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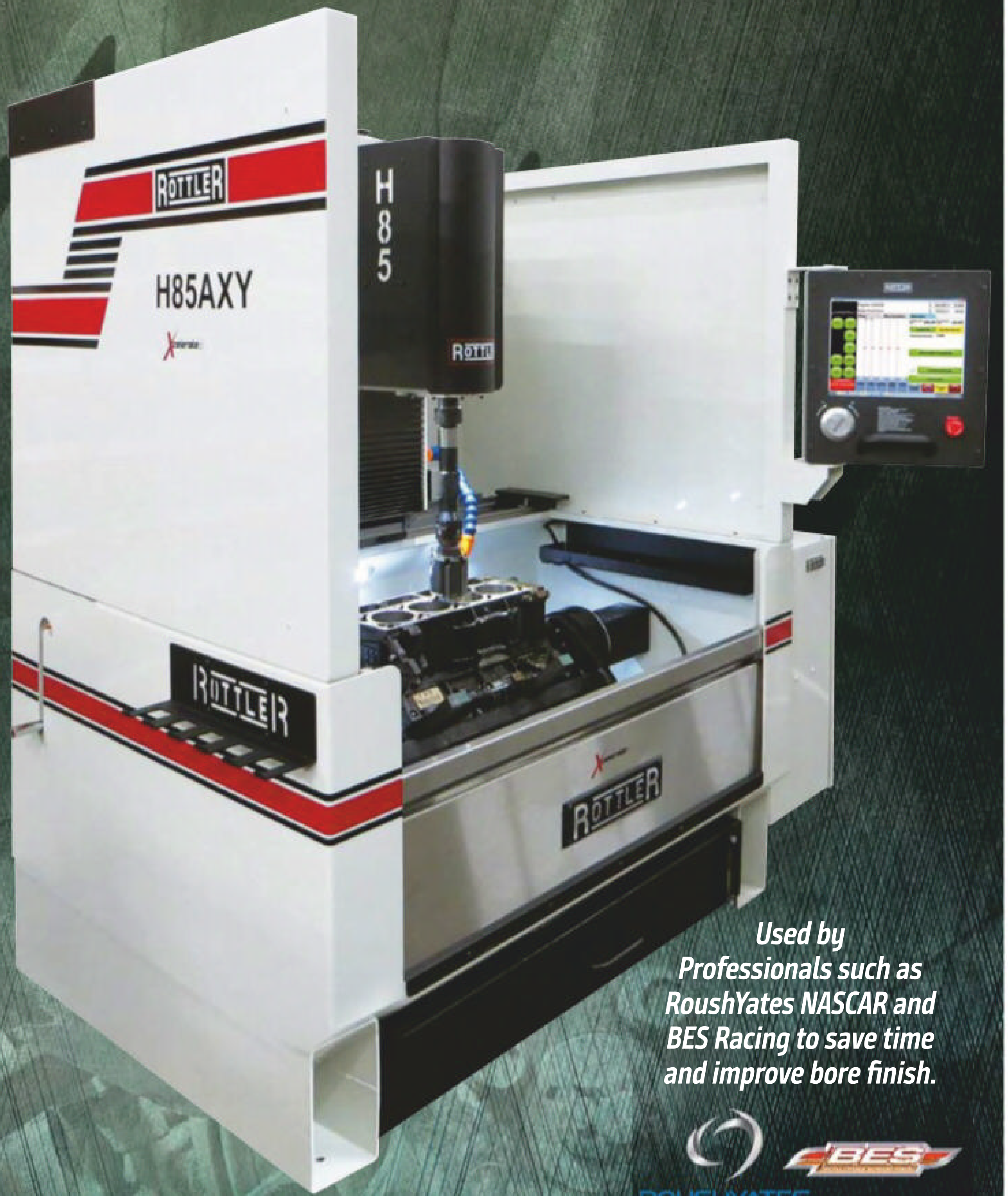

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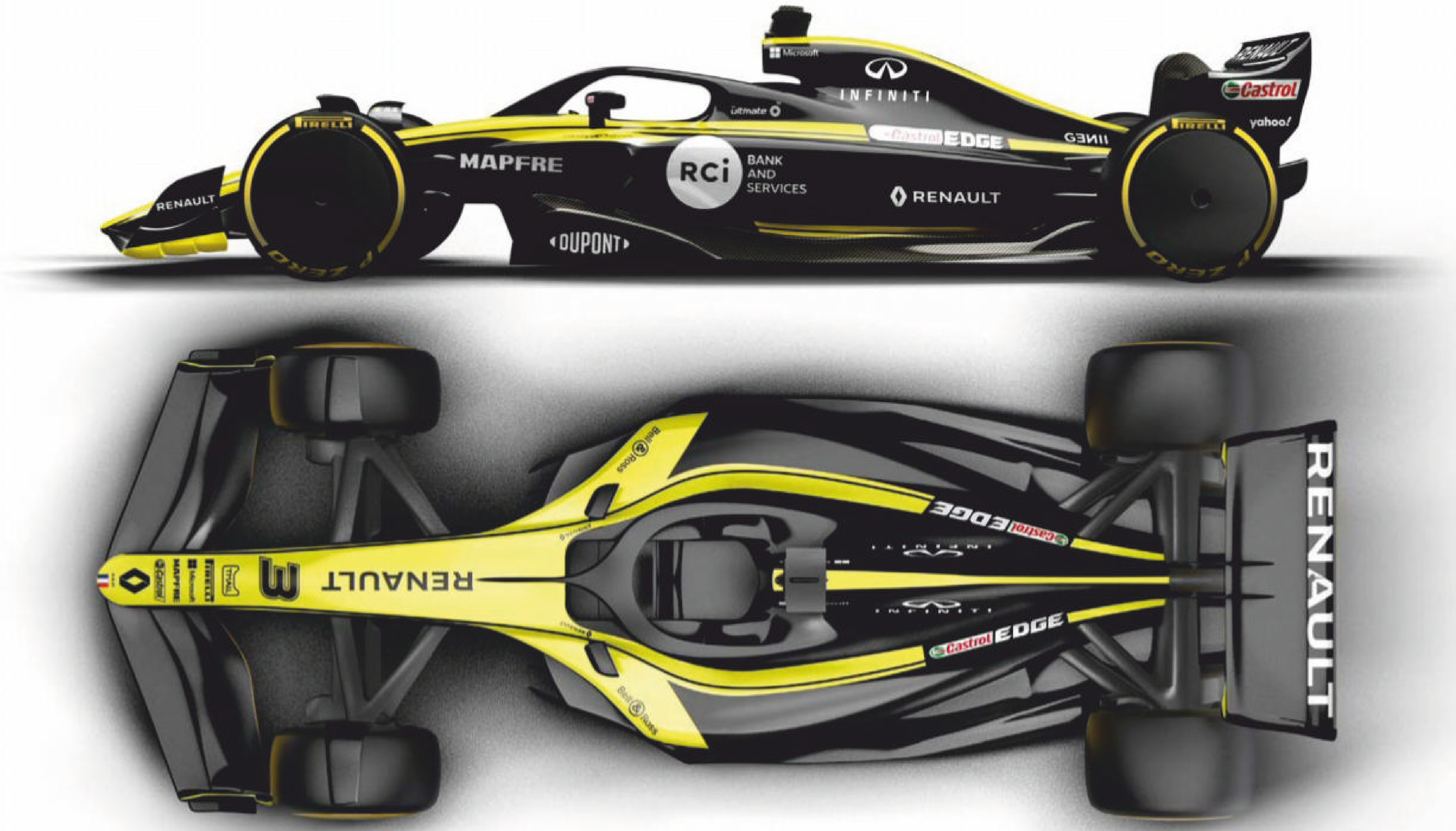
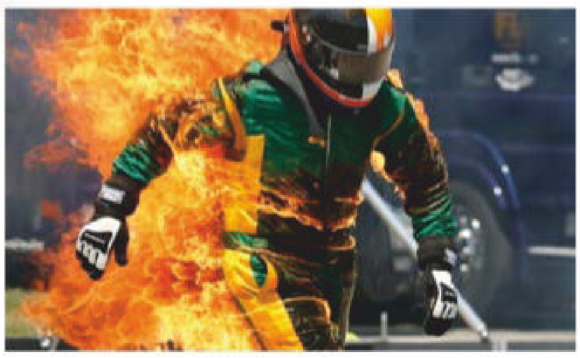
Formula 1 2021

What the new rules will mean for teams and fans



Petrolheads
The inside line on Exxon's GP fuel blending process



Hot pants
How stricter tests are shaking up the racewear business

Formula E goes Extreme
We examine the technology behind the radical all-electric off-road series

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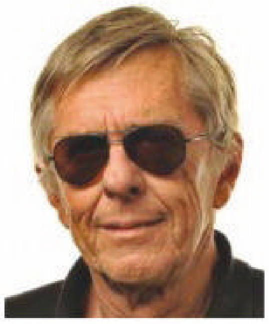
In November Kyalami was the venue for the finale of the Intercontinental GT Challenge, and the former grand prix venue proved a hit for teams, drivers and journalists alike. Turn to page 98 to find out why

Pic: Jurgen Tap/Porsche



Pass notes

The dark art of getting into the paddock without the right credentials

Plastic fantastic. These colourful rectangles are among the most precious items in F1 these days

One of the things that are part of the racing scene are the passes to get into the track. There are many different types of these – paddock and pit passes, brassards, wrist ribbons and differentiated hot pass, paddock passes with pit-lane, grid or track access. And then there are car passes; a source of never-ending bickering, the pit crew always grumbling about getting the farthest parking from the pits, as the more convenient ones were nicked by drivers and marketing, of course.

Let us establish that team passes are allocated for the year and delivered by the series organiser. By necessity they are of a limited number and are part of a lot of horse-trading between manufacturers and the organiser as to the amount available. Nowadays they are individually numbered hard passes, shaped like a credit card, with barcodes and identity photographs. In F1 they have travelling turnstiles where they are scanned to let you through, recording when it came in and being useless for another entry without having been checked out. Not much scope for smuggling extra people in these days, then.

It was not always so. Home races brought in the extra pressure for bringing in friends and family, not to mention all the passes for the factory bods. It is remarkable how many friends you found you had, especially just before the home GP, when the week before you would get a flurry of calls from people you hadn't heard from for months. 'Could you just possibly get some passes,' they would casually drop into the conversation.

Marketing had a routine of snagging the race team passes after they had got to the pits, on the theory that pit-marshals would not stop someone in team gear carrying tyres or parts of the car. Drivers had their passes lifted early on, too, as they wouldn't be checked if famous enough, specially if turning up in a driving suit and carrying a helmet.

Wild ouest

At Le Mans the local teams had the 'cattle truck', with some strategically placed big items of bodywork camouflaging the mob standing behind it. Anyone watching the van beside the pits would think it was a portal into another dimension as it disgorged a sizeable crowd. I am sure the pit-marshals turned a blind eye to the proceedings, as this was repeated for nearly a decade.

The British GP version involved space in the boot of cars coming in. The expertise acquired in this ferrying came in useful in other places too. Practically all tracks on the continent in fact.

And it was often needed, too, as there was always someone in the team who left their pass at the hotel or in the toolbox, usually one of the new lads not yet settled into the essentials of race week.

Ruff justice

Germany could be a bit tricky though as this was probably the only place where the gate checkers had dogs with them. On one memorable occasion, having some young ladies with us who had been quite friendly the previous evening, the seemingly good idea, at the time, of just bluffing our way into the paddock by just having the crowd at the front of the rent-a-car (it carrying considerably more than the five persons that it had been designed for) wave their passes and drive straight through the gate without stopping came a cropper.

The lead checker obviously was a stickler for documents, for with one bound he leapt onto the front bumper of the car and grabbed hold of the windscreen wipers, hanging on for dear life as we careened into the parking lot. Slowing down and then engaging reverse allowed the official to jump off. We merrily disappeared backwards into the parking lot and sneaked to the pits, where we had to duck and dive for the whole day when spotting a determined posse of officials, with the snarling dogs, huge German shepherds, coming past the pit area regularly looking for the *verdammt* hooligans. We survived uncaptured, but it was touch and go. The offending car was abandoned in the parking lot, to be collected the next morning, as we were sure it was staked out by officials.

The British GP was the scene for one of the biggest counterfeiting scams one year. The original card passes had recently been changed into a plastic tag, with 'FOCA' in relief characters, in a bland white. The mistake was issuing them to the teams a couple of weeks early.

Of course, the impending GP brought to the fore the usual dearth of passes for the factory personnel, and something would have to be done about it. Passing through the 'clag-shop', as the fibreglass department was known, one had to turn a blind eye to the intense activity going on, with rows of moulds lined up to be filled with white resin. A full assembly line process, minting passes.

At the GP it rapidly became apparent that several other teams had taken the same route into crime, given the number of people in the paddock, but no action was taken, for the counterfeit passes were impossible to spot compared to the real ones. Even marketing got into the act, duly demanding their share. It was also obvious to FOCA, and it was not entirely unrelated that new triangular shaped passes with embossed writing surfaced a couple of grands prix down the line.

So, it was then back to the usual tricks. Xerox machines did sterling work copying the car passes, and later producing fake hard cards was quite widespread when printer quality improved – racing teams are quite inventive when under stress. But Formula 1 passes are a bit dangerous to scam, previously one did not want to face Bernie Ecclestone's opprobrium, but with the new management it could be even more hazardous. After all, money is involved.

Sticky end

Meanwhile, attaching your car pass to the windscreen in such a fashion that you can detach it without it falling to bits due to the pre-cut slots to avoid exactly this scam is a fine art. The secret? Rub the adhesive side of it over your clothes, it will collect enough lint so it will still stick, but will be easily removable for use on another car.

These days, having been through the hassles of supplying passes, most grizzled racers will avoid asking for passes for a race they're not working at. Because they don't want to cause trouble.

Xerox machines did sterling work copying the car passes, and producing fake hard cards was quite widespread when printer quality improved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Starter pack

Could Formula 1 do more to ease the way for incoming power unit manufacturers?

While I understand Liberty and the FIA's reluctance to accept any new entrants before 2022, it should be realised that F1 is not in as settled a state as it might appear. This is only partly due to the 2021 regulation changes. Twenty cars, as now, is surely the minimum needed to present a grid that deserves the title of World Championship for drivers and constructors, and justifies the loyalty of the fan base, the TV and media coverage and all the effort and commitment required of the whole shooting-match.

Should Dietrich Mateschitz decide any time in the near future that he no longer has the ability (he is now aged 75, after all) or desire to continue funding Red Bull and Toro Rosso (soon to be Alpha Tauri), the numbers would be down to 16 at a stroke, unless both teams were to be bought and supported by new owners. Gene Haas appears to have found F1 more difficult than anticipated, too, despite the clever Ferrari connection, and there are rumours of him considering selling the team (but to who?) instead of strengthening his engineering department, which clearly is what is badly needed.

In the balance

Renault is indulging in navel-gazing regarding its continuation in grand prix racing (maybe fresh F1 management is the answer?), while Honda, typically and unfortunately, tends to decide its motorsport programmes annually, rather than making proper long-term commitments. Should the Japanese giant decide, not for the first time, that it has other priorities it might focus on alternative projects, which would be a mistake and a great shame. F1 is where it belongs and where it should remain.

Although this scenario of the grid shrinking to less than a dozen cars is worst-case, new blood is definitely needed. It used to be that some very successful F2 and F3000 teams, as was, would move up into Formula 1, but the financial and resources gap to make this jump has long been so huge it just hasn't happened. DAMS, just one example, under leadership of my sadly-departed friend Jean-Paul Driot, would have made a great Formula 1 entrant, but was denied this due to such reasons. Oh for the backing of a major manufacturer.

It has to be faced that manufacturer teams will almost always have an advantage. Thus, short of banning manufacturers from competing directly as teams (that's Ferrari out, for a start!), the only way to prevent the status quo from continuing and also to maintain grid numbers is to make it easier – and therefore more attractive – for new manufacturers to enter. If, say, an Audi or a Peugeot or a Hyundai indicated a desire to come into Formula 1, either as a team or as a power unit supplier, existing PU suppliers should be persuaded, coerced or otherwise mandated to combine to supply a 'starter-pack' level of information to give the new guys a leg-up. This would reduce the cost – and apprehension – of taking on the challenge.

As far as I'm aware, the forthcoming $175m budget cap (plus $15m for PU supply) is for team operating costs, but doesn't anywhere address the expense of setting up a new team and/or designing and developing a competitive Formula 1 PU from scratch. Being presented with baseline design information for the ICE and the whole hybrid package, including the hugely complex control software, could dramatically reduce the financial risk and avoid the initial reliability and performance nightmares that Honda and Renault experienced.

XPB

Honda has come good this season with three wins, but this was only after four years of heartache. Should F1 make it easier for new PU providers?

Dyno sore

It has to be realised that Mercedes apparently devoured over 50 power units in dyno testing, with all the massive attendant expenditure, before it produced its definitive first hybrid masterpiece for 2014. The first of a very successful line.

A team running a new manufacturer's engine on its debut might also be permitted additional test days for the first year and, if still playing catch-up, again for year two, although on a reduced basis and perhaps only with the year one car. If this kind of welcome into Formula 1 is not on offer, then it's difficult to see any manufacturer coming in cold under the current power unit regulations. They have seen how difficult and expensive it has been, even for manufacturers with experience and success in previous F1 programmes.

Fit for porpoise

The most recent grand prix, at the time of writing, has been the US at the challenging COTA track. Bumpy it certainly was, and it afforded – especially in P1 – a clear indication of the difference between front-running cars and those nearer the back. Cars from two of these teams in particular were porpoising so alarmingly that they would have been more at home in an aquarium. Although they improved in P2 onwards, I almost felt sorry for the drivers concerned because it was so obvious how much harder their job is compared to those piloting a Mercedes, Red Bull or Ferrari. As for the latter's dramatic absence of pace against recent form at the start of the race and the suspension failure of Sebastian Vettel's prancing horse, had it indeed been an equestrian event there would have been rumours of the red nags having been nobbled! The innuendo, however, concerning Ferrari is about accusations of getting around the fuel flow limitation, thus dramatically reducing its PU performance, and this is typical of the F1 shark pool. Nobody made such a fuss when Mercedes were streets ahead in this respect.

But what I really don't get is that Haas' Guenther Steiner was fined $7500 by the FIA for causing 'moral injury' (that's a new one to me) to a steward by criticising him on the radio, but Max Verstappen's accusation that Ferrari have been cheating seems to have passed unnoticed by the same governing body. Without proof, as well as being defamatory, it surely must also be classified as bringing the sport into disrepute?

Mercedes apparently devoured over 50 PUs in dyno testing before it produced its definitive first hybrid masterpiece for 2014

Tomorrow's world

After many months of speculation the definitive technical, sporting and financial Formula 1 regulations for 2021 and beyond have now been released. But what will all this mean for the F1 teams and for the quality of the show? *Racecar* investigates

By GEMMA HATTON

'We don't think that speed is a key parameter for the spectacle, race-ability is the main target'

The time for speculation is over. The F1 2021 technical, sporting and financial regulations have now been released and include some of the biggest changes seen in F1's recent history.

The objectives behind this new batch of rules was to create a competitive grid filled with financially sustainable teams whose cars could battle out on track, whilst showcasing road relevant and eco-friendly technologies. A tough ask for the FIA, but one that has been supported by a wealth of research and experience from both F1 and the teams. In fact, this collaborative effort has made the research into the 2021 regulations the most in-depth to date.

Thinking cap

But what have they come up with? Well the biggest change is undoubtedly the cost cap. Each team only has $175m to play with for 21 races +/- $1m for each race above or below that. As expected, there are several exclusions to this including marketing costs, driver salaries, FIA entry fee and super licence costs, as detailed in November's *Racecar* (V29N11).

'The financial regulations are a dramatic change for F1,' says Ross Brawn, managing director of motosports at Formula 1. 'I think the crucial thing about the financial regulations now is that they are part of the FIA regulations so the sanctions of breaching the financial regs will incur sporting penalties depending on the severity of the breach. Whereas before we had the resource restriction agreement which was a gentlemen's agreement with the teams. Well there's not many gentlemen in the paddock, I'm afraid, and that was a failure.

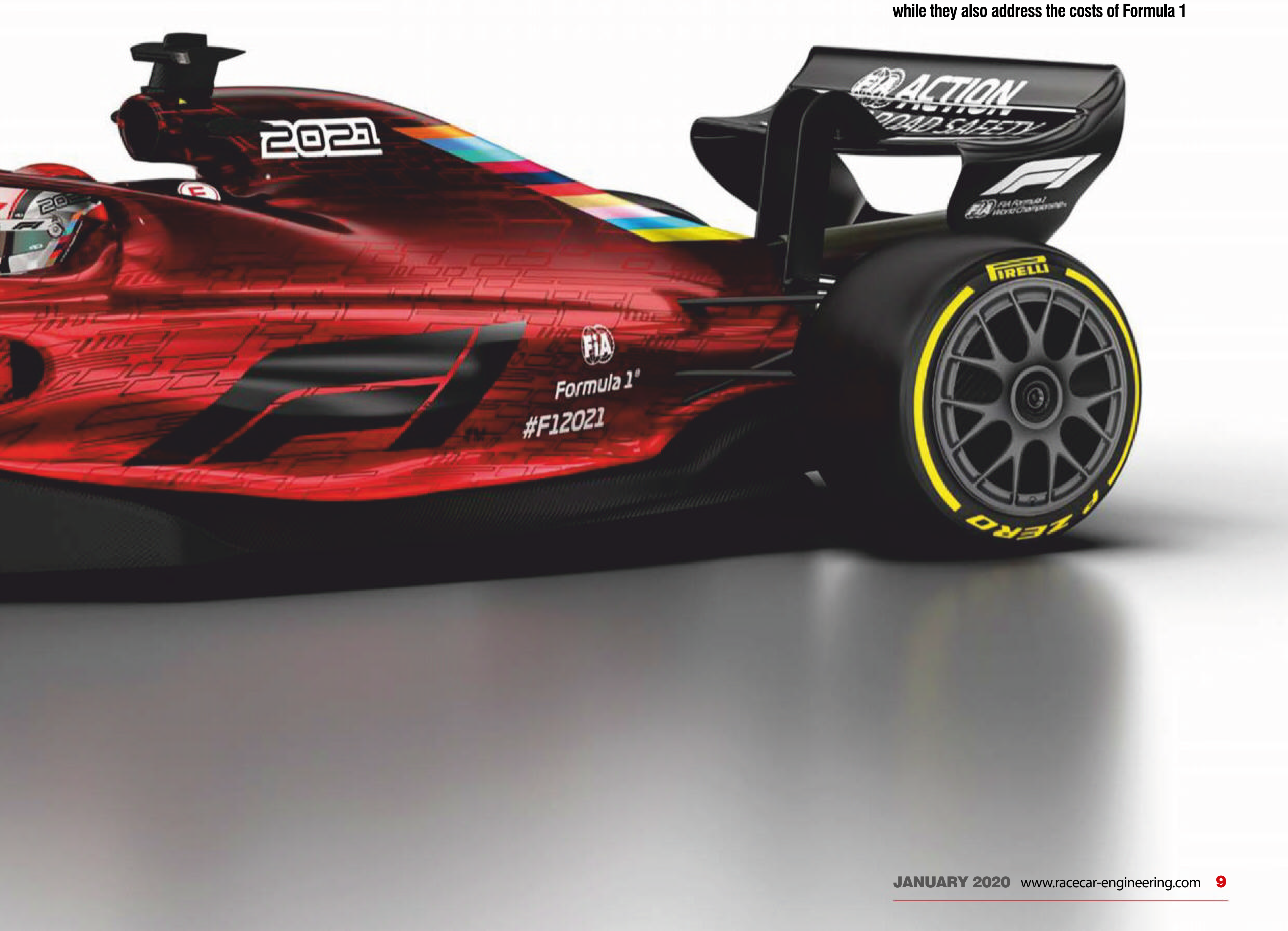
'But this time if you breach the financial regulations you will be losing your championship, so it has serious consequences,' Brawn adds. 'There are a number of exclusions; we've tried to really capture the areas where they can spend money and gain a competitive advantage so we've tried to control some of those. We've got a very strong team of financial experts within the FIA and F1 and we've also sourced outside support with Deloitte and they will continue to help introduce and develop these regulations. They've been pretty well thought out, but they will need development like any new regulations. So, I fully expect that we're going to have challenges in the future but its absolutely essential that we have control on the finances and how much we spend in Formula 1. I think it's a turning point in F1, but it won't be a smooth road.'

The specifics of these financial regulations are to be finalised by December 2019 and by 30 June 2020 the teams can voluntarily submit their 2019 data as a sort of practice run. By 31 March 2021 teams can again voluntarily submit their 2020 financial data as a 'soft introduction' to help the FIA and Formula 1 iron out any issues, and so won't incur any penalties. But, by 31 March 2022, teams will have to submit their financial data and will be subject to both financial and sporting penalties.

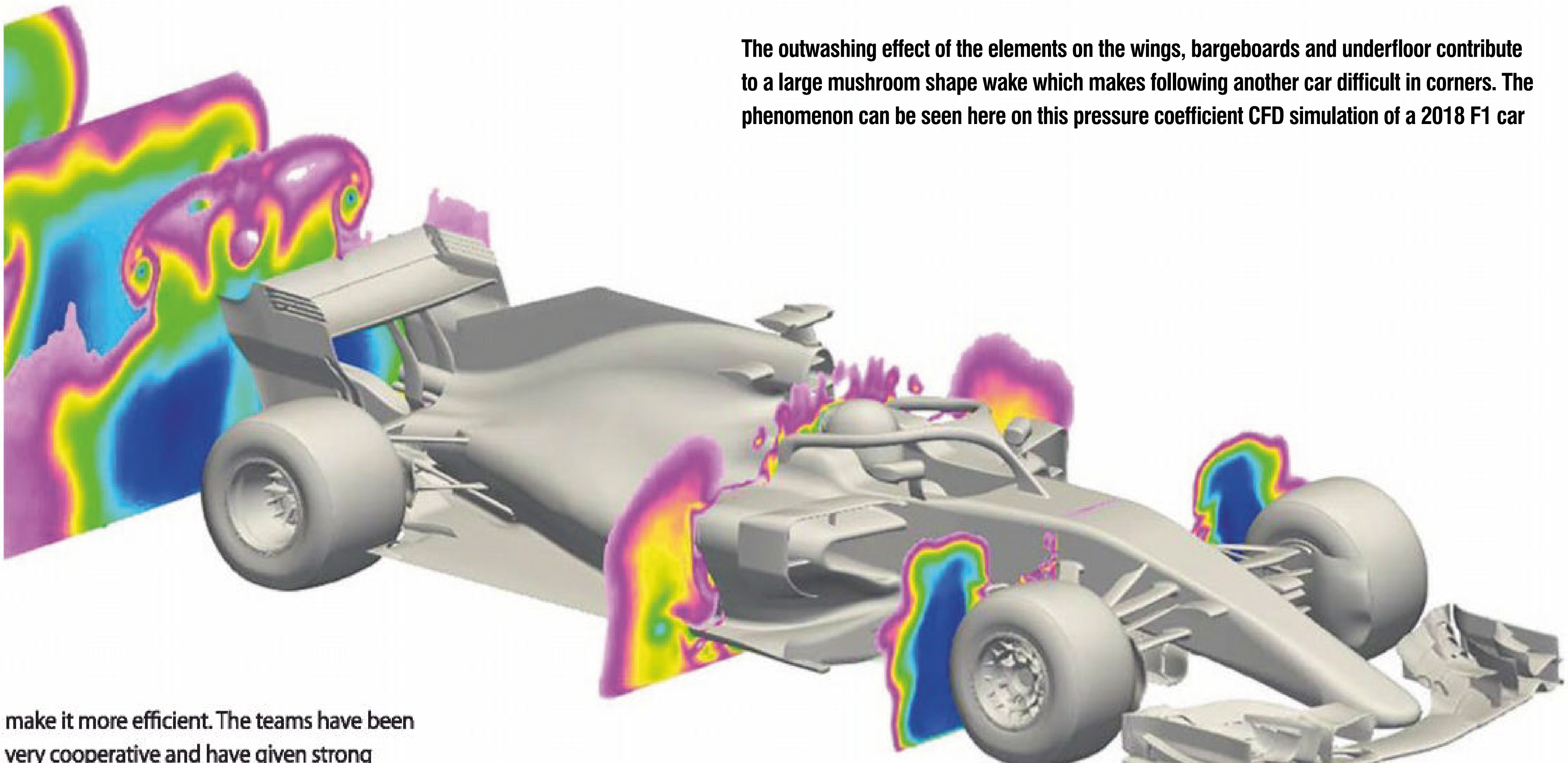
Frantic Friday

From a sporting point of view, the regulations are conceptually similar to 2019, although there are some changes. These include increasing the maximum number of grands prix to 25 and also compressing the current four-day race weekend format into three days.

'Our promoters rely on a three-day race weekend, so we're changing the format of a Friday so that all the activities that used to take place on a Thursday will now be on a Friday,' says Brawn. 'For example, scrutineering will take place on Friday morning and there will be two practice sessions, possibly shorter, on Friday afternoon. We will still get pretty close to the same amount of track time, but we'll



The 2021 regulations will mean a sleeker racecar, while they also address the costs of Formula 1



The outwashing effect of the elements on the wings, bargeboards and underfloor contribute to a large mushroom shape wake which makes following another car difficult in corners. The phenomenon can be seen here on this pressure coefficient CFD simulation of a 2018 F1 car

make it more efficient. The teams have been very cooperative and have given strong feedback that they can come to a race meeting one day later, so that's been the objective.'

Of course, this will completely change the way the Formula 1 teams approach practice sessions. Currently, FP1 is for testing aero items and other new parts, while the track rubbers in. By FP2 the track is in good condition, and the timing of FP2 is usually similar to that of the race which means ambient and track temperatures will be most representative. This is why you see all the teams complete high fuel long runs during FP2 as it is the best time to understand the performance and degradation of the different tyre compounds. Squeezing both FP1 and FP2 into an afternoon means that the most representative temperatures will be during FP1, where the track will be green and have less grip. While in FP2, ambient and track temperatures will drop off, but the track will be rubbered in. Therefore, neither FP1 or FP2 will have race-representative conditions, which will make it impossible for the teams to fully understand the behaviour of the tyres, leading to more variability in the race itself.

Reference spec

Also new for 2021 is a 'Reference Specification' which will ensure that the configuration the car is scrutineered in on a Friday will be what is raced on a Sunday. This means that teams won't be able to run with different bits of bodywork during the race, but they can test new parts on a Friday. 'The idea behind this is to stop the necessity of building lots of parts,' Brawn says. 'Currently, if you want to take a new front wing to a track, you test it and if it works you need to make several for both drivers and have spares. Suddenly you've a huge expense and you're flying parts in at the last minute to satisfy that need. So there's some sensible housekeeping being done on how we operate over the weekend to take a lot of strain off the teams.'

Currently all the aerodynamic elements you see on a Formula 1 car are not only generating downforce but also conditioning the flow

There will also be a stronger curfew, reducing the number of hours a team can work over a grand prix weekend to try and lessen the workload on personnel. Meanwhile, further limitations will be implemented on the number of dyno hours the power unit manufacturers can use and there will be further restrictions on wind tunnel time and CFD simulations in an attempt to reduce costs.

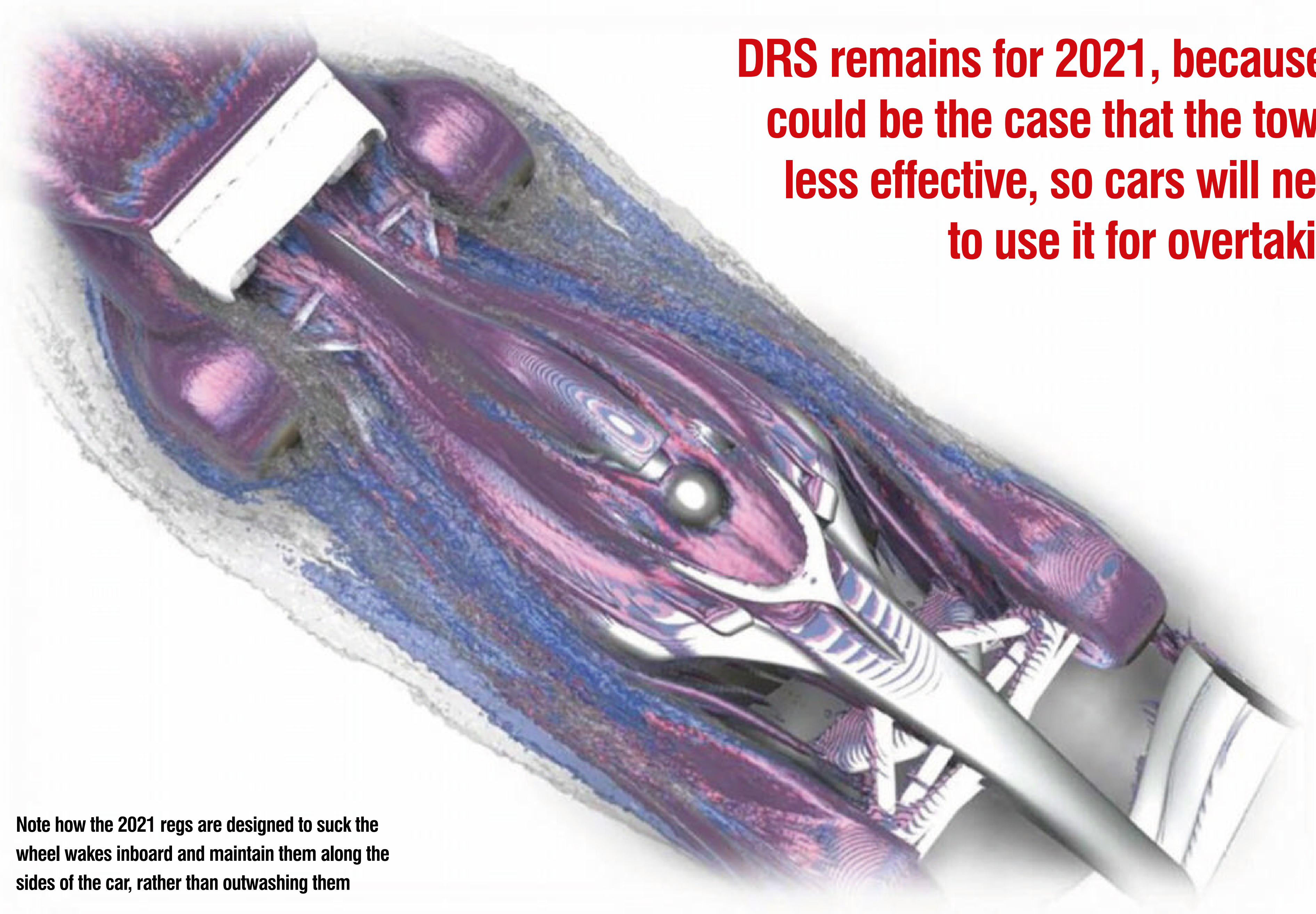
'That's been one of the success stories of F1 in the past few years; the aero restrictions that's been placed on the teams that have reduced the time they can spend in the wind tunnel and how many CFD simulations they can do,' Brawn says. 'To address the comment that there will be a massive rush [for aero development] before the 2021 cost cap comes in, I think we need to remember that the most fundamental change with this car is the aerodynamics and that's the area that is most controlled under the existing regs. So there will be no increase in the effort the teams will put into aero testing because they can't, the ATP [Aerodynamic Testing Period] controls how much work they can do in the wind tunnel [and CFD] so they won't be able to exceed those limits. They'll have to balance that time between their existing car and the new car, as they do every year.'

This segues nicely into the biggest technical changes for 2021; aerodynamics. To fully understand the reasoning behind these changes, we first need to turn the clock back to 2009. You may remember that there was a complete overhaul of the regulations in that year to improve overtaking. The idea was that the new racecars would generate around 60 per cent of the downforce that the 2008 cars did. However, the teams worked hard to recover this loss of downforce and this was achieved through exploiting the outwash effect of components such as the front wing end plates and bargeboards. By the start of the new season, the teams had already recovered this lost downforce, but the consequence was large, with wide wakes which made overtaking more difficult; completely negating the objectives of the regulations. The FIA has continuously tweaked the regulations ever since to try and combat this overtaking problem, but for 2021 it is hitting it head on.

Flow conditioning

Currently, all the aerodynamic elements you see on a Formula 1 car are not only generating downforce but also conditioning the flow. The latter is arguably more important because directing clean, laminar airflow to aerodynamic components is the most efficient way of maximising the aerodynamic performance. Therefore, the turbulent, chaotic air generated by the front wing and wheels needs to be pushed as far away from the racecar as is possible. That's why you will see complex arrangements of winglets and elements

DRS remains for 2021, because it could be the case that the tow is less effective, so cars will need to use it for overtaking



Note how the 2021 regs are designed to suck the wheel wakes inboard and maintain them along the sides of the car, rather than outwashing them

surrounding the bargeboard area and the front of the underfloor on Formula 1 cars.

