing the lateral component of the tyre forces, and this is given by **Equation 5**.

Most elements of **Equation 5** are very straightforward. But f(k) might cause some confusion – this is simply the normalised slip curve that we have all grown to know and love over the years, and it is illustrated in **Figure 2**.

The only difference is that the horizontal axis is normalised (divided) by the peak slip angle. I would also recommend, if you are starting on this for the first time, that you take the normalised force *vs* slip angle curve.

Figure 2: Normalised slip curve



angle	0.00	0.70	1.40	2.10	2.80	3.50	4.20	4.90	5.60	6.30	7.00	7.70	8.40	9.10	9.80
FFact	0.00	0.15	0.30	0.44	0.57	0.69	0.79	0.88	0.94	0.99	1.00	0.98	0.94	0.85	0.73

Stability index

To solve the stability index we just need to find the derivative of **Equation 5** with respect to slip angle. This will give us the $dC_F/da(\alpha_f)$ and

EQUATIONS

EQUATION 6

$$\frac{\partial F}{\partial \alpha} = \partial \frac{\left(f(k)\frac{\bar{\alpha}}{k}\right)}{\partial \alpha}$$

EQUATION 7

$$u = \bar{\alpha}^2 + \overline{SR}^2 = k^2$$

EQUATION 8

$$\begin{aligned}\frac{\partial k}{\partial \alpha} &= \frac{\partial k}{\partial u} \cdot \frac{\partial u}{\partial \alpha} \\ &= \frac{\partial}{\partial u}\left(u^{\frac{1}{2}}\right) \cdot \frac{\partial u}{\partial \alpha} \\ &= \frac{1}{2} \cdot u^{-\frac{1}{2}} \cdot \frac{2 \cdot \alpha}{\alpha_{max}{}^2} \\ &= \frac{\alpha}{k \cdot \alpha_{max}{}^2}\end{aligned}$$

EQUATION 9

$$\frac{\partial}{\partial \alpha}\left(\frac{\bar{\alpha}}{k}\right) = \frac{\overline{SR}^2}{k^3}$$

EQUATION 10

$$\frac{\partial F}{\partial \alpha} = \frac{\partial f}{\partial k} \cdot \frac{\alpha}{k \cdot \alpha_{max}{}^2} \cdot \frac{\bar{\alpha}}{k} + f(k) \cdot \frac{\overline{SR}^2}{k^3}$$

While in pure slip angle the calculation is quite easy, in combined slip angle and slip ratio conditions it can become messy

$dC_R/da(\alpha_f)$ that we are looking for. Since the magnitude of the traction circle is not going to be a function of slip angle this is what we are solving for in **Equation 6**.

Here is where things are going to get a little bit tricky because the level of maths is about to move up a notch or two. In order to help us we'll need a few identities. Firstly, let's define the variable *u*, as shown in **Equation 7**.

We are now ready to solve for **Equation 6** and the first step is to solve for the derivative of *k* as a function of slip angle (**Equation 8**).

Now that we have solved this, we can go on to solve for the derivative of normalised slip angle divided by the combined slip. Using the derivative quotient rule it can be shown by using **Equation 9**. I will leave the interested reader (undergraduate engineering students reading this that means you) to do the working out.

The last step in this process is to finally solve **Equation 6**. We can do this because we have now completed all the intermediate steps to resolve the appropriate identities, and so we can solve this via the differential product rule. This is summarised in **Equation 10**.

All you then have to do is to substitute **Equation 10** into **Equation 5** and now you can calculate the stability index for mixed slip conditions. Again, I leave this to the interested reader to do the working out.

Before we get into providing a hands on example a couple of things should be noted

Table 1: Sample numbers for mixed slip derivative calculation

Variable	Value
Slip angle	2 deg/0.0349 rad
Slip ratio	7%/0.07
Peak slip angle	6 deg/0.1047 rad
Peak slip ratio	10%/0.1
$\frac{\partial f}{\partial k}$	1

about **Equation 10**. Most racing tyres have a peak slip angle of 6-degree or 0.1047 radians and a peak slip ratio of 10 per cent. What this means is that in **Equation 10** the dominant term is the slip angle term. However, it's not as dominant as we would think. This happens because this term is effectively being multiplied by 100 where the slip ratio terms effectively stay at unity.

