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Haas VF-19

The curious case of F1's most inconsistent car

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Putting the *wow* into GT racing's brand new class

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The IndyCar field prepares to take the green flag, but the work to win a race starts long before this. Turn to page 26 to find out more


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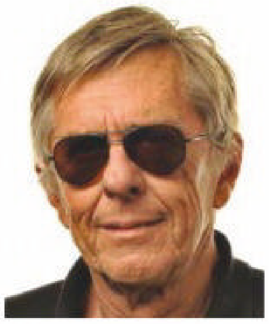

The foreseeable future?

The crystal ball is dusted down as we ponder two vastly different possible fates for F1

So here we are at the race track on this sunny, hot, 18th of August 2050, a Sunday. The sun is pleasant, the sulphate particulate solar umbrella working reasonably well. We have a full grid of sleek Formula 1 rapid competition modules ready to race and millions of virtual drivers mixed in, ready to race real-time with the physically present units.

Most spectators are at home on a holographic ImersoVu™ viewing facility, giving TruFidelity™ experience of the event. There are, of course the deep immersion fanatics who come to the venue for the full experience, the noise now consisting of just squealing tyres. They had to pay many carbon credits for the footprint they were leaving by travelling to the race, the climate emergency now improving, but not yet over.

The cars are electric powered using energy coming from an induction grid under the track. Driver interface is by direct neural connections from an electrode studded skullcap and the cars have autonomous capacity, or could be driven remotely. In fact, some are, but to count for points in the championship the racecar needs to be manned.

The protective suit is light and airy; no combustibles, thus no more Nomex. The only burns anyone could have would be from not having enough sunscreen, spilled scalding espresso or from the faux-charcoal (CleanBurn™) grill cooking Meatable™ meat-free burgers.

Road irrelevance

These vehicles have absolutely no relevance or similarity to most of the transport in the world, where the fleet consists mainly of urban mass transport and hi-speed trains between cities, where 80 per cent of the population now lives.

Individual civilian transport is now just helicopters, for the well to do, and governmental limousines. After all, we are all equal, but some are still more equal than others.

The media frets that the spectator count is slowly declining, most of the fans being millennials who got the bug in their youth, the younger people do not seem to be attracted to it now.

But wait! This is but one view of tomorrow, there are others, of course, and surely the obverse can also have its say. This would be a gladiatorial combat with flame-spouting cars, prone to huge spectacular crashes, with replays in slow-motion, heroes and villains with massive social media presence, mostly groomed and used by big media conglomerates to generate content and grab eyeballs, the root of 21st century wealth.

Thrill seekers

There are a slew of movies for youngsters taking a deep-dive into this, set in a post-apocalyptic landscape with this theme. It gives good box-office and sets trends. It could just be schadenfreude, but it does have a ring of the probable.

You doubt it? Then I suggest having a look at the WWF, stock car racing and random internet viral items. Nobody has gone bankrupt catering to the lowest common denominator, and these traits

Will the future of F1 be all-electric like Formula E (above) or might it go in a very different direction, embracing noise and spectacle?

are not being reduced as far as I can see, humanity being built 'from crooked timber' as the British-Russian philosopher Isaiah Berlin once said.

Life being what it is, neither of these scenarios will come to pass, but there will be a mixture of several of these elements with some as yet unknown factors also thrown into the mix.

If you study history, trends can be observed and plans made with these in mind, but the best laid plans tend to come a cropper because it is very difficult to forecast due to a lack of data. This improves year after year with computing progress, and artificial intelligence, but for societal change it will usually follow feeling rather than logic.

'The heart has its reasons which reason knows nothing of,' the French mathematician and philosopher Blaise Pascal once said. Pascal spoke about faith here, but it is oh so true in too many decisions with massive consequences. Ego, a tinge of lunacy or to put it politely 'unconscious psychological traits' will drive many of the roads taken, often completely against logic, in life in general and particularly in racing.

If you, dear reader, are as addicted to racing as I am, a word of advice here. Maybe it is something that you should not look too closely at: 'O, that way madness lies; let me shun that. No more of that.' To quote William Shakespeare (*King Lear*).

That said, I do feel that we stand in a particular time in history, at a crossroads that will determine long-range consequences for the whole sport. Most motorsport sanctioning bodies are now wrestling with the problems, trying to resolve them, and also trying to recapture past glories, but not necessarily successfully, there is too much of a tinge of *deja vu*, providing old solutions to new problems.

It is a different world we live in now and its centre of gravity – financial, moral and intellectual – is shifting from the Euro-centric one that prevailed in previous centuries. May you live in interesting times, as the saying goes.

A business model that was appropriate for the 20th century when used by motor racing is as obsolete as most other practices of the time, be it economy, social behaviour, politics or clothing styles. It is in its last throes, but no discernible new direction can be seen emerging in the mists. Remember, bell-bottoms and sideburns were *de rigueur* then. I hope they will not return, though.

Given that those in charge are slightly younger than me, but not that much, maybe we need a generational change to see what is the golden way. If there is one; but then that is the cynic in me.

Welcome change

Cycles will come and go, much as beards have made a re-appearance and tattoos are now almost obligatory, but we can say with certainty: 'The bad news is that nothing lasts, also the good news is that nothing lasts'. It will be different, deal with it.

I will close this rant by making a mental note to get some more popcorn in and to sit and watch as it all unfolds, and also to charge the lithium batteries in my flat screen OLED crystal ball, it has been in blank screen mode lately.

I do feel that we stand in a particular time in history, at a crossroads that will determine long-range consequences for the whole sport

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Formula 1 conundrums

There is much that is puzzling in grand prix racing this season argues our columnist

Ferrari continues to receive a lot of stick for its failure so far to unseat Mercedes in the Formula 1 turbo-hybrid era. Yet the fact remains that, prior to Red Bull-Honda recently coming on strongly, only Ferrari has presented a consistent challenge to the Silver Arrows – no mean feat considering the resources that the latter has brought to bear to achieve its current dominance. On top of that Ferrari's PU development, in particular, represents a massive achievement in becoming the current performance benchmark.

One other thing worth mentioning about Ferrari is that it is the *only* manufacturer and racing team that has contested F1 grands prix every year since the world championship's inception back in 1950. Many famous marques have come and gone but Ferrari has been prominent for nearly 70 years, which is amazing. It's fair to mention that McLaren and Williams have impressively chalked up the half-century, also that all but one of the current F1 teams have existed for at least 20 seasons, even if tortuously and under different names.

American dream

Haas, which is the only current F1 team without any such heritage, hopefully will be sufficiently successful in the coming seasons to become part of the veterans' club in due course. Its presence is very welcome and important to grand prix racing, not only in making up numbers but in widening Formula 1's team ownership base outside of Europe – significant perhaps for Liberty's growth aspirations. Its clever business plan is different and to my mind refreshing. If permitted to continue – probably not – it might allow more similarly worthy team start-ups. The regulations do allow a 26-car grid (if there are enough garages, of course).

I have mentioned previously that, given its erratic performances, the American outfit might do better by focussing on extracting the maximum from the existing chassis rather than throwing in developments that may just confuse the picture. Romain Grosjean's insistence on resorting to the as-designed initial car specification, without obvious detriment, kind of proves my point. Perhaps a finger should be pointed at Haas' engineering team, but almost certainly its problem lies in understanding how to optimise 'Pirelli's pernicketies', especially in differing conditions.

Trying to get these tyres consistently into their narrow operating window is a first-order priority. Otherwise, it's almost a case of other developments being just wasted effort. Its drivers' fatal attraction for each other hasn't helped either – I'm not privy to their contract details, but standing them down from the following race's Friday practice sessions in favour of Haas' development drivers would be my way of enforcing their respect for the team and stopping them driving into each other.

Not so Super?

A couple of other happenings have caught my attention recently. Why is Super Formula seemingly the kiss of death for F1 junior drivers? Stoffel Vandoorne and Pierre Gasly both performed very impressively in the highly-rated Japanese championship, but have ultimately failed the test when promoted to F1 teams. The answer could be coincidence, of course, or it could be that the spec Yokohama tyres used in SF do not require anything like the babying of F1's tyres and the cars can be driven flat out virtually all race. This is definitely not good preparation for F1. Plus, with all respect for the professionalism of SF teams and the closeness of competition, their level of engineering is inevitably not to an equivalent sophistication, the depth of data gathering, analysis and implementation of a much lower order, and the number of personnel far less. Added to this, the complexity of the hybrid F1 cars imposes a whole lot more pressure and workload on the drivers when they make the transition. Which doesn't explain why Gasly made such a good impression during his debut year at Toro Rosso before falling apart at Red Bull. So maybe it is just coincidence? Nonetheless, I'll bet aspiring F1 drivers and their management might have second thoughts now about following this route to Formula 1.

Dan Ticktum's case is somewhat different, but still in context. He seemed well on course for a Toro Rosso seat, but was booted out of the Red Bull programme after dismal SF results that belied his initial foray into Japan last year.

Another puzzle. I'm not one much for statistics (lies, damned lies etc.) but how come there was such a discrepancy between fastest laps in the Hungarian GP? The majority of these occurred between laps 49 and 69, logically when fuel loads had reduced. Setting aside Max Verstappen's time, set at the end after deliberately stopping for new softs, there was over 4.6 seconds between Lewis Hamilton (next fastest) and the slowest in that period (Antonio Giovinazzi). Even Charles Leclerc was nearly two seconds down on the Mercedes and fifth placed Carlos Sainz close to 2.5. This is in contrast to qualifying, when the gap between pole and 10th place was only 1.469 seconds.

XPB

It was difficult to make sense of the huge difference in pace between Lewis Hamilton and other F1 drivers during the Hungarian Grand Prix

Hammer time

The tight nature of the track, meaning overtaking is tough and that cars run in traffic in dirty air, has to be a factor. But one would think that qualifying, with the top three teams' cars and PUs optimised to a degree that lesser outfits cannot match, would throw up more of a gap than the race performance did. There can be no doubt that Hamilton, having changed tyres at the beginning of his late-race chase of Verstappen and probably having turned up his PU as well, set a faster lap than if Mercedes hadn't gambled on this strategy. Even so, to be nearly 3.5 seconds slower (example Daniil Kyvat) is an absolute age in modern racing. Such a large delta has not been evident at previous rounds, so did some drivers go into follow-my-leader mode because of the difficulty in passing cars?

Then one of the marks of a great racing driver is the ability to relentlessly bang in very fast lap times throughout the race. Just like Hamilton.

