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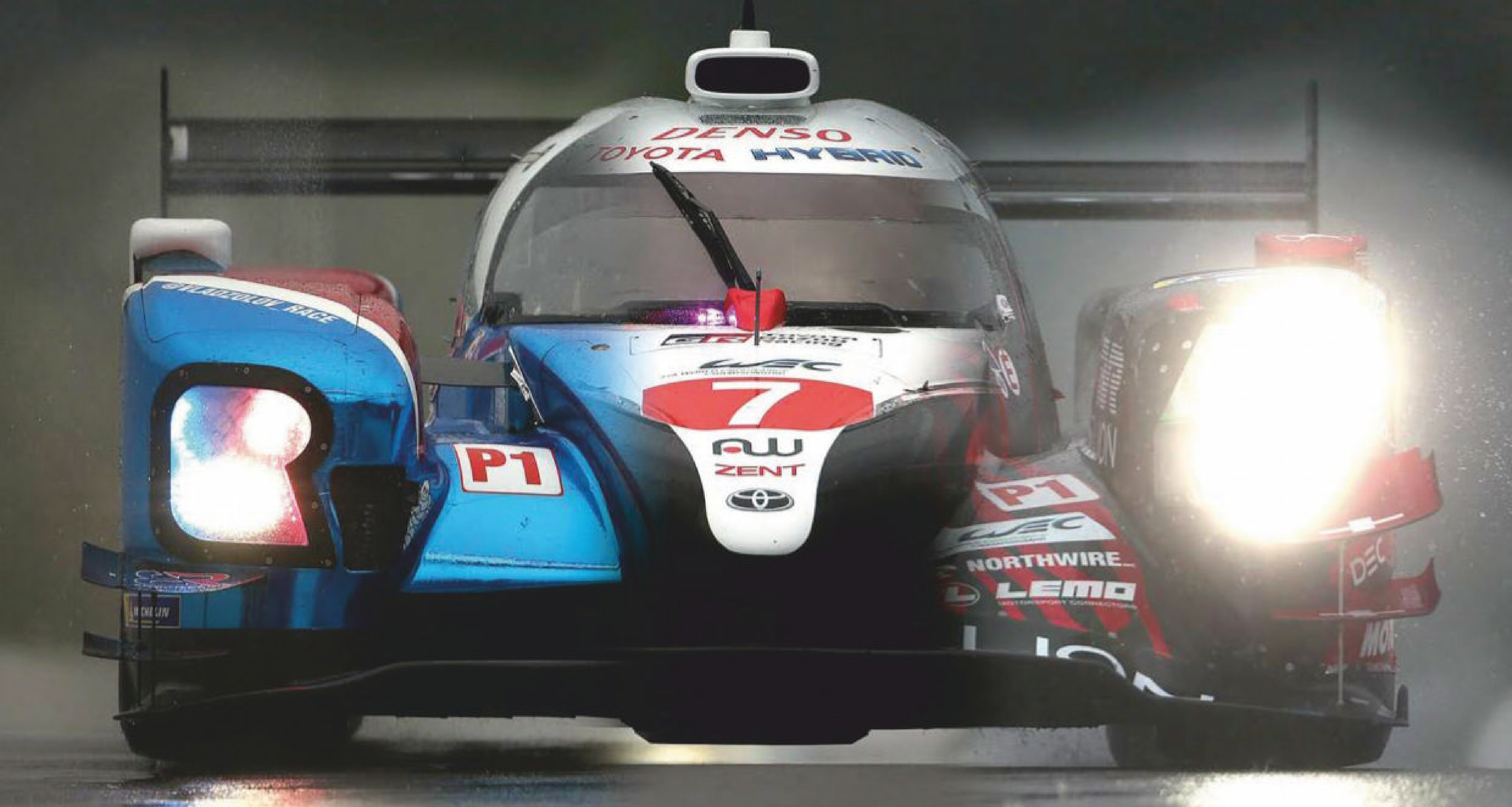
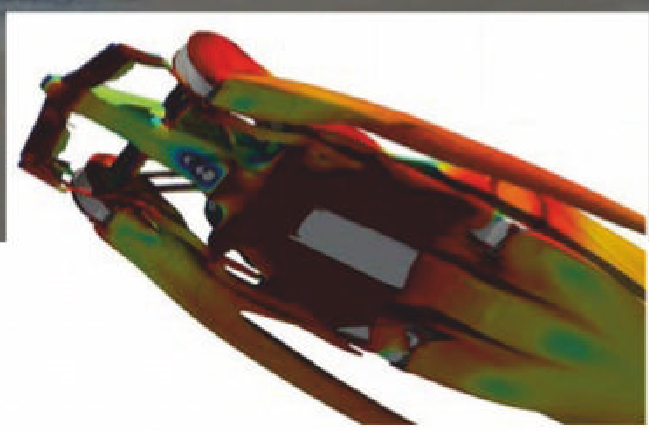
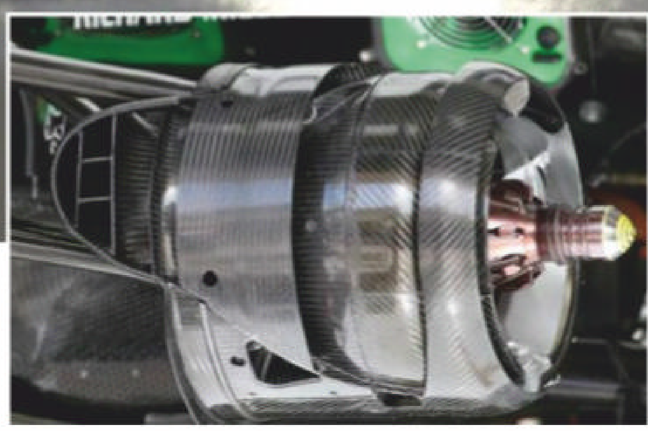
# Le Mans 2019

## The pitfalls of powertrain parity









## Super Prius

Toyota fits V8 powerplant to GT300 hybrid trailblazer

## Turbulent matters

IndyCar continues its CFD studies into wake patterns

## F1 airflow control

We reveal the strategies of brake heat management

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With the UAK18 Universal Aerokit deemed a success, IndyCar continues its efforts to ensure the series remains an exciting spectacle

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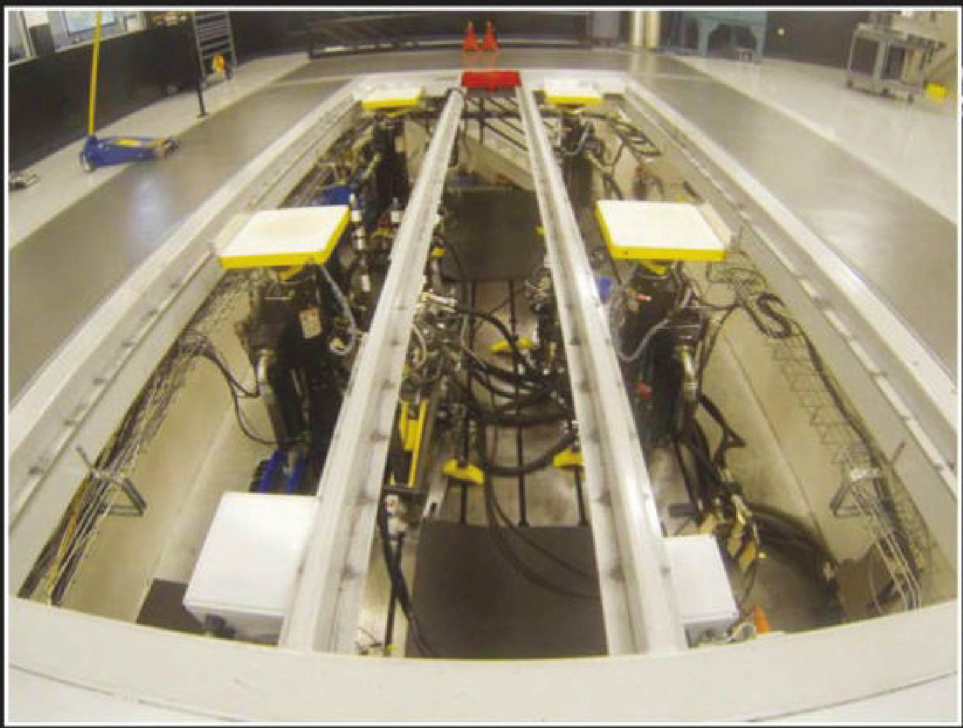

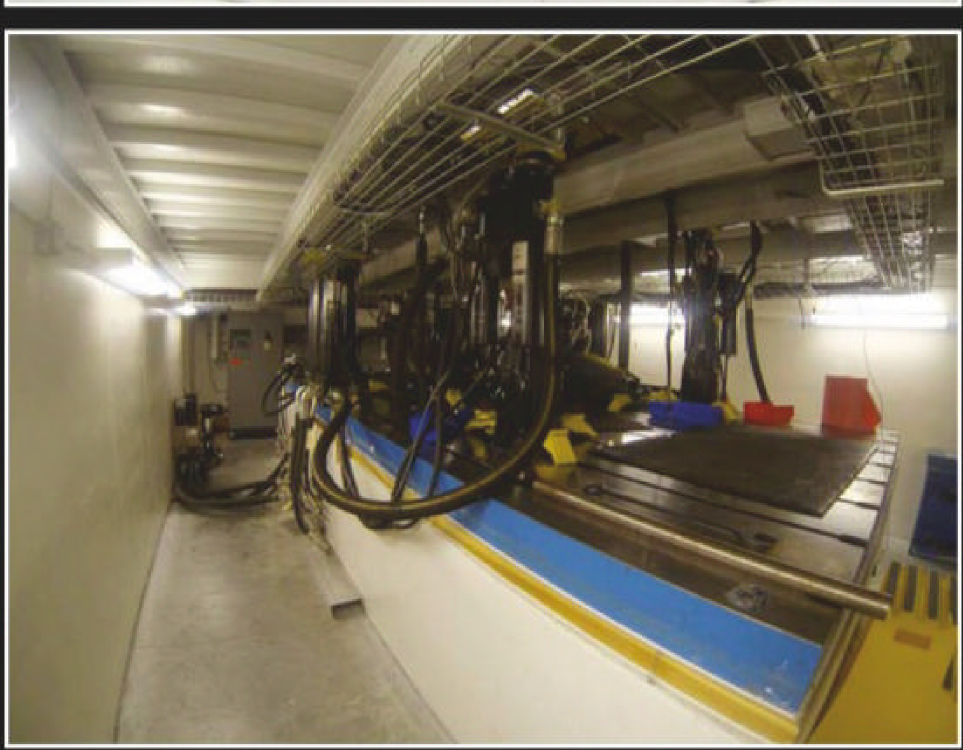


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# Car noir

## Remembering some of the most truly magnificent racecar failures

When you like films, enjoy the story telling, good acting, pace and having a keen eye for the details, you will progress to enjoying films so bad they are unmissable. In the same vein, bad cars, by showing their flaws, make us understand the deeper complexity of crafting good ones.

The 1989 Eurobrun F1 could be an example. Let us examine it. In part, the team were ex-Alfa Romeo Racing, and results in 1988 were reasonable. Eleventh in the Hungarian GP, on the grid several times. But when part of the team left in 1988 and the budget was cut, they were in trouble.

Its best result during the 1989 season was not qualifying for the Brazilian Grand Prix. I say best as for the rest of the season the team did not even pre-qualify. It is the only car ever entered in an F1 season to never qualify for a single race.

The truly magnificent, though, are the failures that succeeded only because they were actually built. The Star Hunter, built in Brazil by a visionary, if misguided, racer had some elements that should have made it a winner. Big block Chevrolet Corvette engine from the 'no substitute for cubic inches' school, check. Spaceframe, check. Mid-ship engine, check. Power-to-weight ratio more than adequate, that's another check.

The fly in the ointment was the driving position, over slung over the front axle. It must have been akin to driving a bad-tempered VW Kombi on steroids. It was an exemplary answer to the question, 'What can possibly go wrong?' But it did have some ideas that were at least related – in a third cousin sort of way – to sane engineering practice.

## The meaning of Life

To stoop to the absolute bottom of the food chain, we have to crawl over to Life. Yet even then there was one redeeming feature. They bought the chassis and suspension from the First Racing Team, where I had drawn the layout, aero and geometry for a Cosworth kit-car.

However, as I had bailed out and was then working for Ligier, to ensure I did not end up connected to this project I brought an injunction to stop my name being associated with it, lest it became an albatross forever around my neck.

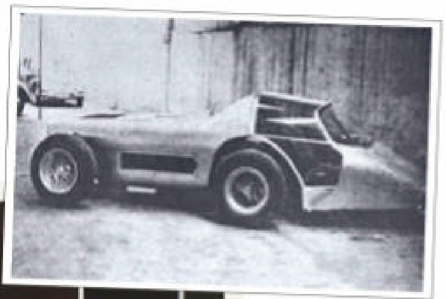
Designed around the then current First drivers, Pierluigi Martini and Marco Apicella, both classable as 'petite', it was a small car. The driver who eventually drove it was the Italian driver Gabriele Tarquini, who was a whole two spans bigger, and had to go on a crash diet just to fit in.

*The best laid schemes o' mice and men, gang aft agley,* it is said, and in this occasion things went agley indeed. The worse scenario outcome was set up when the March 88B we were also running in F3000 turned up for the first race at Jerez. It had thus far performed brilliantly testing at Misano.

We had a head start on most of the other March clients by building up the first example and taking it back to base, in Italy, on Christmas Eve, being ready to test by January 2. All the testing meant it was faster on the smooth sweeping circuit than all the Italian F1 teams, bar Ferrari, shaking down before going to Hockenheim.

It seemed at that point we had a good car.

**Innovative ideas don't necessarily translate into good racecars**



So off to Jerez for the first race of the season feeling smug. The malaise set in at the first session when the drivers would come in wide-eyed and palid, complaining they could not even take the long sweeper flat in top as usual over the bump, lest they become part of the scenery.

Scrabbling around the back of the time sheets was not the place we had envisaged. Hastily wheeling out the previous year's car showed the new car was four seconds off the pace, and the track bump seemed to have healed itself.

## Winging it

The diagnosis of a rather unsettling shift of CP with pitch and detaching boundary layer was addressed between sessions by cutting the rear diffuser upsweep by half and fabricating a new support for the front wing, elevating it a couple of inches to avoid having on-off front downforce due to ground proximity. Talk about winging it.

Returning to base, it was found in the wind tunnel that the model's flat bottom was made out of a too thin ally plate, changing its shape and making the tunnel L/D very good. With the added bonus it would flex and keep the CP stable, per cent migration to front with pitch was a stunning two per cent, a fifth of the usual.

The time spent chasing the solution for a major flaw in the current breadwinner for the team meant I could not spend much time on the F1 project, and it was farmed out to a consulting studio to be detailed and parts subcontracted.

The good thing was that after some major work on the F3000, not only aero but also stiffening the lower engine mounts, plus using the flex floor concept on the car itself, judiciously leaving the flat bottom stay wires slack so it bowed at the edges to produce more downforce, led to its first win four races later.

The con was that the F1 project evolution showed that subcontracting was a major mistake. The first tub arrived with most of the skins having delaminated from the honeycomb. The gearbox casting was porous and lacked material in critical suspension pick-up areas and the steering column had been re-drawn with a 10mm titanium shaft – light, but with a very torsionally flexible linkage. After hitting the lock stops, you could still turn the steering wheel another half turn. Let's call it fuzzy yaw response.

I did forewarn several of the prospective drivers of the cock ups, entreating them to avoid sitting in it with the engine on, lest their stay on earth be foreshortened, but after it was bought by Life and fitted with a W12 engine with a distinctive layout, I washed my hands of it.

It did actually pre-qualify for a race, sort of. At least, the cars ahead couldn't make it and it was called up as a reserve. Next session it blew the engine coming out of the pits.

It turned up at several further races, showing a perseverance only equalled by British Prime Ministers pushing unpopular motions…

If the purpose of the exercise was to bring the team to the public eye, it succeeded, now being the most notorious example of 'it seemed like a good idea at the time', and classed as the worst F1 car of all time, despite some stout opposition.

So next time you feel like pontificating on the results of a racing team, remember you might not know all the facts behind it.

**The most notorious example of 'it seemed like a good idea at the time'**

# Culture clash

## A brief comparison of IndyCar and Formula 1 leaves one lacking and, according to our man, tyres are largely to blame

Maybe I'm being too kind, but I think some of the criticism regarding the Baku F1 first practice farce, in particular Kimi Räikkönen's pop at the FIA – 'Formula 1 was made to look amateur' – was a tad harsh, especially bearing in mind the recent sudden loss of the very capable Charlie Whiting, previously responsible for overseeing track safety.

Anyway, it wasn't only the FIA's responsibility. The circuit organisation was at fault, as evidenced by its commitment to rightly compensate Williams for the serious damage to its FW42. Yes, it was a very embarrassing couple of gaffes, potentially very dangerous, and they should never have happened and must never be repeated. However, it does illustrate just how amazingly well organised and run grands prix are. Especially given the complexity of modern, high-level motor racing, with all the digital technology now incorporated and the fat tomes of Technical and Sporting Regulations to take into account and implement.

I'm no enthusiast of bureaucracy and consider it a necessary pain in the posterior, along with politics. The FIA definitely overdoes both. Nevertheless, maybe the usual smooth operation of a Formula 1 event is taken too much for granted. This particular issue of securing drain covers certainly needs more thinking about. In practical terms, welding or bolting them to their concreted-in frames is no good if the frame itself is broken. As for banging the recovery Hiab into a bridge, words fail me. They really do.


XPB

**Max headroom indeed. Who would have thought it necessary to have height restrictions on bridges crossing race circuits?**

## Amateur hour

Which leads me neatly to a gripe I've been wanting to air for some time. Given the expenditure of Formula 1, with teams boasting of their latest pop-up, multi-storey hospitality-cum-command-centre additions to paddock city, do any of them consider for a moment how incongruous it is to see a highly sophisticated but damaged racecar loaded onto a scruffy local garage low loader? How amateurish is that? There should be a minimum of two purpose-built retrieval vehicles, with trained crews, taken to all events for a fraction of the cost of hospitality.

As for men with brooms clearing debris off track – could we at least have hi-tech brooms? Brooms, and a laughably inefficient leaf blower, were in evidence at the recent NTT IndyCar Series Indianapolis Road Race, due to gravel and earth being spat onto the racing line from off-roading Dallaras – largely a consequence of the track being neither wet nor dry for much of the time.

It has been some time since I last caught-up with IndyCar, and it provoked in me an ironic comparison to Formula 1. Firstly, I never thought I'd say Formula 1 cars look big in comparison to IndyCars, but they do now, so much have the former grown since the advent of hybrid power units and all their aerodynamic appendages.

The IndyCar pit stops looked rather chaotic in comparison to Formula 1, with air jacks and their lines being thrown out of the way, a wheel rolling across the pit road and at least one car exiting with flames briefly blazing from spilled fuel. While Formula 1 stops are almost blink and you miss it, IndyCar's stationary 8-10 seconds appears agonisingly slow, but hardly surprising, as a consequence of just six crew members being permitted 'over the wall'. They also have to refuel, as well as change tyres and tweak the front wing, so actually it's good going. It just doesn't look it.

Even the pits facility, despite being at the hallowed Brickyard, looked less impressive, in contrast to the new and upgraded facilities of grands prix events. Yet the race itself was exciting, not just because of the weather, but due to the different strategies caused by alternative tyre compounds and, most significantly, fuel stops. Formula 1 please take note of the latter. There was plenty of overtaking and the winner was never certain, the lead finally changing on the penultimate lap. So it poses again the long-standing question – where should the emphasis lie, with technological showcase or great racing?

## Star turns

There's long been a divide between US and European-style motor racing in respect of spectacle vs technology respectively, and probably always will be, which is why attempts to amalgamate racing series for both almost always fail.

IndyCar seems fine as it is, although as a series it lost a lot of attraction for me, for one, when it became another Formula Dallara. Here, though, the driver is the star, and behind the scenes the relationship between driver and engineer is sacrosanct, while in Formula 1 it's driver and car, working with the latest technologies, as it always has been, and there is definitely more interest in Formula 1's approach.

Therefore it's interesting, surely, that the US championship seemingly has none of the tyre issues that currently beset Formula 1, proof that attempts to liven up the track action by deliberately manipulating tyre performance are nonsensical.

Way too much time, money and effort is being spent right now on tyre understanding and management. There can be no doubt that a large part of Mercedes' domination lies in the extensive research it must have carried out in this aspect of performance alone.

So what is the point of having a control tyre if it just further advantages the richest teams? If anything, Pirelli's compound and construction offerings this year are even more critical to a few degrees of temperature change than before, with pressures being adjusted constantly (see p20). This is blind-alley stuff, and detrimental to the level of competition among Formula 1 teams and drivers. Better to have an open tyre supply policy, providing, as with power units, that identical products are available to a minimum number of teams.

Unfortunately, after another tender process, the die has already been cast again in favour of Pirelli. The tyre manufacturer must therefore be held to account for better tyres if Formula 1 is to fully benefit from the regulation changes in 2021.

**So, what is the point of having a control tyre if it just further advantages the richest teams?**


# Max attack

**The FIA says it has run out of options to bring non-hybrids closer to hybrids at Le Mans. Now it's up to the teams…**

**By ANDREW COTTON**

There are many who will look at the results of the FIA World Endurance Championship (WEC) this year, judge the performance of the Toyota hybrids far beyond that of the non-hybrid cars, and lay blame at the door of the Equivalence of Technology (EoT). This is the process in which technology is balanced according to the best in class, and was originally introduced with new hybrid rules in 2014. It was intended to allow petrol and diesel engines to compete, as well as the multiple amounts of energy storage each hybrid solution could carry. Once Audi's diesel stopped racing at the end of 2016, and Porsche followed with its petrol-powered 919 in 2017, attention has turned towards the least considered group, that of the non-hybrids that was open to non-manufacturers only.

With Toyota standing alone as a hybrid entrant, the target was to bring the non-hybrid privateers closer in performance to the Toyota to ensure the customer teams on which the series relied stood a chance of competing. However, results in the 2018 / '19 season indicate they have not succeeded. Toyota has set the pole position time at every round of this season, and crossed the line first in every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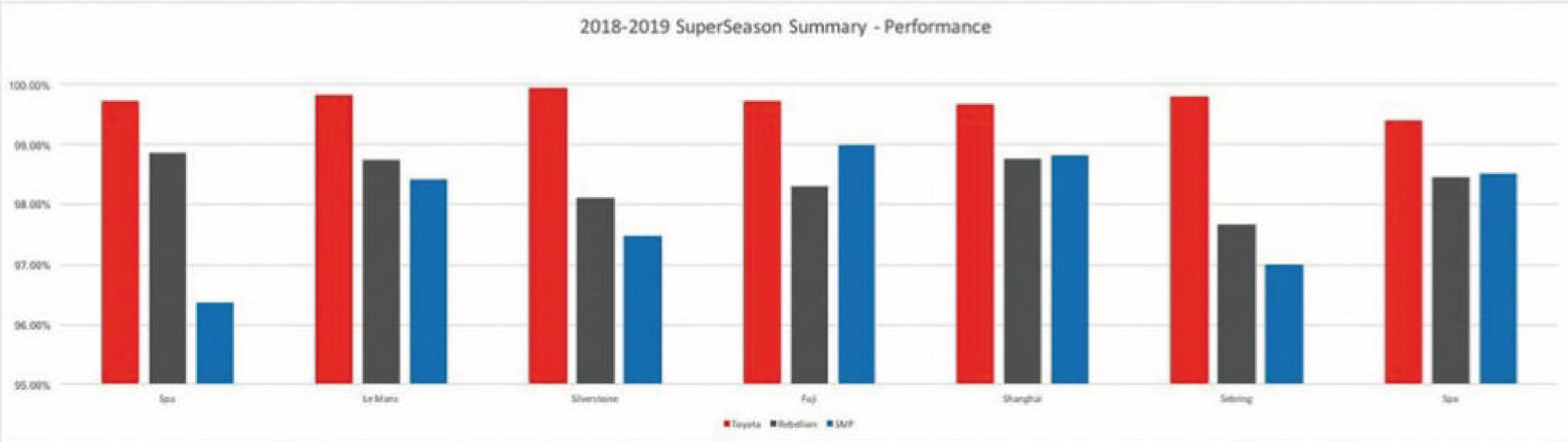
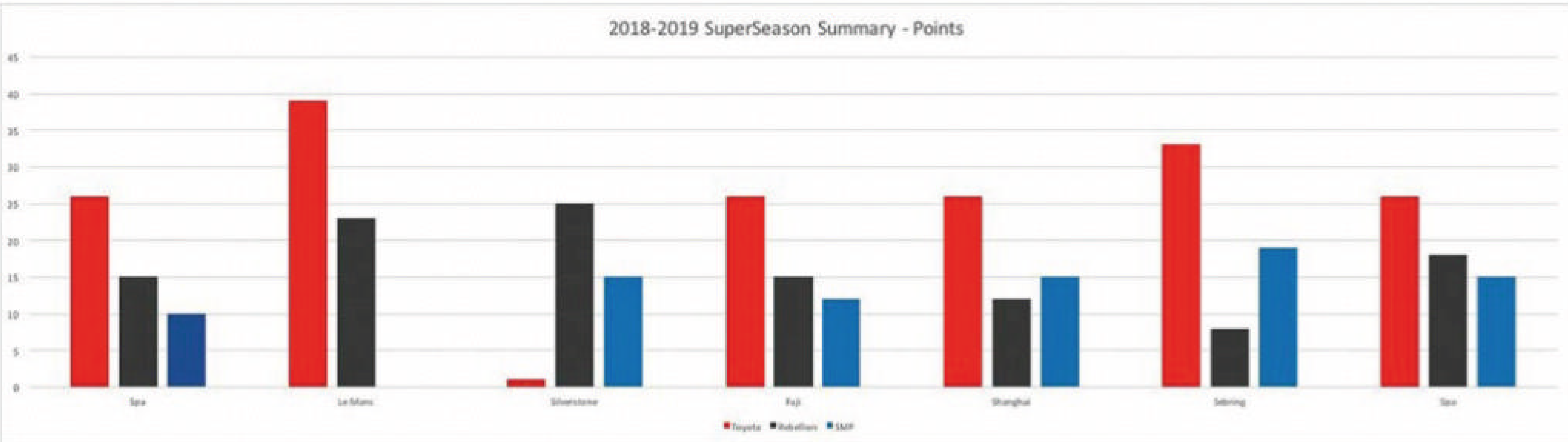
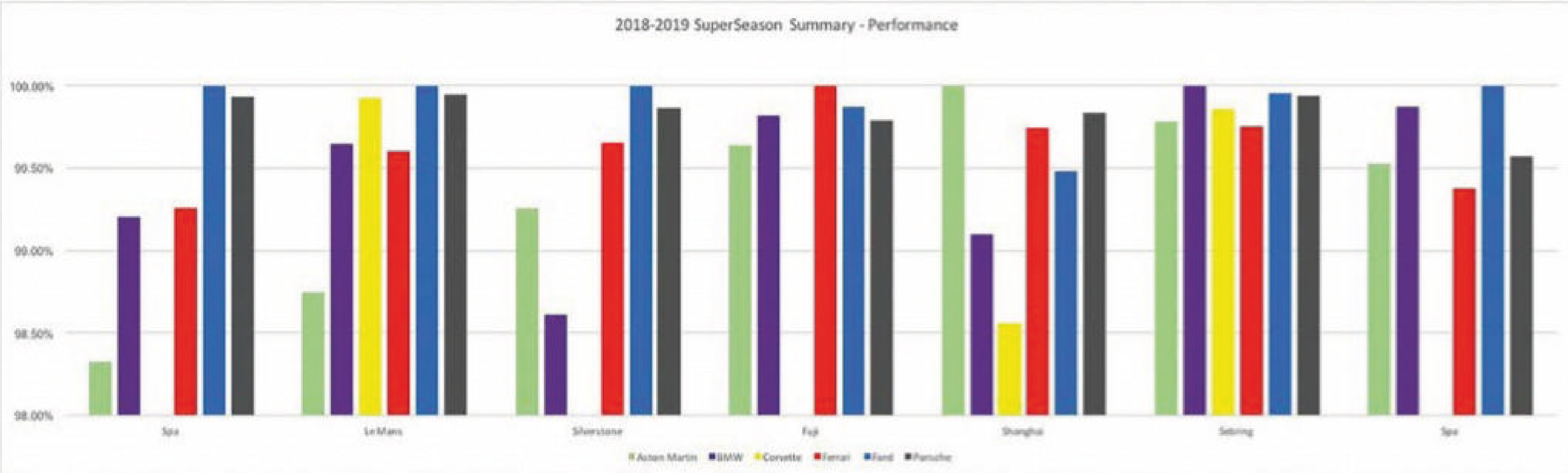


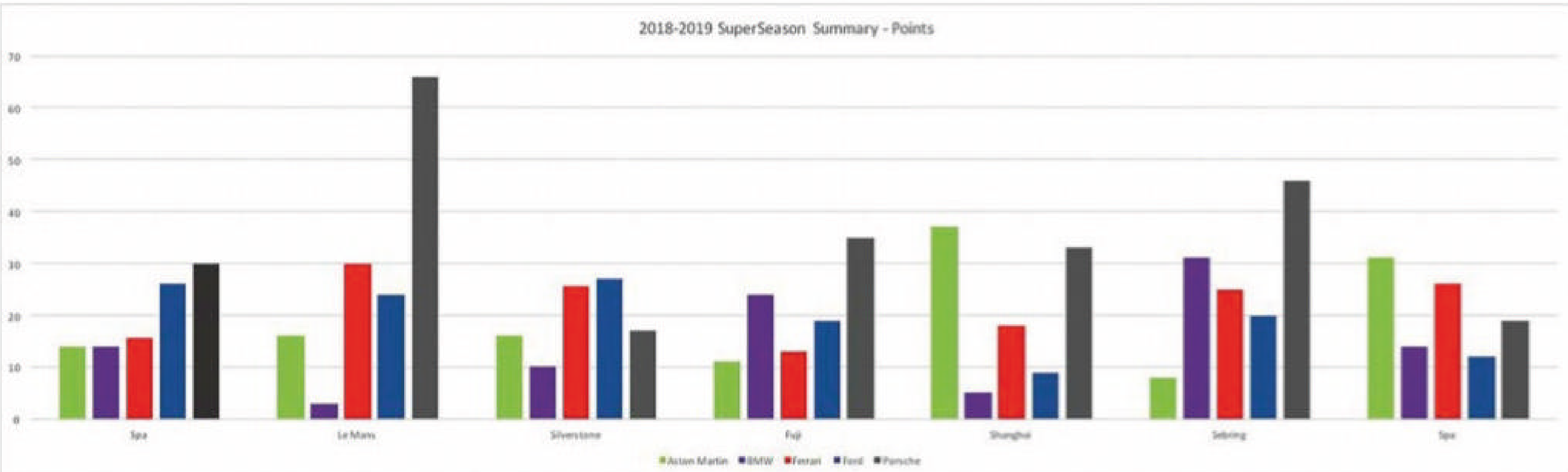

2018 / '19 LMP1 performance comparisons shows the Toyotas were running at close to 100 per cent at every track




Again, the clear winner in the LMP1 points standings, the only dip being at Silverstone where running over kerbs caused floor damage




Compare LMP1 to the 2018 / '19 GTE Pro performance graphs and you'll see there's far more competition in the ranks




And, as a result, points were more evenly distributed in GTE Pro throughout the season

race, too. The only time it was not classed as the winner to date was at Silverstone in August 2018, where the cars were disqualified after running over kerbs and damaging their floors.

The Equivalence of Technology table uses a mathematical formula to balance the cars, but that has not been enough to create close competition. While the factory-run hybrid cars all started from a broadly similar base in terms of funding and development, the non-hybrids operate on an entirely different budget and team structure, as well as design parameters. This makes the maths pretty much redundant, a fact noted by the FIA, which has artificially manipulated the figures to help.

Asking a customer-focussed racecar constructor to design a car with a customer engine or, more accurately, a car capable

With the Toyotas on pole for every race, and crossing the line first at every race this season, their outright dominance is clear, and a problem that the FIA have to deal with

of taking multiple engine installations, *and* compete against a manufacturer car was always going to be a tall order, especially as the hybrid has inherent advantages, not least of which is an estimated half a billion Euros spent on its development.

However, something close to parity is precisely what the FIA and ACO have tried to achieve in order to maintain the interest of existing and new teams, while also recognising Toyota would have to reduce its advantage to help to bridge the gap. The bodies' hands are now tied by the fact that, having reduced Toyota's performance in terms of the number of laps it can complete on a tank of fuel, and added weight mid-season, it will not go any further. That was confirmed in the EoT tables in October 2019: 'no adjustment will be requested to the Hybrid of reference,' according to decision 18-D001, the first decision taken by the endurance committee in 2018. This decision can be changed, but only by agreement with Toyota.

## Learning curve

The 2018 / '19 season was the transition year from summer to winter calendar. Along with the usual races planned for the tail end of 2018, there was also a repetition of the Spa 6 Hours and Le Mans 24 Hours, in the same season. Although the 2019 race at Spa turned out to be cold and wet, to the point it was interrupted by snow, the EoT figures published for the event were the first time like-for-like figures could be compared. The big differences in the comparable EoT tables shows the level of learning by both the teams and the organising bodies. 'I would say it has been a parallel learning process,' confirms the FIA's WEC technical delegate, Manuel Leal. 'Cars were not frozen [in spec]; the teams were learning their cars. Cars were on track very late, so even for the teams it was a struggle. Therefore, we published the EoT with the data sheets they provided. We had two data sheets; one for the engine and one for the aero. We checked this data and what could be the predicted performance of the cars. Absolute lap time is more difficult to predict, but for relative performance you know what the expected differences are.'

## Something close to parity is precisely what the FIA and ACO have tried to achieve

The first item in formulating the new EoT was to define the range of the fuel flow, so that engine builders could start work. This was a key parameter as design would of course differ between an engine capable of delivering a maximum flow rate of 105kg/hr or one that could deliver 120kg/hr. The maximum defined in agreement with the engine manufacturers was 115kg/hr, although the first EoT table came out with the non-hybrids set at 110kg/hr.

The first EoT table was created at the end of October 2017, for the pre-season test at Paul Ricard in April 2018, based on the predicted performance values. As some teams had not even turned a wheel at that point, it was largely based on guesswork. Testing also threw up some anomalous results which confused matters. Pre-season, at the pre-season test at Paul Ricard, Toyota stated its fears that the non-hybrid cars would be close to its performance, and mathematically the manufacturer may have been right. After all, it based its assumption not only on available information from the suppliers, but also on the reported impressive performance of the Dallara-built BR Engineering BR1 that had been testing at Aragon, Spain.

## Huge advantage

In practice, however, they were wrong and the hybrids have enjoyed a huge performance advantage all through the elongated 'super' season. The Toyotas won the first race at Spa

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in 2018 by two laps, and set a fastest lap of 1m57.442s, compared to 1m58.820s for the quickest non-hybrid, the Rebellion R13 – a gap that was far outside the pre-agreed half second per lap time difference by regulation.

Toyota admitted to being flummoxed as to why this should have happened when its maths, and rumour, had painted a different picture. For the FIA and ACO, too, it was something of a surprise and things didn't improve much at Le Mans where a 3m17.658 for Toyota compared to 3m20.046 for the Rebellion in race conditions.

From the start of the 2018/19 season, Toyota had been pegged back in performance to give the privateers a chance, and Toyota had demanded an advantageous lap time and stint length to compensate the performance they had given up to help to balance the privateers. However, in agreement with Toyota, this artificial gap was rescinded mid-season due to the lack of competition from the privateers.

The EoT is adjusted for every race, according to track length compared to the Le Mans circuit, but during the season the FIA and ACO were forced to make changes to the Le Mans figures on which the EoT is based. Recognising that the privateers were not performing or evolving as expected, the FIA and ACO changed the core values, to give non-hybrid cars and teams a helping hand and make them more competitive. They gave such help that by Spa 2019, according to the FIA at least, the non-hybrid cars had a mathematical advantage in race mode and in dry conditions. The picture remains slightly different in qualifying, where the hybrids are still able to use their full energy capacity in a single lap, while they also have an advantage in the wet (four wheel drive), and in traffic where the extra boost on demand can aid passing.

## Acceleration test

At Fuji in October, the core EoT values were changed to balance the stint length between hybrid and non-hybrid cars, and that was combined with a 26kg increase in minimum weight for the Toyota, and an increase in fuel flow for the non-hybrid cars to 115kg/hr. 'What is important is that once the car is on track, we need to have a more lenient approach to allow them some margin to develop because we could see they were struggling,' explains Leal. 'They were racing against a very well proven machine. [Toyota] were in such a privileged position to know what they were doing.

'The tyres are not the same, they can still develop them, and there are a number of factors that will always be in favour of Toyota. However, giving the non-hybrid cars such a big fuel flow allocation, which is above what the calculations say for the weight, we are artificially putting them at the level where they could reach Toyota.'

Artificially manipulating the system to help the privateers, though, can lead to mistakes in the figures. 'In Fuji, we made a mistake in the calculations, and that was in the prediction of fuel for these cars when they were not full throttle, or coasting,' confirms Leal. 'We had a transient regime we had not properly calculated. We ask the teams before every race for their own fuel predictions, and we concur to make sure they correspond, and that the simulations we have performed are correct.'

'This second order parameter is not easy to predict, even for the teams, because you have different driving styles. If you speak to them, between the drivers they have a big difference in fuel consumption. In Fuji they were forced to lift off more than they should because they were short on fuel per lap. We were matching a little bit what they sent us, and we discovered why, and for Shanghai it was corrected.'

**'We ask teams before every race for their own fuel predictions, and we concur to make sure our simulations are correct'**


**Aero is one area left where changes could make a difference, but the FIA acknowledges not all teams have the resources to maximise test opportunities**

## Despite measures designed to bring the cars closer together, there is still a marked performance gap between hybrid and non-hybrid

The Chinese race was also heavily affected by rain, to the point it was red-flagged, so there was less to learn there, but then at Sebring in March the Toyotas were even more dominant than usual. There, in an eight-hour race, the TS050s won by a staggering 11 laps. However, that was less to do with the EoT, and more to do with the Toyota's ability to soak up the bumps, its ride control systems being superior to the non-hybrid cars. 'You did not have to be an engineer to see that one car was driving around, and the others jumping around,' says Leal. 'It was nothing to do with the EoT.'

### Take two

The FIA also points to other variables that differentiate the performance of the privateers and manufacturer cars, including the tyres from Michelin, and privateer teams not taking the full allocation of test days available to them.

Michelin has developed new tyres for the 2019 / '20 season in a bid to close the gap to Toyota, and the FIA held an electronic vote among the teams to establish if they wanted to accelerate the development and run them at Le Mans in June 2019. This e-vote was held at the end of April, and as Michelin was not able to guarantee the number of tyres available for the Le Mans race, or to offer tyres to test extensively before the race, teams rejected the proposal.

At Spa for the 2019 race, it was possible to see how far the teams, and the FIA, had come in their understanding of the new LMP1 cars, and the compromises that had needed to be made. The Toyota ran at its minimum weight of 904kg and had no other changes throughout the season from the opening race.

However, the non-hybrid table looked completely different, with the turbo and non-turbo elements separated into their own columns mid-season. Cars powered by normally aspirated engines saw their weight reduced from 833kg in 2018 to 824kg in 2019, while turbo cars remained at 833kg. This was partly due to the extra weight of turbo cars which carry more hardware and are therefore heavier than n/a cars, plus carry an aero disadvantage due to the cooling requirement. However, the minimum weight reduction has led to other problems, namely the flexibility to play with weight distribution.

### Maximum energy

'We realised that was something that had also evolved from the previous situation in which there were some principles of hybrid and non-hybrid,' explains Leal of the separation in the EoT table of turbo and non-turbo cars. 'Due to complaints, we decided it would be fairer to split these sorts of cars, especially with the gap to the Toyota. The turbo cars could not go lower in weight, and therefore this prevented us from doing the adjustments that would be needed. If we gave them [a maximum fuel flow of] 120 [kg/hr], they would have to change the hardware. They told us clearly that they had designed their engines for 115kg/hr and not more.'

At Spa, 2019, there were further changes to help the non-hybrid cars. Their maximum energy per lap was unlimited for the first time this season, allowing them to complete the lap without a fuel-saving lift. This was a measure designed to help them in traffic, and in qualifying. The original plan was to give them enough fuel per lap that they would not require a lift at all, but the drivers were unable to do so. The maximum fuel flow was maintained at 115kg/hr. Since the same event in 2018 the maximum petrol per stint has increased from 47.1kg to 52.8kg for a turbo car and to 56.5kg for a normally aspirated one. The n/a engines have a larger fuel rig restrictor, and so have a higher flow rate and can get that extra fuel into the tank as quickly as the turbo cars, incurring no penalty for the larger tank.

Despite these measures designed to bring the cars closer together, there is still a marked performance gap between the hybrid and non-hybrid concepts as the cars head to Le Mans for the final race of the elongated season. Despite calls to make further changes, the FIA says its ability to help any more is now restricted not only by physics, but also by its own regulations that were introduced to protect the teams and manufacturers from huge changes.

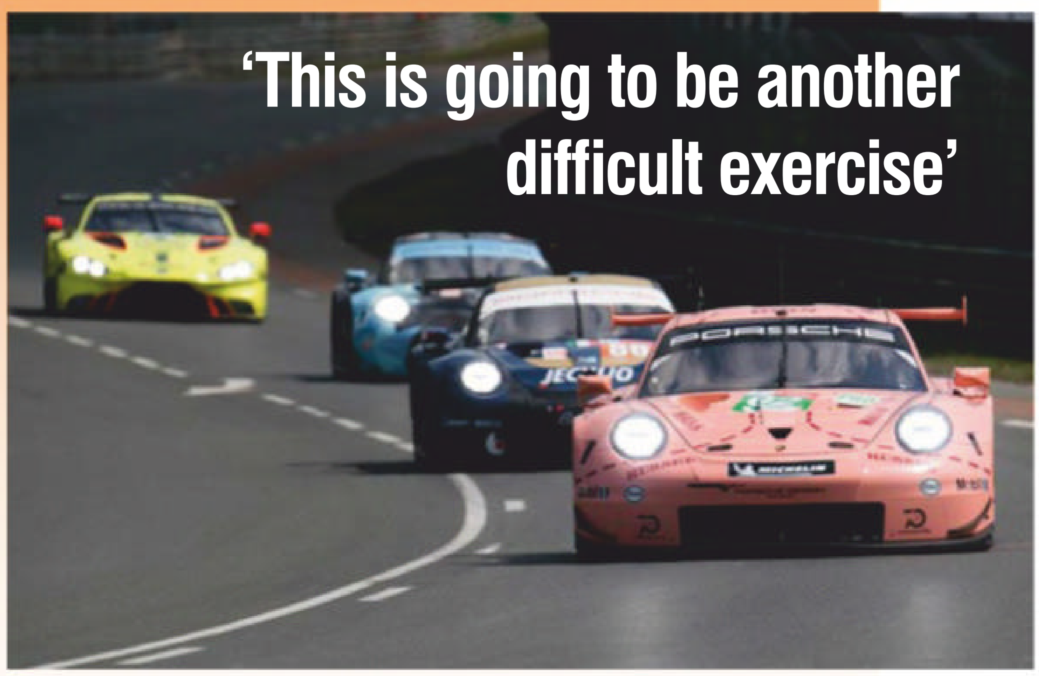
The aero development for the privateer has not come as fast as expected, and the teams have, according to organisers, also not used up their entire allocation of test days. This has limited the visibility that the FIA and ACO have had on the privateer cars.