Also, in the pure slip angle case **Equation 10** reverts back to the terms we used back in **Equation 1**, so this is consistent.

Maths in action

Now it is time to illustrate all this with a hands-on example. The numbers for our example are illustrated in **Table 1**. For the sake of argument and to keep things simple I'm assuming a straight-line fit from the (0,0) point of the normalised slip curve to the peak point of (1,1). The first port of call is, then, to calculate the normalised slip angle and slip ratio and the value of *k*. Substituting this into **Equations 2** to **4**, we have **Equations 11** to **13**.

Now that we have these values to hand we can now calculate $\partial F/\partial \alpha$. Substituting our values from **Equations 11** to **13** into **Equation 10**, then **Equation 14** is arrived at. I should also add the reason we can write *f(k)* as just *k* is because we have used a straight-line fit from the (0,0) to the (1,1) point of the normalised slip curve.

At this point you might be thinking 'so what?' But the devil here is in the detail. If we use **Equation 1** blindly in a braking situation it will indicate that the car will be unstable. The reason for this is that at low slip angle and using our simple unity slip we will be looking at a normalised slip gradient of at least 10. So when we multiply that by say a total traction circle radius of 6000N at the front and 4000N at the rear, this will show the stability index is in the order of +10 per cent, which would indicate that the car is massively unstable.

However, as we have just seen, the true normalised gradient is 2.572. This is a quarter of the value of the stability index calculation based on the pure slip angle slope alone. Consequently, we now have a very powerful tool to review what the stability of the car is doing in mixed slip angle and slip ratio conditions.

EQUATIONS

EQUATION 11

$$\bar{\alpha} = \frac{\alpha}{\alpha_{\max}} = \frac{0.0349}{0.1047} = 0.33$$

EQUATION 12

$$\overline{SR} = \frac{SR}{SR_{\max}} = \frac{0.07}{0.1} = 0.7$$

EQUATION 13

$$k = \sqrt{\bar{\alpha}^2 + \overline{SR}^2} = \sqrt{0.33^2 + 0.7^2} = 0.774$$

EQUATION 14

$$\begin{aligned}\frac{\partial F}{\partial \alpha} &= \frac{\partial f}{\partial k} \cdot \frac{\alpha}{k \cdot {\alpha_{max}}^2} \cdot \frac{\bar{\alpha}}{k} + f(k) \cdot \frac{\overline{SR}^2}{k^3} \\ &= 1 \cdot \frac{0.0349}{0.774 \cdot 0.1047^2} \cdot \frac{0.33}{0.774} + 0.774 \cdot \frac{0.7^2}{0.774^3} \\ &= 1.754 + 0.818 \\ &= 2.572\end{aligned}$$

EQUATION 15

$$\begin{aligned}\frac{\partial F}{\partial \alpha} &= \frac{\partial f}{\partial k} \cdot \frac{\alpha}{k \cdot {\alpha_{max}}^2} \cdot \frac{\bar{\alpha}}{k} \\ &= \frac{\partial f}{\partial k} \cdot \frac{\alpha}{k \cdot {\alpha_{max}}^2} \\ &= \frac{\partial f}{\partial k} \cdot \frac{\alpha}{\frac{\alpha}{\alpha_{max}} \cdot {\alpha_{max}}^2} \\ &= \frac{\partial f}{\partial k} \cdot \frac{\alpha}{\alpha \cdot \alpha_{max}} \\ &= \frac{\partial f}{\partial k} \cdot \frac{1}{\alpha_{max}}\end{aligned}$$

Another thing to point out is that what we have just outlined here is to a great extent tyre model independent. So it doesn't matter if you are using the Pacjeka model, the ChassisSim tyre model, or a first principles tyre model like the Michelin TaMe one. The principles are all the same, so this is a very flexible tool.