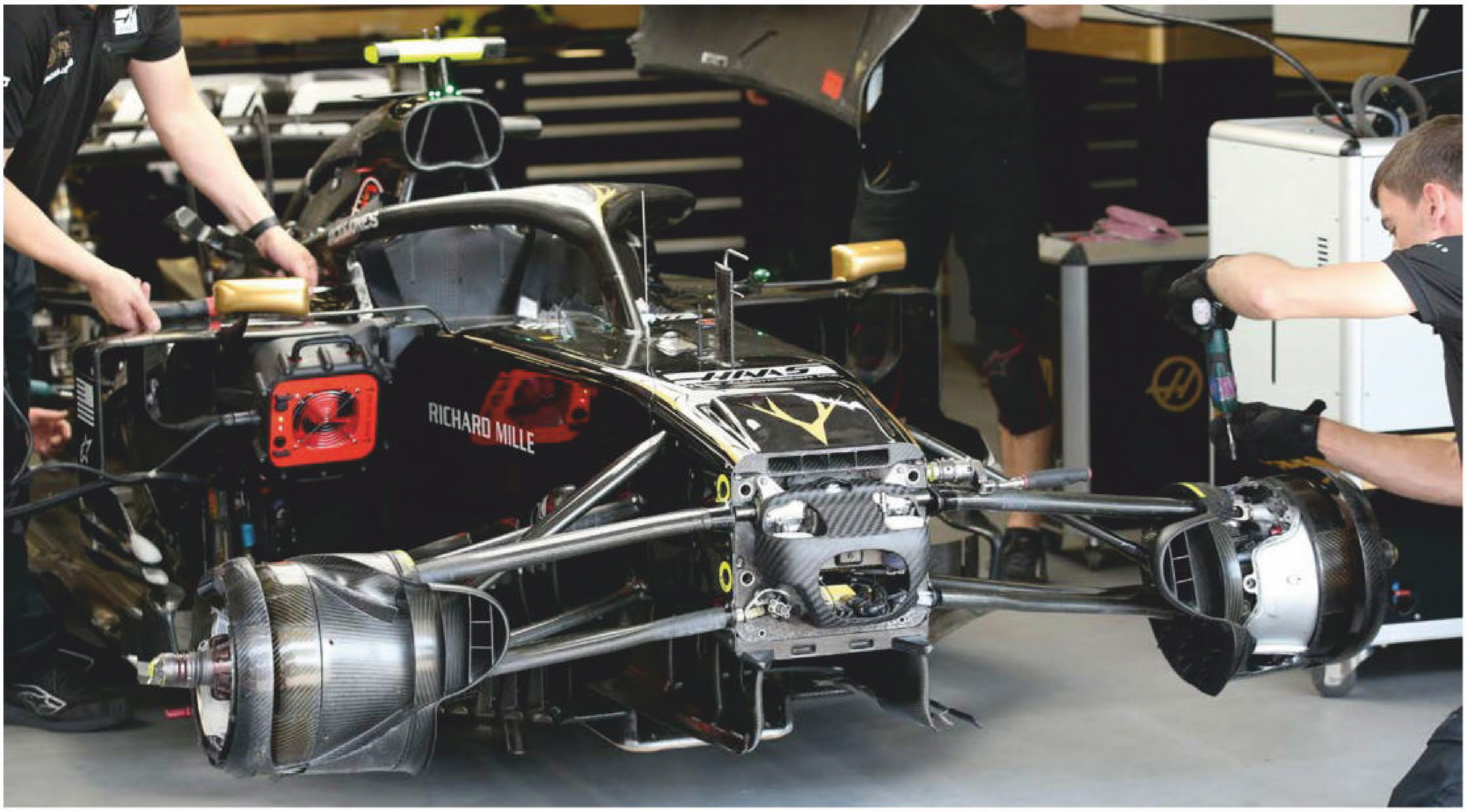
Stoffel Vandoorne and Pierre Gasly both performed very impressively in Super Formula, but have failed the test when promoted to F1 teams

‘We keep fixing things, changing bits, adding stuff, and it keeps getting worse’

There Haas to be a answer

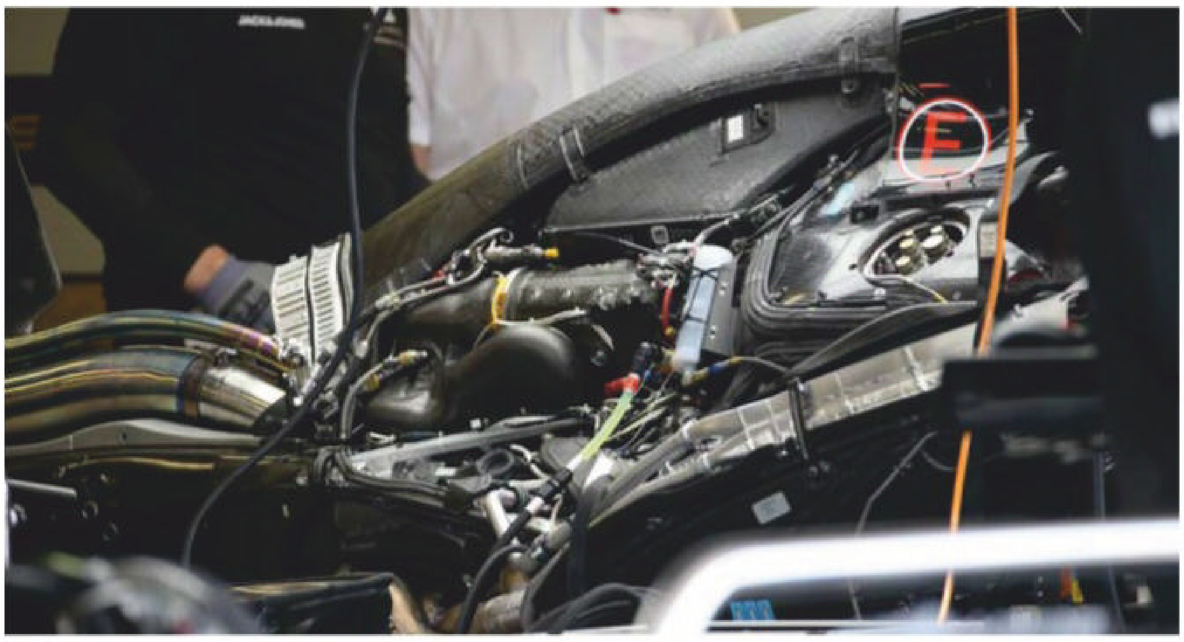
One of the biggest mysteries of the 2019 F1 season is why the Haas VF-19 has shown such great pace and yet failed to deliver solid results. *Racecar* spoke to the car's chief designer, Rob Taylor, to get to the heart of the issue and to find out how the team is attempting to resolve it

By SAM COLLINS



The monocoque needed a new front bulkhead due to a rule change requiring four nose attachment points. Dampers, torsion bars, wishbones and uprights are all courtesy of Ferrari

From the very moment it rolled out for the first time Rob Taylor, the chief designer at the Haas F1 Team, had an issue with this year's VF-19. It had been launched in a predominantly black livery, in deference to a new title sponsor, replacing the grey and white Haas CNC inspired colour schemes of previous years, and, as Taylor explains: 'The black colour makes it hard for the guys back at the factory, because it accentuates all of the imperfections. It's a remarkable difference from the paint last year, which was grey and sombre, but that also sort of camouflaged the surface. I'm not saying that there is anything wrong with it, but the whole car is a fabrication of lots of different elements so trying to get them all perfectly aligned is almost an impossible task, and when it's painted black you can see all of these imperfections and think to yourself, oh my lord, would I buy one of these? And the answer is no!'



Ferrari engine in the rear of the VF-19. Haas has had a PU supply deal with the Scuderia since its inception

Paint it black

To be fair, these imperfections are not that unusual due to the way current F1 machinery is constructed and if every chassis on the grid was painted black like the Haas then they too would likely be showing the same kind of flaws. 'You look at a bare monocoque and what you are looking at it is about 15 or 20 different pieces,' Taylor says. 'You have got the main structure, then you have sidepods, Zylon panels, bits of fairing here there and everywhere. It results in there being a patchwork quilt down the side, and you paint it black and it all shows up.'

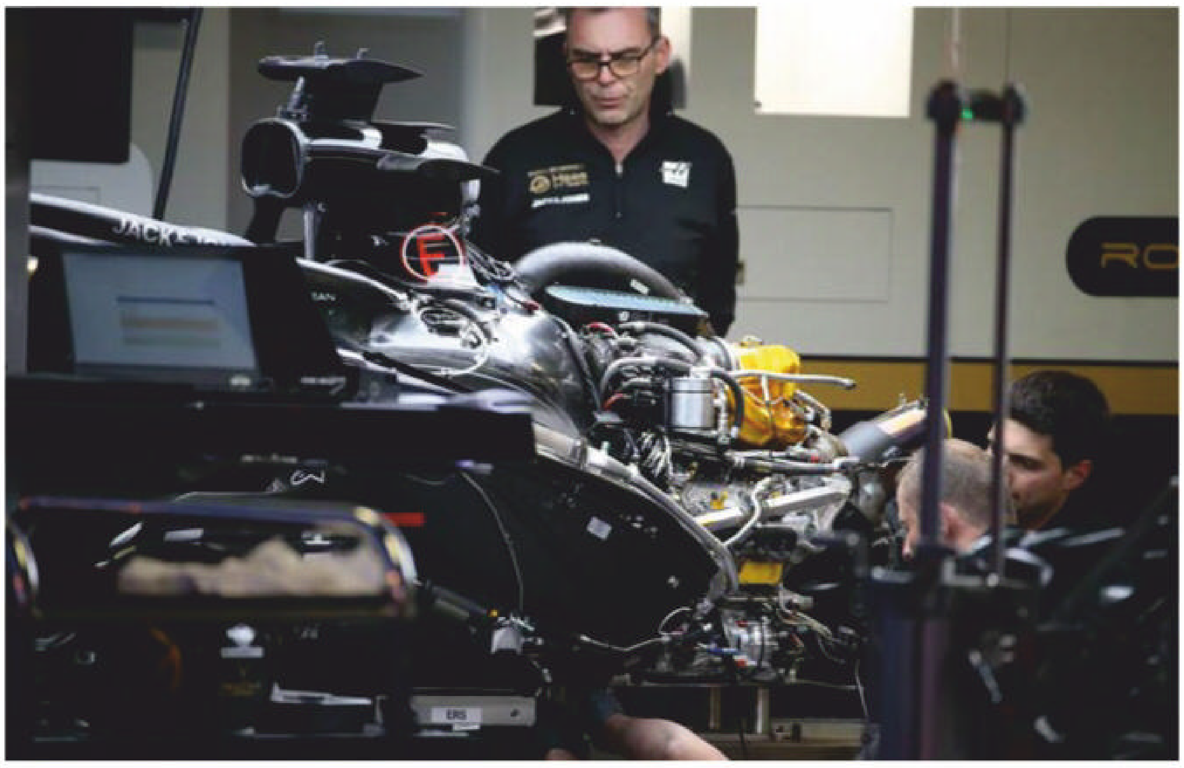
Livery issues aside, the Haas VF-19 is very much an evolutionary design incorporating many of the overall concepts used on the 2018 car. As with all the Haas F1 cars so far it utilises a very high proportion of components supplied by Ferrari and developed for the Italian team's 2019 design, rather than the American branded car. However, the monocoque itself is developed jointly by Haas and Dallara in Italy.

'We have been forced into some changes for this car,' Taylor says. 'For example, we had to do a new front bulkhead as the nose fixation points had to change by regulation. The suspension pickups and kinematics are subtly different but overall the chassis is heavily an evolution of the VF-18. The biggest differences come from investment in manufacturing technologies to reduce the lead time and the weight of the chassis. The parasitic weight can be found in the laminates in places. You have to remember that the monocoque is still a hand-made thing so there is a lot of gain to be had by making it easier to laminate, which in turn probably makes it lighter. Overall, though, it is very close in terms of concept to last year, they are very similar.'

Working with Dallara gives Haas not only a slightly different approach to other teams, but

'The biggest differences come from investment in manufacturing technologies to reduce the lead time and the weight of the chassis'

‘In principle you could take our inboard suspension parts and fit them to the Ferrari’



The cooler positions are an evolution of the VF-18 layout, except now there is one fewer circuit in the system

TECH SPEC: Haas VF-19

Chassis
Dallara carbon fibre and honeycomb composite structure.

Engine
Ferrari 064, turbocharged 1.6-litre V6 featuring direct injection.

Suspension
Ferrari supplied double wishbone with pushrod actuated torsion bars front, pullrod rear; ZF Sachs dampers.

Steering
Ferrari supplied, power-assisted.

Transmission
Ferrari servo-controlled hydraulic limited-slip differential with semi-automatic sequential and electronically-controlled gearbox, quick-shift (eight gears, plus reverse); composite casing; AP Racing multi-plate clutch.

Brakes
Brembo carbon-carbon.

Seatbelts
Sabelt.

Wheels
OZ Racing.

Fuel Cell
ATL.

Weight
743kg including driver.