### GTE Pro takes FFM

**The 2018 Le Mans 24 Hours saw a record low number of overtakes in two classes, GTE Pro and LMP2. The former saw just nine changes of lead at the start / finish line over the course of the 24 hours, while LMP2 was even worse – just three in the first 10 laps, and then nothing for the next 23 hours. Part of that was the balance of performance between the cars, part was the safety car procedure, and part was the pit stop regulations that limited strategic options.**

**The FIA and ACO took a view on that and elected to introduce the Sentronics fuel flow meter into the GTE category for the first time to accurately gauge fuel consumption, eliminate the 14-lap maximum stint, and try to re-introduce some strategic thinking. The meters are used in the US-based IMSA series, and so are familiar to all competitors bar Aston Martin, which ran them for the first time at Spa in 2019. The fuel flow meter does not limit the fuel flow, but does give an accurate picture (to within 0.25 per cent by regulation) of the amount of fuel a car uses.**

**'The purpose is to be able to collect some data to be more accurate with the stint predictions, and see how much fuel we will give to the cars according to fuel consumption,' explains the FIA's Manuel Leal. The BoP is automatic for GTE cars, with specific adjustment permitted for the Le Mans 24-hours. 'This is going to be another difficult exercise,' says Leal. 'We have to see how we keep the strategic component of a race like Le Mans, and the BoP and result on the other side.'**




In an effort to increase strategy, GTE class cars had fuel flow meters fitted this season

**Two other changes are that the pits will close during a full course yellow, to prevent a car being able to take a quick pit stop during a short yellow, and the waiting field will not be kept in the pit lane until the next safety car, an issue that effectively decided the GTE Pro race in 2018.**

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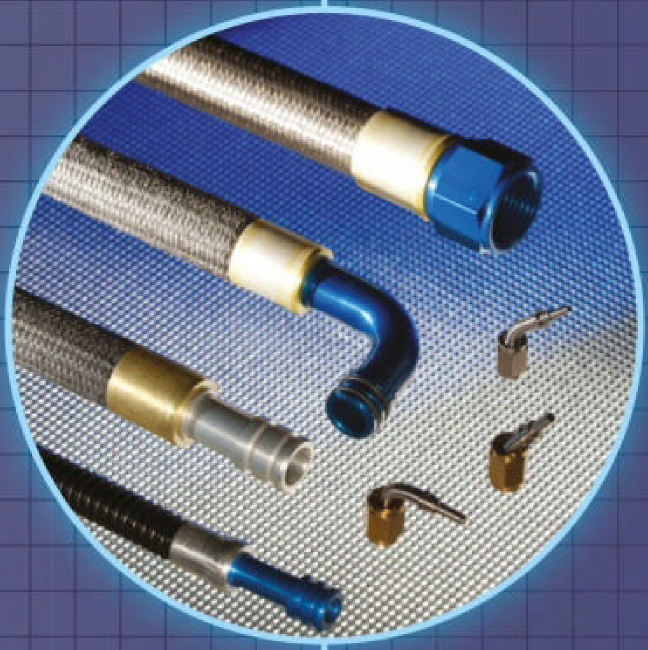

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The non-hybrid cars cannot carry any more fuel as their tub design does not allow for a bigger tank. They can drink the fuel no quicker as the engines are designed to consume at 115kg/hr maximum, and cannot run any lighter. Any remaining performance gap must now be made up by the teams themselves and they must close to within the boundaries of the EoT as set by Endurance Committee. 'We don't have many more things we can tweak apart from weight, power and aerodynamics,' admits Leal. 'Aero they are already working on with some gains, and you can see that if you look at the lap times, but the Toyota is much quicker.

'The Endurance Committee cannot just do whatever it wishes,' continues Leal. 'There are a number of things already agreed with everyone before the season started and that were approved at the Endurance Commission, and we have to abide by them. This stiffness of the system is intended to protect both the manufacturers and competitors, but it also takes away some options from our hands because we have to respect our own regulations.'

## Fuel consumption

For the Le Mans race itself, the EoT had to be set after the test day, held two weeks before the race and after *Racecar* went to press. The non-hybrid cars were confirmed to run during the test day at a flow rate of 115kg/hr, and the privateers hope that they will be allowed to keep this flow rate for the race.

For their part, the privateer teams have stepped up in terms of development. At Spa, Rebellion introduced upgrades to the Gibson engine, better designed to run at the maximum 115kg/hr flow limit but, due to the weather, was not able to set representative comparable lap times to the 2018 race. Likewise, the SMP team, which runs an AER turbo engine competed at Spa in its high-downforce bodywork after it saw the weather forecast for the 2019 event and so did not run its Le Mans spec aero.

The FIA and ACO therefore go to Le Mans needing more information. 'Le Mans being a different animal, if we left things as they are, probably we would be surprised,' says Leal. 'The race pace there is a different thing, too. And traffic. There are many things where having a hybrid would be an advantage. The weight is going to be much less important at Le Mans than here [at Spa]. We work with sensibilities. Each horsepower is not worth the same at Spa as at Le Mans, and it is the same with power and each point of aero.'

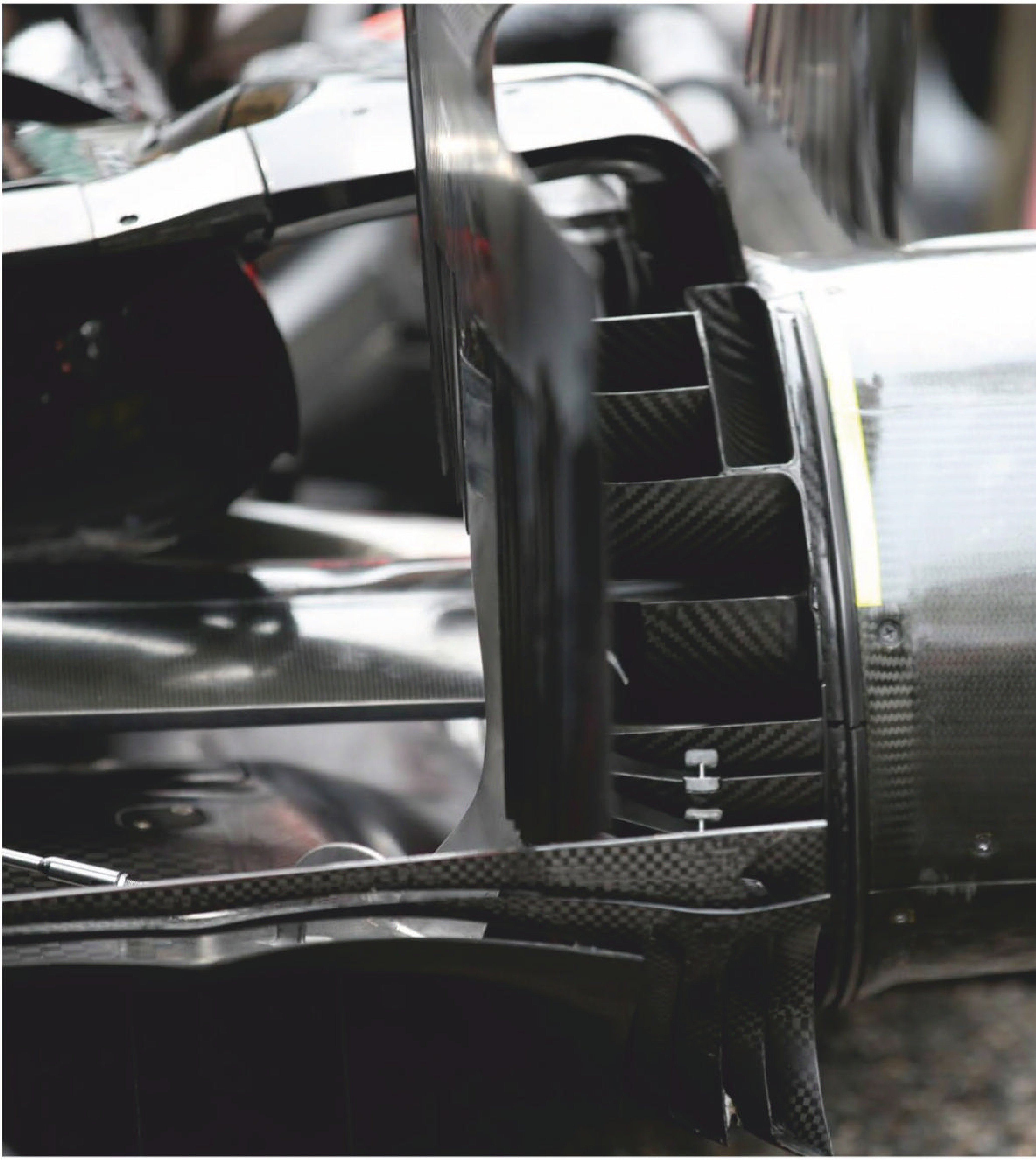
**The battle at Le Mans will still, as always, come down to reliability**

The Gibson engine used by Rebellion is now optimised for the current 115kg/hr fuel flow rate. If that is reduced for the Le Mans race, the engine will need re-calibrating to suit

The battle at Le Mans will still, as always, come down to reliability, but if the non-hybrids can be in a position to apply some pressure on the Toyotas then there is a heightened risk of an incident for the factory cars. Toyota will go to the race with a comfortable pace advantage, even with the EoT figures manipulated in favour of the privateers, and it is their race to lose.

Toyota is only too well aware of this, and will be doing everything it can to maximise its performance at the final race of what has been a long, and for them at least, an extremely successful season.


Even if agreement can be reached on how to better balance hybrids with non-hybrids, it all goes out of the window at Le Mans where the advantage of hybrid is reduced



# Cool runnings

The design of the rims, carbon shrouds and the overall wheel assembly has seen major innovation as teams focus their efforts on manipulating the hot air from the brakes for both rim heating and aerodynamic gain

## How are teams utilising brake cooling for rim heating, tyre warming and additional aero performance? *Racecar* investigates

**By GEMMA HATTON**

There is a reason why the F1 pit lane is obsessed with tyres, and it's because tyre management is the single biggest performance differentiator between all the teams across the grid. You can have all the horsepower and downforce in the world, but if you can't transform that load into tyre grip, you will forever lose lap time.

Teams use every trick in the book to not only try and bring the tyres up to their optimum working temperature, but to maintain that temperature throughout the race. The latter is particularly challenging because as the rubber wears away during longer stints, there is less tread to generate that internal heat, and tyre carcass temperatures decrease and drop out of the working window. When engineers say tyre management is a 'black art', they are not joking.

> **Wherever there is airflow, there is an opportunity for the engineers to extract aerodynamic performance**

'The tyres have a very narrow working window, and it is a real challenge to keep them in that window from start to finish of a stint,' says Andrew Green, technical director at Racing Point. 'It's easy to go over the working window at the beginning of the stint, and it's easy to fall below it by the end. Trying to keep the tyres in that middle region, and all at the same time, is what we aim for. We don't get it right all the time. If I'm honest, we hardly get it right at all.'

### Blowing hot and cold

One of the key tactics to managing this sensitive rubber is to utilise the hot air that has been used to cool the brakes to transfer heat to the rim, which then radiates that heat through to the tyres. This rim-heating effect is not revolutionary, and has been used by teams for many years, across many categories. However, with the 2019 regulations reducing the window of opportunity for aerodynamicists, and the tyres continuing to be so temperature sensitive, this continues to be one of the key areas of development this season.

With each team's design different to the next, it appears no one on the Formula 1 grid has quite found the optimum solution yet. At each corner of the car lies an intricately packaged wheel assembly, the primary structural part of which is the upright. This is where the brake disc as well as the wishbones and pushrods of the suspension are attached to. The upright also carries the stub axle and the bearings, which is effectively what the wheel is bolted to.

'The design of the upright has become increasingly affected by the need to feed cooling airflow to the brake disc,' explains Ben Agathangelou, head of aerodynamics at Haas F1 team. 'When I started, the upright was a triangulated bit of metal that held the wishbones, but it has now become a more integrated design to meet the aerodynamic cooling flow demands. We use FEA to ensure the structures [of the upright] that are compromised by aerodynamics can satisfy the necessary limit or fatigue loads, but you're consciously compromising the ideal in order to satisfy the aerodynamic side of the equation.'

Then there is the braking system, which has seen significant changes this year to cope with the more restrictive aerodynamic rules of 2019. Simplified wings have led to a decrease in downforce, but an increase in top speed and reduced aero braking force. Therefore, the brakes have to do more work to slow the car down, resulting in more energy to dissipate.

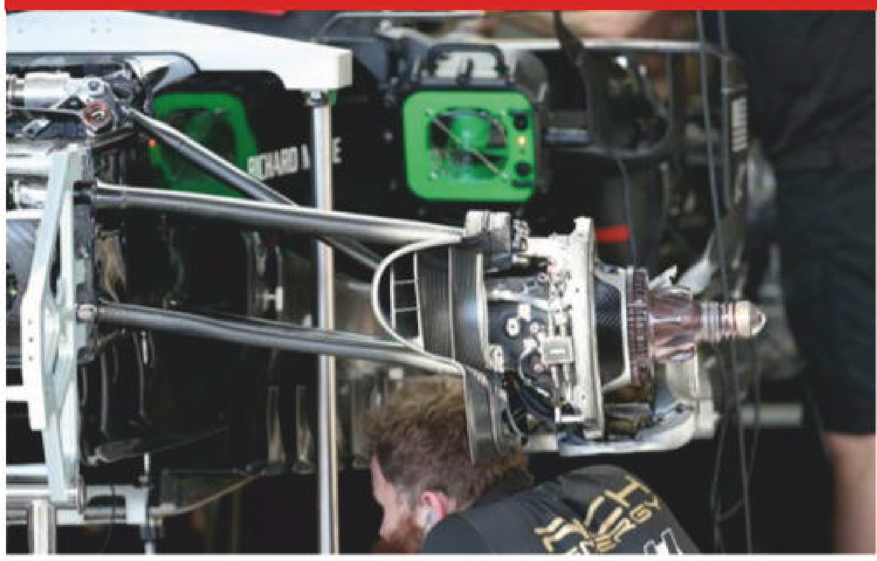
Keeping the brakes cool is a continuous battle for the designers at the factory, the engineers on the pit wall and the drivers out on track. Like tyres, brakes have a working window and if either the calipers, brake fluid, pads or discs overheat, brake performance can fade, affecting driver confidence and lap times.

Carbon discs wear by a chemical process called oxidisation. Carbon breaks down in the presence of oxygen and this oxidised material turns to clouds of black dust, which you can sometimes see during heavy braking. This wear rate is non-linear and after a certain temperature can become exponential. As the disc wears, there is less material to absorb the braking energy, so the disc becomes less efficient and therefore hotter, increasing the risk of further oxidisation.

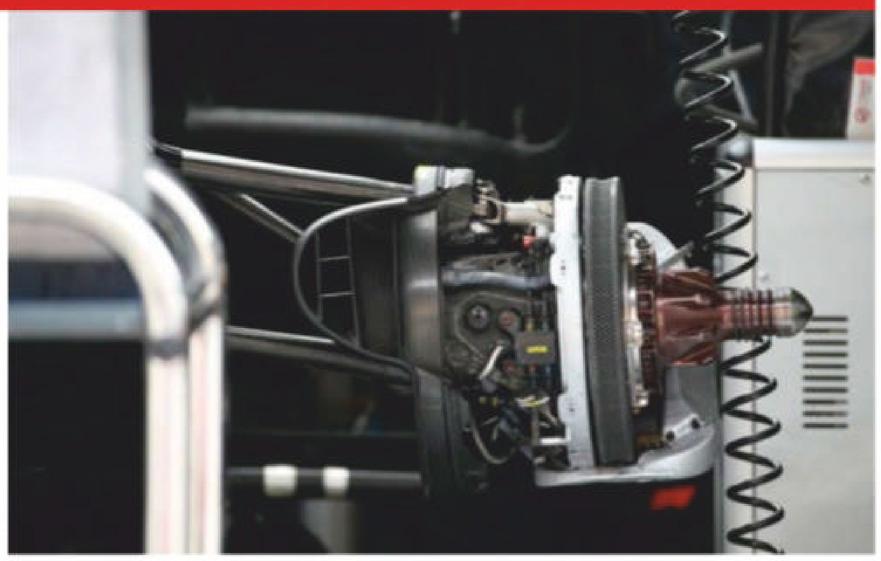
## Braking demands

'To cope with the increased braking demands [of 2019] we have improved a new drilling pattern for the front discs with 1,500 holes, seven layers of them,' highlights Giovanni Clemente, Brembo Racing F1 race engineer and telemetry data analyst. 'Those discs have been introduced specifically to cope with the demands of the new cars, and we will use them

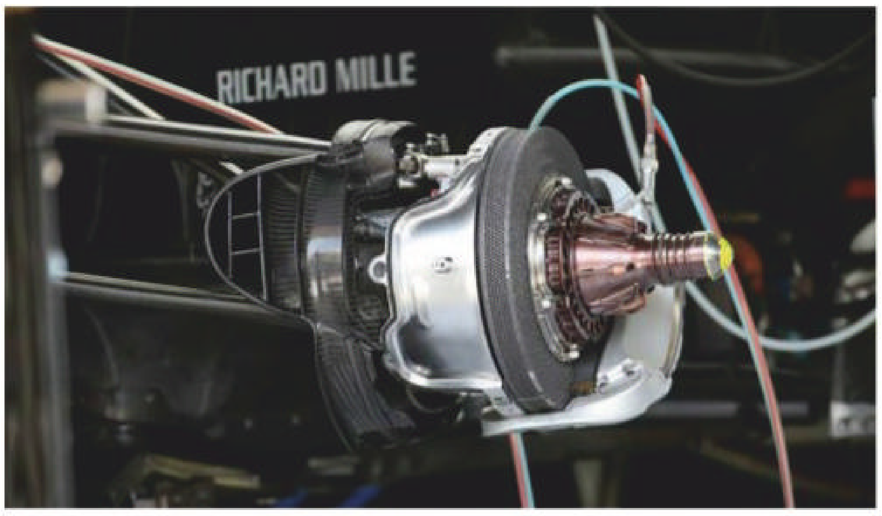
## How the wheel assembly is built up



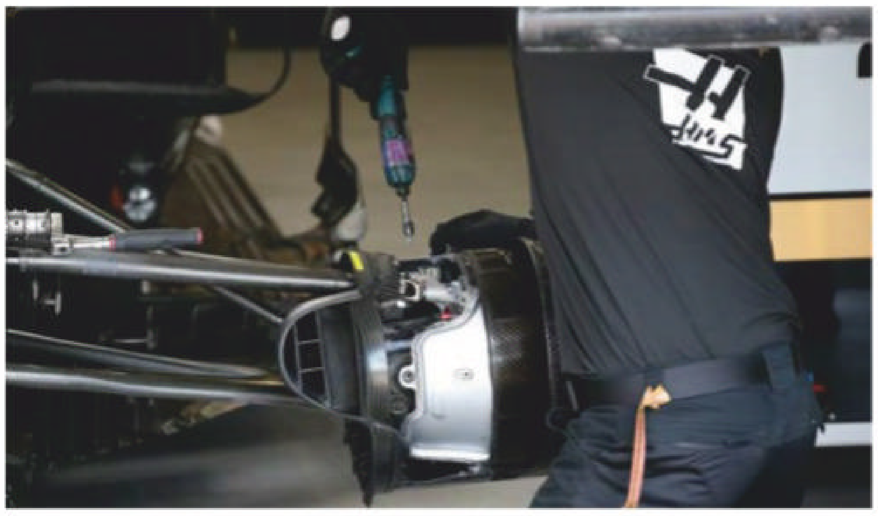
A stripped back version of the Haas VF-19 front left wheel assembly



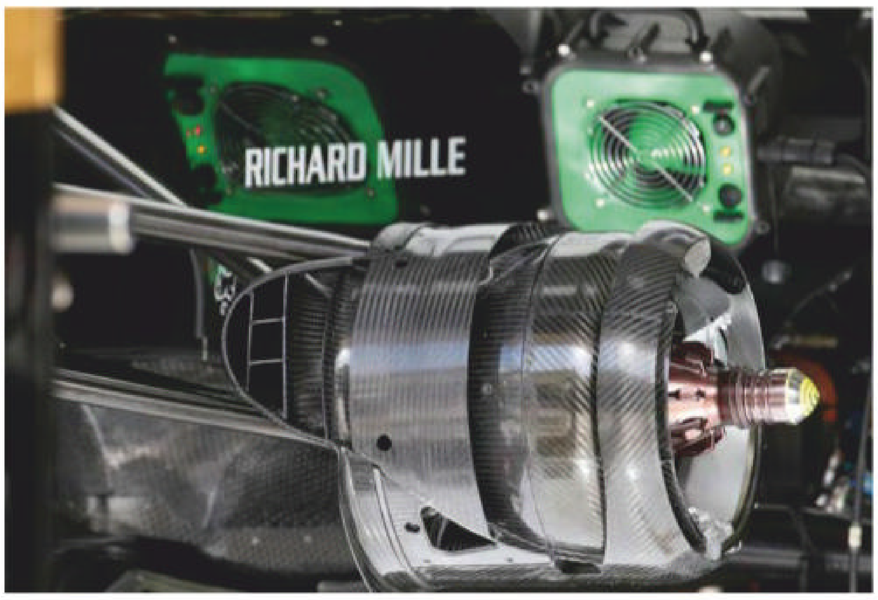
The same front left wheel assembly with the addition of the brake disc



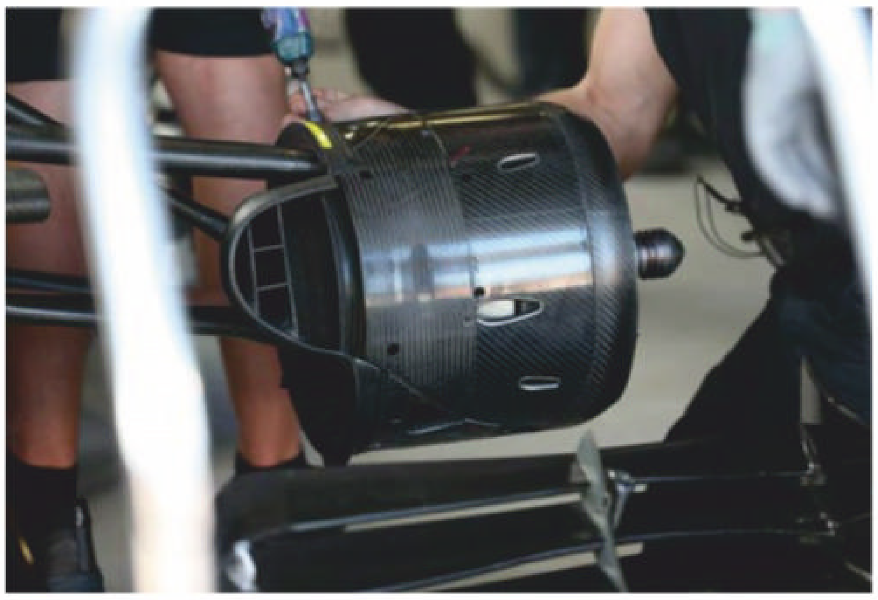

Internal ducts are then added, which appear relatively simple on the Haas VF-19



The outboard carbon composite shroud is then attached to the wheel assembly



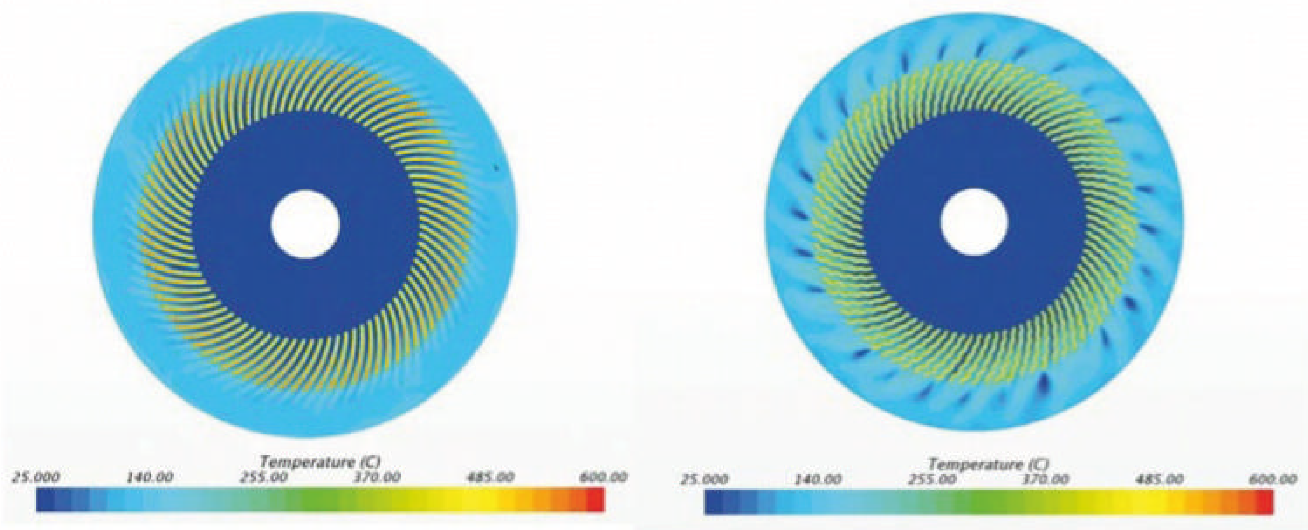

The inboard section of the carbon composite shroud is then added



Finally, the full carbon shroud is added, with some holes to help with rim heating

Cool air is channelled from the brake duct inlet down towards the caliper which is clearly shown on the rear of the Alfa Romeo at Barcelona (left) and the Haas at Melbourne (right)

**'The area around the pistons [in the calipers] is critical to extract the heat from to keep the brake fluid and seals cool'**




CFD analysis showing the temperature distribution of the air as it travels through the ventilation holes in two non-F1 brake discs. These holes can either be curved (left), wavy (right) or more complex, which will be the case for F1 brake discs

at the toughest tracks for us like Bahrain, Abu Dhabi, Singapore, Canada and Monaco. So those are available to teams, along with versions with 800 holes and another with 1,200 holes.'

The temperature of the brake pads also has to be maintained, as overheating the pads can drastically affect the coefficient of friction between the pad and the disc, giving the impression of brake fade. 'There are different patterns for brake cooling with the pads too, but the design priorities are a bit different as the pads play a key role in the stiffness of the whole system. The key with the pad drillings is not to reduce the overall stiffness when compressed [between piston and disc], and for 2019 we have brought in some new patterns and new shapes. This was a lot to do with the way different teams decided to split the heat between the caliper, the disc, the tyre and the rim.'

Adding to this hot headache is the fact that the pads and discs can reach temperatures of up to 1,200degC, while the calipers have a maximum operating temperature of roughly 230degC. Therefore, within the tightly packaged environment of a Formula 1 wheel assembly, the calipers actually require much more cooling than any other part of the braking system.

'If you go beyond the maximum working temperature of a brake caliper then not only will you exceed the temperature limit of the brake caliper body material itself, but you also heat the brake fluid,' explains Oliver Moore, F1 race engineer at AP Racing. 'As soon as you start heating the brake fluid, the pedal feel will drop off rapidly. This is why most teams after each session will flush the brake system with brand new fluid and re-bleed the brakes, just in case the fluid in the caliper has overheated, though most teams can control it pretty well now,' Moore continues.

'You also have the brake disc and pads running at 1,000degC, which the pistons of the brake caliper are in contact with, and these pistons are immediately next to the seals. If the seals get too hot then you have the ultimate failure where the caliper leaks and the pedal goes very long because the driver is pumping fluid through the system and into the wheel rim. So, the area around the pistons is critical to extract the maximum heat from to keep the brake fluid and seals cool.'

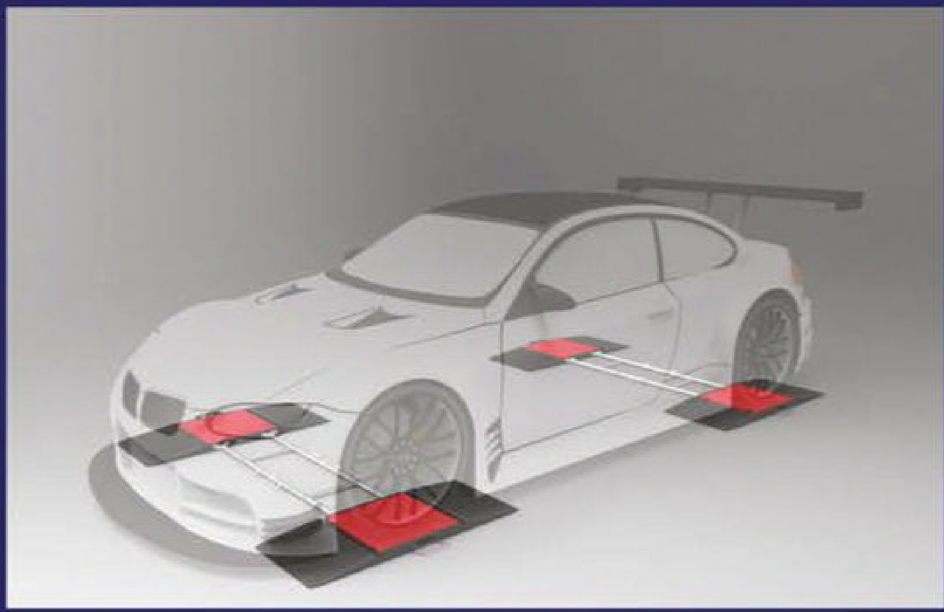
Typically, the cover side of the caliper (the side you could theoretically see through the wheel) is the hottest. This is because it rarely receives air flow and teams don't want a large gap between the caliper and the carbon shrouds. As a result, the air surrounding the caliper can often be hot and stagnant. To mitigate this, calipers can be designed to emit as much heat as possible. 'Some teams have the philosophy that they need more mass in the caliper to absorb more heat, as well as incorporate fins into the design to increase surface area to disperse the heat – similar to radiators,' highlights Moore. 'Other teams just want the lightest caliper possible.'

## Blowing hubs

In addition to the clever design of each individual brake component, the most effective way to mitigate heat is to feed the entire system with continuous, cool air. This is achieved by brake ducts that sit on the inboard side of the wheel on both the front and rear axles.

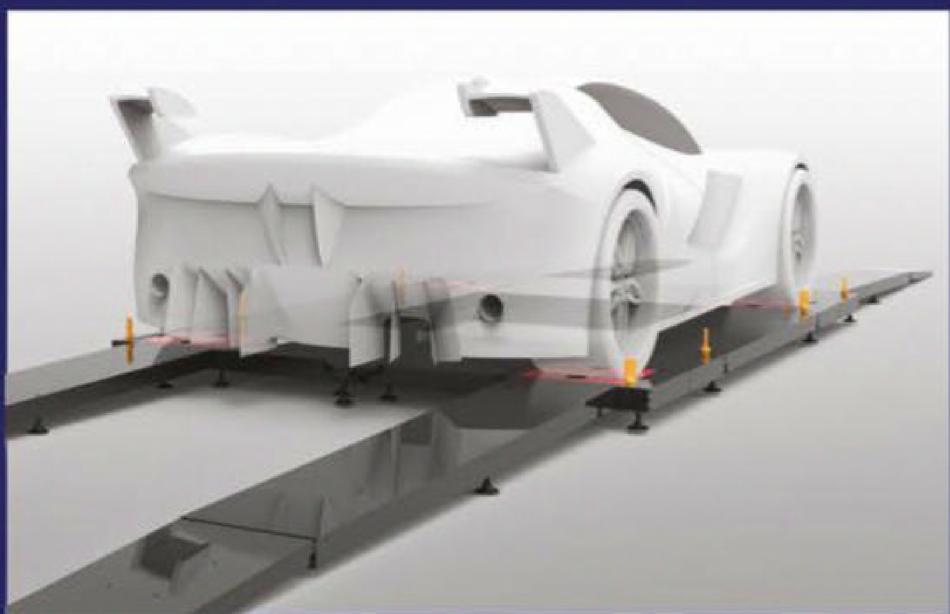
'The entry scoop splits the air up into several different channels, and each of those channels has a different function. The first function is to cool the brake disc, so there's a portion of air that gets sent to the inside diameter of the brake disc, which travels through the cooling vent holes, and that's purely to keep the brake disc temp below its maximum temperature,' explains Green. 'The second channel of air goes to the caliper, which

**Overheating the pads can drastically affect the coefficient of friction between the pad and the disc**





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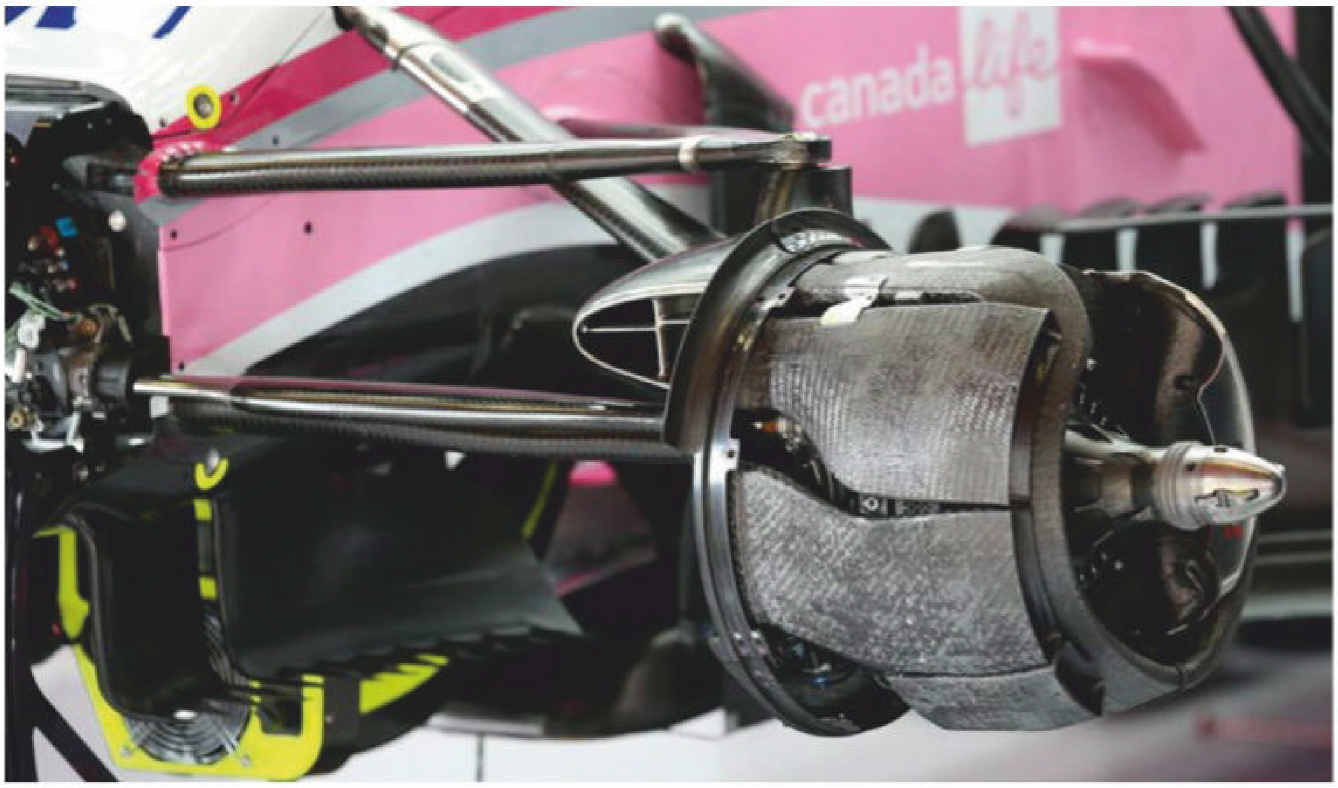
## 'This air that is blown outboard tends to drag all the dirty air that is being created behind the wheel out with it, and that's the aerodynamic part of the brake duct'

has a much lower working temperature then the disc, and that actually requires quite a bit of air to keep it cool because you have a disc at 1,000degC and a seal at 200degC. There is very little aerodynamic performance to be gained from these two methods of cooling.'

However, as is usually the case in Formula 1, wherever there is airflow, there is an opportunity for the engineers to extract aerodynamic performance, and it is no different with brake ducts. 'The third portion of air is what we're really interested in as far as performance is concerned,' says Green. 'We jet this air past the caliper and the disc and then out through the spokes of the wheel as fast as we can. This air that is blown outboard tends to drag all the dirty air that is being created behind the wheel out with it, and that's the aerodynamic part of the brake duct.'

Teams used to achieve the latter through 'blown hubs' where this air would be channelled through the centre of the stub axle, but this was promptly banned. 'These were hollow stub axles that allowed flow to be taken by the brake duct and shoved outboard through the axle,' explains Agathangelou. 'As the cars are faster this year, we need more cooling flow, but the size of the intake is limited for 2019, which makes life much more difficult. So we have to make better use of the flow to cool the now hotter components.

'But the brake ducts in an operative sense haven't actually changed. All that's happened is they've become much more restrictive on what is visible on the inboard side, with respect to how the front brake duct is constructed and how big the inlet is. We used to have these big winglets hanging off the front brake ducts, but we don't have them any more so we've found ways of making little ones, and everyone has done something quite similar within what has been a more restrictive rule set.'




The front left wheel assembly of the Racing Point RP19 with the carbon shrouds removed. The carbon ducts can be clearly seen and channel air towards the caliper, the brake disc and through the spokes of the wheel for rim heating and aero gain

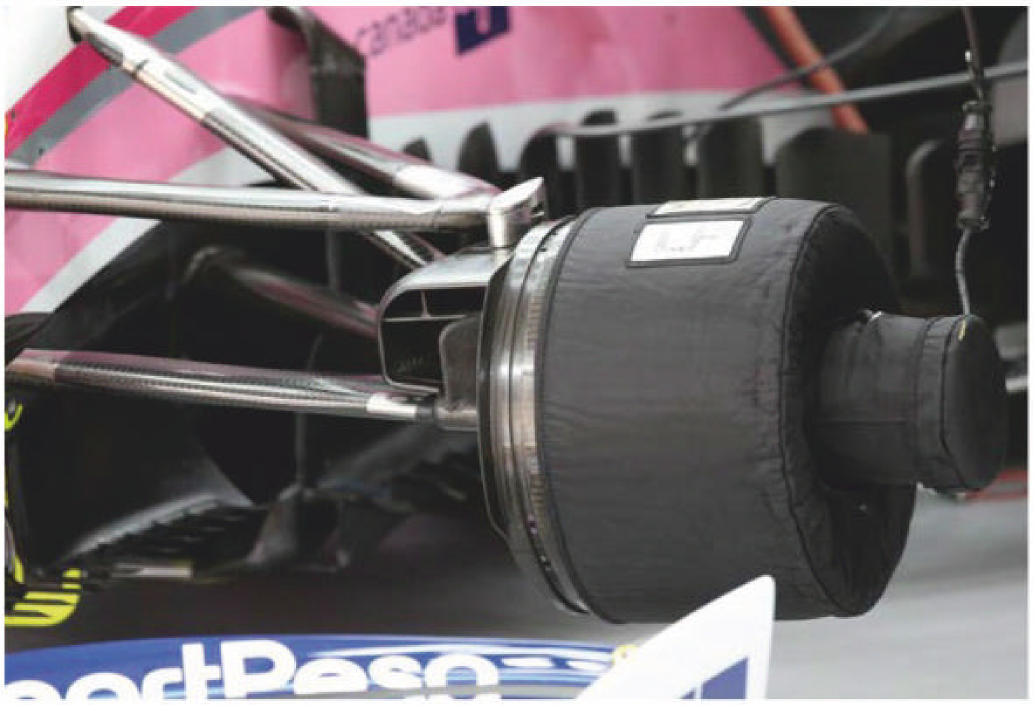
The rear tyres don't usually require warming up and so teams direct the hot air from the brakes out of the rear brake ducts that are located inboard of the wheel. There are also various outlets within the carbon shroud to allow the hot air to escape

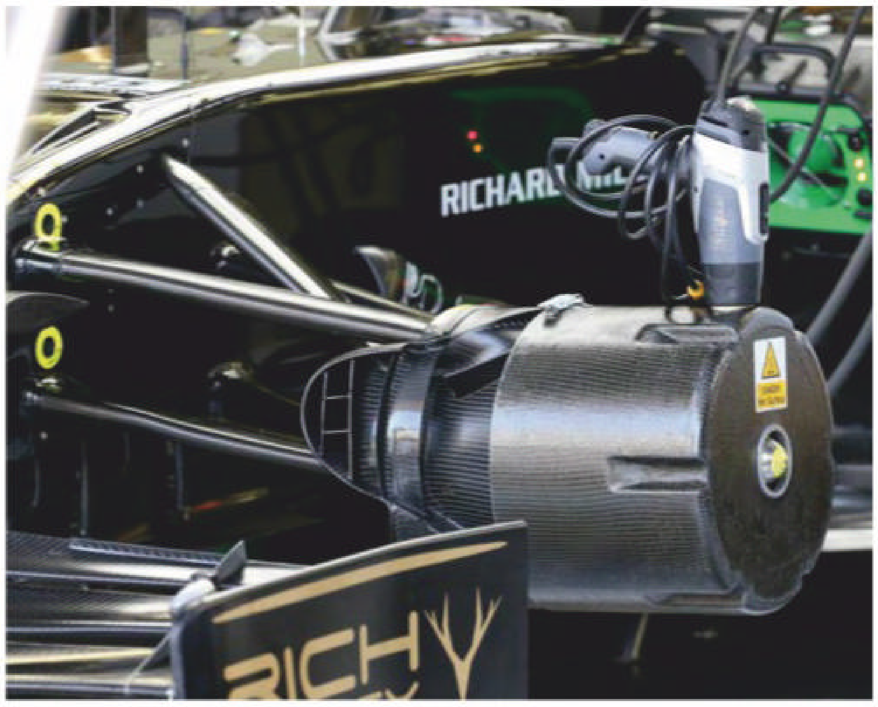
## Rim heating

It's not just aero gains that can be achieved by channelling air through the rims. The real innovative thinking lies in the fact that teams utilise this air to heat the rims, and then the tyres, affecting running pressures. 'If we are at a circuit where we need to heat the front tyres up, then we'll pass the air through the inside of the rim, where we'll put small turbulators to not only increase the surface area, but also mix the air to try and heat the rim,' explains Green. 'It is quite low velocity air that hasn't got a lot of energy aerodynamically, but has a lot of heat because it has just passed through the brake disc, so it is several hundred degrees. The hotter rim then radiates that heat to the carcass of the tyre, which is another six inches away from it. That's what we're trying to achieve with rim heating.'

Green estimates that for every 10degC increase in rim temperature, teams will see approximately one degree increase in tyre carcass temperature. 'It also increases the pressure as well, and increasing the pressure works the tyre harder, which generates heat in its own right, so it works through two mechanisms,' continues Green.

'When you get towards the end of a tyre's life, the rubber is thinner as it has been worn away so it's cooling down and the pressure is dropping at the same time. To increase that pressure and that temperature you can ask the driver to move the brake bias forward to get the brakes even hotter to generate tyre temperature at the front. We have a small amount of freedom to do that, but it is small relative to what we can do at the rear. It uses more fuel, but at the rear we can change the brake bias and engine braking to put more energy into the brakes and heat the whole thing up, which we can then direct onto the rim to heat the tyre up. We'll tend to just do that towards the end of the race, and if the tyre temperatures have fallen.'





**To ensure predictable brake behaviour, the entire hub assembly is heated up to running temperature with either heated blankets or heat guns before the car leaves the garage**

The team's quest for a good car balance often hinges on tyre temperatures. The carcass temperatures on the front axle are usually too cold, leading to understeer, which is why teams experiment with tactics such as rim heating and boosting pressures to ignite the fronts, whereas at the rear, carcass temperatures are usually too high, and this overheating of the rubber leads to oversteer. It's a difficult balance, trying to continuously warm the fronts to minimise understeer, whilst at the same time cooling the rears to avoid oversteer.

'Generally, at the rear of the car we are trying to keep the tyre temperatures as cold as possible. These are rear-wheel drive cars and there is enough energy going into the rear tyres that you don't need to heat them up [apart from at the end of a stint],' says Green. 'So we don't even want to blow the hot air at the spokes because that will still heat the rim, which will radiate onto the tyres.

'We actually insulate the disc and caliper and, after blowing the cool air through these components, we'll exit that air inboard of the tyre and keep it away from the rim altogether.' This is why at the rear of all Formula 1 cars you will see a complex arrangement of horizontal fins inboard of the wheel.

## Adjustable cooling

Of course, tyre temperatures not only vary between the axles, but also between the circuits, and the nature of the track defines the amount of brake cooling required, and how much of that is used to warm the tyres.

'All the teams have a level of adjustability, where we can go from one extreme to the other,' says Agathangelou. 'If we have a circuit with a high cooling demand then we do less work on the flow because we have to allow it to work wholly on its prime task of cooling the brakes.

'When we are at a circuit that demands less braking energy, we can interfere with these flow streams and the heat exchange can be delayed, diverted and re-purposed to heat the rim. Every team has their own interpretations of how and why they do that. It has as much to do with vehicle dynamic demands as aerodynamic cooling demands.'

With both the brakes and tyres only working effectively within a specified temperature window, to maximise performance the moment the car leaves the pit box, warming rigs are used in addition to tyre blankets. These rigs can consist of heat guns or additional blankets that go over the wheel assembly. 'The heat gun heats anything with a thermal mass, so that includes the discs, uprights, brackets and wishbones. It essentially conditions the systems before the car goes out,' highlights Agathangelou. 'If you go out on a cold morning in FP1, there will be no temperature in the system, so the effectiveness of the brakes will be reduced. To minimise that discrepancy for the driver, we try and condition those elements close to running temperature to achieve a similar level of performance as soon as the driver goes out.'

## Rims and shrouds

With rim heating helping the teams on their hunt for predictable and stable tyre temperatures, each racetrack has become an exhibition of new rim designs and new complex carbon shrouds. These shrouds can feature a variety of inlets and outlets, with some blocked or unblocked depending on the requirements of the circuit. The rims now incorporate turbulators, fins and holes, as well as differing surface treatments and finishes as some teams try to increase surface area to dissipate heat, while others try to change the behaviour of the airflow to maintain heat.

But what impact does all this development have when Pirelli try to fit their tyres to these complex rims? 'In the past we have faced some issues with fitting the tyres on the rims, which is why we now distribute some rim design guidelines so the teams stick to some parameters that help us guarantee we can fit the tyres in the right way,' explains Mario Isola, head of F1 and car racing at Pirelli.