One last thing to complete our discussion is a simple proof that in pure slip angle conditions **Equation 10** reverts to the normal slip angle curve. In this case we have $\bar{\alpha}=k$ and all the SR terms revert to 0. Substituting this into **Equation 10** we then have **Equation 15**. This shows conclusively that in a pure slip angle situation **Equation 10** reverts back to either $dC_F/da(\alpha_f)$ or $dC_R/da(\alpha_f)$ depending on which end you are interested in calculating.

In closing, we have just outlined a very powerful technique for calculating racecar stability when both slip angle and slip ratio are applied. This may seem somewhat esoteric, you might think, but what has been provided is the mathematical proof and backbone that will let you look at a racecar's stability well beyond the mid-corner condition. You can now evaluate the racecar stability from turn-in, through mid-corner to turn exit. This will give you much greater insight into what the car is doing, so you can make those critical calls when you need to make them.

We now have a very powerful tool to review what the stability of the racecar is in mixed slip angle and slip ratio conditions

Interview – David Brabham

Keep it in the family

David Brabham, Le Mans winner and, after a legal battle, custodian of the name explains why, and how, he is taking the Brabham marque back into motor racing

Interview by ANDREW COTTON

'From a brand point of view what can we race that has a world presence? The WEC does that'

What's in a name? When it belongs to a three-time Formula 1 world championship winning driver, a four-time F1 driver's championship-winning team, and also happens to be your own, then you would have to say quite a lot. That's the reason why David Brabham, son of former champion Sir Jack and a successful driver in his own right – winning Le Mans in 2009 and reaching Formula 1 – fought so hard to protect the use of the family moniker, even taking the matter to court.

With the court case resolved in Brabham's favour in 2012 the next step was to find something on which to put the illustrious name, and what better than a car? In this case it's the stunning Brabham BT62 supercar that was unveiled in 2018 – a mid-engine track day rocket which packs a 5.4-litre naturally aspirated V8 and produces around 1200kg of downforce, which is marketed at a cool US$1.4m.

But the Brabham name is all about racing, not track days, so it was perhaps no surprise when it was announced that the BT62 was to be raced, at Le Mans no less, with plans for a GTE version of the car to compete at the 24 hours as soon as 2021.

World stage

For Brabham the reasoning behind all this is simple. 'At the end of the day we have to race our products,' he says. 'Brabham has been world champion in Formula 1. From a brand point of view what can we race that has a world presence? The World Endurance Championship does that. GTE is obvious because we are not in a hybrid space yet. Further down the road we may be, but now we have to go racing, have to be on a world stage, and we have a car that will be quick enough.'

That last point was recently proved beyond doubt when the BT62 comfortably eclipsed the unofficial closed car lap record at Bathurst, previously held by an unrestricted Audi GT3, during a demo run at the legendary Mount Panorama circuit. It was also fitting that the car showed its potential in Australia, for at heart this is an Aussie company.

'The company is based in Adelaide [in the old Holden factory] and the cars are produced there,' Brabham says. 'Fusion Capital are my partners in it, and they have had experience for a long time in the market of advanced engineering capabilities and working with manufacturers to supply components for them, so they are a good group of people who understand that world. They also have the finance to get this thing going …We were introduced by a mutual contact who knew what I wanted to achieve, and what they wanted, and so we started to talk. They wanted a halo product in their group, and needed a brand.

'Ultimately when I started thinking about bringing Brabham back 12-13 years ago, I wondered how I would turn this into a global brand, not just a race team,' Brabham adds. 'If I had a race team, what would support it? A team on its own is bloody hard work, and didn't interest me. I wanted something bigger. I had bigger ideas in my head, but had no idea how to do it, or what it would look like. It was a dream and nothing more.'

But that dream was put on ice for a while, thanks to the court case. 'I didn't anticipate [the court case] was going to sap seven years of my life, but when I got that back in 2012 it was like rebuilding again,' Brabham says. 'I went from a world of being a racing driver which I knew very well, to another one where I had no idea what it was about. I had to go through a massive learning curve and rely on things that I relied on in racing to get me through. You hear so much noise, and all I went on was what made sense to me, and what my gut told me until I found the right partners.'