Disc world

The Haas VF-19 features a braking system from Italian specialist Brembo. It is unsurprisingly extremely similar to the version used on the Ferrari SF90. The aerodynamic rule changes introduced into Formula 1 at the start of the 2019 season have had a noteworthy impact on the design of the brake discs and pads used by the teams, as the reduction in downforce and simplified wings have seen top speeds rise, but apex speeds fall.

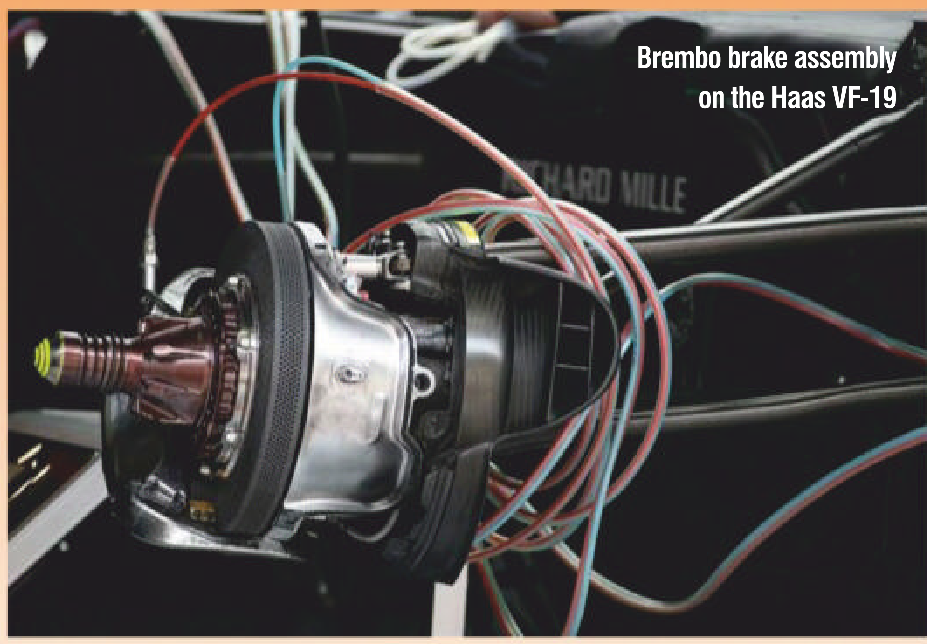
‘This meant we had to make a big step from 2018 as a result of the new rules, as obviously the brakes have to do a lot more work,’ Giovanni Clemente, Brembo Racing’s Formula 1 race engineer and telemetry data analyst explains. ‘This year’s brakes are under a much higher thermal stress but the peak torques are actually slightly lower than they were last year. The peak torque is dependent on the tyre and the grip that you have from the track surface, and with the lower downforce level the cars have lower grip.’

The brake manufacturers involved in Formula 1 have long supplied a range of varying friction materials for different race tracks and at times for different driver preferences, and as a result of the aerodynamic regulation changes Brembo has widened its offering for 2019.

‘To cope with the increased demands we have a new drilling pattern for the front discs with 1500 holes, seven layers of them,’ Clemente says. ‘Those discs have been introduced specifically to cope with the demands of the new cars, and we will use them at the toughest tracks for us, like Bahrain, Abu Dhabi, Singapore, Canada and Monaco. So those are available to teams along with versions featuring 800 holes and another with 1200 holes.’

Changes have also been made to the brake pads for the exact same reason, and again a range of different pad designs is available to the teams. ‘There are different patterns for brake cooling with the pads too, but the design priorities are a bit different as the pads play a key role in the stiffness of the whole system,’ Clemente says. ‘That means that the key with the pad drillings is not to reduce the overall stiffness when compressed [between piston and disc].

‘For 2019 we have brought in some new patterns and new shapes,’ Clemente adds. ‘This was a lot to do with the way different teams decided to split the heat between the caliper, the disc, the tyre and the rim. At some tracks the teams want to retain heat in the disc for longer, for example at Silverstone, where most of the heat goes into the tyres, so it’s important to keep both at high temperature as the track layout there means you may not be able to keep the friction material in the operating window. The other extreme is Bahrain, where you can easily overheat them, so there they want to get the heat out.’



Brembo brake assembly on the Haas VF-19

‘At some tracks the teams want to retain heat in the disc for longer’

A rare shot of a Brembo F1 disc, as used by Haas, showing internal cooling channels

'We attempted to change the configuration of the aerodynamics on the VF-19 without losing the good things from last year's racecar'

also opens up some different ways of working for both it and the Italian firm. 'Most of Dallara's other products are built to a budget as they are trying to make a profit from selling them, but ours has a different focus,' Taylor says. 'While we keep an eye on the cost it is not the top priority. [On the other hand] it's completely alien to everyone else in the paddock, in that your technology partner has a totally different viewpoint to anyone else in F1.'

Carbon copies

Having a lot of carry-over on the monocoque is not likely to leave a great deal of performance areas unexplored, and indeed next year's VF-20 is probably going to be another similar design too. 'The rules with the monocoque are fairly constrained,' Taylor says. 'The size of the cockpit opening is defined, as is the fuel cell, and the overall length of the car is dominated by that. 'Even the leg box and the front of the tub is constrained, [and] if you stripped off all the stuff around it then you would struggle to tell [all the different F1 monocoques] apart.

'To say how much performance comes directly from the monocoque is very difficult,' Taylor adds. 'Yes we can make it lighter and we can calculate what that in theory brings in terms of lap time, but otherwise it's very hard to quantify how much performance gain comes from the chassis. You can make a monocoque really bad, really easily. It is not just weight, one wishbone point which is compliant, for example, could plague you for the whole year. That is an extreme example, but you can't ever really say that this year's monocoque brings 0.2 seconds a lap compared to last year.'

The iterative approach to development has also been taken with the cooling system of the Haas VF-19, with coolers located in each sidepod along with those mounted in the centre of the car above the bellhousing and fed by ducts inside the roll hoop.

'You can see that the sidepod duct is slightly different to the VF-18 but the size of the aperture is about the same. Under the bodywork we have evolved it quite a bit and you could not say it is a cut and paste from last year,' Taylor says. 'The cooling layout has one fewer circuit than in 2018 but in general it is a reasonable revision of what we had before. We have learned more about how to optimise the drivetrain we have and how to manage the cooling demands in terms of different tracks, ambient temperatures, throttle loads and deployment modes. With one of these cars you are trying to get it to work in 10 or 15 different configurations, and the more efficient you can be about optimising all of those into one package without making too many changes the better you are. With the first Haas [VF-16] we had an excess of cooling capability a lot of the time because we could not trade the demands off against each other all that well, but with the more you do, the more you are able to trade things off against one another. That shows in a lot of the implementation of the cooling we have on the car this year.'

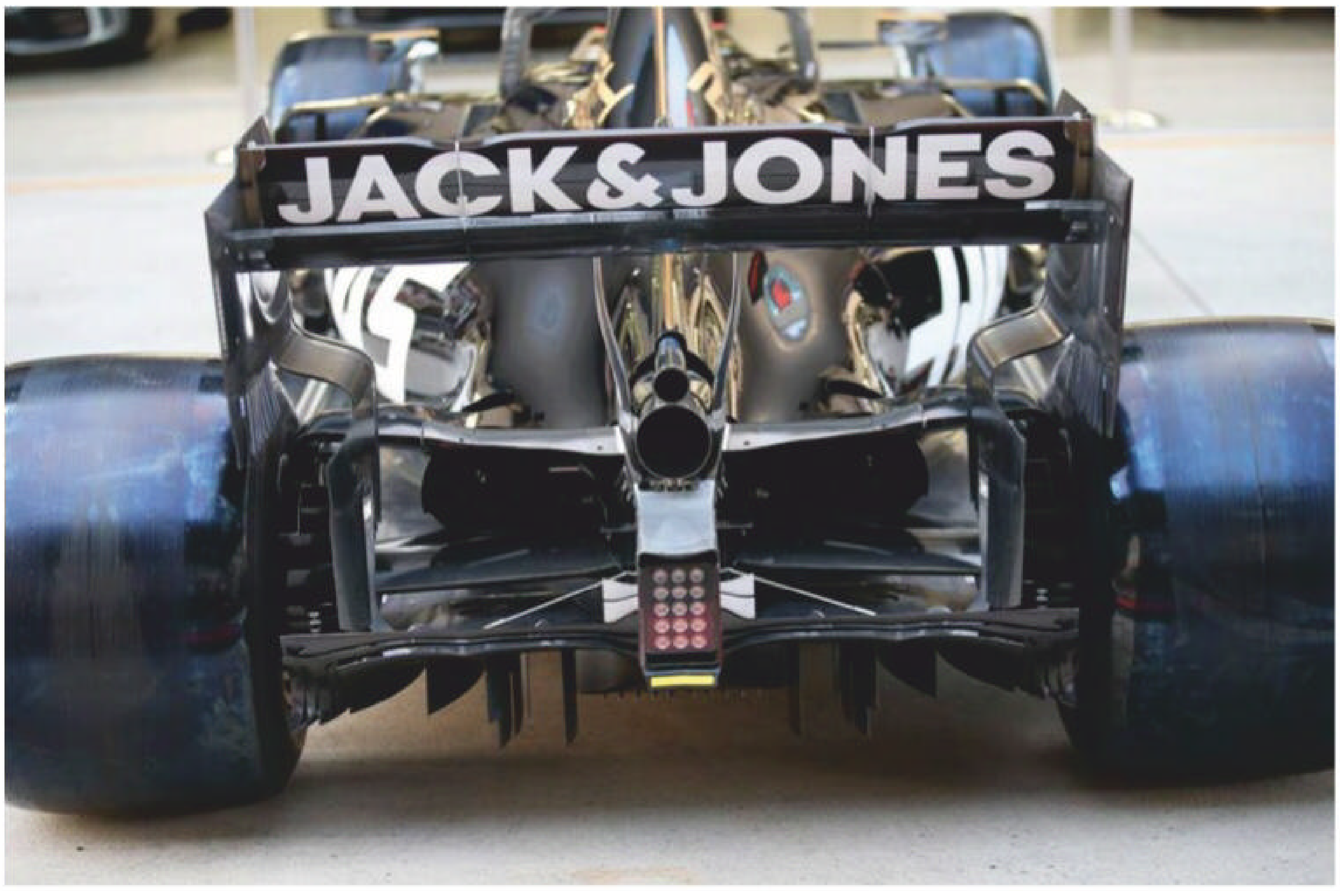
Aerodynamic demands also played a key role in the cooling system layout, and this is another area where Haas has to develop its own concept and parts separately to Ferrari. Using the Ferrari wind tunnel along with the team's own CFD capability (split between the US and UK) work on the VF-19's aerodynamic package was aimed largely at resolving a number of shortcomings identified with the VF-18.

'We knew we had some Achilles' heels with that car, especially with low speed aero, so for this year's car we set about targeting what it was that was causing those issues,' Taylor says. 'We attempted to change the configuration of the aero without losing the good things about it as we recognised that last year's car had some very good things about it and we wanted to retain those. It did, however, have a recurring negative theme in one particular circumstance, and that is what we attacked in terms of aero.'

Clipped wings

Another factor the team had to cope with was the new regulations aimed at improving the quality of the racing in general, with simplified front and rear wings along with smaller bargeboards. 'It ultimately was not a dramatic

While the Haas livery might evoke F1 cars of yore the relationship with its new sponsor has caused its own issues this year



A lack of rear downforce is plaguing the Haas VF-19 this season, resulting in overheated rear rubber at some of the races

In the first quarter of the season both of the VF-19s normally qualified in the top 10, before a quite sudden and unexplained drop in form

change, certainly not as dramatic as you might expect,' Taylor says. 'The changes were made not to slow the cars down, they were to change the wake. Whenever the FIA try to slow the cars down they take 20 per cent off and we find 25 per cent over the winter, so it cancels out. By the roll out we were back to where we started from.