'Sometimes there can be issues with TPMS sensors, which can be quite big, and especially the antenna is quite weak, so we have to be careful of that when mounting and dismounting the tyres. The important part is the contact area between the bead and the rim because we need to be sure we don't have any rim turning, which can lead to vibrations and that would affect performance, but in our experience in Formula 1 we never face too many issues relating to the rims.'

However, with the move to standardised wheels and brakes on the horizon (see feature starting on p30), Pirelli's job will become much easier. Unfortunately for the teams that have invested so much energy on perfecting their rim heating strategies, having even less control over such a key performance differentiator will make their jobs that much harder.

'If there is a standard brake disc or diameter, how much will that allow us to reduce our braking load and therefore temperature during re-generation? How much volume will be available to do other work with those airflows?' asks Agathangelou. 'The more restrictive rules become, the more emphasis you can place on what isn't regulated against, because that's the area of performance differentiation.

'All it does is push you into finer levels of detail. Having less macro to work with and making you work more on a micro scale. Why? Because it's simpler and cheaper. But is it?'

**Every 10degC increase in rim temperature sees approximately one degree increase in tyre carcass temperature**

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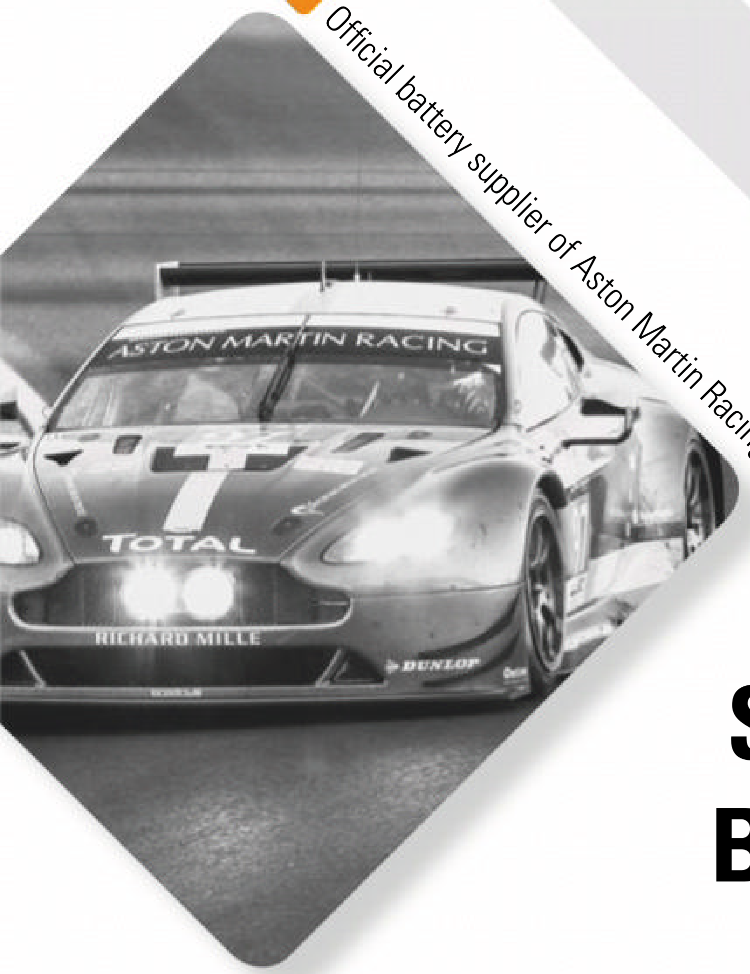


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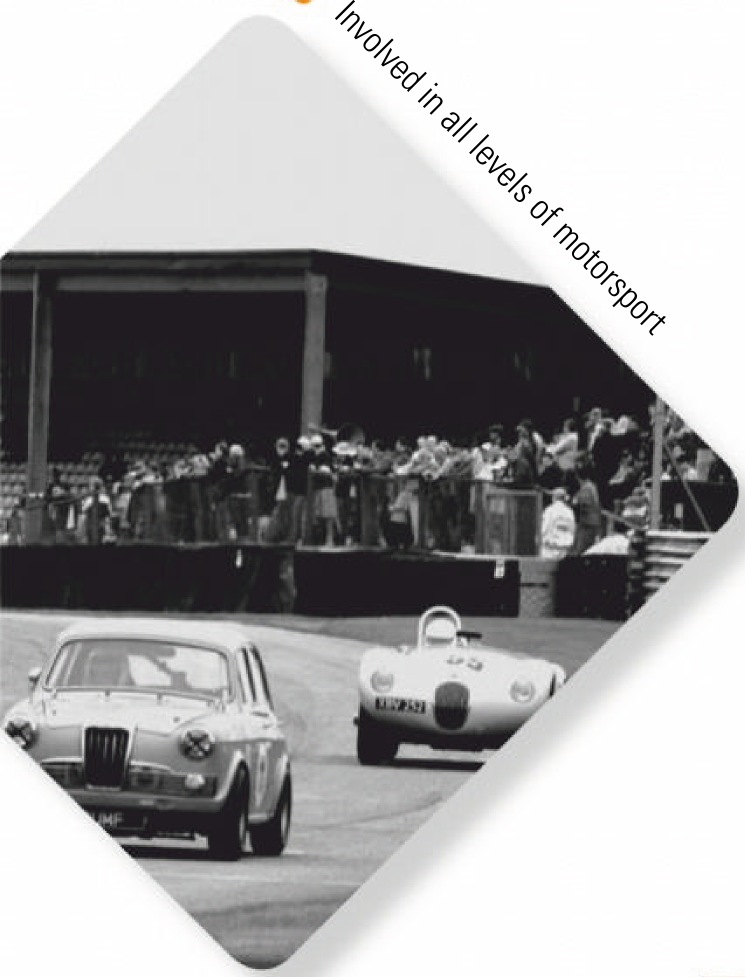

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# Formula 1 2021


## With wheel rims and brake system components all set to become spec parts, *Racecar* considers the impact on engineering, the teams and the show

**By SAM COLLINS**

In 2021, Formula 1 is controversially set to adopt single make brakes and wheels. As the sport seeks to create a radical new set of technical regulations, it has targeted a number of areas to introduce spec components to reduce costs, and the entire brake system and wheel rims are the latest parts of the car for which the FIA has issued an invitation to tender for a single design supply deal.

When it was announced in 2018 that the wheel rims will increase in size from the current 13 inch to 18 inch – a direct result of the adoption of new, low-profile tyres – it had been expected that the present situation where teams work with outside companies to develop bespoke wheel centre designs would continue, but it now seems this will not be the case. The single design, and supplier, that is selected will remain for 2021-2024, with a possible extension through to the end of the 2025 season.

At the moment, there are four wheel manufacturers active in Formula 1: OZ Racing, which supplies about half the grid, Enkei, App-Tech and BBS. Both Dicastal and Advanti have been involved in recent years, too.

### Wheel detail

The tender issued by the FIA ahead of the Spanish Grand Prix calls for the new spec wheels to be largely similar to those used at the moment, at least in terms of material used, though dimensions will be enlarged to 13.2 x 18 inch front and 16.9 x 18 inch rear.

**Captive nuts, used by teams in 2019 to speed up pit stops, will be outlawed**

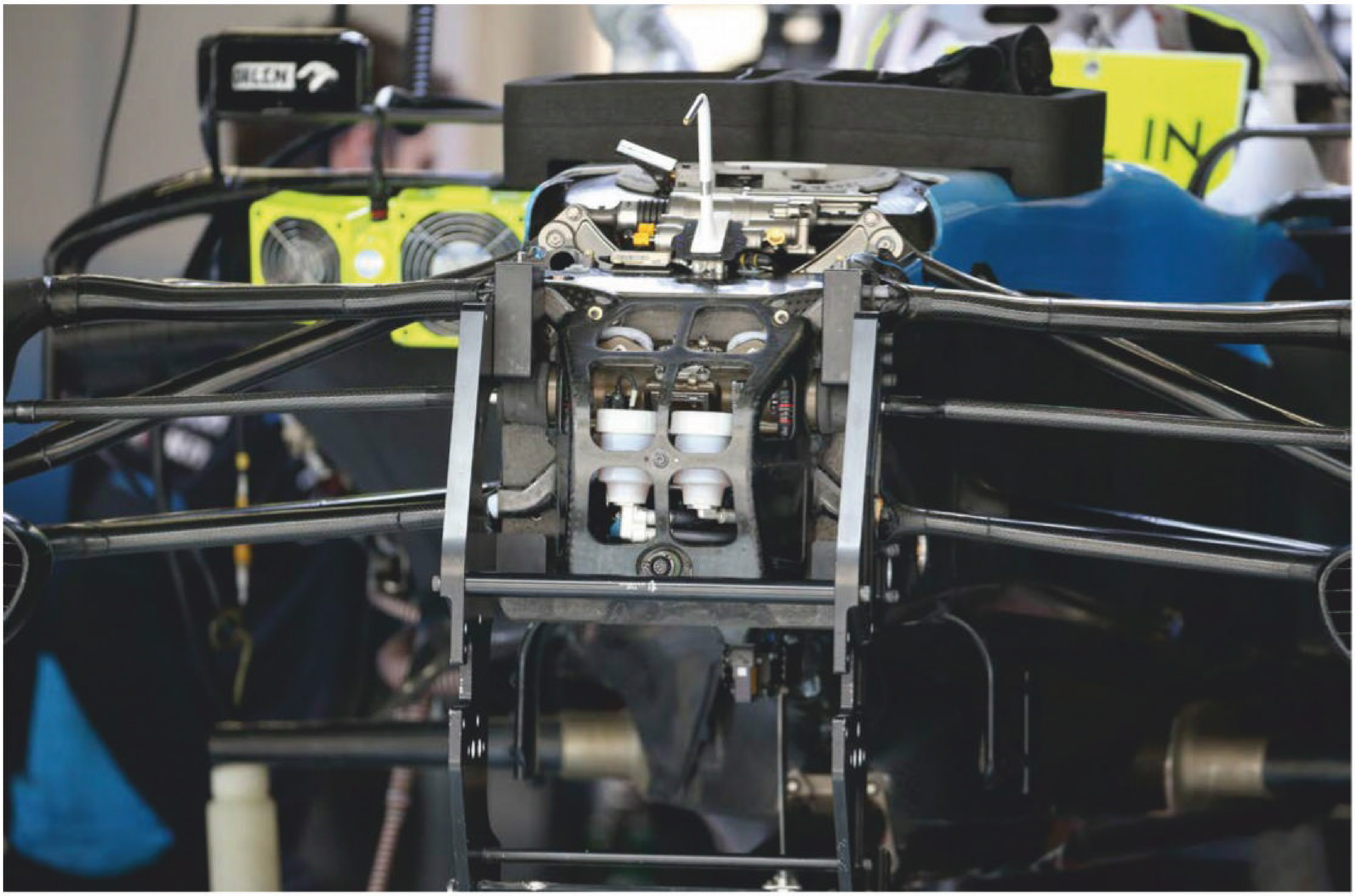
One key difference, though, is that captive wheel nuts, used by all teams in 2019 to speed up pit stops, will be outlawed. Drive pegs and any spacers will be part of the axle, and the responsibility of teams, and are not included in the tender. However, the tyre inflation valve is, as is a mounting for an internal tyre temperature and pressure system. This TPMS sensor will also be a spec part in 2021, though a tender for it has yet to be issued.

Understandably, the proposal has not met with universal approval from teams, many feeling it is a restriction too far. 'As Ferrari, we always relay that we are against the standardisation principle, but we know that we need to control costs and expenses. So, with a budget cap, we need to find the right balance,' states Ferrari team principal, Mattia Binotto, continuing; 'standardisation only makes sense if you save money, which has to be proved first.

'And as well we need to take care of the DNA of Formula 1. For example, if all the cars have exactly the same rims, then I think – in terms of

FIA F2 will introduce 18 inch wheels in 2020, a year ahead of F1, giving Pirelli experience with 18 inch rubber

**'Wheel dimensions will be enlarged to 13.2 x 18 inch front and 16.9 x 18 inch rear'**



**Master cylinders and BBW systems could become one-make parts in 2021, which are likely to be larger and heavier than the current designs. The 2019 Williams FW42 is pictured**

aesthetics – that is not good because you end up not differentiating the cars from one car to the other, beyond maybe just the paint. But it's not something we should look at.'

One organisation in favour of the standardisation of wheel rims is Pirelli, already announced as Formula 1's sole tyre supplier in 2021. 'Standard rims are a good thing for us, though we understand that some teams don't like it as they lose identity, and feel Formula 1 should be about technical development,' admits Mario Isola, head of F1 and car racing at Pirelli.

'At the moment we supply rim design guidelines to the teams as, if we did not, then the teams come up with exotic designs that make tyre fitting very difficult without damage, and that becomes a safety issue. So we give them constraints on the bead area. But once we have a standard rim, then it is just the same for everyone and it's no issue.'

The argument that the wheels are a key visual differentiator between cars may lack merit as it is expected in 2021 that all cars will carry wheel covers, similar to those used in Formula 1 in 2008 / '09, meaning the wheel itself will be barely visible. This has raised questions about the cooling techniques and heat management (see p20) something which saw most of the wheel covers used a decade ago feature small cut outs, though the final shape and regulations around the proposed wheel covers in 2021 has yet to be finalised.

**'It is not a negative for us that the brake is not exchanging heat through the rim'**

## Brake me tender

Formula 1 brakes could also well become spec components, with two separate tenders already issued; the first for friction material, the second for master cylinders, brake by wire (BBW) and calipers. There had been some uncertainty around the size of the brake discs to be used in 2021, after the increased wheel size was announced with no corresponding announcement regarding the brakes. However, it is now clear from the tender documents that the disc size will increase from 270mm at the moment to between 320mm and 330mm, with the thickness likely to remain at 32mm.

Only two types of disc will be offered to teams, including a heavy-duty version for demanding tracks such as Bahrain and Canada, along with a standard version. The tender also calls for the drilling patterns on both to be significantly simplified in an attempt to reduce costs, with a small number of larger drillings instead of a large number of small drillings. This could see the 2021 products looking more similar to those used in LMP1 then those currently seen in Formula 1.

'When you increase the diameter, you also change the effective radius. So, with the same pressure and same friction you end up with a different, higher torque,' explains Giovanni Clemente, Brembo Racing F1 race engineer and telemetry data analyst. 'If you have a bigger diameter, you have more volume, and that makes a difference with the cooling, but also means more space for drilling.

**Disc size will increase from 270mm at the moment to between 320mm and 330mm with thickness likely to remain at 32mm**


**Wheel covers such as those used in 2009 are likely to re-appear in 2021, making arguments about car identity from the wheel design perhaps a little less valid. Note the OZ Racing branding on the wheel cover and holes for heat management**

'Le Mans Prototypes use a similar material to F1, but the budgets are quite different and with the LMP brakes there are really different targets. In WEC, for obvious reasons, the teams put the emphasis on the life of the material, reliability and consistency of performance. LMP cars have thicker pads, more robust discs, and the drillings are a lot simpler in comparison. In Formula 1, it's all about lightness, stiffness and performance. So even with a similar material, the objectives of design are quite different.'

While the discs will be larger, the increase in diameter is not of the same proportion as the increase in wheel rim size, which results in a gap between the disc and inner face of the wheel rim. Currently, teams work hard on using the rims to conduct heat between disc and tyre, but that is a practice that will cease in 2021.

'It is not a negative for us that the brake is not exchanging heat through the rim,' states Isola, 'with the new 18 inch tyre the volume of air in the tyre is lower, so the pressure increase will be higher, and not having heat coming through the rim could actually help us a little bit.'

With no captive nuts, no tyre warmers, and no thermal exchange from the brake discs is there a possibility that the resulting longer pit stops and slow out laps will result in race strategy becoming highly predictable, with every team opting for a single stop?

'Yes, there is a risk of that,' concurs Isola, 'as we cannot design a tyre that takes five laps to warm up. We have to make a tyre that warms up quickly – in not more than one lap – but that can create a risk of overheating. It is a big challenge.

'We are already designing tread compounds that can generate the temperature without the tyre warmers. We have some experience from Formula 2, but that series puts a lot less energy through the tyre than Formula 1 does.'

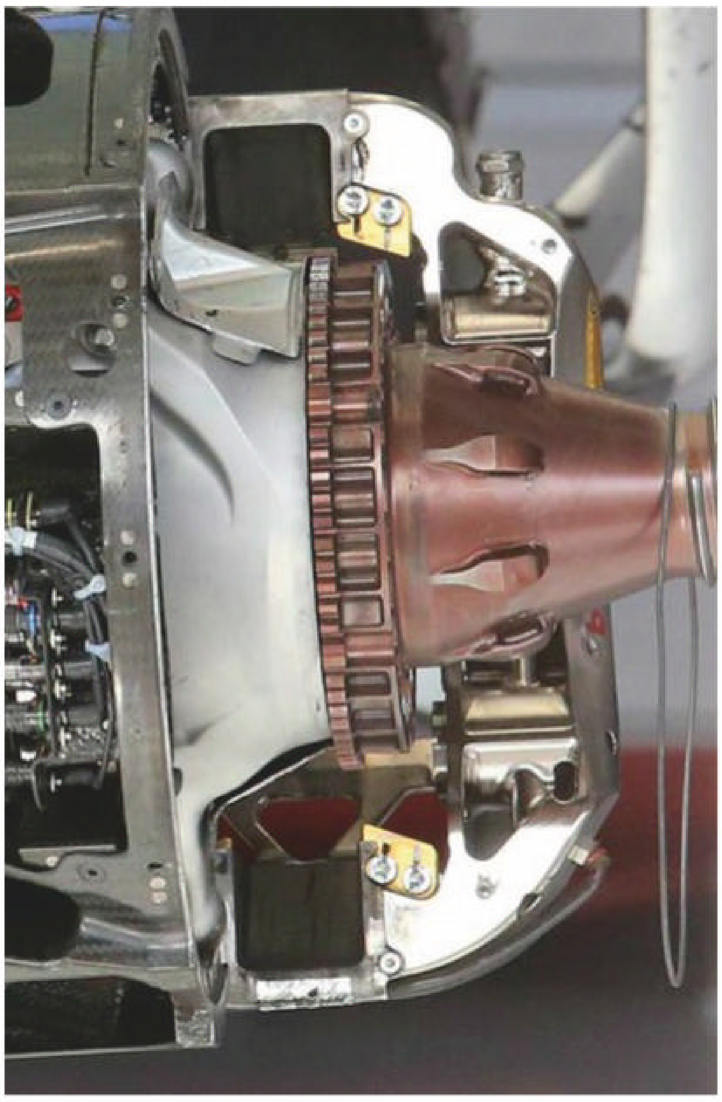
## Pad and caliper design

Brake pads will be simplified too, with a single, multi-directional pad designed for the front, and another for the rear. These pads will not be wedge shaped, and will not feature cooling holes at all. Housing the pads will be a new, single design caliper, with all cars using identical parts, rather than each team having its own bespoke design as they do currently.

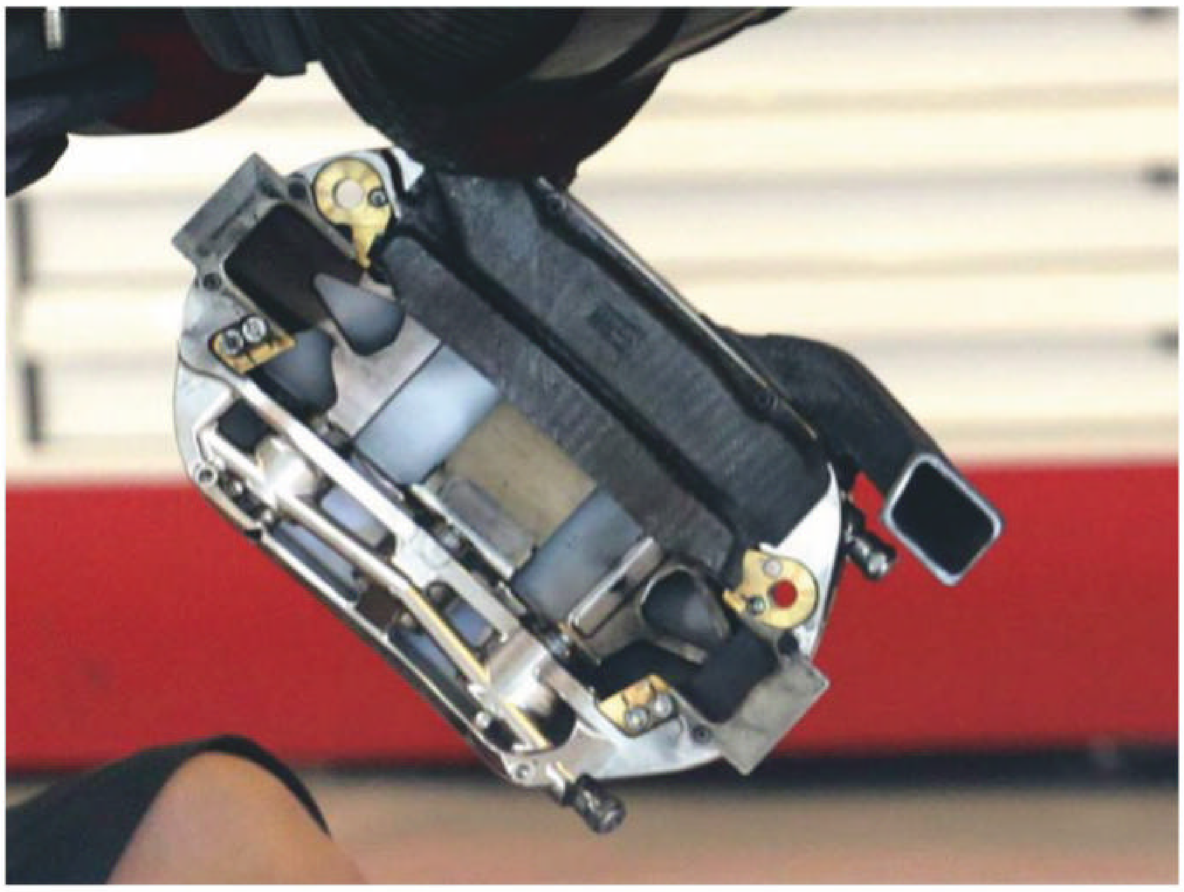
While Brembo supply the majority of the field, 920E, AP Racing and Akebono also supply calipers to Formula 1 teams, so all but one of these manufacturers will lose out if the plan goes ahead. This obviously has a knock-on effect for the wider motorsport supply chain.

'In terms of variance in design from team to team, they are really all bespoke products, but

## A single spec caliper… will have a direct impact on the design of the upright



**2018 Sauber front caliper mount. Note bleed nipple position**



**2018 Sauber rear caliper**

McLaren front wheels supplied by Enkei – one of a number of wheel suppliers presently in F1

Red Bull's 2019 wheel rims are one of the most complex on the grid, but it is likely a spec wheel will have a far simpler design

it goes beyond that,' continues Clemente. 'Right now, the calipers even vary from driver to driver. Some drivers are stronger than others, or have different styles, so you have to generate a slightly different force for each. Within the same team you might find one driver who is very aggressive on the brakes while the other is a lot softer and wants more pedal travel.

'As the calipers are monoblocs, there is not much that can be done with the stiffness, so you have to work in the hydraulics, looking at the master cylinder diameter and the size of the pistons in the calipers. But, overall, the focus of design remains on optimisation, so we are constantly pushing to be able to make a caliper that is lighter than the previous season, but also stiffer.'

**'We need to be careful not to go down the slope... ending up with everyone having the same cars'**

## End of the line

Again, that technology race will all come to an end in 2021, with heavier, more basic calipers that takes advantage of the increased space between disc and rim to allow a more effective bridge section. The aluminium-lithium alloys used now will also be replaced by 2618 aluminium alloy (or similar), which has both a lower Young's modulus and a lower cost.

'In terms of alloys there is already a limitation of 80Gpa as a maximum in the current rules. In the past we could use beryllium, but that is banned now. So with the materials we focus on other characteristics, like having an alloy that is able to cope with a much higher temperature. That means its life can be extended somewhat,' Clemente adds.

The life cycle of the 2021 caliper unit is expected to be around 10,000km, which is roughly the same as the current life expectancy of a Formula 1 caliper if it is kept within its design tolerances, which few are.

'They are so extreme in the way they are designed at the moment that every time the car brakes it puts the components close to the limit,' says Clemente. 'As with all components, calipers have an operating range. This is why we have the thermal sensors and stickers on them to make sure the teams are not overheating them. You can even deform the bores for the pistons if the unit goes over its maximum temperature.

'If this happens, teams are obliged to send them to us to go through a thorough check to see if they are safe to be used again. This happens quite often. There are a lot of examples of misuse of the brakes. The calipers are designed to have a life of 10,000km, but most of them only last for half of that due to the teams pushing them out of the range.'

It is hoped that with the proposed larger, more basic caliper they will be more resistant to abuse, and more likely to last the full 10,000km. But not everyone agrees that restricting caliper design and development will save any money. 'I think they will find it difficult to produce calipers cheaper than we get them now,' states Green.

Naturally, cost is a key factor in all of these tenders, and they explicitly state that if cost savings for the teams cannot be delivered, the tender will effectively be abandoned.

If a single spec caliper is used in 2021-2024, it will have a direct impact on the design of the upright of every car. Currently, there is no consensus of design on caliper position, with few teams using the same position. Mounting a caliper at the base of the disc gives a lower c of g, but this low-slung position makes bleeding the brakes harder, and some teams prefer to have the caliper in a higher (generally trailing) position to raise the bleed nipple. Which means the bleed nipple position itself could, to some extent, limit upright design.

## Heavy metal

If the proposals all go ahead, the brake-by-wire system will also become a single design, single supplier unit, as will the master cylinder. Like the rest of the brake system, both are expected to become slightly larger and slightly heavier.Still, teams can take some comfort from the fact that they will be free to develop their own hydraulic pipework between the brake components.

McLaren, Renault and Mercedes will each build a special test mule for Pirelli to test its new tyres, with both OZ Racing and Enkei expected

**'The [current] calipers are designed to have a life of 10,000km, but most of them only last for half of that due to the teams pushing them out of the range'**

# 'I don't agree that the DNA of Formula 1 is just about technical development. We have to find a way to reduce costs, and no one cares which brakes we have on the car, or which rims we use'

to make special sets of 18 inch wheels for tests in late 2019. These test cars, however, will not feature the new spec wheels or brake system, as the tenders do not require the successful companies to deliver the first parts to teams until the end of October 2020.

That being said, there is scope for a prototype brake system to be track tested in late summer 2020, and the wheel rims a little earlier in June of the same year.

## Ongoing debate

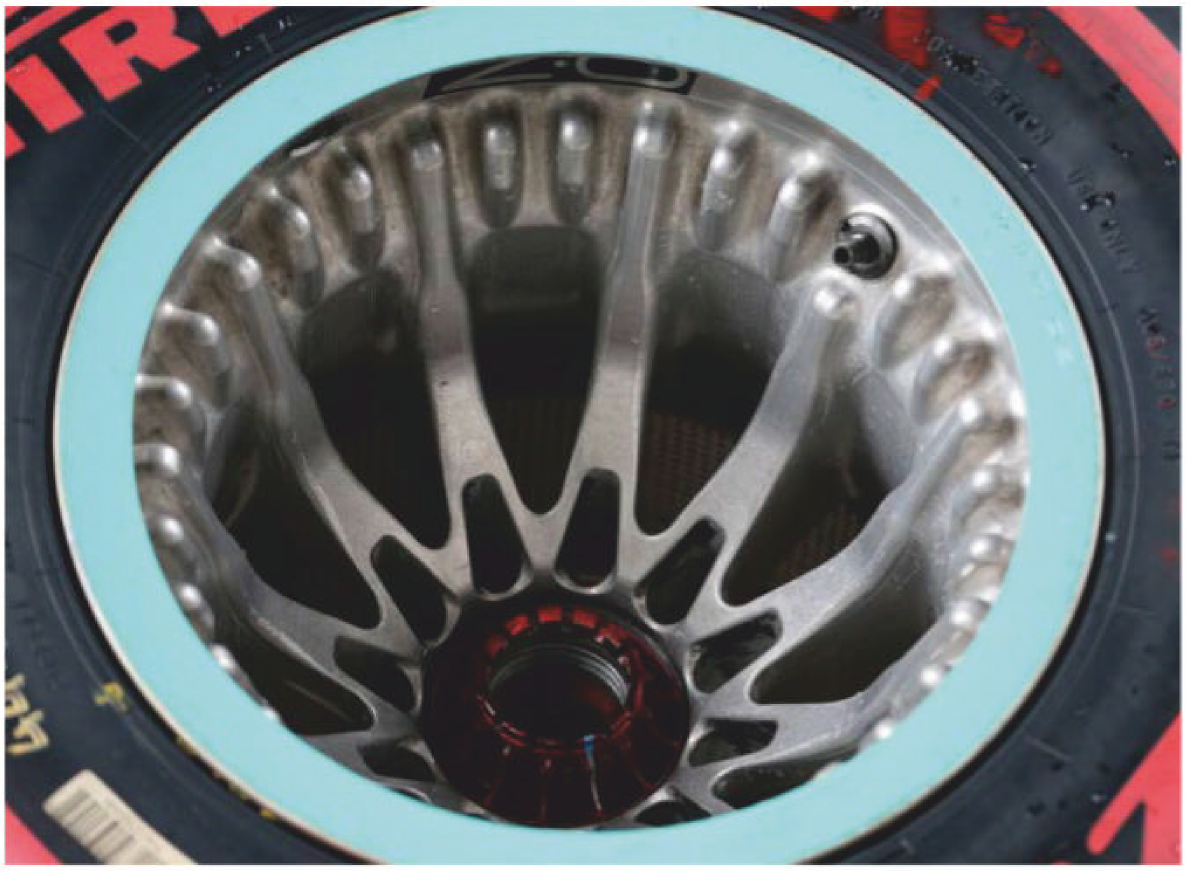
The moves to standardise the brake system, tyre sensors and wheels come in the wake of previously announced measures to standardise the transmission internals, and rumours of standardised power unit components and suspension parts. This is an on-going discussion, and the proposal for a standard gearbox cassette was rescinded at the end of May.

'We need to make sure Formula 1 keeps its DNA, and that DNA for me is about technical development,' contests Haas team principal, Guenther Steiner. 'It is the only motorsport that is free for technology. Once you start standardisation, it can be a slippery slope in my opinion. We need to be careful not to go down that slope, and all of a sudden ending up with everyone having the same cars. A lot of people are interested in our technology, and that is why they watch Formula 1.'

But this perspective, while widely held, is not universal, with some directly countering the view of the engineering-minded figures in the paddock, notably Toro Rosso boss, Franz Tost. 'I don't agree that the DNA of Formula 1 is just about technical development. We have to find a way to reduce costs, and no one cares which brakes we have on the car, or which rims we use. The people want to see some interesting races, some overtaking manoeuvres. Therefore I am in agreement with as many standardised parts as possible.'

Others offer cautious optimism about an increase in spec parts. 'Formula 1 was able to do it on the ECU 15 years ago, so I think we can manage a situation on the brakes or the rims,' comments Frederic Vassuer, Alfa Romeo team principal. 'The only issue for me would be the timeline. We need to be aware quite soon, and we need to have more details quite soon about the technical aspects. If we are in a rush, then everything is more and more expensive.'

Timescale is a major concern for many of the teams, as the 2021 rules remain incomplete at the time of writing, just 21 months before the cars take to the track for winter testing.

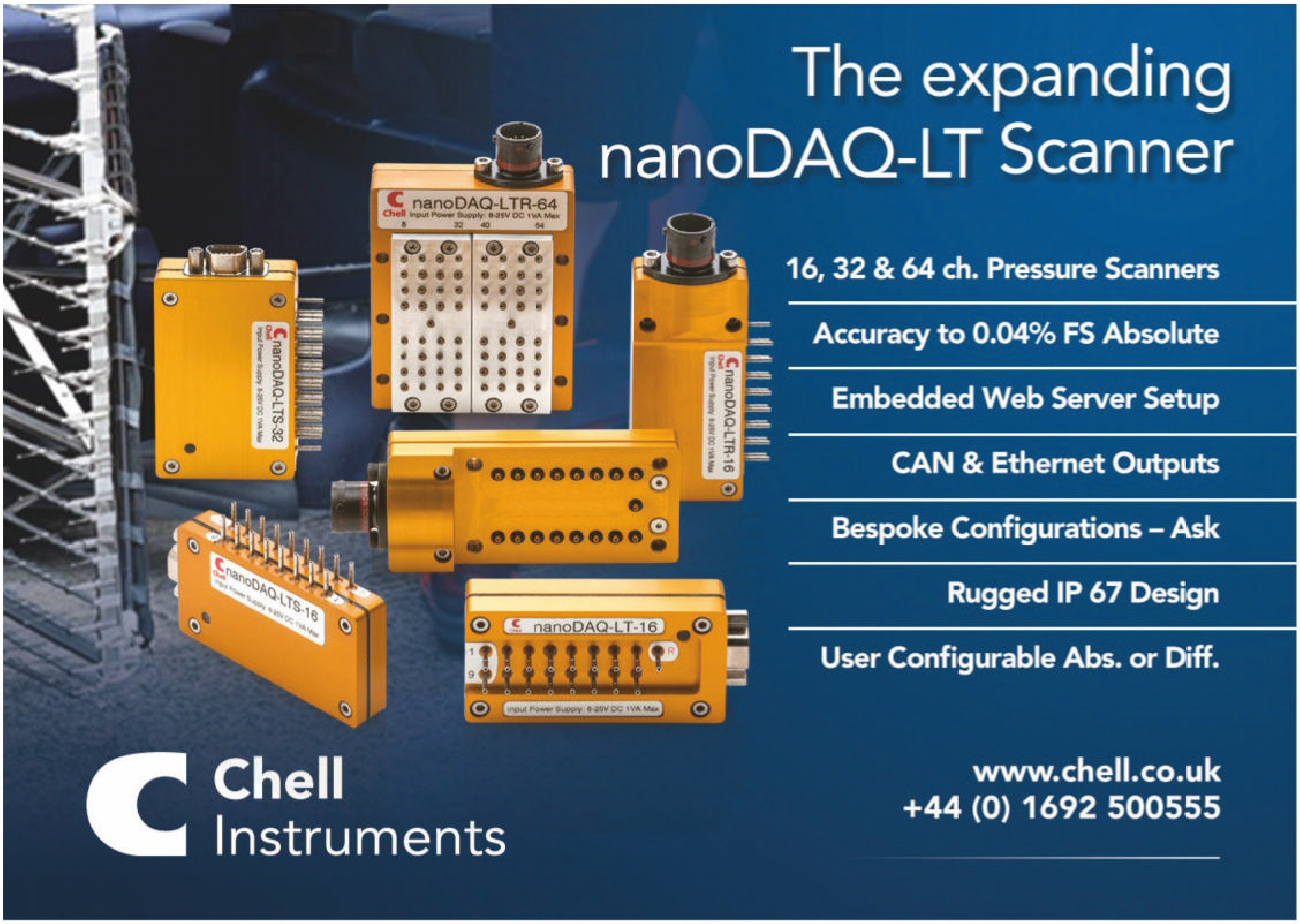


The complexity of the wheel rims has increased dramatically in the last few years. Mercedes rear pictured

Eighteen inch wheels have been on the cards for a long time, with the first track tests taking place in 2014. As a result, few expect the rims to become a spec part in 2021. It has still to be proven that this will save money

'I just want the actual rules to be published, not some skeleton framework, I'd rather not mess about,' says Green. 'It is a huge change, so I think it will be better for everyone to just get the real regulations. We have seen how difficult it is to write watertight regulations – just look at what was required to do the new front wings this year. It was a massive amount of work. We were clarifying things for months, and that was just for a small part of the car. Imagine doing that for the whole car. The sooner we see the real regulations the better,' Green concludes.

If any cost saving can be realised, the tenders will have been signed off in mid-June this year, and signed off in the FIA World Motorsport Council before the end of the year. From that point in June, serious development on the new parts will begin, even if many involved in the sport feel that goes against 'the DNA of Formula 1'.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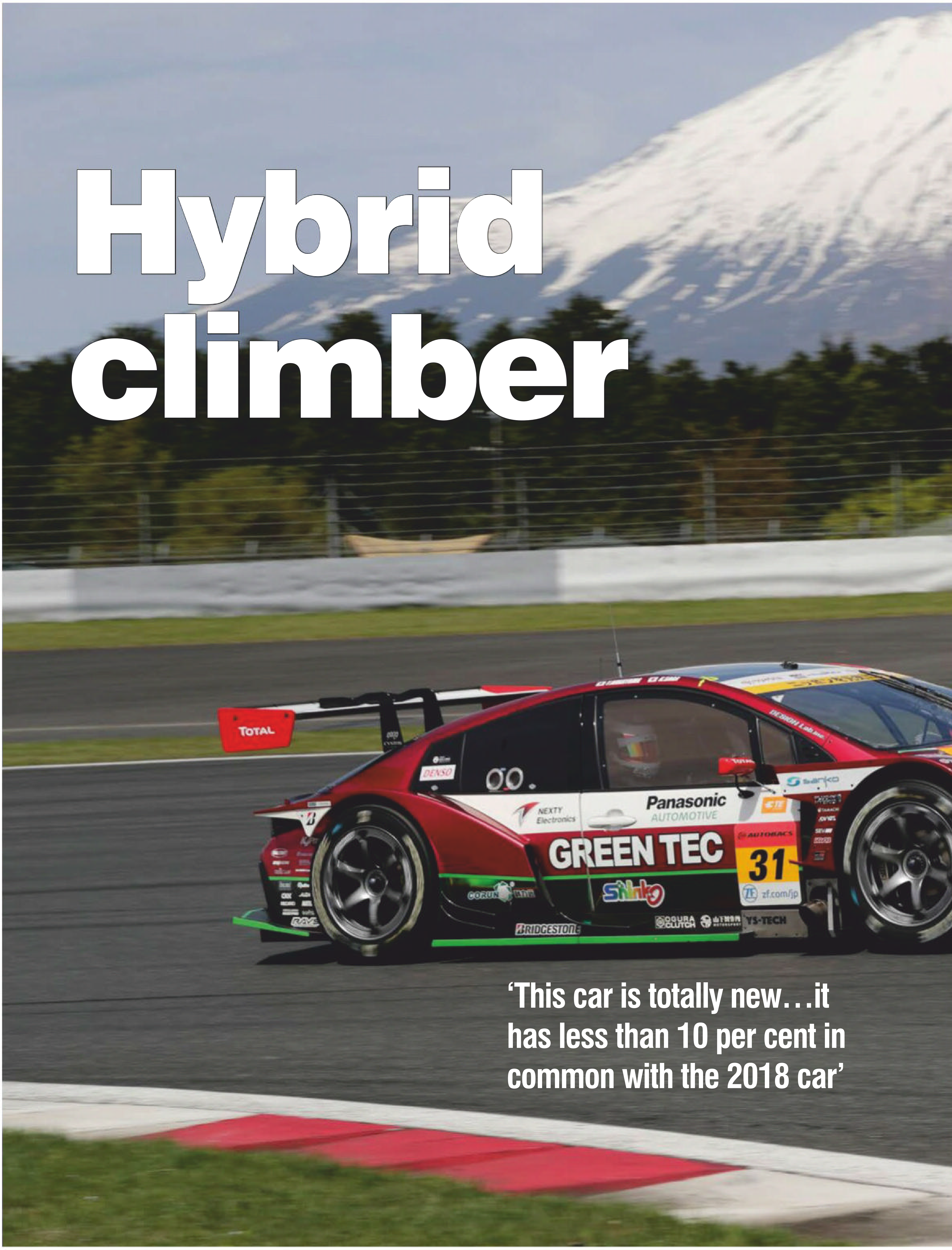


'This car is totally new…it has less than 10 per cent in common with the 2018 car'


**Though still very much a work in progress, apr Racing's all-new GT300 hybrid is pushing technology boundaries in Japanese Super GT**

**By SAM COLLINS**

The seismometers that pepper the landscape around Oyama town in Japan are some of the most accurate in the world. A few months ago, though, they recorded an entirely new sound, a vibration that could be felt through the floor of structures nearby the epicentre. This time it was not a sign of the impending eruption of Mount Fuji, it was a somewhat more unlikely source – the engine sound of a Toyota Prius.

The world's best selling hybrid road car has been a fixture of Japan's Super GT championship since 2012 but, for the 2019 season, a new version of the car is competing in the series. Two classes of car contest the championship, GT500 for works teams running to the new Class 1 technical regulations, and GT300, which is aimed at small tuning companies and privateer teams. It is in this second tier that the Prius runs.

However, it is not quite that simple. The GT300 class allows for three different types of racecar: FIA GT3-specification (including, at times, pre-homologation versions), 'Mother Chassis', which use a common carbon fibre monocoque and a spec V8 engine, and JAF GT300, which is a specific set of regulations for highly modified production cars.

Based in Atsugi, Japan, the small apr Racing team has designed and built Toyota-based cars to the JAF GT300 rules for many years. These regulations require cars be based on an existing production car, though only a few parts of the original chassis must be retained. The rest of the chassis is a bespoke tubular steel frame. Powertrains can be any engine produced by the same manufacturer as the base car, and placement in the chassis was at teams' discretion. That meant front-engined production cars like the Prius could be built as mid-engined competition cars.

## Evolution of design

Over the years, the loose chassis regulations allowed apr to evolve its tube frame design gradually, through various iterations first with the Corolla and now with the Prius. However, a recent change in the technical regulations that says engine location must now be the same as in the base model means this chassis evolution has come to an end.

'In the past we carried over a lot of concepts from previous cars, so a lot of the Axio Corolla GT300 went into the first Prius we built in 2012. Then a lot of that went into the new Prius in 2016,' admits Hiroto Kaneso, founder and technical director of the apr Racing team. 'This car is totally new, though. It has less than 10 per cent in common with the 2018 car.

'Right now the old cars are in use by the Corolla Mie dealerships as promotional vehicles, the number 30 in running condition and the number 31 in static condition. But this new chassis is the best we have done yet.'

To make best use of the new chassis design, the base model was changed, too. Rather than the standard Prius (XW50) used in 2018, Toyota approached apr and asked it to use the new Prius PHV, known as the Prius Prime in some markets. 'It was something we had discussed with Toyota a lot. In terms of design and engineering, the most effective and efficient Eco vehicle on the market is the Prius PHV, with its plug-in hybrid


**Back-to-back testing was done with the final Prius PHV GT300 (in yellow, behind), and this interim version (front), which used modified 2018 bodywork as well as the 2019 updates shown by the red parts**


**The chassis is developed in house by apr and has little relation to the previous GT300 Prius**

### TECH SPEC: Toyota GR Sports Prius PHV apr GT

**Class**
GT300 (JAF GT300 subset)

**Chassis**
Tubular steel frame with some structural production chassis parts

**Engine**
Toyota 2UR-G 5.4-litre normally aspirated V8, tuned by TRD

**Hybrid system**
Toyota production car electric motor and PCU, prototype capacitor-based energy store

**Transmission**
Hewland six-speed sequential, Ogura multi-plate clutch

**Suspension**
Double wishbone all round with inboard, pushrod-actuated dampers and coil springs

**Wheels**
Rays, 13J x 18in all round

**Weight**
1,250kg

**Dimensions**
Length: 4,650mm
Width: 1,950mm
Height: 1,130mm
Wheelbase: 2,750mm

system. But for many people the older-style Prius without a plug-in hybrid system is much better known, so it was a good way to promote the PHV. On top of that, a GR [Gazoo Racing] version of the Prius PHV has just gone on sale, so it was a great opportunity for both us and Toyota to bring in this new car and promote it positively,' Kaneso explains.

Around half of the roof, the front bulkhead, much of the floor and the a-pillar remain from the base model, albeit in modified form, along with the headlights, tail lights and the badges. The rest of the car is a bespoke racecar.

## Freedom of engine

The freedom of engine rule has seen a surprising range of different engines used by GT300 teams used over the years, including units from Formula 1, the World Rally Championship and Le Mans. From 2012-2018, the apr Prius used the same Toyota RV8K LMP1 engine previously used in the Toyota TS030.

That engine was initially developed for Toyota's IndyCar programme in the 1990s and, although there had been extensive development of it over the years, parts were becoming increasingly scarce. As a result, TRD made it clear to apr that it would have to utilise a different powerplant this season.

A number of options were considered, including the 2019 GT500 2.0-litre, four-cylinder engine, the similar commercially available TRD BIZ001 engine, or a production-derived unit. Ultimately, in consultation with TRD, the team chose the latter, and opted for the Toyota 2UR-G. This is the 5.4-litre, normally-aspirated V8 engine utilised in the Lexus RC F GT3 car but, according to Kaneso, the version used in the Prius is very

**Single-caliper rear brakes are from Japanese company Endless. Twin-caliper set up was abandoned after testing on GT300 Prius**


**Both apr Racing Prius PHVs; the yellow car is the non-hybrid version. Note 'Mother Chassis' Toyota Mk X in background**

## ‘The energy store…is capacitor based, and is a thing for the future. It is still under development and not yet commercialised’

different: ‘The ones we have are only roughly similar to those used in the GT3 cars,’ he says. ‘For us, TRD has done a dedicated specification but is keeping some details confidential, even from us. We know that the intake system is different to the GT3, with two throttles instead of eight independent throttles. There are internal changes too, but they are only known to TRD!’