On the road

Now it's all about expansion, and building up the BT62 business, which will be a run of just 70 cars. These were originally marketed as pure track day cars, but now there will also be an option for a road car conversion package. 'We have just announced a road car compliant conversion, because a lot of our customers want to drive the car to the circuit,' Brabham says. 'We looked at how we could make that happen. It wasn't designed to be on the road, but let's have a look at it, and we can make the changes to make it road legal, so that opens up the market a bit and there is interest.'

Beyond that Brabham does see a future for the company as a road car business. 'Doing a road car programme is a massive undertaking and investment, but how do you build the brand and get it out there to attract that kind of investment?' Brabham says. 'It has all been planned out. What I lack in experience in business, these guys [Fusion] have been there and done it with different businesses and been very successful. The two groups

The BT62 in the original Brabham team colours, the green and gold of Australia. The car could be racing at Le Mans by 2021 coming together, the brand, racing DNA and my experience in racing … [and Fusion], it is a pooling of resources in terms of rebuilding the house that my father built.'

But Brabham Automotive, to give it its full name, is no Ford, Porsche or Aston Martin, so will it be possible for it to meet the minimum build requirement that will allow if to compete in GTE by 2021? 'We are talking to the ACO about that at the moment, and they are nervous about that,' Brabham admits. 'But we are in it for the long term. We are not in it to win and then be out. Brabham Automotive has a long-term plan, and racing is a long term plan. We are not around for just one car.'

Which begs the question, what else are we likely to see bearing the Brabham badge? 'You will have to wait and see,' Brabham says. 'We have other cars. In terms of where we want to get to, we started first with the BT62, and the design cues that you see will carry through.'

De-risky business

If the brand grows, so too could its racing programme, perhaps in other sportscar arenas and Brabham admits he has also looked at GT3. 'That's something that could happen in the future, and we are looking at a customer programme for that too,' he says. 'This is a brand-building exercise as well as showcasing the car. There is logic to it all. To have that stability down the road, and sustainability, you have to build the platform of your house solidly. We have been doing this for a while, and we want it to last a long time. We have de-risked the business, we have the name out, and the car looks the bollocks, and drives like it too. It's fast, it's a great car.'

Competing in the Le Mans 24 hours is a major part of that rebuilding programme, says Brabham. 'The plan is to be there in 2021/22, which is ambitious, but we need to stake a claim and say that's what we are aiming towards. We can start talking to partners about that journey and it is a huge moment in Brabham history, having done what it has done, fell quiet, and now it is building again.'

Brabham knows how to succeed at Le Mans as a driver, but the big test will be succeeding as a constructor. There is more at risk here than just money too; there is also the reputation of the family name to think of. And you can't put a price on that.

RACE MOVES

XPB

John Wickham is to retire from Bentley Motorsport, a company at which he has enjoyed two stints, including being team director during its winning Le Mans assault in 2003. Wickham has also worked in Formula 1 in the past, leading the Spirit team in the 1980s, and before that he helped run the Surtees Formula 2 operation. He has also worked as a race team manager in the BTCC, Formula 3, F3000 and A1GP.

Chip Ganassi Racing co-team manager **Scott Harner** has left the IndyCar champion team and joined AJ Foyt Racing, where he has taken on the role of vice-president of operations. Harner had worked at CGR for over 25 years, starting out as a truck driver and fabricator. In his new role he will work closely with team director **George Klotz**, and as well as overseeing the day to day operations of the team he will also be the race strategist for **Tony Kanaan**.

US single seater team owner **Kris Kaiser** has died at the age of 45 after a heart attack. Kaiser's K-Hill Motorsports team, based in Pennsylvania, has run a number of drivers to SCCA National championship success in recent times in Formula Atlantic and Formula F, while it has also now moved into the SCCA F4 US Championship. Kaiser started his career in motorsport as a race driver.

Billy Vincent has been promoted from chief mechanic to competition director at IndyCar operation Arrow Schmidt Peterson Motorsports. Vincent, who joined the team for the 2017 season, will now oversee the cars driven by **James Hinchcliffe** and Formula 1 refugee **Marcus Ericsson**.