When a Formula 1 car is behind another on a straight, this outwashing effect means that the wake of the lead car flows around the following car. With the lead car effectively punching a hole through the air, the following car then travels through less air, experiences less drag, increases in speed and can capitalise on this additional boost with an overtake, otherwise known as a tow or slipstream.

The problems come in the corners, where this outwashing of the wakes directs this dirty air onto the following car, reducing its aerodynamic performance, making it almost impossible to overtake. For 2021 the aero regulations aim to not only reduce the size of the wakes, but also suck this turbulent air inboard and then eject it up and over the car behind. In this way, cars should be able to follow each other closely through the corners.

Teardrop wake

Initial simulations suggest that this is indeed the case, but there is a side effect on the straights: the wake now comes onto the following car in a teardrop shape. This means that the following car will not experience a reduction in drag and so the slipstream will no longer be as effective. On the other hand, if the so called 'mushroom' wake is being ejected higher over the following car then there may still be a hole behind the lead car for the slipstream to work. This is why DRS remains for 2021, because it could be the case that the tow is less effective, so the cars will need to utilise it for overtaking.

One of the philosophies the FIA and F1 have used to reduce the wakes is to exploit the ground effect of the underfloor. The underfloor is the most efficient downforce-generating device and currently produces around 60 per cent of a Formula 1 car's total downforce.

For 2021 the current flat floor and diffuser set-up will be replaced with two venturi tunnels and a long diffuser starting at the front of the sidepod. Ground effect is a way of modifying the airflow underneath the racecar to create an area of low pressure due to its close proximity to the ground. This will be achieved by the two venturi tunnels, which are effectively a narrow tube, or tunnel, that join together two wider sections of tunnel. In this case, the front of the underfloor and the large diffuser.

The low pressure created at the narrowest section of these tunnels will accelerate the flow in accordance with Bernouill's principle. Accelerating this flow creates suction, which

These quirky winglets will sit above the front wheels to help reduce the wheel wakes, while also guiding the airflow inboard increases downforce. This will also help to draw in the wheel wakes inboard of the car and along, with the revised wing, eject the turbulent air higher up and over the following car.

'The research has been focussed on reducing the wakes to improve the performance of the following cars,' says Nikolas Tombazis, head of single seaters at the FIA. 'We've also seeked to simplify the cars, the final shapes and sensitivities in some areas, leading to lower performance differentials. So we hope that with these new aero regulations the difference between the fastest and the slowest cars will be smaller than it is currently.

'We've simplified the front wing to create weaker vortices around it to give less opportunities for the teams to control the wake of the front wheel,' Tombazis adds. 'There are no bargeboards, as currently these are massively complicated. The [2021] cars are fundamentally a ground effect car, with a long diffuser starting from the front of the sidepod going underneath and finishing at the very back. That is fundamental for the flow structures that we have been trying to achieve with this. Some areas of the car are going to be prescribed because we felt that if we didn't restrict those shapes then we would end up with teams potentially finding ways to overcome the key objectives [of the regulations].'

Follow closely

The initial results of the RANS simulations can be seen in **Figure 1**. The black line shows the loss of downforce experienced by the following car at increasing distances behind the lead car. Currently, a following racecar only has around half of the downforce of the lead car, when it is one car length behind. Even at seven car lengths behind, the following car still only has 79 per cent of the lead car's downforce. For 2021, however, at one car length behind the following car will have 31 per cent more downforce than in 2019, achieving almost maximum downforce at seven car lengths.

However, these simulations are based on a concept which has not yet been optimised by the full force of an F1 team. Therefore, as teams continue their hunt for downforce this could increase the wakes and consequently reduce the downforce of the following car.

'When teams do their aero development clearly this number will reduce a little bit but we still expect a huge chunk more performance available to the following car compared to the lead car,' Tombazis says. 'The simulations so far show that cars will be following much more closely and will be able to attack more.'

Another tactic to try and control the Formula 1 teams' aerodynamic development is to define the legality volumes by CAD. 'We have introduced a coordinate system, so a lot of legality of the cars will take place on CAD,' says Tombazis. 'We will simultaneously be taking scans of the cars and comparing these scans to

Above and left: Venturi tunnels and the large diffuser will create an area of low pressure to help accelerate flow under the racecar to increase suction and therefore downforce

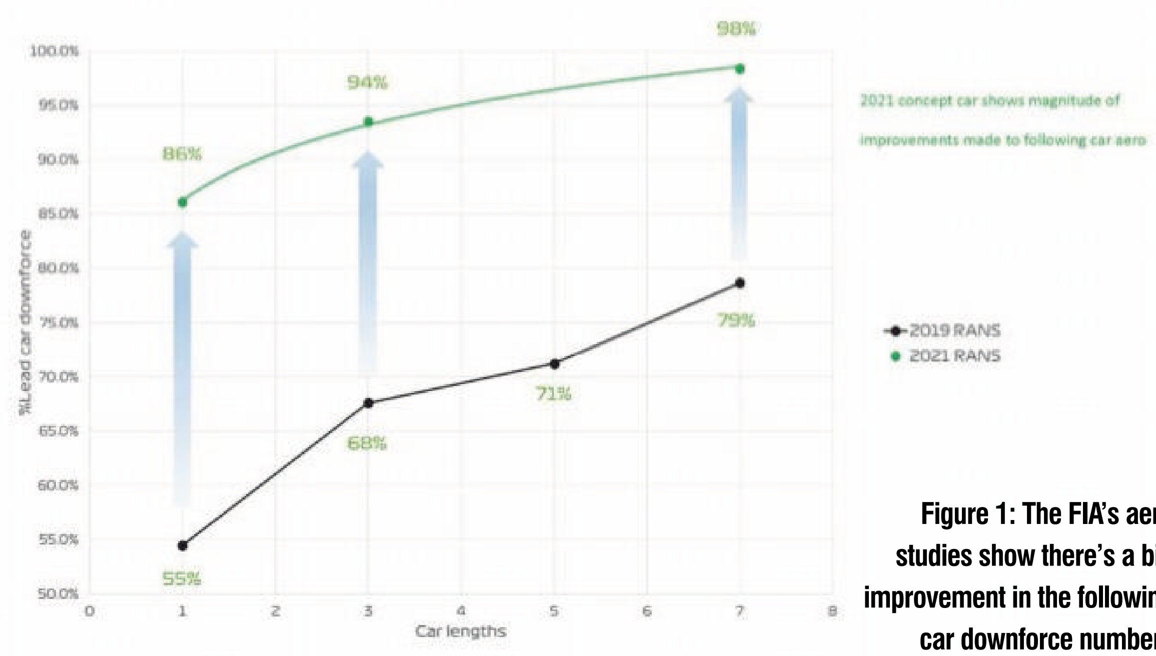


Figure 1: The FIA's aero studies show there's a big improvement in the following car downforce numbers

Another tactic to try and control the teams' aero development is to define the legality volumes by CAD

CFD simulations show the car's wake is not only reduced but is being ejected up and over the following car. Below: Rear wing end plates remain a free area

the CAD shapes to ensure the cars are legal in all aspects of the regulations.'

With such tight control you may be wondering how on earth we'll be able to tell the cars apart? Well the FIA has assured us that there are numerous areas of differentiation, including the nose, front wing and end plates, engine air intake, sidepod inlet and overall shape, brake ducts and rear wing end plates. So visually the cars should still be quite different.

Power addressing

The power unit was originally pitched as another big change for 2021, however this is now not the case. 'It's true, we did start with more ambitious plans to change the engine and in a way I'm glad we didn't because I think it has enabled us to change our focus,' Brawn says. 'We've all seen the increasing concerns of the environmental impact of the things we do and I think refocusing the engine suppliers on how we contribute to the solution we need to find for the future is very important. I think all the manufacturers know it's not a single answer; electric cars are one part of the solution, but also finding fuels which are sustainable and renewable is another part. There are a billion fuel powered cars on the planet and we're not going to get rid of them in two years, so we have to find other solutions and I think F1 can be a really strong figurehead in that. So, in a way I'm glad we didn't change the engines that much because we're now [giving] the power unit suppliers [the opportunity] to provide solutions to that problem.'

The 2021 power unit is, then, largely carried over from the current regulations, along with the MGU-K and the MGU-H, but with many more cost-driven initiatives. These include simplifying particular components, restricting the use of exotic materials and introducing some non-exclusivity clauses which prevent teams from purchasing turbochargers from suppliers which are exclusive to that team.

The fuel system will be much more prescribed with standard high pressure and primer pumps, piping, fuel flow meter, collector and several internal components. The fuel itself will have double the renewable content, at 20 per cent, and for 2022 onwards the FIA has committed to an ambitious roadmap to increase renewable fuels, which the power unit and fuel suppliers will work together to achieve.

'The reason we kept the same power unit in the end was also to do with the fact that we have the most efficient engine on the planet in terms of what percentage of energy consumed as fuel actually gets transmitted to the wheels,' says Tombazis. 'So we felt that any change we would have made would have taken a step backwards and that is the wrong direction to go.'

Safety drive

Safety has been another focus of the 2021 regulations. A rubber membrane will be incorporated into the carbon lay-up of some components in an attempt to try and contain the sharp debris resulting from any bodywork damage. The frontal energy absorption of the nosecone will be increased by using a longer nose, while the side strength of the chassis will be improved, along with a more comprehensive side impact structure. The headrest and how it is attached to the chassis will also be improved and some parts will now be tethered to the rear of the car to avoid detachment during an accident.

The result of the standardising of the power unit, along with the increased safety, plus the move to 18in wheels, is an increase in the racecar's minimum weight from 743kg to 768kg. 'This is not an attractive element of the 2021 car, but it is a consequence of the safety and the hybrid power system we have implemented, which is essential,' says Brawn. 'We did look at if there were any significant ways of reducing the weight of the car and we haven't found any that wouldn't have been a massive reversal of where we are today.'

This weight increase will mean that the cars will be approximately 3.0 to 3.5s slower per lap than currently. 'We don't think that [speed] is a key parameter of the spectacle, race-ability is the main target, so we haven't been focusing on the overall level of performance,' Tombazis says.

Brawn agrees: 'To put that into perspective that's the performance of a 2016 car,' he says. 'Remember from 2016 to 2017 there was a huge increase in downforce. It's worth thinking back on that experience. It was done for reasons that I don't understand because the huge increase in downforce was to make the cars go faster and make F1 better but all we've done is actually make it worse because the cars can't race each other. It's an example of rules that haven't been thought through. The cars are very quick now but they're not raceable and the reality is that the performance of these new cars are going to be where we were in 2016, which I don't think anyone was complaining about.'

Frozen too

Moving rearwards, the transmission has been a key focus area for cost reduction. This was originally going to be achieved through a tender. However, the FIA has now decided to instead freeze the transmission spec for several years, with teams allowed to do a complete re-design every five years.

'We have analysed the cost that teams incur and have found that a large proportion of costs is really the R&D that gets carried out from one year to the next for marginal gains which we don't feel add anything to the sport,' says Tombazis. 'So we have created rules that freeze the transmission spec for a number of years. Teams will still be able to use their own designs but will have to keep the transmission within certain volumes. In this way we feel that the transmission as a performance differentiator between cars will not play a significant role.'

Another area that's been simplified is the suspension. Hydraulic suspension is now banned, along with inerters, while the inboard elements of the suspension such as the springs and dampers will be far simpler. Restrictions on kinematics will also be in place and the outboard suspension points will now be inside the volume of the wheel rim.

Of course, the new, larger, 18in wheels and tyres will have a significant effect on the suspension design. Especially as the tyres will be low-profile so there will be much less suspension travel within the tyre itself, therefore more suspension travel will have to be incorporated elsewhere in the system.

Regarding tyres, there was lots of hype earlier in the year about Formula 1 doing away with the tyre blankets for 2021. However, this has been postponed until the end of 2022, although the number of blankets and temperatures will be reduced for cost savings. Meanwhile, the construction and compound of the tyres themselves will be completely redesigned for 2021. The testing programme for this has already started with several of the Formula 1 teams running 18in wheels, and this will continue throughout 2020.

'In fairness to Pirelli, they have had so many diverse inputs to what has been demanded from them,' Brawn says. 'They have been struggling to have clarity on what they should focus on. For a long time everyone was telling them we need tyres with high degradation and lots of pit stops, which created tyres that were thermally fragile so the drivers couldn't push. Now with the FIA, teams and drivers we've had a much better process to try and identify what we need to aim for. We still want to have a reasonable number of pit stops, but we're changing the objectives for Pirelli and giving more clarity on what F1 really needs and I think they've been responding quite well.'

Brake clause

In terms of brakes, the larger wheels can accommodate a larger disc, which will increase from 278mm diameter to 330mm. The geometry of the discs will be simpler with fewer ventilation holes of larger diameter. Again, a standard brake system was expected to come in for 2021, but this will be delayed until 2023.

Talking of standardisation, for the first time ever in the technical regulations components are now classified into five different categories. 1) Listed Team Components (LTC) – made by each team; 2) Standard Supply Components (SSC) – single supplier chosen via tender, currently wheel rims, brake discs and tyre blankets; 3) Prescribed Design Components (PDC) – design is owned by the FIA but teams can manufacture it themselves; 4) Transferable Components (TRC) – parts that can be transferred from one team to another such as the transmission; 5) Open Source Components (OSC) – parts where teams submit their designs to a server and a rival team can make a component based on that design.

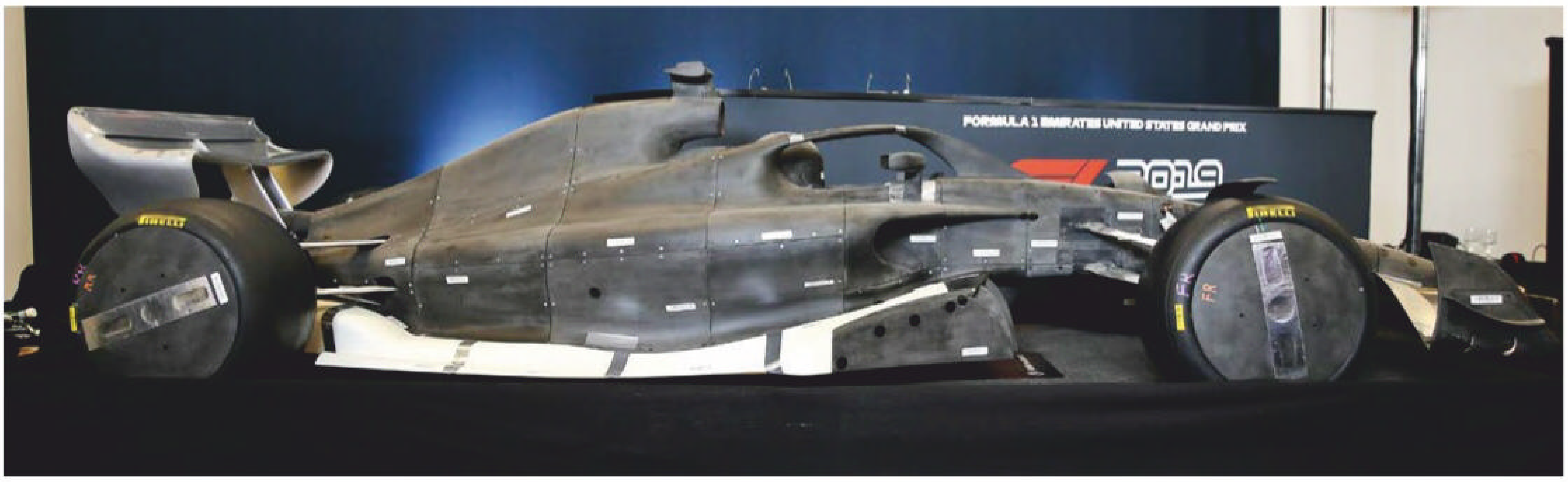
'[Open Source Components], are not critical areas of the car,' says Tombazis. 'These are relatively small details that teams spend a lot of resource on trying to redesign each year for maybe a little packaging advantage or weight advantage, so we don't feel we're altering any DNA aspect of F1 by making these components more widely spread across the grid.'

Golden rules?

Whether you agree or disagree with the finer details of the 2021 regulations, overall you have to commend the effort that has gone on behind the scenes to try and establish a set of regulations that will improve the race-ability of the Formula 1 cars and hence, hopefully, improve the show. Also encouraging is the fact that F1 and the FIA will continue to refine and develop these rules with every new piece of information, data or study that is conducted.

'One of the things which we have built collectively over the last two years is a lot of simulation models to understand how cars race each other and what the important elements are,' concludes Brawn. 'The governance has to be a better balance of stability for the teams, with the ability to make developments when they're really essential. The priority of F1 and the FIA is to make the sport as great as possible, we don't have any other objectives, so when it comes to changes that are going to happen in the future, it's all with those principles in mind.'

The construction and compound of the tyres will be completely redesigned for 2021



The 2021 cars will feature 18in wheels. Covers will also be used so teams will no longer be able to blow air through the rims for tyre heating, or to force the wheel wakes outboard


ASTON MARTIN
Red Bull
RACING
ASTON MARTIN
Red Bull
RACING
ASTON MARTIN
Mobil 1
Esso
Synergy
RACING FUEL

‘It’s part science and part art, in the sense of understanding how the differences will react in the combustion chamber’

Special brew

Before Honda introduced its new Spec 4 RA619H F1 power unit at the Japanese Grand Prix Red Bull’s fuel partner had to formulate, produce and deliver a bespoke blend of Esso Synergy for it to run on. ExxonMobil’s technicians talked us through this fascinating 13-week process

By DIETER RENCKEN

Honda debuted its Spec 4 RA619H F1 power unit at the 2019 Japanese GP. ExxonMobil's chemists had to concoct a fuel blend that was just right for the new PU in a limited time

Formula 1's increasingly restrictive regulations have effectively blocked off loopholes of the type that once enabled engineers to find two seconds per lap (or even more) simply by varying the shape of underbody venturis.

Thus, improvements are eked out in incremental steps measured in tenths (or even hundredths) of a second, with virtually every area of a car coming under constant scrutiny in the hope of finding a number of tiny improvements that collectively deliver that elusive magic second. Over a season teams generally improve by around two seconds, equating to 20 or so of these tiny steps.

Although the historic focus has primarily been on aerodynamics, a new battle front has recently emerged: relentless power unit development, and hand in hand with this bespoke fuels that optimise internal combustion engine performance. However, as with the aerodynamic regulations, stringent restrictions on the formulation of fuels also apply.

'It's actually quite restrictive,' says David Tsurusaki, global motorsport technology manager for ExxonMobil, which is Red Bull Racing-Honda's fuel and lubrication partner. '[The fuel has to comprise] components that are used in commercial fuels, at least at some time, current or in the past, anywhere in the world. Someone has to have used it in a commercial blend. You can imagine, in all the years of fuel formulations, lots of different blends have been tried and lots of variations of things have been tried, and usually it's a combination of things that haven't been tried.'

Pump action

Article 19.1.2 of F1's current technical regulations demands that 'fuels are composed of compounds normally found in commercial fuels' and further prohibits 'the use of specific power-boosting chemical compounds', with additional clauses defining the acceptable compounds and their classes.

Where, for example, the 1961-65 Formula 1 regulations demanded only that 'Commercial fuel specified by the FIA be used', the full Article 19 that governs all things F1 fuel runs to almost 1200 words – over half the length of this feature – spread over seven paragraphs, mostly with sub-paragraphs, which vividly illustrates the constraints, and thus challenges, faced by ExxonMobil's fuel formulators.

This 'commercial' clause holds the key to the relative affordability of F1 fuels, for by definition only what Tsurusaki refers to as 'affordable molecules' may be used. It stands to reason that commercial blends would not include exotic ingredients such as constituted F1's 'rocket fuels' used during the turbocharged era in the 1980s, which were allegedly developed from fuels used by V2 ballistic missiles during WWII.

Tsurusaki says: 'It's not necessarily the availability of [a specific] component, it's the development of the fuel just for the combustion of that engine. That's what makes it unique. So it's not necessarily just the fact that you have come up with something new that has never been used; it's the fact that you have got the combinations of something that fits very, very well with that engine.'

While the sport's governing body, the FIA, is responsible for F1's regulations, the Formula One Fuels Advisory Panel, a consultancy group comprising all major fuel suppliers, provided input to ensure a modicum of road relevance and that costs are contained by mandating 'everyday' components.

As with the aerodynamic regulations, stringent restrictions on the formulation of fuels also apply

Chemistry set

Thus, the permitted 'combination' of components consists of strictly controlled aromatics, olefins, di-olefins, and styrene and alkyl derivatives, with the regulations currently mandating a 5.75 per cent bio-components quota, with the last-named expected to increase

A Formula 1 team will typically use 750 litres of fuel during a race weekend with both cars across all track sessions, equating to around 15,000 litres during a season

David Tsurusaki (centre) pictured with Red Bull's Paul Monaghan (left) and Honda F1 boss Toyoharu Tanabe

substantially over the next five years (see box out). Colorado-based chemical company Gevo currently supplies bio-derived iso-octane substances to all the F1 fuel suppliers.

'That engine' referred to by Tsurusaki above, is the Specification 4 Honda RA619H, which draws on turbine technology from Honda's HF120 jet engine, used in the six-seater HondaJet HA-420 light business aircraft. It was introduced for the Japanese Grand Prix, effectively the home race, at the Honda-owned Suzuka circuit, for the engine supplier to both Red Bull teams; Red Bull Racing and its sister Scuderia Toro Rosso. No pressure, then.

'The new fuel that we introduced in Japan was one of two fuels we were working on for upgrades,' Tsurusaki explains. 'And we actually had a mid-season upgrade planned and ready to introduce, but, as we were working on that, the objective then changed to one of, "let's concentrate on fuel number two".'

ICE sculpture

The process began at Honda's Research and Development base in Sakura, Japan, where engineers developed the Specification 4 power unit, in turn advising Tsurusaki's team of the internal combustion engine's data points.

'They give us the data with the current fuel on the Spec 4 engine, and then we have a good understanding of where our starting point is,' Tsurusaki says. 'You are looking for more power, you are looking for reduced lag; you are looking for all the positive things you can get out of it. So then you try to design the fuel for the new spec, [in this case] the Spec 4 engine. So, it's really a further tweak of what you had, but you try to make it that much better.'

Honda's data points were in turn provided to ExxonMobil's team of two fuel formulators situated in Clinton in New Jersey, both having extensive experience in formulating Formula 1 blends. They in turn have access to advanced-research chemists. This multi-step process starts with a matrix of different fuels, each one of which varies slightly from the other, displaying incremental differences.

'The formulators try to create a matrix of what the variations will look like. Obviously, that's a key part of it,' says Tsurusaki. 'It's part-science and part-art, in the sense of understanding how the differences will react in the combustion chamber. So that may end up [with], say, six fuels, and you may end up

ExxonMobil also supplies Red Bull's sister team Toro Rosso. All fuels must be made up of component chemicals that at some time have been used in a commercial blend

The shipping process is every bit as complicated as formulating the fuel in the first place

with an upper-left hand corner [of the matrix] or a right-hand corner that's the best: highest performance, best protection, least knocking. Then [you] pinpoint the one that seems to be best in all categories. Then there's maybe a slight tweak to that last one, which may take another two or three steps.'

Once a matrix of blends has been formulated, the actual physical blending and pre-testing is all done in the UK before the fuels are shipped to Sakura for single-cylinder engine testing, a process that takes around a week over six cycles of different blends.

The next job is to ensure the selected Esso Synergy superbrew is totally compatible with the Mobil1 lubricant that is specified for the engine; if not, a new lubricant needs to be developed. 'That's just as important, and often you're modifying the lubricants [at] the same time [as] you're modifying the fuels,' says Tsurusaki. 'Because every time you make a performance change in the spec of the engine, it changes the demands on the oil.'

Once the single-cylinder tests are completed and the final fuel formulation is approved, full six-cylinder dynamometer testing commences, with the engine typically being subjected to six or seven full grand prix simulations. Simultaneously samples of the final blend are submitted to the FIA for both approval and building of the gas chromatographic fingerprint against which to check future batches.

Ship of fuels

The entire process will have taken around 13 weeks – from data point to race readiness of the formulation – and then the fuel needs to be shipped to whichever event will see the debut of the new specification power unit, in this case the Japanese Grand Prix. However, the earlier specification fuel will also be shipped as fall-back, just in case the team decides to delay introduction of its latest engine for some reason. 'We are allowed two fuels on site at one time, and I think you can do [up to] five formulations in a year,' Tsurusaki says, adding that submission of approval samples to the FIA is unrestricted, but that 'there is an expense involved'.

Thereafter the shipping process commences, a task which is every bit as complicated as formulating the fuel in the first place, for not only are there restrictions on airfreighting of hazardous materials, but utmost care needs

Lubricant sampling. The fuel needs to be totally compatible with the oil that's used in the PU

ExxonMobil has its own lab in the Red Bull garage. Here Dario Izzo examines a sample

Getting Formula 1 fuel to the track is a delicate business; the utmost care must be taken to make sure it's not contaminated

'There is a cleaner chemistry that goes into fuel making these days, not only for the environment but for the people working with it as well'

to be exercised to ensure that the fuel is not contaminated in any way. A stray drop of water could cause it to fail FIA fingerprint tests, with a penalty of exclusion even if the fuel is found to be totally within specification.

'Our duty starts with coordinating with our teams about how much they need of each [specification], says Sean Dunnett, ExxonMobil's F1 technical advisor. 'Then, our assistants at [F1 contracted freight forwarder] DHL, ship that amount to each event, and add some extra.'

A team will typically use 750 litres during a race weekend with both cars across all track sessions – equating to around 15,000 litres used by both cars during a season, or 150,000 litres across 10 teams. Yet F1 consumes almost a million litres per annum, six times actual race weekend usage, illustrating just how much dyno testing is undertaken by PU manufacturers.

'When it arrives at the track, we will check and re-check every single drum,' says Dunnett. 'We have machines down here that basically split all the different compounds in the fuel to check density and any contamination that it might have got during the journey.

'Our fuel has a lot of very volatile components and if drums have been damaged in the journey, there's a chance [some components] could have escaped,' Dunnett adds. 'So, we're looking on this machine to check they're all in there in the right concentrations. And then when it's out into the car that the FIA isn't going to find anything untoward with it.'

Handle with care

Although ExxonMobil prefers to sea-freight wherever possible, inevitably some supplies are airfreighted on hazmat [hazardous materials] flights that transit through airports with applicable licenses, while road transportation within Europe is via an assigned DHL driver, who shuttles between a designated depot and the circuit. At the track all fuel is stored in an off-site lock-up facility, to which only DHL and the on-site ExxonMobil chemist have access.

All drums are sealed and resealed using single-usage tamperproof seals, thus flagging up any unauthorised opening, while all the storage facilities and the equipment also have anti-static protection. Dunnett also highlights up another recent development: 'cleaner' chemicals that present less of a danger to personnel and the environment. 'As with any fuel, Formula 1 fuel is not a particularly nice substance. Race fuel no more so than a road fuel, but it's got a lot better,' he says. 'If you go back, say 20, 30 years ago, it was really nasty stuff. It had lead and sulphur in it, and other compounds. Technology has moved on so much so that you don't have to rely on these nasty chemicals anymore. There's a lot cleaner chemistry that goes into fuel making these days. Not only for the environment, but for the people working with it as well. So, I think probably we're at an all-time high as to how clean the fuel is; the chemicals that go into it. I think it's because the chemistry and the understanding of fuel development is there now that you don't have to rely on these old chemicals.'

Winning formula

Honda will, of course, develop Spec 5 (and beyond) power units during 2020, and so the entire 13-week fuel development cycle will continue as the manufacturer and its fuel/lubrication partner eke out the tiniest improvement in the never-ending quest for lap time and, by extension, victories – the only true arbiter of performance improvement.

Ultimately, though, the lessons learned in Clinton by a compact team of chemists as they mix and match a matrix of commercially available ingredients to create world-beating Formula 1 formulations will eventually trickle down to the forecourts of the world, with road users benefiting from cleaner, denser fuels that are also safer to handle.

Natural selection

The next big challenge that awaits ExxonMobil's fuel formulators is delivering on Formula 1's recently stated objective of 100 per cent bio-fuels by 2030. This is all part of F1's new sustainability project, one of the pillars of this being net zero carbon racecars powered by hybrid engines running on fully sustainable, second-generation bio-fuels that do not divert farmland or crops to the detriment of the food supply.

Thus, Formula 1 will phase in bio-fuels over the next decade, having given power unit manufacturers a commitment that they will not be required to substantially modify their existing internal combustion engines until 2025. The first step will be an almost-doubling of the existing bio-fuel content from 5.75 per cent – achieved through the use of iso-octanes – to a 10 per cent ethanol content and steadily upwards thereafter.

Symonds believes in a bio-fuel F1 future

'Initially we said, "What we should probably do then is try and go up to 20 per cent in 2023,"' F1 technical director Pat Symonds says. 'But our thinking at the moment is that that's not aggressive enough. Our thinking is that we really ought to say, "Our target is 100 per cent, how soon can we get there?" We don't know the answer to that question yet, but that's where our work is going [towards], into seeing what we can do beyond 2021.'

Challenging Formula E

The end game is to challenge battery electric vehicles (BEV) in the sustainability stakes, think Formula E, cars which Symonds reckons are great at displacing pollution but have limitations. 'Our view is if you could get to a net zero carbon fuel in a highly efficient hybrid engine, it needs to be highly efficient because these fuels will always be slightly more expensive than digging it out of the ground. So, you need to use less of it. In '24 we target better efficiency, [and] I think then you have a very real challenge to full-electric vehicles,. One of the great things about a BEV is that it displaces the pollution. You don't get the pollution in the city centre, and that's a really good thing. It means that battery electric vehicles absolutely have their place in society.

'But when it comes to needing high-energy content trucks, trains, things like that – let's say aircraft – you still need a liquid hydrocarbon fuel because of the energy density in those. Current fuels [contain] about 43 megajoules per kilogramme. That's an awful lot of energy you can get out of fuel. And if we can start to convert that at a rate of 60 per cent, which is my next target, you're starting to have a very, very viable [alternative].'

The first formal step was to consult with the Formula One Fuels Advisory Panel (FOFAP) to determine the way forward, and a meeting was held in the summer. FOFAP is supported by the FIA, but members are cautious about being seen to be acting as a cartel, and thus restrict their input to matters technical. 'Each fuel company has different sorts of objectives and things and there was some variation in what they are going to do,' says Symonds. 'Some are very, very keen to get involved with low-carbon fuels, others feel that the road car industry won't necessarily go that way, and therefore they were a bit more cautious.'

Cautious or not, one thing is absolutely clear: F1 does not wish to be overshadowed by Formula E in the sustainability stakes, and this competition between them can only benefit future transportation technologies.

Remote control

Formula E is looking to escape the confines of city-centre tracks with its new take on electric motorsport, Extreme E, which is set to compete in Arctic, desert and jungle wilderness locations in 2021. But how do you build an EV that's able to race in such hostile environments?

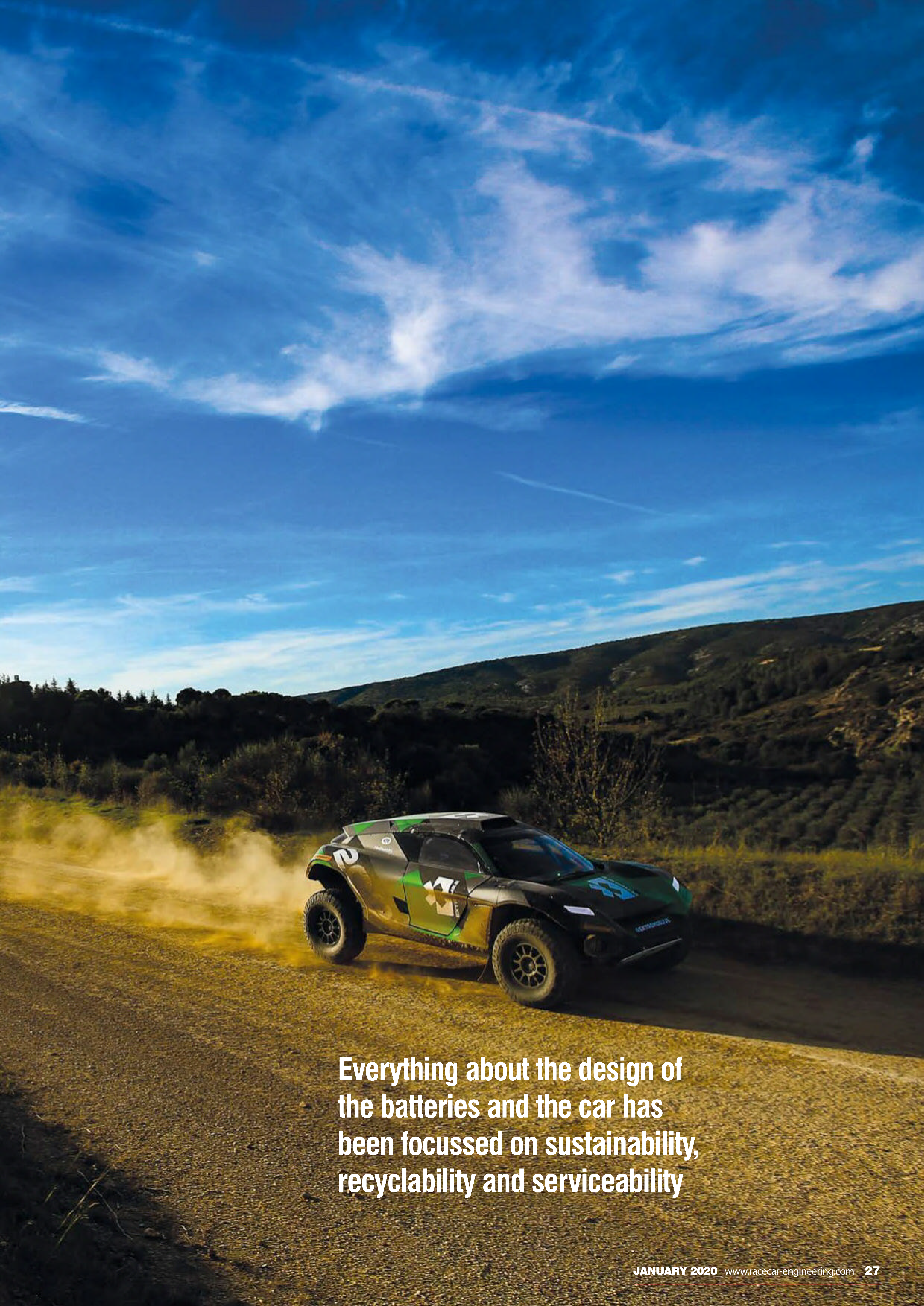
By ANDREW COTTON

Since its inception in the autumn of 2014 Formula E has grown rapidly. But while it has been an engineering challenge and has led to great advances in battery and motor technology, the series misses the history that established racing series have. What Formula E has done, however, is to normalise electric racing.

Now, though, is the time to build the back-story, and there are a few proposals out there to do so. One is Stephane Ratel's idea to go back to the grass roots of racing and compete in rallies from town to town with exotic electric vehicles. The other is rather more radical; to take electric cars to remote locations and rally them off-road. This is Extreme E.

Everything about this new electric championship is, in fact, suitably extreme, from the locations such as the Arctic, in rainforests and deserts, to the teams' base, which is a mother ship which will house the cars between events – the RMS St Helena has been selected as it offers vastly reduced carbon emissions compared to the more traditional air travel used by motorsport.

Spacesuit Media/Shivraj Gohil



Everything about the design of the batteries and the car has been focussed on sustainability, recyclability and serviceability

The designers of the Odyssey 21 have made sure it's ready for anything, which means plenty of suspension travel

This series has two main functions; one is to raise awareness of climate change by bringing the eyes of the racing world to the remote locations, the other is to shine a spotlight on electric technology and its versatility, in that it can actually work in these environments. As such, everything about the design of the batteries and indeed the car has been focussed on sustainability, recyclability and serviceability to allow teams to compete, and bring this environmental message to the racing audience.

As with all new start up series (it begins in 2021), the regulations have to be carefully designed and they remain a work in progress, which has presented the engineering teams the opportunity to shape them accordingly.

The Odyssey 21 car comes from Spark, the company that developed the first Formula E chassis, and Williams Advanced Engineering, which created the first battery for the street circuit-based electric series, will provide the battery for Extreme E. Together, they have created a package that will deliberately bring EVs into hostile environments. As a result, the challenges that will be faced by the teams have had to be anticipated by the product suppliers.

'Formula E exists in a clinical environment of the race track and white room where batteries can be diagnosed with faults or upgraded, serviced and repaired,' says Glen Pascoe, principal design engineer at Williams Advanced Engineering. 'One challenge of Extreme E is that there is no clean room in the middle of the jungle. Thankfully, at Williams Advanced Engineering we have teams with experience of rallying, Dakar and other forms of motorsport, which we can leverage and apply to battery design as a result of their real world experience. And often solutions don't need to be as complicated as might first appear.'