It is worth noting the Lexus GT3 car uses twin 38mm air restrictors, compared to the twin 34.5mm restrictors used on the Prius. The FIA-specification car is also heavier, though despite this the pace of the two cars is similar.

Of course, as the Prius production car is a hybrid, it makes sense the GT300 version is also a hybrid. As with engine selection, the hybrid system largely comes from the Toyota production car family. ‘It is basically the same as the 2018 car,’ continues Kaneso, ‘with capacitor-based energy storage and a single, production car-derived motor. The motor and the power control unit comes from the one used on the Lexus 350h (Crown HV, IS 350h, RC 350h). The energy store is a bit different. It is capacitor based, and is a thing for the future. It is still under development and it has not yet been commercialised.’

The hybrid system is installed with the energy store and PCU in the passenger seat area (on the left of the car as this is Japan), while the motor is mounted at the rear of the car on the specially adapted Hewland six-speed sequential transmission. However, of the two apr Prii (that’s Toyota’s official declaration on the plural by the way) built for 2019, only one of them is currently equipped with a hybrid system – the red number 31 car – while the yellow number 30 car runs with V8 power alone.

## Performance differential

‘We have only fitted the hybrid system to one car,’ explains Kaneso. ‘This lets us fully understand the difference in performance between the hybrid system and the non-hybrid powertrain. With the difference of motor performance alone, and the overall performance when you take into account the whole system weight, it has put a real emphasis on reducing the weight of the energy store.’

For running a hybrid system, the no.31 Prius is hit with a 51kg weight handicap and, even with bespoke Bridgestone tyres, it has so far run slightly slower than the non-hybrid in qualifying trim. However, it is clear the team is still to get the best out of both new cars. Both were slower at Fuji Speedway than the now outlawed, mid-engined Prius, and part of that is down to a significant increase in overall weight. The 2018 Prius had a minimum weight of 1,150kg, with the additional 51kg hybrid penalty applied

Squeezing the large V8 under the bonnet of the Prius was tough, but apr did it with less than a millimetre to spare

## ‘The front suspension was hard to get right because of the sheer width of the engine’

on top of that, but the 2019, front-engined version tips the scales at 1,250kg even before the hybrid penalty is applied.

‘It is a lot heavier than the old car, and this is mostly down to the engine,’ admits Kaneso. ‘The RCF V8 is based on a large production car unit, it alone weighs almost 100kg. The engine we used last year was a purpose built racing engine designed for single seaters and Le Mans cars, so it was quite a bit lighter.’

The heavier engine also gives quite a different weight distribution, as you might expect, with the 2018 mid-engined car demonstrating a 46 / 54 per cent distribution, compared to the new car’s 54 / 46 per cent balance. But, as Kaneso points out, the additional weight and layout change does bring with it at least one advantage: ‘We have managed to increase the torsional stiffness of the car substantially. This is a natural consequence of a more even distribution of parts in an FR chassis.’

With such a major change of car concept after years of gradual evolution, the team is having to re-learn a lot of its set-ups and ways of working, especially with the tyres. The two 2019 cars currently run on different rubber, the non-hybrid on off-the-shelf compounds from Yokohama, the hybrid car, as previously mentioned, on bespoke tyre war specification products from Bridgestone. To get the best out of these, a completely new suspension layout had to be developed and, while quite

Packaging the front suspension around the engine was a major headache


Cooling layout sees hybrid and combustion engines cooled from nose-mounted radiators, while the transmission and A/C system are fed from the rear bodywork

conventional in design, installing it on the car proved to be a major challenge.

'The suspension layout uses inboard dampers, double wishbones and pushrods. But the front suspension was really hard to get right because of the sheer width of the engine. There really was no space at all. You can see the dampers are right next to the engine, but with some work we have actually managed to get a lower damper temperature than we had on the mid-engined car,' Kaneso explains. 'To really get a clearer idea of how it was all working, we went on the seven-post rig that Team Le Mans (GT500 Lexus team) have in Gotemba, near Fuji Speedway. We used a special car for that. It has the right chassis and engine, but used the old body panels and a few other parts, as the new designs had not been finalised at that point.'

Indeed, when the final body shape was being developed, Kaneso discovered the sheer size of the engine wasn't only a problem with the suspension. 'It was a huge challenge to fit such a massive engine into the body of the Prius PHV, especially at the front,' he says.


Rear-end layout uses triple dampers with pushrod actuation mounted on top of the Hewland transmission

## Tight fit

'A lot of the work in that area we did in house and made the parts ourselves. In the transaxle there is less than an 0.5mm gap between the crankshaft centre line and the transmission centre line. In fact, the only thing that was a bit easier compared to the mid-ship cars was the cooling system, but the drivers are not so keen as it gets a lot hotter in the cockpit now, though we have worked hard to manage that, too. We have the main water and engine oil cooler mounted at the front of the car, along with the hybrid system cooler, then at the rear on the sides we have the transmission cooler and air conditioner,' Kaneso continues.

With such a change in cooling, weight distribution, suspension and a new base model to work with, it was clear the aerodynamics of the car would have to start from scratch, too. However, a new tool was available to the team.

**'We had to completely start again, but this time we were able to test the car at scale'**

With a little help from TRD, apr was able to raise its game here in terms of development by using a scale model for the first time. 'We had to completely start again, but this time we were able to test the car at scale,' adds Kaneso. 'We used the 25 per cent scale wind tunnel at TRD, and found we could get a good improvement in rear downforce by adjusting the shape of the rear hatch to get more air to the wing.

'Actually, that area was probably the biggest reason we went to the wind tunnel for this car. In the past, I had relied on experience, and a few basic full-scale tests, to tune the shape of the car, but with the PHV I really wanted to know what impact the basic rear shape of the car had, and if I had gone the wrong way in 2018.'

At the time of writing, the new Prius cars have raced twice, at Okayama and then at the Fuji Speedway. The team has been quite open about the fact the car is still very much in development at this early stage of the season, and admit to date that the drivers have struggled with the braking system, as well as the aforementioned cockpit heat.

'At apr we are not impatient, we are climbing up one step at a time. There is still work to do but we are developing well, and it is a long season. We are really looking forward to it,' Kaneso concludes. If he is right, the Toyota PHV could, like its Prius predecessors, leave some more conventional GT3 runners quaking at the prospect of taking it on.

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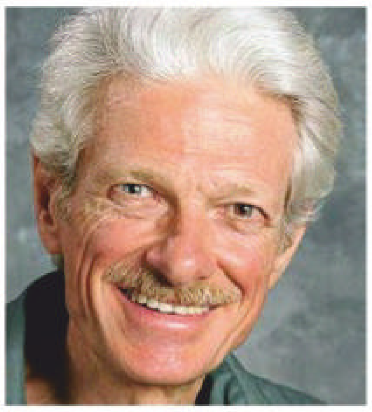

# Worth the weight?

## Answering some questions about NASCAR pavement Late Models

**Q This question is about circle track racing of a Late Model. At the speedway where I race a Late Model (Dominion Raceway and Entertainment, Thornburg, VA) the rules require we have a minimum of 1,450lb chassis weight on the right-hand side and a total weight, with fuel, of at least 3,100lb. When I asked how the track arrived at the 1,450lb weight requirement, no one could provide the rationale, simply saying, 'Because we said so.'**

**At other tracks where I've raced, the right-hand weight requirement was different. May you please explain how and why these tracks arrive at their right-hand weight numbers since it impacts the chassis set up?**

**Ideally, at a circle track I'd like as much weight as possible on the left-hand side, provided it is in the right places. Please help me understand and appreciate how these weight numbers are determined / calculated.**

Every race series has its own regulations, but it's not very helpful when the regulators cannot explain them

### THE CONSULTANT

A You are correct that you want as much of the weight on the left as possible for an oval track. There are some challenges involved in making a very left-heavy car work, but generally the car will be faster. Restrictions on left percentage are arbitrary, rather like displacement limits, spoiler height limits, tyre size limits and so on. They can take the form of a minimum right-side weight or a maximum left percentage.

According to http://ovaltrack.dominionraceway.com/wp-content/uploads/2019/02/2019-Late-Model-Division-Rules-2-15-2018.pdf, for 2019 the minimum right-side weight is 1,400 lb (about 45.2 per cent of 3,100lb, while 1,450 is about 46.8 per cent).

Although left percentage rules are arbitrary, there is some science and logic involved. In what we call Stock Car racing, the rule makers try to create racecars that at least bear some resemblance to production vehicles. Part of that is not letting them be too obviously asymmetrical. However, even in Supermodifieds, we now see some limitations on left percentage, and there is an engineering justification for this from a safety standpoint. Even when the track has no right turns, a car will occasionally have to turn right at speed, for evasive manoeuvres, passing, jockeying for position in traffic etc. In such circumstances, we want the car to at least be able to do this without flipping too easily.

## Unique track rules is really more a political matter than an engineering decision

On most tracks, this will require a limit of around 65 per cent left – less for steep banking. But without a lot of ballast, it's difficult to build a car with more than 65 per cent left. That's about where Supermodifieds end up, though I've heard of 70 per cent (the Super I helped with in the 1980s had 62 per cent left). In some cases, Supermodifieds are limited to lower values, in which case they are allowed to run more wing than more left-heavy cars.

### Politics vs engineering

The general question of whether to have unique track rules is really more a political matter than an engineering decision. It's somewhat akin to the question of protectionism vs free trade, which relates to the question of whether to have unique product standards and regulations for your country, or have them the same as other countries. If you have unique rules, that favours local competitors. If you have the same rules as your neighbours, that encourages competition from outside the area. Neither of these is necessarily right or wrong, fair or unfair. It all depends on your objectives.

**Q The topic of rear skew is a 'hot button' issue among the Late Model community. Could you please explain the advantage gained by rear skew, and how much is too much? I would also appreciate understanding how to arrive at the correct (legal) amount of skew.**

### THE CONSULTANT

A What's referred to here by skew is aiming the rear wheels to the right, to make the car travel in a more sideways attitude. There isn't really any theoretically correct amount of this, but there are predictable effects when we increase or decrease it.

The benefits of skew are mainly aerodynamic. We get some aerodynamic lateral force, and we get a bit more clean air to the spoiler. A potential problem is that rear tyre thrust is directed partly to the right, and this

Fuel burn off can change the suspension characteristics of a racecar, depending on where the fuel tank is situated

tends to make the car looser under power. Also, rear tyre retardation force tends to pull the rear more to the left, which may actually tighten the car on deceleration.

However, there are ways of dealing with these effects, using other tuning variables.

We have two ways of effecting skew: either angle the whole axle with respect to the car, or angle the wheels with respect to the axle. With a full floater axle, we can angle the snouts, but I believe NASCAR severely restricts this, for both camber and toe. However, where it is permitted, it is possible to angle the snouts as much as two degrees, or perhaps even a little more, if we use axle shafts with barrel-shaped splines.

There can be an actual angular limit on static rear wheel toe angle, but more often we simply see a limit on snout angularity, combined with a limitation on inequality between right and left wheelbase.

If the limit is on wheelbase, or wheelbase inequality, one possibility is to stagger the front wheels a bit – have the right one trail the left a little. DR track rules measure engine setback by the right front spark plug hole and the right upper balljoint, so for a given right front wheel location, we can get a little extra engine setback by setting the right front wheel back and also by using a lot of caster.

This is perhaps something for the car builder to be thinking about, more than the car buyer, but the racer who has an existing car can at least work these ideas within the existing limits of adjustment.

With truck arm rear suspension, we can make the rear wheels aim a little more to the right dynamically when the suspension compresses in response to a banked turn. We do this by angling the Panhard bar down to the left ie frame (right) end higher than axle (left) end.

**Q During a recent oval track race I found myself losing my ability to turn left upon mid-entry into the corners. No matter what I did, I couldn't turn the wheel left. As a result of my car understeering, I was forced to race my next 75 or so laps on the high side because that didn't require me to turn the wheel as far to the left.**

**After the race we determined I was constantly hitting my 'bump stop', a small part in the suspension system often called a 'spring aid' by engineers. Is it therefore possible we aren't using the right bump stops? May you please explain how to choose the right bump stop to achieve the right wheel loads in all parts of a corner so a chassis will handle better.**

**Does the material used in the bump stop make a difference? If so, can you please explain what are those differences?**

## THE CONSULTANT

A I'm assuming you mean you could turn the steering wheel far enough left but the car pushed so much it had no effect. If you really couldn't turn the wheel far enough, that would indicate a problem with the steering rather than the suspension, or perhaps something in the suspension preventing the steering from working properly.

If the car is not intended to ride on the bump stops, you mainly just want to keep it off them. You want the bump stops to do what they normally do, which is just to cushion impacts from big bumps that bottom the suspension, and not do anything the rest of the time. As long as they do that, the nature of the bump stops isn't very important.

However, the bump stops become highly significant when the car is set up to run on

## If the car is not intended to ride on the bump stops, you mainly just want to keep it off them

them most of the time. The usual reason for doing that is to work a ground clearance rule that requires the car to have more ground clearance to pass tech than it actually needs on the track. In such a case, the car is set up with very soft springs and hold-down shocks (ones with very stiff rebound damping). When the car is set up that way, the bump stops can be the lion's share of the springing, and you want to actually test them to find their rate characteristics, which will be non-linear.

In classes where cars are set up to run on the bump stops, it has become common to use bump springs instead – small coil springs on the shock shaft, where the bump stops would be. These have a constant rate.

If the car is not intended to ride on the bump stops, the suspension becomes much stiffer than intended once the bump stop comes into play. If this occurs at the front, it increases front load transfer and decreases rear load transfer. The front tyres are then less equally loaded and the rears more equally loaded. That increases rear grip and decreases front grip, due to load sensitivity of the coefficient of friction.

If the car just did this on that one occasion, with a set up that normally works fine, and the track officials suddenly imposed an additional 50lb right weight requirement, that could explain the problem.

If the problem only surfaced as the race progressed, it could be related to fuel burn off. As the fuel load lightens, the front wheel loading actually increases. The rear decreases more, but the weight of the fuel actually takes weight off the front wheels because it's behind the rear axle.

### CONTACT

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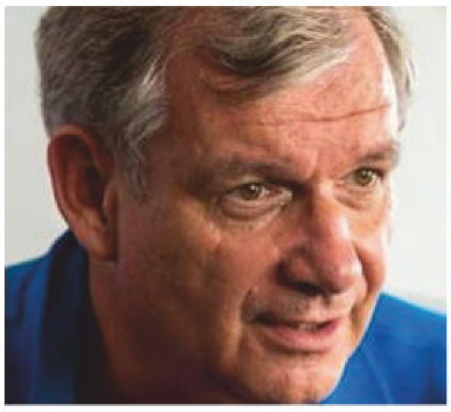

Slip Angle is a summary of Claude Rouelle's OptimumG seminars

# Application analysis

In this month's article, OptimumG looks at how maths can be used to improve driver braking performance on track

**Having a physical marker to contextualise the brake application point can help your driver be performant and consistent, as well as qualify and quantify the results seen in the data**

**Table 1: Equations for creating the brake application point**

| Math channel name | Math channel equation |
|---|---|
| Total brake pressure | total brake pressure [bar] =^(') brake pressure front^' [bar] +^' brake pressure rear^' [bar] |
| Brake application point | brake application point=choose('total brake pressure^' [bar]>0,^' lapdistance^' [kilometre],1/0) |

In our previous article, we discussed how braking aggression can be used to understand if a driver is performing at their limit. We discussed how to correlate brake lock-up to brake aggression, and help conclude if the driver needs to change their driving technique, or the engineer needs to make a set-up adjustment.

To expand on what the braking aggression is telling us, we can consider the brake application point for each corner to determine when the driver is braking. In this article, we will discuss how to create a trigger to find the brake application point, how to create a radar plot to track how the relative brake application point is changing in each corner and how to gauge which corners have the greatest effect on the overall vehicle lap time based on brake application point. This analysis can provide the driver and engineer with a tool to help them to improve braking performance during a race weekend.

## Single lap analysis

Before we dive into creating the maths channel, we will define what the brake application point is. It is the distance, inside a defined braking zone, in which a driver starts to brake for a corner.

As described in previous articles, we can define the area to search for the brake application point by using the section tool on the track map to set boundaries to include braking. In addition to having the range within the data to track the application point, it is also good to have a reference for the braking zone so the driver and engineer can visually compare the brake application point to the data driven point.

To create the brake application point math channel shown in **Table 1**, we will create a trigger to record when brake pressure is applied using the 'choose' function available within the MoTeC i2 program. The choose function acts as an 'if' statement that can be found within other programming languages. If there is a non-zero value for the total brake pressure, the distance will be recorded for the sequence. If the brake pressure returns to zero, then there will be nothing returned by using the 1/0 value.

Within each braking zone, we can then define the minimum point at which a driver starts braking using a channel report table. We can then export the data and thereby create a radar plot to compare the capabilities of the two drivers.

In **Figure 1**, each edge of the plot corresponds to a corner on the track where braking is occurring, with the bands representing a percentage later or earlier braking by the second driver relative to the first. We are using a percentage as each corner will have its own unique application point based on the corner radius, the incline leading up to the corner, the camber of the corner and the visual references within the corner. Using the percentage normalises the results and allows us to see the consistency of the driver more clearly in sections that will not have the same distance.

In our example, we can see that the second driver (shown in pink) out-braked his competitor in all but two braking zones on their best lap. This can provide an indication of where to look within the laps afterwards to find differences in driving ability and overall performance that will explain the different brake application points.

In addition, we can find where a driver is inducing a vehicle balance shift in a corner, the wheel locking that comes from a different brake application point and the impact of brake application point on tyre

**We can define the area to search for the brake application point by using the section tool on the track map to set boundaries**

wear, driver fatigue and fuel usage through an event by using different braking strategy to trail brake or to straight-line brake.

## Full session analysis

Knowing the delta between the two drivers during their best laps, we can now go on to look at their consistency across a session. We will look at the average application point in a race situation and compare the overall results to what we see in the one-lap peak. We can then look at the standard deviation of the three situations to see driver consistency and find how much fall off the driver is seeing in an event through, for example, either their own fatigue, loss of focus, or tyre fall off.

The greater the delta between the two values, the more potential fall off is present in that session.

# Understand how close they are able to get to their best lap times on average

We can make this inference if we assume lower cornering speeds are required for the driver to get through the corner, therefore warranting an earlier brake application point.

This analysis is one of the tools that can help drive decisions like pit strategy if running a longer event as it can be used to determine the trade-off between more pit stops but a faster average lap vs a longer tyre run but potentially greater tyre fall off. The same data can also be used to coach a certain driving style to conserve or be aggressive with tyres if running a shorter event.

We will now create another radar plot showing the average brake application point across a session with the upper and lower standard deviation for the two drivers.

From the full race results shown in **Figure 2**, we can see from the average brake application point that the two drivers are significantly more split in brake application point than would appear in the one-lap result.

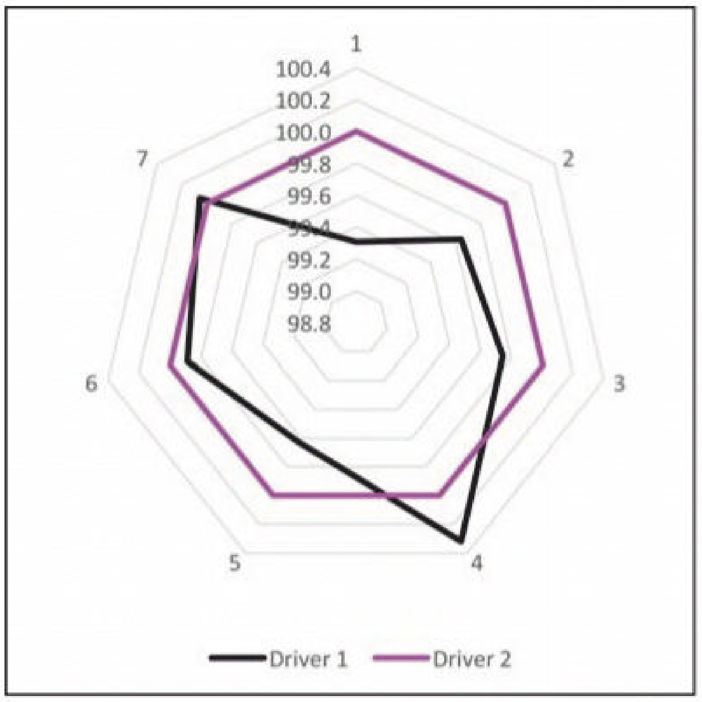


**Figure 1: Relative brake application point radar plot**

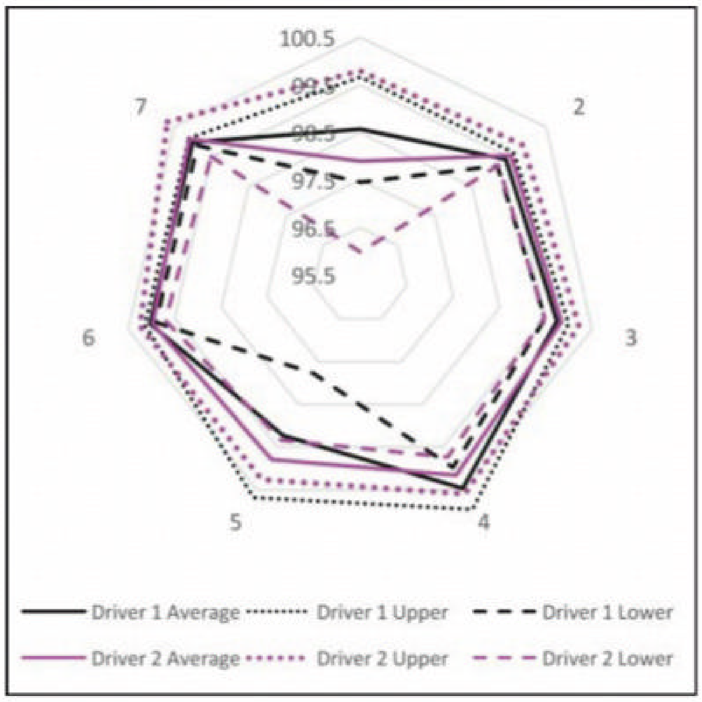


**Figure 2: Brake application point across a full race session with upper and lower bounds for each corner**

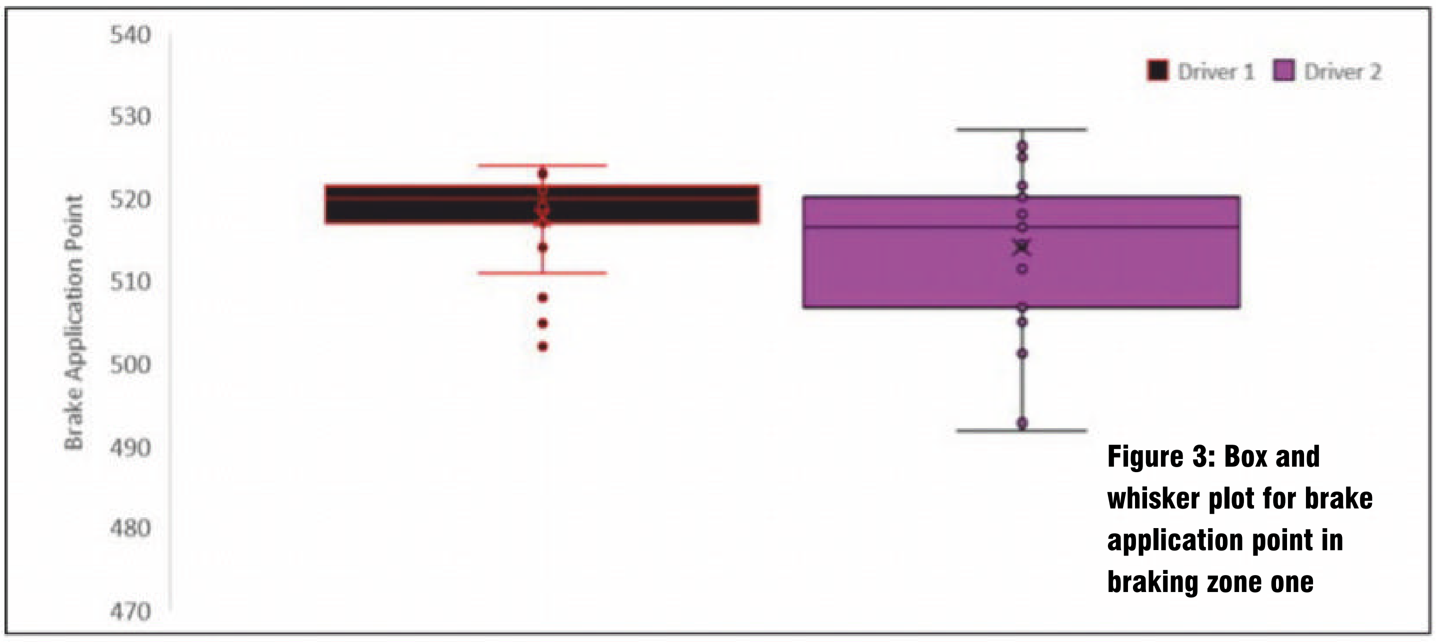


**Figure 3: Box and whisker plot for brake application point in braking zone one**

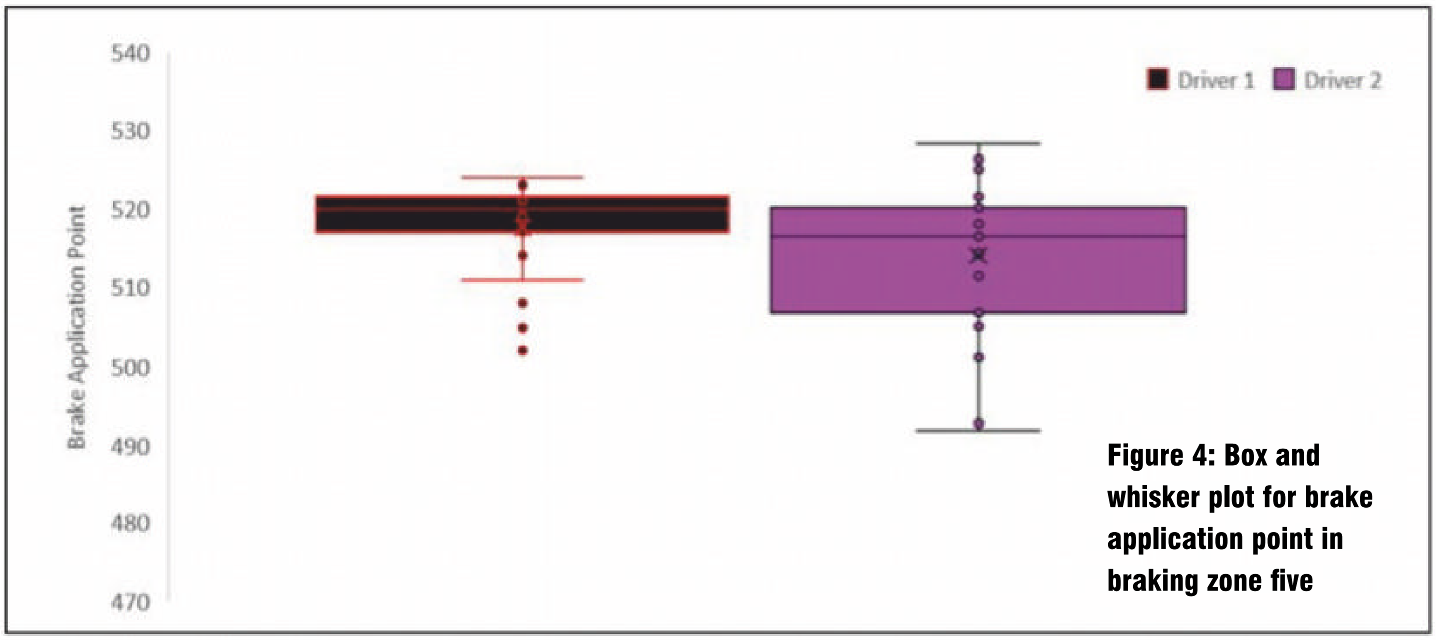


**Figure 4: Box and whisker plot for brake application point in braking zone five**

For instance, while the first driver was braking earlier on their best lap in braking zone one, they are braking much later in the full race pace compared to the second driver. We can also see that the large variation we saw in braking zones two, three and six is not as exaggerated as we would have expected.

From this, we can begin to understand the sustainability of the brake application points seen in the fastest laps and understand how close they are able to get to their best lap times on average.

Looking beyond the average, we can look at the upper and lower bounds to see how the application point is developing throughout the race. In this example, we can begin to predict that the second driver is using more of their tyres as they had a much larger variation in braking zones two, three, six and seven. This data can be misleading, though, as it does not consider events such as overtakes, which can cause great variance in the data depending on the location of the overtake. To see if this is the case, or if there is inherently an inconsistency in that braking zone, we can create a box and whisker plot. The plots for braking zones one and five are shown in **Figures 3** and **4**.

To read the plot, the quartile boxes correspond to the range in which the driver was most often braking, with the centre line being

# When looking at the same plot for the first braking zone, we see the later the driver was able to brake, the faster their lap was

the median brake application point. The whiskers off the box correspond to the upper and lower 25 per cent of the range of the data in relation to the median. The smaller the plot area, the more consistent the driver was in that range. In this case, we see that for both braking zones where drivers were inconsistent, the inconsistency was beyond just a few outlier laps (maybe attempting to overtake, or defend position). In both instances, we see that lower bound of application had the larger variation for both drivers.

This does not tell us the cause of the variation in brake application point, and the effects that using the different point had on the overall performance of the vehicle. But at least we have identified a problem, the causes of which can be analysed with other data and / or during debriefing conversations.

## Critical corners

To look at the effects of the brake application point on the lap time, we can compare the lap time of the car to the brake application point to determine if there is a correlation. This will show how much the inconsistency is affecting overall performance during the race, and how much the drivers will need to change their style for future runs. This can also help the driver and engineers determine which corners can be compromised to emphasise fuel, tyre saving, or overtaking, and which ones should not be compromised as they will cause a more significant fall in performance.

When looking at the correlation between the time and brake application point, we see that for braking zone five (**Figure 5**) there is very little correlation between a faster lap time and a later, or earlier, brake point with driver two. We can therefore determine this is a corner that would leave more ability to compromise as driver one appears to have done.

To see the more far reaching effects of the driver one approach, we could look at the braking stability and turn-in point to see how they are approaching the corner, the line being taken and the balance of the car as the turn in is induced. In contrast to braking zone five, if we look across the course at the first braking zone (**Figure 6**), we can see there is a much larger correlation to lap time. When looking at the same plot for the first braking zone, we see the later the driver was able to brake, the faster their lap was, especially for driver two. This suggests to the driver and the race engineer that this is then not a corner to compromise their application point for as it can have a significant effect on how much the driver can gain on a competitor, or how quickly they can be caught by a chasing competitor.

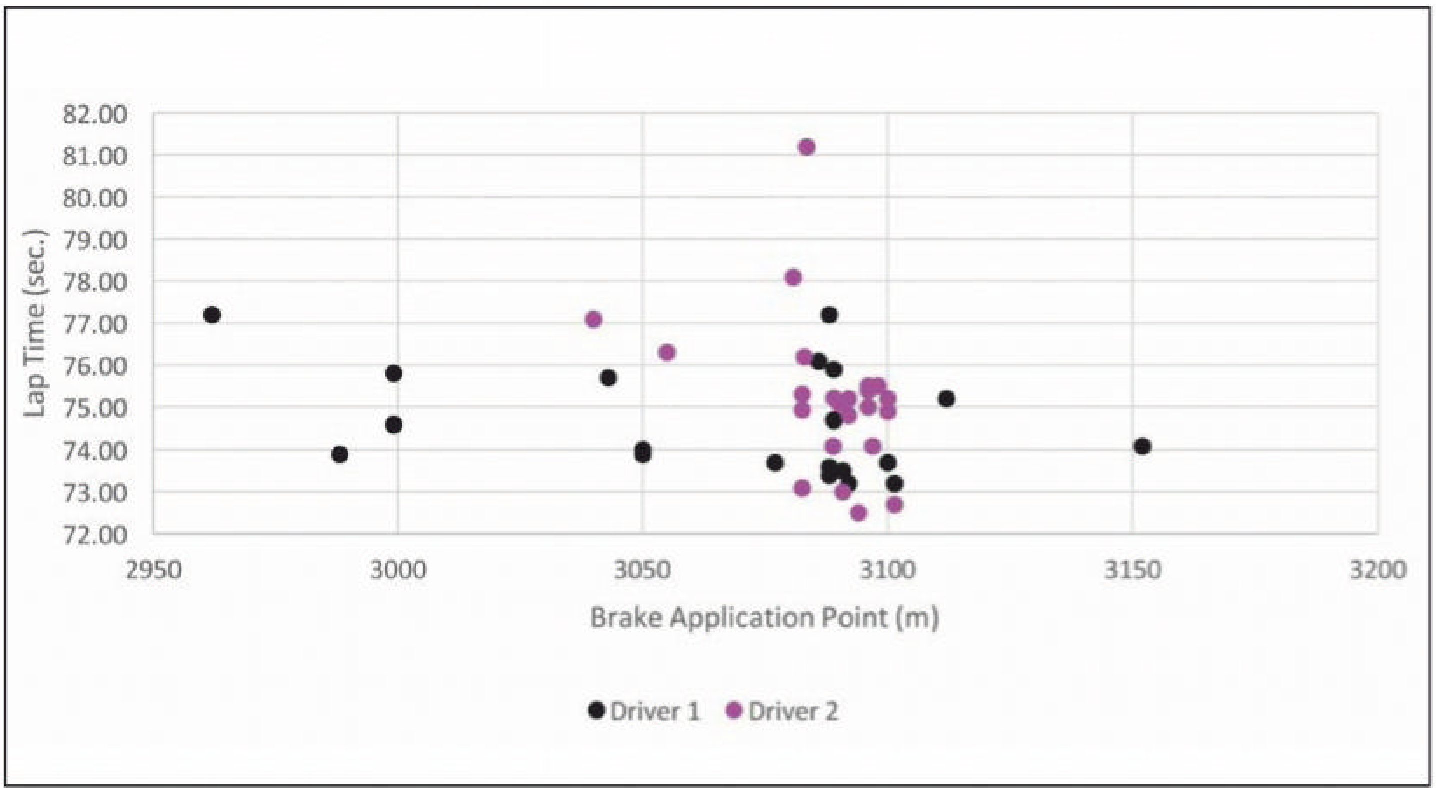


**Figure 5: Comparison of brake application point in braking zone five to lap time**

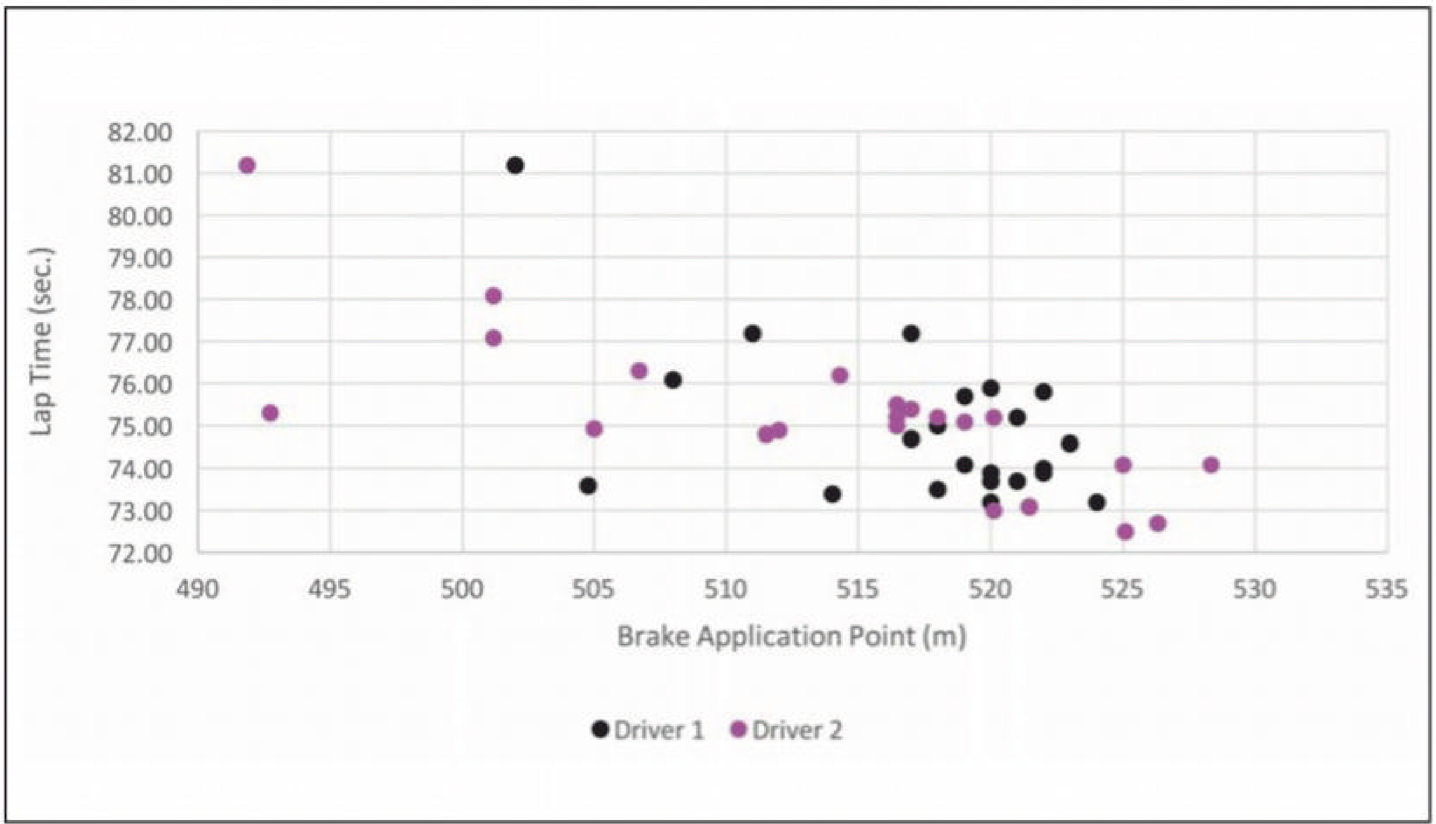


**Figure 6: Comparison of brake application point in braking zone one to lap time**

In supplementing our brake aggression KPI, we can now understand not only how a driver is braking, but also when the driver is braking, and the effects of that application point on the overall performance of the vehicle, be it over a short or a longer stint. We can see which corners are the most important to be consistent within and which ones can be used for race craft or vehicle consolidation.

This now adds another useful tool within the engineer's arsenal to find an advantage and provide context to how the racecar is behaving on course.


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# A question of balance

A new project starts this month, a BMW M3 E46 Britcar, looking to reduce drag and find a good aerodynamic balance

The Britcar BMW M3 E46 tested this month featured attention to detail in key areas

Despite lacking a flat floor and rear diffuser, aero performance was very respectable

Our subject car's owner, Piers Reid, previously raced his 3.2-litre BMW M3 E46 in the UK's Kumho BMW Championship and the CSCC New Millennium series. However, after sampling a Britcar Sprint race late in 2018, he has now moved into that series, where longer race durations are popular with drivers. We shine the MIRA full-scale wind tunnel spotlight on this Britcar BMW.

As its principal downforce-inducing components, the BMW featured a decent sized splitter integrated with a nicely designed underside incorporating wide front diffusers. At the rear, a high downforce, single-element wing was installed at roof height, with some overhang over the boot spoiler. Other lift-reducing details were to be found in the front end, the bonnet and the wheelarches.

The car arrived at the wind tunnel after a recent outing at Silverstone, where wet conditions had prompted an increased rear wing angle over that used in earlier dry testing. Initial adjustments therefore focussed on wing angle reductions from 'wet' to dry setting.

The owner's main wind tunnel objectives were to reduce drag and find a good aerodynamic balance, with a static weight distribution of around 53 per cent front. Our target downforce balance range was in the upper 40s to 50 per cent front.

By session's end, both high downforce and low drag balanced set-ups had been achieved, as **Table 1** illustrates. How we reached that will be covered in the next two issues. This month we'll focus on the overall numbers and put them into context in various ways.

Looking at **Table 1**, the shift from 'wet' to 'dry' baseline was achieved with wing angle reduction, which produced a 15.6 per cent reduction in overall downforce and a 6.5 per cent drag reduction, but usefully the balance shifted more forwards. Clearly, though, more downforce was required on the front end, even to balance the lower wing angle used for the dry baseline set-up, and that's where efforts for the first part of the session were focussed.

This yielded the 'high downforce' balanced set-up (actually, a higher downforce balanced set-up was also achieved, but at a practically unachievable high rake angle). Our achievable high downforce set-up yielded 22.6 per cent more downforce than the 'dry' baseline, with just 3.2 per cent more drag, hence efficiency (-L/D) was up 18.7 per cent.

Most importantly, balance was right in the target range at 48.5 per cent front.

On the other hand, the 'low drag' balanced set-up gave 6.9 per cent less drag than the dry baseline set-up, yet still achieved 2.4 per cent more downforce, this the result of increased front downforce through various means and decreased rear downforce through further reduced wing angle.

**Our target downforce balance range was in the upper 40s to 50 per cent front**

**Table 1: Baseline aerodynamic coefficients and optimised set-ups**

| | CD | -CL | -CLfront | -CLrear | %front | -L/D |
|---|---|---|---|---|---|---|
| Wet baseline | 0.494 | 0.698 | 0.178 | 0.519 | 25.5% | 1.411 |
| Dry baseline | 0.462 | 0.589 | 0.205 | 0.384 | 34.8% | 1.275 |
| 'High downforce' balanced set-up | 0.477 | 0.722 | 0.351 | 0.372 | 48.5% | 1.514 |
| 'Low drag' balanced set-up | 0.430 | 0.603 | 0.295 | 0.309 | 48.9% | 1.404 |

**Table 2: Cars with similar aerodynamic data to the BMW (low drag and high downforce data given for the BMW)**

| | CD.A | -CL.A | %front | -L/D | Static weight split, %front |
|---|---|---|---|---|---|
| BMW M3 E46 | 0.946 / 1.058 | 1.327 / 1.635 | 48.9% / 48.5% | 1.404 / 1.546 | 53% |
| Ferrari F430GT3 | 1.103 | 1.772 | 44.1% | 1.607 | 44% |
| Porsche GT2 | 0.950 | 1.347 | 38% | 1.418 | 39% |

## Respectable company

How do these overall numbers relate to cars we have previously tested? First, let's multiply the coefficients by frontal area so direct comparisons can be made. The two nearest comparators, as shown in **Table 2**, are the Mtech Ferrari F430 GT3 and the Paragon

Big splitter with diffusers, dive planes and bonnet louvres all helped front-end aero

The front wheel arches were vented on top and at the rear in order to help excavate air

Porsche ALMS GT2 we tested in 2010, which puts our test BMW into very respectable company. The BMW's low drag set-up was very similar to the Porsche's, while the high downforce set-up was not so far away from the F430 GT3. Had the BMW needed a slightly more rear-biased balance like the Ferrari, more rear wing angle would have elevated the downforce into the same region. With no flat floor or rear diffuser at this stage of its development, the BMW has the potential to comfortably exceed these figures.

Another obvious car to compare is the Saxon Motorsport BMW 1 Series that we tested in 2017, and its basic numbers are shown in the same format in **Table 3**. This car was being prepared to run in the Nürburgring 24 Hours and other selected endurance events, including Britcar, and also came to the wind tunnel with less front downforce than was desirable. Efforts in the wind tunnel eventually brought the %front value to around 45 per cent on a car with a 53.6 per cent static weight split (and with a rather large V10 engine up front!).

Although the 1 Series featured a flat floor and rear diffuser, and despite the fact that it was running quite a steep angle on its rear wing, its total downforce was 19 per cent less than the M3's, yet with a similar drag level. The 1 Series could clearly have benefited from more front downforce. Its hatchback configuration would probably not have helped the car's rear end efficiency either.

## Drag effect

Referring back to the low drag and high downforce settings, it's interesting to analyse the difference that the change in drag would make. First, let's compare the theoretical top speeds on the assumption the car had 400bhp at the wheels using the formula:

$$V_{max} = \sqrt[3]{[(bhp \times 1225)/CD.A]}$$

Using the low drag CD.A value of 0.946, this yields a maximum speed of 179.8mph. Substituting the high downforce CD.A value of 1.058 yields a maximum speed of 173.2mph.

**Table 3: Comparison data from a BMW 1 Series tested in 2017**

| | CD.A | -CL.A | %front | -L/D | Static weight split, %front |
|---|---|---|---|---|---|
| BMW 1 Series | 1.048 | 1.074 | 45.2% | 1.026 | 54% |
| BMW M3 E46 | 0.946-1.058 | 1.327-1.635 | 48.9%-48.5% | 1.404-1.546 | 53% |


Top-mounted, single-element, well-cambered rear wing with swan neck supports, overlapped the boot spoiler

Another way of looking at this is to calculate the power absorbed at a specific speed with different drag levels using the equation:

$$bhp\ absorbed = (CD.A \times V^3)/1225$$

At, say, 60m/s (134.4mph) – a speed easily reached on fast straights – the lower drag value would absorb 166.8bhp, and the higher drag value would absorb 186.6bhp, roughly 20bhp more power absorbed at the same speed. Depending on the nature of any given track, this difference could be significant in terms of both lap time and ability to overtake.