'The biggest change would be to write the rules to force teams to build an overtaking car. If you started the fast cars at the back, for example, you would develop the car in a different way, but it's not, it's a fast car [that's needed] now and that is all we are interested in,' Taylor adds. 'We don't design the car with running in a wake in mind, I think that is an area beyond our knowledge. We have never researched or developed the methodology to even assess that. We can certainly note the influences of cars following, but to develop the car in that direction is not part of our remit. We simply try to develop a fast racecar, and hopefully along the way you start to understand, perhaps from past experiences, what makes a car sensitive to following and minimise that. Particular yaw angles or particular instances of onset of wind or something, if it works in that respect it is probably good at following another car. But it's a relatively immature set of metrics for us.'

Black ops

The bodywork of the VF-19 did draw a huge amount of media attention around the mid-point of the season, but not because of its design. Instead it was due to social media comments made by the CEO of the team's title sponsor, the company responsible for that revealing black livery. At the time the sponsor was embroiled in a legal fight about the origin of its logo, and just before the British Grand Prix the sponsor's twitter feed announced that it was ending its partnership with the team, citing poor performances. The now deleted tweets referred to the VF-19 as 'a milk float at back of grid – a disaster for us.' Ultimately the partnership was not ended and the CEO left the company. The branding has remained on the Haas cars.

But the VF-19 is no milk float. Indeed it has proved itself to be a fairly rapid and capable racecar. In the first quarter of the season both cars normally qualified in the top 10, before a sudden and unexplained dip in form. From that point on it was clear that the car could produce quick laps, as one of the two VF-19s did in Austria to qualify fifth, but it was very inconsistent and generally struggling for pace.

'It was clear after Barcelona that there was something anomalous happening, enough to make us have a think,' Taylor says. 'I wouldn't say that the car has not responded to upgrades, but it is difficult to tease out what the problem is. We keep fixing things, changing bits, adding bits and it keeps getting worse. At the moment it is proving rather hard to put a finger on. We know what is wrong, we are just losing rear downforce. Racing is a funny thing. Sometimes it just slaps you in the face and you realise it was obvious. You have to build yourself a set of metrics you believe in, it is an evolutionary process. You look at the data, you look at what you were doing last year, you think you understand what was good with the changes you made last year. Every engineer must say this, you think you understand what it is that makes a car go fast, what the good features are, and you set yourself the task of improving those features.'

The bargeboard height in F1 was reduced for 2019, but they are still very complicated. Note the reshaped sidepod inlet

'I wouldn't say it's not responded to upgrades, but it is difficult to figure out what the problem is'

A quick look at the results from both races and qualifying this season show clearly that the performance of the VF-19 is very erratic. At some tracks it is capable of setting fast times in qualifying, but fading in the race, while at others it is just off the pace all weekend.

'It would be ever so easy to just look at the headline numbers from the wind tunnel and think that is the answer, just the headlines. As with most things in life it is the detail that is the bit that really kicks you in the nuts, so you try to fix those things,' Taylor says. 'Sometimes you are not chasing a particular number, sometimes it's about reshaping the aeromap to create a benign car that turns in better, isn't effected by crosswinds or yaw, then you can get more lap time out of it. Those are quite subtle things to tease out as they are just moments in time, but moments that have a big effect on the driver.'

Pain in the Haas

Indeed, the driver comments about the way the car feels have at times livened up some of the race broadcasts as the pit to car audio is played out to the media and fans.

'It's hard to judge what makes a driver comfortable, but you have to design the car to the best data you have, the physics of the thing, not what a driver might feel, then it's about making them believe in it,' Taylor says. 'For one thing, you have to tease out of the drivers what they are actually talking about, to try to understand what it is that is making them feel uncomfortable. That is a challenge in itself as sometimes the language is a bit intense and until you sit down and have a long term discussion about it you don't always understand what it is they want. You really want to see if you can see a recurring theme when they say something, sometimes they are picking up on something very subtle and it's interpreting what they are trying to say and linking that to a physical outcome. We use this word *stability* all the time, for instance, but what the hell does that really mean? The drivers rank the stability of the car on turn-in, but really that is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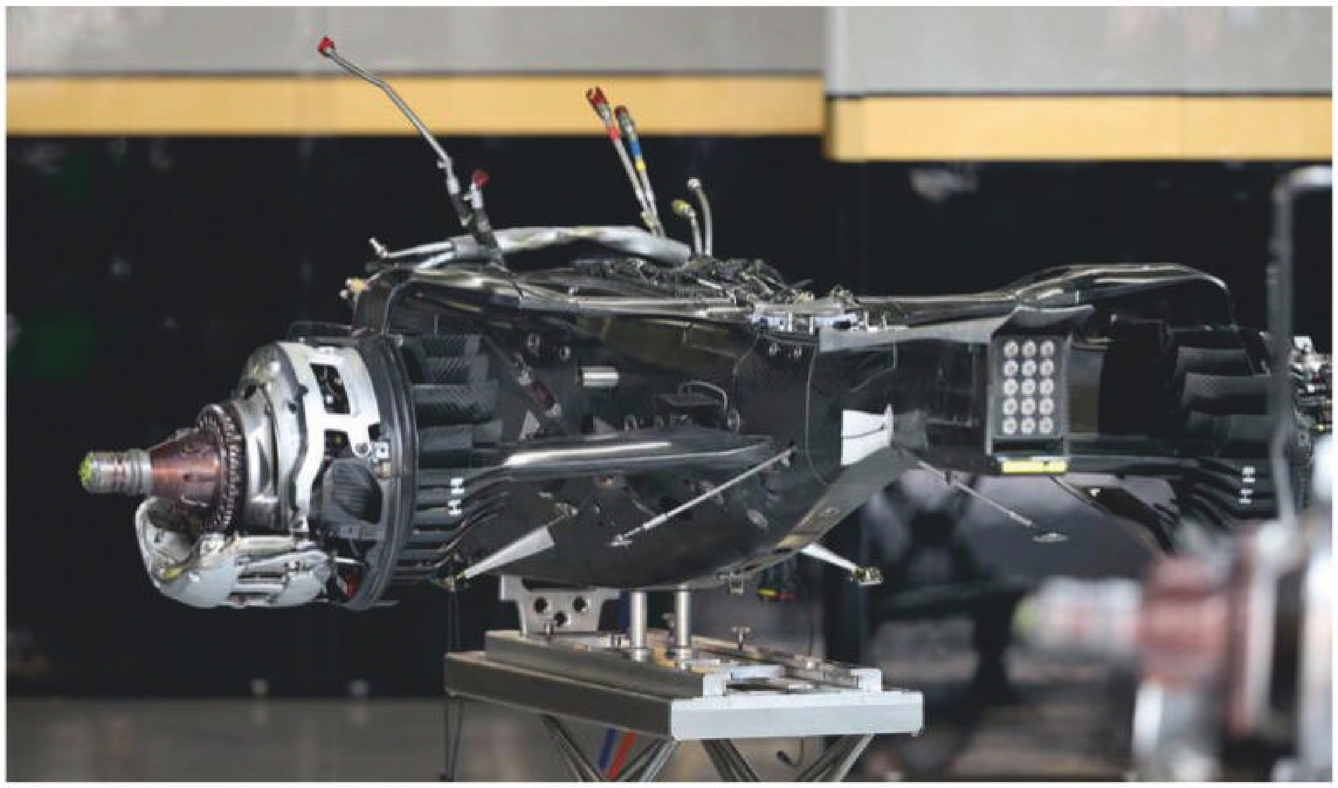
just about his intuition on what it feels like … The things we see as the good things we have enhanced, but they have just not delivered overall. It is a head scratcher.'

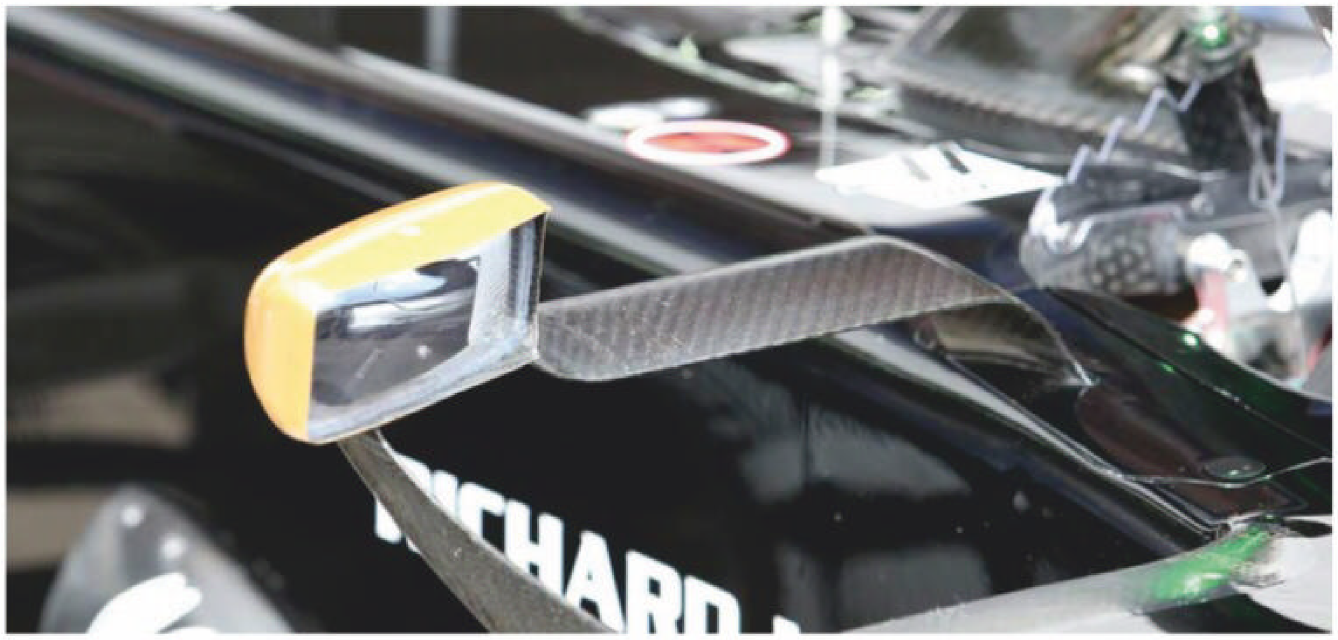
Hot and tyred

Tyres are part of the issue for Haas, and the thinner tread of the 2019 Pirellis is thought to be a major factor in its struggles to find consistency. 'The rear tyres are getting very hot, you could put more wing on, get more drag and just go slower down the straight, that is the problem you have to consider,' Taylor says. 'In Monaco there is the old thing of sticking a lot of dirty downforce on, Gurneys and things, because you don't care about the drag. Doing that does not get you a fast car, though. It's been infuriating, but this is a really good car, we know it has got the speed. But it's got speed on a new set of tyres and it's got speed if it likes the circuit.'

Adjusting the car to suit different tracks and conditions would be the obvious solution, but it may not be possible to get the VF-19 into the window where it needs to be aerodynamically while at the same time making the tyres work.



Much of the rear suspension layout on the racecar was dictated by the use of the composite-cased Ferrari transmission



The mirror housing treatment on the VF-19 is not quite as complex as it is on some of the other 2019 Formula 1 cars

The Haas team has been fairly extreme in its attempts to resolve the VF-19's handling issues

'It may not have the scope to be set up the way it perhaps needs to be, so you need to decide what you want to give up,' Taylor says. 'The tyres this year need more downforce. You could argue that we should have pointed at the headline figures rather than the subtle stuff we did, but we thought the headline figures were in the right place, so our focus wasn't there. At the end of last season the bits that we concluded that we needed to focus on were not the big headline numbers as the weaknesses of last year's car were not to do with headline figures, but you might argue that the weaknesses of this year's car are to do with those headline figures.