Extreme sports

When Formula E promoter Alejandro Agag approached Spark Racing Technology to create a chassis for Extreme E, it was with a clean sheet of paper, with no pre-conceived ideas of what the car should look like. 'We did a benchmark on what was state of the art in rally raid, so we looked at Dakar and tried to pick up the best from everywhere,' says Pierre Prunin, development engineer at Spark. 'Because we have no regulation so far, we are writing our own rules, this championship is not FIA yet, so we can have, for example, as much suspension travel as we want, and we went a bit crazy.'

The solution that Spark found was to use the maximum suspension travel allowed for a two-wheel drive car in rally raid, and it then applied that to the four-wheel drive model. 'Obviously you can have more travel than a traditional Dakar car, so [it] will have huge ground clearance, we will have four-wheel drive,' Prunin says. 'As the front and rear motor are the same, but not physically linked, you can do a lot of interesting stuff on the torque distribution, for example. And this is one of the things we looked into.

'Another important aspect for us is that we wanted to get something reasonable in terms of cost, and try to be as sustainable as possible,' Prunin adds. 'So we designed the whole car in a clever way, so the front and rear powertrain are identical, so you can swap them easily and need fewer spare parts. Even the front suspension is all symmetrical with the rear, so you could have the front left suspension on the rear right. The brakes are all identical, uprights and so on, so the logistics are much simpler for the teams.'

The Spark team opted for a steel tube frame chassis which, while it is not up to the same strength or weight of a carbon tub, was selected for serviceability. Whatever safety aspects could be transferred from Formula E have been applied to Extreme E, including side intrusion panels.

'Chassis-wise, safety mass and costs are always big challenges, but additional to these we have a logistical challenge because the teams will be limited in terms of resources, in terms of the number of people in the team, so

There are still no clear regulations on the length of the stages, and the different terrains will offer up varying battery demands

The battery will need to operate between the temperatures of -30degC to +40degC

The Williams Advanced engineering battery can produce over 400kW at peak power and has been designed to cope with the extreme conditions

five including the driver, and they will need to be able to repair the car and change parts with a very limited number of tools,' Prunin says. 'Everything needs to be simplified. When we were testing, we were trying to replicate these kinds of conditions [with] a limited number of people working on the car and not go crazy. It is a big change, coming from the circuit where in Formula E the teams are 20 people or more to operate one car.'

Batteries included

The battery design had the same clean sheet of paper approach as the chassis. There are still no clear regulations on the lengths of stage, and the different terrains will offer up different battery demands, so Williams Advanced Engineering has worked hard with the series organiser in order to spec the battery.

'Are [the cars] able to do a 20km stage in some of these places, or is the location so remote, so dangerous or unpredictable, that we do a 1km stage and go around it three or four times?' asks Pascoe. 'We have rough vehicle targets. We know what they should weigh, and what proportion of that [weight] we can allow for the rechargeable energy store, using the existing knowledge in lithium ion technology and cell selection, and seeing what technology is available. Are you going for high-power cells, commercially available energy cells, for example? You have different price points you have to feed back into the budget, what will the car cost, who will buy or race this car at that price point? And you work through the issues and refine the concept. There have to be some bookends. You can say five minute stages is too short, or 25 minutes is too long and people will lose interest, so you have to find something with a multidisciplinary view on what is going to create ultimately the greatest awareness about climate change. That is what we are doing.'

What Williams Advanced Engineering came up with was a battery that can produce over 400kW at peak power, and continuous power on a par with the Formula E battery. As yet there is no limit on the amount of energy or power that the battery can use by regulation, but that will come more from the sporting side of the regulations. Williams Advanced Engineering had to cater for the extreme conditions when specifying the battery requirements and pare that back according to demand.

'Generally, you want a bit of head room in the selection of components, but for motorsport that is redundant material that you don't want to carry around,' says Pascoe. 'We have done a lot of simulation and pre-design work with tools and techniques that have been honed over the past five or six years to understand cell selection, duty cycle, and how you use the battery. The nice thing is that we have a product that can combine the high intensity, high power, and still drive off that boat and get to the event.

'When it comes to the design of the pack, the normal usage scenarios need to be redefined,' Pascoe adds. 'With Extreme E there are a high number of unknowns. We need to factor in additional scenarios such as the cars operating whilst immersed in water, for example, or unusual *g*-loadings. A far higher number of scenarios need to be considered'.

Extreme heat

One of the key demands on the battery is heat management, and Williams Advanced Engineering had to work hard to create a solution that would work in extreme and remote conditions. The battery will need to operate between the temperatures of -30degC to +40degC, cope with moisture and water ingress, and also cope with extreme vibration and high anticipated crash loading following jumps. The sealed unit needs to be protected from sand and dust, as well as ice and snow. In a bid to reduce the energy intense nature of cooling a high power battery, an alternative to using dry ice and chilled fluids has been developed by Williams Advanced Engineering.

'Cells generate waste heat proportional to current or pack power,' explains Pascoe. 'Throughout the stage we expect the temperature of the pack to increase, due to the cooling power not meeting the thermal power input. Balancing this thermal requirement with state of charge, so that both are synchronised and optimised, means reduced pack mass, materials usage and packaging volume. Once the state of charge is depleted, the rest is recharged, but this phase also generates heat, so charging is limited until the thermal state is managed. Williams Advanced Engineering has studied the use of ambient air conditioning combined with very high thermal conductivity

HWA is one of four teams already signed up for the debut season of Extreme E in 2021. The off-road series is to visit Greenland, Brazil, Nepal and Saudi Arabia, with other locations yet to be announced

Extreme E will test the limit of what can be achieved with an electric car, and will change the perception of both battery design and EV capability

components inside the battery pack. A considerable design effort has been made for optimal heat transfer through the pack and we are expecting to see a higher heat exchange within the pack to aid air conditioning.'

Seal of approval

There is still much to consider with the pack, though. 'You start with understanding what the conditions are going to be and challenging where the current battery technology will work and where it won't work,' says Pascoe. 'Quite a lot of the direction of the battery design has been in the sealing of the unit, and improving the way it is sealed to the external environment. But with the innovative cooling method, where ambient air is introduced, the conditions inside the battery must be carefully monitored to maintain the required performance levels within the pack. This may require a further conditioning cycle that dries the air and filters it. In essence, we are considering not just what the environment is like inside the battery, but also what we want it to be like; treating the air as part of the conditioning scheme.

'Quite a lot of the packaging volume inside the battery is not as dense as you might find in a typical track application of this battery technology because operating at altitude there is a voltage resistance breakdown which is lower at higher altitudes, so we have to ensure there is a larger gap between everything that is of differing potential,' Pascoe adds. 'That is one of the key considerations inside the battery and is a different approach to Formula E.'

Another key consideration to the design of the battery is that of recyclability. One of the main unknowns of electric motoring is what happens to the battery at the end of its life. But Williams Advanced Engineering has already had a great deal of experience in recycling batteries through its work in Formula E.

'We evaluated the expected life and what will happen at the end of the usage phase,' Pascoe says. 'Does it get used in another formula or can it be used for other means? Can it be repaired for a second life, or can it be recycled? We have partnered with a company to do just that after the Formula E Gen 1 battery and that has been put to good use. With that in mind, how do we select materials to achieve the performance required? Our design serviceability gives access to all these precious materials and components for repair and re-use and second and third life battery use. Our product can talk back to us through its battery management system (BMS) on its state of health, warning us of parts approaching end of life, and [giving us an] understanding about the conditions in which it is working. Our designers have built in feedback cycles so that we can learn from the inputs through the journey, [and] … the testing feedback from the Extreme E driver programme, and this is already influencing the way that the battery is designed and handled.

'From the first battery test to launch, the opportunity to learn and improve is built into the way that we work,' Pascoe adds. 'Efficiency is considered in terms of energy and useful work done. Every component has to pull its weight in form and function, and no more. Additive manufacturing usage keeps increasing as materials and processes improve. It allows reduced material waste, whilst modelling geometries too expensive to produce through other equivalent means, opening the door to new designs of modules, power distribution electronics and systems within the rechargeable energy store, [plus] light-weighting and vehicle efficiency. Lithium cell life is a key consideration, [too], and choosing the number of cells to support the life span, or second life.'

Call of the wild

Extreme E will test the limit of what can be achieved with an electric car, and no doubt will change the perception of both battery design and EV capability. With no regulations written, the battery has been designed to be able to be changed mid-season without major investment should the series require it. That said, Williams Advanced Engineering does not anticipate any in-season changes, but it has future-proofed its design as a precaution.

Underlying all of this is a need to raise awareness of climate change and to recognise that the transport industry can safely take vehicles to extreme environments.

'For us, it is a privilege to be part of a programme that is committed to raising awareness of climate change through the medium of motorsport, which in turn should contribute to greener future products and electromechanical systems,' Pascoe says. 'It will be interesting to see how we all get on.'

Image: The FIA

Gear change

The FIA standards for racewear have gone up a notch in top level motorsport with more stringent tests for driving kit to pass. But why the change and how will manufacturers still balance safety with comfort?

By MARC CUTLER

The FIA has brought in stricter standards for race suits and other protective clothing for F1, WEC, WRC and Formula E in 2020

During the 2018 Punta Del Este E-Prix Audi Formula E driver Lucas di Grassi was fined €10,000 and given three penalty points on his racing licence for not wearing the correct fireproof underwear. Some observers claimed that the penalty was harsh, but di Grassi immediately accepted it. 'It was a mistake on my part,' he said at the time. 'It was a decision that I took today because of the extreme heat and I ran out of underwear, and I didn't think this would be an issue. But of course I must be aware that I should wear compliance [kit] during a race.' There is a reason di Grassi didn't protest the penalty when others around him did – he knows these rules are there for the safety of him and his fellow drivers.

Photos: Alpinestars

The Alpinestars development laboratory. The well-known Italian company was the first manufacturer to pass all the tests for its professional level motorsport kit for the 2020 season

From 2020 all drivers in Formula E, F1, the WRC (priority one driver and co-driver) and World Endurance Championship (season 2020-21) will have to pay attention to what they wear. This is because the FIA has released an all-new Protective Clothing Standard, known as 8856-2018, which will be mandatory for drivers in those championships; and the same goes for Formula 2, World Rallycross and the FIA World Cup for Cross Country events from 2021, too. This means that drivers can only wear clothing – race suits, underwear, gloves, shoes – that have passed stringent new tests.

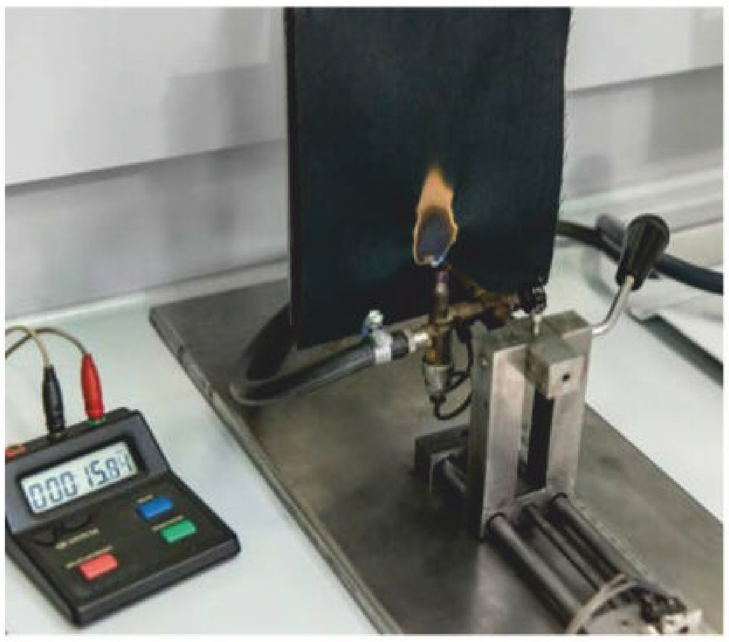
Changing vroom

These latest developments in protective clothing have been almost 20 years in the making, developed by the FIA alongside leading racewear manufacturers to ensure the highest levels of safety for drivers.

In previous seasons, drivers would wear heavy suits, but in recent years they have moved to more advanced materials such as Nomex – a lightweight artificial fibre solution. These used to be homologated under the 8856-2000 standard, published 18 years ago, but the new update has necessitated a major upgrade in all racewear in high-level motorsport.

The new FIA Standard 8856-2018 offers several advances by enhancing the tests that each piece of clothing must pass. One major improvement has been to what is called Heat Transfer Index (HTI), which has increased by 20 per cent. Nuno Costa, the FIA's head of competitor safety, says this was key when

These latest FIA developments in protective clothing have been almost 20 years in the making, to ensure the highest levels of safety



The material must withstand a direct flame for at least 12 seconds

The underwear material is stretched in a frame …

… and then made to withstand direct heat for a set period of time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transitioning from the previous standard, to help protect the drivers against direct flames and the chance of second-degree burns.

'The problem we had with the previous standard is that while we were doing heat transmission on the overalls and gloves, for underwear, balaclavas, socks and shoes we only had a requirement with the density of the material,' explains Costa. '[But over] the years the drivers then started to wear materials that were better adjusted to the body for comfort, so density was not relevant anymore.'

The move away from using dense materials in favour of slim-fitting race suits is partially down to drivers wanting to save on weight in the racecar. In Formula 1, racewear manufacturer Puma developed a new, lighter and disposable race suit that weighs just 650g, while Lewis Hamilton has been known to ask racewear manufacturers to take the seams out of his race underwear to save 10g.

Vested interest

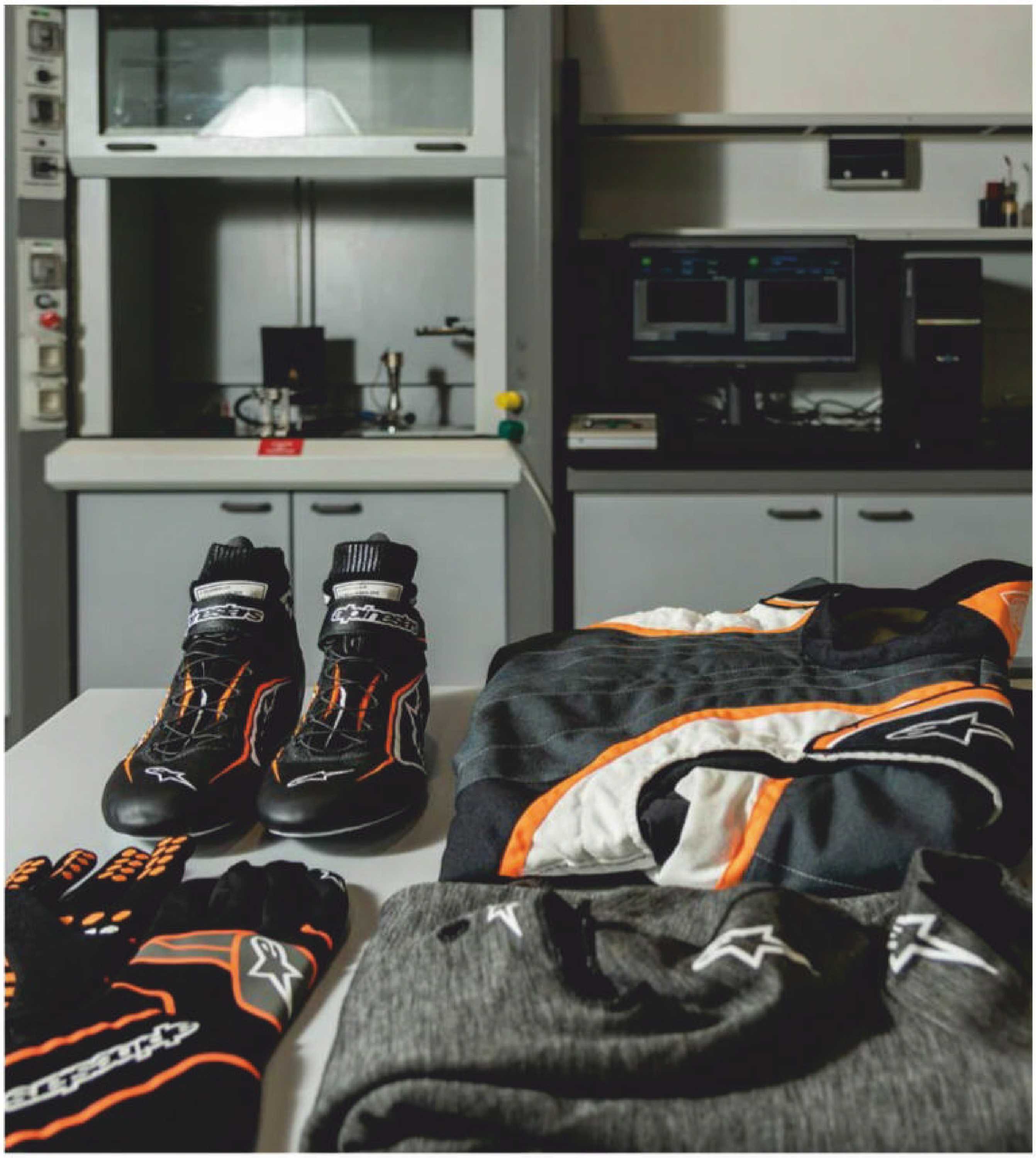
Underwear has been a key focus for the new standard because it is now part of the heat transmission test, which means it has to meet a new set of requirements. 'What we decided to do for the new standard is to introduce a new heat transmitting test on underwear,' says Costa. 'We are stretching the materials to represent the way vests and pants are being worn by the drivers in the car. So even if the driver wears a material that is stretched we can still ensure that we are giving the right protection.'

This has made the new underwear standards particularly difficult to pass as it now involves testing heat transmission under stretching while the garment has a flame applied to it for a minimum of five seconds to achieve a temperature rise of 24degC.

It's one of the key areas that manufacturers have struggled with, because of the tension that the underwear is put under during the test. This is partly down to how they make the underwear, which has prompted manufacturers to find new technology to produce it. 'It's more about the knitting of the material, not so much about the type of material used now,' Costa says.

The strict design requirements that each manufacturer must adhere to are part of what makes the standard rigorous, which is why each piece of protective clothing is subjected to these tests. The HTI test stipulates that a driver's suit must withstand a direct flame for a minimum of 12 seconds, while the underwear, socks and balaclava must withstand a minimum of five seconds, the shoes 11 seconds, and the gloves 11 seconds – with exception of the palm which must withstand eight seconds.

This has all proved to be a major challenge for the manufacturers. Nico Buzzatti, quality manager at well-known racewear manufacturer Alpinestars, says: 'The HTI test on the drivers' suits was the most challenging of the tests we experienced. We had to ensure that the suit was able to meet the more rigorous standard while still keeping the same low weight, by continuing to develop new materials, and ensuring that they still delivered the same high levels of breath-ability, for which we are known.'



The new regulations apply not just to the race suits but also the underwear and balaclavas, plus gloves, socks and boots

'For the new racewear standard we decided to introduce a heat transmitting test for underwear'

Overall results

Modern race suits are light and breathable to improve the comfort of drivers in the car. The dilemma was how to maintain this while meeting the new tougher standards. 'If the overalls are too thick the drivers may start getting fatigued because of the lower breath-ability level of the garment,' Costa says. 'That is why comfort is so important, the overalls need to be still wearable for the type of events that we have in FIA championships.'

As racing drivers are competing at high speed in a precision environment they can often feel even the slightest bit of discomfort in the cockpit. This is why Alpinestars works with the drivers to provide bespoke clothing to manage this. 'Often the driver's body shape and the structure of the seat causes discomfort, so we will move the position of a seam by 1mm or 2mm to combat this,' Buzzatti says. 'We also make the suits extremely breathable by incorporating honeycomb structured linings and, where possible, strategically-positioned breathable stretch panels located in the lower back, crotch, and underarm areas which provides more freedom of movement.'

These demands can be slightly different for rally drivers because they sometimes work on the car during stages, spending a large amount of time leaning over or even lying on the floor which can be a rough and dirty surface. 'The main focus for Alpinestars is to ensure that a suit will be as flexible as possible for rally drivers,' says Buzzatti. 'Our WRC suits feature extensive stretch panels on the lower back, crotch and knee area for optimal levels of comfort.'

Under the new standard each piece of clothing will only have a validity period of 10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Attire testing

Tests to meet the new FIA standard	
Flame resistance:	Material is subjected to a direct flame for a prescribed amount of time.
Heat transmission:	Material must withstand a direct flame for a minimum of 12 seconds, while the underwear, socks and balaclava must withstand a minimum of five seconds, the shoes 11 seconds, and gloves 11 seconds with exception of the palm, which must withstand eight seconds.
Heat transmission for undergarments:	Material is tested to see how it performs when fixed on a surface and stretched, and then subjected to heat.
Mechanical resistance:	Test to see how much the material bends and stretches under load.
Thread flame resistance:	Test to check the resistance of sewing thread on exposure to a flame.
Tensile strength of structural seams:	Strength of seams tested using a tensile-testing machine.
Tensile strength of shoulder handles:	Strength of shoulder handles tested under tension, which is increased gradually until rupture.
Dimensional change:	Material tested to check the dimensional change when subjected to washing and drying procedures.
Convective heat resistance:	Convective heat resistance properties of non-textile materials tested with a temperature of 260degC.
Glove fingers:	Flame-resistance of the seam of the fingers of the glove is tested.

Alpinestars says it was a challenge to keep its kit the same weight while meeting the demands of the new test criteria

'It's more about the knitting of the material now, not so much the type of material used'

years, the FIA has mandated, after research demonstrated that the clothing may lose its safety performance following prolonged usage.

Meanwhile, to ensure that each product purchased and worn by drivers on a race weekend is genuine, there will be a new marking system in place that makes it easier than ever for officials and National Sporting Authorities to identify original products.

For the future, there are also plans to have a helmet extrication system in the driver's balaclava, which enables a helmet to be removed from the driver's head without transmitting loads to their neck, and in turn reducing the chances of causing further injury. 'Until now there wasn't standard requirements to approve products that reduce the loads transmitted to the neck while removing the helmet,' says Costa. 'For that reason, the FIA Medical Commission asked the safety department to come up with design requirements and performance assessments.'

Follow suit

Even though fires are not usually seen in top-level motorsport events these days, due to welcome advances in racecar safety, Costa believes this does not mean there should be a relaxed attitude towards protective clothing. The new standard gives drivers access to the safest race suits they have ever worn, with a minor cost increase, and their improvements demonstrate how the FIA is constantly evolving safety research in these areas.

Manufacturers have already homologated a number of their products to the new standards with the FIA. Alpinestars is the first of them to have passed the tests for all of its pro-level kit, but the other manufacturers are not very far behind.

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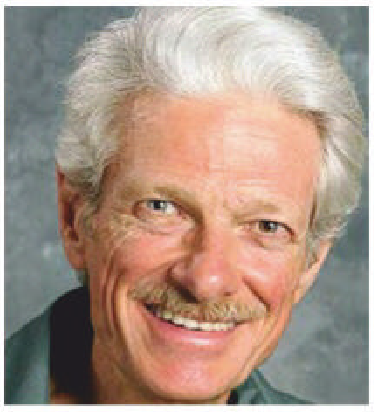
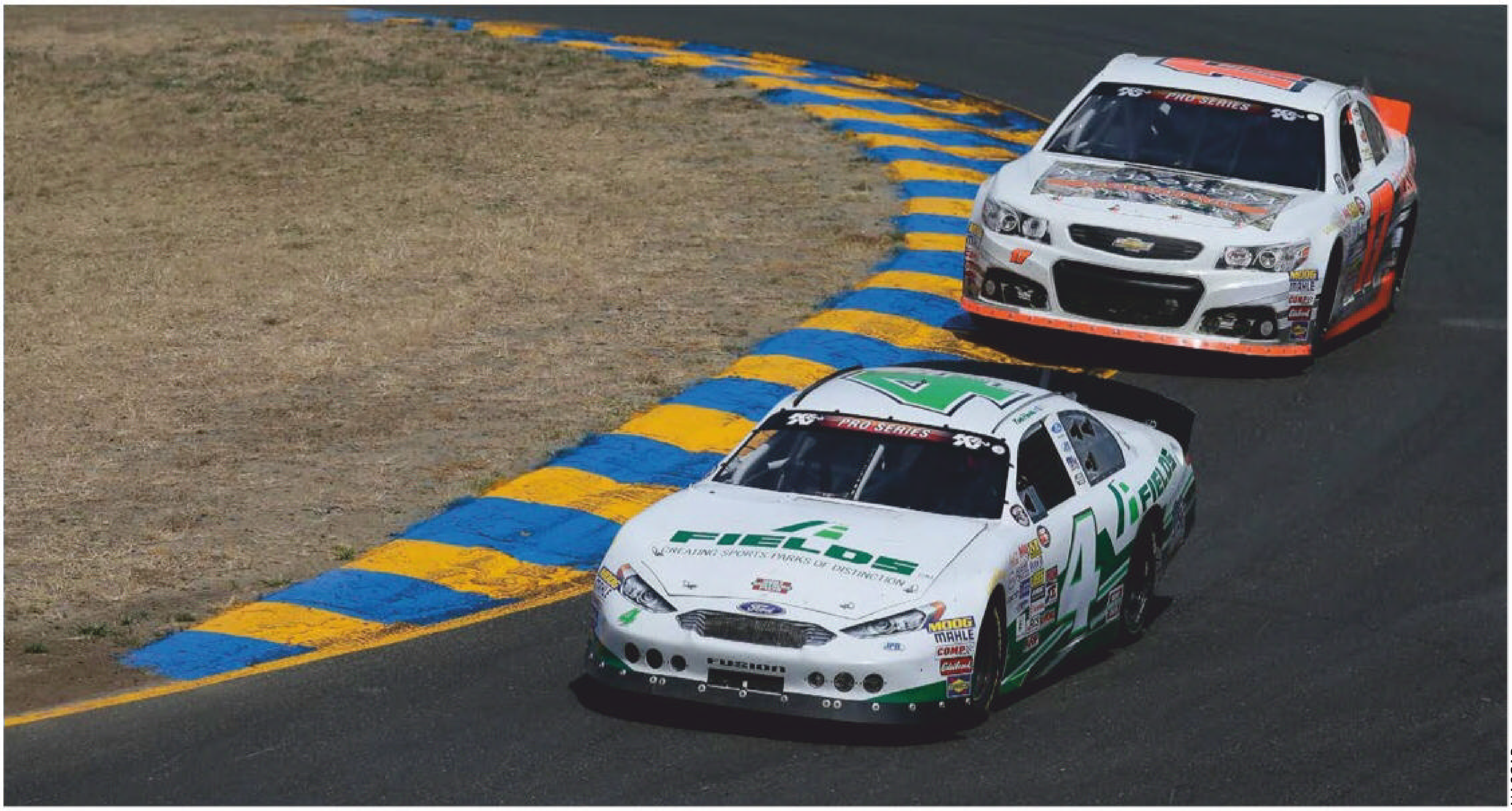


After shocks

Is it better to use coil binding or bump stops on a late model stock car, and how do truck arms affect the turn-in on banked corners?

By MARK ORTIZ



Late model cars have suspension that's optimised to make the best of the ground clearance regulations; though this needs to be modified for running on road courses

Q What are the differences between coil binding and bump stops on asphalt circle track late model stock cars and what are the advantages and disadvantages of them both? Also, which one is preferred for a better handling racecar?

Another thing I would like to know is how do rear trailing arm or truck arm angles affect the racecar's turning ability when entering a corner? And finally, how do different size arms affect the car?

THE CONSULTANT

A Coil binding, bump stops, and bump springs are all ways to work ground clearance rules, and/or body template rules, that require the car to statically sit higher than we would ideally like to run it. Because of this we then use very soft springs and hold-down shocks (lots of rebound damping) so that the car will run either on the bump stops or bump springs, or with the springs in coil bind.

If my memory serves me correctly, coil bind set-ups came first. This is because bump stops were actually prohibited. This meant that the shocks could not be used to limit bump travel; bottoming a shock with no snubber on it will damage the damper. So the suspension was set up so the spring would reach coil bind before the shock ran out of travel.

Quite often only the front of the racecar was run in coil bind. The car then behaved something like a Bandolero car: the front end rigid but adjustable; rear end beam axle on coils with Panhard bar (Bandolero is a US category for eight to 14-year-old drivers which uses scaled-down racecars).

When the car has a rigid front end and functioning suspension at the rear, the rear has no elastic load transfer due to lateral ground plane force, although it can have some due to car-vertical (*z* axis) forces if it has some spring split or the c.g. (centre of gravity) is laterally offset. The rear does still have geometric load transfer, which is controlled by Panhard bar height. The Panhard bar then becomes a dominant tuning tool.

Unless the track surface is really smooth it's better to have at least a little suspension movement

Having the front of the racecar that rigid is actually good for aerodynamics, because it keeps the valance or splitter a closely controlled distance from the track surface. But it's bad for mechanical grip. Unless the track surface is really smooth, it's better to have at least a little suspension movement. Therefore, rules permitting, it's preferable to use bump rubbers or bump springs, which are small, stiff coil springs that go over the shock shaft and replace rubber snubbers.

Snubber rubber

Rubber springs or snubbers have a rising rate. They also change stiffness with age and with temperature. When subjected to a sustained load, the rubber cold flows: it takes a set, or sags. When the snubbers only see an occasional load over big bumps, this doesn't matter, but when the car rests on them continuously for long periods it can have an effect. The non-linearity of snubbers can be

A suspension using truck arms, as on many NASCAR late model stock cars, will be sensitive to Panhard bar angle tweaks. The name comes from their original use on GM pick-ups

advantageous for a class where other forms of rising rate springing can't be used, but it does complicate analysis or modelling.

Bump springs, in contrast, are metal coil springs. They have an approximately constant rate, and are sold with an advertised rate, just like other coil springs. This simplifies tuning.

Whichever of these options we choose, our task is complicated by the fact that the car does not spend much time running at the height it has statically. Even down the straights, it's at a 'second static' height, running coil bound or on the bump rubbers or bump springs. We really want to set the car up for this condition, in terms of wheel alignment and corner weights. To facilitate this, people have come up with various designs of pull-down rigs.

Truck and trail

As for rear trailing arms or truck arms, it matters a great deal whether we are talking about truck arms as used in most NASCAR divisions, or trailing links (usually two lowers and one upper, creating what is commonly called a three-link system) as is permitted by many other sanctioning bodies. Both types have effects in all parts of a turn.

Truck arms are a pair of trailing arms that bolt rigidly to pads near the ends of the axle housing and run to bushed pivots near the driveshaft somewhere around the mid-point of the wheelbase. Usually each arm consists of two rolled sheet metal channel sections welded together to form an I-beam. The arms

The torsional rigidity of the truck arms and the stiffness of the bushings do become important

are thus fairly rigid in bending but flexible in torsion. They can also be made of rectangular tubing, in which case they are a lot stiffer in torsion. The design was first used in GM pick-up trucks; hence the name.

The system could roll freely if the arms converged to a single central spherical joint pivot, but as generally configured, things have to flex a bit for the suspension to roll. The torsional rigidity of the arms and the stiffness of the bushings become important, particularly if rear anti-roll bars are prohibited.

Because the pivots approximate a single central one, simple roll does not create appreciable rear steer. However, any lateral movement of the axle creates steer. This makes the system sensitive to Panhard bar angle, especially in banked turns. Usually, the Panhard bar attaches to the frame at the right and the axle at the left. If the bar is higher at the right, the axle moves to the left as the suspension compresses, as it does in a banked turn, and the wheels are aimed to the right. This creates what we might call ride or heave oversteer. That can be aerodynamiclly advantageous. It gets more air to the spoiler and can generate a bit of lateral force.

The length of the truck arms affects the anti-squat and anti-lift properties of the rear suspension. So does the height of their front bushings. Shorter arms or higher pivots increase anti-squat and anti-lift.

With most three-link set-ups, lateral movement of the axle does not create rear steer, but roll often does. The angles of the links affect roll steer, ride steer, and anti-squat/anti-lift. Lengths don't matter, except that this affects how the angles will change.

To get ride or heave oversteer in banked left turns, the right lower link needs to slope up at the front more than the left one, or slope down less. To get roll oversteer, both lower links need to slope up toward the front. Having the lower arms slope up toward the front, or having the upper arm slope down toward the front, adds anti-squat and anti-lift.

CONTACT

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Accelerated learning

Throttle control is a vital part of the driver's skill set, so it's important that engineers have the understanding and the tools to measure it

By CLAUDE ROUELLE

Even the very best can get a bit greedy on the throttle – this is Michael Schumacher winding on some opposite lock to deal with power oversteer at Silverstone back in 2005

If you've been following this series of articles from OptimumG during the last year, you will know that we have shared some of the data analysis techniques used by our engineers in their day-to-day racing activities. These have mainly been on the race driver's inputs: steering, braking, and throttle. So far, we have presented the steering and the braking performance metrics. But this month we're going to focus on the throttle channel.

Throttle control

The throttle has two main functions: accelerating the racecar and, in some situations, using the longitudinal tyre grip to balance it.

The tricky part is to apply the correct amount of throttle. A driver can easily apply too much, or too little, or apply it too fast, or too slow. And as a race driver moves to higher racing series, which typically means more engine power, then the more difficult it will become to find the perfect throttle modulation.

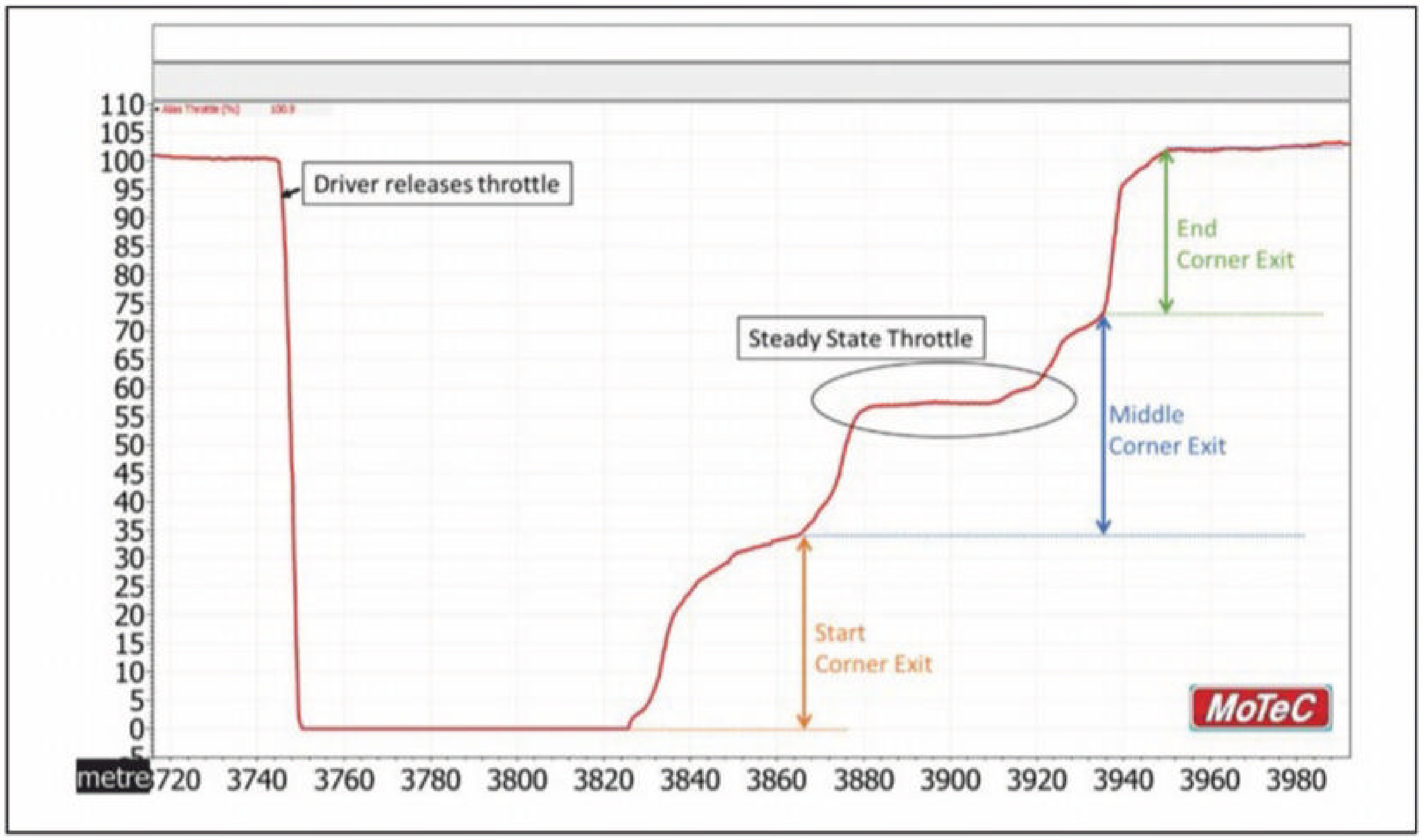

Figure 1: Throttle trace by sections through a long corner with a late apex; the latter is indicated by the steady state throttle period

Before we start looking at ways to analyse the throttle channel using key performance metrics, it is important to first understand what a throttle trace looks like. **Figure 1** shows a trace for a long corner.