Cameron Kelleher is now PR and communications manager, motorsports, at IMG Events, which is the company responsible for promoting the FIA World Rallycross Championship.

Former Australian Supercars team boss **Jeff Grech**, best known for his time as the head of the Holden Racing Team through its successful years in the late 1990s and early 2000s, is now the manager of the Winton Motor Raceway in Victoria. For the past three seasons Grech has overseen the Charlie Schwerkolt Team 18 outfit in Supercars. The Supercars series is due to visit Winton at the end of May.

Well-known turbocharger manufacturer Turbo Technics has appointed **Stephen Hynes** to the post of general manager, based at the company's headquarters and manufacturing base in Northampton. Hynes brings extensive international sales and marketing experience to the firm, we're told, having worked for both SMEs and large international corporations.

Paul Buddin has been appointed chief financial officer (CFO) of the McLaren Group. Buddin has been acting CFO since March 2018 and CFO of supercar maker McLaren Automotive since January 2016. He will now have financial oversight of the combined McLaren Group, which comprises McLaren Racing, McLaren Automotive and McLaren Applied Technologies.

New Zealander **Mark Bryant** had joined the Andretti Autosport IndyCar team, where he will engineer the **Marco Andretti** driven No.98 car. Bryant was race engineer for **Patricio O'Ward** for his title winning Indy Lights campaign last season. **Nathan O'Rourke**, Andretti's race engineer in 2018, has now taken on another position within the team.

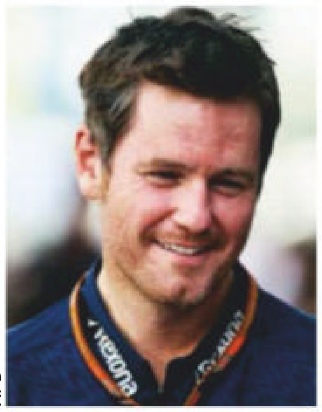
SJ Luedtke, a Nike sports marketing executive for the past decade, is now IndyCar's vice president, marketing. Luedtke joined Nike in 2010, rising to senior brand director of football, but before that she spent 14 years working in a number of areas of motorsport marketing, including leading client services at Andretti Green Racing.

Also at IndyCar (see above) **Mike Zizzo** is now communications consultant. Zizzo is an award-winning PR executive with more than 22 years of experience in the motorsport industry, including managerial roles with two of North America's racing sanctioning bodies, Auto Racing Teams (1996 to 2002) and NASCAR (2002 to 2005). He has been the vice president of communications at the Texas Motor Speedway for the past 13 years.

Former Williams tech boss joins F1 in consultancy role

Rob Smedley has joined Formula 1 in a consultancy role, with a brief of helping to de-mystify F1 technology for the benefit of race fans.

The former head of vehicle performance at Williams, a post he left at the end of last season, will work alongside F1's managing director of motorsports Ross Brawn. The pair have previously worked together at Ferrari, where Smedley was Felipe Massa's race engineer from 2006 to 2013, while before that he was an engineer in the test team.



XPB

Smedley's new role is to help explain F1 tech to fans

Explaining his new role, Smedley said: 'It's about trying to get a coherent message in terms of the technical side of Formula 1. How the events unfolded, why people have made certain decisions, and putting that out across the various different platforms, and hopefully telling a better story of Formula 1. It's about really bringing the inner beauty of Formula 1 to the viewer, to the fan.

'In conversations with Ross [Brawn], we were both of the opinion that there's this really rich seam of technical content, of data, of the way that teams operate, that actually never gets told,' Smedley added. 'And it's part of the whole story that underpins Formula 1, which actually the paying public, the F1 fan, never ever gets to see – or they get to see very little of it. So there's an opportunity in front of us to put that together at some level.'

Smedley had a 20 year career in grand prix racing before he announced last year that he was to take a break from F1. During that time he worked for Stewart, Jordan, Ferrari and then Williams. It had been widely rumoured that he was set to return to Ferrari this season.

OBITUARY – Dr Robert Hubbard

Dr Robert Hubbard, the engineer behind the life-saving HANS device, has died at the age of 75 after a long battle with Parkinson's Disease.