'We have tried everything we can in terms of set-up to try to compensate, we change lots of stuff on the car, nothing stands still,' Taylor adds. 'We are trying to use all of the adjustability we have got to deliver what the tyres need. But there is a limit to what we can do and there is not enough of a lever to pull.'

In terms of the suspension design the VF-19 shares almost all of its suspension components with the 2019 Ferrari and a significant number of parts with the Alfa Romeo (formerly Sauber). This includes the dampers, torsion bars, most linkages, wishbones and uprights.

'In principle you could take our inboard suspension parts and fit them to the Ferrari, but there are some subtle things which are different, not so much in terms of performance, but for installation things,' Taylor says. 'So we have different thicknesses in place for some parts, and we have holes in some components that the Ferrari does not have as we use them in a different way to Ferrari. So you couldn't swap the wishbones between our car and the Ferrari, for example, because the brake lines are different, but fundamentally the kinematics of our car and their car are the same.'

Prancing Haas

This commonality with the Italian car results in the Haas being largely limited to the range of adjustment designed by Ferrari for the SF90, and this may be hampering the efforts to improve the consistency of the VF-19. 'We have basically the same range of adjustment as the Ferrari, though we can make our own bits and fiddle around with the bits they supply too,' Taylor says. 'It is very difficult for us to change the end conditions as the two extremes are fixed by the geometry of the bits we get from our partner. But with intermediate steps we can do stuff, so it might be that they don't supply us shims to get to the position we want so we simply make our own. To get outside the main goalposts we would have to make more parts and we have done that in the past, we are quite capable of making stuff ourselves. Homogeneous steel bits are quite easy. We can make brackets, shims, camber bits, and that is no problem. However, if we then decided that we wanted to make a set of wishbones then we could do that, but it's a change of condition, it's the reaction time and making sure that you have done your homework to make sure you get what you wanted. They have got to be safe and repeatable.'

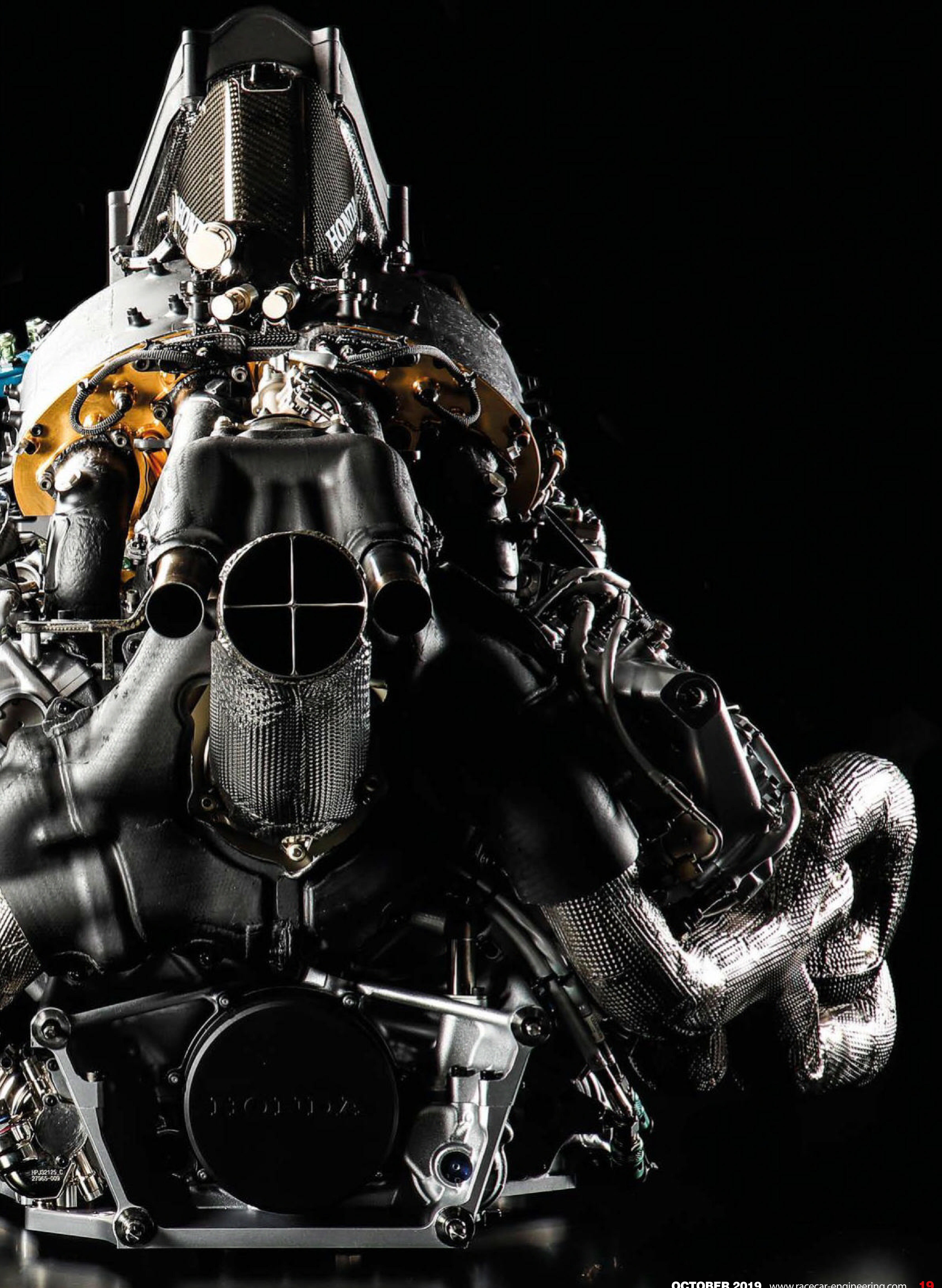
Haas has been fairly extreme in its attempts to resolve its car's inconsistent handling, going as far as fitting the season-opening Australian Grand Prix aero package to one of the two cars for both the British and German GPs. Perhaps infuriating, or perhaps revealing, the car fitted with the old spec bodywork qualified sixth for the German Grand Prix, ahead of the car with the latest specification parts. It shows that there is indeed a very fast car concept at the heart of the Haas VF-19, but the team needs to understand why it remains inconsistent.

The power of dreams

Major power unit changes in F1 are now on hold for a few years but the shape these new rules will take is still a hot topic in the paddock – we asked Formula 1's movers and shakers what they would dearly wish to see in the 2025 engine regulations

By SAM COLLINS

'We are in motor racing for two reasons: firstly marketing and secondly technical development'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It was all going to change in 2021. Alongside the massive aerodynamic and chassis rule changes Formula 1 was meant to be introducing a completely new power unit; but that will not now happen. There remains some speculation that a higher rev limit and a more potent MGU-K will be utilised, but for the next five seasons the power unit will remain largely as it is right now. Yet the revolution has not been cancelled, merely delayed.

Early in 2019 F1's chief technical officer, Pat Symonds, revealed that completely new power units would be introduced in 2025. Right now the discussions are starting on this, but there are some varied opinions in the paddock about what should be in the new regulations, and simply by asking a selection of team bosses and technical staff what they would like to see you end up with a very long wish list.

Racing Point technical director Andy Green is clear about what he thinks is needed. 'I think what we have now is an incredible piece of engineering in the back of the car, but it could just be too incredible. I think what we have is potentially something where the technology bar of the power unit is just way too high and I think I would like to see something that is just slightly simpler. I think I'd never say no to more horsepower, the sport can't have enough horsepower. We need to make the cars harder to drive. I think more power coming from a simpler power unit is what it should be.'

Even though the current power units have reached previously unthinkable levels of efficiency and are now producing in the range of 1000bhp, more power is something that is a common theme in the paddock. 'More power would be great. Less expensive would be outstanding,' chief executive of McLaren Racing Zak Brown says. 'I don't know that it's achievable but if we could have some diversity in the engine itself and not be limited to a certain amount of cylinders, things of that nature, I think that would maybe spice up the show too.'

Search engine

Yet while there seems to be a hunger for more power there is also a note of caution from some quarters. 'The romantic in me says let's go back to loud noise, high revs, normally aspirated,' says Red Bull Racing team principal Christian Horner. 'To have a normally-aspirated, high-revving V10 or V12 engine would be a wonderful thing to have back in Formula 1, but unfortunately I think they are rather outdated now. We have now got a period of stability with the engines, so it's important that Formula 1 makes the right decision for the future. Obviously the automotive sector is moving an awful lot at the moment and what technologies are going to be relevant then? Because when that engine comes in in 2025 that's going to have to be for a five- to ten-year period, so we are actually talking up to 2035, which is a long way down the pipeline.'

'From our perspective we still believe that internal combustion engines are part of the global picture'

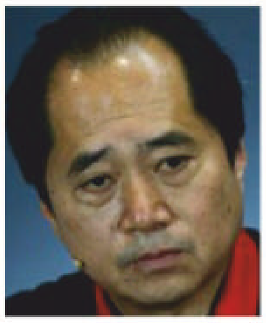
And 2035 is an important year. A number of major European nations will have introduced legislation to outlaw the sale of new combustion engine only passenger cars by then, and that has led some to say that the future of F1 is as a fully electric racing category. While not going that far, Mercedes F1 CEO Toto Wolff does agree that the hybrid element might increase. 'I think that we are in the middle of a transition of technology, at least on the road car side, and as much as we, most of us, are fans of the loud, traditional engines, it's not where the technology goes and where the perception on sustainability goes,' he says. 'I believe we've done the right thing in keeping the regulations almost stable for the next term because it would have caused a tremendous amount of development to come up with the new formula. Also, it is not quite clear where this next generation of power unit actually should be. Listening to our chairman of Daimler, we expect 50 per cent of our fleet to be either hybrid or electric by 2030, so I think if this is the direction technology goes, we could as well have an engine that will have a higher hybrid component, renewable energies

'We could have an engine that will have a higher hybrid component, renewable energies or electricity'
Toto Wolff

'More power would be great. Less expensive would be outstanding'
Zak Brown

'A normally-aspirated, high-revving V10 or V12 engine would be a wonderful thing to have back in F1, but unfortunately I think they are rather outdated'
Christian Horner

'There will be new forms of fuel coming up in the next few years, whether you are talking about more biofuel so a different composition, or even synthetic fuel'
Cyril Abiteboul



'We want to see even higher efficiency, and green technologies used … it is developing and promoting that kind of technology that is the reason Honda is racing in F1'
Toyoharu Tanabe

The 2025 power unit could have an ERS to match or exceed the potency of the one used in the Toyota LMP1

Mercedes power unit in the Racing Point. The team's tech director says that the current F1 PUs are simply 'too incredible'

or electricity. Today, it's maybe around 20 per cent, maybe that ratio is going to go to 50 per cent. As long as it's an exciting engine, the sound is something that we need to address or at least talk about it, but I believe the hybrid component is going to increase after 2025.'