A throttle chart will have on the *y*-axis the throttle percentage, the value going from zero per cent to 100 per cent, where zero means the throttle is closed and at 100 per cent the throttle is fully open. Values in the middle represent part of the throttle opening. As for the *x*-axis, that can either be in distance or time.

In **Figure 1**, up until the 3750m marker the driver is applying full throttle (straight line). At the 3750m

The throttle has two main functions: accelerating the car and, in some situations, using the longitudinal tyre grip to balance it

marker the driver releases the throttle and is braking to enter the corner. The driver then picks up the throttle at 3825m, the corner exit.

Similar to the April 2019 edition (V29N4) where we broke down the different stages of braking, we will be applying the same methodology for the throttle by looking at the different stages during the corner exit: *Start Corner Exit*; *Middle Corner Exit*; and *End Corner Exit*.

Smooth application

Start Corner Exit begins with the initial application of the throttle. Being smooth on the throttle is crucial (see January 2019's edition, V29N1, to further understand what we mean by being smooth). If the driver applies too much throttle, or applies it too quickly, it can create an understeer behaviour in the car due to the longitudinal weight transfer from the front to the rear axle. Additionally, the driver could be creating unnecessary wheel spin. On the other hand, if the driver doesn't apply enough throttle, or at a slow rate, it could be an indication of room for driver/lap time improvement, or simply that there's not enough grip available.

The Middle Corner Exit is the longest section. The driver gradually increases the throttle while exiting the corner. In **Figure 1**, the corner that we are analysing has a late apex. This is confirmed because, from 3880m to 3920m, the driver is maintaining a constant throttle (steady state throttle). The driver is providing the necessary amount of throttle that keeps the racecar at a relatively constant speed. The driver reached a steady state (equilibrium) point of the car, which tells the race engineer that there probably isn't any more additional grip available. The length of the corner, as well as the type of trajectory used, will have an effect on how long this throttle will be held in a steady state.

After we exit the Middle Corner Exit we enter the final section: End of Corner Exit. This is characterised by a rapid increase to 100 per cent of the track trace, which is possible because the driver is no longer tyre limited. It means they can apply 100 per cent throttle without having to worry about wheel spin.

With the throttle trace sections defined, and having gained an understanding of what a throttle trace looks like, let's now analyse the throttle trace of two drivers. **Figure 2** shows the data of our pair negotiating the same corner. The upper chart is the throttle trace; the lower chart shows the car's velocity.

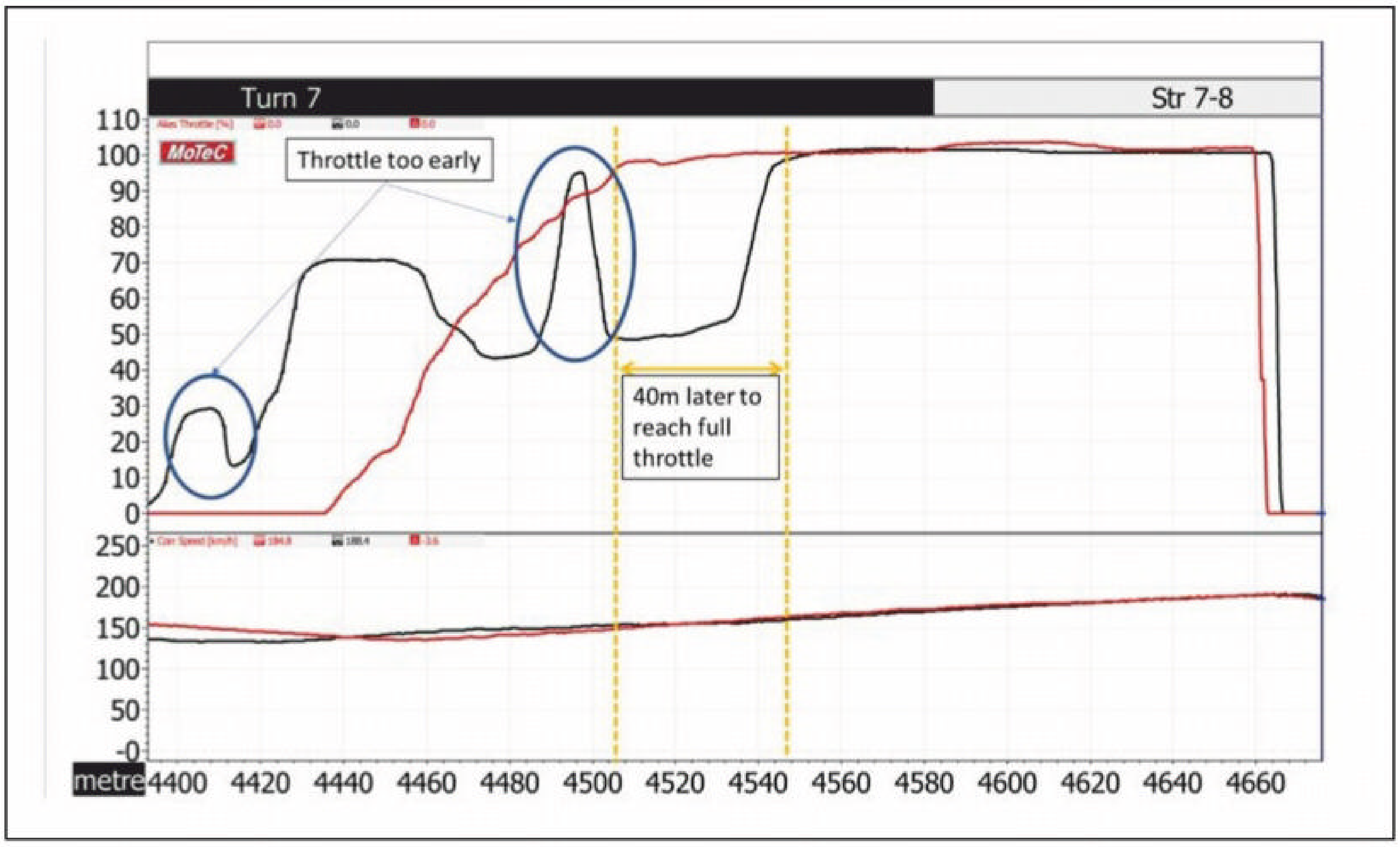

Figure 2: Throttle comparison between two drivers. Note how the black trace shows an early application, while red is much smoother

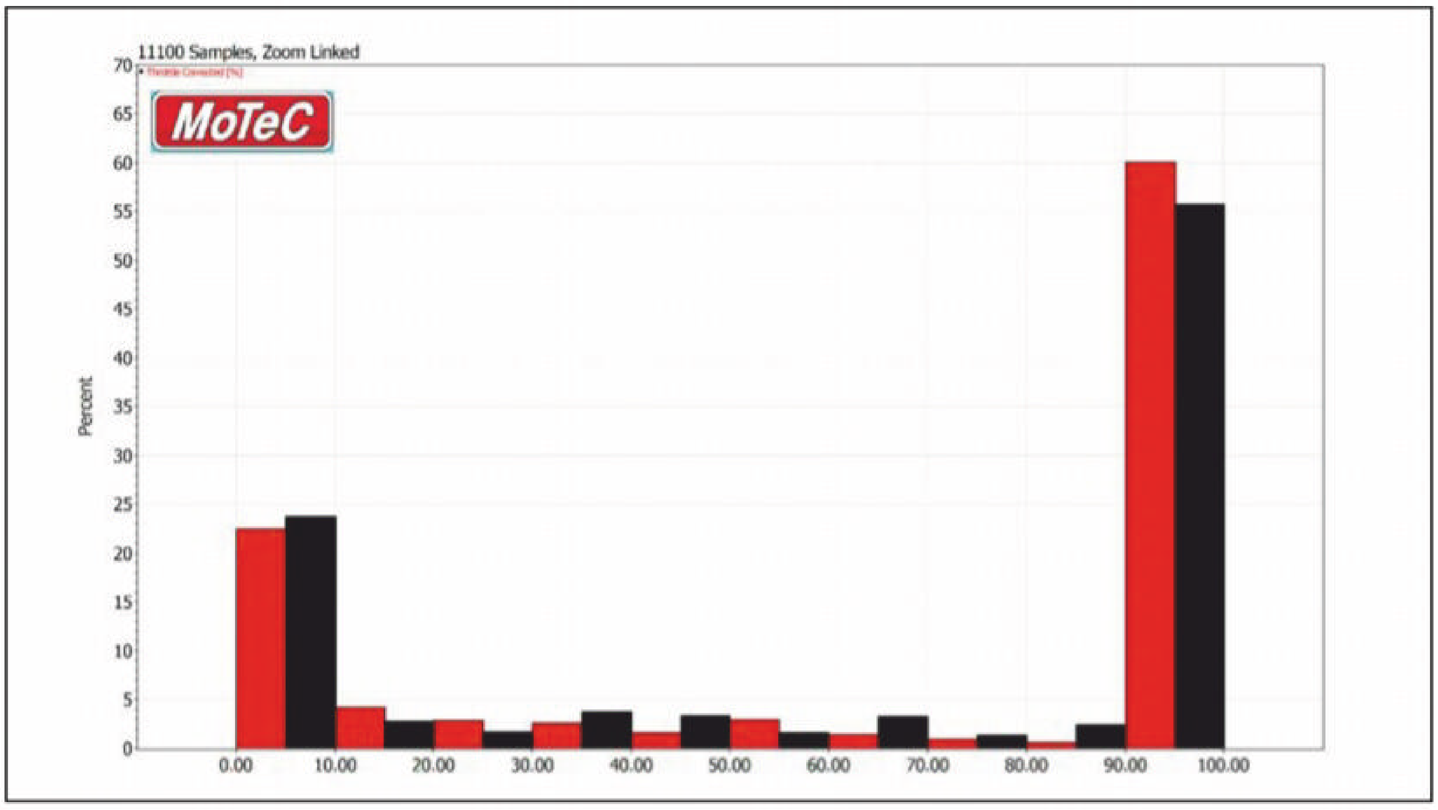

Figure 3: Throttle histogram for the two different drivers on their fastest lap. The red driver has a higher percentage of full throttle

The driver is no longer tyre limited, and this means they can apply 100 per cent throttle

Tracing drivers

Right at the beginning we can see that both drivers have different throttle traces. The driver with the black trace applies the throttle sooner than their counterpart. This happened because they braked too hard and/or too early. Therefore, they reached the corner much earlier than expected. The driver then tries to compensate by applying the throttle earlier. With the traction ellipse definition in mind, the problem is that the driver has a limited longitudinal grip available because the tyres are probably close to the maximum lateral grip. When the driver tries to accelerate, if the wheels spin, they need to lift off the throttle, thus creating that up and down throttle trace. In the end, the driver gets back to full throttle 40m later compared to the red driver.

On the other hand, the red driver had a smoother and quicker rise of the throttle, and exits the corner with a higher speed compared to the black driver. The red driver has a higher average throttle position compared to the black.

A typical first analysis of the throttle trace is a throttle histogram. A histogram represents a distribution of data. The values are separated into bins which represent a series of intervals. We can count how many values are in each interval. For our convenience MoTec i2 already comes with a pre-built histogram. The user just needs to click on *Add -> Histogram*. A window will pop up, and the user just selects which channel they want to create a histogram for. In **Figure 3** (the

To obtain an overview of the lap section, a simple and useful performance indicator is to calculate the throttle average

histogram obtained from MoTec i2), we separated in bins of 10 per cent. From 0-10 to 11-20, etc.

Here we are comparing two different drivers on their fastest lap. The red driver had a faster lap time compared to the driver in black. By looking at the histogram, we can see that the red driver has a higher percentage at full throttle (90 to 100 per cent), and lower percentage at no throttle (0 to 10 per cent). If we look at partial throttle (11 to 89 per cent), we can see that the black driver spent more time in that area compared with the red driver, and was modulating the throttle, which we noted in Figure 2.

Throttle average

A histogram provides an alternative to a time/distance chart. It provides an overview of the complete lap. Unfortunately, in the fast-paced environment of a race day a data engineer doesn't always have the time to look at each lap's throttle histogram. But to obtain an overview of the lap section, a simple and useful performance indicator is to calculate the throttle average.

For our convenience, MoTeC i2 allows users to create math channels to calculate the throttle average (described in **Table 1**). *Stat_mean* is the function that calculates the average. The average is calculated by summing all the select channel values and dividing them by the total number of data points. Alternatively, in MoTeC i2, by going to *Add-> Channel report*, the user can create a channel report and select the average. This option will show a table with the average per lap, which is easier to further analyse.

Figure 4 shows the results of using the throttle average math channel and plotting it against lap time. At first, the obvious conclusion is that the more time on average the driver spends on throttle, the lower his lap time is. We can also see that, depending on the driver, there could be a stronger correlation with the

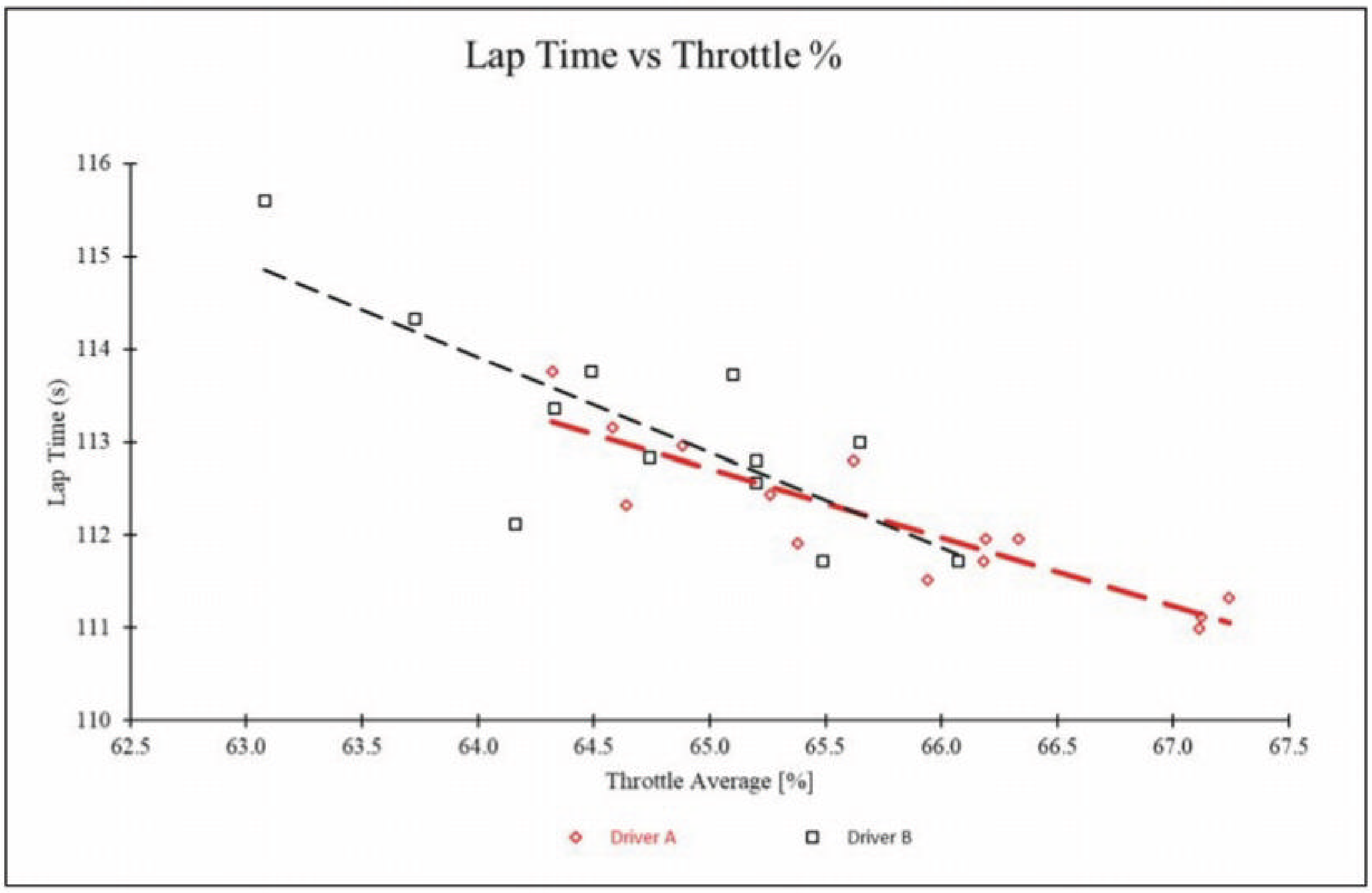

Figure 4: Driver A and B comparison between the lap time and throttle average. Note that driver B has a wider lap time variation

Table 1: Average throttle math channel

Math channel name	Math channel equation
Throttle average	stat_mean('Throttle' [%])

throttle average. In this case, we can see, by looking at the slopes, that driver B has a higher sensitivity to the throttle average on their lap time compared to driver A. Also, notice that driver B has a wider variation of lap time, which might indicate that the driver could be modulating the throttle. If the values are lower than the driver's throttle average, it's an indication that a safety car has been deployed, or the driver is trying to save fuel or decrease tyre wear.

Key points

To summarise the key points made above, most data analysis software packages have an option to calculate the average for each lap. This number will be different depending on the circuit, car, and driver. In general, the more time spent on full or nearly full throttle, the lower the lap time. But this might not always be the case, as a driver who carries more speed in the corner will then get on the throttle later, which will lower the throttle average. It is up to the engineers to look at multiple laps and find a baseline to compare their drivers.

A histogram is a useful tool to quickly assess the driver's throttle profile, as long as that driver is being smooth or modulating the throttle. Also, throttle position is one of the simplest channels that can be used, and it shows us one of the vehicle's main controls.

Although we simplified our observations by only looking at the throttle channel, it is necessary to plot at least one more channel to get a full picture of what is happening in the corner. Some other channels you might look at are: RPM, GG diagram and speed, for example.

As a final tip for the reader, you might want to create a key performance indicator called *throttle smoothness* to smooth out the throttle channel and compare it with the raw channel. Consult the steering smoothness article in January 2019 edition, V29N1, and you will get an idea of how you can apply what you learn for the steering smoothness metric to the throttle.

The more time spent on full throttle the lower the lap time, but this might not always be the case

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

OptimumG seminars are held worldwide throughout the year. The Data Driven Performance Engineering (DDPE) seminar presents several data acquisitions and analysis techniques which can be used by engineers when making decisions on how to improve racecar and race driver performance.

The next DDPE seminars will be taught in Indianapolis, Indiana, USA (09-11 December) and in Birmingham, UK (11-13 January 2020). Register by sending an email to: seminars@optimumg.com

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Splitting the Atom

The Ariel Atom that's our new aero study subject is quick enough to win a championship, but what happens when we remove its wings?

By SIMON MCBEATH

Our MIRA full-scale wind tunnel test subject for the next three issues is the 2019 Javelin Trackdays Sprint Series-winning Ariel Atom. Owner/driver Stuart Drewell had developed the spaceframed, semi-open-wheeler in all areas including increasing power to 450bhp-plus, fitting wide-span dual-element wings front and rear and panelling in the sides of the otherwise fairly open chassis. Needless to say, a raft of ideas was evaluated.

Back to front

For variety, this project will begin at the end, with the results of the last test conducted; running without either front or rear wings. The objective was to be able to evaluate the effects of fitting the wings. The differences between the wingless configuration we tested and a standard car included the wing support plates; the owner-installed side panels; and some taped on covers over the front damper recesses and small Gurneys on the front mudguards, the effects of which we evaluated.

Table 1 shows the wingless data versus the best balanced configuration achieved during the session with wings; differences or delta values are shown in counts (one count = a coefficient change of 0.001). The wingless car developed aerodynamic lift, hence the positive lift coefficients, and most of it was at the front. The winged car developed significant downforce, split similarly to the front to rear static weight split, as shown by the negative lift coefficients. The delta values showed the wings added about 12.5 per cent to overall drag. However, the change to lift, that is the actual downforce added in counts, was over 10 times the increase in drag.

Consideration of these downforce gains in terms of forces at a specific speed, and in particular as proportions of the vehicle's own weight, can give an idea of the gains in grip that arise. In this case we can look at this in two distinct ways. The usual approach is to calculate the downforce at each axle as a percentage of the static weight on each axle. In this instance, though, we have figures for the aerodynamic lift generated at speed too, so we can also calculate the vertical force gains that downforce has brought to each axle compared to the losses that aerodynamic lift created without the wings fitted. In the former case, in aerodynamically balanced trim, the downforce represented around 14 per cent of the weight on each axle at 100mph, meaning simplistically that there would be 14 per cent more grip at 100mph than at 0mph (if grip could be developed while not moving). But comparing the axle weights at 100mph 'with downforce' versus 'with lift' showed that the aerodynamic increase in grip potential at the front was actually 30 per cent compared to about 15.5 per cent at the rear. This may in part help to explain the numbers we obtained in the baseline 'as raced' configuration at the beginning of our session.

Illustrations: Simon McBeath

This Ariel Atom sprint car sports wide span, dual element wings front and back to help generate some useful downforce

With the wings removed from the car the vertical forces were very different, although drag did not change much

In the beginning

As delivered to the wind tunnel, fresh from its last outright win in a clean sweep, maximum points, season, the Atom generated the

Table 1: Aerodynamic coefficients and delta values with and without wings

	CD	CL	CLfront	CLrear	%front	L/D
Wingless	0.522	0.219	0.194	0.026	88.4%	0.420
With wings	0.587	-0.450	-0.160	-0.291	35.4%	-0.767
Δ, counts	+65	-669	-354	-317	-	-

Despite the Atom's wide cockpit area and its roll cage there was still some wing span that was working pretty efficiently

Table 2: Baseline coefficients

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.658	-0.597	0.020	-0.616	-3.3%	-0.908

numbers in **Table 2**. The precise direction that the first wind tunnel session on any car takes is frequently driven by the baseline run's results and this was no exception, although we had planned on refining aerodynamic balance early on. However, an amount of chin stroking followed, while we reconciled the baseline data with the car's successful performance on the track, for the data showed this car developed a decent amount of rear downforce but actually also produced a small amount of positive lift at the front.

Revisiting the notion in the previous paragraph, reversing the inherent lift of the wingless car with the baseline wings meant that although there was still a small amount of front lift in the baseline wing configuration, the driver would still have felt a substantial increase in front grip as speed increased and the original lift was much reduced. And doing the same calculation to see what the approximate grip increase would be at 100mph between wingless and baseline wings shows that front end grip would be around 15 per cent up and at the rear it would be around 32 per cent up on the wingless set-up. Thus, despite the lack of an ideal aerodynamic balance, relative grip at speed would still have been much better, even with unbalanced wings.

Back to back

Before we progress to seeking that all-important downforce balance in the next instalment of Aerobytes, it's worth pausing to put the Atom's overall numbers into perspective by comparing with other cars we have previously tested. The drag coefficient in the 'with wings, balanced' set-up in Table 1 of 0.585 doesn't sound too bad. Indeed the Caterham with single element wings we evaluated in V29N4 to V29N6 had a drag coefficient of 0.661 in 'best balanced' configuration.

However, the Atom was a much bigger car with a frontal area of 2.1 square metres compared to the Caterham's aproximately 1.3 square metres. Thus the respective CD.A values (drag multiplied by frontal area), which are directly proportional to the actual drag forces at any given speed, were 1.229 for the Atom and 0.937 for the Caterham. So the Atom's drag was around 31 per cent higher than the Caterham's drag, and this puts the winged Atom on a par with the 1983, 1999 and 2007 Formula 1 cars we have tested, which all produced CD.A values between 1.1 and 1.3.

However, comparing the –CL.A values, which are the (negative) lift coefficient multiplied by the frontal area, the Atom in best balanced configuration gave 0.945 compared to the Caterham's 0.318, meaning the Atom created roughly three times as much downforce. Aerodynamic efficiency, as indicated by the L/D values, in the best balanced configurations were -0.762 for the Atom compared with -0.368 for the Caterham.

For drag, the Atom was on a par with some Formula 1 cars we have tested

So the more powerful wings of the Atom meant that it was around twice as efficient. As an aside, the wingless CD.A values were 1.096 for the Atom and 0.842 for the Caterham, so the Atom had inherently more drag.

Look out for More Atomic testing next month. Racecar's *thanks go to Stuart Drewell and DJ Engineering for supplying the car.*

CONTACT

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

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With a large frontal area plus those wings it was no surprise that drag was relatively high

Headlamps are drag contributors while their wake also impinged on the rear wing flow


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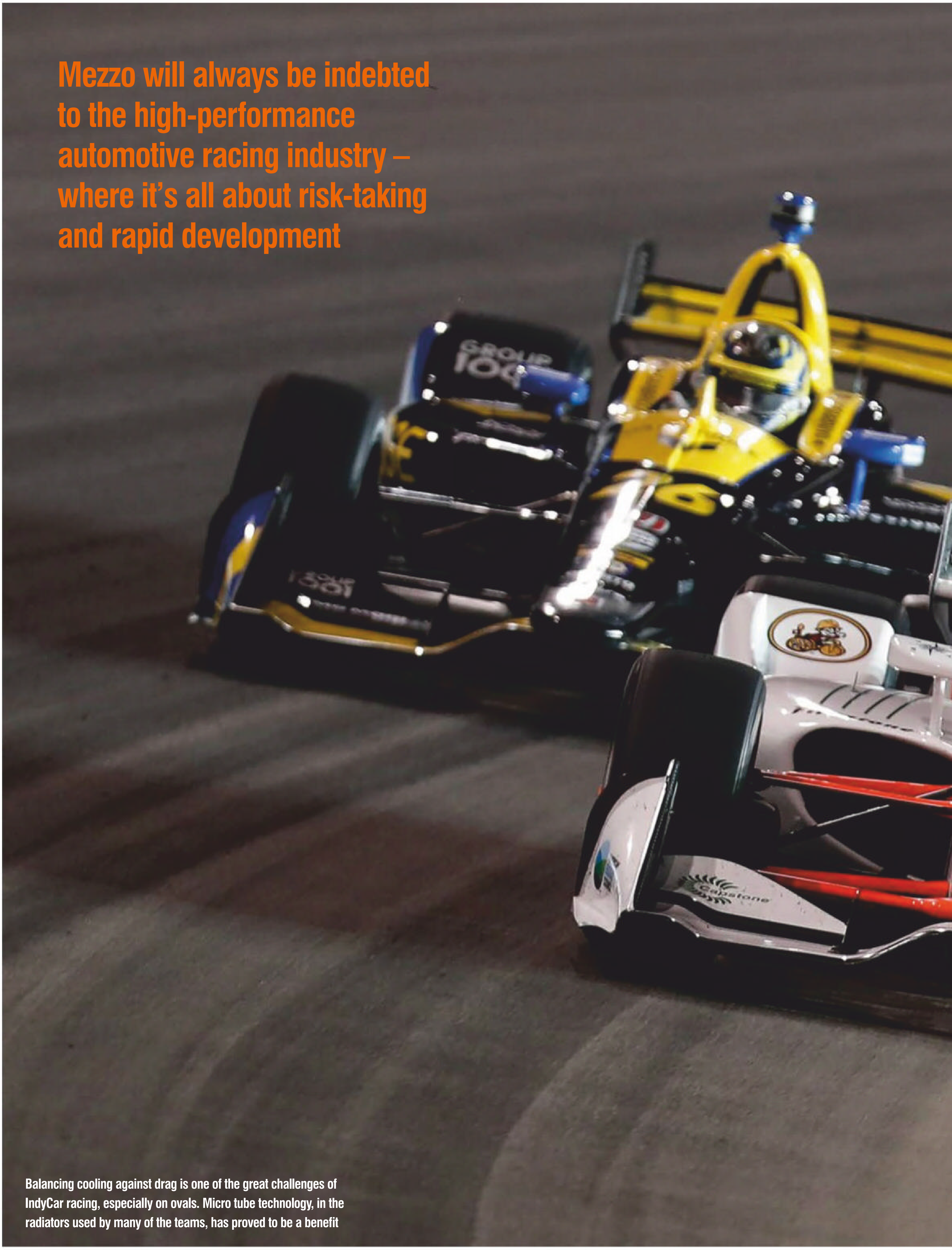


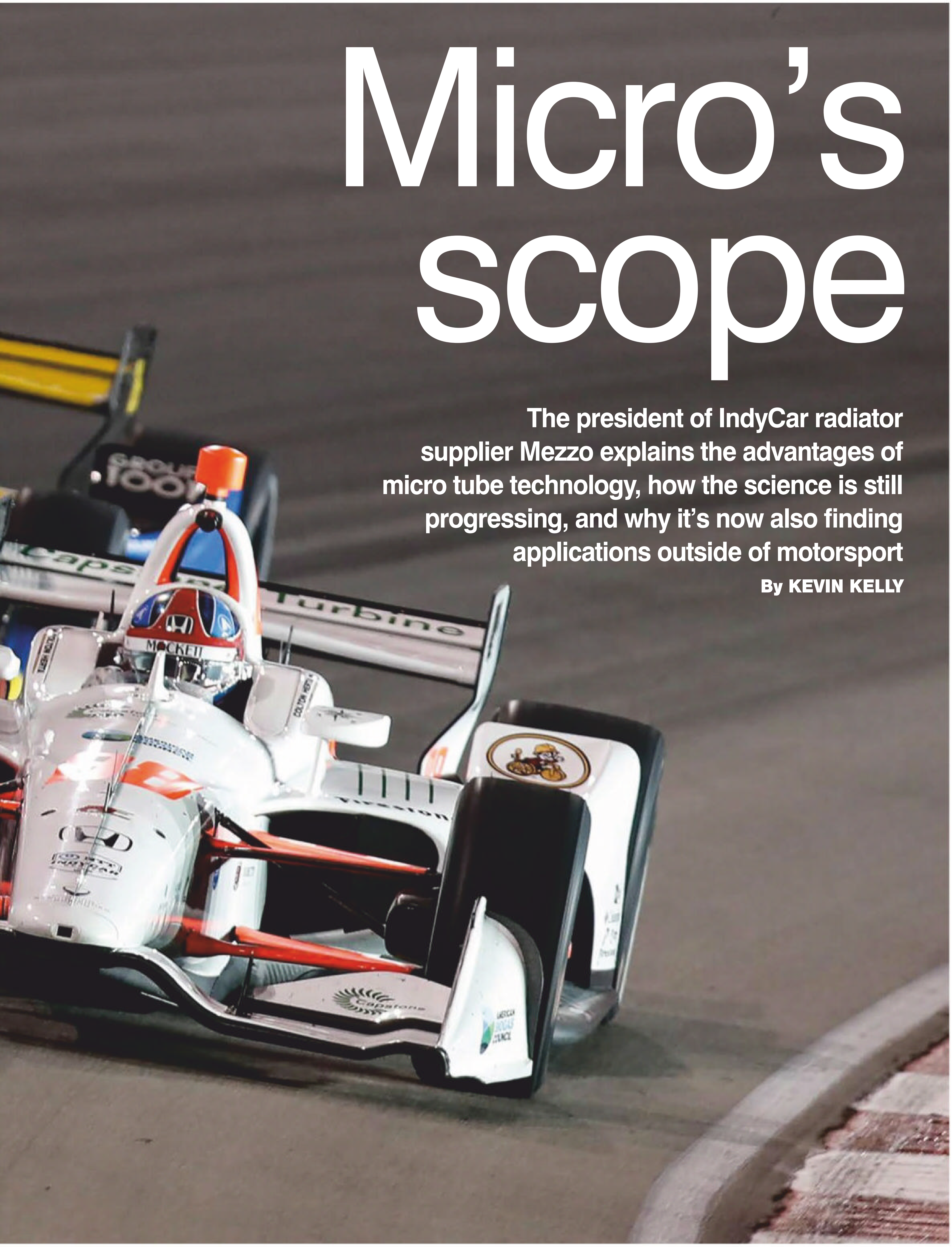
Mezzo will always be indebted to the high-performance automotive racing industry – where it's all about risk-taking and rapid development

Balancing cooling against drag is one of the great challenges of IndyCar racing, especially on ovals. Micro tube technology, in the radiators used by many of the teams, has proved to be a benefit

Micro's scope

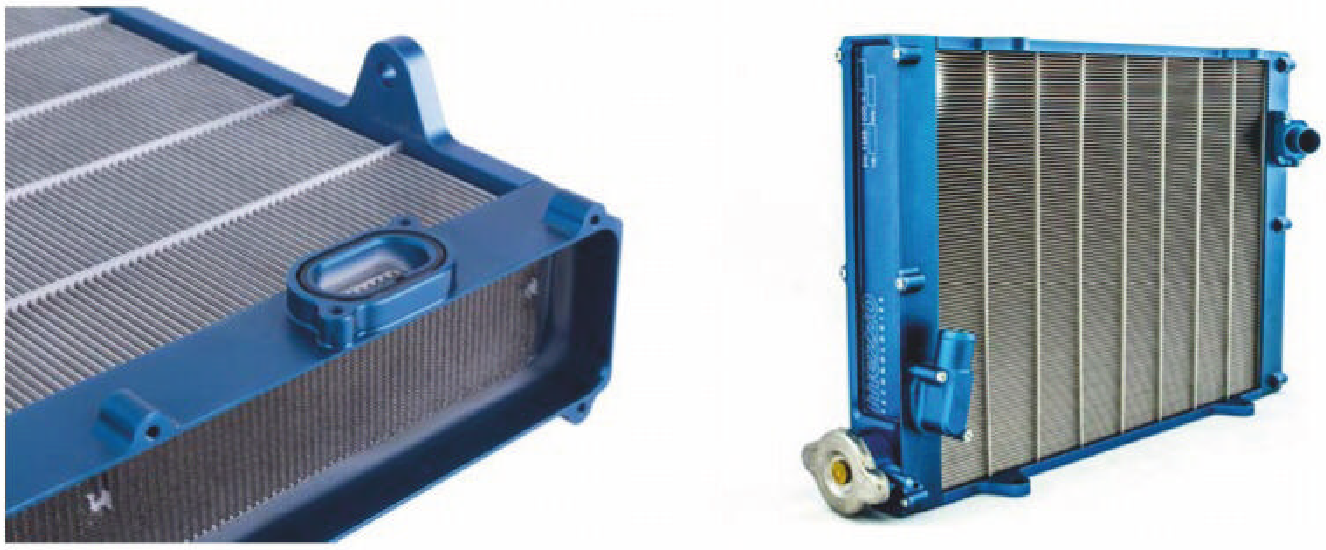
The president of IndyCar radiator supplier Mezzo explains the advantages of micro tube technology, how the science is still progressing, and why it's now also finding applications outside of motorsport

By KEVIN KELLY



Cooling is paramount in all forms of motorsport, but it's a delicate balance and too many surfaces will mean an aero disadvantage. This is why in racing where drag reduction is vital, such as IndyCar, solutions like micro tube heat exchangers are always very welcome.

The definition of a micro tube heat exchanger is one that is made using hundreds to many thousands of small tubes, usually stainless-steel, having outer diameters in the range of 0.5-1.0mm. Micro tube heat exchangers can be considered a subset of micro channel heat exchangers, where the characteristic dimension of the fluid channels are small and the surface area/unit volume is high.



Above right is an example of a radiator manufactured for kart racing, with an end view showing the internals on the left

Exchanging numbers

The scaling laws of micro tube heat exchangers relating heat transfer/volume to tube diameter are relatively straightforward. The surface area/volume of a micro tube heat exchanger scales with *1/Dtube*, where *Dtube* is the outer tube diameter. The heat transfer coefficients on both the inside and outside of the tube also scale with tube diameter (*1/Dtube* for the case of laminar flow, ~ $1/Dtube^{0.5}$ for turbulent flow). So, the overall heat transfer coefficient/unit volume ($W/K\text{-}m^3$), which is the product of heat transfer coefficient and surface area/unit volume, scales as $1/Dtube^{1.5}$ to $1/Dtube^2$.

The image above provides an example of a micro tube product: an external view of a radiator manufactured for kart racing, along with an end view showing the internals of one end tank. All micro tube heat exchangers share some basic common principles of the heat exchanger shown here. The core consists of an array of tubes, bonded to a tube sheet on either end. Header tanks are attached to the tube sheets. One fluid flows inside the tubes from one header tank to the other. The other fluid flows on the outside of the tubes (the shell side).

A variety of configurations (tube-side multi pass, shell-side multi pass, rectangular shaped cores, cylindrically-shaped cores, etc.) are available. It is often the case that mid plates are positioned at regular intervals between tube sheets. These mid plates contain a pattern of holes identical to the pattern of holes in the tube sheets and provide two services: they maintain proper spacing between the tubes (for heat transfer performance) and they support the tubes (for physical integrity).