Hubbard was a professor of materials science and mechanics at Michigan State University up until his retirement in 2006. He had completed his PhD on the mechanical properties of the skull bone while working at the University of Michigan Highway Safety Research Institute. During the 1970s he worked for General Motors, where he did research into road crash injuries and also developed crash test dummies.

He was, then, well placed to develop HANS (which stands for head and neck support), and was prompted to do so after his brother-in-law, IMSA racer Jim Downing, lost his friend Patrick Jacquemart after a crash in 1981.

The HANS device has been mandatory equipment in Formula 1 since 2003

Hubbard and Downing concluded that drivers were being killed due to basilar skull fractures, which were the result of their heads not being restrained during an impact. This spurred the pair on to invent the HANS device.

Research was conducted with limited funds and the first example of the device was patented in 1985, Downing going on to compete with one fitted at an IMSA race at the end of 1986. The device was sold for the first time in 1991.

Like many safety measures, the worth of HANS was not recognised at first and it took two tragedies, the deaths of Ayrton Senna at Imola in the 1994 San Marino Grand Prix, and of Dale Earnhardt in 2001 at the Daytona 500, until it really started to gain wide acceptance.

It is now used in motorsport series around the world, often as mandatory equipment, and while there has been no research conducted into how many lives the HANS device has saved it's likely that the number is significant.

Dr Robert Hubbard 1944-2019

RACE MOVES – continued

XPB

Former Formula 1 driver, Le Mans winner and race team owner **Jan Lammers** is now overseeing Dutch venue Zandvoort's bid to secure a place on to the Formula 1 calendar. Lammers, who was actually born in the resort town of Zandvoort, intends to help the fabled circuit to return to F1 by 2025. The track last hosted a Formula 1 grand prix in 1985.

Derek Stamets is **Darrell Wallace Jr's** new crew chief for the 2019 NASCAR Cup series. Stamets has been the lead engineer on the No.43 Richard Petty Motorsports car since 2012, but has now been given the opportunity to step up into the crew chief position following the departure of **Drew Blickensderfer** (see below).

Drew Blickensderfer is now the crew chief for **Michael McDowell** on the No.34 Front Row Motorsports Ford in the NASCAR Cup. Blickensderfer takes over the post from **Derrick Finley**, who has now taken on the new role of technical director at the team. Meanwhile, **Donnie Wingo** is to return to the organisation as its competition director.

Also at Front Row, **Mike Kelley** has joined the team to crew chief for **Matt Tifft** in the No.36 Ford, returning to the Cup after a long stint in the Xfinity Series with Roush Fenway Racing, while **Seth Barbour** is now crew chief for **David Ragan** in the No.38 car.

The Road Racing Drivers Club (RRDC) has presented IndyCar team boss **Bobby Rahal** with the 2019 Phil Hill Award – which has been awarded annually since 1993 to a person who the RRDC feels has given outstanding service to road racing. Rahal, who is now in charge at Rahal Letterman Lanigan Racing, alongside **David Letterman** and **Michael Lanigan**, has had a successful career as both a driver and team owner, winning the Indy 500 in both capacities.

McLaren had said that former Porsche LMP1 chief **Andreas Seidl** will start working for the Formula 1 team as its managing director at the beginning of May, after the Azerbaijan Grand Prix. Seidl has had previous F1 experience with both Williams and BMW-Sauber.

John Haynes, the founder of the UK automotive publishing company that bears his name, has died at the age of 80. Haynes made its name producing workshop manuals although it later branched out into more mainstream books including many motorsport titles. In 1985 John Haynes founded the Haynes Motor Museum in Sparkford, Somerset, which now displays over 400 vehicles. In 1995 he was awarded an OBE for services to publishing.

Australian entrepreneur **Jason Gomersall** has become an equity partner in the Matt Stone Racing (MSR) Supercars team. Gomersall has sponsored the organisation's cars through his iSeek and Bigmate businesses, while he has also raced an MSR-built and prepared Holden Torana in the Touring Car Masters series.