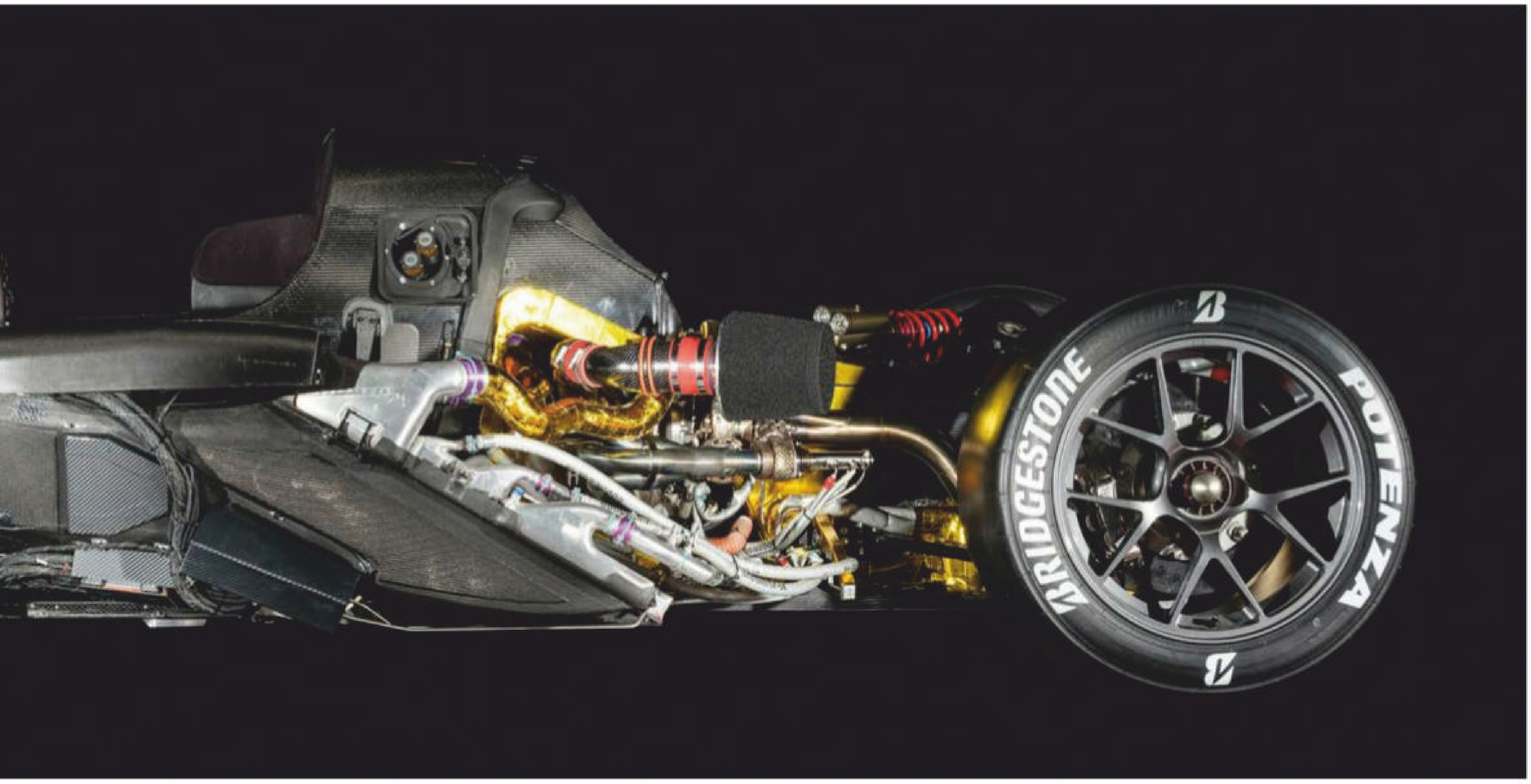
Remi Taffin, F1 engine technical director at Renault Sport, agrees. 'I think they should be more electrified, I think there is a lot we could imagine, but I would still see a kind of power unit like we have now with a combustion engine and an ERS,' he says. 'I think the electrification proportion will go up, and maybe the technology we use to store energy will change, or how we generate electricity, but I think you have to bear in mind that the units we have now are only five-years-old. I will be very happy to keep working on this type of power unit, we so often hear people saying that the future is full electric, but people are starting to realise that we won't get rid of internal combustion engines tomorrow, and actually it is a very efficient way to turn fuel into propelling energy, or even into electricity. I think it is fine to continue developing ICE technologies in F1, already there is a lot of technology we are using in F1 that has not yet transferred to road cars because it needs to be affordable, but it is coming.'

Road relevance

It's been said that F1's current power units lack relevance to production cars. Regardless of whether this criticism is justified or not there is a clear desire to make the 2025 units much more relevant to production car technology.

'For Honda that is the right direction, we want to see even higher efficiency, and green technologies used,' Honda F1 technical director Toyoharu Tanabe says. 'Actually it is developing and promoting that kind of technology that is the reason Honda is racing in Formula 1. So those for us are the key technology pillars of Formula 1. Actually to increase the efficiency is something we need to think about how to do, as it is really not easy. When we [came] back to Formula 1 in 2014, one per cent improvement

By 2035 a number of major European nations will have introduced legislation to outlaw the sale of new combustion engine only cars



'I think Formula 1 needs to retain some level of internal combustion engine in the power unit rules, otherwise what is it, Formula E?'

was not easy but it could be achieved, but now we are chasing gains of 0.1 per cent. We believe that it is very important for the technologies we develop in racing to be used on future road cars. Not just the technologies, though, we also use it to develop the skills and knowledge of our engineers, and that too can be shared within the company. It's a good training place.'

Heat retention?

While the current power unit regulations were instrumental in bringing Honda back into Formula 1 not all the manufacturers remain convinced that every element of the layout is right in terms of road relevance. 'In my opinion we need to look over the next couple of years at the MGU-H and its road relevance, because it's clearly a component that was introduced for that purpose,' Renault F1 managing director Cyril Abiteboul says, before adding a caveat to that statement. 'Right now, we don't see any application on road cars but it may come. It may actually be in the pipeline of some manufacturers, so we need to be careful not to be basically in reverse in that respect. And then diversity of technology would be great, but we also need to be careful not to open up the field and create some discrepancy.'

Wider technological relevance is a major reason that many companies, not just car manufacturers, are active in Formula 1, and many are warning against any steps being taken to reduce that relevance. 'We are not looking at it to be a commercial engine, we are looking at it as the future,' Mobil 1's global motorsports technology manager David Tsurusaki says. 'From our perspective we still believe that internal combustion engines are part of the global picture. Sometimes you talk to people and the assumption is that everything will be all-electric, but actually a lot of them are giving a misleading statement. When they mean going all-electric they mean actually going hybrid, but I think that is a little down to media hysteria, and wanting to get that headline. The all-electric headline sounds better but it's not reality. The reality is that you will have to have multiple things to meet global transportation demand. It's a combination of electric and internal combustion, including diesel. So I think Formula 1 needs to retain some level of internal combustion engine otherwise what are they, Formula E? Besides, if everything went all-electric there is not enough power generation, as you have to build more power plants and there is no appetite for that in certain parts of the world, you just end up in a debate about nuclear power and things like that.'

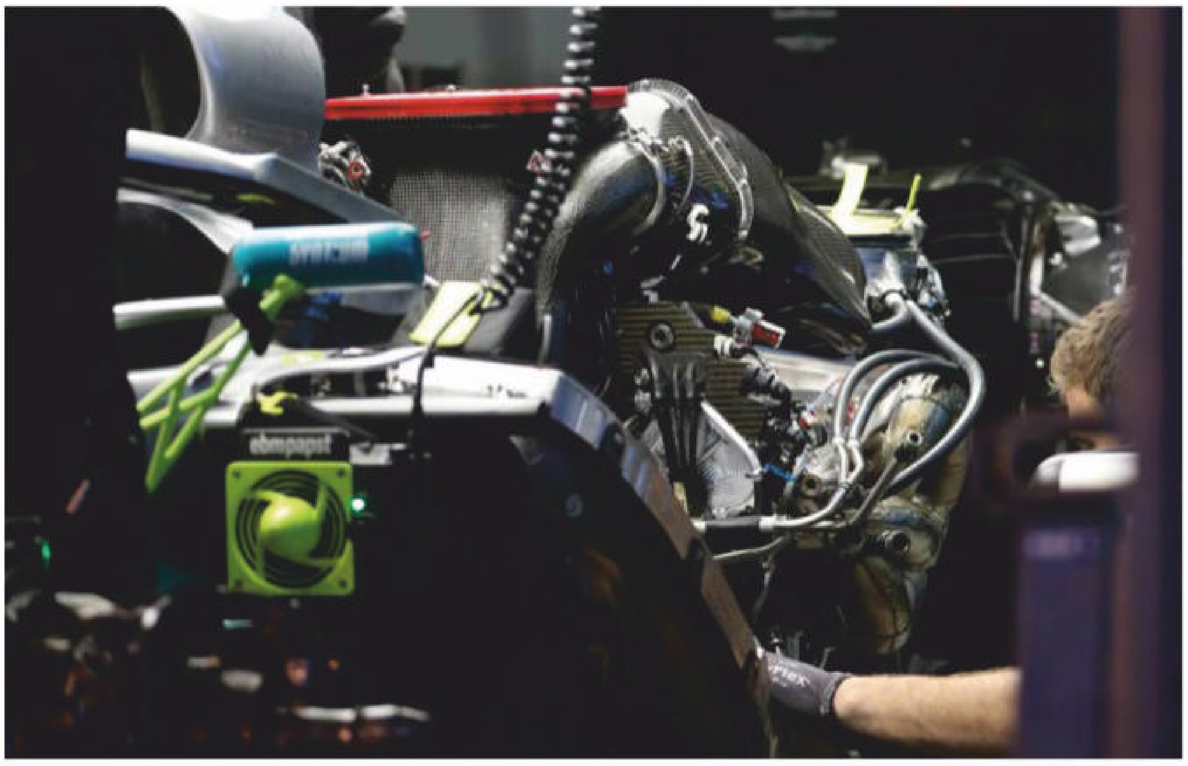
Fuel for thought

One area where road relevance could be directly increased is with the type of fuel used in the cars and Renault in particular is calling for the sport to consider this with the new rules. 'Something to be discussed is not necessarily the next generation of engine but the next generation of fuel, because we still believe that Formula 1 is about hybrid technology, not full-electric, for a number of reasons,' Abiteboul says. 'Clearly we need more power and sustainable power and long races, but there will be new forms of fuel coming up in the next few years, whether you are talking about more biofuel, so a different composition, or even synthetic fuel, coming from non-fossil sources, that could be attractive and that would require new development. So, probably the way forward. Less exciting, obviously, than a very high-revving, normally-aspirated engine, but still probably the way forward if we want to be relevant, not just to car makers, but to society.'

The form (or indeed formulation) that the 2025 fuel may take is actively under discussion, as the sport aims to increase its relevance to the wider industry. 'I think it's important to look at the fuel that we might use on the road tomorrow in road cars and we keep on working and developing new technologies towards that,' Taffin says. 'With the fuel it is early days, we have had some discussions about what the fuel of tomorrow should be. For example, you look at the percentage of biological components we use in the fuel, we are quite happy to increase that percentage, but we need to make sure that whatever we use is available around the world.'

It may be the case that Formula 1 does not settle on a single fuel (or a single engine configuration) and will open it up to entirely different fuels to compete against one another. 'I think it would be a challenge to police, but in the auto industry they have been pushing hard for separation on specifications of engine oils and transmission fluids as they all want the best protection and fuel economy for their product,' Tsurusaki says. 'The manufacturers don't really care about an industry standard that they have to sacrifice something for. That's already happened with engine oil and it could happen with fuel too. There is technology that could see fuel pumps mix a specific blend tailored to your car. So you drive up to the pump which then dials into your car and delivers the perfect fuel for the engine which might be a 98.3 octane with particular additives, for example, rather than the standard 98 available now.'