## Vertical loads

Lastly this month, how significant were the vertical loads at the M3's downforce levels, in relation to its weight? In highest downforce trim, with a 48.5 per cent front aerodynamic balance, the car generated the equivalent of 9.8 per cent of front axle weight at the front tyres and 11.8 per cent of rear axle weight at the rear tyres at the wind tunnel test speed of 80mph. These figures would scale up at 150mph according to the square relationship with speed to around 33.6 per cent and 40.3 per cent. The car's downforce was therefore appreciable.

More on the BMW next month.

Racecar Engineering's *thanks to Piers Reid for providing his racecar.*

### 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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# On the right track

## While the IndyCar 2018 Universal Aerokit hit its target window for aerodynamic performance, improving it and modelling its effect on racing is proving to be a very complex task

**By ANDREW MOSEDALE**

When IndyCar introduced the Universal Aerokit (UAK18) last year to try and encourage cost-effective, safer, more pure racing than when Honda and Chevrolet produced their own kits, there were a range of reactions. The one thing everyone agreed on, though, was it would make things different.

Certainly, the 2018 edition of the Indy 500 was a different kind of spectacle to the previous years, requiring patience, stability and commitment to work one's way up the field. The drivers and teams relished the challenge of getting the best out of the new package throughout the year as they continued to discover more about how UAK18 behaved.

Meanwhile, that same learning was feeding into the aerodynamic development group at IndyCar as they got to work on what changes could be made for 2019.

Aerodynamic development is rarely a straightforward task, even when in control of the regulations. The Universal Aerokit landed in the target window for aerodynamic performance, but there is more to consider than simple calculations of drag and downforce. Safety has remained paramount in planning any changes and this usually requires modelling the aerodynamic behaviour of the car in unexpected positions, as crashes rarely happen for a lone car powering down the straight. Matters of cost and weight distribution also have to be factored in.

With a benchmark level of expectation from the first season of the new Aerokit, any changes had to meet, or exceed, these measures of performance, while also proceeding on track to deliver better racing. And with the launch of the traffic study, in partnership with the Reynard-owned Auto Research Center LLC (www.arcindy.com) and R-Systems NA (www.rsystems.com), IndyCar had a new way to predict if developments would correlate with better on-track entertainment.

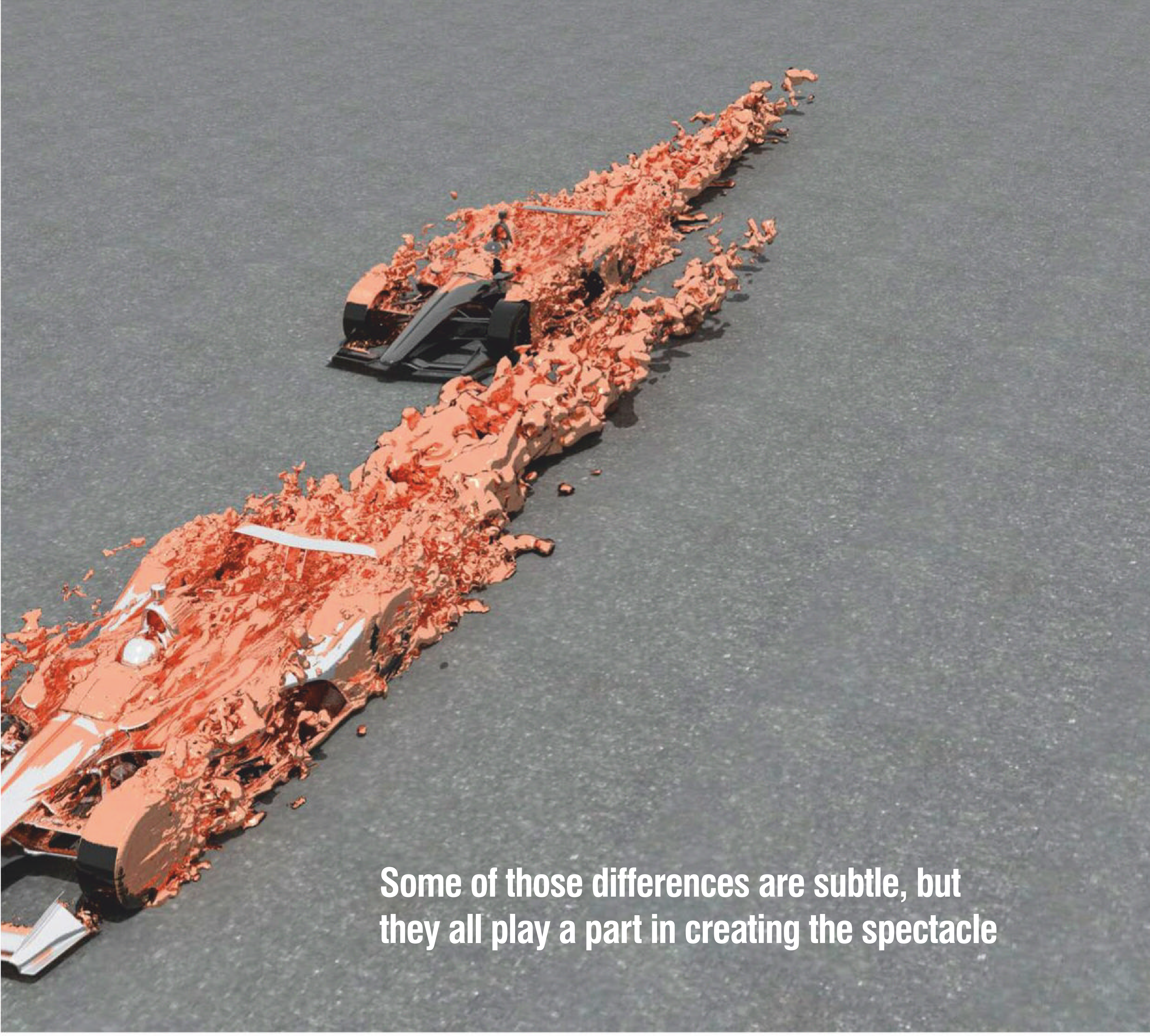
In the March issue of *Racecar* we saw how the shift in downforce production from the wings to the floor in the UAK18 had a knock-on effect for the car in traffic. Drivers reported having less front grip than they were used to when following another car, and also a lack of stability. Analysis of the forces with CFD (computational fluid dynamics) from ARC's Elements software with two cars in multiple positions showed evidence for this shift in balance towards the rear axle, and revealed some interesting features of the front wing.

**Figure 1a** shows the flow under the wing for a car running in isolation. The main-plane element is unremarkable, but the flow inside the concave surface under the end plate draws attention. In simplest terms, the area for the air to travel through is expanding too quickly and loses too much momentum to remain attached to the surface. The resulting turbulent flow bleeds onto the main plane, as clearly seen in track testing (**Figure 1b**).

This flow feature is useful in creating low pressure to reduce drag on the front tyres, but **Figures 1** and **2** do not tell the whole story. The flow separation is inconsistent. While the wind tunnel can provide the overall forces on the car, and the track visualisation captures the extent of the turbulent region, neither method is ideal for measuring how steady and reliable those forces are.

Flow sensitivity itself is nothing new. Teams regularly test to see how performance varies with different wing angles and suspension settings. But these tests usually assume the forces don't change if the car is held still. Regardless of the effect on drag or downforce, a car needs to have stable and predictable aerodynamics. This was not the case with the

**Regardless of the effect on drag or downforce, a car needs to have stable and predictable aerodynamics**



**Some of those differences are subtle, but they all play a part in creating the spectacle**

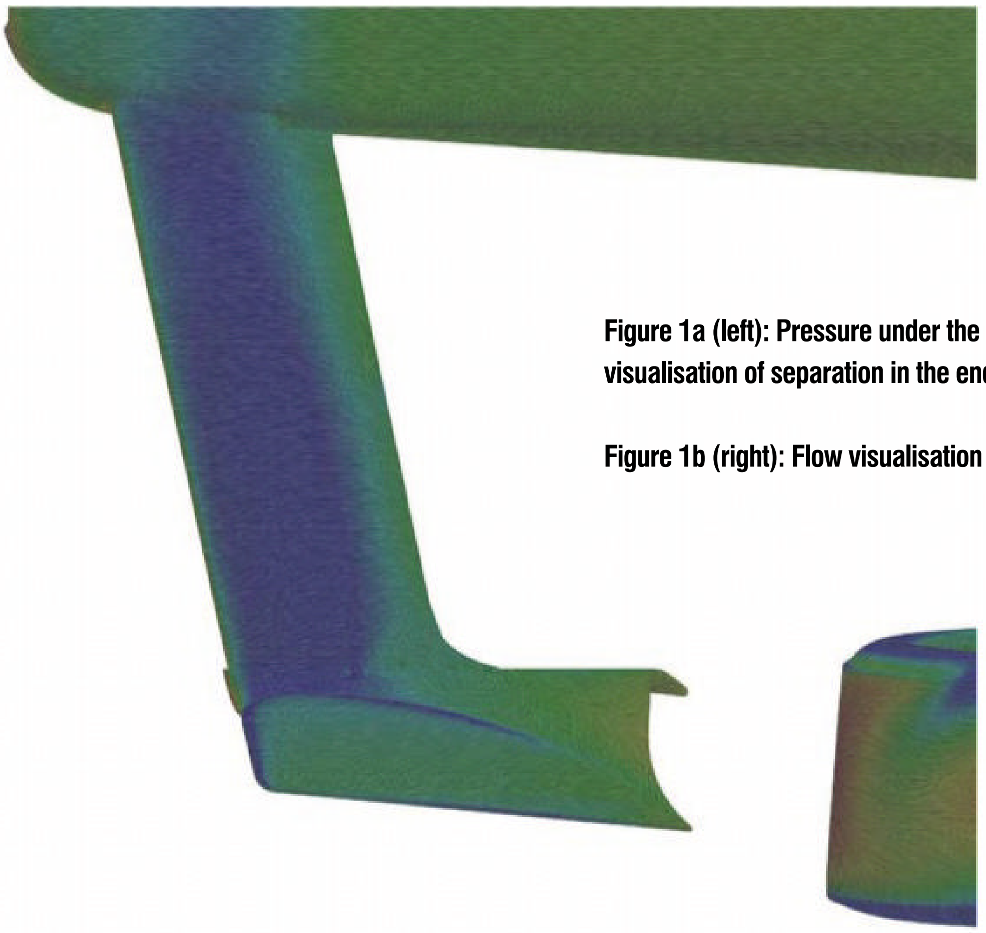
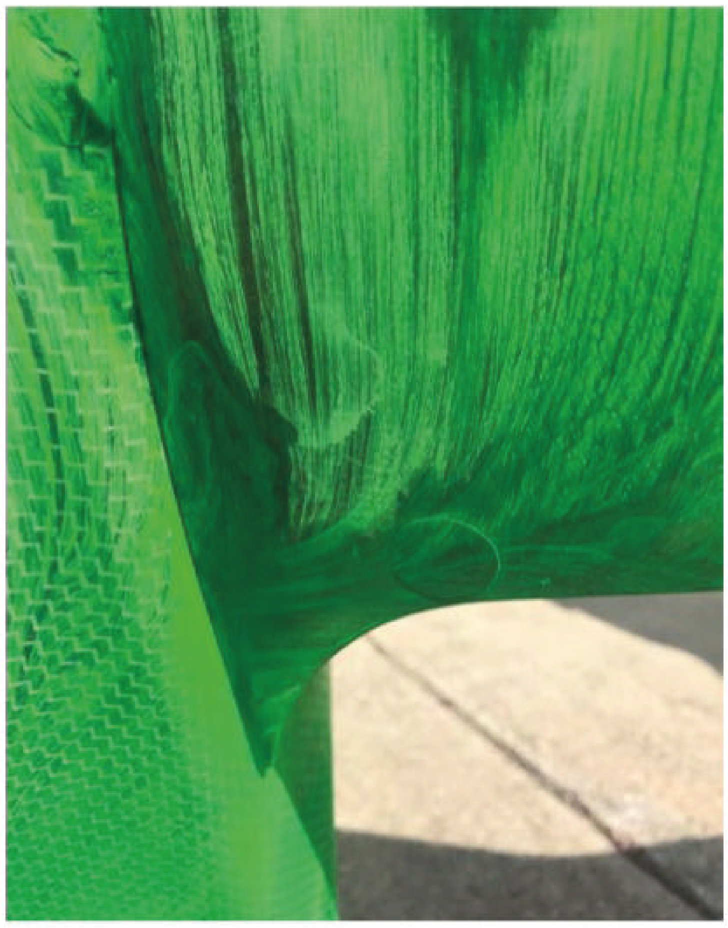


Figure 1a (left): Pressure under the UAK18 wing and visualisation of separation in the end plate

Figure 1b (right): Flow visualisation from track testing



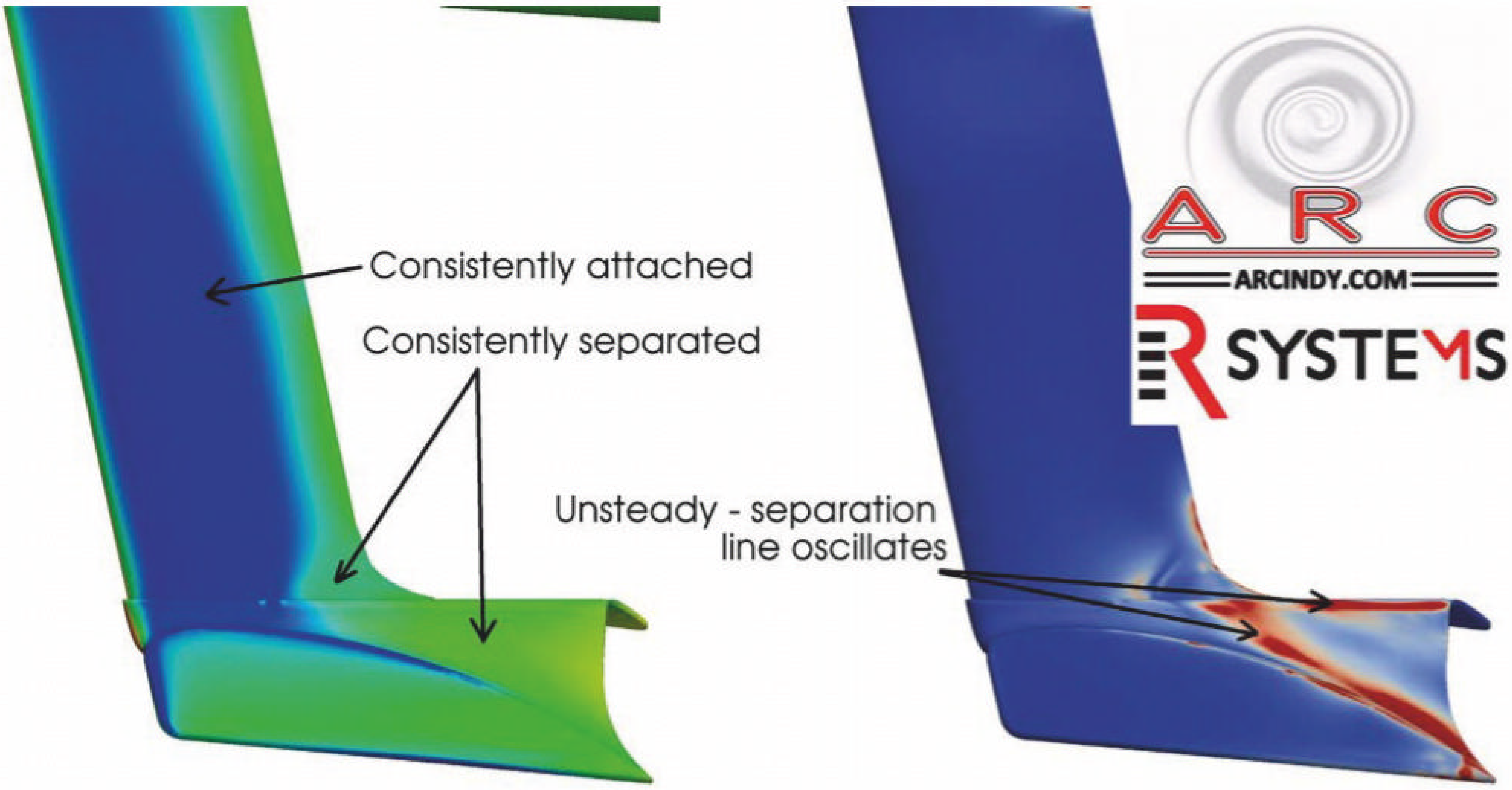



**Figure 2: Mean surface pressure (left) and regions of pressure fluctuation (right) under UAK18 wing**

**The size of the separated region, and the wing area affected, fluctuated significantly over time**

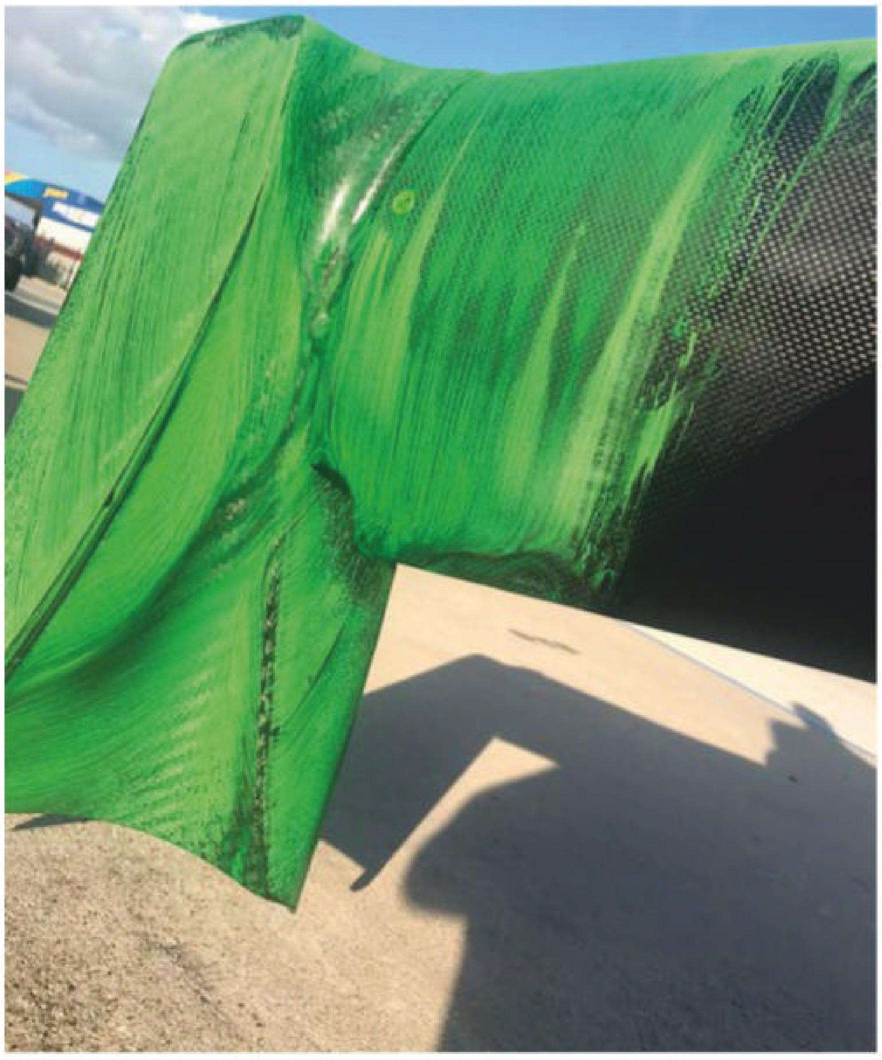


**Figure 3a: Surface flow of 2019 notch wing from testing**

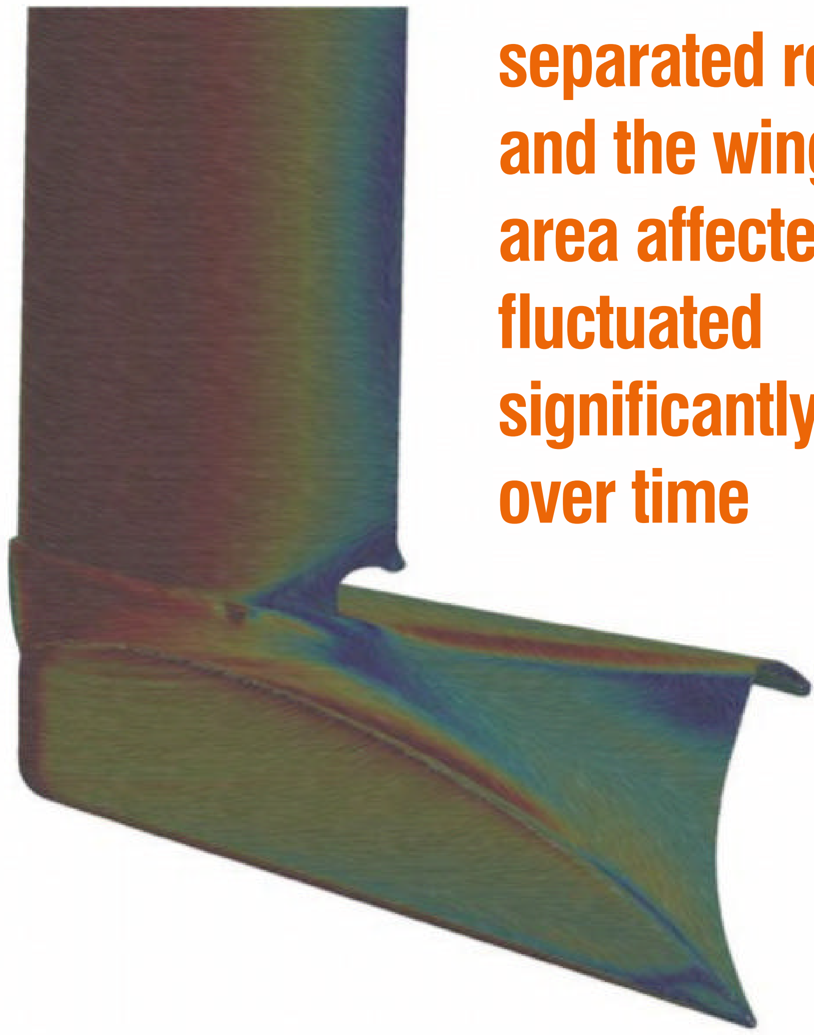


**Figure 3b: CFD surface velocities on notch wing**

UAK18 front wing end plate. The size of the separated region, and the wing area affected, fluctuated significantly over time. Aside from the feedback from the drivers, the evidence for this is from the transient CFD solution.

**Figure 2** shows the average pressures under the wing, alongside the variation in that pressure with time. Some regions show very low variation, and in these the flow is steady and can be well modelled with steady techniques. But a large section of the wing cannot be properly predicted without accounting for how flow changes over time.

Given how important this area is to predicting the flow past the front wheels and onto the rest of the car, selecting appropriate CFD methods can make a big difference to understanding car performance, and is critical to being able to simulate effects downstream on a following car (see side panel on p66).

## Stepping up a notch

Having identified that the intersection of the wing element and end plate was underperforming, several changes were considered. One such change can be seen on the 2019 cars in the form of a notch at the end of the wing, as shown in **Figures 3**.

This cut reduces the wing area and allows air to leak through to the suction side of the wing. This is normally a bad idea, but the high pressure air in this case stabilises the flow and leads to better performance. **Figure 3a** shows the flow in the end plate region during testing, and **Figure 3b** its correlation with CFD, while **Figure 4** indicates that the influence of the concerning transient separation is now greatly reduced. While a simple change, the notch in the front wing passes the combined

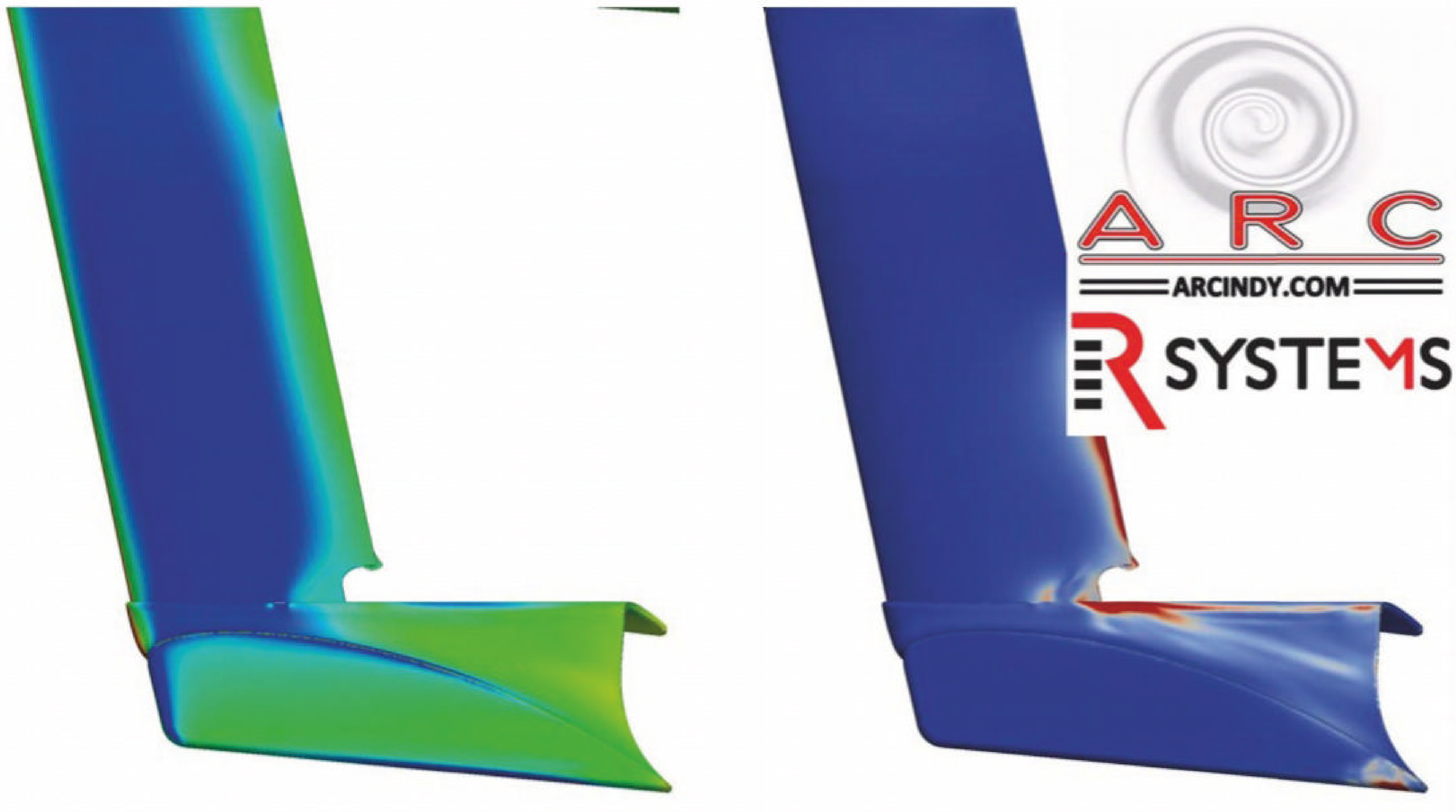



Figure 4: Notch in 2019 wing significantly reduces unsteady separation in end plate

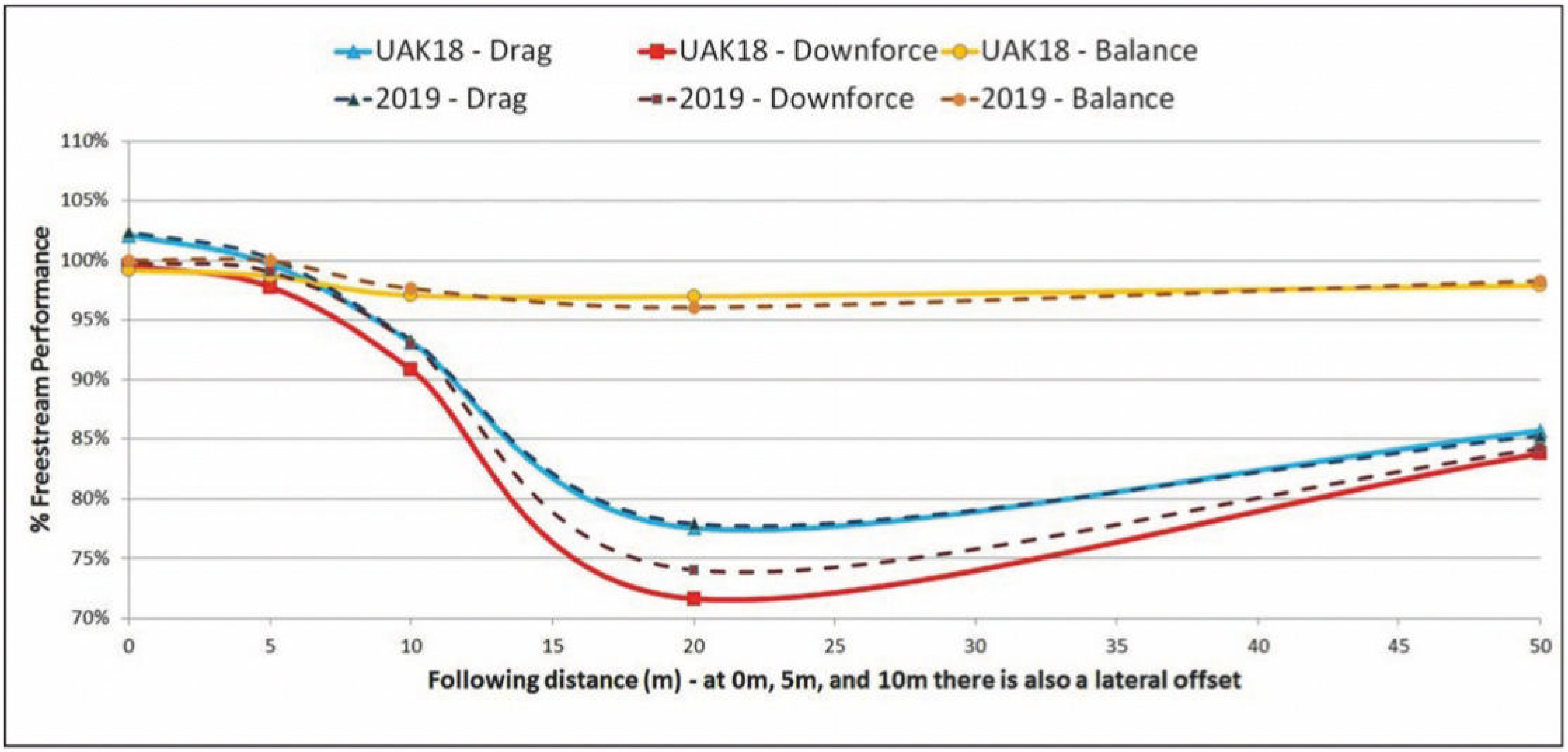



Figure 5: Change in aero performance of car due to position in overtaking manoeuvre

**Front downforce recovers more quickly as you move out from behind the car ahead, providing better balance at the crucial moment**

tests of improving outright performance, being cost-effective and not compromising safety. But does it improve racing?

In the past, that question would have to wait until the cars are on track at the speedway. Now, with the CFD traffic study, we can assess part changes for overtaking potential before they are even made. As part of the study, a generic overtaking trajectory was determined from GPS data of previous iterations of the Indy 500 race. By simulating the changes in the drag, downforce and balance of the car at key points along this trajectory we can anticipate what the effect of new geometry will be in the race. The results are shown for UAK18, and with the 2019 notched wing, in **Figure 5**.

The points relate to specific parts of putting together an overtaking manoeuvre. Drafting is a fundamental part of overtaking at the speedway, so it is good to see that drag was unaffected. Last year showed that downforce and handling were still critical to follow through the corners, as it took longer than a single straightaway to close the gap. The more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# The regulations go to the heart of what it means to design and develop not just a fast car, but an entertaining racecar

stable wing shows more consistent downforce available as you close in from 50m to 20m.

The next two points are critical to evaluating driveability of the car as it pulls out of the wake of the leader. With the 2019 wing, the front downforce recovers more quickly as you move out from behind the car ahead, providing better balance at the crucial moment. Once alongside, knowing if you should expect oversteer or understeer may influence whether you want to hold on to the inside line or go high.

## Take the high road?

As is seen from just this one simple change, there are many things to consider in your race strategy, on the pit wall and for the driver. Making the car stronger in one area will almost always compromise you somewhere else.

An example of this is **Figure 6**, which shows a sample of other configurations available to teams in 2019. These have all be designed to give the same bottom line performance in free air, but react in different ways in traffic. Some of those differences are subtle, but they all play a part in creating the spectacle.

Deciding whether to sacrifice some drafting benefit for more downforce behind the car, or taking oversteer when you pull alongside in exchange for less understeer as you close the gap, these trade-offs have always been part of the set up on race day, but now they go to the heart of what it means to design and develop not just a fast car, but an entertaining racecar.

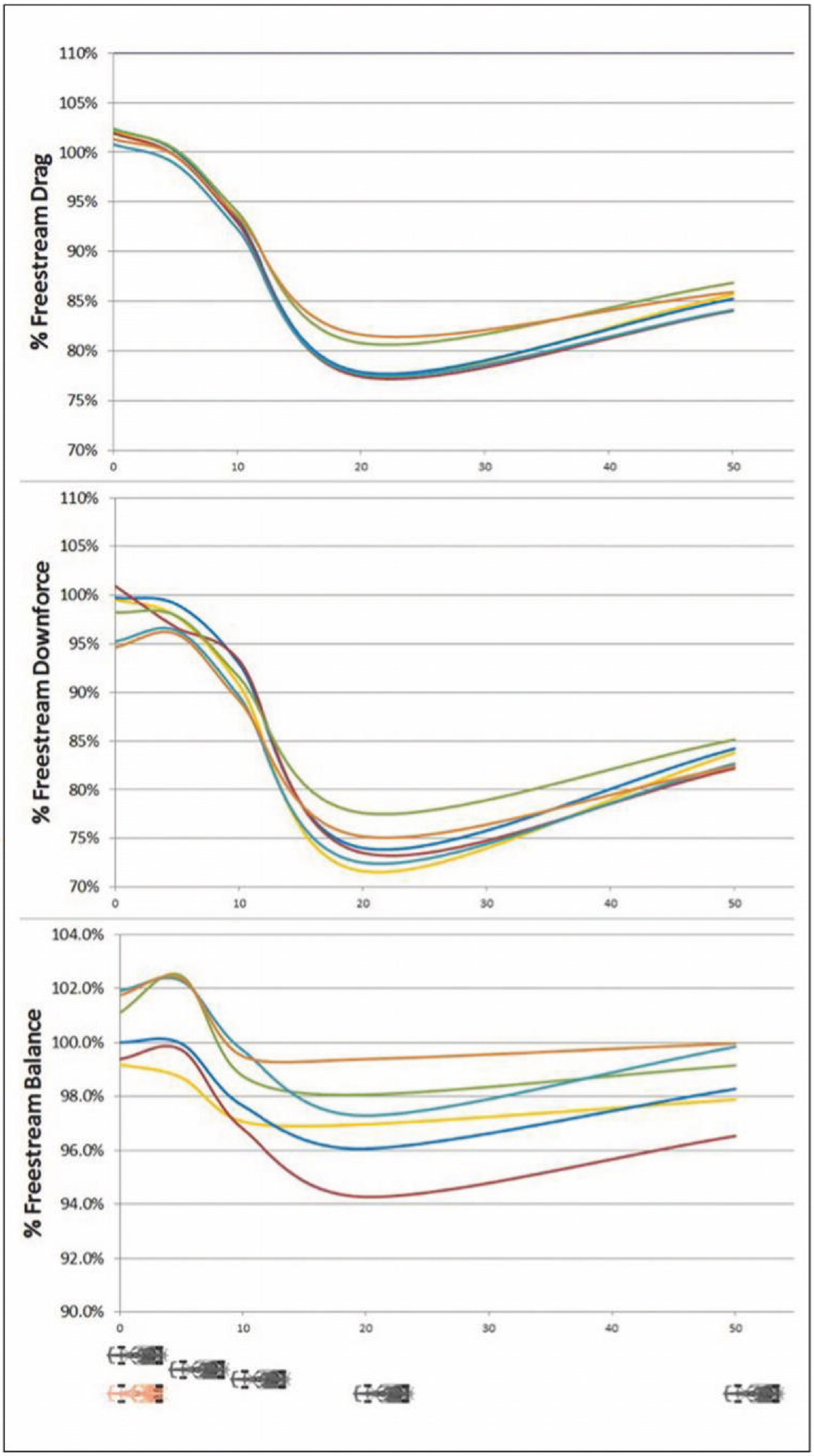



Figure 6: A range of configurations that give the same performance in isolation, but behave radically differently in traffic

**There are many things to consider in your race strategy. Making the car stronger in one area will almost always compromise you somewhere else**

## Choosing CFD carefully

Despite the progress made in computational methods in the past decade, there is still a level of compromise required by the CFD engineer in determining how best to model the real world. While the aerospace industry has developed highly specific and efficient models for its streamlined bodies, the automotive industry has almost entirely transitioned to a physically accurate, but more expensive option of resolving large-scale turbulence in both time and space. Due to the influence of large areas of turbulent flow on the forces of ground vehicles, these models are seen as necessary to move development forward.

The CFD used in IndyCar's traffic study uses such a turbulence model in its detached eddy simulation (DES), but the older approximations from aerospace that solve the simpler Reynolds-averaged Navier-Stokes (RANS) equations are still regularly used in some areas of motorsport. Identifying which model to use in different situations requires a comprehensive understanding of the errors associated with each.

The difference between an instantaneous snapshot of the DES flow, the average of the flow, and the output of a RANS model (k-ω SST) is shown in **Figure 7.** The most immediate observation is that the averaged views give a much stronger impression of big flow structures that may not relate intuitively to the 'real-time' picture.

Detail of the flow structures under the car in **Figure 8** shows how the front wing generates coherent vortices in both models, but immediately the resolution of the front wheel wake changes the picture with the RANS model implying much more outwash from the front of the car than is realistic.