Indy beginning

The use of Micro tube heat exchangers in high performance automotive racing is believed to have begun in 2008 when Mezzo Technologies developed a radiator for the Andretti Green Racing (AGR) team in IndyCar. That product utilised about 15,000 stainless steel micro tubes with outer diameter of around 0.5mm. Wind

Wind tunnel testing showed it had superior characteristics in terms of good heat transfer and low air side pressure drop

© Chris Beaty

Left: A micro tube radiator as used in an IndyCar. Above: The same shown in the sidepod of the racecar

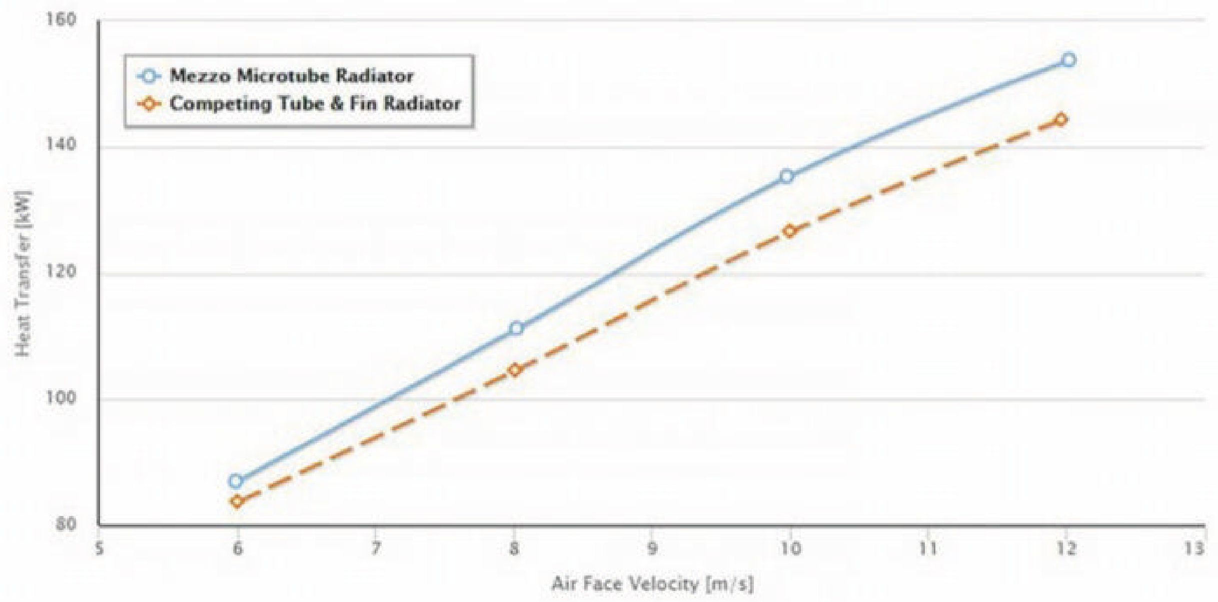


Figure 1: Typical comparison of a micro tube radiator using an in-line tube pattern versus plate-fin or tube-fin radiators

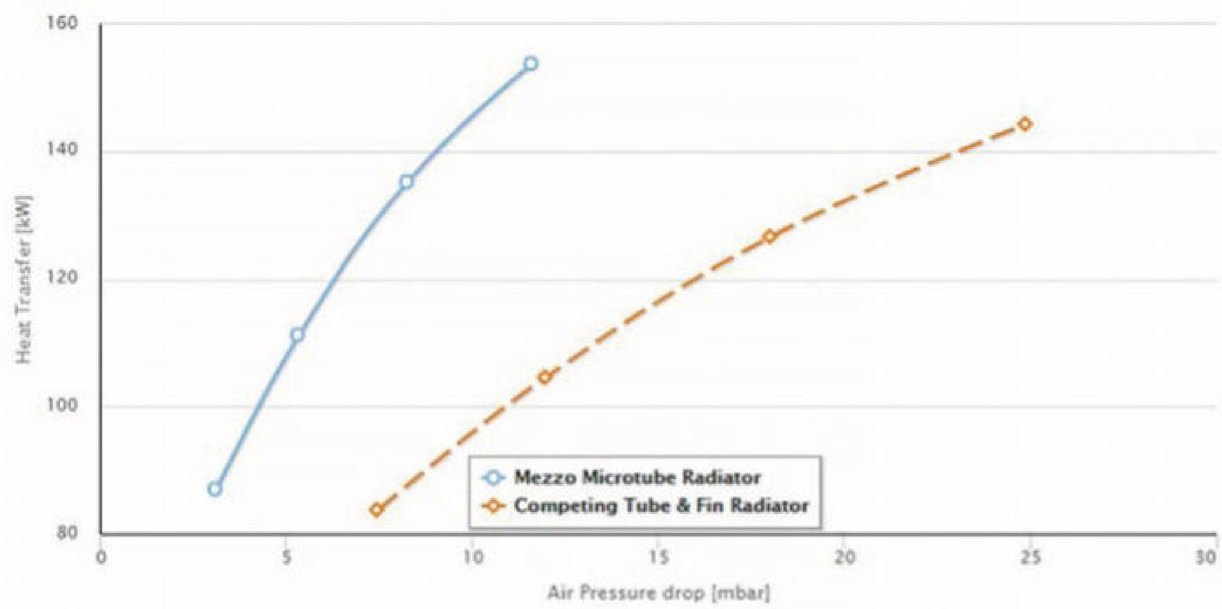


Figure 2: Comparison of heat transfer versus air-side pressure drop between micro tube radiators and tube-fin products

tunnel testing showed that the product had superior characteristics in terms of good heat transfer and low air side pressure drop.

Over the years, the design has changed slightly, and the current unit offers an excellent combination of thermal performance, durability (some IndyCar teams have used a single radiator for multiple seasons), and low maintenance cost (it is easy to clean, and there are no fins to unbend). This product is now widely used by most of the IndyCar teams.

Radiator tech

With radiators, micro tubes are usually patterned with in-line arrangements that promote low resistance to air flow while providing surprisingly good heat transfer. An in-line pattern involves placing tubes one behind the other in the direction of the air flow. **Figure 1** and **Figure 2** show typical thermal performance curves of micro tube radiators using an in-line pattern compared to aluminium-fin counterparts. **Figure 1** plots heat transfer versus air face velocity of both a micro tube radiator and an aluminium finned radiator for identical frontal areas and given air face velocities (if the frontal areas and air face velocities are equal, the air mass flow rate is also equal). In **Figure 1**, the micro tube product is shown to provide slightly more heat transfer than the aluminium finned product, but sometimes the differences are quite small.

The big difference between the products is shown in **Figure 2**, where the air-side pressure drop of the same two heat exchangers is compared. It is not uncommon for the micro tube product to provide an equal heat transfer while requiring 40 to 50 per cent lower air side pressure drop. It is up to the racecar designer to utilise this potential advantage.

An intriguing potential advantage of micro tube heat exchangers, which is only just beginning to be utilised more regularly, is the use of polymer micro tubes, to greatly reduce weight. Stainless steel micro tubes are used in the radiators shown on page 56. The mass of the micro tube radiator at the bottom of the page is slightly greater (on the order of 0.5-0.75kg out of a total of around 9kg wet weight) than the mass of the aluminium fin counterpart, and the tube mass of that total is around 5kg. If polymer tubes were used here the total radiator weight would decrease by around 4kg!

Polymer tubing can be substituted for the stainless-steel tubing with very little loss of thermal performance

Direct swap

The use of polymer tubes has great weight saving potential because the polymer tubing can be substituted directly for the stainless-steel tubing with very little loss of thermal performance. Micro tube heat exchangers are sometimes called primary surface heat exchangers because they do not rely on fins to increase the effective area of heat transfer between air and the solid structure. Fin-based architectures cannot effectively utilise relatively low thermal conductivity materials such as polymers without severely lowering performance. In the case of a micro tube product, the thermal resistance through the thin polymer tube wall is small compared to the thermal resistance associated with the air-tube wall interface. So, switching to polymer tubes provides a tremendous weight saving that can be added to the already excellent thermal performance of stainless-steel products.

Of course, polymer tubes are less damage tolerant than stainless-steel items, and are currently more expensive, while the upper temperature at which they can be used is between 100 and 120degC (depending upon the pressure and the polymer). But polymer tube products are seen to offer something extremely useful for battery-powered vehicles where coolant temperatures are relatively low (a fact that makes electric car cooling challenging).

Oil coolers

In high performance, top level racing, micro tube architecture is also often used in intercoolers and oil cooler applications, and the relative advantage of micro tube-based

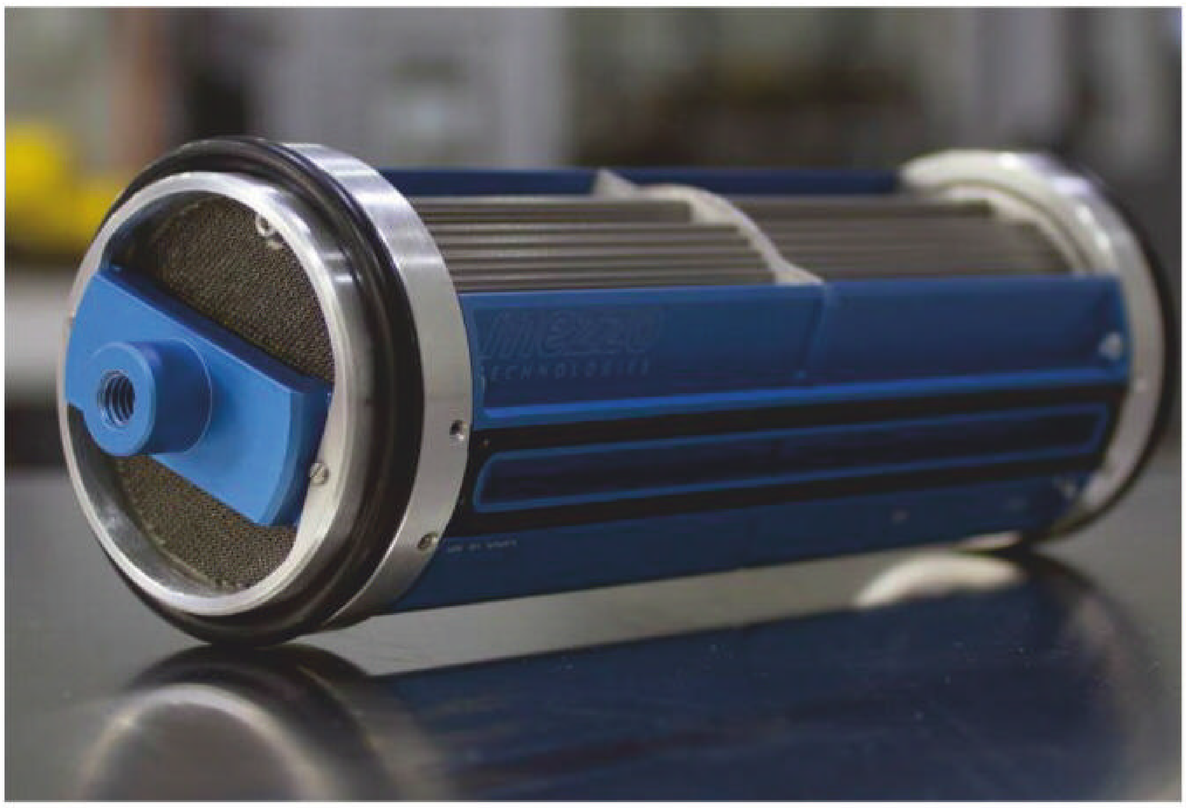
In high performance, top level racing micro tube architecture will often also be used in intercooler and oil cooler applications

Now other industries such as aerospace, defence and energy are beginning to discover niches where micro tubes provide advantages

products compared to competing approaches depends upon that application.

Focusing first on liquid-liquid applications, micro tube products are extremely compact and usually offer weight savings. One of the more common applications for which micro tubes are used are oil/coolant heat exchangers. It is almost always the case that the coolant flows inside the tubes, and the oil flows through the tortuous path over the outside of the tightly-packed bank of tubes. For a typical high-performance racecar (with about 50kW of required oil heat transfer, 30-40degC of inlet temperature differential, and a required effectiveness of 85 to 90 per cent), the core volume will be on the order of 0.5 litres, and the core mass will be between 0.5 and 0.75kg. These metrics compare favourably with the competing architectures.

Furthermore, the pressure drops of both fluids, especially the oil, is typically much lower than competing approaches. This is often a surprising result to the customer, who often expects higher pressure drop due to the narrow characteristic dimension of the flow passages. The low-pressure drops make it feasible to implement strategies where coolant or oil flows in series through heat exchangers in series.



Micro tube oil cooler core. The technology allows very compact pieces of equipment, thus reducing car weight

Micro tube intercooler. This example was used in drag racing and provided a good performance improvement

Intercoolers

Micro tubes provide an excellent platform for liquid-air intercoolers, whereas they are usually not a great starting point for air-air intercoolers. A micro-tube liquid-air intercooler can be very compact, lightweight, and offer great thermal performance, but it usually needs to be coupled to a high-performance radiator to give the customer full benefit. Intercoolers have been made in an increasing array of styles and complexity. An example is shown on this page (right). This intercooler was used in a drag racing application and provided substantial improvement by reducing charge air temperature to the engine and reduced pressure drop across the intercooler. It is fairly typical for an intercooler to provide an effectiveness above 99 per cent (meaning the air temperature exiting the intercooler will be in the order of 1-2degC greater than the temperature of the coolant entering the intercooler). Equally important, a properly designed liquid-air intercooler will require a minimal coolant flow rate (of the order of 10-15 litres per minute), which reduces the required size of the intercooler radiator.

Wider applications

As far as Mezzo Technologies is concerned, the high-performance automotive industry was the first industry to embrace the use of micro tubes. Now other industries such as aerospace, defence and energy are beginning to discover niches where micro tubes provide advantages over competing technologies.

The in-line tube patterns used in radiators provide excellent fouling resistance in extremely dusty environments – a fact that is important in certain military and aerospace applications. In addition, the low air-side pressure drop significantly reduces power consumption of fans which are routinely required in many military platforms (ground vehicles). In the energy sector, where power plants seek heat exchangers that can operate at increasingly aggressive combinations of high pressure and high temperature, micro tubes made from either stainless steel or high temperature nickel alloy provide a promising starting point – a micro tube is an efficient pressure vessel.

In conclusion, there are niches where micro tube heat exchanger products offer significant value to the customer, and the reasons a customer may find a micro tube heat exchanger solution attractive (or not attractive) depends very much upon the application. But it is also true that, at least for Mezzo Technologies, the eventual use of micro tube heat exchangers in a much wider variety of fields will always be indebted to the high-performance automotive racing industry – where it is all about risk-taking and rapid development.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Computer says yes

Racecar examines how simulation and automation has transformed the design and manufacture of composite parts, and considers whether this might signal the dawn of a 'fourth industrial revolution' approach to motorsport engineering

By GEMMA HATTON

One phrase often heard when a mistake is made in the high-pressure environment of motorsport is 'we're only human'. But this does little to justify and nothing to rectify the error. So, is there a way we can limit our mistakes in the first place?

People can, of course, improve themselves through practice, or they can improve the accuracy of the tools and equipment that they make use of. Or, alternatively, the human element can be removed all together.

It's this latter approach that modern simulation and machining techniques are now allowing within the composites industry, all of which is to do with what's described as a fourth industrial revolution termed 'Industry 4.0'. This is where technologies such as cyber-physical systems, Internet of Things (IoT), cloud based and cognitive computing, as well as automation, are completely transforming the way composites are designed and manufactured.

These new methods are already proving their worth in industries such as aerospace and automotive, but the question is: how automated can motorsport get when each part is effectively a complex, constantly evolving prototype?

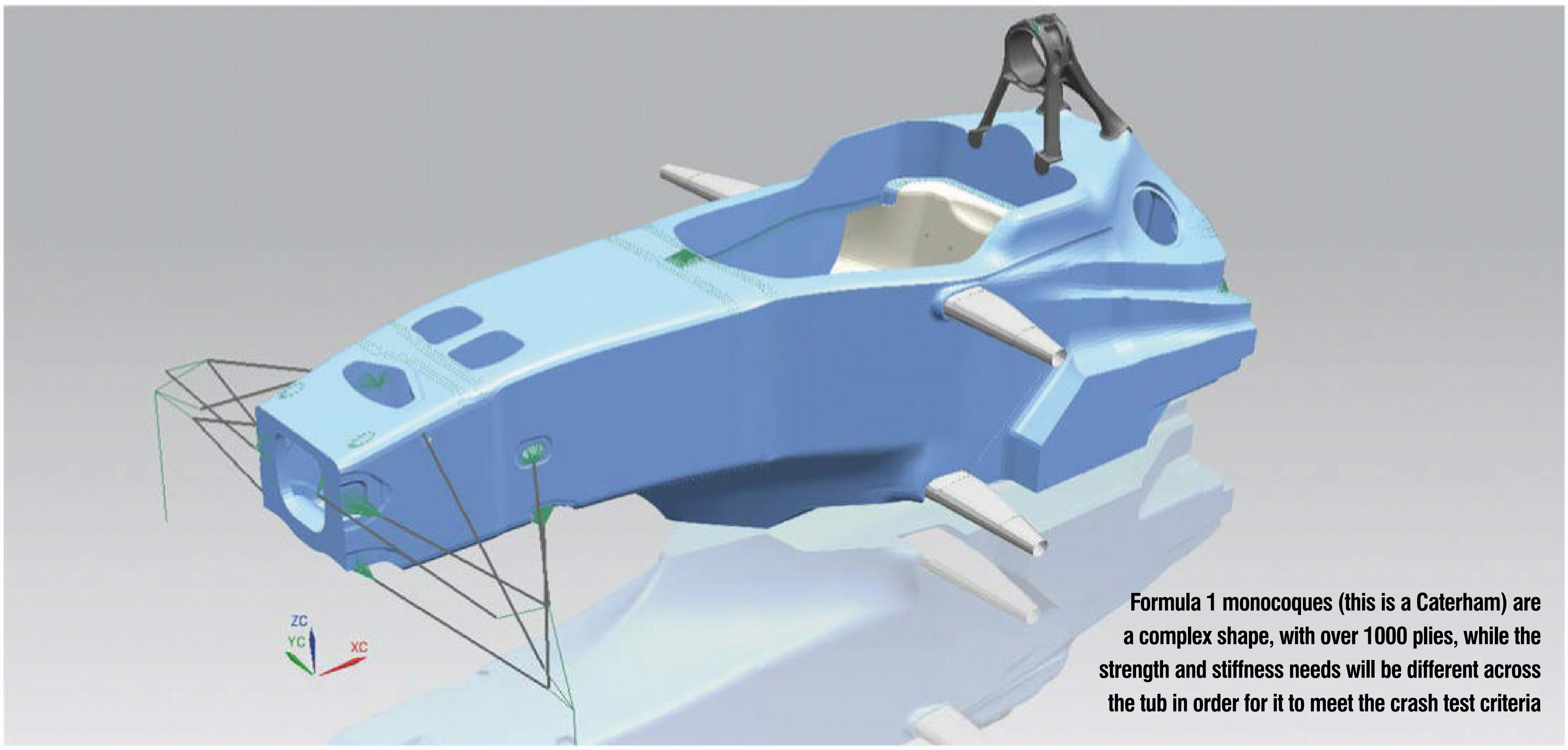
Finite and beyond

Unsurprisingly, the biggest steps over the last few years have been in simulation. Just like CFD is used to optimise aerodynamic performance, software tools are now used to optimise a composite part. This can include improving stiffness, strength to weight ratio, shape, as well as cost and manufacturability. But to improve these parameters they first need to be simulated, and this is where Finite Element Analysis (FEA) comes in.

FEA effectively simulates and predicts how a designed part would react to force, vibration, heat and many other physical effects. It does this by breaking down the part into hundreds of thousands of finite elements, often small cubes. Mathematical equations then predict how each element would react to the simulated inputs and these are all added together to predict the behaviour of the part as a whole. The results can show if and how a part would break, wear or defect, which can then be fed back into the design stage to improve the part's performance.

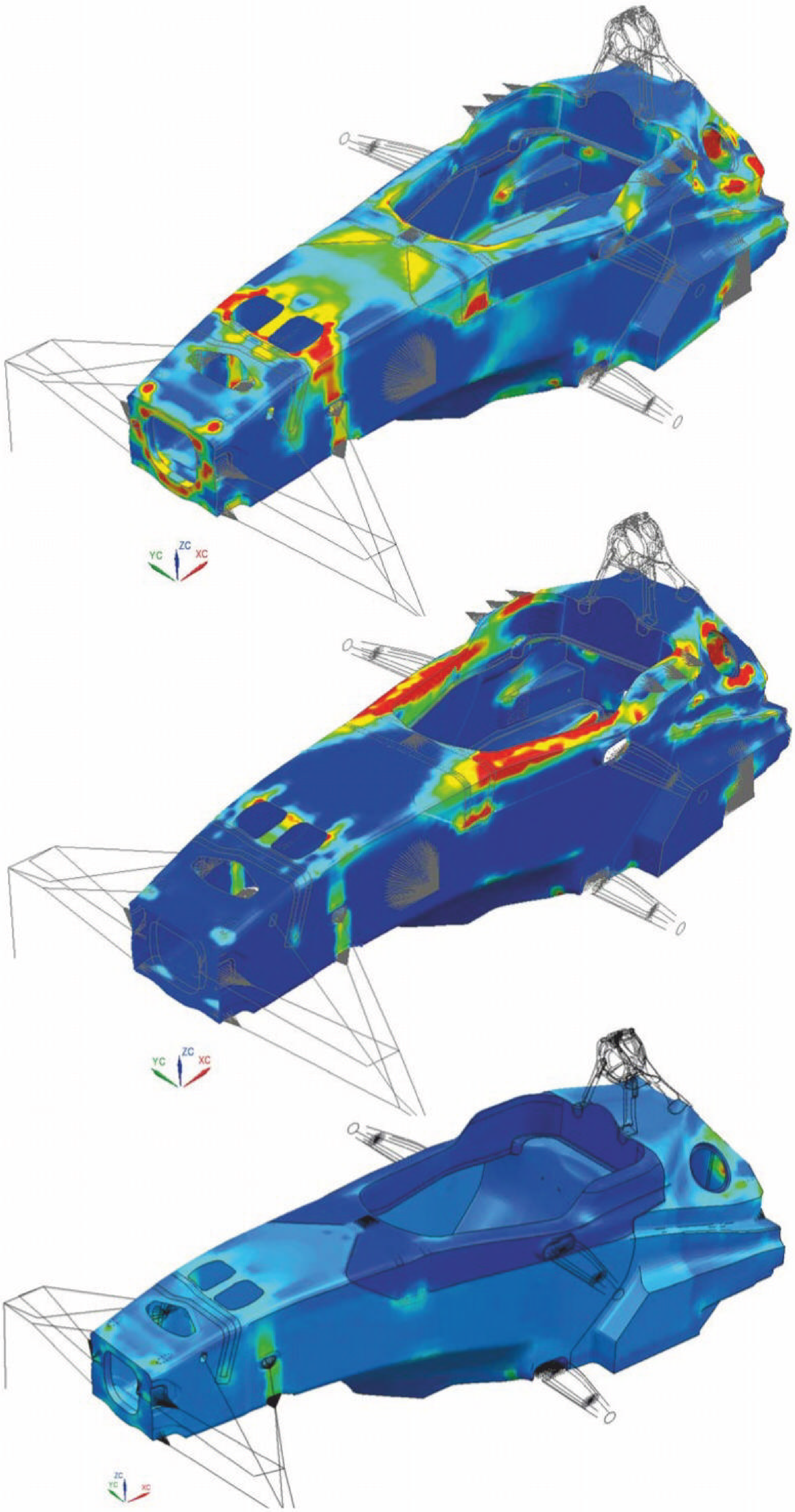
FEA has been utilised for optimising designs for decades, but modern simulation tools now incorporate a whole host of other capabilities as well. 'Our advanced composite modelling software is a multi-scale technology which means we can simulate everything from the molecules at the microscale, right through to the coupon level, the part and even an entire system of parts,' says Sami Daouk, business development manager at E-Xstream Engineering, part of Hexagon's Manufacturing Intelligence division. 'So the software can really help engineers to model and understand the complex non-linear behaviour of the composite throughout its life cycle. We actually bridge

Just like CFD is used to optimise aerodynamics, software tools are now used to improve the performance of a composite part



Formula 1 monocoques (this is a Caterham) are a complex shape, with over 1000 plies, while the strength and stiffness needs will be different across the tub in order for it to meet the crash test criteria

Optiassist helps engineers to design the ply shapes and pattern to meet strength, stiffness and weight requirements. Here we can see the progression from the cloth fibre thickness (top right) to the UD fibre thickness (middle right) and the final optimised chassis (bottom right)



the gap between the virtual world and the real world and ensure that we are heading to a composite industry 4.0 future.'

These tools are not only helping engineers to understand the behaviour of composites more than ever before, but achieving this in shorter time-scales; reducing development times.

High fibre

Another technique now used across motorsport is 'laminate optimisation'. Composites are made up of several layers or plies of reinforcement fibre. These fibres carry load along their length, providing strength and stiffness in one direction. But when subjected to compression and bending loads the fibres become weak. Therefore, fibres are embedded in a polymer matrix such as a cured resin. This resin not only binds the fibres together, but also provides support, allowing them to absorb higher compressive loads as well as helping them to transfer shear stresses. As a result, external loads are more evenly distributed across the fibres in a composite compared to fibres in a dry bundle.

To improve the properties further, layers of plies are stacked on top of each other onto a mould at different orientations and then bonded together. This results in a composite structure or laminate which achieves the desired properties in the desired directions for a specific application. By modifying the orientation and number of plies, engineers have the ability to tune the material properties within a part, which is a powerful tool within the harsh, expensive and rapid environment of motorsport.

Previously, an engineer would define the requirements such as the load cases, the materials available, the regulatory volumes, the allowable deflection, cost and so on, and then determine the number and orientation of plies required to meet these targets. Simulation tools such as FEA would then be used to simulate the stresses the part would be subjected to. The results would then be analysed and the engineer would optimise the design. The process would repeat until the part achieved the desired performance.

Take the example of an F1 monocoque. Not only is it a complex shape with over 1000 plies, but the strength and stiffness requirements

'You still need a pragmatic engineer to look at results and determine whether they are sensible'

Mathematical algorithms can not only reach a solution quicker, but they will also often achieve a more accurate answer

are continuously changing throughout the topology of the part in order to meet all the load cases resulting from the 20-plus FIA crash tests it needs to undergo. Factor in regulatory materials and volumes, cost and manufacturability, and how on earth does the engineer know where to put which ply? It is a near impossible task for a human to complete within the time available, but for algorithms it's a piece of cake.

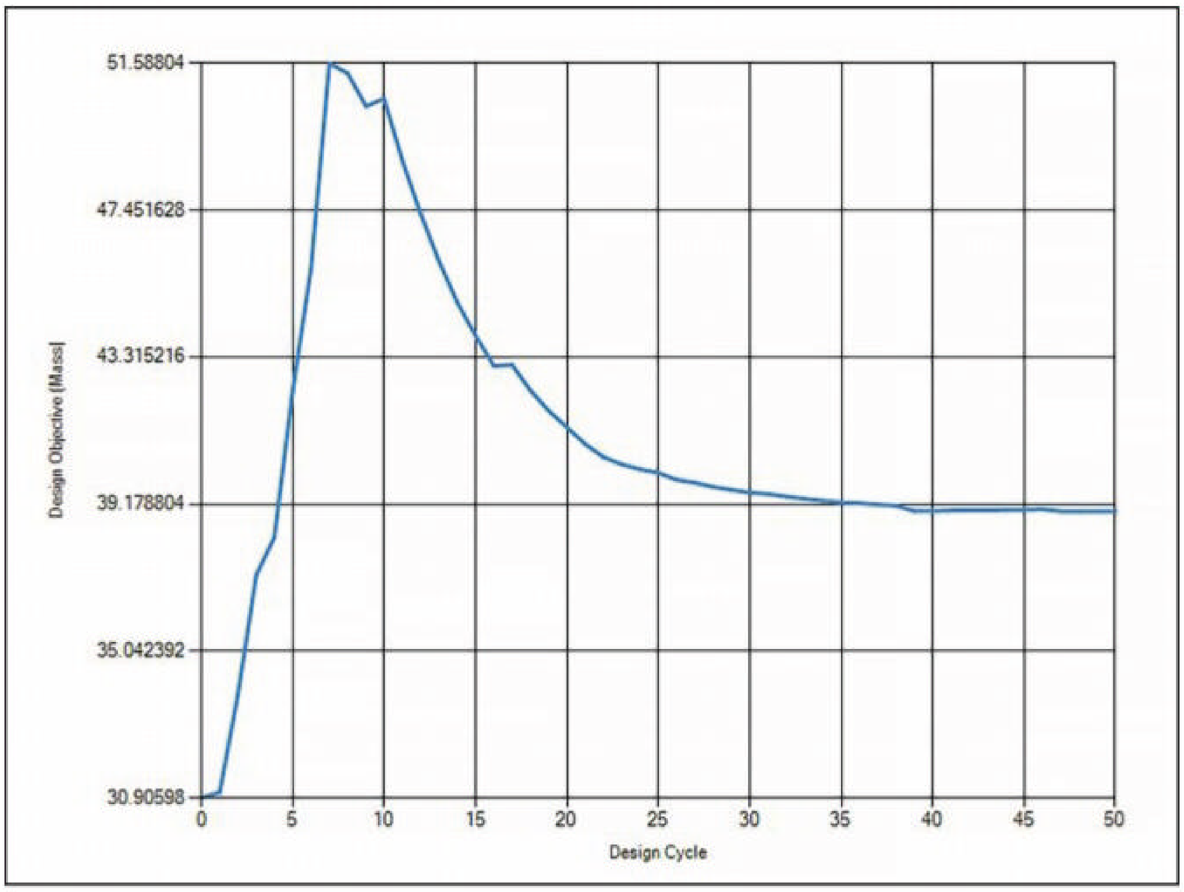
Computing power

In fact, given the right information, mathematical algorithms can not only reach an answer quicker, but they can often achieve a more accurate answer, because the computational power has allowed the software to iterate through hundreds of design variants – which could never be achieved by a human

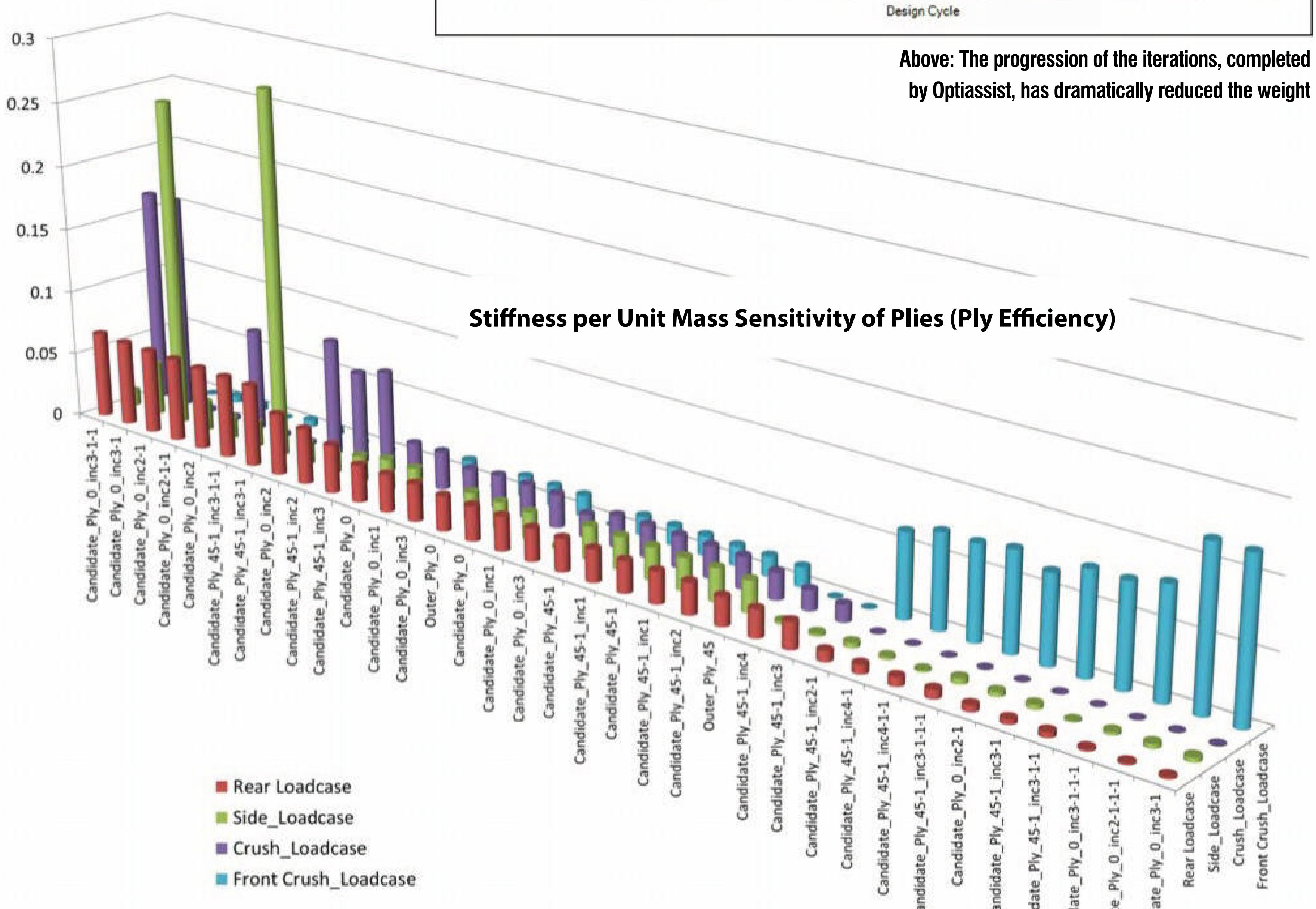
'In motorsport, and particularly in F1, aerodynamics is so dominant, the aero guys are all trying to extract as much aero performance out of a part as is possible,' says Martin Gambling, managing director at GRM Consulting. 'This means that they release the final surfaces at the very last moment possible, leaving minimal time for the stress engineers to optimise the part. From speaking to teams I found that, in the past, this iteration process was not happening anywhere near as [fast] as the stress engineers wanted it to.'