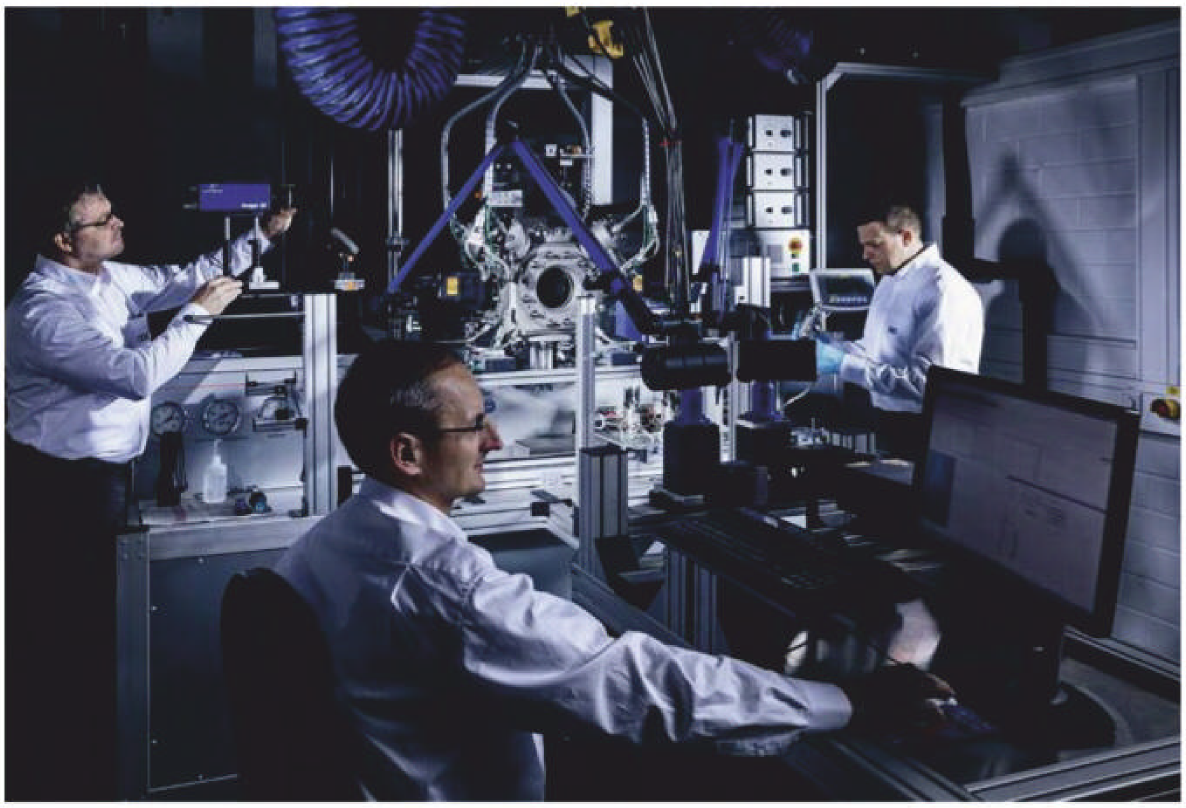
One of the biggest demands from independent teams is that whatever the new



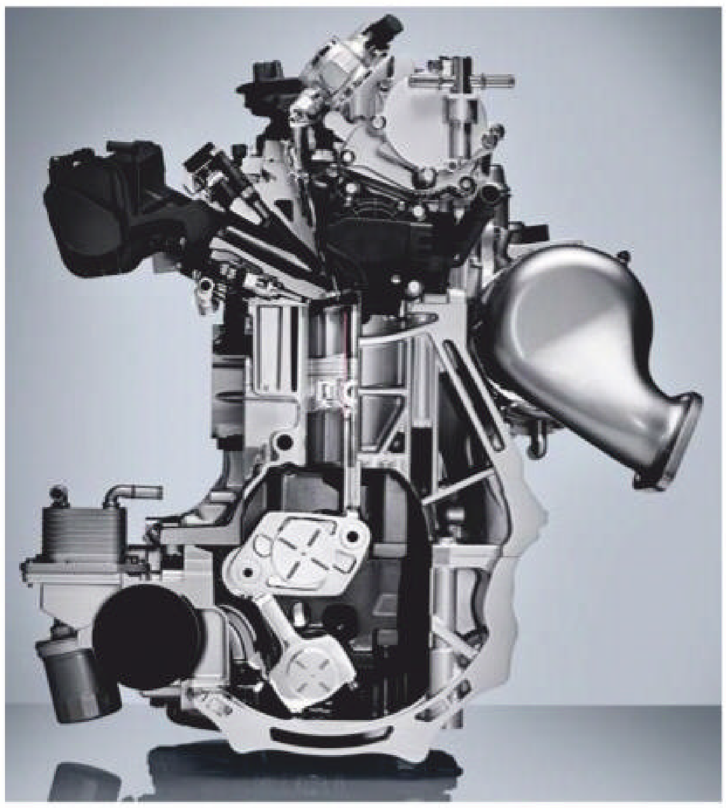
Most of the F1 teams are calling for a lower cost unit. The current 1.6-litre V6 hybrid era started back in 2014

Honda says it is in Formula 1 to help develop road car technology

It may be the case that Formula 1 does not settle on a single fuel but will open it up to entirely different fuels competing against one another



Audi has invested heavily in developing synthetic fuels. Could this sort of tech play a role in the future of F1?



Variable compression ratios could be a feature of the 2025 PUs

power unit is it needs to be affordable. But with the manufacturers calling for increased road relevance it is not clear exactly how this could be achieved. One suggestion is to follow the lead set by the 2021 chassis regulations and increase the amount of control parts used, with the electronic systems, MGUs, energy store, fuel system and even the fuel itself all candidates for standardisation.

'We obviously don't want Formula 1 to go to a spec fuel or to be very restrictive,' Tsurusaki says. 'We are in motor racing for two reasons, firstly marketing and secondly technical development. Remove the technical development then all we need to do is put up a billboard. There is a lot of commentary out there saying that the fuel used in Formula 1 is not road relevant, but we don't agree with that at all because it does have relevance to what we will do in future. This power unit is not relevant to what is on the road today, but it features a lot of things which could be relevant in the future and it's the same for our fuel.'

Tighter controls

Another cost reduction could be a tighter homologation of parts in the power unit. It might be argued that this will reduce the potential R&D gains and technology transfer to production cars, but surprisingly some PU developers are in favour of it. 'I think we could accept having only one specification of energy recovery system per year, but that is not saying we have to keep the same system for five or ten years,' Taffin says. 'Should we be throwing our resources away by trying to get 0.03 seconds per lap by having three different ERS specifications per year? If we worked on an incremental basis year to year or every two years, it is not stopping you from developing but it is saving you the big money from when you go racing. This may sound weird but it is cheap to develop, but very expensive to race.'

'Over the next couple of years we need to look at the MGU-H and its relevance to road cars'

Powering on

As the process of developing the regulations for the 2025 power units has only just started there is an opportunity to ensure that the rules are written in a way that satisfies all of the objectives stated here, even though some of them do seem contradictory.

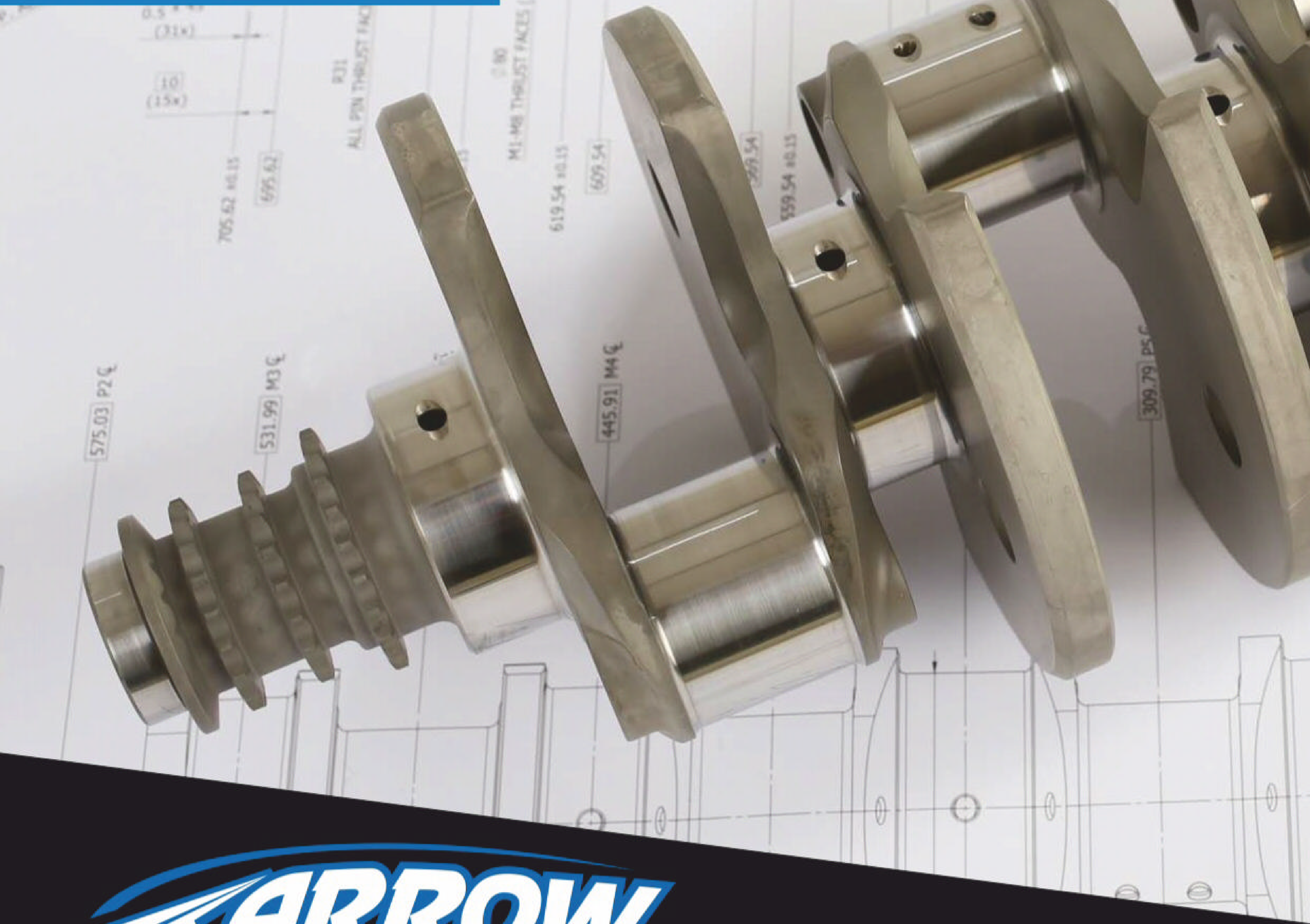
'At the end of the day I think there is still a question about what is going to be next,' Taffin says. 'We could argue that Formula 1 should go back to a V8 or a V10 but this simply will not happen. We have to be realistic, closer to what is going on in the wider world. I think that applies to everything, the ERS, the fuel, the ICE. What should we do for 2025? We need to take a wider look at the world and see what is happening. There are plenty of companies around, not only in the automotive industry but other areas, studying how people will travel in 10 years. I feel that [it's up to] the FIA or F1 or us, the people in Formula 1, to start thinking like that, to start caring. It may be strange as competitors but we need to have those high level discussions, to care a lot more about the wider world.

'We need to get together and tackle it from A to Z,' Taffin adds. 'It may seem unrealistic but we could have a roadmap for the next 30 years. It could be sustainable, reasonable and good for all but this is not happening in any state in the world. You look at the world, and think of it in five or ten years time, but then ten minutes later we go to the pit wall and try to win a race. We could have that care, to have it drive us, but it's going to be costly. But if we have a 30 year roadmap it would allow us to select an area to develop and then freeze. Incremental development could work, we need to set the goals, set the roadmap and do it all step by step, the regulations should drive us to achieve those goals. That would help in preventing us spending massive money on small things that give us just milliseconds, instead we spend all the money in areas that give a real benefit, very specific matters that will be a performance differentiator but also tackle a wider problem.'

Before we conclude, it has been quietly suggested that a proposal for further power unit downsizing has been tabled, which calls for a turbocharged 850cc engine with an extremely high (but potentially variable) compression ratio, gasoline compression ignition and variable valve timing. This would be mated to a much larger and more potent hybrid system. At present there are very few details on this.