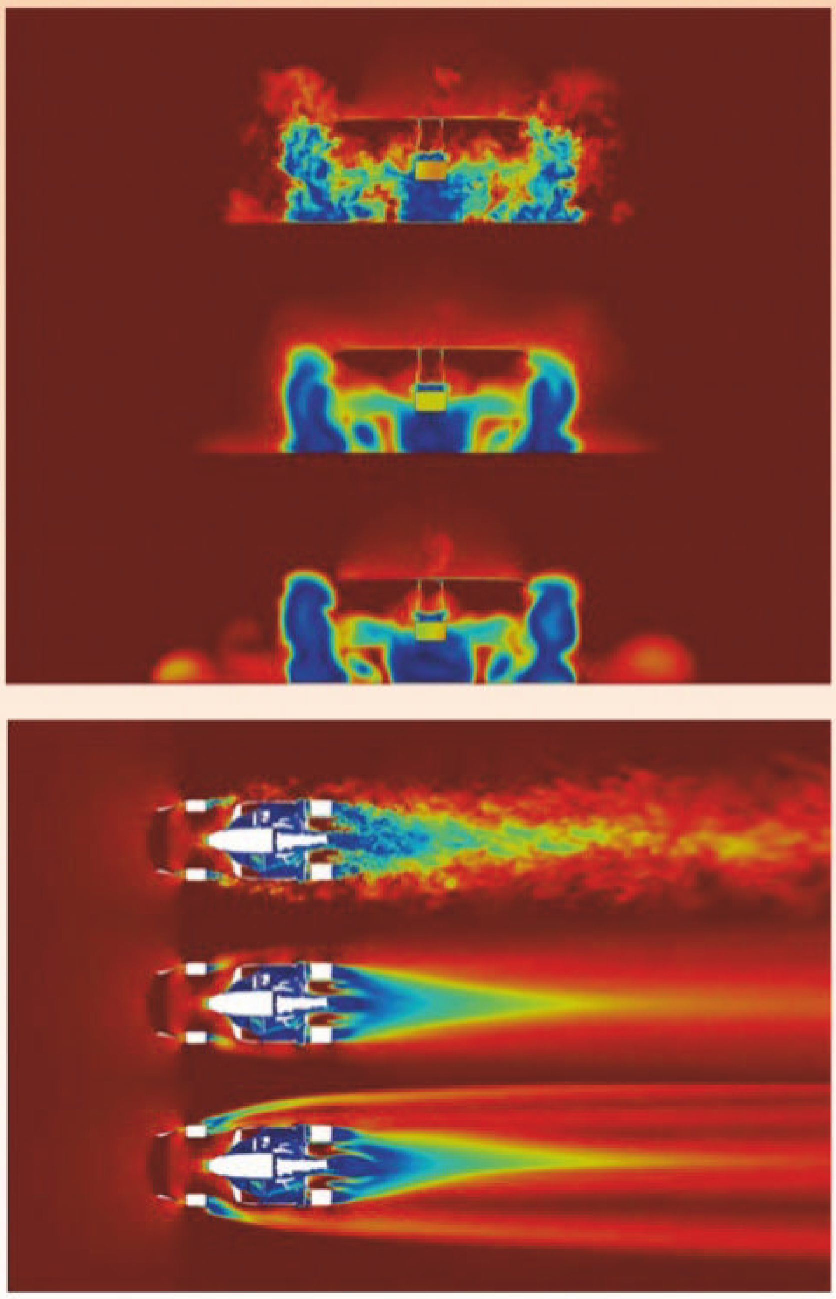


Figure 7: Instantaneous velocities during a typical transient simulation (top), compared to the mean flow field (middle) and the output of a RANS solver (bottom)

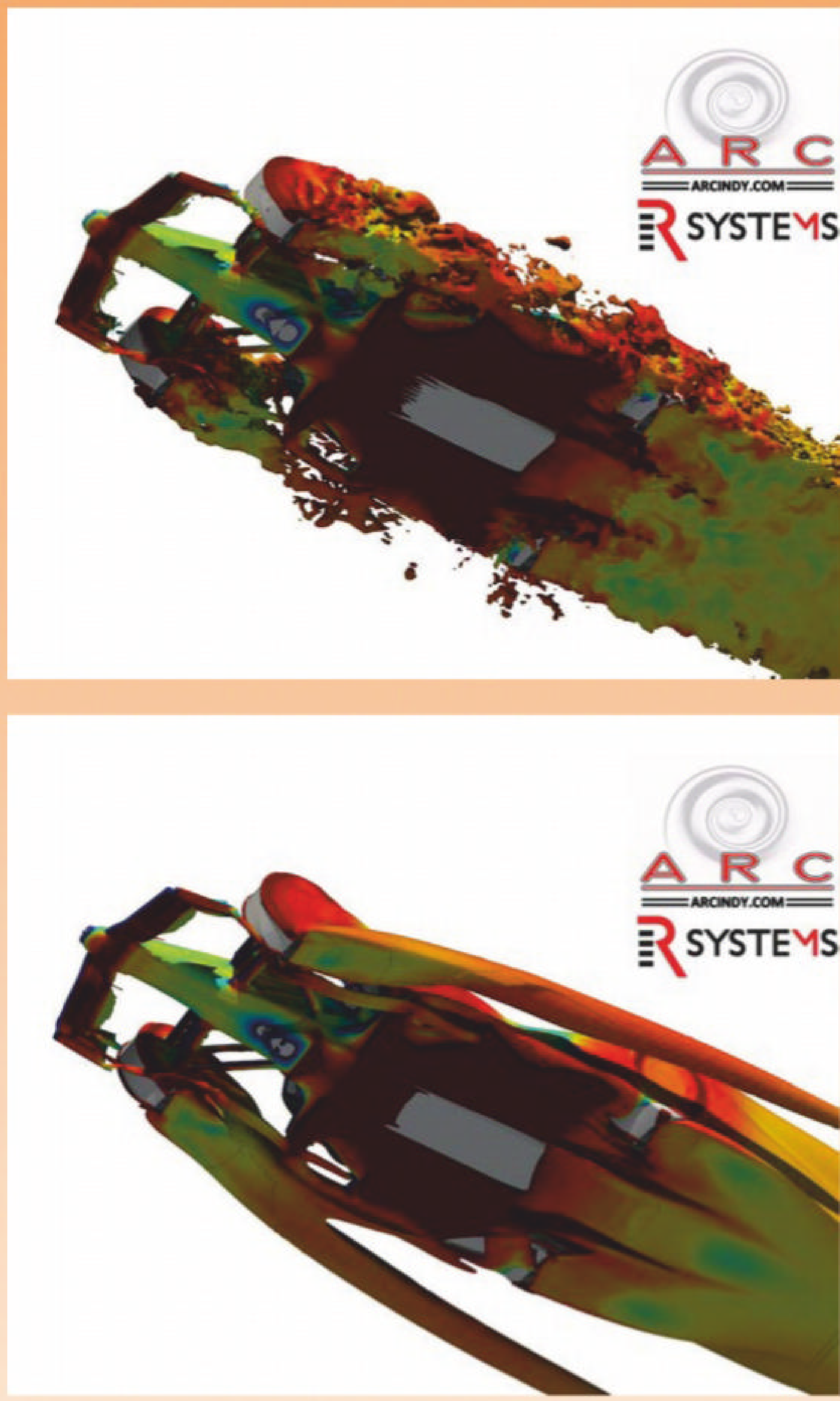



Figure 8: Total pressure isosurfaces from DES (top) and RANS (bottom). Much of the flow is broadly similar, but for certain areas the differences are significant

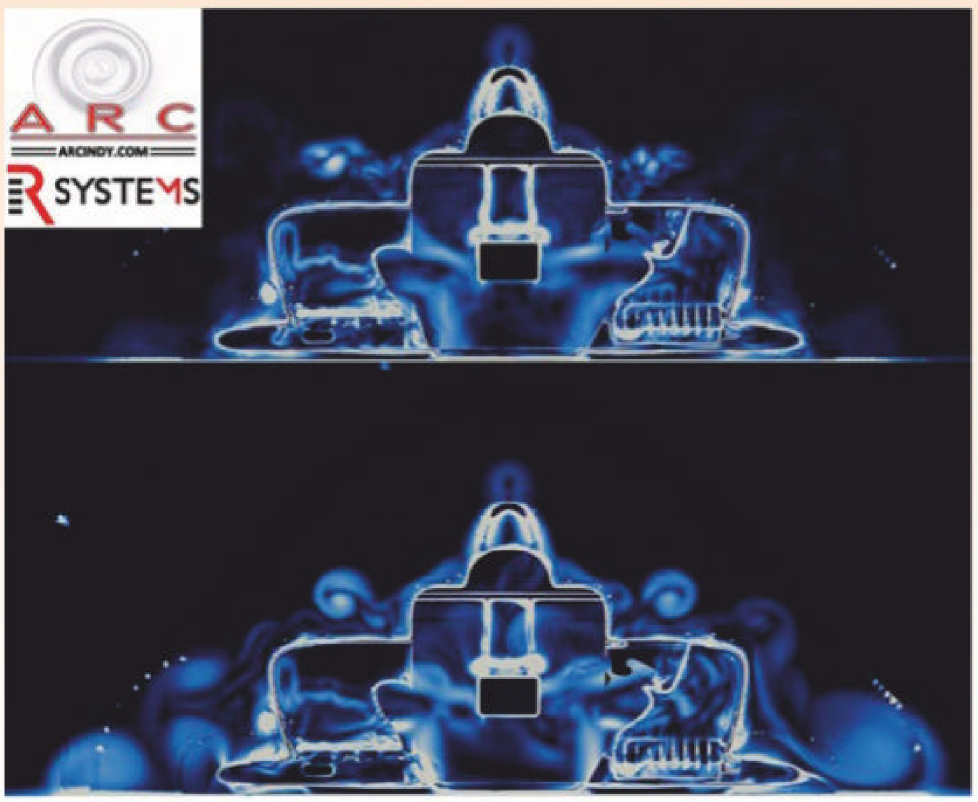



Figure 9: Resolved mean vertical structures in DES (top) vs RANS (bottom)

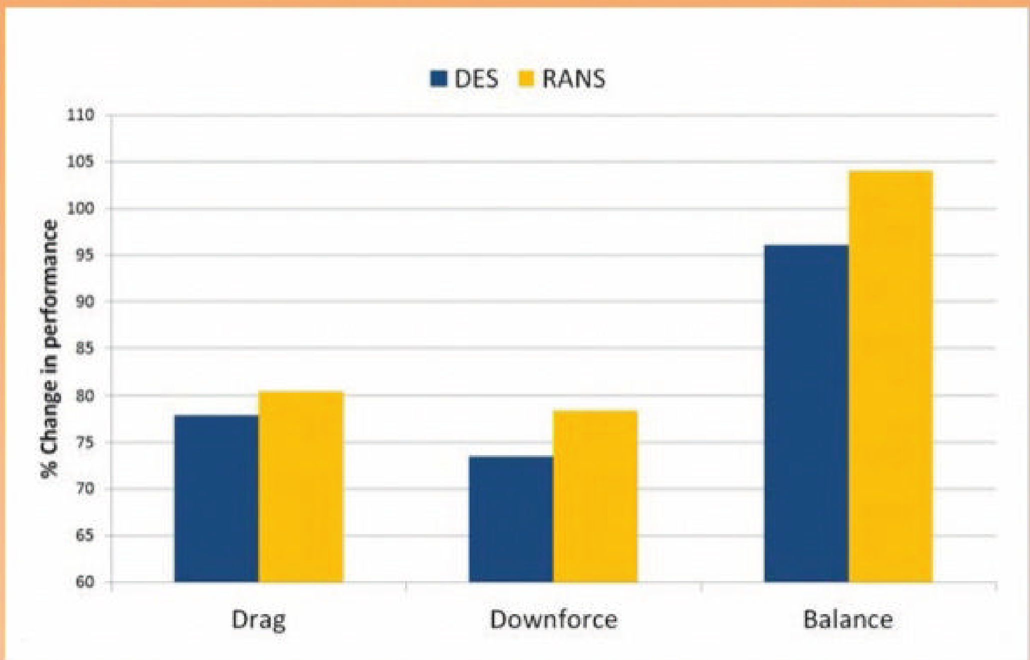



Figure 10: At 20m following distance, RANS under predicts wake effects and significantly indicates a forward shift in balance. This is the opposite trend to that reported by the teams and observed in the DES study

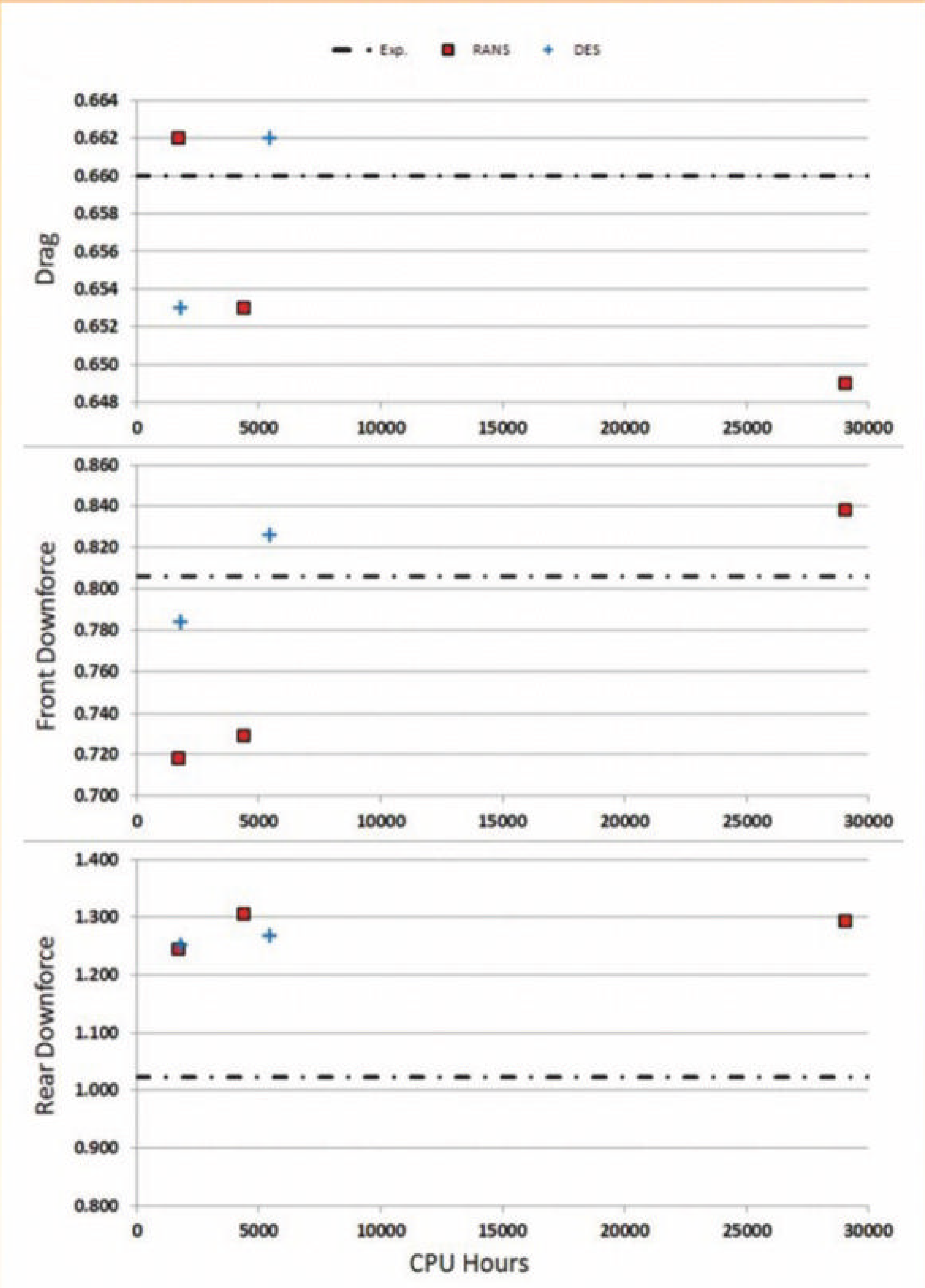



Figure 11: Accuracy of simulation to wind tunnel data of UAK18 by method and compute time

## Using RANS methods to model the impact of a following car can result in misleading information

## In a cost-equal analysis, a low-resolution DES result is typically more accurate than high-resolution RANS

While the time-averaged DES is simply a post-processing technique, the coherent structures in the RANS (**Figure 9**) are seen as real, and can come to dominate and skew the final result. This can lead into a vicious circle with engineers chasing artificial vortices that may not represent the underlying physics well at all.

Using RANS methods to model the impact of a following car can result in misleading information. The data in **Figure 10** shows the trend for balance is in fact reversed in this case from both the DES result and the reported on-track behaviour. The impact of the wake on drag and downforce is also understated, a consequence of the idealised vortices persisting rather than breaking down into smaller turbulent structures.

A strong argument in support of RANS is that it is quicker and cheaper for a given size of simulation. This allows for studying more options that may outweigh the loss in accuracy. However, this advantage can be undermined without great care. Without knowing which trends to trust from RANS simulation, time is lost in wind tunnel testing and on track attempting to verify ideas, and over half the output can be wasted.

Also, the tendency historically has been to tackle the lack of physical accuracy by minimising the error in the simulation from numerical dissipation. The nature of RANS is that the results are sensitive to using smaller cells in the computational mesh. It is routine to use hundreds of millions of these cells, even for a single car, but this increases the cost and cannot capture the type of transient physics needed to correlate fully to the real world. Although DES is often assumed to have even higher mesh requirements for accuracy, in practice only the largest eddies need to be resolved correctly to characterise the underlying physics of open-wheel racing to a high degree.

In a cost-equal analysis, a low-resolution DES result is typically more accurate than high-resolution RANS. In effect, the error caused from numerical dissipation is not as significant as the error introduced from the turbulence model.

Of course, this conclusion is dependent on the physics involved, but it has been observed repeatedly to be true for a range of motorsport applications, and **Figure 11** demonstrates its relevance to IndyCar.

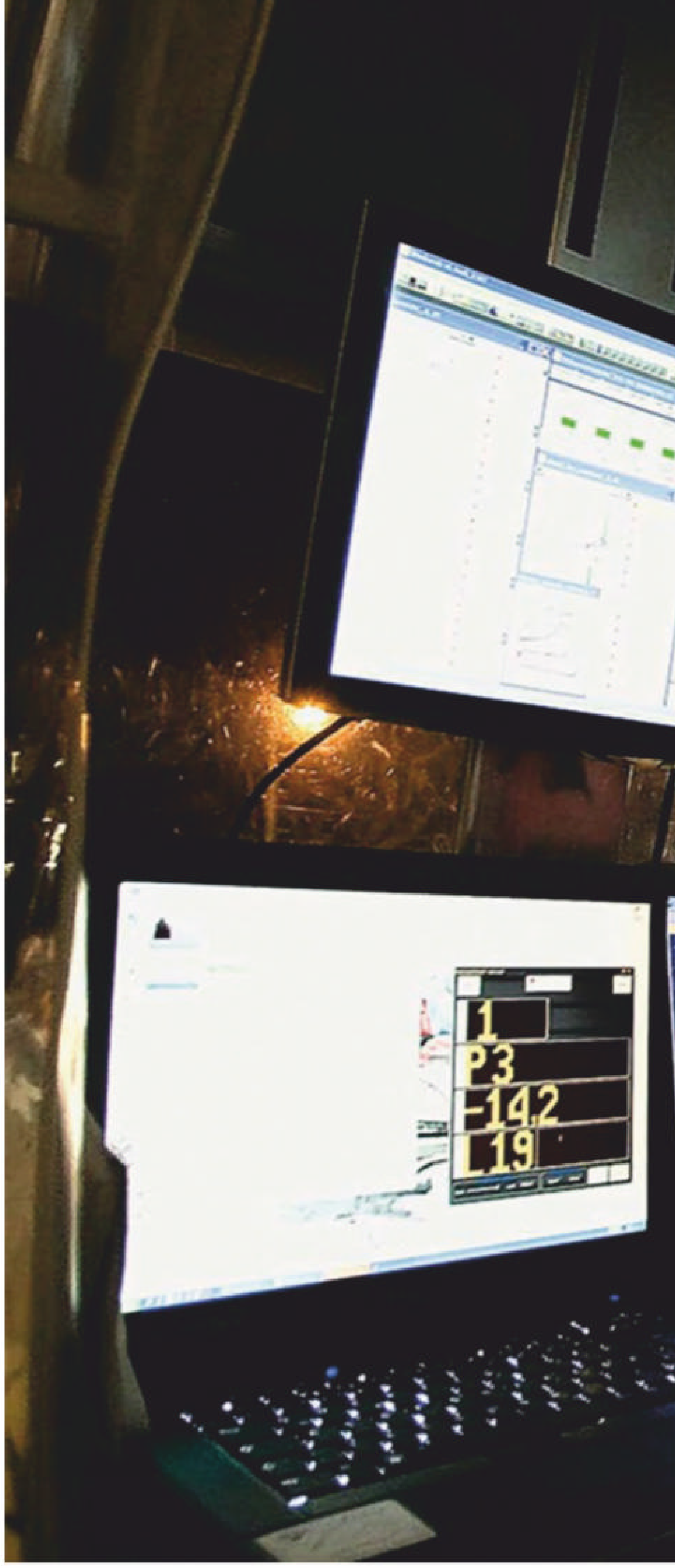
Drag is captured fairly well, although the RANS solution trends in the wrong direction, even with a significant increase in computational effort. This longer run time is necessary for the RANS approach to get close on front downforce, although it is still not as accurate as either of the quicker DES results. Rear downforce is similar between the different solvers.

So in conclusion, for the purposes of rapid development, the DES approach gives a better prediction of overall forces in a matter of hours, and also allows for multi-car studies with good correlation to the track. To see the effect on the racing spectacle, we will have to wait a little longer.

# Data entry

## Operating a racecar involves having an accurate view of what all the individual components are doing, including the driver. Enter the world of the data engineer

**By RICARDO DIVILA**




Putting a number on suspension movements, lateral and longitudinal acceleration, wheel speeds, rpm, throttle position, line brake pressure, steering angle or rack stroke and gear position are channels that enable you to quantify each of these factors, and to see how they will influence the car's dynamics and behaviour. At the same time, if you can examine what actions the driver has taken and so analyse his inputs, driving style and the results, you and your driver will be able to improve the use of the racecar.

The second element is to monitor the engine, gearbox and other ancillaries to check their health, logging abuses for subsequent maintenance. In the worst case, it at least enables you to know what factors led to a failure, such as over revving, wrong gear selection, bottoming out your dampers, overheating, lack of oil pressure etc.

Alarms built into your panel and linked to the software can also lighten the driver's load, only warning him when necessary, so he or she does not have to monitor instruments continuously. If connected to the pits by telemetry, it also allows the team to monitor and advise in real time.

Otherwise, data logging is an invaluable tool for aero development, measuring pressures and loads to correlate with the measures taken in wind tunnel or CFD simulation. Likewise, correlating values with dynamic simulation.

### Early days

In the early days of racing, some of this information was available through instruments and gauges, but was dependent on the driver to monitor and remember for later description to the engineers. The driver already had a heavy working load under stressful conditions, including high *g* forces and huge physical effort, all while also visually monitoring the track and opposition at high speeds.

Given all this, taking eyes off the environment to look at instruments, and remembering the values and where it happened, is not helpful to the core job of driving as fast as possible. Data logging records all the information measured during the run, for thorough analysis later, providing a permanent log for future reference, independent of any driver, freeing them for their duties.

But imagine for a moment only having one logged parameter; rpm for example. Yes, you can derive a massive amount of information from just that, providing you know the ratios, final drive and tyre diameters.

Add driver input to say what gear they were in around the track will give you the (derived) speed, acceleration and exact position on track, pinning down engine performance, drag (from maximum speed attained over a given distance), braking performance and so on. Including a couple more inputs – steering angle and throttle position for example – will also help analyse driver performance and handling problems.

### Cross correlation

As we delve deeper into the car responses by adding more and more sensors, we can reduce the amount of deduction necessary because more parameters can be monitored directly and cross-correlated.

Finer analysis by adding wheel speed sensors to each of the four wheels, for example, can then determine tyre slip and / or deflection under load from the deltas front-to-rear and side-to-side. As speeds vary by wheel, the small differences can be broken down by slip, but also by back calculating what force would deflect the tyre if you know the vertical tyre stiffness.

Conversely, if you don't know this value but know your axle roll couple, you can derive them, as everything is inter-related and all four wheels are attached to the same body. This relatedness giving us the differential work, brake lock-ups by individual wheels and wheelspin (the delta between driven wheels and freewheeling ones.) Analysing a four-wheel-drive car can complicate things a little bit, but the same deductive process can find a plethora of information.

For the engineer, this is all vital information to complement the driver description of events, piecing together what the handling problem it might have had is, and determining the cause to be corrected. It can compare different laps, pinpointing what part of the process is due to the driving, and what is due to the set-up. Sometimes even the interaction of both, and possible solutions.In some classes, where you have more than one driver, you can compare their respective performance and driving styles to glean even more information.

**Data logging is an invaluable tool for… correlating values with dynamic simulation**


## My operating principle is not to trust anything that has wires or chips

Having covered why, let us look at how. Sensors can be passive, using variable resistance (voltage drop) across the sensor, or a potentiometer, varying the resistor length.

Active sensors need electrical power to create a signal, as in linear transducers, where power creates a magnetic field. You use them to measure position. They can be rotary potentiometers, linear potentiometers, linear transducers, optical sensors or inductive, also known as Hall effect. Hall effect is also used for speed. For example, teeth on a hub with a Hall sensor logs the number of teeth passing for a given time. Using dia*PI outputs the speed.

Pressure is measured with piezo-resistive, piezo-electric and inductive sensors.

Acceleration also uses piezo-resistive for low *g* forces, and piezo-electric for high acceleration or shocks / impacts.

Capacitive sensors are used for very low acceleration, usually used for chassis modal analysis, not on the track.

A future article will go into further detail of the minutiae of analysis, but for now we will cover the operating principles and procedures.

## Lessons learned

Having used data acquisition for a very long time, there are some lessons that could be useful for anybody starting out using it, often gleaned from bitter experience.

The interface presenting your data and analysing programs are all thoroughly de-bugged and easy to use, but some common pitfalls are a lack of precautions, and you should always prepare for the worst.

All of the equipment and parts of a racecar have spares. Computers used for your data and analysis can go down also, so I have a habit of keeping a spare computer with the software I use up to date and checked, with adequate memory for what I will store for that race. Racing teams should do the same.

My operating principle is not to trust anything that has wires or chips. Just being paranoid about it does not mean it won't happen. Having a spare download cable in your briefcase will save you a lot of scrabbling around and misery one day.

Calibration of your sensors should be verified and validated. All too often this is the last procedure done, just before the car is tossed into the transporter, as the mechanics have been too busy to let the data guys set it up. Bludgeons might be required to assert your priorities, but they are just as important. Interpolate, don't extrapolate values. Then

## All the data in the world is useless if you cannot identify when it was recorded, where and which session

check the values and see if they correspond to reality. Having to offset your values or re-zero them will take up time you won't have.

All the data in the world is useless if you cannot identify when it was recorded, where and during which session. Car and driver information and identification should be part of the file name. Now that we have moved away from DOS (What's that? say the lads…) there is no limitation on the file name lengths you can use. Just have a system, and stick to it.

## Storage protocol

I have over 10 terabytes of data in my hard disks, which I struggle to identify through lack of appropriate file naming systems in my past. Don't fall into the same trap. You will accumulate data quicker than you think, and you might remember it for a couple of weeks, but over the years you will amass an unbelievable amount. And it could be useful, if only you could find it.

The hardware will have vulnerable sections. Cables are a favourite, and prone to damage. No matter what car you work on, inspect the cable runs and mountings of sensors yourself, plus the data logging unit mountings, making sure you don't have end-of-travel problems or bottoming out of the sensors.

Tie-wrap it yourself and examine all runs to avoid chafing. Mechanics are usually good, but make sure, under the Paranoia Act.

Nicely laid out cable runs, labelled at both ends by the connectors, will facilitate troubleshooting when the inevitable glitch turns up at the worst possible moment. Snarled masses of wiring will make it difficult for a quick diagnosis. Not least because Murphy's Law states that whenever you have a faulty or missing signal it will be in the middle of a session, where fast correction is essential.

Don't over do it though, taut cables can almost guarantee connectors being unplugged with the *g* forces encountered during a run. The good old fashioned tug test helps here. Again, Murphy says the sensor disconnected will be the crucial channel you need when it happens. Do all this and you will have good data, and sensors that last longer. Throttle pots are a critical example, for obvious reasons.

All data systems come with a manual. RTFM. Read The Frigging Manual! And learn it by heart.

| | | |
|---|---|---|
| Logging 8 channels at 200Hz | • 1600 | • Total 6000 samples/s |
| Logging 4 channels at 100Hz | • 400 | • 32 bit logger |
| Logging 32 channels at 50Hz | • 1600 | • 32 ÷ 8 bytes /sample |
| Logging 67 channels at 20Hz | • 1340 | • 4 bytes /sample |
| Logging 72 channels at 10Hz | • 720 | • 24,000 bytes/s |
| Logging 6 channels at 5Hz | • 30 | • 23.43 kB/s |
| Logging 310 channels at 1Hz | • 310 | • 0.02289 MB/s |
| | | • 1.373 MB per hour |

**Table 1: Logging time example**

| Brakes | | | | |
|---|---|---|---|---|
| Channel | Telltale | Tell Status | Burst Channel Name | Burst Added |
| Brake Pres F | max | Added | BRAKE Pres F Max | Added |
| Brake Pres R | max | Added | BRAKE Pres R Max | Added |
| Brake Pos F | max | Added | BRAKE Pos F Max | Added |
| Brake Pos R | max | Added | BRAKE Pos R Max | Added |
| Brake Bias | Min | Added | BRAKE Bias Min | Added |

**Table 2: Burst logging example for brakes**

| SENSOR CHECKS | | | | Status | | |
|---|---|---|---|---|---|---|
| Sensor | Car 23 | Car 22 | Car 21 | Car 23 | Car 22 | Car 21 |
| Accel Lat | OK | OK | [illegible] | | | Fixed |
| Accel Long | OK | OK | [illegible] | | | Fixed |
| Accel Vert | OK | OK | [illegible] | | | Fixed |
| ACO Cockpit Temp | [illegible] | [illegible] | [illegible] | Check, need to update CAN and check ACO number | | |
| ACO Oil Level | [illegible] | [illegible] | [illegible] | Check, need to update CAN and check ACO number | | |
| Aero 1 Channels | [illegible] | [illegible] | [illegible] | DHP work on in workshop | | |
| Aero 2 Channels | [illegible] | [illegible] | [illegible] | | | |
| Ambient Temp | OK | OK | [illegible] | | | James is checking |
| Brake Bias | OK | OK | OK | | | |
| F Brake Caliper Temps | OK | OK | OK | | | |
| Brake Pos F | [illegible] | [illegible] | [illegible] | Make sure zeroed | Test why the sensors are drifting | Make sure zeroed |
| Brake Pos R | [illegible] | [illegible] | [illegible] | | | |
| Brake Pressure | [illegible] | OK | [illegible] | Make sure zeroed | | Make sure zeroed |
| Brake Rotor Temps | [illegible] | OK | OK | Replaced RR | | |
| Chassis Alternator Current | OK | OK | [illegible] | | | Fixed |
| Chassis Battery Current | OK | OK | [illegible] | | | Not going to have |
| Clutch Position | OK | OK | OK | | | |
| Dash Fuel Strat A-F Set | OK | OK | OK | | | |
| Dash Zone 1-11 Set | OK | [illegible] | OK | | Fixed | |
| Diff Entry | OK | OK | OK | | | |
| Diff Exit | OK | OK | OK | | | |
| Distance | OK | OK | OK | | | |
| ECU ACT1 RH | [illegible] | OK | OK | Check with cosworth | | |
| ECU ACT2 LH | [illegible] | OK | OK | Check with cosworth | | |
| ECU ECT | OK | OK | OK | | | |
| ECU EOP | OK | OK | OK | | | |
| ECU EOT | OK | OK | OK | | | |
| ECU FP | [illegible] | [illegible] | ok | Now only an ACO channel. Check the ACO channel | | |
| ECU FRP RH | OK | OK | OK | | | |
| ECU FRP LF | OK | OK | OK | | | |
| ECU Oil Level Status | OK | OK | OK | ere we running less oil on 22? | | |
| ECU P Wat | OK | OK | OK | | | |
| ECU PPS Stat | OK | OK | OK | | | |
| ENG Charge Cooler Pres | OK | [illegible] | OK | | Test on Monday | |
| FLSpeed | OK | OK | OK | | | |
| FRSpeed | OK | OK | OK | | | |
| RLSpeed | OK | OK | [illegible] | | | Complete. Remind all DAGs that triggers will change on new hubs |
| RRSpeed | OK | OK | OK | | | |
| FUEL Collector Level | [illegible] | OK | [illegible] | Log during a fill | | Get Oeters to check |
| Fuel Flowmeter 1/2 Fttemp | OK | OK | OK | | | |

**Table 3: Partial view of a sensor check sheet (it goes all the way to yaw rate, 40 items later)**

## Being familiar with the operation also means knowing the range of values you should expect from sensors

Then try out procedures in good time at the shop, not the track. One hour before the next session is not the time to discover glitches, or wrong approaches.

Being familiar with the operation also means knowing the range of values you should expect from sensors. If they are far off correct operating values, you will catch them quickly and repair, replace or re-calibrate, rather than discovering they are wrong back at base. There is very limited run-time available now, and track time is very expensive, so every second of data captured is precious.

Still on hardware, *g* sensors should be checked to see if they are adequately mounted and isolated from vibration. Remember, a carbon chassis will vibrate more than an aluminium or steel one. Paying close attention to the direction of the box ensures vertical, lateral and longitudinal values are

| CHECKED? | Gate Area | Channel Name | Rate | Telltale |
|---|---|---|---|---|
| Checked | Aero 1 | Gate | 50 Hz | |
| Checked | Aero 1 | Gate | 50 Hz | |
| Checked | | Lap Reset | 1 Hz | |
| Checked | Brake 1 | Gate | 50 Hz | |
| Checked | Brake 2 | Gate | 50 Hz | |
| Checked | Aero 1 | Laser FL | 50 Hz | Min |
| Checked | Aero 1 | Laser FR | 50 Hz | Min |
| Checked | Aero 1 | Laser RL | 50 Hz | Min |
| Checked | Aero 1 | Laser RR | 50 Hz | Min |
| Checked | Aero 2 | Laser FL | 50 Hz | Min |
| Checked | Aero 2 | Laser FR | 50 Hz | Min |
| Checked | Aero 2 | Laser RL | 50 Hz | Min |
| Checked | Aero 2 | Laser RR | 50 Hz | Min |
| Checked | Aero 1 | Speed Min | 50 Hz | Min |
| Checked | Aero 2 | Speed Min | 50 Hz | Min |
| Checked | Aero 1 | Aero 90 FL | 50 Hz | Avg |
| Checked | Aero 1 | Aero 90 FR | 50 Hz | Avg |
| Checked | Aero 1 | Aero 90 RL | 50 Hz | Avg |
| Checked | Aero 1 | Aero 90 RR | 50 Hz | Avg |
| Checked | Aero 2 | Aero 90 FL | 50 Hz | Avg |
| Checked | Aero 2 | Aero 90 FR | 50 Hz | Avg |
| Checked | Aero 2 | Aero 90 RL | 50 Hz | Avg |

Table 4: Gated sensor check sheet

**Most maths channel calculations will resolve to the channel with the slowest logging rate**

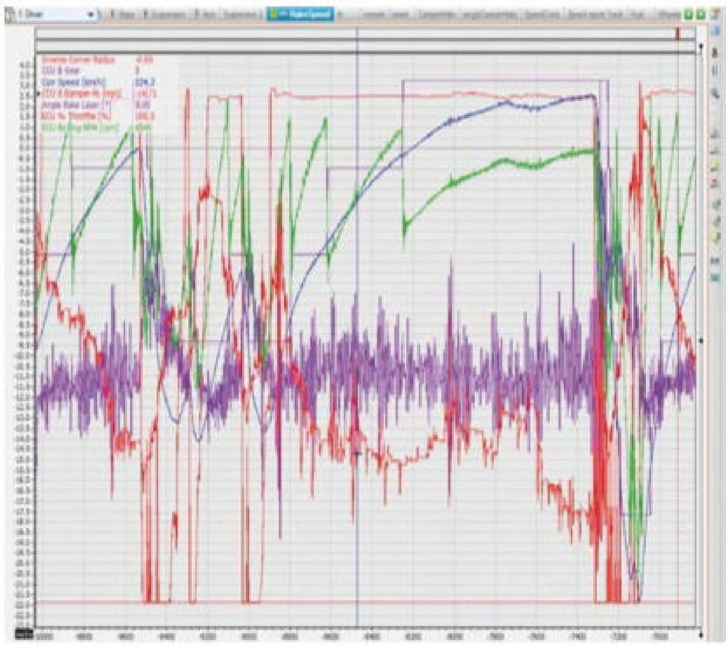


Figure 1: Too many lines on the screen will make it difficult to read and distract the driver. They are only interested in their own inputs and the basic results. For example, speed and time difference from lap to lap or outing

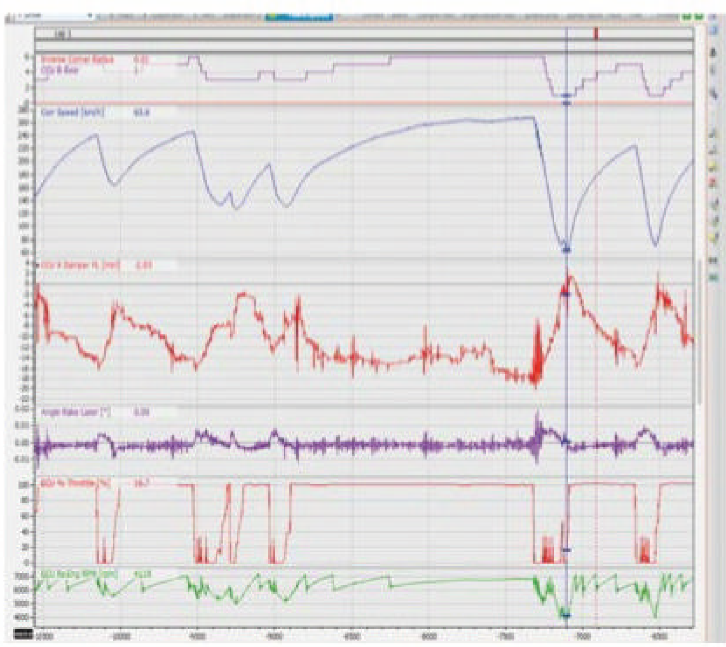


Figure 2: The same data as shown in Figure 1, but tiled and scaled to suit for better comprehension

correct. Angled mounting will introduce false values. Gravity from the earth itself is a useful tool for checking orientation, and up to now it has been pretty reliable.

## Log jam

Build yourself a logging table to ensure you are logging at a useful rate. The table should take into account what stroke you will need on your LVDTs or stroke transducers and what Hz equivalent to distance on track is. The example in **Table1** shows how building up your logging tables with logging rates enables you to know how much data you will generate and tells you how much running time you have, easily translatable in how many laps you have available with full logging.

Water or oil temperature can be logged at slow rates, say five or 10Hz, as it will not move very quickly, but damper stroke should record the wheel position at least four times per revolution to have any meaning.

Burst logging at up to 1,000Hz can define your damper work quite accurately. Logging at 100Hz is almost meaningless for this type of analysis. It can be triggered by a value from a given channel, not necessarily the one you want a burst from as long as it is related, either by track position from a distance channel or by a button on the steering wheel. Even complex maths channels combining for a particular condition. An example is show in **Table 2**.

High logging rates will use more memory, and subsequently will have longer downloading time, although with the computing power available nowadays this is not as critical as it once was. In brief, many channels or higher frequencies generate more data, needing more memory. Consider Formula 1 cars routinely log over 130 channels simultaneously, but I have had test cars with 300 channels and still have nightmares about fault finding on those looms. There is no free lunch in data acquisition.

## Data postmortem

For some monitoring, say for the race, you can set up so you have a high logging rate for critical channels that, if space is limited, will overwrite when at EOF (End Of File), but will record any problem for postmortem later to define cause of failure with data just before it happens.

As all this data is also going to be archived for future reference, you must have all pertinent information so it can easily be retrieved and used. The procedures to set up and operate should also be built into your sheet.

If you cannot identify what data was generated by whom, when and where, it is useless, equivalent to not logging at all.

All sensors have to be checked and calibrated (see **Table 3**). This generates an enormous amount of work in preparation but, once again, if not done correctly will make your data useless or misleading, which is even more dangerous. We also have the gated sensor check (**Table 4**), depending on a separate channel, both to be verified, and so on.

In short, learn which sensors and sensor values are critical and create a table you can fill out quickly after each session. Then use data software to create the same table from the logger (transfer the data in txt to CSV form, some loggers will do this directly).

Again, I cannot emphasise enough, have a meaningful data / file naming system and storage procedure. Use colours that make sense at a quick glance, and graphs in such a way as they give you the best information at a glance. Use alias channels to allow multiple graphs for the same data, and zero the channels at the start. Have a zeroing pad or offsets at the pits to do this. In the worst case, note offsets when the car stops as you can correct later, but it's better to be correct from the start.

Create a track map, keeping the map open will indicate oversteer or understeer when overlaid with the correct track map. This can be obtained from Google Earth. Finally, lay out your worksheets in order of importance.

## Data dump

Depending on the class you are running in, you may have standalone data logging, but higher classes send the logged data to the pits for real-time live monitoring.

When a system is validated and working well, it frees up the driver to concentrate on driving, releasing them from housekeeping and checking role. Big teams end up having engine, gearbox, suspension, performance etc. monitoring specialists, which is why you see the rows of display screens at the back of some pits.

Maths channels and functions enable you to use logged data in specific applications. 'Mathchanns' are powerful tools for further analysis, showing details of any relatable behaviour, or even creating virtual channels by derivation, not direct measurement.

One simple example would be to create an rpm channel for alternate gears. Given the speed you have logged over the lap, and the rpm you are at any point, you can substitute

**Burst logging at up to 1,000Hz can define your damper work quite accurately. Logging at 100Hz is almost meaningless for this type of analysis**

the drop gear, or final drive, or even individual gear pairs to see what the difference in rpm would be using the alternatives.

Rpm will be displayed as a single channel. The mathchann for individual gears can then be coloured differently and will be discriminated without having to have a line on display just for the gear position. Or you can discriminate just the gear under acceleration.

You get the drift. Play with the combinations and there are a multitude of channels you can explore and use to find out a particular problem.

However, you also need to be flexible in case of problems. If one channel drops out through sensor failure or mis-calibration (if calibration is out of range, for example, leading to flat lining) data for that channel can sometimes be created by using other channels recorded. One example might be damper stroke. If one channel drops out, or is not recorded, the wheels will be on a plane and the equation of a plane will give the missing stroke. Remember to bear in mind tyre deflection and ground imperfections, though.

Sanity check; if using load cells-RDs rule, a car running down pit lane at low speeds must have sigma weight equal (four corners sum always equal - aero effect minimal) all the way down pit lane. And when a car comes in, weight must be less (pit exit weight minus fuel used).

## Pitfalls and tricks

Most maths channel calculations will resolve to the channel with the slowest logging rate, so it is no use expecting a series of channels in a mathchann to give accurate results if one logs at a small rate. For example, if using four channels logging at 300Hz, don't expect results at 300Hz if you also have one channel logging at 10Hz as the lines on the screen will resolve to the 10Hz channel data, straight lining in between and maybe losing important information

As some channels interact, though, you can use them to check each other. For example, a load channel compared to LVDT or rotary pot for damper displacement can be correlated. A given force will give a displacement for the damper, for a given spring, and vice versa.

Conversely, a nominally linear spring plotted against load will show binding, friction and hysteresis when being loaded and unloaded.

But overlaying too many channels on the same display leads to visual confusion (see **Figure 1**). A display like the one shown is both difficult to read and easy to make mistakes from, so it is better to have dedicated tabs in separate tiled windows, as in **Figure 2**. Having said that, dumping them all in an overlay can highlight a channel to examine in detail. Flashing active channel in PI Toolbox is a good way to highlight the channel you

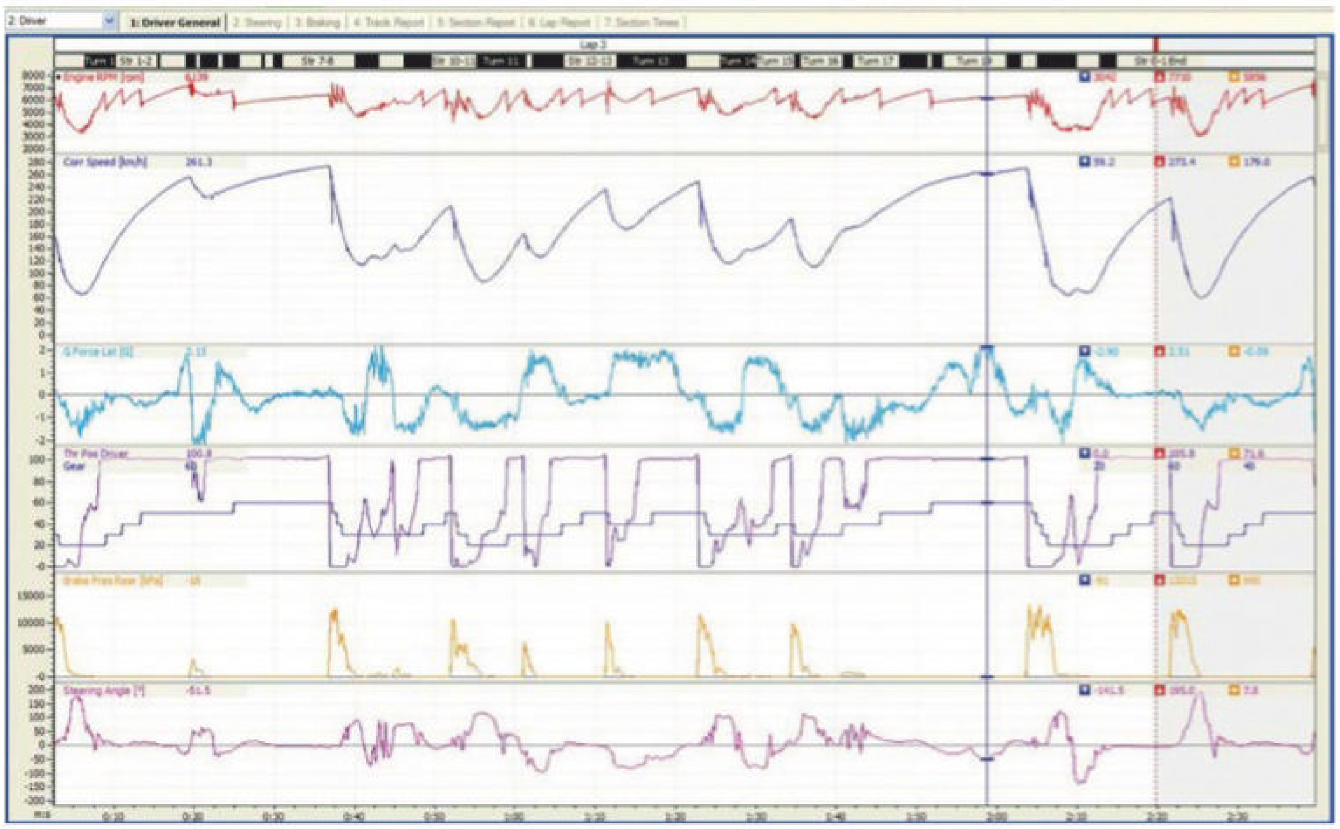


**Figure 3: Example of a driver data template**

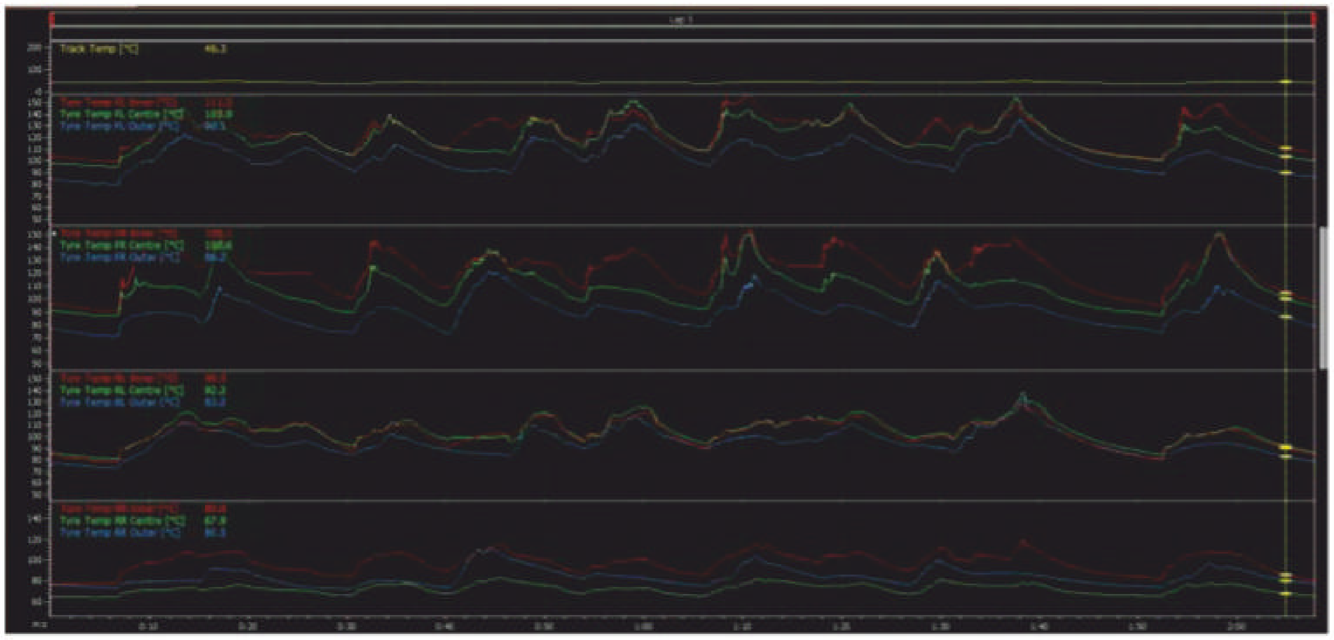


**Figure 4: Use gates to bracket displays (here tyre temps) to see if things are working in the correct operating window**

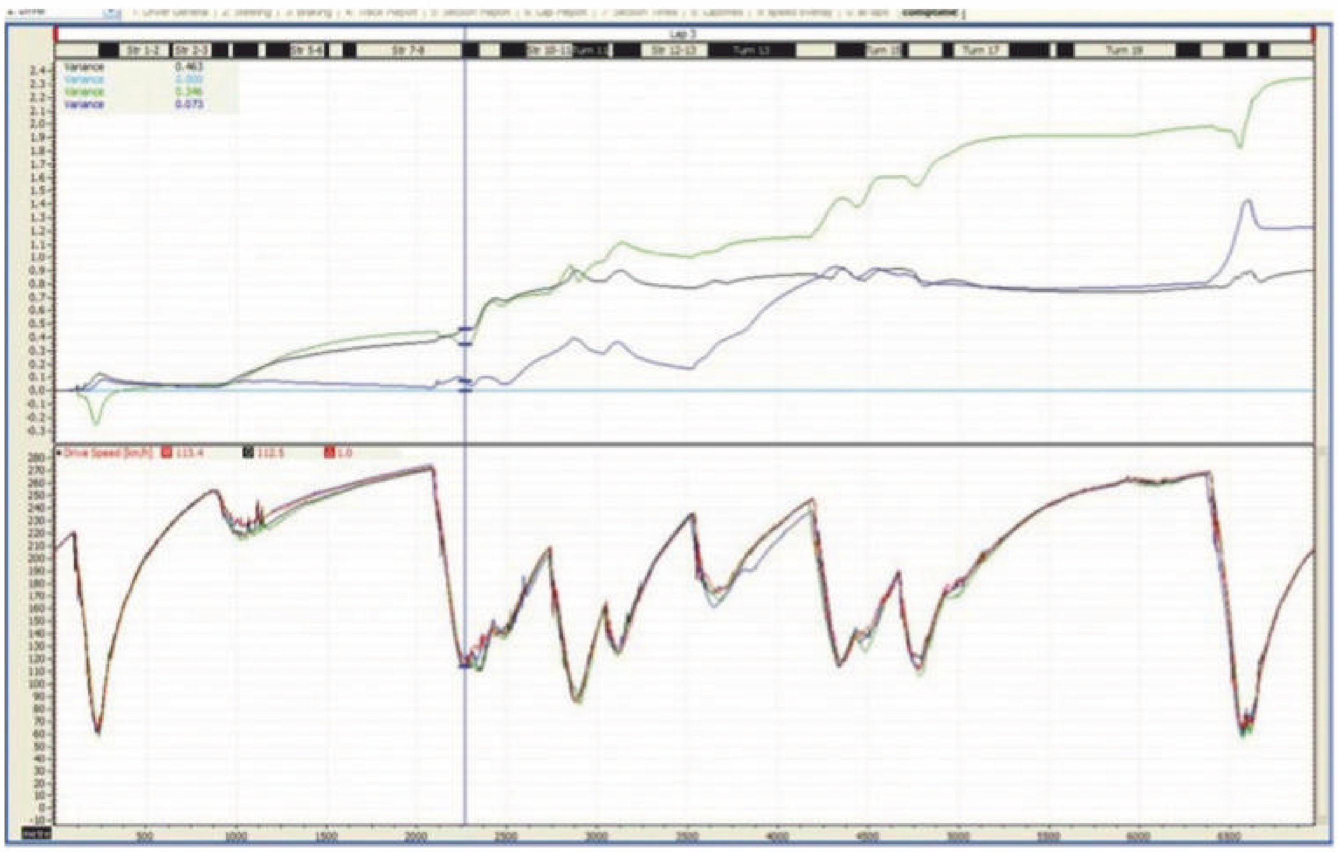


**Figure 5: Overlay of speed in a sequence of laps. Variations show potential problem areas**

**Play with the combinations and there are a multitude of channels you can explore and use to find out a particular problem**

**It is always better to do calibration checks on the complete racecar**

are looking at in detail, but still show possible related other channels when you run your datum line across a lap.