So, to help achieve the desired number of design iterations within the short time-scales of motorsport, GRM Consulting developed a laminate optimisation software called Optiassist

'These types of tools give you the ability to design a very complicated structure such as an F1 monocoque,' explains John McQuillam, director of engineering at Prodrive composites. 'You input all of the requirements such as the load cases, areas of prescribed laminates such as the side penetration laminate area, as well as the extra materials and different orientations that you want to make the structure from. The software has an algorithm which basically runs



Above: The progression of the iterations, completed by Optiassist, has dramatically reduced the weight



Sensitivity analysis. This helps engineers to identify which plies are the most important to optimise for each load case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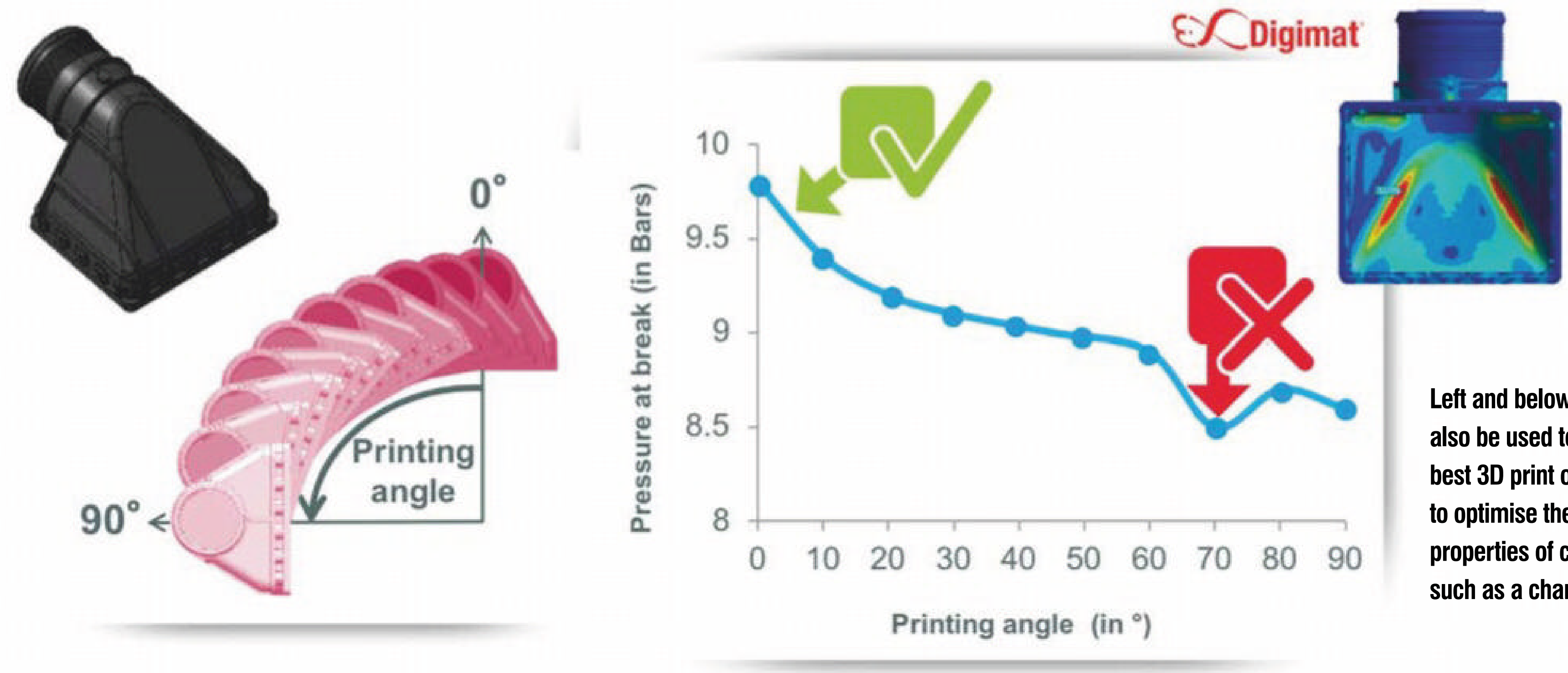
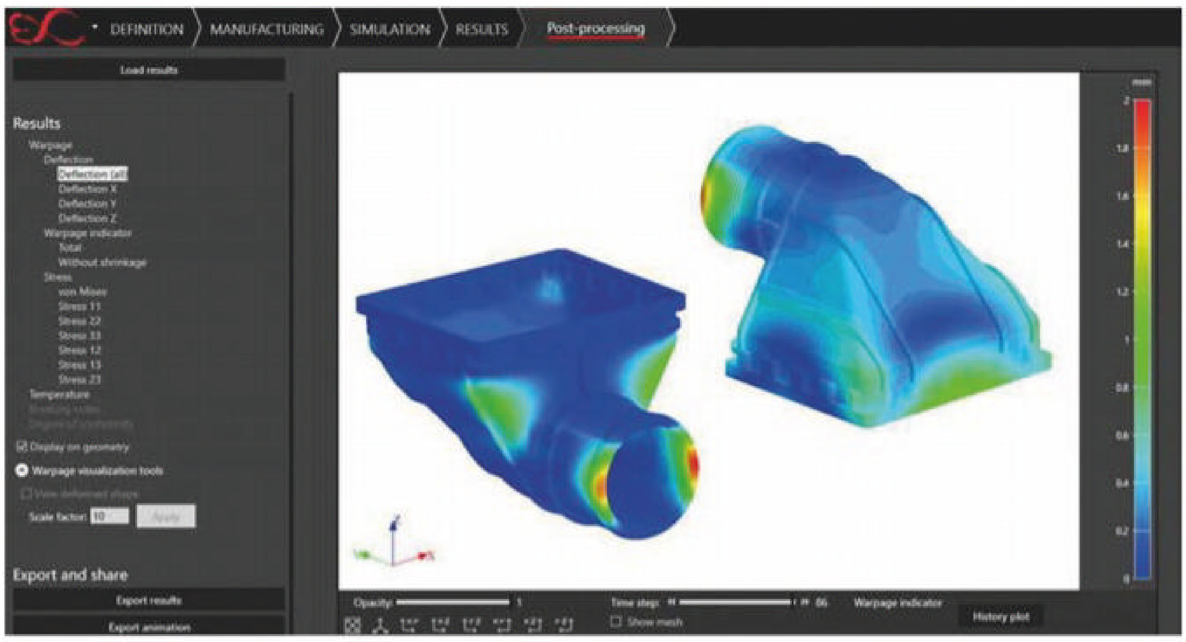


Left and below: Digimat can also be used to simulate the best 3D print orientations to optimise the mechanical properties of composite parts such as a charge air cooler

the FEA, it can then look at the results and see the trends from making small adjustments to areas and number of plies and either backtracks on that adjustment or takes another step in that direction depending on whether it was beneficial or not. So effectively the FEA is performed after each step of this iteration loop and the software will go through all the different permutations until it reaches an optimised solution based on your input requirements.'

'The software will output a laminate thickness for the component, as well as the optimum fibre orientation,' says Phil Charles, technical manager at Formula E team Panasonic Jaguar Racing, which has used Optiassist for both composite and non-composite parts. 'We can then ask the software to optimise the laminate in patches of different sizes or to freely define an optimum laminate at any location. It is particularly useful to reduce the mass of the component and helps us define the final laminate before going into production. In Formula E, as we are limited by the amount of electrical energy we can use, having the lightest car possible is very important. Even if we achieve the minimum weight for the car, we are still trying to lower the centre of gravity and so the desire to reduce the mass of the components never ends. Laminate optimisation plays a significant role in this development process.'



Images: Solvay

Human touch

Of course, we all understand that computers make mistakes, too. Therefore, as ever with engineering, the results need to be further scrutinised with common sense and a level of scepticism. 'I still believe you need a pragmatic engineer to look at those results and determine whether they are sensible or not,' says McQuillam. 'You can then run another round of FEA just as a final verification that that structure is adequate on stiffness and strength. In this way you are combining the power of computing with the sanity of an engineer. If you know what you're doing with this type of software then it really is a game changer.'

'Optiassist was not designed to replace the engineer, in fact if a good engineer can inform the software of the limitations, then that's when you get the most out of it,' says Gambling. 'It's a tool that guides the engineers. Engineers can be quite clever, and so can computer programmes, but together they can begin to achieve incredible things.'

But the vast amount of calculations conducted by laminate optimisation software requires a substantial amount of computing power, with some engineers estimating that the magnitude of calculations and waiting times are on par with that of CFD software.

Gambling says: 'Chassis' are a big challenge for optimisation software, because the teams use large FEA models that have a high complexity and many load cases, which can take 45 minutes to solve, for example. But when you want to optimise something, the software

This kit cutting machine, which is used in conjunction with a digital manual, provides the laminators with everything they need in order to accurately lay-up a composite component in a repeatable way

The vast amount of calculations conducted by laminate optimisation software packages does require substantial computing power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Laser systems and video systems can be used in order to further improve the accuracy of positioning the plies on the mould tool

could need up to 30 variations to get the optimum answer. The engineer might then want to conduct several studies to ensure all the load cases have been simulated.

'So to really understand the system and fully explore the design opportunities you may have to run a 45-minute model through 30 iterations for 10 different studies, which is a lot of computing time,' Gambling continues. 'To get round this you can run a sensitivity analysis. For example, if you haven't got time to run a full optimisation and you just want to understand which plies are doing the most work for a variety of load cases then you can run a transient analysis. This will simply rank all the plies in order of importance for each load case.'

Interestingly, this laminate optimisation technique is not new. In Formula 1, the first composite monocoque came in in 1981, with teams starting to run FEA simulations in the mid-1990s. As the demand for simulation grew, so did computing capabilities, and by 2004 several teams started to use optimisation software for the development of their laminates, and 2005 saw the first championship-winning car that had utilised this type of software within its design process. The popularity of these simulations has continued to grow ever since.

Manufacturing

Once the design has been finalised, the next challenge is to manufacture it. Although the parts manufacturability would have been considered within the design process, being able to actually make the component to the required accuracy as well as repeating this accuracy for a batch of parts is a challenge for even the most experienced laminators. So surely automation is applicable here?

'Repeatability is absolutely essential in motorsport, particularly for parts like crash structures,' says McQuillam. 'Usually you would complete a private test without the FIA present and once you are happy with the results you then want an exact replica for the official test with the FIA, because the stakes are higher. The way to achieve that is to make sure there is no laminator's liberty, so every single piece of carbon fibre needs to be fully defined. So we have a CNC kit cutting machine which cuts out all the pieces of material to the correct size and shape and also labels it with a unique identifier code for extra clarity. Each laminator receives the same kit and a digital manual that specifies the exact location of each ply as well as all of the overlap conditions, to try and remove the human variability.'

To further improve the accuracy of positioning the plies on the mould tool, laser systems and video systems can be used. The former has lasers incorporated into the ceiling which then project a beam onto the mould tool, signalling the location and orientation of each ply. However, to lay-up the plies, the laminators naturally have to move over the mould tool, and so block the line of sight. Lasers also can't be used when laying up parts like nose boxes, whereas video systems can. This alternative combines the actual image of the mould tool and the ply that is being placed on a screen with a virtual image of the ply as it should be derived from 3D CAD, but to physically place it the laminator has to look away from the screen to ensure its been placed correctly.

'I've heard it described as it's similar to shaving in the mirror. It's not quite right but you get used to it very quickly,' says McQuillam. 'There have also been developments in virtual reality where headsets superimpose the image of the ply onto the mould tool, but there can be a slight time delay. So just like racing simulators, it can make some people feel nauseous if they turn their head and what they "see" hasn't moved. Both the video and lasers are good systems which again just takes away that human interpretation and can pinpoint the exact location of each ply to within a millimetre.'

Post process

Another area which sees automation is the post processing. Five-axis CNC machines now play a huge role in the drilling and trimming of composite parts and in motorsport are regularly used for gearbox cases and wishbones. Meanwhile, autoclaves are now completely computer controlled with accurate heat up rates, dwell times and pressure profiles to achieve a reliable cure cycle for each part.

However, the majority of high-end motorsport parts are still made by hand lay-up, which in today's techno-era seems almost ancient, particularly with the rapid production rates required in the sport. But might there be a robot that could do the job?

'Hand lay-up has been done for decades and there doesn't seem to be a drive to change that,' says Christian Fleischfresser, business development manager of composites solution provider, Cevotec. 'The status quo in the industry is in the hand lay-up of small production volumes, which requires high skilled labour that is expensive and hard to find. Other problems include the low repeatability of most parts, as well as high scrap rates.

'A solution to these difficulties could be automation, but does this make sense in motorsports? The low production volumes, high variety, high complexity and continuous development of parts suggest not,' Fleischfresser continues. 'However, motorsport also has short development times and it requires high production flexibility to quickly increase productivity of replacement parts, during a race, for example. Therefore, I believe that there is an application for a flexible 3D fibre lay-up platform in motorsport, based on Fibre Patch Placement technology.'

While there's ever more automation in motorsport composites much of the skilled work is still done by hand

Patching up

Fibre Patch Placement technology is based on laying up individual patches of prepreg or dry fibre tape directly onto a complex 3D mould. A vision inspection station checks for correct patch sizes and patch position, whilst discarding those with material defects and ensuring that only good-quality material is used in the final part. A robotic arm then picks up the patch and a second vision inspection station checks the position of the patch relative to the gripper. Any deviations are corrected on the fly before laying the material on the tool. This automated process can be completed within a few seconds.

'One thing that is very interesting about Fibre Patch Placement is that because you are placing individual patches you can really tailor the exact orientation of the fibres to suit the load cases,' says Fleischfresser. 'Furthermore, one machine is capable of delivering several different types of parts, you just need to change the programme and the tool – just like with CNC machining.'

Gripping stuff

Of course, there is quite a lot of science behind delivering such flexible automation. The gripper, for example, must be flexible enough to follow the curvature of the mould, allowing consistent pressure to be applied evenly across the entire patch to ensure it has adhered to the mould and expelled any air bubbles. Different gripper sizes can also be used to suit the application, with smaller grippers used for intricate components with high complexity, while larger grippers are better for simpler geometries and higher throughput rates.

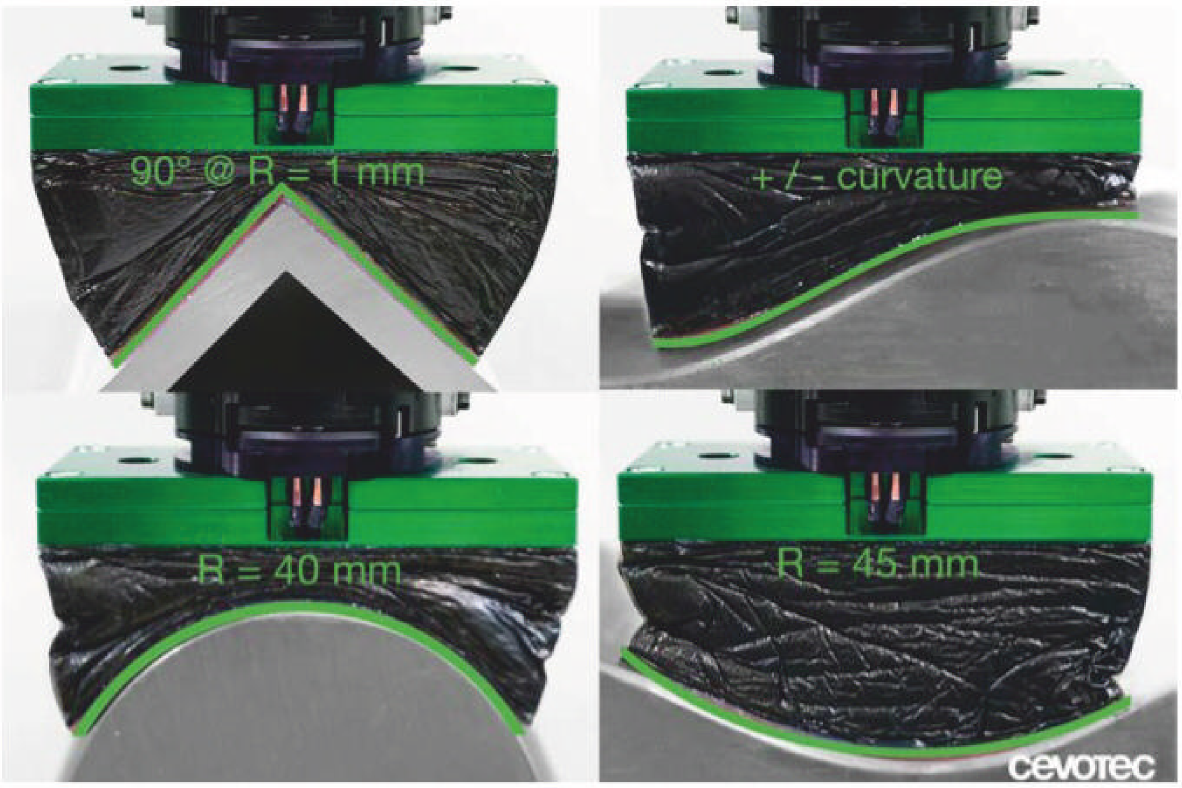
The patches themselves can also range in size from 12.5x50mm to A4 size. However, dividing a carbon fibre ply into many small patches can lead to gaps and overlaps within the same ply when the chain of patches is curved. This can cause unwanted thickness variations. To tackle this issue, Cevotec has developed a laminate design software called Patch Artist which allows the user to specify the gap and overlap limits as well as optimise these boundaries to evenly distribute these variations throughout the part.

'Our technology can minimise the effects of overlapping patches within the same layer,' explains Fleischfresser, adding: 'But the overlaps *between* the layers is essential for the transfer of loads throughout the part.'

Tight corners

Another restriction to this automation process is the laying up of female moulds. Current gripper designs can patch minimum internal radii of 12mm, which can be limiting for tight, intricate corners, often found in motorsport parts. 'It's possible for our robots to work with female moulds, but they are better for male moulds because there are limitations of where a robotic arm can actually reach. But we believe that parts such as bonnets, roofs, spoilers and maybe even the main elements of front and rear wings can be automatically manufactured in this way,' says Fleischfresser.

'Most of these automated composite processes use materials that are different to what motorsport traditionally uses, says McQuillam. 'So they put down strips of typically unidirectional material, either dry or impregnated with a thermoset or thermoplastic, and they are effectively doing it like a broad brush stroke. On the other hand it is very easy for a human to lay down a piece of high performance prepreg material and be able to manipulate it into the corners and around any joggles or recesses in the part.'



Fibre Patch Placement. Consistent pressure needs to be applied to the patch, whatever shape the mould is

The mould is controlled by a robot and it is able to rotate and move freely as the tape is being applied to it

For larger, simpler and repeatable parts there is no question that fibre placement is a necessity

Then there is the cost benefit analysis. For larger, simpler and repeatable components there is no question that fibre placement is a necessity, which is why aerospace composite factories are now nearly fully automated. But the varying demands of motorsport and the engineering required to ensure a part exhibits motorsport-spec quality is intensive.

'We work on a rule of thumb that it takes approximately 10 times longer to do the engineering for a part than it is to physically make the part,' McQuillam says. 'So if something can be made in four or five hours, that equates to about a week's work for engineering to fully define the processes so that anyone could complete those four hours of work and make the part in exactly the same way. If you are not making 10 parts or more and there's not the need for perfect repeatability, then it's quicker and cheaper to miss out this stage. Let's say it takes five hours to make a part, that's 50 hours of engineering, and if you only need five, its only 25 hours of manufacturing, so the numbers just don't stack up.

'It's said that you are only as good as the day you're having and fortunately motorsport is full of highly motivated and skilled people who mostly have good days, so the confidence in a part manufactured by hand is already quite high,' McQuillam adds. 'Whereas the robot doesn't have an opinion on whether it's right or wrong because it's incapable of having the vast amount of in-process monitoring and feedback loops that a human has. These things are all possible, though, but introducing any new technology, product or process into the competitive world of motor racing adds several more layers of complexity.'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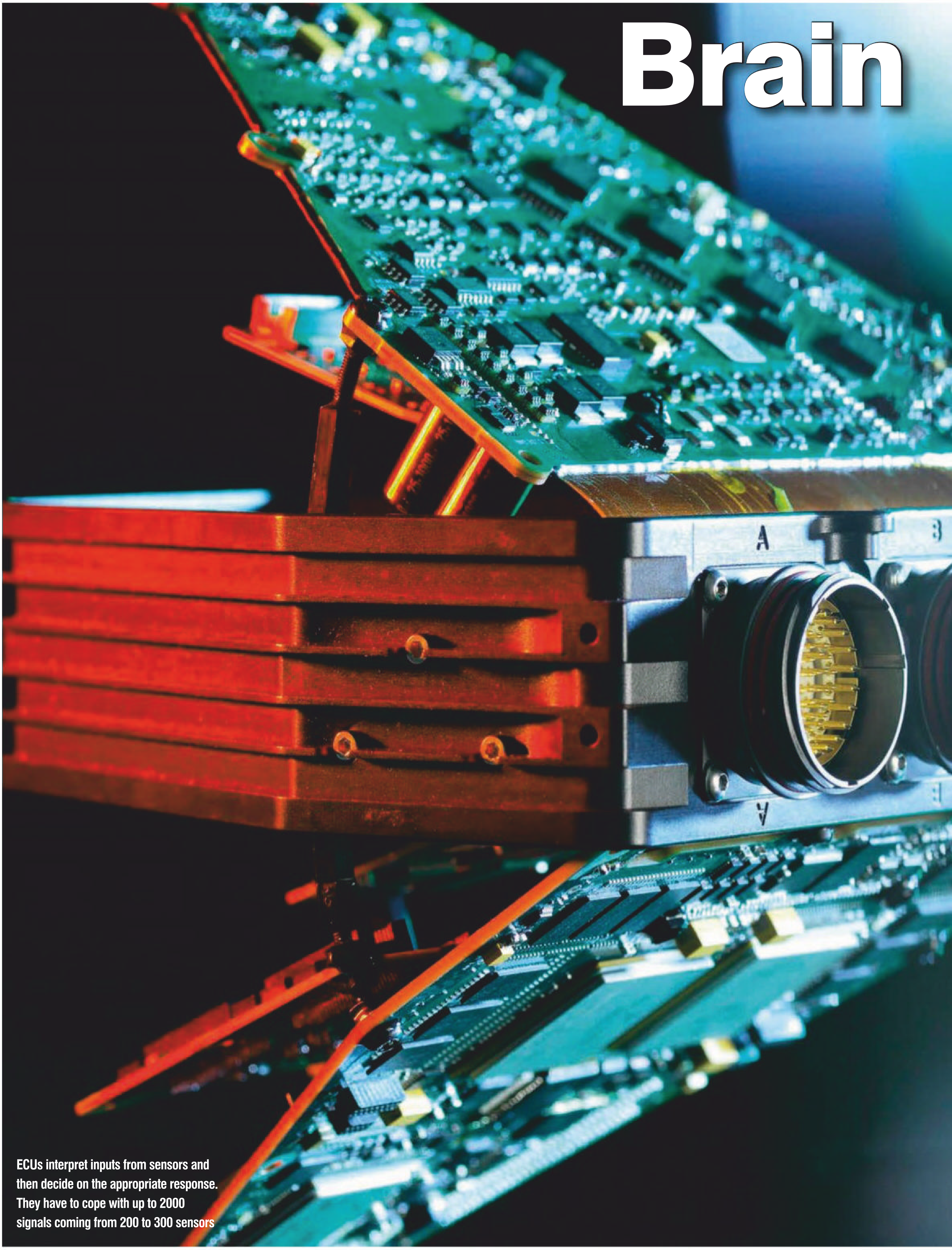
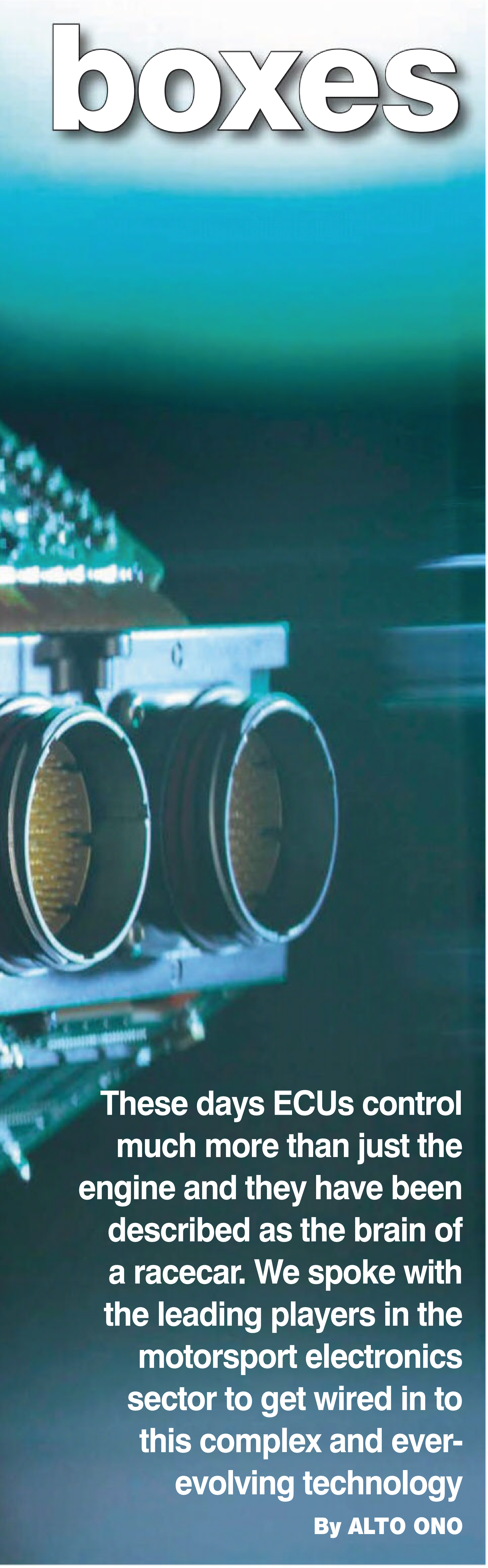


ECUs interpret inputs from sensors and then decide on the appropriate response. They have to cope with up to 2000 signals coming from 200 to 300 sensors



boxes

These days ECUs control much more than just the engine and they have been described as the brain of a racecar. We spoke with the leading players in the motorsport electronics sector to get wired in to this complex and ever-evolving technology

By ALTO ONO

Engine Control Units, more commonly known as ECUs, are an integral part of any modern-day vehicle. Whether you drive a hatchback on the road or an open-wheel racecar on the track, the ECU controls vital parts of the vehicle to ensure that your inputs turn into actions.

Modern day ECUs are a far cry from the earliest forms of engine control system, developed by BMW for its 14-cylinder aviation engines in the '40s. Gone are the open looped analogue controls of the '70s and '80s, too, and replacing them are completely digital ECUs making thousands of decisions per second.

'The ECU is like our brains,' says Rodi Basso, motorsport business director at McLaren Applied Technologies. 'We have our senses, and the brain translates our five senses into actions by actuating the muscles for a reaction. This is exactly what an ECU does for the car'.

The number of sensors on modern racecars can range anywhere from 200 to 300, with the total amount of signals amounting to a whopping 2000, either from direct or derived measurements. 'All these inputs come into the ECU for decisions to be made in real time,' Basso says. 'The responses are then carried out by actuators to improve the performance and guarantee the reliability of the car.'

Command and control

These actuators can fulfil traditional ECU purposes such as fuel, spark, or valve timing to control the engine; or create smoother and faster shifts in the gearbox. But the days when ECUs only served the function of adjusting fuel mixture, ignition timing, and boost pressure are far behind us and more chassis related controls are now being carried out by the ECU as well.

'Over the last 10 to 15 years, the box has evolved to become much more than just the thing that runs the engine,' says Tom Roberts, application engineer at Cosworth. 'It became much more intrinsic to the entire control system of the car. Now, the term "VCU" is being thrown around a lot, which stands for "Vehicle Control Unit". And that kind of reflects the direction that we see in the technology movement.'

The variety of power units in modern racecars are greater than ever. From naturally aspirated V8 Supercars, to the most complex hybrid turbo V6 engines in F1, and to completely electric solutions in Formula E, the sport is full of differing powertrain layouts. This presents ECU manufacturers with a unique challenge. For example, F1 engines can go up to 15,000rpm, which means that at this speed, each revolution takes roughly four milliseconds. During this short time, multiple ignition or injection events are occurring as there are six cylinders. Furthermore, with the exhaust turbines of modern F1 engines capable of spinning beyond 120,000rpm it is easy to understand that the frequency at which an ECU must sense, log, and respond has grown exponentially. This has led to the most obvious improvement in modern ECUs, the processing power.

'If you're trying to control a vehicle where you have both an engine and electric motor, you've now doubled your requirements,' Roberts says. But increasing processing power and running at such high frequencies all the time would not only drastically increase power requirements and cost, but also the amount of data that would have to be stored.

To combat this, 'now, ECUs have developed systems so that you can increase the frequency only for specific events,' says Basso. This means that a specific action, for example a gearshift, could trigger the ECU to increase its frequency in order to ensure that the right level of synchronisation can occur. This allows the rest of the system to operate at a lower frequency level under normal operation, thus conserving power and bandwidth, but gives the flexibility and functionality of performing events at high synchronisation levels.

Following this trend, Cosworth is also introducing a next-generation of ECU with high-speed logging being utilised for in-cylinder pressure measurements. While obtaining in-cylinder pressure measurements have been done for a fairly long time on engine dynamometers, being able to measure and respond on the fly, in the vehicle on the track, is pioneering technology. By integrating this on the ECU, this technology could pave the way for a very advanced pre-ignition control system and give teams an edge on engine control.

Taking control

But controlling different types of powertrains is not the only way advances in hardware are being utilised in ECUs. With the focus on efficiency and reliability becoming more prevalent than ever in motorsport, race strategies are playing a larger role than ever. A few years ago, deploying custom strategies for each race series or even racecar meant that these had to be developed individually and tested, which could take months. However, ECU manufacturers are now rapidly moving to create a single unified base layer software to conduct basic ECU functions for all applications and then

> 'We have definitely seen a much bigger uptake in customers opting to do their own custom strategies'

adding customised applications or software layers on top for each individual use case. This means that series organisers, OEMs, or race teams can take matters into their own hands to build their own strategies.

'We offer basic software that will run an engine,' Roberts says. 'I say basic, but it is an extremely complex piece of software that will run your engine as much as you need. But now we have an additional interface with the ECU that can be programmed with Simulink or MATLAB. Here, either we can create strategies in the Simulink environment, or the customer can create them. If the customer creates them, then even we don't get any visibility, so they then get full confidentiality.

'We've definitely seen a much bigger uptake in customers opting to do their own custom strategies,' Roberts adds. 'And the real benefit of that is, if the strategy is not quite working how you want it to work and you're at the side of the race track testing, you can change your Simulink model on the fly, so you can very quickly improve and iterate and resolve issues.'

Tom Hyder, head of motorsport R&D at Magneti Marelli, echoes this point. 'By utilising a single software architecture, it allows us to rapidly customise for each series,' he says.

In series

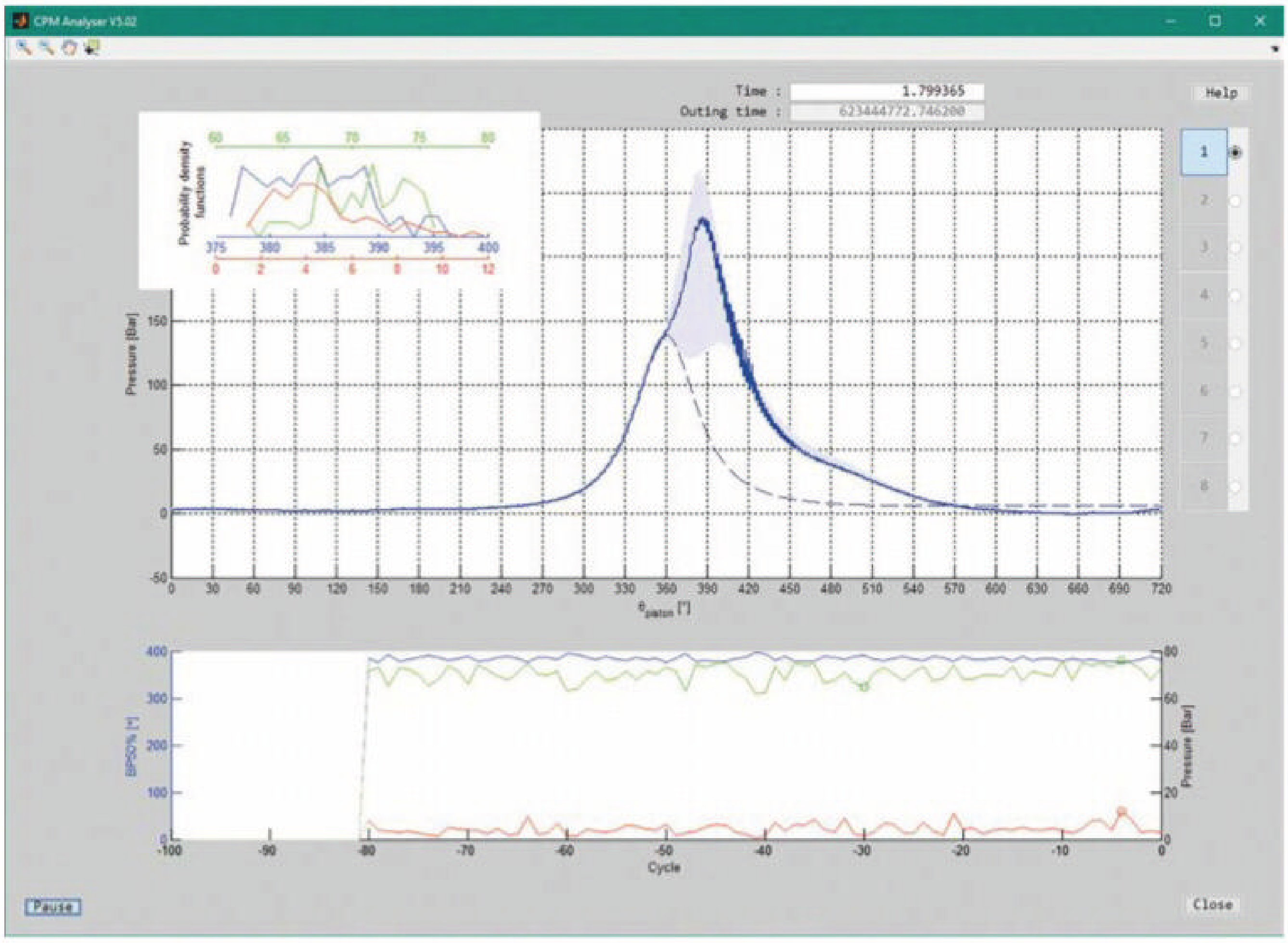
But for a series supplier this also means that accurate models are more important than ever, while understanding the diverse environments an ECU may encounter is vital. 'There is a lot of domain knowledge required in modelling, especially to understand what to expect from the signals before even getting the measurement,' Basso says. 'This is a, sort of, future treatment control so that you keep forecasting what's happening next. And when the measure does come in, you can then say, "Okay, this is reasonable? Is this possible?" If the criteria are met, the ECU can then start crunching the numbers and respond.'

With race ECUs now being developed with a single base layer software which enables them to have a wide range of functions the gap between the race and the road car is shrinking. 'Our ECUs and any modern motorsport ECU can do pretty much anything,' Roberts explains, 'So the ECU in your car probably can't run a racecar, but an ECU from a racecar could run your car. The idea has always been to remain flexible so that we have an ECU that can run a direct injection V8 or it can run a hybrid V4, or even a motorcycle. We want to try and be in a position that it can run absolutely any engine that a customer could come up with.'

And while the ECUs in most consumer level cars are not necessarily derived from racecar technology, some supercar and hypercars are seeing this technology trickle down. Because modern racecar ECUs allows for the development of custom features on top of the baseline software architecture, it provides McLaren automotive with a unique opportunity as both a luxury supercar manufacturer and as an ECU supplier. 'For some models of McLaren Automotive vehicles, we provide a hardware and software platform and they are able to plug in with their specific application,' Basso says. 'This allows the automotive team to change features like traction control or yaw control or some specific feature that we left enough flexibility in the software for, to enhance the driving experience and the excitement.'

However, automotive ECUs overall continue to be very different from motorsport ECUs, as they are more cost driven due to the large number of production units. Motorsport ECUs, on the other hand, generally tend to still be manufactured at prototype-level quantities and are often hand assembled. That said, specific technologies are likely to trickle down to the automotive sector as more OEMs explore cutting-edge control strategies in motorsport.

ECU traditionally stood for 'Engine' Control Unit, but these days it makes more sense to call it an 'Electronic' Control Unit



Using MATLAB and Simulink teams can create and deploy their own control strategies for the Cosworth Antares ECU

Quality control

Because motorsport ECUs are collecting more data than ever, one of the unique challenges they face is the safety, quality, and distribution of data. With Formula 1 cars reportedly collecting up to 300GB of data a race, one of the most important things is to ensure that the ECU is receiving uncorrupted data. Not only does each piece of information have to pass a series of inspections before it gets computed, the ECU constantly checks with its own internal models to ensure that the output signal is also reasonable. As this must all be done in real-time, there is an incredible amount of data that must be moved in a very short amount of time.

With Formula 1 cars reportedly collecting up to 300GB of information a race it's important to ensure that the ECU is receiving uncorrupted data

Magneti Marelli's SRG-340 is compatible with the Global Race Engine. It can log up to 2kHz across 250 channels

'The ECU in your road car probably can't run a racecar, but an ECU from a racecar could run your road car'

As well as controlling most of the racecar functions ECUs can also be used to communicate information to data loggers such as the FBO unit from Magneti Marelli

'What makes our industry unique is the density of data moving out,' Basso says. 'When I say density, it is the amount of data per second that you need to measure. That's what we call here in McLaren the digital journey or the data's journey. We have to measure, input, and elaborate, make a decision and move forward.'

Secure data

But the importance of the quality and security of data goes beyond the race track. In homologated racing series, it is important for organisers to ensure that teams are 'using engines according to spec and only using homologated software,' Hyder says. And with racing series such as Formula 1, where multiple stakeholders including the teams, the regulating body (FIA), the promotional company (FOM), and engine manufacturers are involved, the distribution of data must also be secure.

'There are all these different actors who may have the need to see data but they don't want the same data being seen by the other stakeholders, or they may want to distribute the data to everyone by a different sample frequency,' Basso says. 'This takes a lot of effort because it's a really key point for making sure that the show is fair and there is no corrupted data or wrong messages going around.'

With such a broad range of applications for ECUs, it can be difficult to imagine how the development cycle of an ECU begins. In most cases, this starts with a customer's specific requirements for new functionality. This allows manufacturers to develop an ECU that meets that particular customer's needs, but also technology that could later be implemented in other models. While most of the development cycle remains common between OEM and regulators as customers, there are some subtle differences in the approach.