Chris Stilwell is now chairman of Australian Supercars team Tickford Racing, as well as its sister road car division. Stillwell will remain in his post as chairman and CEO of the Stillwell Motor Group alongside his new Tickford role.

◆ 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**

Boom and bust economy

In the late '80s, there was nothing that could touch the housing market and there was nothing that could touch the rise of the yuppies. Their world was of Filofaxes and Porsche 911s. Young people with little understanding had more money than they could cope with, and believed the good times would never end. They did, and with it went the car market. It was not only the normal cars that went west with the setting sun of the financial world, it was particularly the supercars. For various reasons, including economic, the Jaguar XJ220, Bugatti EB110 and Aston Martin Virage flopped.

Out of the ashes rose the BPR series, and 10 years later Stephane Ratel's FIA GT Championship accommodated McLaren, Porsche and Mercedes, but there was not the appetite for the manufacturers to spend the money to compete with Mercedes, and the series collapsed. It was kept alive by the investment of Chrysler, along with private teams run by the likes of Lawrence Pearce, Toine Hezemans, Cor Euser and Fabien Roock. Now we are in the same cycle, the hybrid LMP cars had a great era, but it's over, and yet the FIA is still trying to breathe life into its hypercar programme.

Car crash

According to findings from ACEA, reported on Bloomberg, new car registrations have fallen for the fifth month in a row in Europe. Italy is battling a technical recession, there is political uncertainty in Spain and the UK, while car sales fell in Germany, France, the UK, Italy and Spain. Audi and Porsche saw double digit percentage declines having struggled with the new emission targets set by European governments, while China saw its first fall in car sales in more than 20 years. This is not a blip, this is real, and it is hurting car companies.

It is time to look at history and understand that not every Le Mans 24 hours can be great

In the UK, Honda is to close its plant after 30 years, Nissan has decided to build its new model elsewhere, Ford has issued a warning over viability of its business if there is no deal over Brexit, while other major companies, including Airbus, are moving out too. Why is Airbus such a problem? There is a technology cluster in the Bristol area that focusses on composite materials, where Bloodhound is based, and this is a valuable asset to the UK and motorsport economy.

Against this backdrop, and without even considering the impact on European manufacturers exporting to the US with all the associated taxes that the US government is considering, the FIA and the ACO are pressing ahead with hypercar, having agreed the regulations with manufacturers.

It's not only them, it has to be said; racing is avidly chasing manufacturer money, without that, it seems that it is not worth carrying on. The major manufacturers have these cars planned, but are they in the right ballpark or in dreamland?

It would be easier to sell a project to a board if there was a racing programme attached to it, but is the market really there? Are those who would buy such cars hurting as much as the car companies are right now, or are they simply making enough money that they don't care?

Business plans

Motor racing is not a business that ever made money; if you want to finish up with a small fortune, start with a large one. Or be called Bernie Ecclestone. Racing is either a passion, or it is a place of development. Right now, the manufacturers are pulling in money and resource in order to survive.

There is little sense in Audi and Porsche racing each other in Formula E. Motorsport chief Dieter Gass is right on that score. It only made a small amount of sense that they raced each other at Le Mans, and only then because one raced diesel, the other gasoline. With both investing heavily in the electric racing series, I very much doubt that the VW Group will get double the return on its investment.

If there is a sustained contraction of the market, it may be that the governing bodies have to put in place a holding pattern. While they may wish to be at the forefront of technology, they cannot do that all the time. History will not judge whether or not there were hybrids on the grid at Le Mans; it will only judge if there are no entries. Back in the 1990s, Le Mans hurt badly as the 3.5-litre engine formula was introduced, and Ecclestone tried (and succeeded) in killing off the endurance World Championship. It left the ACO with its smallest grid, fewer than 30 cars, before Ratel turned up with his Venturis and started to bring back big GT cars

If hypercar fails, and it would then be the third year in succession that the ACO and FIA have presented a plan at Le Mans that hasn't reached fruition, it must be time to look at history, understand that not every Le Mans is great, and accept that the good times will come again. It could be hydrogen, it could be biofuels, it could be something else that is altogether new, but they have to accept that their glorious time has ended. The next one is just around the corner.

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