## Template building

To speed up analysis, build templates that always come up on screen and keep driver data templates simple (remembering the KISS rule). So, using **Figure 3** as an example, only include throttle position sensor, speed, gear, engine rpm, steering, brake pressure front and rear and perhaps lateral acceleration and longitudinal *g*.

Gating is a useful tool here, too. A good example is to easily show whether your tyre temperatures are in the optimum operating range. **Figure 4** shows split tabs simply displayed for temperatures. Gating can also be used to display only values we are interested in.

Even a plain overlay of speed in a sequence of laps, as shown in **Figure 5** can be very informative. Using the exact overlay means it is easy to reproduce, and the places where it varies show where the driver has a problem in that area.

## Calibration

Above all, when dealing with sensors, calibration is very important. I repeat, very important. As the legendary Keith Duckworth once said, 'No data is better than bad data'; calibration done incorrectly can induce very wrong decisions.

When calibration is being done there are two methods: extrapolation and interpolation. Normally, pushrod or pull-rod calibration is done over two points. If you have time to do more, at least three, so much the better. However, too often it is done from zero load and a given value. When that value is low, and there is less than maximum expected load, the straight line given by the two points can have a very big drift at high values.

When pushrods are calibrated on a press and converted to force at the wheel by motion ratio it does not take into account system losses, deflection and friction, nor hysteresis. Loading your chassis to the expected total load with aero will give you pushrod calibration points at zero load and over maximum. Measures should not be extrapolated from two low load points as that gives potential for drift at the maximum.

As shown in the pictures above, car loading for calibration can be done with ballast bags, cast iron tare weight or even weighed sandbags. The medium itself is not important, as long as it is accurately weighed.

**LMP2 pushrod calibration, with a 2,500kg load on the platform. Always best to check the weights before you start**

**LMP1 with weight load. It is possible to calibrate items out of the car, but best results come from in situ tests**

Reading your data and comparing it to weight as it is being added, and then subtracted, will give an accurate hysteresis check. Some smaller items can be calibrated off car, at a pinch, on a dedicated rig, but it is always better to do calibration checks on the complete racecar if at all possible.

## Engineering job

So, to summarise, the data engineers' work consists of monitoring the running of the car and its systems, checking the data acquisition system and configuring it for channels to log. They must then decide how best to present the data for the driver and engineers to use during a run and, after the run, download the data and check all the session data is there.

Before analysis, as the driver is no longer the primary source of information, after each run a quick check of alarms recorded must be done, in case the driver does not mention it. If there is telemetry, it would have been noted on screens in the pits, but if there is only logged data, it must be downloaded immediately after a run so any problems can be spotted in the shortest time before the car goes out again.

As well as constantly verifying all systems are working correctly they must review the data and suggest ways of improving car performance. For example, checking rpm drops, acceleration, throttle response and brake usage. At a deeper level, the data engineer will review and inform the driver how to improve his driving performance with a quick discussion.

After the session, they will go into a full-scale verification of everything, looking at the data to see if all channels recorded properly. No data is better than bad data! Only then will the data engineer begin the debrief with the driver, discussing what they have been doing, looking at the results in terms of car behaviour and time through particular sections.

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Discussing reactions and having comments from the driver will help identify areas to work on as just logged data cannot pinpoint everything. Any unusual data values will also need driver input as to what caused it.

## Pit work

The important thing in the debrief is not to jump to conclusions, or ignore the driver. Often they are able to give tangible clues about an excursion over a kerb, or change of trajectory because of debris, or a car spinning ahead, which might have caused the anomaly.

If there are supporting video recordings, the engineer will be able to see this, possibly, but the driver is the one sitting in the car and should know what is going on. At that point, get into any handling or performance problems you may have, and verify if driver or car-induced.

## The data engineer will review and inform the driver how to improve his driving performance

If problems are found, look at the relevant sensors and closely review the data. Sequence events to understand what happened first, and what followed, and then expand the view to as wide as possible and locate the exact points where the problems have occured. It can take time and effort, but is worth it.

Before anything else, define the problem, and take into account how much time you have to dedicate to solving it. There is a whole team that has to work and prepare the car for the next session and, if anything needs replacing or repairing before going back out, they need to know about it straight away.

Again, if you haven't got telemetry, checking temperatures, pressures relevant to the engine, gearbox, brakes and fuel systems can give the team the all clear and allow them to do their own job lists. Any areas of the racecar cleared can be worked on immediately, and no one likes to have a job list late in the evening, or a late change just before a session. Trust me, I know.

Finally, prepare the correct storage and naming of the data and video footage so it can be easily found and accessed later. This will help in developing a fuller understanding of your car.

Next issue we will look at analysing all the data captured and filed in more detail.

## Conditioning the data displayed

**You can use several methods to display the data clearly, and so others can easily understand it. For example, you can filter the data to show smooth values, rather than all the bumps or high-frequency vibration the sensor may log. Be aware electrical interference, which can come from power lines, or other sensor wires running in parallel in loom. Figure 6 is an example of a lateral *g* force trace, unfiltered. Figure 7 is the same trace but with the smoothed line also shown in red.**

**Figure 8 shows a section of trace in greater magnification. You can see the peak values are clipped, so it tells the same story but in a simplified fashion. Beware the use of filters though. If used with care they are a useful tool, but if data is over filtered, while it might be nice to look at, you can miss peak values that might be important sources of information.**

**A good rule is to look at sensitive data unfiltered first, and then only apply a filter when you know you are not losing vital information. With experience, you will know to pre-set filters for particular channels.**

**Again, for displaying information more manageably, you can also amplify, attenuate or scale differently, examples of which are shown in Figures 9a and 9b.**

**The resolution comes from the digital data, which is logged in 'bits'. The number of bits, or steps, the signal is separated into is called the resolution. If it is in 8-bit, it will separate into 256 steps as the 5V of sensor in 8-bit gives 0.01953 V/step, so 100mm in 8-bit -> 0.3906 mm/step**

**If in 16-bit, it is separated into 65,536 steps, so 5V in 16-bit gives 0.00007629 V/step, so 100mm in 16-bit -> 0.0015256 mm/step.**

**In a MoTeC ECU, the signal is 32-bit, so you will have 4,294,967,296 steps capable of being logged, which can give you a very fine resolution indeed. Conversely, small variations in voltage due to interference (inductive field, vibration etc.) can alter the value, so you need to be aware of what is important.**

**On several cars I have run, the earth line was not very good, and all signals had a constant 5Hz variation on all channels because of it. Once you are aware of this, and can judge if it is critical or not, you can take steps to correct it or choose to ignore it.**

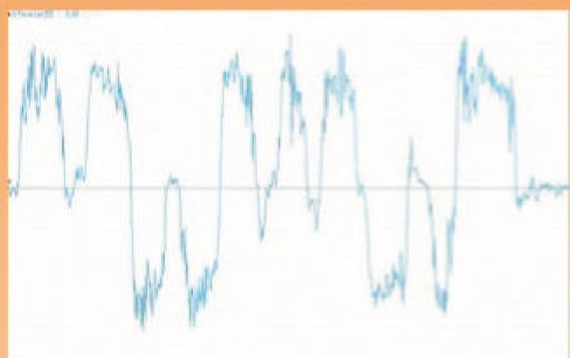

**Figure 6: An unfiltered lateral *g* force trace**

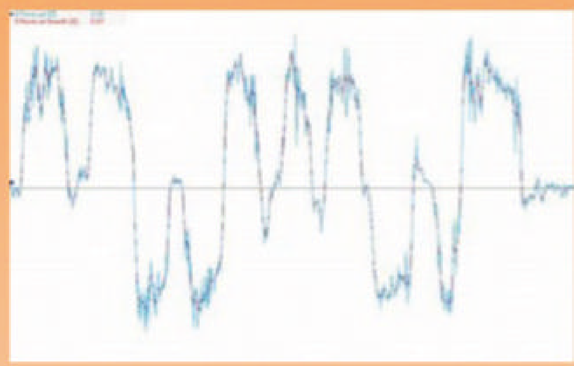

**Figure 7: The blue line is the unfiltered signal, the red the same signal smoothed out by a filter**

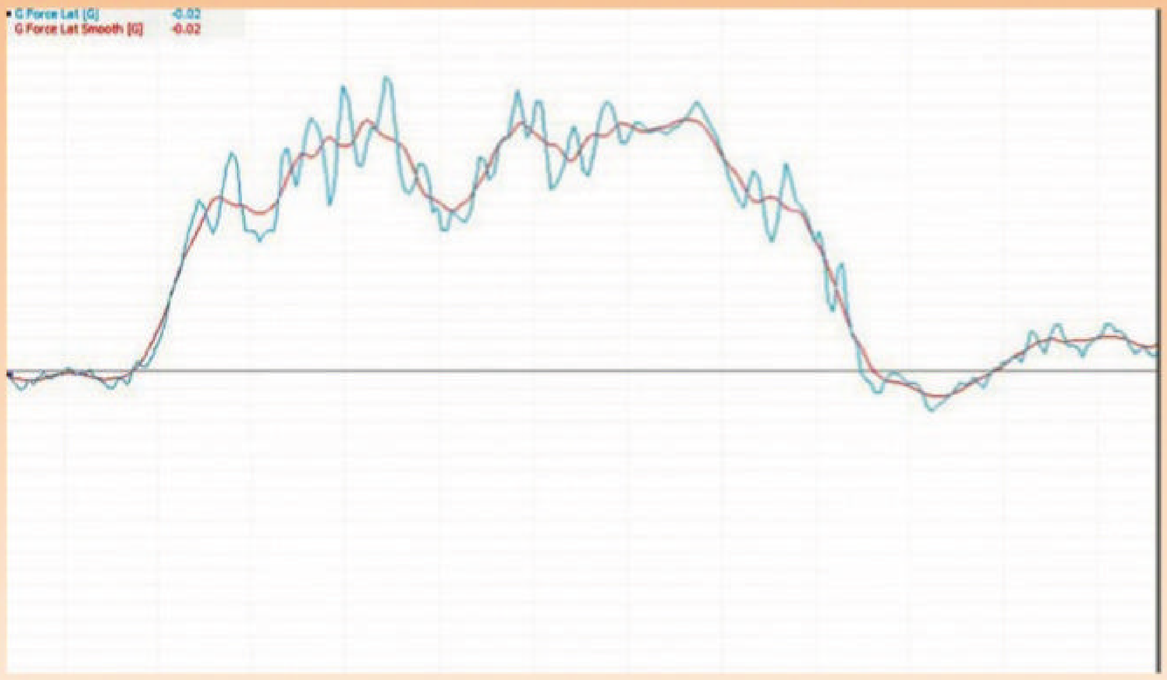


**Figure 8: Close-up section of trace showing how peak values are clipped**

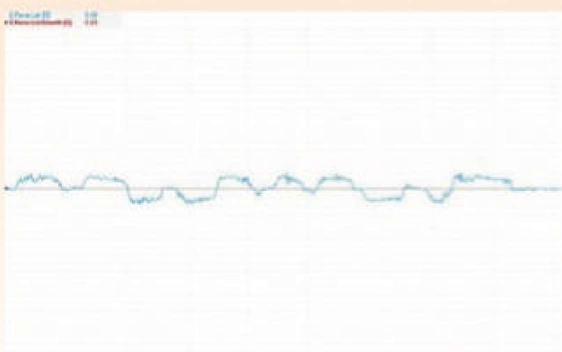

**Figure 9a: In this example, the scale is too small to examine in detail**

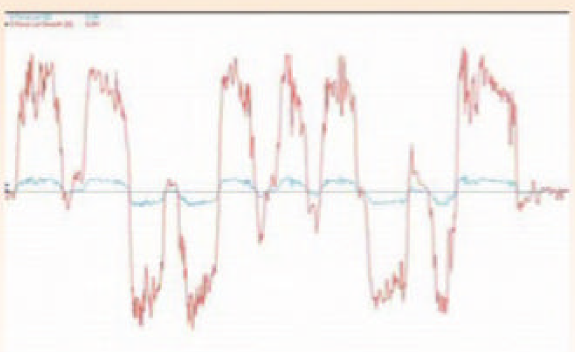

**Figure 9b: Using the appropriate scale will allow you to analyse the data better**


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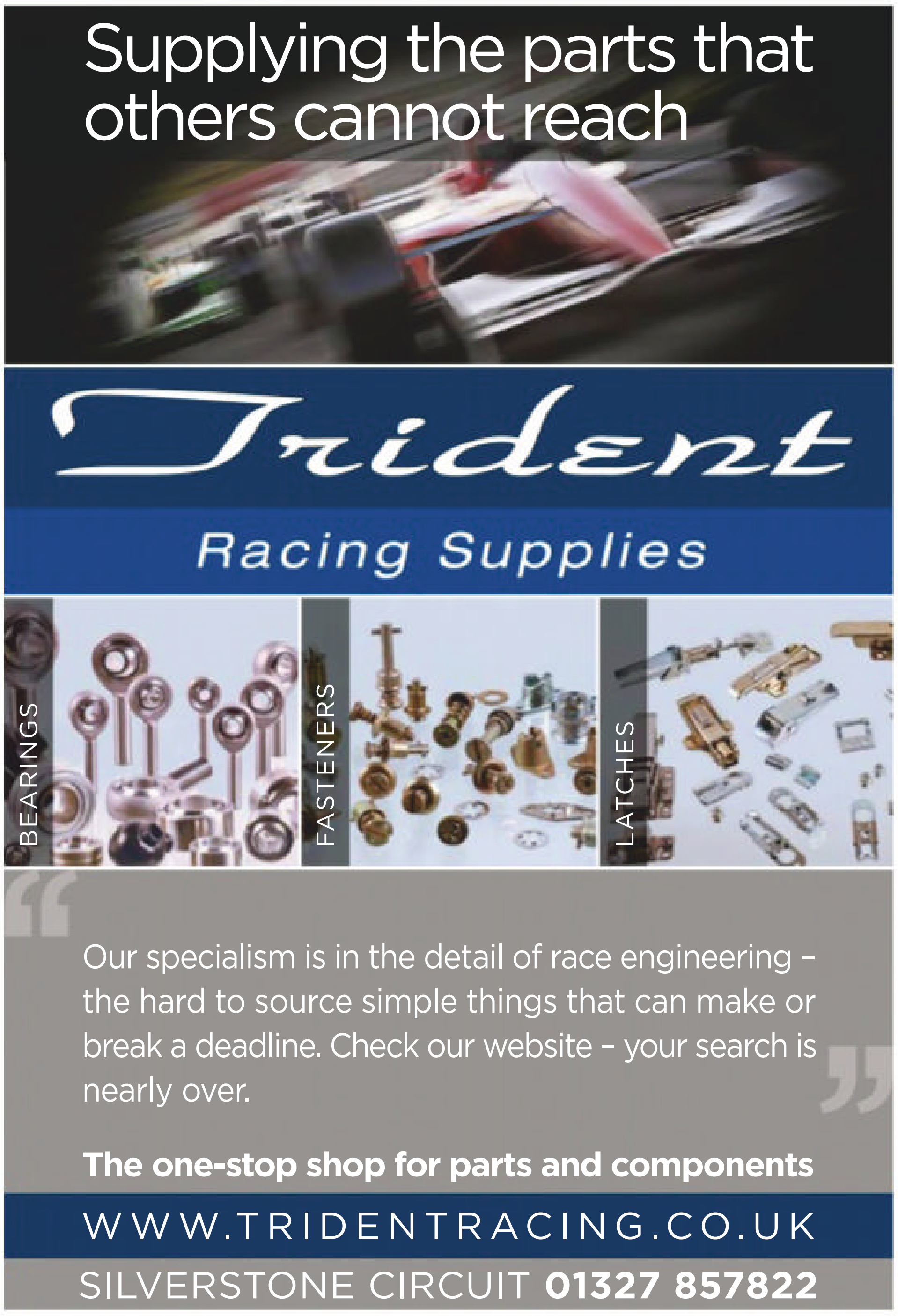
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# New model armies

**How SBG's RaceWatch modelling software has made race strategy an engineering discipline in its own right**

**By GEMMA HATTON**


The complexity of modern race strategy now demands significant brain power and computing power to predict the probability of each race scenario, and then how a team should react to win

Surely the optimum strategy in any race is to go as fast as possible from the moment the lights go out to the moment the chequered flag is waved? That is correct. However, this can sometimes lead to a boring race, with the best driver and car combination continuously winning. Motorsport, after all, is a form of entertainment and so to spice up on-track action in the top tiers of racing, the regulators have engineered the need for pit stops.

But when should a team pit? How many times should they pit? When will everyone else pit? Consequently, the optimum strategy is influenced by many factors, the significance of which evolves with every lap.

To induce pit stops, the governing bodies have manipulated the rules, particularly with regard to fuel and tyres. In F1, refuelling is banned so the focus is the latter. The FIA stipulates that during a dry race all drivers must use at least two different compounds, and therefore must pit at least once. Furthermore, the FIA is heavily involved in defining the specific degradation and wear rates, as well as other performance characteristics it wants from an F1 tyre. How this is achieved and manufactured is Pirelli's problem.

Overall, the FIA's aim is to have tyres that degrade and lose performance, or have a sudden drop in performance (the infamous 'cliff'), forcing drivers to go slower. It then becomes beneficial for a team to complete a pit stop and gain time back by going quicker with fresher rubber than to continue with worn tyres.

Because overtaking is so difficult with such aero-dominant racecars, track position is critical, and so the undercut is extremely powerful in F1. This is where a driver pits, straps on a fresh set of tyres and returns to a clear track. Their rivals react and also pit but, because they've had an extra lap on older rubber, are slower and emerge from their pit stop behind the driver who pitted first, often asking their race engineers 'what just happened?'

## Different story

In the FIA World Endurance Championship, it is a different story and the rule makers there use both tyres and fuel as tools to create exciting racing. The maximum amount of fuel teams can use during a stint is restricted, as is the rate of fuel flow into the engine. This dictates the number of laps a driver can achieve within a stint before they have to make a pit stop.

Then there are the tyres, and although some endurance tyres are capable of completing the equivalent distance of two and a half Formula 1 grands prix, they can't last for a full six, 12 or 24-hour race. Tyre degradation and the consequent drop in lap time is another incentive to pit.

'In endurance racing, we are playing the long game, and a team's approach to the balance of risk and reward is quite different from the approach taken in a sprint race,' explains Dominic Gardener, senior manager of chassis R&D and vehicle dynamics at Toyota Motorsport GmbH, based in Cologne. 'Yet simulation tools still play an important role, and often a mix of custom tools, together with commercial software such as RaceWatch, can offer the best combination for a top LMP1 team.'

Furthermore, managing the driving time of three drivers per car adds another strategic variable into the mix. Certain drivers perform better in different conditions depending on car balance, visibility or level of fatigue and often a driver who is quickest during one phase of the race is slowest in another. Yellow flags, safety cars and traffic are also issues, with an LMP1-H car typically passing up to five GTs every lap. Not only does this require constant and careful focus from the driver, but a skilled driver can actually adapt the hybrid boost deployment to overtake with minimal time loss.

In Formula E, instead of restricting the energy provided by fuel, the regulators restrict the amount of available energy from the battery. Previously, this was limited to 28kWh as battery technology was not capable of lasting the whole race, and meant drivers had to pit to swap cars. With the battery a spec part, all drivers would run out of energy within one or two laps of each other, leaving little strategic wiggle room to gain on your opponents. For Season 5, batteries last the entire race, so there is no need to pit, but drivers still have to manage the energy from the battery in the same way that a driver might manage fuel consumption. Once the maximum energy capacity of 52kWh has been reached, the rules specify that the maximum total power of 250kW that is supplied to the motors 'must linearly ramp down to 0kW in five seconds'.

Essentially, if drivers exceed the maximum energy of the battery, the car enters limp mode.

## 'Everyone was working on spreadsheets and not watching the race'

This led to the extraordinary scenario at the Mexico E-Prix where Pascal Wehrlein was fighting so hard for the lead against Lucas di Grassi that he ran out of energy metres before the finish line and di Grassi snatched victory.

Regardless of race category, there are so many factors that affect the optimum strategy, and their influence varies with every changing condition, driving style and racecar.

Take the example of Formula 1 tyres. The layout of each track subjects individual tyres to different lateral and longitudinal loads, resulting in differing levels of wear and degradation. It is not just the amount of degradation that changes, but also the type. Three different compounds are raced at each event, the behaviour of which changes with every degree of track temperature and every newton of load. Therefore, some combinations of force, temperature and compound can lead to heavy blistering and graining, whilst others lead to consistent and manageable wear rates.

Trying to determine the degradation of your tyres to predict how many laps they will last, which then defines your strategy, all while managing your driver during a race is almost impossible. After that, add in fuel, engine modes, traffic, safety cars, yellow flags, blue flags and you begin to appreciate the monumental task facing strategists. Suddenly Ferrari's sometimes questionable strategic choices become a little more understandable. Engineers are clever, but not superhuman.

## Original idea

However, with an average computer operating approximately 10 million times faster than a human brain, there *is* a superhuman alternative to processing the necessary information to define an optimum strategy, and in real time, too. Enter SBG's RaceWatch strategy software. This is the software behind the graphics you see on the pit walls.

'The original idea was to try and provide a review of the race where all the important information is accessible on one screen, including the live stream video of the race,' explains Gareth Griffith, founder and CEO at SBG Sports software. 'When we started in F1, there were many different data sources and the volume of data was growing, so teams would develop individual strategy tools for each bit of data.

'The first thing I noticed was everyone was working on spreadsheets and not watching the race. For example, at the Monaco Grand Prix in 2008, when Jenson Button was driving for Honda, he was stuck behind a Toyota. James Vowles, the chief strategist, was trying to work out how to get Button past when up on the screen above his head the Toyota was in the wall.'

Griffith continues: 'So James and I started extracting the key information and putting it on the same screen with the video so engineers could actually watch the race whilst doing their strategy calculations.


RaceWatch is a software package from SBG that combines all the vital information for a strategist on one screen, together with the live video stream, while also adapting the displays to the context of the race


Calculating the degradation of your tyres, as well as those of your competitors, is key to defining the optimum strategy. Tyre degradation is sensitive to changes in car balance and pace, as well as ambient/track temperatures, so requires monitoring

## There *is* a superhuman alternative to processing all the necessary information to define the optimum strategy

'It started off being TV with data on it, but we have added more and more strategy tools as the software has developed over the years.'

By the Brawn era in 2009 and with Button going for the World Championship, RaceWatch had become the main strategy tool for the team. But it was not just strategists who were benefiting from this software, as many other types of engineers within the sport also began to utilise it. 'The next stage was to allow engineers to adapt it to whatever they want. So Lewis Hamilton's engineer is interested in Lewis, the tyre engineers need information on tyre performance, while the strategists are analysing everything,' explains Griffith. 'So we have a completely configurable workbook system, which allows every engineer to customise their displays, views and data to exactly the way they want it.'

## Key principles

There are two key principles to developing a successful strategy software package. Firstly, display the relevant information clearly. Secondly, continuously plan for the unknown. RaceWatch does not just simply display data clearly, it processes it, allowing engineers to extract an additional layer of information. For example, the GPS data used to show the position of cars on track is processed by RaceWatch to also work out the predicted lap times and pit windows. This helps teams to time their pit

## Software allows every engineer to customise their displays, views and data to exactly the way they want it

stops to within tenths of a second to either complete an undercut or protect against one.

'There is a whole second level of strategic data we can extract from the original data, which makes it much quicker for engineers to see at a glance what they need to know at any time during the race,' highlights Griffith. 'We also adapt the displays to the context of the race, so when there is a safety car, there is different information displayed that is critical to know during a safety car period.

'We try to make it easy for engineers to derive the information they need from a single glance at RaceWatch, regardless of the phase of the race they are in, or the decisions they are managing at that time.

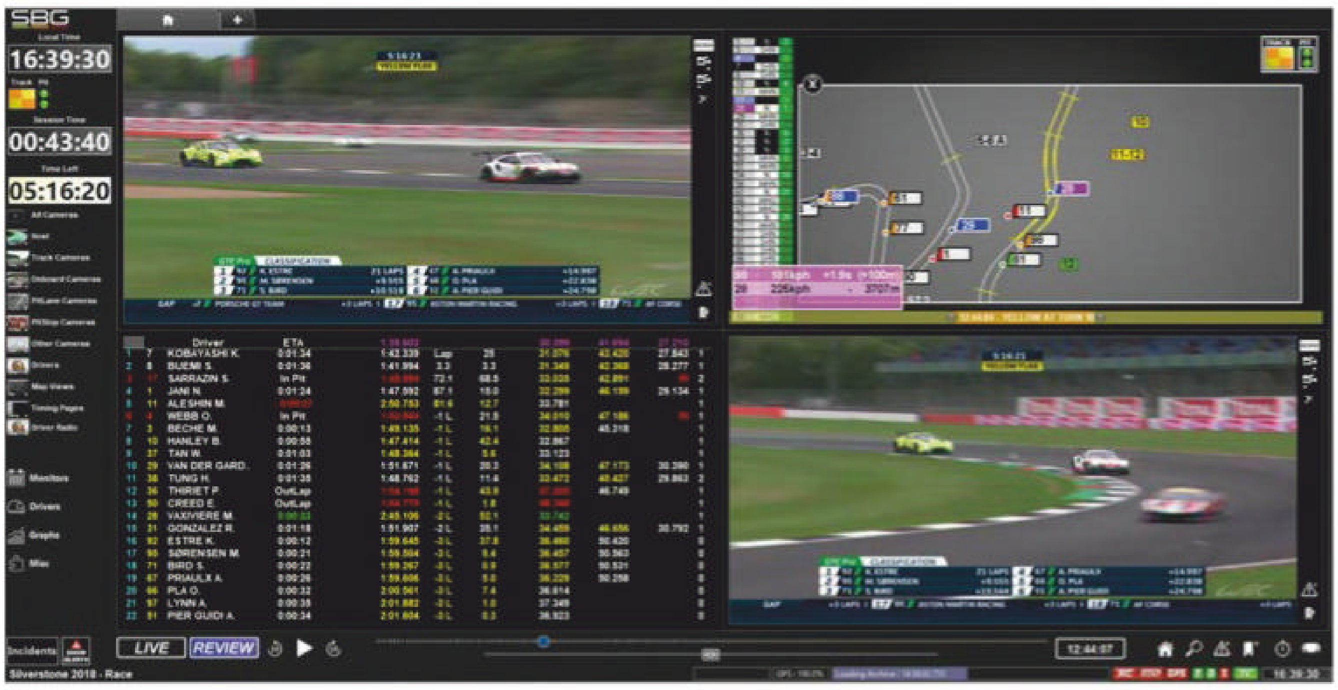
'One of the benefits of RaceWatch is its capability to synchronise a diverse range of data sources together such as lap timing, race control messages, GPS, video, radio and even telemetry.' Gardener concurs: 'Its flexibility for quickly reviewing a video of an incident such as a pit stop or car contact while simultaneously 'rewinding' all other race data together in context is invaluable for rapid and confident strategic decision making.

'An interesting twist particular to Le Mans is the deployment of three safety cars on track simultaneously. Any car pitting under the safety car will therefore emerge in the next queue down. But unequal time gaps between the three safety cars means our decision to stay out or to pit all depends on exactly where your car is on track at the time the safety cars are deployed.

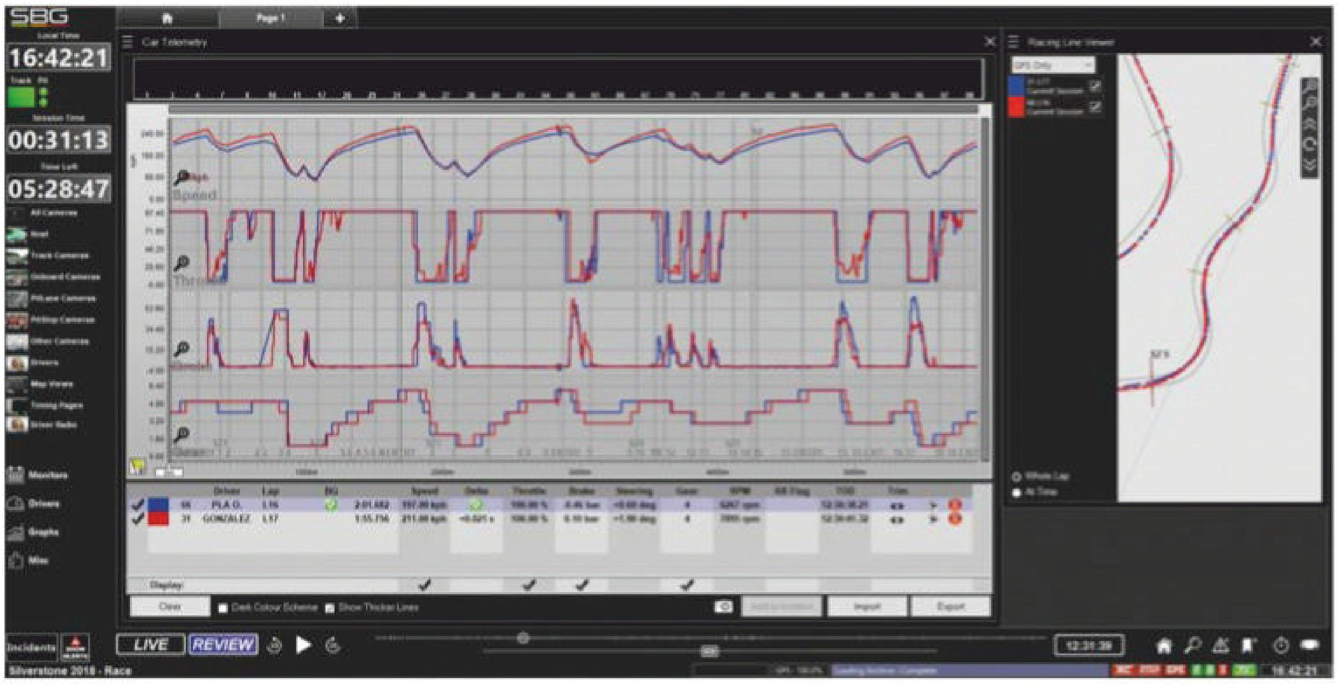
'This scenario is where a tool like RaceWatch is invaluable, because it's often necessary to quickly review the exact moment of deployment to determine our best course of action.'

The second tactic is to always prepare for the unknown. 'Throughout the race, the strategists are constantly making contingency plans for all the 'what if?' scenarios,' says Griffith. 'Pit window open is a simple example, which means the team is now at the stage where their strategy is within the bounds of the optimum that they can stop. There are probably 20 or 30 different things at any one time the teams have contingency plans for.'

Currently, RaceWatch is utilised by five F1 teams, including Mercedes, Renault, Alfa Romeo, Haas and Williams. RaceWatch has also helped




When there is a yellow flag or safety car, RaceWatch defaults to displaying the important information during this phase of a race. This is of particular importance in endurance racing at Le Mans where the size of the track means that three safety cars can be out on track at the same time, so pitting depends on the position of your car relative to the safety cars




Today's Formula 1 teams generate thousands of channels of telemetry data, but only around 40-80 are relevant to the strategy models within RaceWatch

all the three big WEC manufacturers (Porsche, Audi and Toyota) win Le Mans, while other teams from Formula E, DTM, IMSA, VLN and even the FIA are all using the software.

## How does it work?

Firstly, we need to understand the various streams of information that are input into RaceWatch, and these can be divided into two distinct categories: track data and car data. The former includes the standard timing page that comes from FOM and details such as sector times, speed traps and the tyre compound being used by each driver.

Then there is an FIA feed, which supplies three different sets of information: GPS of all the cars at 10Hz, Race Control messages and a weather feed that updates track and ambient temperature conditions every minute.

'Today, Formula 1 teams can generate thousands of additional channels of telemetry data from their car, although only 40 to 80 of these channels are relevant to strategy,' says Griffith. 'It's a two-way process. The engineers feed to the driver what lap times he or she needs to achieve, but then they are also receiving information back from the car such as fuel load, which can then lead to engineers sometimes having to make sacrifices with their strategy to look after the car.

'We take any information that can have a bearing on strategy into RaceWatch, which for a race session now is around 1.6GB of data, and that's without counting the video channels. In Race Control we obviously have to cope with a lot more data because we have 10 times that amount, as well as around 120 video streams, so that is a significantly bigger data management task.' (See box out on p84).

RaceWatch is essentially the engine that processes and analyses all the incoming data through the use of complex models. But these models are not just trying to determine the optimum strategy for a specific team, they are also doing the same for their competitors. Indeed, today's top tiers of racing are so tactical that it is even more important for teams to pre-empt what their rivals are doing, and react quickly and correctly, to have any chance of beating them on track.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One of the key models is the overtaking one. This predicts the probability of being able to overtake a car given the performance advantage of a particular car at a specific track. For example, according to SBG, at circuits like Shanghai a car needs to have a 0.7s advantage over a competitor to have a very good chance of completing a successful overtake. At Monaco, that leaps to around a six-second advantage.

The model gives a two dimensional probability distribution, based on a number of input performance differentials. But if that differential comes from tyres, for example, that is given greater value than car performance. For example, if you have two cars with a one second performance difference but on identical tyres, the car behind is less likely to overtake. However, if that one second difference is due to tyre performance, the chances of overtaking are higher because tyre advantage occurs in the key places for overtaking. Usually, if the model says a driver has more than a 50 per cent chance of overtaking, they should be able to achieve it within two or three laps.

'The possibility of overtaking is a huge factor in strategy, because if you can overtake you can risk making more pit stops, explains Griffith. 'Whereas if you can't overtake, such as at Monaco, you would choose a one-stop strategy and manage the tyre degradation to suit.

'Tyre life and degradation curves are a key part, and we provide the tools for the teams to analyse the tyre data and conduct live analysis. But as with all simulations, the accuracy of the models is very reliant on the data that is put into them, and the teams all have their own ways of doing things. Ultimately, it's the teams' responsibility to generate accurate data to feed into RaceWatch, and that's how you have a variation in strategy between them.'

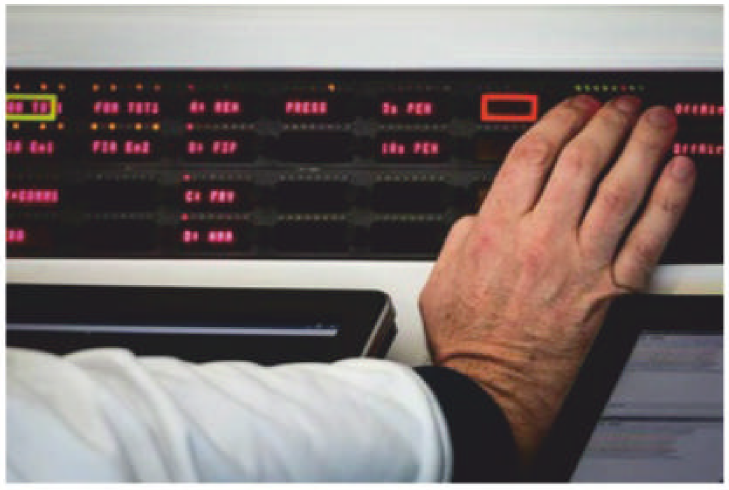
Another model predicts the pace of each driver during the race. Each team will have its own way of estimating a driver's relative pace, and to that they apply the effect of fuel (each 10kg of fuel equating to approximately 0.3s per lap) and the tyre degradation figures from FP2.

## Automated analysis

'We have a lot of automated analysis for predicting driver pace, but it is still reliant on the team using their own estimates of relative pace,' says Griffith. 'Of course, pace varies throughout the race, so the models need to adapt, and we do that through automated analysis – although you have to be careful with pure automated responses.

'For example, Lewis in Singapore in 2018 was driving 12 seconds off qualifying pace, but the moment he needed to prevent someone undercutting him, he went four seconds faster. This is why teams have the capability to override the automated calculations, and the larger teams have around 30 people working in the background to help do that.'

This automated analysis is done through a complex model, which runs in three different ways. There is a live snapshot view, a Monte Carlo simulation tool and then a game, or race,



As well as visual information, engineers have to absorb audio, too. Race engineers can listen to up to 12 channels, communicating with their driver, mechanics and engineers on the pit wall as well as the support team working at the factory during the race weekend

simulator. The live snapshot view gives the teams a constantly updated prediction of how the events of the race are most likely to unfold for each competitor.

The Monte Carlo simulation method forms the basis of all modern motorsport strategy simulations by allowing the generation of statistically probable numerical solutions to problems that cannot be analytically solved.

During a Monte Carlo simulation, values are randomly sampled from input probability distributions. Each set of samples is called an iteration, and the resulting outcome from that sample is recorded. The process is repeated thousands of times and the result is a probability distribution of possible outcomes with an associated probability of the likelihood

## Race Control

It is not just the teams that utilise RaceWatch to process and analyse data, it is also widely used in Race Control for various international race series.

The software can be used to monitor the sporting and safety aspects of a race, as well as provide information such as fuel figures, starting tyre pressures and everything that needs to be regulated. 'Race Control is very calm but there is a lot going on,' highlights Griffith. 'There is a huge amount of data coming in and it's all being analysed all the time, although the Race Director is usually only concerned with data relating to something that could be potentially dangerous, or potentially breaking a rule.'

There are essentially two parts to any Race Control: the governance of the race and the management of the race. The former is focussed on utilising the vast amount of video footage captured at the track and using the data to point the Race Director to the relevant sections of video. There is normally a full line of sight around the entire racetrack, which means anything up to 30 cameras can be located around the lap, in addition to all the on-board cameras Race Control may have access to.

Usually there is a full line of sight around the track due to 30 or so cameras. RaceWatch uses the cars' GPS to switch the cameras to follow each car. This is particularly useful for teams lower down the grid whose cars are often not featured on the main video feed

'On the Thursday before a race we calibrate the track management system in Race Control and work out which bit of track is covered by each camera,' explains Griffith. 'When the cars are on track, we use their GPS to determine their location, and therefore which camera is covering them. We then automatically switch cameras to follow each car as they complete the lap and send feeds relating to their two cars to each team.'

The second element to Race Control is managing the race and this includes things like deciding when the safety car comes out and controlling the light panels around the track. 'This data stream is related to a map, and sometimes the data can pick up incidents before they even show up on the video, as the data triggers an alert and the video is approximately one second behind. So, by the time it appears on TV, we know what has happened and Race Control are already reacting to it.'

any such outcome will occur. This method does not therefore just show you what *could* happen, but also *how likely* it is to happen.

'When any decision has to be made, we use a probability distribution as the input,' continues Griffith. 'These are not always normal distributions. In fact, we don't just do a random Monte Carlo, we try to make every iteration a sensible and feasible outcome for the race.

'For example, we reckoned that in the 2018 Singapore Grand Prix, the last eight cars would have had a much better result if they had pitted on the first lap when there was a safety car. The Monte Carlo will run all of these simulations and the teams will experiment with different things to see what the statistical success is.'

## Game Theory

The third and final modelling tactic is the 'game', which is based on Game Theory. This is a decision mathematics technique that allows teams to better react to the changing circumstances of a race. For example, if the optimum strategy for a team's competitor is to complete a two-stop race, and for some reason they switch to a three-stop strategy, Game Theory can help a team decide on its optimum response to try and beat its competitors.

Today's top teams have the capacity to complete up to 20 million Monte Carlo simulations in the run up to a Grand Prix. Add that to the armies of engineers working to continuously improving the accuracy of every piece of data put into RaceWatch and you can see how race strategy has progressed to become its own engineering discipline.

'You think you have considered every possible scenario, and then something happens in the race that you didn't think of,' says Griffith. 'After every race we analyse what happened and ask ourselves if there was anything RaceWatch could have done to help make a particular decision at any point easier. Over a 21-race season we will introduce at least 15 new types of view to help the teams. Some of those are never used again, because that specific situation never arises again, but at least we are ready for it if it does.'

Of course, all these models and simulation tools attempt to predict the rational strategic decisions of the teams, yet still sometimes teams will make apparently irrational choices, either due to a mistake, an attempt to try and confuse their competition or through taking a risk to try and achieve a result out of a poor situation. This means that both the strategists and the software have to react quickly to decide whether any counter-action is needed, and it is these 'curve balls' that make things interesting and can change the entire complexion of a race.

So not even advanced strategic tools such as RaceWatch can fully predict human behaviour, but they can accurately define the scenarios most likely to happen. It is then up to the engineers to decide which of those scenarios will help them beat the competition.


**Simulation tools can still only predict how *likely* something is to happen. So engineers still need to use common sense, and sometimes just look up to check the weather themselves**

# We need to talk about electric powertrains

## The good, the bad and the ugly, but nevertheless, the facts

By DANNY NOWLAN

Without a shadow of a doubt, one of the most polarising subjects in motor vehicle engineering, whether it be automotive or motorsport, is electric powertrains. I've never seen a subject promote such extreme reactions. On one hand you have utopian optimists who contend that battery-powered electric propulsion will eat internal combustion engines alive. Then you have the other extreme who contend that electric propulsion is nothing more than a smoke screen and this is a false dawn.

It's become such a divisive issue that it has actually turned into a political football in the current Australian Federal election.

The purpose of this article is to drill down into what is the current state of play with electric powertrains. We'll present the good, the bad and the ugly on the matter. Given how divisive this issue is, the goal of this article is to give you the facts, good and bad, so you can make informed decisions. Unfortunately this is something that has been sadly absent in general discussions about electric vehicles.

Firstly, before we begin it might be wise for me to lay my cards on the table. I've written before on a number of occasions on electric powertrains. Initially laying out the basics, and then exploring their use in categories such as GT3 and Time Attack. Where this comes from is the development of the ChassisSim Electric Powertrain module. This has been used in electric series such as Formula E, and some other projects coming down the pipeline that I have to remain tight lipped on.

### Flying high

In addition to this, for the last 20 years, day in day out, I have been flying high performance electric-powered pylon racers and extreme aerobatic aircraft. I started off with NiCad / brushed motor-powered gliders that could barely cope with 20km/h winds 20 years ago. Now I fly LiPo, brushless-powered monsters that will blast into winds of 40km/h with complete abandon and are able to hit 160-260km/h with no problem.

To underscore the advancements of electric propulsion, I've never needed to fly internal combustion motors.

Electric cars are a political hot potato, with those throwing arguments around rarely in possession of all the facts

So, in summary, it is fair to say I have some skin in this particular game. But to understand the current state of play, we need to understand why contemporary electric vehicles have received the press they have. When you started to get a Tesla Model S that could go 400km on a charge and blow away Porsches on the standing quarter mile, a lot of de-skilled politicians and senior bureaucrats figured it was the dawning of the new age of Aquarius and got very amorous with their nearest tree. However, the devil is, as always, in the detail.