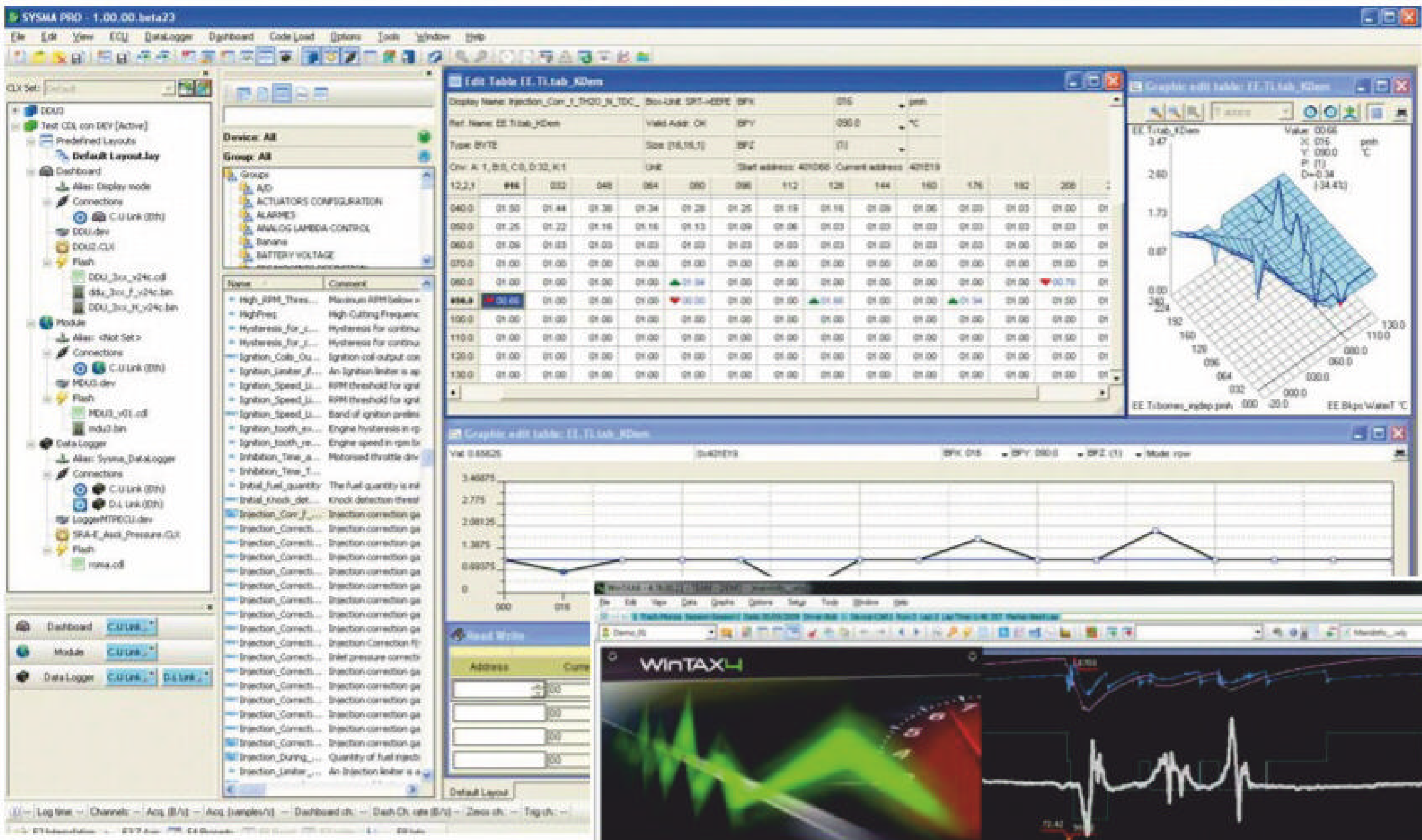
'From an OEM point of view, they tend to come from the automotive sector, and they bring with them a lot of capabilities that they can see the advantage of in the motorsport world,' Roberts says. 'And then we would bring them our expertise in the motorsport world. We would fine tune the technology and then, often, they'll bring technology back over to the automotive world as well. With regulators and series organisers, it tends to be much more about an idea in mind that they don't want people to take advantage of. They don't want the ECU to be too open so that someone runs away with an idea. But they do want to encourage advances in technology, engineering efficiency, and vehicle technology.'

This can be particularly challenging if the series is not running a single type of engine, such is the case with the TCR touring car class that Marelli will be supplying ECUs for next year. 'One of the big challenges with TCR is managing so many different engine models all in one ECU,' Hyder says. Because the TCR series is homologated, Marelli must be able to ensure that the control strategies on its ECUs do not provide an unfair advantage to one powertrain whilst also making sure that each manufacturer is able to extract the maximum performance from its engines. Understanding how each powertrain works, designing an ECU to work with all powertrains in the series, and making sure there are means of checking the parameters for the regulators, is all part of the journey to developing a new ECU.

Technology transfer

The development of new ECU platforms is not only reliant on customer needs and industry trends. Manufacturers must also continue to research the market and look for cutting edge technology being explored both in the automotive and the motorsport industries. Historically, motorsport has driven technological advancements and this technology eventually found its way to road cars. While for the large part this continues to be true, examples of technology moving the other way seem to be more commonplace than they were before.

'I think direct injection is a prime example of this happening,' Roberts says. 'That technology was first put into road cars by OEMs for the sake of passing the emissions [tests]. But because



Left: Sysma is a software package which runs ECUs, data loggers, dashboards and other modules. It helps to calibrate and manage a wide variety of control strategies

The WinTAX4 program from Marelli is a data acquisition and analysis software package used in motorsport categories right across the globe

Further testing of the software can be conducted using a real race driver in a simulator

performance benefits were found from it, it is now used in motorsport.'

But with the greater reliance on software and computation, technological advancements from other industries will make a difference in the future as well. 'The latest software technologies, AI, deep learning and all these other things are already contributing in making faster validation and improving the model in real time,' Basso says. 'Through AI and machine learning we can keep improving the model in order to be closer and closer to the actual scenario. This is making the correlation between the simulation and the real thing even closer.'

ECU testing

One key component of development that's evolved greatly over the years is testing. With the increase in complexity, the reliability of each piece of software must be rigorously tested. Engineers now test the software using multitudes of simulations. 'We run hours and hours of races in simulation in order to make sure that the ECU will perform the right action, will make the right decision,' Basso says.

But these software simulations are just the start of the modern-day testing phase. More manufacturers are opting to conduct Hardware-In-the-Loop (HIL) simulations which Roberts explains as 'you might call it a car in a box. It's a series of simulated inputs/outputs and does everything you would expect a vehicle to do.' By hardware testing the software, engineers can ensure that no glitches will affect the hardware and that all failure modes are safe for the driver. This also allows the hardware and software to be tested under race conditions.

Further testing of the software can be conducted with driver-in-the-loop (DIL) testing using a real driver in a driving simulator. This is as close to the real race conditions that manufacturers can get without going on to a track. DIL is particularly useful for any functions that the driver can control, as the actions of a driver can sometimes be unpredictable.

Software testing is only half of the story. ECU hardware must be able to withstand harsh conditions of vibration, noise, temperatures, and water, too. 'All of our ECUs are IP rated and they're dunk tested, they're vibration tested, heat cycled, cold cycled,' Roberts says. 'A huge amount of testing goes into that.'

Hyder adds that they 'often conduct thermal and vibration endurance testing at the same time and subject the ECUs to representative vibration profiles for their environments.' But with the hardware inside becoming more sensitive to weather than ever, the challenge of ensuring that the ECUs can work under harsh conditions continues to get tougher.

The modern motorsport ECU is leaps and bounds ahead of the previous generation. With advances in system architecture, software, control strategies, and testing, they are able to take on any challenge by being modular, flexible, and innovative. But as we look towards the future, interesting advancements lie ahead. 'In order to go to the next level in the motorsport industry, the key is connectivity,' Basso says. 'So, in the future, we can talk about a connected ECU, but at a bandwidth level that will allow it to get even more information from the environment and provide a completely different performance for the car, but also provide a new take for entertainment. When I say the car, I mean not only the performance, engine, all the actuation gearbox, differentials, etc. but also the safety of the car, providing what some people call an "electronic horizon", having a better understanding of what's around the car in order to avoid dangerous scenarios, but without affecting the show.'

Brain storm

This idea is already being explored in the automotive world with autonomous driving and connected cars but with the rise of connectivity, it will be interesting to see the future for racing. Will it enable drivers to evade crashes? Will there be new systems to automatically slow cars down under caution? Will new systems help overtaking of back markers? Whatever the case may be, the development of ECUs is certainly no longer linear and these are far more complex systems than the simple, black, box of electronics that once made engines run.

Shock tactics

Racecar's simulation expert offers some game-changing damper tuning tips – and presents a real life case study to back them up

By DANNY NOWLAN

With an aerodynamic package like this Tominoko 'Under' Suzuki's Time Attack Silvia needs a great damper set-up. Our man Nowlan was able to oblige

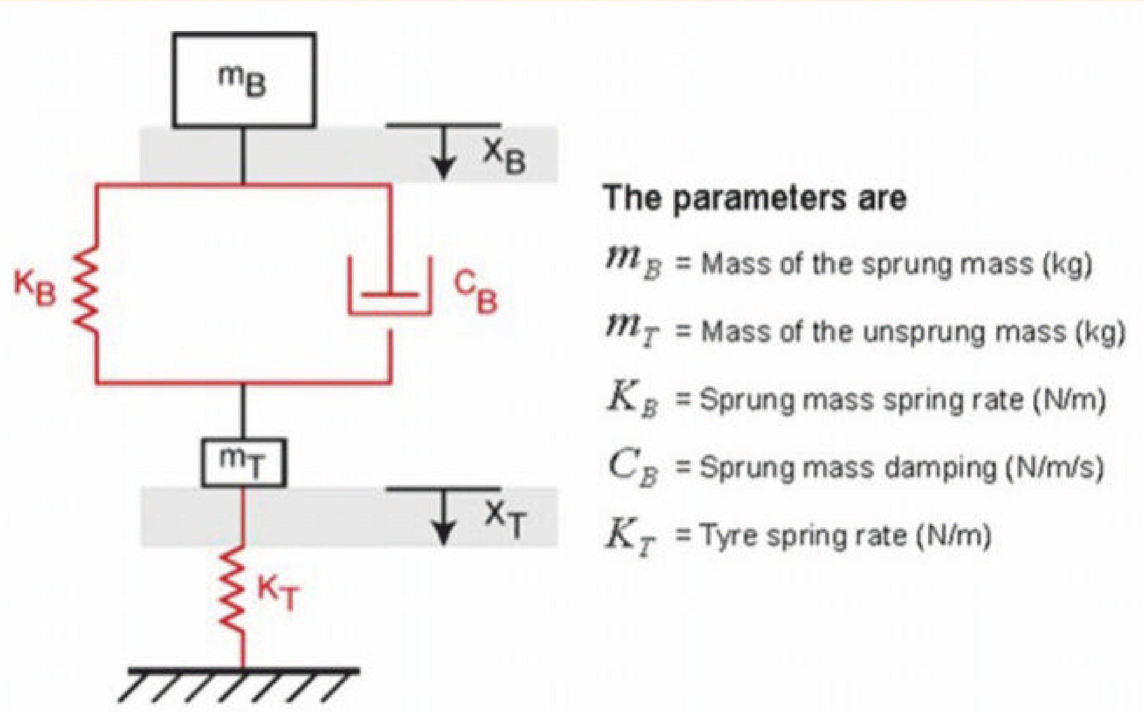
One of the most popular articles I have ever written for *Racecar* and one of the most downloaded items on the ChassisSim website is the Damper Workbook. The reason for its popularity is that this is a hot topic, while there is also a lack of genuine information on this important aspect of racecar tuning.

What we will be doing in this article is applying this knowledge while showing where simulation tools enter the equation, by using a racecar I have recently worked on as an example. This is the Scorch Racing Silvia S15 raced by Tominoko 'Under' Suzuki in the Pro class at the World Time Attack Challenge at Eastern Creek Raceway, Australia.

This car is a fire-breathing monster, with pretty advanced aero; we are talking 900bhp and CLA numbers well north of seven here. Bottom line, if you put DTM slicks on this thing, over the course of a lap it would make most circuit cars look rather modest.

As things stand, the tyres are a halfway house between a performance road tyre and a racing slick. Consequently, this makes this car a great case study on just how effective the approach we're outlining here can be.

Figure 1: The quarter car model



To get cracking on this your start point as always is the quarter car model. To refresh everyone's memory this is illustrated in **Figure 1**. The quarter car model is the most basic building block of racecar damper analysis. Yes, in order to use this you cut corners by assuming the body rate is much less than the tyre spring rate; and note that this is an assumption that leaves a lot to be desired for high downforce cars because of the high spring rates you need to hold the car up. However, the power of the quarter car model is that it is

EQUATIONS

EQUATION 1

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

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

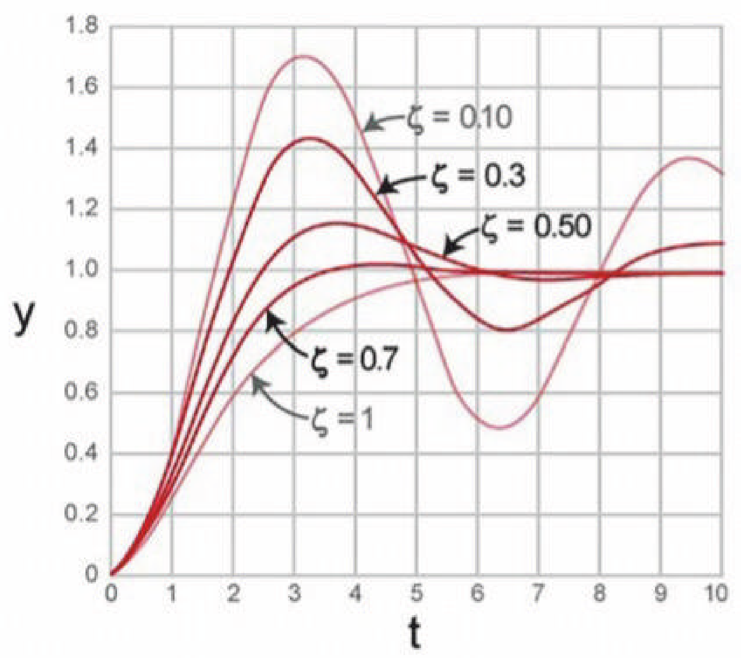
EQUATION 2

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

Here we have:

ω_0 = natural frequency in rad/s
K_B = spring rate of the quarter car in N/m
m_B = quarter car mass in kg
ξ = damping ratio
C_B = damping rate in N/m/s

Figure 2: Second order system response



The reason the second order damping response is so important is because it closely resembles the quarter car model

simple and when used intelligently it gets you a fair way down the road.

Now, in my previous articles I've done the derivation of this to death, but then these two equations **(Equations 1** and **2)** really do need to be committed to memory.

There are a couple of traps for new players here. Firstly, all the wheel and damping rates are wheel rates. We will talk about what they look like at the damper shortly. Also, you should work this in strict SI/metric units. To my many American readers, I know this annoys you, but you'll get over it.

Second order

The next step in this process is to understand what you want the damping ratio to do. To get our heads around this we will need to consider a typical second order system response. This is shown in **Figure 2**.

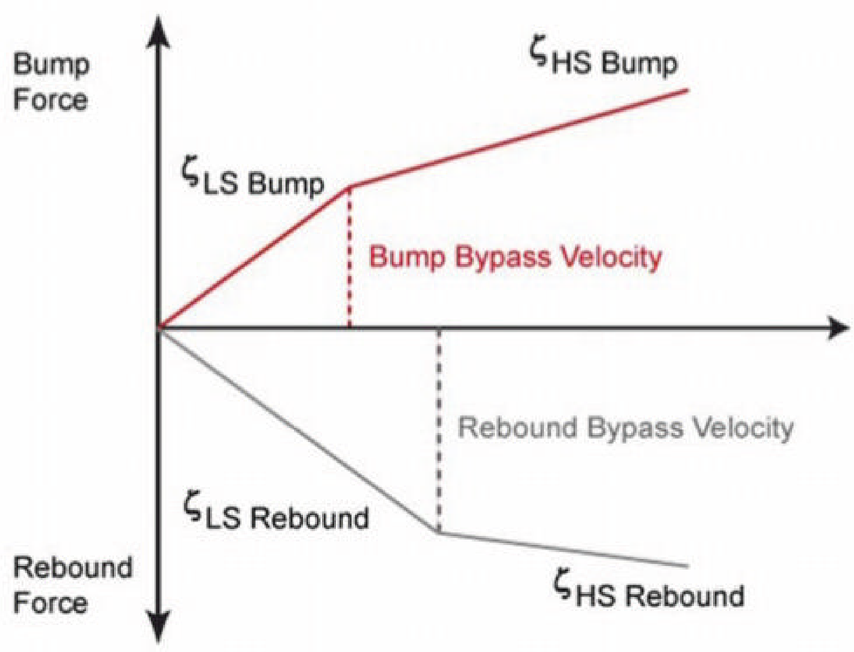
The reason the second order damping response is so important is because it closely resembles the quarter car model. So, as we can see from the chart, when the damping ratios are quite low, at about 0.3 to 0.4 we have a lot of oscillatory behaviour; not great for body control, but really good for riding bumps. However, with damping ratios greater than 0.5 the damping response is quite good. Bad for bumps, but great for body control. If you can understand these two principles you are well on your way to specifying a damper curve.

These guiding principles about bumps, body control and the damping ratios moves us along nicely to the damper selection guide. This is presented in **Figure 3**.

For low speed damping, body control is paramount. Consequently, for cars which are about mechanical grip we are talking damping ratios of 0.7, and for high downforce cars we are talking damping ratios of at least one. My hard limit is 1.4, but you get the idea. In

Figure 3: Damper selection guide

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



EQUATIONS

EQUATION 3

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{MR \cdot MR \cdot K}{m}} = \sqrt{\frac{0.8 \cdot 0.8 \cdot 300 \times 10^3}{250}} = 27.7 rad/s = 4.41 Hz$$

Where:

K = spring rate

MR = motion ratio given by damper movement/wheel movement

m = quarter car mass

EQUATION 4

$$C_{BR} = 2 \cdot m \cdot \omega_0 = 2 \cdot 250 \cdot 27.7 = 13856.4 N/m/s$$

Where:

C_{BR} = damping base rate

EQUATION 5

$$C_{LS} = C_{BR} \cdot \zeta_{LS} = 13856.4 \cdot 1 = 13856.4 N/m/s$$

$$C_{HS} = C_{BR} \cdot \zeta_{HS} = 13856.4 \cdot 0.5 = 6928.2 N/m/s$$

Where:

C_{LS} = low speed damping rate

C_{HS} = high speed damping rate

EQUATION 6

$$C_{D\_LS} = \frac{C_{LS}}{MR^2} = \frac{13856.4}{0.8^2} = 21650.6 N/m/s$$

$$C_{D\_HS} = \frac{C_{HS}}{MR^2} = \frac{6928.2}{0.8^2} = 10825.2 N/m/s$$

Where:

C_{D_LS} = low speed damping rate specified at the damper

C_{D_HS} = high speed damping rate specified at the damper

low speed rebound for mechanical cars you are talking damping ratios of 0.4 to 0.5. For high downforce racecars you are looking at damping ratios of 0.7. There is an outlier with this, but I will discuss this at length in another article. In the high speed riding over the bumps dominates, but we'll also discuss this at length in another article.

Damping rates

So, with this as our guiding principle let's work through an example of how you figure out the damping rates and put together a damper curve. To kick this off let's consider the quarter car parameters shown in **Table 1**.

Now we have this we now need to figure out the natural frequency. This is shown in **Equation 3**. And once we have figured this out, we need to figure out the base damping rate. This is shown in **Equation 4**.

Now that we have the base damping rate we can choose the actual damping we need. For the low speed rates we'll choose a damping ratio of one and for the high speed we'll choose a damping ratio of 0.5. Then we get to **Equation 5**. Here *CLS* and *CHS* are the low and high-speed damping rates respectively.

The last step is getting the damper rates at the damper. For this we need to divide by the motion ratio squared assuming the motion ratio is damper movement/wheel movement. Crunching the numbers we get **Equation 6**.

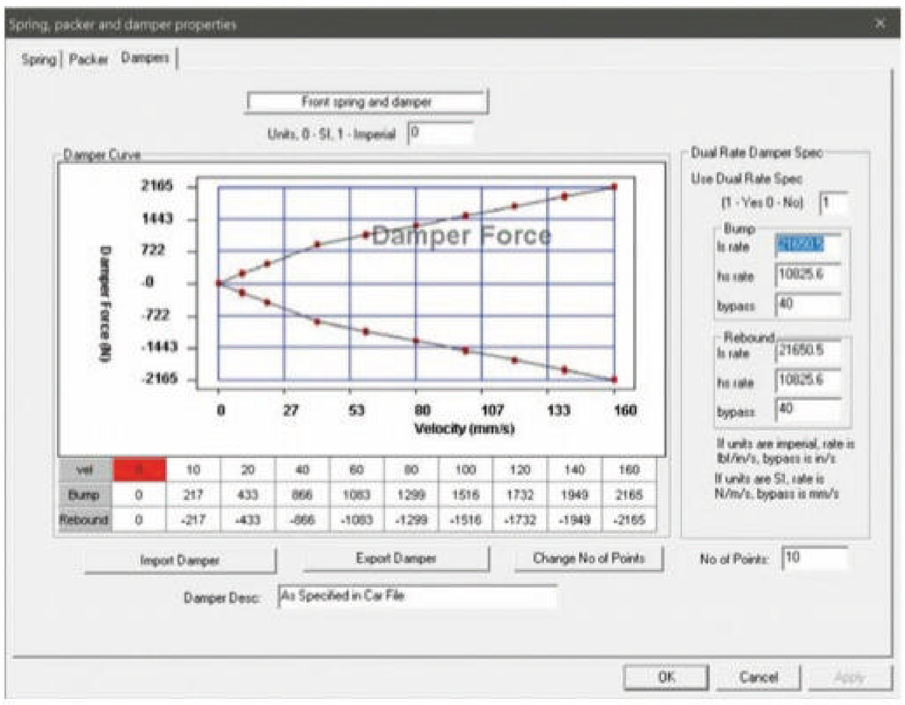
So, at this stage of the proceedings you might be thinking, well this is all great; but how do we get a damper curve? Here is where the dual rate model in ChassisSim is about to become your best friend.

If you have ChassisSim all you have to do is click on the damper tab, choose the dual rate model, and fill in the numbers and when you press *okay* you'll see what's shown in **Figure 4**.

Table 1: Quarter car parameters

Paramaters	Value
Quarter car mass	250kg
Motion ratio	0.8
Base spring rate @ damper	300N/mm

Figure 4: Entering a dual rate model in ChassisSim



When this process is finished you will have a base damper curve, but there is still a bit of work to do. The next step is to use the ChassisSim shaker rig toolbox. Usually for a mechanical grip racecar I will focus on minimising contact patch load variation and then tune the frequency response. For a high downforce car, the frequency response, and in particular minimising the cross pitch mode, is dominant because controlling the aero platform is your number one priority.

Real world

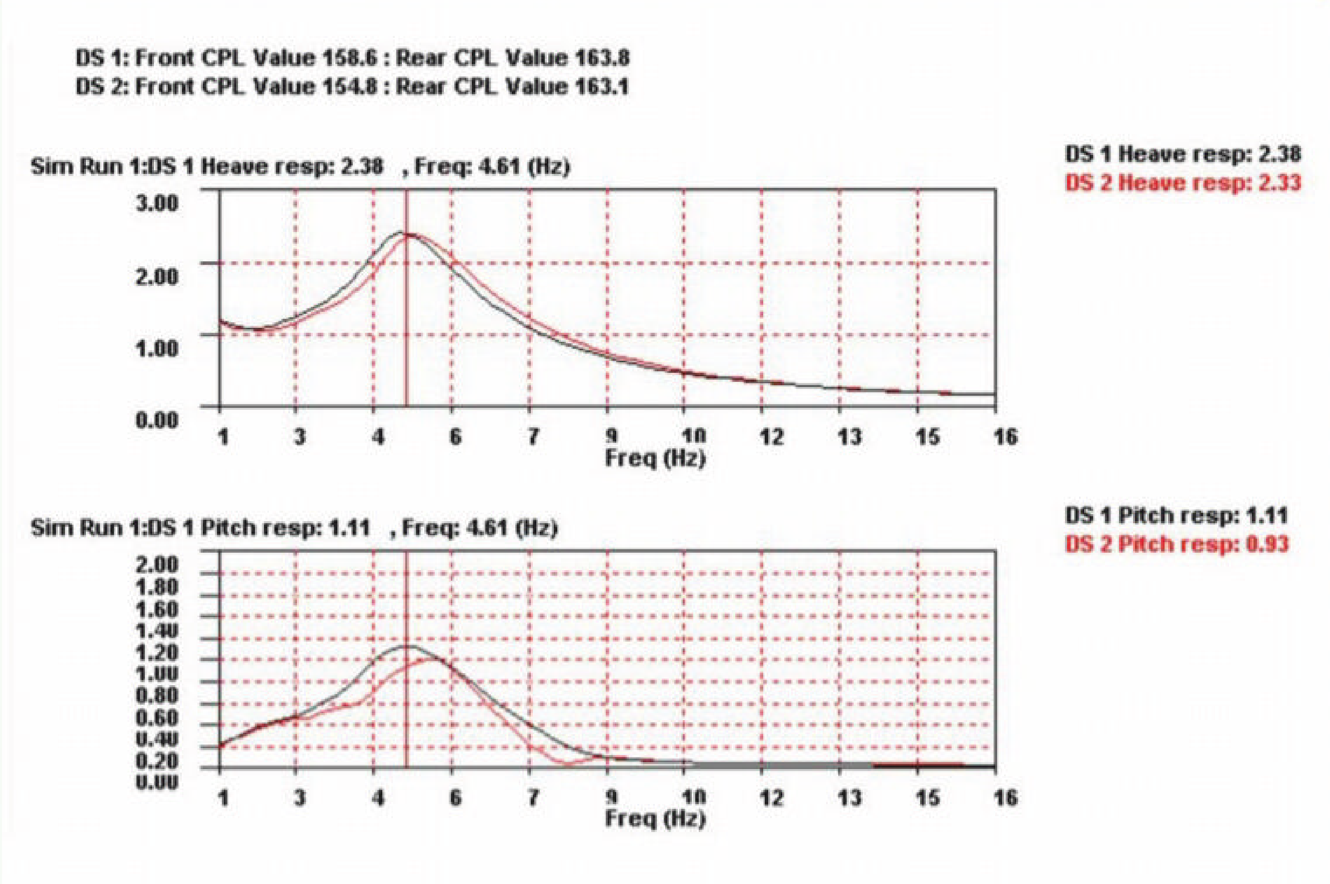
However, when this was applied to Suzuki's Time Attack Silvia there were a number of challenges. Firstly, due to the nature of these tyres you couldn't muscle it out with big tyre spring rates. It was a total non-starter. Significant support had to come from the third spring, and when you do this you have to factor it in to your natural frequency and damper calculations, which we showed earlier.

The other thing that made this job very tricky indeed is that, due to the high aero load and the nature of these tyres, both the aero response and the contact patch load variation become equally important. What all this translated into was a lot of simulation work. The end result of this is shown in **Figure 5**.

In Figure 5 the initial damper spec is black and the final damper design is red. As can be seen the contact patch, load variation has dropped by 4kg at the front and 0.8kg at the rear, while the cross pitch mode response has dropped by nearly 20 per cent.

If you see this, then you put it on the racecar! And when this was applied to Suzuki's Silvia, to say it was a step change in performance is very much an understatement. The net result of this work is shown in **Figure 6**.

Figure 5: End result of the shaker rig analysis work



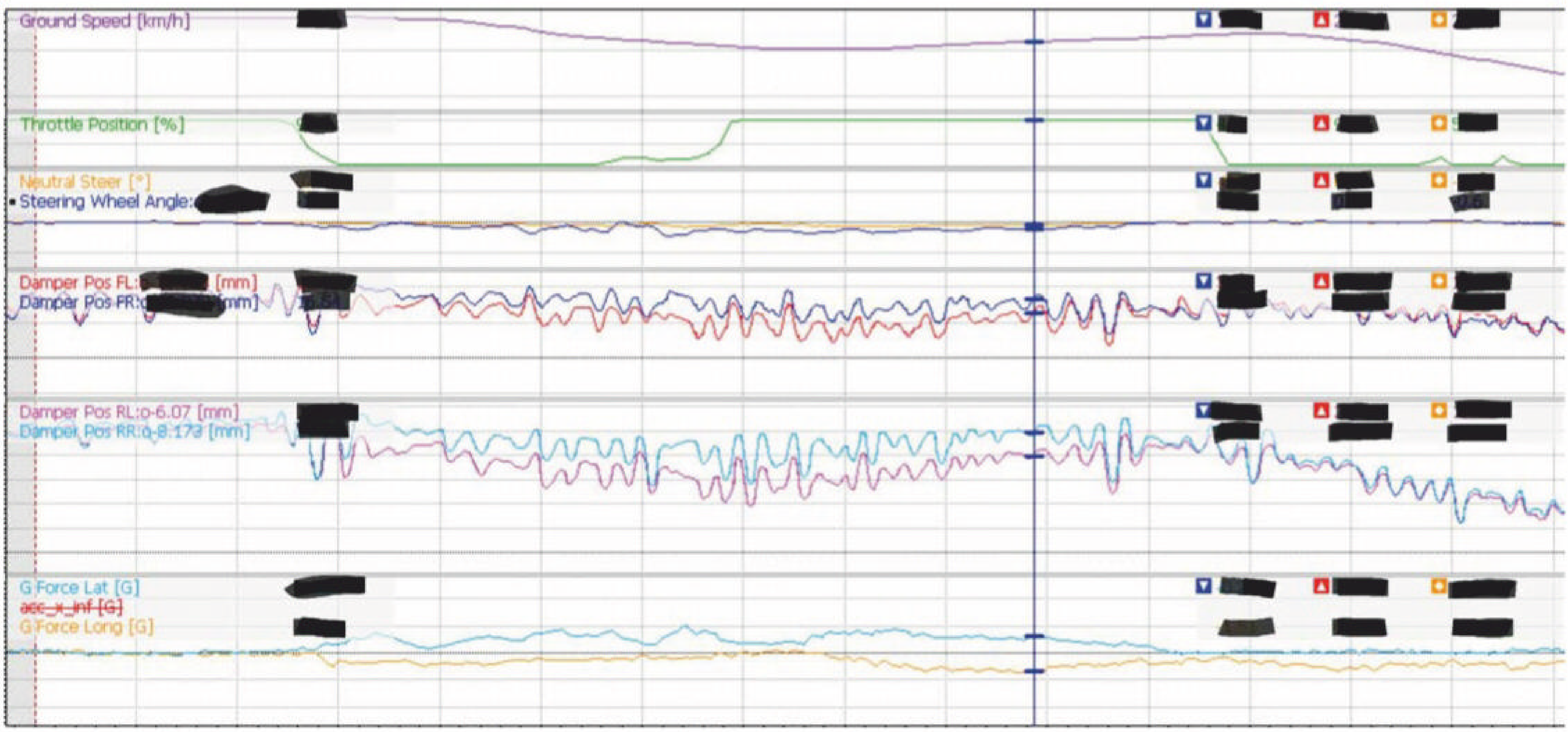
Due to confidentiality all the scalings in Figure 6 have been blanked out. However, the traces are speed, throttle, steer, front dampers and rear dampers followed by longitudinal and lateral *g*. In the low speed section the racecar response is excellent. However, there where issues in the high speed and I have no doubt that this was something that was lost in translation. That said, it was resolved by going up in the high speed damping.

Old rubber

But the really great thing here was that this translated into car performance on used tyres. On tyres that where over 12 laps old, Suzuki recorded a lap time of 1:22.3s at Eastern Creek. This is significant because Pro class cars in Time Attack are brutal on their tyres. They are lucky if they last three laps. So, this was unheard of. Unfortunately, an accident in Thursday morning practice put the car out of commission, so its true pace has yet to be seen.

In closing, what we have just outlined is a very powerful technique, and case study, for tuning dampers. While this method is not perfect it is practical and simple, while it gives you a feel for the numbers. Also, when we combine this with simulation and use it as a calculator as opposed to a magic wand the end results will take care of themselves.

Figure 6: Damper response at Eastern Creek

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Grand prize

The Bloodhound LSR vehicle has managed to break the 1000km/h barrier (628mph) during its high speed testing runs. The next step is the record …

By JULES TIPLER

The Bloodhound Land Speed Record car has reached a new top speed of 628mph (1010km/h) at the Kalahari Desert 'racing track' in South Africa, as it completed the crucial high speed testing phase of the project.

Just to help get your head around the speed, at that rate of knots the 'car' would get from London to Edinburgh in just 39 minutes.

The successful high-speed tests have seen Bloodhound blasting down the Hakskeen Pan in Northern Cape propelled by an EJ200 jet engine, which is normally found in a Eurofighter Typhoon fighter plane. It reached maximum velocity as it passed the five mile (8km) mark, just 50 seconds after it set out.

Sand blaster

This 628mph sprint was called Run Profile 8, a pre-defined and exacting set of parameters set out by the Bloodhound LSR engineering team. Driver Andy Green rolled off the line using the EJ200 in 'max dry' (no flames visible out of the back), then up to 50mph, at which point he put his foot down past the 'detent', and pushed the jet engine into reheat (the afterburner). Bloodhound LSR then reached maximum velocity. Green lifted off the throttle at 615mph (989 km/h), stabilised the car and then deployed a drag parachute to slow the car safely to a halt at the 11km mark.

The runs formed part of a high speed test programme to examine how much drag the record car creates in a number of scenarios and at various speeds, using the wheel brakes and drag parachutes, and with the giant airbrakes locked into position.

Data from 192 pressure sensors on the car has been monitored and compared with the predicted CFD models to check whether they correspond. Bloodhound's engineers are now working with assistant professor Ben Evans and Jack Townsend from Swansea University to examine the data. During the last run, analysis showed airflow beneath the car went supersonic and stripped the paint from an area three metres back from the front wheels.

The crucial data generated from the runs will reveal the amount of drag experienced on each pass. This data is critical to determine the size of the rocket that will be fitted to the car for the attempt to set a new world land speed record in 12 to 18 months' time.

The EJ200 jet engine generates 9kN of thrust, roughly equal to 54,000bhp, which on its own is not enough to set a new world land speed record of more than 763mph, as set by Thrust SSC in 1997 and faster than the speed of sound. Norwegian rocket expert Nammo is thus developing a mono-propellant rocket that will produce the additional 60kN of thrust needed for Bloodhound to set a new land speed record on Hakskeen Pan.

Ian Warhurst, Bloodhound LSR's owner said: 'Our speed objective for these tests was to reach 1000km/h. Hitting this is a real milestone and shows just what the Bloodhound team and the car can achieve. With the high speed testing phase concluded, we will now move our focus to identifying new sponsors and the investment needed to bringing Bloodhound back out to Hakskeen Pan in the next 12 to 18 months' time.

'Not only am I immensely proud of the team, I'm also delighted that we've been able to demonstrate that the car is eminently capable of setting a new world land speed record,' Warhurst adds.

From the cockpit

'We had the perfect conditions for a high speed run; cool temperatures and virtually no wind,' Green says. 'After a slick start procedure from the team, the car handled superbly once again. The stability and confidence the car gives me as a driver is testament to the years of world class engineering that has been invested in her by team members past and present. With all the data generated by reaching 628mph, we're in a great position to focus on setting a new world land speed record in the next year or so.'

© Charlie Sperring

Bloodhound's high speed runs were successful and the record attempt will be in 12 to 18 months' time

Airflow beneath the car went supersonic and stripped the paint from an area three metres back from the front wheels

The jet engine is the same as the one used in a Typhoon fighter

These solid aluminium wheels have been specially designed for the desert surface and can spin at 10,200rpm

The EJ200 jet engine generates 9kN of thrust, roughly equal to 54,000bhp

The team's next objective is to secure the sponsorship that will be needed for it to make its record attempt

Interview – John Doonan

The winning post

IMSA's new president explains why it's the perfect job for him and tells us how he aims to grow America's premier sportscar series

By MIKE BRESLIN

'There was really only one opportunity in the sport that I would consider departing Mazda for, and that's this role at IMSA'

When *Racecar* last spoke to John Doonan, a couple of years ago, it was difficult to imagine him ever leaving his post as the boss of Mazda's motorsport efforts in North America, such was his obvious enthusiasm for the role. In 2019 it seemed even less likely he would want to move on, after all the firm's RT24-P DPi had finally won its first IMSA race and had then gone on to rack up another two victories. Yet it's now turned out there *was* another position that could lure Doonan away from his dream job with the Japanese manufacturer.

Doonan was confirmed president of IMSA, the US sportscar racing governing body, soon after it was announced that his predecessor Scott Atherton was to retire in September, but leaving Mazda has not been easy, he admits. 'It's really bitter-sweet to depart my friends and family at Mazda, but as I shared with Mazda's CEO and chairman [North America], Masahiro Moro, there was really only one opportunity in the sport that I would consider departing Mazda for, and that's this one at IMSA. I've had the opportunity to work in IMSA for the last 14 years, on the Mazda programme, both in what is now the Weathertech Championship as well as at the level of the Michelin Pilot Challenge. I feel that I have built a really strong relationship with the other OEM partners, and with the IMSA staff and leadership, as well as relationships with the team owners, and I am so honoured that Mr [Jim] France [chairman], Mr [Ed] Bennett [CEO] and Mr Atherton identified me as someone who could continue with this amazing platform, and hopefully continue to grow it in years to come.'

While Doonan certainly has the right credentials, one of the other things that must have marked him out as an ideal candidate for the role of president has to be his sheer enthusiasm for IMSA, something that was there long before he started looking after Mazda's campaign. 'I started going to IMSA races when I was a nine-year-old, at Road America and throughout the Midwest, and it's absolutely amazing,' he says.

Presidential address

Some might say IMSA's never been quite as amazing as it is right now, too, and Doonan recognises he is overseeing a prospering series and he has a clear idea of what needs to be done to ensure it remains that way. 'I walk into an opportunity that is quite stable right now,' he says. 'We have a long-term television partner with NBC, a long-term tyre partner with Michelin, and a long-term entitlement partner with Weathertech. I think the secret to success is maintaining and growing the existing relationship with those partners, as well as the OEM partners. And then I think, at a basic level, keeping the costs of competition down for the competitors; whether that's the OEMs or the individually owned teams. That to me is critical as we continue to drive growth.'

One thing that is sure to help Doonan is his recent experience at the head of an OEM DPi operation, yet he is also aware that it's not just about the big teams. 'I tried to identify with and think like a small team owner when it came to running the Mazda programme,' he says. 'I tried to think like an OEM when I was in the meeting room for balance of performance or OEM marketing. I've tried to think like IMSA staff members, because when I was little I'd help my mom with registration, I'd help my dad with tech, or race control, and things like that. So I've tried to be a student of the game my entire life, and I hope that that plays well here in my new opportunity'

Charge forward

For it to really play well, though, some pretty big decisions will need to be taken at IMSA, perhaps the most important being to do with the 2022 regulations, and the talk that these may revolve around hybrid power. 'I've been in those OEM meetings from a technical standpoint [as Mazda boss], Doonan says. 'And I'm encouraged by the amount of research that's been done. I think it's too early to tell exactly where everything is going to shake out. The technical staff at IMSA, led by Simon Hodgson [VP Competition], has done a massive job in trying to gather all the relevant information from the different potential suppliers, and things like that. It's something that we have heard from OEM partners that is of interest, in remaining relevant, but exactly what will be done is yet to be seen.'

Incidentally, although Doonan had heard the rumour that IMSA was also looking at Class 1 (DTM/Super GT) regulations, he said that – at the time of the interview, when he had just started as president – he had heard nothing concrete on this.

If IMSA does go hybrid, then chances are that it will do so in a coordinated effort with NASCAR, as the merger that formed the Weathertech Championship was between Grand-Am, which was owned by the US stock car racing governing body,

New IMSA president John Doonan believes its flagship championship needs to attract a younger audience to thrive in the future and the ALMS. 'One of the massive advantages of IMSA and NASCAR being in the same portfolio is the ability to share ideas, share strategies, to share resources,' Doonan says. 'I think as we continue to look forward to the future years there will be more and more of that collaboration on the technical side, and the marketing side, and the leveraging of all the resources that make IMSA, and its part in the NASCAR family, so strong.'

Fan boost

All this is in the future, though, and for now Doonan has other things to think about. 'One [priority] is to immerse myself in every aspect of the programmes that are currently in place, to get ready for a successful 2020 season,' he says. 'But I've always thought that it is important for us to also have a crystal clear strategy in identifying our next audience, the next generation. I hope that we can put IMSA in front of a younger and growing demographic … Without a doubt, growing the audience is critical for us, not only to sustain the future but to provide our current partners with the greatest value that they can get from their investments.'

One way that the audience might grow would be if there was more crossover between IMSA and the WEC, and the showcase Le Mans 24 hours in particular, and Doonan admits that this is a frustrating aspect of sportscar racing right now; with the WEC not looking at going to DPi rules, for instance. 'I stated this in my previous role at Mazda,' he says. 'And I think it's safe to say that I'm not alone, and many people around the world think it would be amazing for all the stakeholders, fans, everyone who is the audience of sportscar racing, if, at some point we can all come to a common set of regulations that allow teams, manufacturers, drivers, all the best in the world, to come together in many different venues.'

As for the new hypercar regulations that the ACO and FIA has chosen, Doonan says: 'It wasn't something that Mazda were looking to invest in, I think those that have studied DPi are keen to [stay] involved there, [but] obviously these folks have announced they are heading down the hypercar route. But, as I said, it would be lovely to have everybody come together with a common set of regulations down the road, it would be a dream come true for me, because I am still a fan, and I want to remain a fan. And if I ever lose that then you can tap me on the shoulder and tell me it's time to give it up.'

RACE MOVES

NASCAR has now fully acquired track operating company International Speedway Corporation. Following the purchase **Jim France** (pictured) is now the chairman and chief executive officer of the newly merged entity, with **Lesa France Kennedy** executive vice chair. **Steve Phelps** has been appointed president and will oversee all operations of the company.

Peter Bonnington, the race engineer for **Lewis Hamilton** at Mercedes, missed the Mexican Grand Prix to undergo a medical procedure. **Marcus Dudley**, usually Hamilton's performance engineer, took Bonnington's place for the race, while **Dom Riefstahl**, who usually heads up the race support team at the factory, took on the performance engineer duties.

Nelson Cosgrove is to replace **John Doonan** *(see Interview)* as Mazda's director of motorsport in North America. Cosgrove arrives at Mazda from Toyota Racing Development, where he spent nearly five years in a variety of senior technical roles. Before TRD he worked at NASCAR operation Joe Gibbs Racing, as its engineering director and then its chief technical officer.

Andrew Cowan, the former Mitsubishi Ralliart World Rally Championship team principal, has died at the age of 82. Cowan guided **Tommi Makinen** to four straight WRC titles from 1996 to 1999, while he was also successful as a rally driver in his own right, winning the London to Sydney marathon twice, in a Hillman Hunter in 1968 and then in a Mercedes 280E nine years later.

Mike Raymond, the commentator who was the voice of the Australian Supercars series until he retired in 1995, has died at the age of 76. Raymond also played a key role in establishing the 5-litre V8 engine formula that has been synonymous with the series for many years.

Cara Adams has been promoted from the post of Firestone chief race engineer to Bridgestone/Firestone's director of race tyre engineering and production, which will see her expand her trackside role at IndyCar. The company is also in the process of building a brand-new racing tyre manufacturing and development facility in Akron, Ohio.

Jacob Brown is now director of motorsports at helmet manufacturer Bell Racing in the US. He will be responsible for managing its amateur and professional racing and its sponsorship programmes, while representing the brand at events and overseeing its trackside personnel and support programmes. Brown has replaced **Chris Wheeler** in the role, but the latter will continue with the firm in a consultancy position focused on new sales and brand initiatives.

Luke Lambert will be the crew chief for **Chris Buescher** on the No.17 Roush Fenway Racing Ford in the 2020 NASCAR Cup season. Lambert is to leave Richard Childress Racing (RCR), where he has been a crew chief for the last eight seasons, to take up the position. In his place RCR will promote **Randall Burnett** to crew chief the No. 8 Chevrolet.

Seven-time Supercars champion **Jamie Whincup** is to join the Supercars Commission, the body which makes recommendations to the series' board on racing rules, regulations and formats. Whincup bought a 15 per cent share in the Red Bull Holden Racing team he drives for last year and he has made it known that he intends to move into team ownership when he hangs up his helmet.

Well-known Canadian motor racing commentator **Jim Martyn**, who for many years was the track announcer at Mosport – now known as Canadian Tire Motorsports Park – has died at the age of 64. Martyn also played a part in the formative years of the American Le Mans Series' radio broadcasts.

Renowned Indianapolis 500 engine builder and chief mechanic **Louis 'Sonny' Meyer** has died at the age of 89. Meyer was directly involved in the preparation of 15 Indy 500 winning powerplants over his long career. He started in motorsport in 1946, when his father – three-time 500 winner **Louis Meyer Sr** – bought the Offenhauser engine business.

Renault F1 hires Pat Fry for 2020; aero team restructured

Former Ferrari man Pat Fry is to join the Renault F1 operation in an as yet undisclosed position in 2020, while the team has also made a number of changes in its aerodynamics department.

Having started his F1 career at the Enstone team when it was known as Benetton, this will mark a return for Fry – his last stint there finished with him in a race engineer role in 1992. From Benetton Fry went on to work at McLaren, rising to the post of chief engineer. Then he joined Ferrari as chassis technical director in 2010, before becoming its engineering director. Fry then worked at Manor for a short while and more recently at McLaren on a consultancy basis, a position that he left during the 2019 season.

XPB

Pat Fry's role at Renault F1 has not yet been revealed

Currently Renault's engineering efforts are managed by executive director Marcin Budkowski and chassis tech director Nick Chester.

Meanwhile, Renault has also announced that former Williams and Ferrari man Dirk de Beer, who has been on gardening leave since departing Williams last year, has joined as head of aerodynamics. He replaces Peter Machin in the role.

Elsewhere in the aero department, Vince Todd has been appointed interim deputy head of aerodynamics, until the as yet unnamed new deputy arrives from another team, while James Rogers has been promoted to a new post of chief aerodynamicist. He was previously principal aerodynamicist in charge of future car projects.

Renault F1 managing director Cyril Abiteboul said of the changes: 'We've been focussed on growing, in terms of quantity, making up the numbers. It had to be done, but in parallel we need also to look for a bit stronger technical leadership and making the team stronger in that area where we were a bit lean, at that level. So that's exactly what we've done by restructuring our aero department with a mix of external recruitment and internal promotion.'

Penske snaps up IndyCar and Indianapolis Motor Speedway

Roger Penske has cemented his position as one of the most powerful people in world motorsport, and perhaps the most influential man in US racing, by acquiring the IndyCar Series and the Indianapolis Motor Speedway from Hulman and Company.

Penske, who already owns race teams in NASCAR, Australian Supercars (co-owned with DJR), IMSA and IndyCar itself, acquired the series and the track, plus other assets, through Penske Entertainment Corp, a part of his vast US business empire.

XPB

Roger Penske now owns one of the series he competes in

The buyout means that Penske's four-car single seater operation, which won the Indianapolis 500 and also the IndyCar series in 2019, will now compete in a championship that is owned by its parent company.

Hulman and Company said in a statement: 'The board of directors of Hulman and Company are announcing the sale of the company and certain subsidiaries, including the Indianapolis Motor Speedway, the NTT IndyCar Series and Indianapolis Motor Speedway Productions (IMS Productions), to Penske Entertainment Corp, a subsidiary of the Penske Corporation.'

Meanwhile, Roger Penske received the Presidential Medal of Freedom, the highest civilian honour for a citizen of the USA, from President Donald Trump at the White House in October. Penske is only the second person from the world of motorsport to receive this accolade, the first being NASCAR legend Richard Petty in 1992.

RACE MOVES – continued

Catherine Bond Muir, the CEO of W Series, the single-seater championship for female drivers, has been appointed to the board of Motorsport UK, the sport's governing body in the United Kingdom. W Series, which uses an FIA F3 spec Tatuus T-318 single seater chassis, was launched in October of 2018 and completed its first season in August 2019.

Mack Gouge and his Columbus, Georgia-based Team 7 Racing Inc organisation has been signed up by the Trans Am Race Company to help the burgeoning US race series attract new sponsorship deals.

Ron Watson, the founder and later president of the Motorsports Hall of Fame of America (MSHFA), has died at the age of 72. Watson is to be replaced by long-time board member **George Levy**.

Aston Martin factory driver **Maxime Martin** will launch his own GT team next season. The Martin Racing Team, which will be based near Charleroi Airport in Brussels, Belgium, will enter a pair of Aston Martin Vantages in both the European GT4 and the ADAC GT4 championships.

Martin Down, the man behind the Getem FF1600 marque, well-known for the pace and success of its cars at Brands Hatch, has died at the age of 75. Down was involved in Formula Ford for over four decades, the first Getem having hit the track in the 1970s.

Dr Michael Olinger, the former medical director for the IndyCar series, has died at the age of 69. Olinger joined the then-new Indy Racing League in 1996 as a trackside physician. He held the IndyCar medical director role between 2006 until 2018. He had a remarkable life and was an army pilot before completing his medical training, while he was also a responder at the World Trade Center after 9/11.

Danny Stockman has stepped down from his post as the crew chief on the No. 3 Richard Childress Racing car in the NASCAR Cup. He will be replaced by **Justin Alexander** for the 2020 season, the latter was crew chief on the No.3 Chevrolet for the 2017 and 2018 seasons, but for 2019 he worked in the Xfinity Series. Stockman will remain with the team in a post that had yet to be revealed at the time of writing.

Mercedes Formula 1 boss **Toto Wolff** missed his first grand prix since 2013 when he skipped the penultimate race of the 2019 season in Brazil. The decision not to attend the Interlagos event was made easier as both drivers' and constructors' championships had been tied up by then – the sixth double in a row for the Brackley-based team.

NASCAR fined crew chiefs **Paul Wolfe** (Penske) and **Mike Hillman** (Rick Ware Racing) $10,000 each after their racecars were found to be running with improperly secured lug nuts at the ISM Raceway round of the Cup Series.

Brian Hampsheir, who for many years produced racecars bearing the Elden name – which were designed by his brother **Peter** – has died at the age of 80. Over 200 Eldens were built, for formulae such as FF1600, FF2000, F3, Formula Atlantic and the original UK, non-spec, Formula Renault.

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


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Show and tell

Why January's ASI offers a fantastic opportunity to debate the future of motorsport

While many come to ogle shiny new racecars or buy fresh kit, ASI is also a talking shop for the motorsport industry

The 2020 motorsport season will kick-off with the Autosport International Show in Birmingham, as always. Alongside showcasing the stars and cars of championships including Formula 1, Formula E and the World Rally Championship, there will also be a hub for the motorsport industry to network and debate the trends, innovations and developments in the sport.

Thursday 9 and Friday 10 January encompass two trade-only days for members of the motorsport industry to connect, while brand new for 2020 is the Autosport Business Forum, which will be the perfect place for networking discussions. Here, in celebration of 70 years of Formula 1, a panel of industry thought leaders will discuss how the last seven decades of technological advances have made the motorsport industry into a global leader in innovation. The forum will also turn to the years ahead, asking the experts how this drive to win through speed, safety and efficiency will shape the future of motorsport.

Future focus

Autosport International will also be focussing on the next 70 years, with an #Autosport2090 initiative that asks engineering students to predict the future direction of the sport.

One innovation that has already transformed the sport is the development of composite technologies. Ever since the successful introduction of a carbon fibre chassis into Formula 1 by McLaren in 1981, the wonder material has gone on to revolutionise the manufacturing processes, efficiency and safety in a wide variety of industries; all because it proved itself in the brutal environment of racing.

Appropriately, the future of composite manufacturing (which is covered on page 60 of this issue) will be a topic for the Autosport Business Forum. A panel of experts will give their view on both imminent and far-reaching progress. The motorsport industry has long been at the forefront of composite technology, driven by the need to decrease weight, improve efficiency and increase safety. A session in the Motorsport Engineering Business

The industry has long been at the forefront of composite tech, driven by the need to decrease weight, improve efficiency and increase safety

Forum will also explore new composite material developments in discussions with industry leaders and innovators.

Motosport's innovations in composite manufacturing may rival traditional metal-based manufacturing, but another immersive session at the forum will highlight how another technology, incremental sheet forming (ISF), can put metal back at the forefront of low-volume manufacturing.

Roger Onions, director of GTMA, which is the trade association representing the precision engineering and tooling technology industry, states the case for motorsport engineering companies to consider this cost-effective and precise process: 'The GTMA is excited to be able to present the benefits of ISF to motorsport engineering leaders,' he says. 'This process allows the automation of metal pressing but it also removes the need to invest in a conventional press tool. The ISF process is far more cost-efficient for low volume production, such as prototypes, rebuilding classic cars and creating replica body panels for production-based racecars. Using a resin tool, the process follows a cutter path and can make panels in a couple of hours. It is a viable and efficient alternative to composite manufacturing and can open up many new manufacturing opportunities for the motorsport sector.'

Tuner torque

A third forum will look at the future of tuning. The Performance and Tuning Car Show, that runs alongside Autosport International, attracts tuners from across the world. Some of the challenges, and opportunities, facing the industry will be discussed on stage, including the tuning industry's £34bn challenge. That's the estimated value of counterfeit parts running rampant in the aftermarket sector.

Spark and ride

An opportunity for the tuning industry is the growth of hybrid and electric cars, as the days of induction and exhaust modification may be replaced with a different approach. The Business Forum will also debate this fast-changing landscape. MAHA dynamometer specialist Louis Tunmore says: 'I firmly believe that people will still want to modify electric, hybrid and hydrogen cars to get more performance out of them. We've been through big changes before, such as the move from carburettors to fuel injection in the 1980s, and the industry embraced it.'

We've been through big changes before, such as the move from carburettors to fuel injection in the 1980s, and the tuning industry embraced it'

As an industry going through a period of change, tuning companies are certainly aware of the implications of the take-up of electric, hydrogen and hybrid technology to their products. Tarox UK manager Nicholas Counsell explains how the brake manufacturer has adapted to the influx of electric vehicles: 'EV cars are heavy so they are demanding more from the brakes,' he says. 'From a tuning point of view in 25 years I think we are going to be a million miles away from where we are now. On our stand at the Performance and Tuning Car Show last year we had a car that was 25 years old and a car from the present time, we are hoping to do the same this year and I hope in 25 years' time we'll do the very same, too.'

Old racecars like this BTCC Sierra Cosworth always draw a crowd; but ASI is much more to do with the future than the past

AUTOSPORT INTERNATIONAL

ENGINEERING SHOW

Show information

Opening times

Autosport International opening times: 9am-6pm across both trade (Thursday and Friday) and public days (Saturday and Sunday).

Trade tickets

The trade tickets (Thursday and Friday) cost £27 (per day) with a two-day ticket costing £45. MSA members will be able to purchase a ticket for £22.50 while BRSCC members can attend the trade days for free.

Public tickets

- **Advance public tickets** (Saturday and Sunday) £19 for children (5-16) and £31 for adults.
- **Standard tickets** provide entry to Autosport International and the Performance and Tuning Car Show, plus a seat in the Live Action Arena.
- **Family** (two adult tickets and two child tickets) £84 valid for the Sunday and the Live Action Arena at 10am.
- **Paddock tickets** adults £41, children £29 including Live Action Arena, access to the backstage paddock area in the Live Action Arena and a Paddock guide.
- **VIP tickets** £113 (advance price) include all the perks of the paddock ticket as well as access to VIP Club Lounge, the VIP enclosure in the Live Action Arena, with complimentary refreshments, access to exclusive driver signing sessions in the VIP Lounge, plus a gift bag.

To purchase your tickets and take advantage of Autosport International's 10 per cent ticket offer visit the website: www.autosportinternational.com/tickets/

Last year we had a car that was 25 years old and a car from the present, and I hope in 25 years' time we'll do the same'

Ahead for business

Racecar's deputy editor argues that trade shows are better than race days for getting things done

By GEMMA HATTON

There's an ongoing argument in the *Racecar* office: race events or trade shows? The editor sides with the former and claims that the race track provides the most useful time to interview engineers because they can show you around the car.

I, however, disagree. I think that trade shows give the best opportunity to speak to engineers in a calmer environment. One reason for this is that suppliers and teams who attend motorsport trade shows are trying to sell their products to other companies as well as the public. Therefore, their stands are not just full of sales and marketing personnel, but engineers too. In fact, often you'll find several engineers at the stand throughout the whole duration of the show and the best thing is they're standing right next to their new products. What better time to ask them questions and delve into the engineering behind their technologies?

Stands are not just full of sales and marketing personnel, but engineers too

This is exactly what happens during the trade days of the Autosport International Show, and Autosport Engineering in particular. Companies, teams and suppliers from across the globe descend on the NEC, all with one aim; to promote their cars, products and technologies and do business.

Perfect platform

Every component that makes up a racecar will be represented in some form at the show, along with every type of motorsport. This provides the perfect platform for businesses to interact and network with each other, and to get to understand the technology behind the latest products and services that are now on offer.

So whether your company or team wants to learn more about dampers, composites or batteries, the engineers who have actually designed, built and raced these parts will be there to answer your questions. That's why I relish trade shows, because after every one I return home with a pocket full of business cards, a head full of article ideas and a much deeper understanding of the wonderful world of motorsport engineering.


ASI is about the people as much as the cars and there's no better environment in motorsport in which to do business

EXHIBITOR PRODUCTS

Turbosmart

Turbosmart is an Australian manufacturer of boost control and performance products and is the 2018 SEMA Best Performance-Street New Product Award winner.

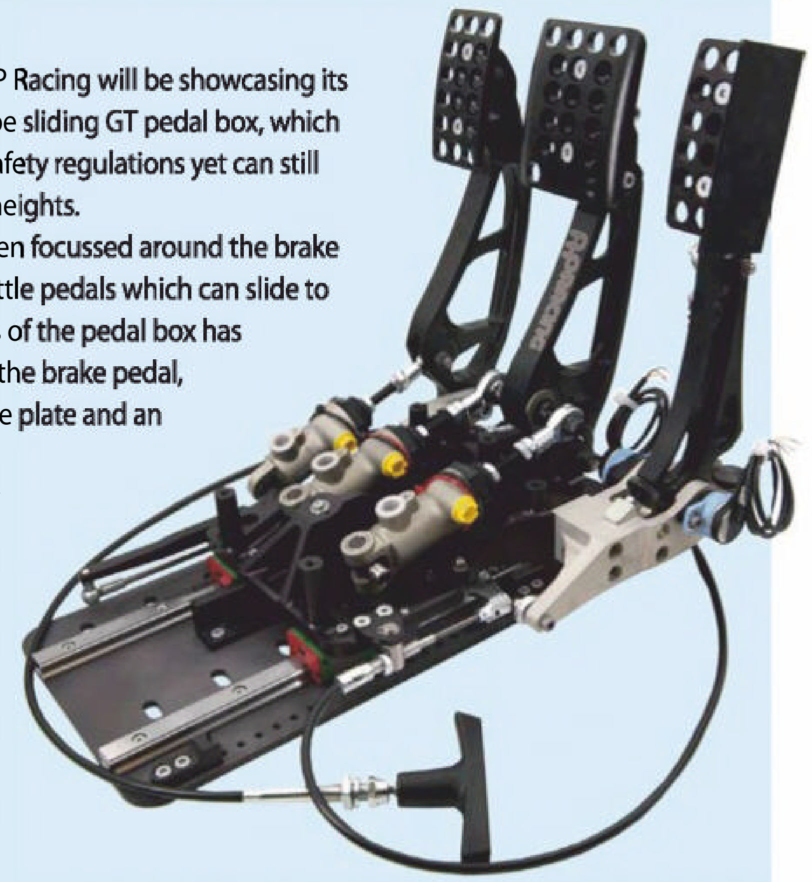
It has recently released its much anticipated eWG Electronic Wastegate – a fully electronic actuated external wastegate which is available in 45mm and 60mm versions.

These wastegates will give all the flow and interchangeability of Turbosmart's Gen-V range of external wastegates, we're told, with the kind of control 'never seen before', which is independent of any reference signal, without the need for compressed gas or boost hoses. They are also fully adjustable from a tuning interface, so boost control is completely adjustable from your laptop.

Turbosmart says: 'The Gen-V range in particular has proven itself in the harshest of environments with its reliability and performance. As boost control strategies become more and more complex, however, Turbosmart went back to the drawing board to come up with a solution that maintains all of the performance and reliability of the Gen-V range, and adds truly infinite control.'

www.turbosmart.com

AP Racing



Well-known brake manufacturer AP Racing will be showcasing its new and improved CP5548 pull type sliding GT pedal box, which complies with the new fixed seat safety regulations yet can still accommodate drivers of different heights.

The new modular design has been focussed around the brake pedal, with bolt on clutch and throttle pedals which can slide to suit any configuration. The stiffness of the pedal box has also increased, particularly around the brake pedal, due to the addition of a central base plate and an inboard sliding mechanism.

The front and rear stops are now more rigid while the throttle pedal is fully adjustable, incorporates a compression spring and adjustable hydraulic damper, and can now accommodate two throttle sensors if required for redundancy.

apracing.com

Lane Motorsport

Lane's motorsport division markets Souriau's 8STA miniature circular connectors.

These are designed for motorsport applications that demand high performance, small size and weight saving.

They are among the smallest and lightest circular connectors of their type currently available and, to complement them, Lane Motorsport also offers a number of compatible accessories made by HellermanTyton and Weald Electronics.

The connectors are derived from established military specifications MIL-DTL-38999 and Eurofighter JN1003, and feature a rugged aluminium body, plated with conductive black zinc, as standard.

These circular connectors are the preferred connectors across the world of competitive motorsport for sensors and electronics systems, in applications such as engine management, data acquisition, steering wheels, telemetry, fuel tanks and hybrid energy recovery systems.

www.lanemotorsport.com

Helix Autosport

Helix is an expert in precision engineered, handmade clutches and flywheels for the high performance, race, rally, classic and historic car markets.

All Helix clutches are manufactured from new components to the highest standards using the very best materials available, and they are designed to give a higher torque capacity together with an increased engine RPM.

The units can be fitted as a direct replacement for the standard unit without modification to the flywheel, while retaining the standard clutch release mechanism.

Helix also produces a range of aluminium billet covers that are made from high grade aluminium. These covers are stronger than many others, are more durable, increase performance, while they also reduce weight, we're told.

Helix can also re-pad, re-line, re-test, re-balance and recondition an old Helix clutch, plate and/or flywheel instead of customers having to buy a full new unit.

helixautosport.com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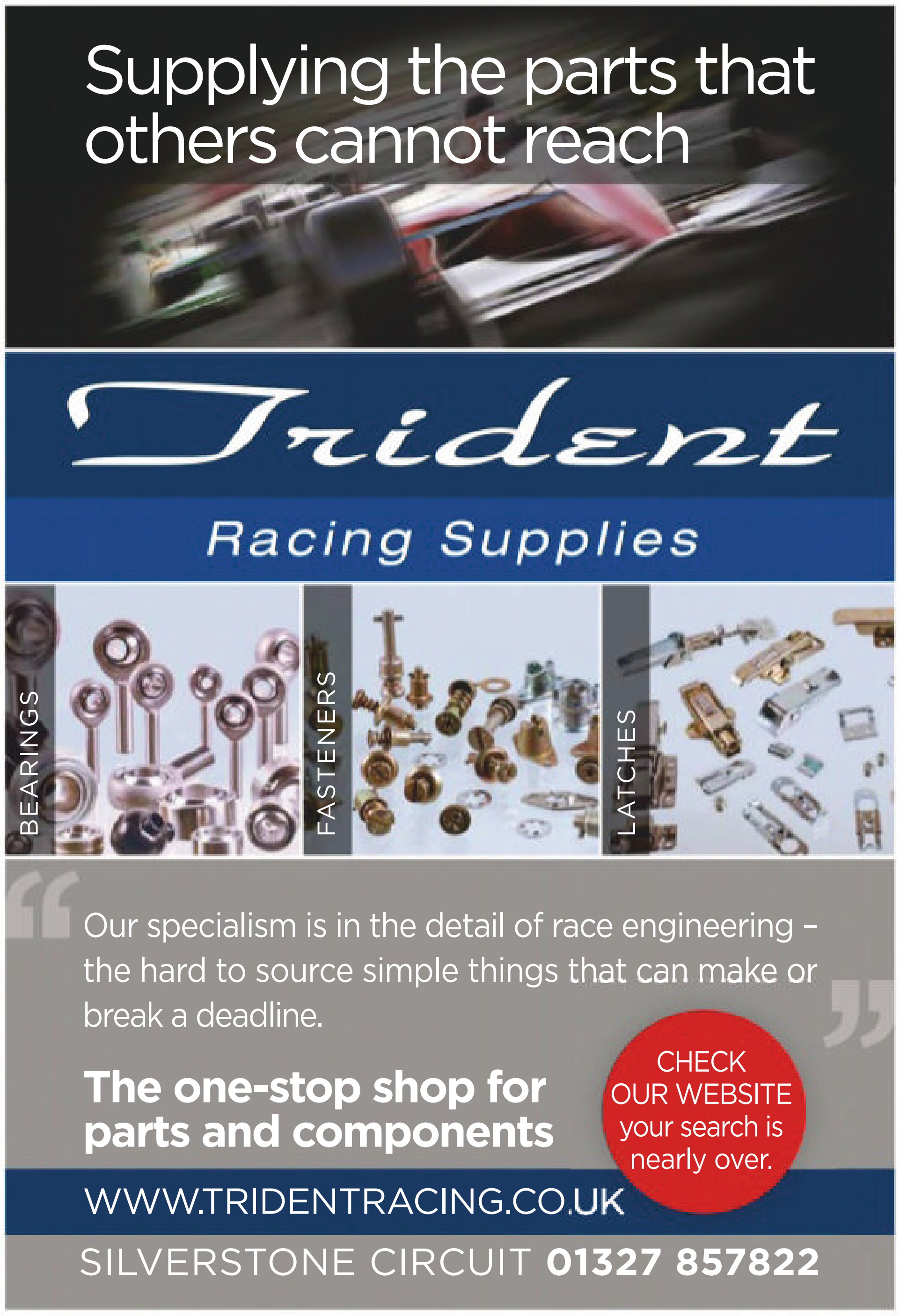
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Racing green

The MIA's CEO congratulates Formula 1 on its bold new sustainability plan

I have to say I was delighted to hear boss of Formula 1 Chase Carey's recent announcement of plans for a sustainable future. 'F1 will continue to lead and work with the energy and automotive sectors to deliver the world's first net-zero carbon hybrid internal combustion engine that hugely reduces carbon emissions around the world,' he said.

This is just the message needed to attract the attention of many industries and direct them towards the unique, energy-efficient capability of motorsport engineering companies. I congratulate F1 owner Liberty for taking this leadership position, it's a credit to the company. Let's hope the FIA will now pro-actively encourage others to promote the work in many series in the field of energy efficiency.

As Carey said, from aerodynamics to improved brake designs, the technological progress led by F1 teams has, over time, benefited hundreds of millions of cars on the road today.

Power to change

We now all need to make more people aware that the current Formula 1 hybrid power unit is the most efficient in the world, using less fuel to deliver more power, hence creating less CO_2, than any other car. This result was achieved, partly, as the result of the innovative, technical expertise from many suppliers working with the leading engine manufacturers.

It's good to see, at last, that the outstanding progress made by teams and their suppliers in energy efficiency is being recognised and it will be promoted more widely. The MIA will work hard to bring this to the attention of governments, so they appreciate and support the role which motorsport engineering plays on this complex journey to zero carbon mobility.

Our industry and suppliers are an invaluable development resource for energy efficient solutions which can rapidly demonstrate the right, and also the wrong, directions to take.

Formula 1, and motorsport in general, captures the attention of the wider public like no other medium, so we can expect this message will reach around the world and be beneficial to all motorsport, not simply F1, in the long run.

This exciting plan for sustainability in motorsport will be one of the highlights of the MIA's Energy Efficient Motorsport Conference (EEMS) on 8 January at the NEC during the Autosport International Show. Pat Symonds, the chief technical director of F1, will discuss with the audience how this plan will change the perception of engineering in grand prix racing and reach a wider audience, which will ultimately benefit our whole industry.

Joining the discussion, amongst many other key individuals from the motorsport industry, will be Andrea Toso, head of R&D at Dallara, the world's largest racecar manufacturer. This great Italian company will undoubtedly be at the centre of many of the changes which embrace energy efficiency, including those in American motorsport, which is the largest export market here in the UK.

F1 is racing towards a sustainable future, and as its expertise in energy efficiency is brought into focus this will only be good news for the wider motorsport industry

Talking of the US, the news of the new NASCAR 2021 programme and its many new suppliers is welcome, exciting and full of potential. It seems NASCAR has truly embraced the international supply chain of motorsport to work alongside the excellent US suppliers, and is to be congratulated for doing so.

Window of opportunity

Another opportunity will also soon arise as F1 embraces significant budget controls for the teams, a move which will potentially open the door to new suppliers. Teams will be looking for winning solutions which offer the very best value. Obviously, current suppliers are best able to capitalise on this going forward, but it's possible that a window of opportunity for new suppliers may open. Now is the time for those who feel they have the potential to supply Formula 1 teams to get themselves well prepared and be ready to take advantage when the window opens. They need to start building connections and networking with the correct people in the F1 operations right now.

Class act

I've recently had the honour of presenting graduation diplomas to this year's students of the MIA School of Race Engineering; excellent young people from around the world – Brazil, Australia, Portugal, China, the USA and the UK.

Knowledge and skills required to be a successful race engineer can best be learnt directly from world class tutors with unbeatable experience. It's also right that the only such school specialising in race engineering is in Motorsport Valley.

The Racing Point Formula 1 operation, Cranfield University and many teams and specialist companies help to deliver this course, which has proved to be very popular. The spring school in April is almost full, as businesses are now sending staff to learn more about the challenges which race engineers face, so they have a well-informed advantage to help supply future solutions.

I also remind you to make sure you take the chance to meet and question Pat Symonds at the Energy Efficient Motorsport Conference (see www.the-mia.com/events) and to visit the Autosport International Show. It promises to be a great event which will need good preparation in advance to make sure you get to meet all those of value to your business.

But before all that we close 2019 with a General Election in the UK, the outcome of which is vital to the future of all Motorsport Valley UK businesses. One political party offers Brexit with a deal, one will keep the UK within the EU and the other offers another referendum but no certainty as to what outcome they will support – exit or stay in. I must strongly urge everyone to use your vote and encourage others to do the same, or you may live to regret the outcome, but in silence. This is no time to stand back. Let's just hope the result is good news for 2020, and that it marks an end to limitless, pathetic 'debate' amongst politicians.

The technological progress led by Formula 1 teams has, over time, benefited hundreds of millions of cars on the road today

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South Africa's back on track

The South African circuit of Kyalami hosted its first nine-hour race for 37 years when the Intercontinental GT Series visited in November for the concluding round of its 2019 season. The race was the first international race since the track was taken over by the national Porsche importer Tobi Venter, and then renovated to become a Grade 2 track, which means its capable of hosting cars up to but not including Formula 1.

Pre-race interest in the track was at an all-time high. This is a circuit with tremendous history, having hosted sportscar and Formula 1 in the past, the last grand prix having been held here in 1993. And there is a clear ambition from the management to continue to attract more international events.

The first question to Venter was an obvious one; do they want Formula 1 return? Chase Carey and Sean Bratches have been to the track, as has Jean Todt, and Venter says that it is a small leap to get from Grade 2 to Grade 1. I am not so sure.

The historic nature of the circuit has been retained, with fans able to get close to the cars. Also, the circuit layout was an immediate hit for all the competitors in the ICGT series, with a 50m elevation from the lowest to the highest point of the track, fast sweeping corners and tricky combinations that caught some of them out as they had to learn the circuit. The drivers had to take some risks here, too, and they were tempered by the proximity of the barriers – Venter admitted that they eschewed the advice to make the track easier for the cameras and preferred to make it a drivers' track.

And here lies the problem. While Venter believes that there would need to be minimal changes to the track to get it to Grade 1 status, introducing Tech-Pro barriers and building grandstands, I would hazard a guess that the barriers would need to be moved far back, gravel traps would need to be replaced by high-grip asphalt, and all that would very probabaly rob the circuit of its wonderful 'old school' charm.

African opportunities

But there is a clear desire to bring international racing back to South Africa. According to Venter there is a whole generation of South Africans who have missed out on seeing top cars and top drivers racing on their shores. Corruption and a weak Rand have hurt the industry over the last 20 years, but the new Kyalami facility is now an attractive option in South Africa. While the ICGT was there, so was the promoter for the FIA WEC, Gerard Neveu, who made no secret of his desire to increase the reach of the series onto the African continent.

Apparently the rental of the circuit was expensive, costing far more than a European circuit, and that may be off-putting for the FIA WEC although there are ways around everything. The track could be considered as an addition to the WEC calendar, or to replace Shanghai. Having watched the GT3 cars race around the Kyalami track, I know that the LMP1 machines would be thrilling to watch and I hope that Neveu finds a way to take the series there in 2021. The Frenchman said that 2020 was too early and so it cannot be a replacement for the Sao Paulo round in February should a replacement be needed, and the November date is secured by Ratel, as is the nine-hour format. The only issue with the November date was the weather; regular thunderstorms swept the circuit, and interrupted the race on Saturday night for two hours.

Drivers loved the layout; the corners were all linked in sequence so a mistake in one would cost dearly in the next two. It made a change, said one driver, to the straight, 90 degree corner, straight, hairpin layout of modern circuits. The track surface was also old, but had not been used. Tyre degredation was low, which meant drivers could really push.

Broad vision

The pit facility has been completely rebuilt and now hosts car presentations for multiple brands, including Porsche. It is a conference centre, too, and one of its biggest events is the Delicious food festival that attracts 35,000 people for a smorgasbord of food and music. Chaka Khan headlined in 2015, and it has got better since then. The idea was to generate interest in the circuit itself, and then as the next stage to bring more international racing to the track. Venter has an interest in bringing South African drivers and riders to the circuit, so the MotoGP series are on his radar.

> **There is no doubt that the LMP1 cars would be thrilling around Kyalami**

Having bought the circuit in 2014 at a bankruptcy auction, Venter has spent a fortune to get the track to its current level. Even though the crowd figure was not high for this first international race, this is a five-year agreement and promoters are hoping that next year will be better. Venter was clear; the international racing programme has to make financial sense if it is to continue and grow.

It was hard to judge the return of international racing to this majestic circuit as anything other than a tremendous success, lifting as much South African motorsport as the entire Intercontinental GT Series. As an advert for the circuit and the region, Venter and his team could not have done better.

ANDREW COTTON Editor


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