The reason an electric vehicle can do 400km is that the way you use engine torque for a road car application is different to motorsport. In motorsport we spend 60-70 per cent of our time on full throttle. In an aerospace application, that figure can rise to upwards of 70-80 per cent engine torque all the time. But for road cars, it's unusual to go beyond 10 per cent throttle.

**Figure 1** is an analysis I did for one of my re-sellers, Altair Engineering, about using the ChassisSim Electric Powertrain module for road car use. This was a typical usage pattern I came up with for mixed city / highway driving, with a cruise throttle of 10 per cent and the stab to 20 per cent when you wanted to be naughty. I simulated a 10km drive pattern, and you can see the Ah usage of the battery pack was 4.3Ah.

So, given the pack voltage was 700V, this is about 3kWh for this usage. For a Tesla Model S with a battery pack of 85kWh you can get about 270km range with this usage. Given I have been a bit generous with throttle application, this is the reason a Tesla Model S will achieve a range of 400-500km. However, the major reason it can do this is because you can be gentle with the throttle. You don't have this luxury with motorsport or aerospace applications.

## Electric engines have a flat torque curve that responds instantly

The other reason electric vehicles have created so much publicity is in drag races, where you see a Tesla Model S leaving the more familiar muscle cars with large internal combustion engines for dead. The reason for this comes down to the torque delivery of an electric motor vs an internal combustion motor. With an internal combustion motor, particularly a high torque one, you are doing handstands if you can typically reach 10,000rpm. And one of the Holy Grails of internal combustion tuning is getting the torque vs rpm curve as flat as you can.

Electric engines have a flat torque curve that responds instantly and, in a lot of cases, can rev up to 20,000rpm. This is why a Tesla Model S configured in insane mode will beat its equivalent spec internal combustion motor counterpart in a drag race every time.

## Advantage electric

This of course segues into one of the advantages of electric powertrains, and that is powertrain responsiveness. Talk to anyone who has tuned an internal combustion engine and they'll tell you to spend a lot of time on tuning so the torque vs rpm curve is as wide as possible. Also you need to tune the throttle response.

With electric motors, the only thing you are playing with is the timing on the brushless motors (the angle between the rotor and the magnets) and the pulse width modulation (PWM) frequency. Most electric speed controls will have a linear response anyway, so it's effectively an afterthought.

A case in point is in radio controlled (RC) 3D aerobatic aircraft powered by an internal combustion motor. Here you are always chasing the throttle response map. In the electric community, we set the motor timing and then range check the throttle when we first install the electronic speed control. After this you never have need to touch it.

A further advantage of electric powertrains is motor packaging. A really good case in point is the Remy HVH 250 motor. The higher end applications can punch out 250kW, weighs in at 57kg and can be packaged in a space of 300 x 200 x 200mm. This is simply inconceivable for an internal combustion motor, and offers a plethora of opportunities you don't have with ICE.

A really good case in point is with the electric motor fitted to both axles, which handles the nightmare of the differential quite elegantly.

Yet another advantage of an electric motor is maintenance, or lack thereof. Internal combustion motors are notorious for their maintenance requirements. Just try running a modern road car well past its 10,000km service interval and see what happens. This is doubly critical for a racecar or aerospace engine.

In complete contrast, if you run an electric engine within its voltage, current, load and temperature limits it will last forever. This is one of the primary reasons why OEMs have been so spooked by electric vehicles, because where car makers make their money is finance and parts. The minimal maintenance of electric engines mean the latter part of that equation falls apart. That being said, there is a flip side to this, but we'll discuss that shortly.

Where electric engines shine, particularly in motorsport use, is in sprint events, from Formula Student upwards. It is no accident that Volkswagen, with its all-electric I.D.R, was able to smash the Pikes Peak record.

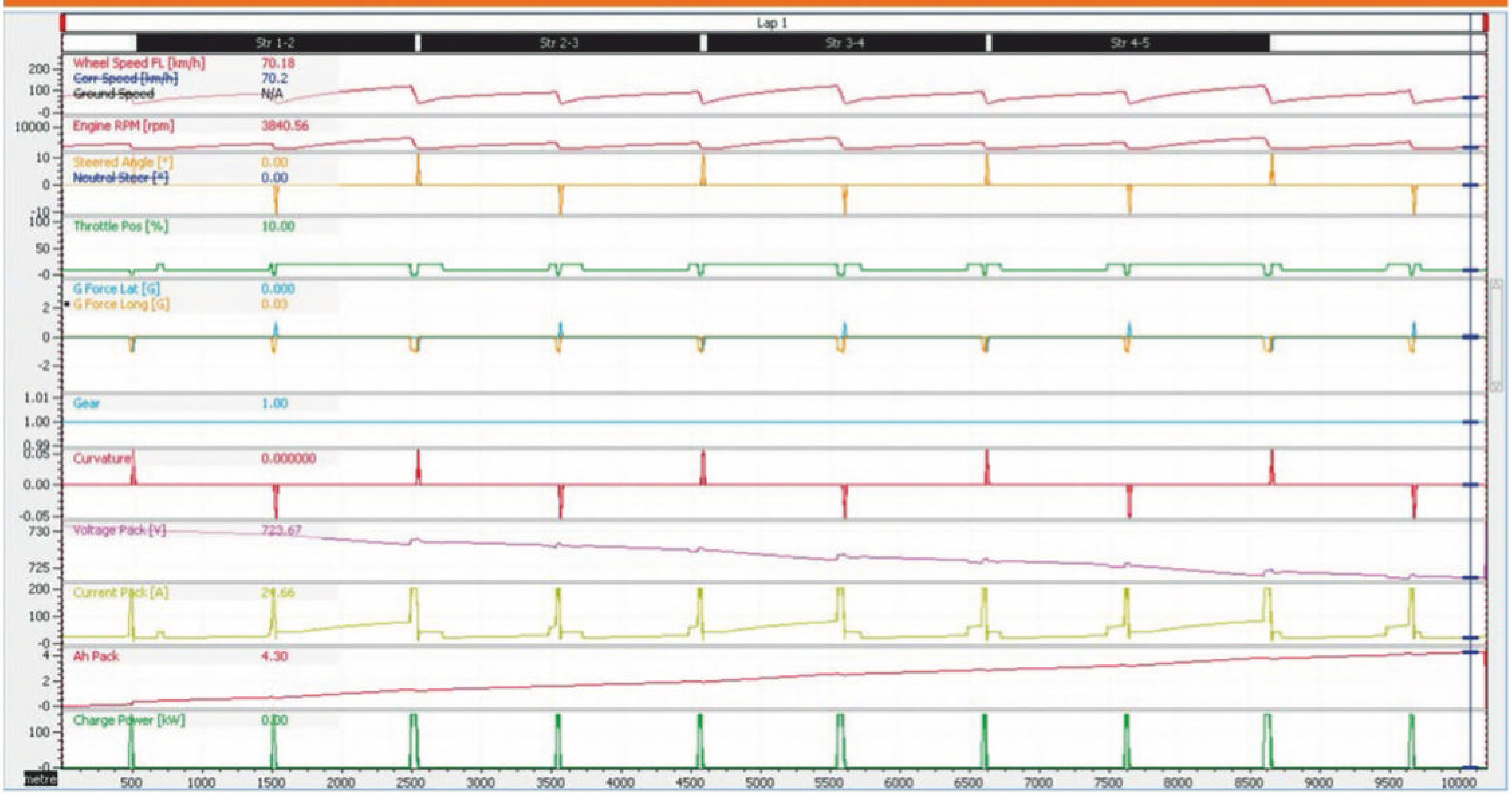
You might also recall I did an analysis on an electric-powered Time Attack Lotus Elise for the Open Class category for World Time Attack Challenge that is held at Eastern Creek raceway in Australia every October. With the like-for-like replacement, the results found are shown in **Table 1** below.

**Table 1: Lap time analysis ICE vs electric for Lotus Elise Open Class Time Attack challenger at Eastern Creek**

| Item | Lap time (s) |
|---|---|
| Internal combustion | 84.72s |
| Electric | 85.9s |

## If you run an electric engine within its voltage, current, load and temperature limits it will last forever

**Figure 1: Typical road car use of an electric powertrain**



Further studies found that when the electric car was reduced to 930kg, there was little difference between the internal combustion and electric engine equivalent.

The other area where electrics could shine is club motorsport sprint events. The reason I say this is because in these formulae all costs are at a premium, and the lack of engine maintenance for an electric-powered contender could be quite enticing. That said, this only holds true if you can charge the car up.

Where electric engines really come into their own is in urban road car use. If we refer back to **Figure 1**, in a road car application you are in the range of 0-20 per cent throttle. And one of the worst things you can do with an internal combustion engine is turn it on and off all the time. Also, if you want to make it last, you have to warm it up before putting it to use.

An electric engine has none of the above drawbacks so, if your operating radius is 100-200km, and the car will always be parked in front of a charger, electric vehicles offer a genuine and enticing alternative. Again though, there is a flip side, which we will come to shortly.

## Disadvantage electric

Where an electric powertrain struggles is when you need persistence. One of the things that has largely been left unsaid is what can fit into a tea cup and take you a kilometre? The answer: petroleum! This is one of the most significant challenges to going carbon neutral, particularly when it comes to transport.

As a case in point, let's review an analysis I did of an all-electric GT contender at the Bathurst 12 Hour. For a 380kW motor, **Equation 1** shows how the numbers shook down for the battery pack. Given that we'll be running 20 laps over a 45-minute stint, we'll need at least 253Ah of capacity. So the number of cells we'll need is shown in **Equation 1**.

You don't need to be a rocket scientist to figure out a pack mass of 1264.8kg is simply not practical in a car. Referring again to the Lotus Elise Time Attack study, even for a sprint event we need a lot of cells in the battery pack. Refreshing your memory with the highlights, we had a working cell voltage of 3.5V and we need a capacity of 38Ah. The pack configuration in this case is given in **Equation 2**.

Bottom line, we need 200 cells in series and 10 cells in parallel. This came in at a battery pack price of USD $51,000. So even for a sprint event you still need 2,000 3.3Ah lithium polymer cells.

What this shows is that with current battery technology, the energy density is still very marginal. As much as some commentators love to gloss over this, there is no avoiding it. Now compare **Figure 1** for a road car application, where throttle is at 10-20 per cent (and this is being generous) with **Figure 2** for a motorsport application.

**With current battery technology the energy density is still very marginal**

As can be seen from the throttle trace, you are at full throttle for at least 70 per cent of the lap. So this means over 3.8km we have chewed up 6.25Ah. Also, this was for a motor power of 200kW and the pack was sized for a 15-minute session! This illustrates the primary reason an all-electric, battery-powered vehicle will struggle at an endurance event.

The other thing this analysis shows is that if the battery pack fails, you are on the hook for a big ticket expense. The dollar value for a Tesla Model S/3 battery replacement is, at the time of writing, USD $27,000. In fairness, the battery is rated for 120,000 miles / 190,000km but, should the battery pack fail, it invalidates the maintenance advantage offered by the electric engine in one fell swoop.

The other thing that has been left unsaid about electric propulsion is charge time. Typically, charge rate battery is referred to as C of the battery pack. If you charge at 1C, the battery pack will charge in an hour. If it charges in 2C, it will charge in half an hour. Most modern lithium polymer batteries can be charged at 5C, though for longevity you want to charge at 4C. This means it takes 15 minutes to charge the battery pack. For a motorsport application you can get away with this. But if you have electric cars in numbers on the freeway, just imagine the tailbacks at the service stations. You'll need more than a cup of tea while waiting.

Also, we cannot discuss battery-powered electric vehicles without discussing the charging infrastructure and power grids it is plugged into.

Firstly, if you are going to fast charge an 85kWh battery at 4C, your power usage will be 340kW. This is the equivalent of plugging in 140 electric heating fans at full noise. This presents considerable challenges, but is not insurmountable. However, what will be the more critical problem is the demands this will place on the electricity grid.

Depending on where you live in the world, a typical household will use 8-12kWh per day. So over the week you are using about 60kWh. An 85kWh electric car will increase domestic demand by a factor of two at least. This is a significant problem that needs to be addressed.

## Environmental impact

Lastly, we need to talk about the environmental impacts of producing batteries in numbers. Some to the political right of Attila the Hun will say this disqualifies electric propulsion entirely, but there are two aspects to this discussion: mining the raw materials and recycling them.

Supplying the raw materials for battery-powered electric propulsion is a significant concern that can't be swept under the carpet. Let's say for the sake of argument, over the next 20 years two billion electric battery-powered cars are built. To make the numbers simple, let's use a battery pack mass of 1,000kg. This means we need 2 x 1012 kg of raw materials. Presuming the demand is provided linearly, we

## EQUATIONS

**EQUATION 1**

$$No\_of\_cells = \frac{V_T}{V_{CELL}} \cdot \frac{Ah_{TOT}}{Ah_{CELL}} = \frac{650}{3.5} \cdot \frac{260}{7.7} = 6324$$

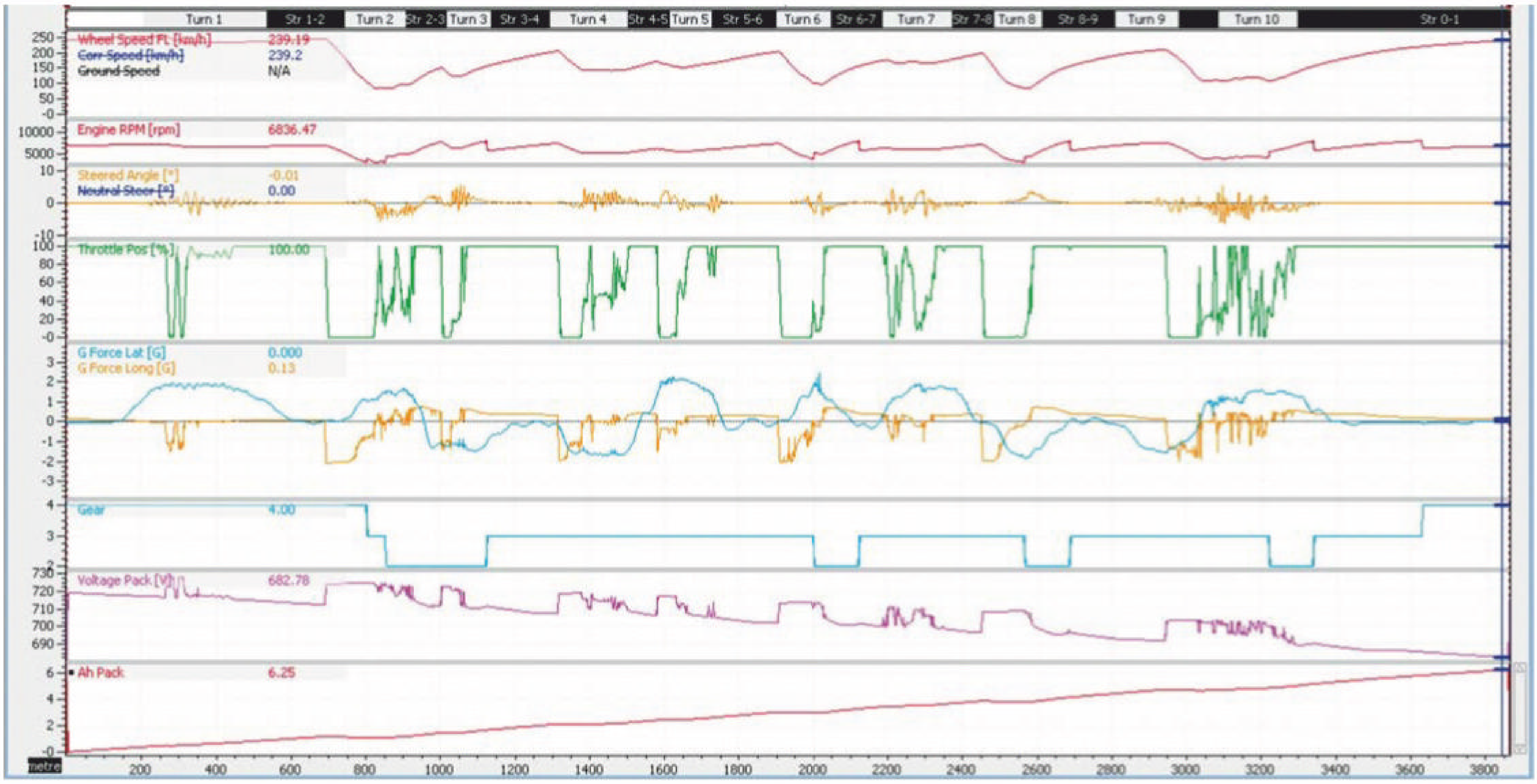
$$Pack\_mass = No\_of\_cells \cdot m_{CELL} = 6324 \cdot 0.2 = 1264.8kg$$

**EQUATION 2**

$$PackConfig = \frac{700V}{3.5V} S \times \frac{38Ah}{3.8Ah} P$$
$$= 200S \times 10P$$

**The development of electric powertrains represent a fantastic opportunity for the wider motorsport community**

**Figure 2: Electric vehicle response parameters for a motorsport application**




# Should the battery pack fail, it invalidates the maintenance advantage offered by the electric engine in one fell swoop

divide this by 20 or so per year you need 1 x 1011 kg per year of raw materials. Equate that into tonnes and you need 100 million tonnes of raw materials per year, or about a quarter of Australia's total annual coal output.

Given what a political football this has turned into, again this is something that can't be ignored. It also underscores why significant steps still need to be taken to improve battery energy density.

On the upside, recycling batteries is not as problematic as some would like to present. One of the things that has been known for over a decade in the RC community is that once a lithium polymer has finished its operational life, once it is discharged it will readily break down. Indeed, the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) recently published a feasibility study that showed not only that lithium polymer / ion can be readily recycled, but that it represents a great economic opportunity. So recycling in and of itself is not a huge show stopper.

## Hydrogen power

While we're back on the positives, there is one potential solution to the electric energy density problem, and that is hydrogen-powered fuel cells. A company, GreenGT, has demonstrated an LMP2 test bed that weighs 1420kg and has a maximum power of 480kW (the ACO is now getting behind this as well).

Range is stated to be equivalent to its internal combustion counterpart, and the refuel time is three minutes. However, while Ricardo Divila, reporting in the March 2019 edition of Racecar, stated that hydrogen as a gas got an unfair reputation, significant testing would have to be conducted to validate this in motorsport use, particularly when it comes to safety. After all, hydrogen is technically rocket fuel and is not to be trifled with lightly, particularly in competition.

The other issue with hydrogen is producing it in quantities that rival the world wide supply of petrol and diesel.

Before we wrap this discussion up, let me throw in my two cent's worth on this matter. The current push for electric vehicles is being driven by the climate change debate. I'm fully aware there is a part of this readership who regard climate change as nothing more than a hoax, and I'm leaving this one alone since it is beyond the scope of this discussion, but there is another important reason we need to take electric vehicles seriously, and that comes down to energy security.

Right now, a significant part of the world's fuel comes from the Middle East. It only takes one crackpot to get into power in an oil-rich country before we find ourselves in a world of hurt. It was no surprise when Iraq invaded Kuwait in 1990 that no one had any reservations about using military force. But to have all our eggs in the fossil fuel basket is optimistic.

The other thing I'll say is that the development of electric powertrains represent a fantastic opportunity for the wider motorsport community. Since motor racing will push electric powertrains to their very limit, it allows us to take back the high ground, particularly in research and development. This is something that is sorely needed in our community.

## Mixed bag

In closing, electric vehicles as they are right now offer a mixed bag. Aside from the lack of visceral noise, electric powertrains offer some very exciting possibilities in terms of car running costs, throttle response and are the natural choice for sprint events. However, the battery-powered route offers significant challenges in both energy density and demands on the electricity power grid, while the environmental impacts of the production of batteries in significant volume remains a valid concern.

Yes, hydrogen offers some enticing opportunities too, but its safety and production needs to be a lot more thoroughly tested and again, motorsport may put itself in a position to be able to help with that development.

In challenge comes opportunity, though, and we in motor racing can play a leading role in this. After all, from an energy security perspective, we would be mad not to do it, and in my personal view, the planet does deserve the benefit of the doubt.

Interview – Koji Matsuura

# Lord of the 'Ring

## Falken's motorsport tyre engineer explains why its unique, Nürburgring-based racing programme is the perfect fit for the Japanese company

**By MIKE BRESLIN**

Gruppe C Photography

**'To start selling racing tyres, we need to think about the balance between tyre performance and cost'**

These days it's tough to be a tyre supplier in motorsport. For the sake of the show you will be asked to make rubber that degrades more than it needs to, is perhaps not as sticky or fast as you would like it to be, and then you will get the most publicity of all when things go wrong. But then all that simply comes with the territory when you have a control tyre deal with a major series.

Yet there are other ways to showcase, and indeed develop, tyres in motor racing, including setting up a team and then running cars fitted with your rubber at the most challenging arena of them all, the Nürburgring Nordschleife. This is the path Falken has chosen for many years now with much success.

Falken has been racing its products at the Nürburgring 24 hours (N24) for two decades, and its tyre engineer, Koji Matsuura, has been a part of this effort and the wider VLN Endurance Championship campaign – which also runs at the Nürburgring – since 2016, having previously worked on the company's programme in the ALMS.

'In Europe, Falken is only involved in VLN and the 24-hour race at the Nürburgring, and this year marks 20 years since an R33 Nissan and Escort Cosworth [first] entered the N24 using Falken tyres,' Matsuura says. 'This is one of the few racing series where the tyres are not restricted to one single brand within the competition. The VLN is a great series; it is growing and getting more international relevance and prominence all the time.'

Falken is a Sumitomo Rubber Industries brand and its motorsport history, while not high profile, has certainly been eclectic. This includes the American Le Mans Series, Japanese endurance series Super Taikyu, a one-make category in South Africa and club racing support in the UK, Australia and the US. Its rubber has also been widely used in rallying in Asia and Falken tyres are a popular choice for off-road racing in North America.

But its main motorsport programme is the VLN and the N24, where its own race-winning team, Falken Motorsports, runs two cars. Unusually, this is actually two quite different cars, a new Porsche 911 GT3-R and a BMW M6 GT3, with two distinct teams within the operation running each racecar. Yet while this approach may be out of the ordinary, it does bring benefits when it comes to tyre development.

'One key benefit is having data from multiple cars,' explains Matsuura. 'Running both the BMW and the Porsche means we have double the amount of information. That means data from two cars and eight drivers. I think that was a key factor in accelerating our tyre development.' This split approach has also meant producing different tyres for each car, one of the benefits of open tyre competition in the VLN. 'We have come to a point where we wanted to go different ways with tyre development to achieve the best results and have the optimum tyre,' continues Matsuura. 'That's natural because the vehicles are not the same.'

### 2019 focus

For this year there's also the challenge of a new Porsche to develop rubber for. 'An important thing we had to focus on in 2019 was to understand the characteristics of the Gen 2 Porsche as soon as possible, and adjust our tyres to suit that car,' Matsuura says. 'The new Porsche retains some similar parts to the Gen 1 Porsche. However, some elements are completely different. There is a larger front tyre and double wishbone suspension up front. That larger front tyre helps to improve grip, especially under braking. We also have a different brake supplier and the ABS software has been changed, too.

'At the rear, there are some minor differences in the suspension set-up, but the weight distribution is similar to the previous car. We've had work to do but that was to be expected.'

Yet while all that has been a challenge, the really tough thing to crack at the Nürburgring is the track itself, with its high speeds, bumps and jumps. 'There are a few things that differ from other tracks, which makes the Nordschleife a unique challenge for both tyres and teams,' says Matsuura. 'The track has a lot of gradient changes and jumps, which mean a lot of load on the tyres and you need a lot of stability. There are also many different kinds of tarmac so you need to build tyres which perform equally well on grippy and slippery surfaces. There are a lot of kerbs too so you need a tyre that can handle that.'

And then there's the notorious Eifel weather to think about. 'One lap in one of the Falken cars takes about eight minutes in dry conditions,' explains Matsuura. 'But when the weather changes suddenly, the driver needs a lot more time to finish the lap than on a usual track to get to the pits for a tyre change. The challenge is to have tyres that can be used for a long time, even when the conditions are not ideal, to avoid too many unnecessary stops.

With tyres for Porsche GT3 Cup cars coming this year, Falken looks to be positioning itself as a race tyre manufacturer

Gruppe C Photography

'Also, during the N24, or even within a VLN race, you can see track temperatures reach 40degC, yet drop to 5degC, have heavy or light rain and sometimes snow, all in one weekend.

'Nürburgring is much longer in length than other tracks, so even in one lap the track conditions can vary from place to place,' Matsuura adds. 'These are all factors that make the Nürburgring such a challenging, but rewarding place to develop tyres. I'm still learning and will always respect this circuit.'

## Future business

While its two-car approach has proved fruitful for Falken over recent seasons, last year the company also started to offer its rubber to other teams. 'This is a new challenge for our future business,' explains Matsuura. 'To start selling racing tyres, we need to think about the balance between tyre performance and cost, compared to other tyre makers such as Michelin, Dunlop, Pirelli, Yokohama and so on. Developing and supplying tyres just for our own teams is costly, so selling tyres is appealing.

'We've been happy with the feedback from our customers so far. We will be releasing more sizes this year, including tyres suitable for the Porsche GT3 Cup cars.'

But what about the wider motorsport market and, more specifically, would the company be interested in a control tyre deal with a series? 'We are open for supplying tyres in other racing series,' Matsuura says. 'And that [a control tyre deal] would definitely be one target for the future for Falken in Europe.

'With some time for planning and producing the tyres, we could prepare for a smaller series using one of the existing sizes, but it would be very challenging. There are lots of other factors such as warehousing, logistics and a support infrastructure, which would also have to be taken care of by Falken.'

For the time being, though, Falken is content with its 'Ring programme, and especially with the way it has helped with road car tyre development as there is a direct link to the racing project. 'We firmly believe motorsport is one of the best places to develop and try technologies,' concludes Matsuura. 'Because the Nürburgring is very similar to a normal road, [VLN] is more relevant than some other championships for our road tyre developments.' And a tyre maker can't ask for much more than that from its motorsport programme.


## RACE MOVES

XPB

**Mario Illien**, the boss of race engine manufacturer Ilmor, is to take a month off to compete in the 2019 Paris Peking Rally in a 1955 Citroen 11B he's prepared himself. The F1 and IndyCar powerplant designer will be joined in the car by his daughter, Noele, who takes on navigating duties for the event.

The rally covers 8,500 miles, starting in Peking on 2 June and finishing in Paris on 7 July.

McLaren Racing has appointed NFL executive, **Mark Waller**, to the role of managing director, sales and marketing. Waller has 25 years' experience in global businesses and is currently executive vice president of International at NFL, driving the growth of the American football league outside of the US. Waller will oversee all aspects of the company's commercial and marketing activity and will report directly to McLaren Racing CEO, **Zak Brown**.

Former NASCAR Truck Series team owner, **Mike Mittler**, has died at the age of 67 after a battle with cancer. His team, MB Motorsports, fielded trucks in over 300 races from the very first season for the popular third-tier NASCAR series in 1995 until last year. While the team never won a race, it did run many drivers who would go on to greater things in the sport, including **Carl Edwards**, **Justin Allgaier** and **Jamie McMurray**.

**Oliver Hoffmann** and **Julius Seebach** have taken over the management responsibilities at Audi Sport following the retirement of **Michael-Julius Renz** from his post as managing director. Hoffmann, who is Audi's head of sport technology, is now also responsible for technical development at Audi Sport's Neckarsulm HQ, in his new and concurrent role as managing director. Seebach will be responsible for the commercial side of things at Audi Sport.

**Piet Daenen** has been appointed chief operating officer at well-known motorsport and automotive transmission specialist Xtrac, where he is now also a full member of the board. Daenen has been brought on board to help manage the company's growth. He has previously worked for major engineering companies around the world, including BMW, Rolls-Royce and JCB.

**Tommy Sopwith**, an early BTCC star from when it was known as the British Saloon Car Championship in the 1950s, who then went on to become a team owner in touring car and sportscar racing with his Equipe Endeavour operation, has died at the age of 86. Sopwith was also partly responsible, and helped to organise, the 1968 London-Sydney Marathon rally, and he was a director and chairman of the British Racing Drivers' Club.

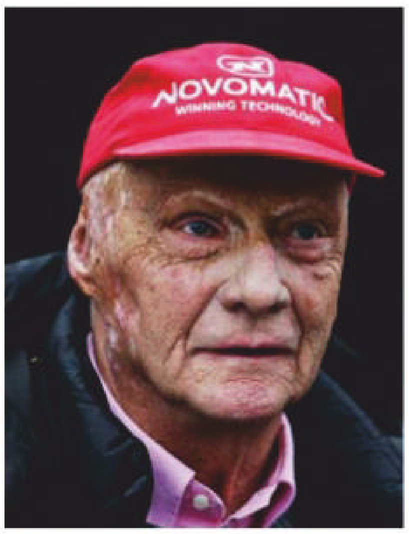
Well-known Canadian motorsport journalist, **Dean McNulty**, has died at the age of 70 after losing his battle with leukaemia. Having started his career on *The Toronto Sun* in 1979, McNulty, who was nicknamed 'The Dean of Speed', was known for his ability to spot driving talent. During his career he covered IndyCar, NASCAR, Formula 1 and many other categories at all levels.

**Rodney Gooch**, who for three decades was the marketing director at UK circuit, Castle Combe, leading up to his retirement last year, has died at the age of 73. Gooch, a very popular character at the Wiltshire track came to Combe from Brands Hatch, where he had previously worked with **John Webb**.

**Brenda Jackson**, the mother of **Dale Earnhardt Jr**, who had worked at JR Motorsports as an accounting specialist, has died at the age of 65. The former wife of the late **Dale Earnhardt Sr**, Jackson was the daughter of well-known NASCAR fabricator **Robert Gee**, who built racecars for several well-known drivers, including Earnhardt Sr.

**Jose Munoz** is now global chief operating officer for Hyundai, as well as its CEO in America, where he is responsible for the entire market, including Hyundai Motor North, Central and South America. Munoz was most recently the chief performance officer for Nissan Motor Corporation and the chairman of Nissan China. He joined Nissan in 2004.

## OBITUARY – Niki Lauda



XPB

**Motor racing legend, Niki Lauda, has died at the age of 70. The three-time world champion driver and, more recently, non-executive chairman of the Mercedes F1 team, had been suffering with severe health problems since last year and had recently undergone a lung transplant, but there had been talk of him returning to the paddock this season.**

Lauda's first two world championships were won with Ferrari in 1975 and 1977, but in the intervening season he suffered horrendous burns after a crash at the Nürburgring. He returned to the track at Monza just six weeks after his accident in Germany, after having been extremely close to death, and then lost the 1976 title to James Hunt by just one point. He went on to win his third championship at McLaren in 1984.

After retiring from racing to run the airline that bore his name – he had earlier retired in 1979 but made a comeback – Lauda returned to Formula 1 in a managerial capacity with Ferrari in the 1990s. This was followed by the team principal role at Jaguar in 2001, but this lasted for just a year and was not considered a success.

However, Lauda was far more successful at Mercedes, a team he joined as non-executive chairman in 2012. Since then, working alongside team principal, Toto Wolff, he has played a key role in overseeing its dominant spell in Formula 1, which has included a run of five manufacturer championship wins since 2014.

**Niki Lauda 1949-2019**

# Renault restructures Formula 1 tech management team

**Renault has reorganised the senior engineering management in its Formula 1 engine and chassis departments, with the aim of helping its technical chiefs focus on increasing the performance of its 2019 RS19 contender.**

As part of this management restructure, Christophe Mary is to start work at Viry – Renault's engine development base – as director of engineering, the role starting at the beginning of August. He will report to the team's engine boss, Remy Taffin.

Mary, who held a senior post with Ferrari's power unit team from 1994 until 2007 and also worked at Mercedes for four years, was most recently employed at PSA, where he was chief systems and powertrain engineer in the French manufacturer's motorsport division.

Stephane Rodriguez, a long-time Renault employee, has been appointed to the all-new position of project and purchasing director within the technical department and will also report to Remy Taffin.

On the chassis side, Matthew Harman, who joined the Enstone-based team last year as deputy chief designer after 17 years with Mercedes, has now been promoted to engineering director, reporting directly to technical director, Nick Chester.

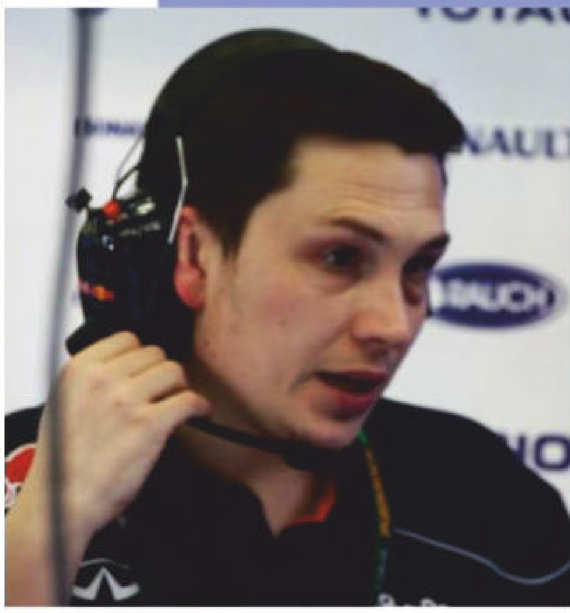
XPB

**Will changes at Renault improve the RS19?**

Renault says these moves will allow Taffin and Chester 'to increase their focus on the performance of the chassis and engine, while overseeing the entire technical programme with internal and external stakeholders.'

Mary, Rodriguez and Harman will all have seats on the management board of the Renault Formula 1 team.

## RACE MOVES – continued



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**Tim Malyon**, formerly an engineer at Red Bull and Sauber in Formula 1, has been named as the FIA's head of research for safety in motorsport. He will be based at its safety department, which is in the Geneva office. The governing body has stated that this new role 'has been created to oversee the growing number of safety research projects undertaken by the FIA.'

**Christian Tilbury** has joined automotive technology PR specialist, Market Engineering as senior account manager. Tilbury has spent 20 years in motoring journalism and PR.

Sports car maker, Lotus, has hired **Geoff Dowding** as its global sales and after-sales director. He joins the company from Al Habtoor Motors, where he was chief operating officer. Prior to that he held a variety of senior roles with companies such as Volkswagen, Nissan, Porsche, Harley-Davidson and Bentley.

Famed Formula 1 car designer, **Gordon Murray**, has launched an internet-based virtual exhibition of 40 different racecars and road cars produced during the past 50 years of his career in vehicle design and engineering. The online exhibition, called *One Formula*, is free to access and can be found at www.oneformulagordonmurray.com. It has been timed to coincide with his new book, also called *One Formula*, which is described as a 'two volume, 900-page epic'.

Motorsport personalities featured prominently in *The Sunday Times Rich List* – the annual guide to wealth in the UK – with **Bernie Ecclestone** up four places to number 60 with an estimated fortune of £2.48bn, while his ex-wife **Slavica**, who owns the Paul Ricard circuit, is at 196th (£740m). Former F1 track ad' and corporate hospitality man, **Paddy McNally**, is 230th (£610m), **Ron Dennis** 304th (£450m), while **Toto** and **Susie Wolff** are jointly listed at 390th (£335m).

The new class of interns for the NASCAR Diversity Internship Program (NDIP) has started working with the US stock car governing body, with 28 students taking up posts within NASCAR. The scheme offers college students from diverse backgrounds practical experience within motorsport, and more than 400 students have participated since it began in 2000.

NASCAR fined two crew chiefs in its Cup Series after the lug nuts on the cars they tend were found to be improperly fastened following the Dover International Speedway round. **Billy Scott**, crew chief on the no.41 Stewart-Haas Racing car, and **Chad Johnston**, who looks after the no.42 Chip Ganassi Racing entry, were fined $10,000 each for the infractions.

**Danny Stockman Jr**, crew chief on the Richard Childress Racing no.3 Chevrolet in the NASCAR Cup, was fined $25,000 after the car was found to be running with a rear deck lid that did not comply with the regulations after the Talladega Superspeedway round.

NASCAR Cup crew chiefs, **Paul Wolfe** and **Peter Sospenzo**, were both fined $10,000 for lug nut infractions at Kansas Speedway. Wolfe tends the no.2 Team Penske Ford and Sospenzo the Spire Motorsports no.77 Chevrolet.

◆ 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**

# Opportunity knocks

From east to west, north to south, Motorsport Valley is growing fast

As I was recently researching themes for the MIA Business Growth Conference, supported by *Racecar Engineering*, on July 11 at Racing Point Team HQ, Silverstone, I noticed double the number of delegates have already booked (see www.the-mia.com). I was curious to know the reason behind the hunger of motorsport-based engineering companies for more business ideas.

Clearly shrugging off the effects of Brexit, these companies are growing. Despite depressing business news in recent months, the Motorsport Valley business community is creating a bright future by exploiting motorsport-based engineering capabilities to deliver mobility and other prototypes to many sectors.

I'm often asked to explain the value to companies of being part of the Motorsport Valley business cluster. Primarily, I say, it's the name. Being globally recognised and promoted, it attracts investment and new business. The name, created by the MIA to achieve this aim, is owned by its members. Recent investment from Liberty in F1 and Formula E, Mercedes, NIO, Haas, Lawrence Stroll, Geely and Renault are just a few examples of its positive effect.

Well-structured, collaborative business clusters, facilitated by a central organisation of their choosing, help that community handle change more successfully than those outside. In close proximity, similar minds, techniques, resources and capabilities provide the agility needed to grasp opportunities, and overcome the challenges of change.

Business is booming across the Valley from Geely's Lotus to Titan, RML, Delta, Alcon and AP Racing, plus the hot bed of Formula 1, Mercedes, Haas, Racing Point, Toro Rosso and Williams, Xtrac, McLaren and Ricardo. These are just a few of the companies who've increased sales in recent years.

To help achieve this, they invest heavily in R&D, the very best machinery and world-class talent to stay ahead of any competition. They hone their approach to business challenges in the white heat of competitive motorsport, and their rapid delivery of innovative solutions is needed, demanded even, by many sectors during this period of change.

Whether automotive, mobility, marine or aerospace, all seek new energy efficient solutions, which need to be developed and prototyped before production. MIA member companies across Motorsport Valley have that experience, from decades of creating, and competing in, prototypes every weekend. This combination of expertise ensures a bright future for the UK as an international base for mobility Research and development.

At the Business Growth Conference in July, the MIA will announce a new collaboration partnership with British Marine, the UK marine industry's trade body. Over the next decade, the 5000+ marine companies who generate over £10 billion in sales must begin to meet Clean Air targets set by government, and they will better achieve this by linking to motorsport suppliers and, in doing so, will bring more business growth to our members.

**Motorsport Valley boasts a strong business base, and has the ability to broaden its horizons into new, energy-efficient mobility industries**

## Global cluster

The global impact of Motorsport Valley and other leading clusters is invaluable. 100 years ago, the Hollywood film cluster delivered silent, monotone movies, but embraced change to include sound, colour, widescreen displays and, most recently, online entertainment technologies.

Silicon Valley, now a $3 trillion technology-based neighbourhood home to Apple, Google, Tesla and others, was in the 1930s an early centre for aerospace. Messrs. Hewlett and Packard made radar equipment as their inventive neighbours built the semi-conductor sector.

In the '70s, Stanford University was involved in the creation of the internet, and a journalist named the community 'Silicon Valley USA'. The name stuck, and it has dominated the computer industry since.

Motorsport Valley can, and is doing, the same thing. Nearly 80 years ago, motorsport departments in the shrinking UK automotive industry were closing down. As a result, hundreds of talented, competitive engineers built small, successful businesses to deliver high-performance, on-time solutions to meet a boom in motorsport.

In 1969, two Oxford University graduates created March Engineering in Bicester, the UK's first commercial racecar builder to serve a global market. As Formula Ford and other formulae boomed, Titan, Royale, Van Diemen and Reynard enjoyed international success, as did Formula 1, many of whose teams chose to be close to the UK's specialist motorsport supply chain.

## Support organisation

Twenty five years ago, these same people created their own support organisation, the MIA, to protect and promote their industry and help members utilise their race-bred capabilities. To do this, they named the community Motorsport Valley.

Just as in Silicon Valley and Hollywood, these companies have embraced change and now profit from delivering energy-efficient mobility solutions to the global market. Each month, a new 'solution' seems to appear, whether autonomous, hydrogen power, fully electric, hybrid, cleaner ICE, and all need agile suppliers to meet demand.

Major companies find it difficult to meet such fast changing demands, but not motorsport businesses. Their speed of reaction, coupled with innovative minds, mean they are ideally placed to operate within these exciting new arenas.

This ability to change direction rapidly requires collaboration, and the MIA delivers this by facilitating new networks to deliver growth. In turn, long-established global business clusters seek out and bring community members together.

These 'growth drivers' will speak at the MIA Business Growth Conference in July, sharing their vision and knowledge with those keen to learn how to deliver growth over the next three to five years.

I'm proud of the 25 years of success the MIA has helped deliver, but even more proud that Motorsport Valley has enjoyed 50 years of success, and has become just as influential and important to those in the world of motorsport as Hollywood or Silicon Valley in their respective industries.

**This combination of expertise ensures a bright future for the UK as an international base for mobility R&D**

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# Tunnel vision

I have written before about the failure of series organisers to provide teams with a return on investment that allows them to spend on innovation, but the problem now seems to be getting even worse. Formula 1 is looking at its new rule-set for 2021 and seeking to drive manufacturers to a single supplier for seemingly inconsequential items such as brake calipers. That is not to say that those creating brake calipers are inconsequential, but these are not the most expensive part of a racecar, and development is also limited in scope. If Formula 1 is looking to cut costs and improve racing, brake calipers are not the right place to be looking.

In the meantime, the brake industry employs staff, trains young engineers with vivid imagination, can bring about innovation and affect material design. Standardising wheel rims has been another recent talking point as modern rim designs now have a large influence on overall performance as this is where teams get control of their tyre temperatures. This is the very essence of competition but, rather than allow such skill to flourish, the FIA is again trying to stamp it out in the interest of cost control, rather than increase exposure and ROI or, in the case of F1, distribute prize funds more sensibly.

Anyone who watched qualifying for the Indy 500 could not fail to be impressed with the level of competition. The difference between pole position and the back of the grid was just over 1.8 seconds, which when split over four laps equals an average of 0.451s/lap. Less than half a second every 2.5 miles is an impressive statistic, and made for great television. However, to say that was exceptional is to ignore the fact the cars run with standard chassis (Dallara), aero (Dallara), gearbox (Xtrac), brakes (PFC) and tyres (Firestone). The engines have standard turbos (Borg Warner) and there is a standard ECU from McLaren Applied Technologies. Around the Indianapolis super speedway there is only a certain amount a driver or team can influence lap time. For that reason, experience and skill has to be of the highest level in order to compete, but we are far from the dramatically different concepts that have defined racing in the past. It is great competition but having the technical freedom to innovate is long gone.

**The solution is the proper distribution of funds, but instead F1 is looking to restrict competition**

We don't accept big differences in performance, either. Witness the dominance of Toyota in the FIA WEC, for example. Yet racing has always been like this; look at Lotus in 1978, McLaren in 1988 or Ferrari in the Schumacher years. It seems that we don't accept Mercedes' dominance of the hybrid era either, and expect to close the gap through fakery.

If Formula 1 goes ahead with this idea, it must accept that it is not the pinnacle of technology, and that it is an entertainment formula. If it is to be an entertainment industry, then it has to eliminate development of the parts of the car no one in the grandstands can see, such as an energy recovery system. The last time anyone wrote about hybrid was when a failure cost Charles Leclerc his first win. Other than that, no one has paid any attention to the incredible work of the engine guys at Mercedes, Ferrari, Renault or Honda in increasing thermal efficiency to mind-blowing levels.

The difference between IndyCar and Formula 1 could not be more stark. IndyCar has shamelessly followed the 'fast and loud' mantra, eschewing the concept of hybrid as well as embracing close competition. It is not pretending to be anything other than an entertainment sport, and has two manufacturers (Chevrolet and Honda) providing engines. The series craves a third, but only to help out at Indy where they are more stretched than usual.

Formula 1 is also relatively comfortable with where it is in terms of manufacturer participation, it could always have more, but religiously follows the mantra of technical innovation, only to then prescribe ever-decreasing boundaries. This is a matter of keeping things reasonable, and must be in place to prevent manufacturers from overspending to destruction, but sending out a tender for a single supplier signals that F1 has lost its way.

Many years ago, I wrote a column suggesting jobbing F1 drivers should be weeded out. The only way to do this is to give them a maximum career span in Formula 1 of five years. They have to be ready when they arrive, so investment in feeder categories would be encouraged, and consequently component supply companies throughout the sport would be better served. It garnered not one single letter of support, a record in the newspaper at the time.

However, I still believe motor racing needs investment in tools, teams and drivers from the grass roots of the sport to the top levels, and to restrict any of these in the name of cost cutting is ridiculous. There are limits, but the defining point cannot be the ability of one company in a field of many to mass produce a spec part. The reward for innovation is not there, it simply becomes a business case.

But motor racing is a passion. To turn it into a business is to ignore everything that has made racing great.

**ANDREW COTTON** Editor


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