The new regulations are likely years from taking any tangible form, but the work is only just beginning. It is clear, though, that the resulting power units will be different to what Formula 1 is using now, quite how they will differ will remain unclear for a while yet.

At the heart of the world's most demanding engines



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Ed Carpenter, driver and owner at ECR, pits during this year's Indy 500

Ever wondered what it takes to ready a team and racecar for a top flight motorsport event? A performance engineer at the Ed Carpenter Racing IndyCar operation gives us the inside line on a procedure that is as fascinating as it is vital

By STAN SANDOVAL

A wise engineer once told me that 90 per cent of the work you do in the office is simply to make your life at the track easier

This is my first year working as a performance engineer for Ed Carpenter Racing (ECR), and I've already come to appreciate that, while races will always be the showcase events, the work that goes on behind the scenes is equally impressive. A team's preparation for an IndyCar race weekend is an amazing feat of engineering in and of itself.

Not only that, but it is massively influential on how competitive a team is on a given race weekend. A closer look at the extensive resources committed by each team to prepare for an IndyCar race reveals just how competitive the series has become, both on and off the track.

The first opportunity teams are given to run the car is during pre-season testing. In-season testing is so limited in all forms of motorsport these days that every chance to get on track is vital. And so while the winter snow piles up in Indianapolis, we'll usually head out to Florida, Texas, or California in search of suitable testing conditions. Winter testing is the first chance teams get to shake down a new car, work out the kinks on a new development project, or begin honing in on the race set-up.

Learning curves

Another benefit of pre-season testing can be the chance to gain familiarity with a new track. From the very moment testing begins, teams are always trying to learn just as much about the race track as they are the cars. For new tracks, this information is doubly valuable as there is no prior circuit data to work from.

While track time is far and away the best method to mimic race conditions, due to its restrictions other avenues are often sought to continue to develop the car away from the track. For instance, aerodynamic testing can be carried out in full-scale and model wind tunnels. Similarly, seven-post shaker rigs can be used for damper development, as well as gearbox dynos for drivetrain testing. Much of this can be carried out close to where the team is based, too.

The Auto Research Center in Indianapolis possesses all of these testing facilities and is right down the road from the ECR shop. Each of these methods helps to develop the car in individual areas without having to use any of our allotment of test days (though full scale wind tunnel testing is also restricted).

Not only do these methods improve the car, but they also help us make the most of our track time. From the wind tunnel, shaker rig, or

From using the wind tunnel, shaker rig, or gearbox dyno, we can narrow down our test plan to the things that look most promising

gearbox dyno, we can narrow down our test plan to the things that look most promising, and then spend the time moving forward with our plan and investigating other areas of the car that we might not otherwise have had time for.

Data-driven

Without data, we engineers would really struggle. Analysing data is a huge part of every engineer's job. Practically every decision we make these days is data-driven, and going through all the information at our disposal is essential for making an informed decision.

A wise engineer once told me that 90 per cent of the work you do in the office is done simply to make your life at the track easier, and going through all the various forms of data is the best way for engineers to be prepared heading into the race weekend.

Setting the car up right is also vital, of course. Before a race weekend we turn to set-up data from the year before to use as a starting point. This usually begins by us asking what was the most effective set-up we ran last year? Often you see first-year teams struggle because they don't have any reference to start from. Conversely, you see teams perform well at the same tracks year in and year out because they've figured out a set-up that works for them there.

Set-ups can vary so much from track to track, and from street course to road course to oval, that having a good starting place for each track can make a huge difference. At ECR, it's no secret that Indianapolis Motor Speedway is a strong track for us. A large part of that is simply having a good baseline to start from every year and then continuing to improve it.

With a starting set-up selected, data from past years can also be used to assess set-up changes. If, say, you wanted to reduce mid-corner understeer, what is the most effective way to do it? Having a log of set-up changes that have been tried in the past can be very useful when confronted with handling deficiencies.

Often there are many adjustments that can correct the same issue. However, knowing that a set-up change was effective in correcting the balance, and whether it may have also compromised another area of the car, can help keep an engineer on the right path. Every race engineer has a story about 'going down the rabbit hole' on a set-up that didn't work out; it is not a fun position to be in.

Simulation

Of course, you won't always have all the data you require, and simulations are a great way to generate data that you otherwise wouldn't have. Using numerical models and historical data, with proper correlation, simulation can be a very effective and useful tool. There is a tonne of innovation and development that goes on behind the scenes that is constantly improving the accuracy, efficiency, and capabilities of simulation. Even when not 100 per cent precise, it can be used to detect trends or relate things comparatively, which is still crucial.

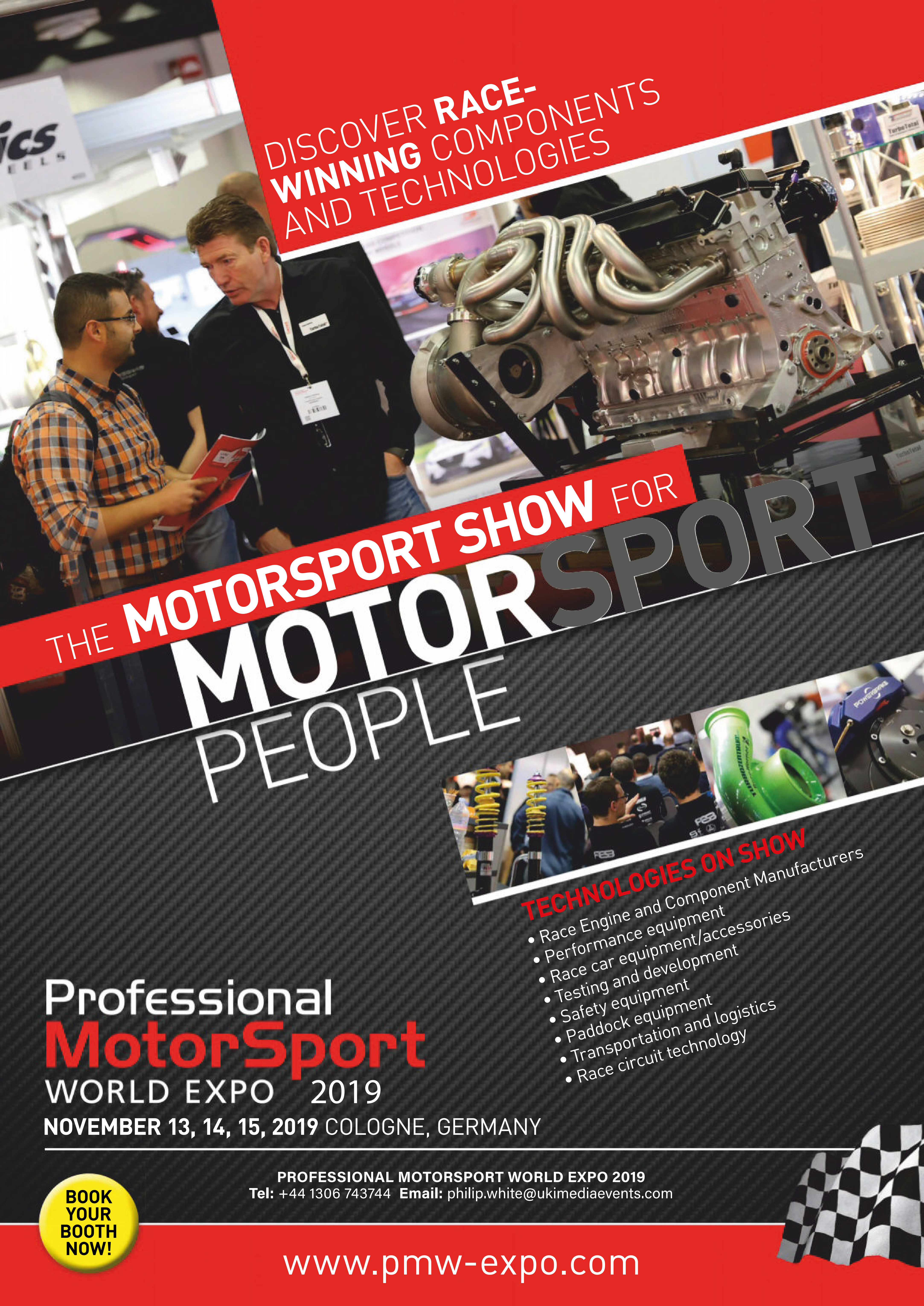
With track time being so limited any additional data generated by simulation can help engineers determine what would be a worthwhile use of track time when writing a session plan. The two primary forms of simulation we use to prepare for a race weekend are the driver-in-loop simulator (DIL) and lap time simulation. While the DIL is thought of primarily as a training tool for drivers, it is also a method that engineers can utilise along with the driver to trial potential set-ups. Engineers can use this simulation data along with driver feedback to come up with a short-list of possible set-up changes to try during the weekend.

Lap time simulation can also be used to compare set-ups, and this is done completely numerically and does not require a driver to sit in a simulator. With the car fully modelled mathematically, it can be used to compare how various aspects of its set-up, such as gear ratios, aero configurations, or ride heights, would change the performance of the car.

Lap time simulation can also be used as a predictive tool throughout the race weekend, as factors such as changing conditions can wreak havoc with a car's performance. Sometimes the weather can change in an instant; the wind

Nothing beats track time but with testing limited dynos and simulation will also play a part in preparing for an IndyCar race

The ECR team moving equipment into place at Indy. It has plenty of data from the speedway and usually goes very well there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at Indianapolis Motor Speedway is notorious for affecting a car's top speed, and thus how it should be geared, while ambient and track temperature can have a massive effect on downforce and thus ride heights. This can leave engineers scrambling for answers.

But with lap time simulation – and some amateur meteorology – they can make a more informed decision on how to set up a racecar using simulation to get data in cases where historical data might not be sufficient.

Action plans

Similar to set-up data, we also look at how past races have played out strategy-wise to try and predict the best course of action for the race at hand. The primary consideration for any strategy is how many pit stops do you plan on making, and on what laps do you plan on making them.

This is dictated by a number of factors such as fuel consumption, tyre degradation, traffic, and cautions. Some of these we can investigate before the race weekend has even started, others we wait for track data from practice before making a decision. By looking back at previous races though, we can get an idea of strategies that typically work well. We will look at the winning strategy from the year before, the strategy of the car that made up the most positions throughout last year's race, as well as the strategies that our cars used.

Going through the old timing and scoring files we can see where time was made and where time was lost to try and understand why it was that one strategy worked better than another. Was the tyre degradation too great that a car lost time late in a stint? Or was the car consistently slower over the course of the stint because they were trying to stretch their fuel in order to make one less pit stop?

Maybe the strategy itself wasn't necessarily quicker, but then a timely yellow made it look like a stroke of genius on the day. Having a good understanding of how races have played out in the past can be very handy in the heat of the moment, as similar situations will often present themselves year after year.

Engineers Justin Taylor, Peter Craik and Matt Barnes discussing set-up with general manager Tim Broyles at the Indy 500

Proceed with cautions

Historically, some races are littered with cautions (often starting at turn 1, lap 1), while other races have typically gone all-green. Because cautions slow down and bunch up the field, when a caution falls, it has knock-on effects on fuel consumption, traffic, and therefore strategy.

But predicting when a caution is going to occur is almost impossible, so analysing how teams have reacted to cautions in the past can help us come up with a game plan should one occur during the race. For example, if a caution comes out early in the race, typically cars towards the back of the field will take the opportunity to pit for fuel and tyres (it's a pit stop that opens up your fuel window, gives you a fresh set of tyres for very little, if any, track position loss, with the majority of the race still to be run). Similarly, if a caution comes out just before a normal fuel window were to open, most cars would pit anyway and stretch their fuel rather than wait for the window to open when the race is back under green.

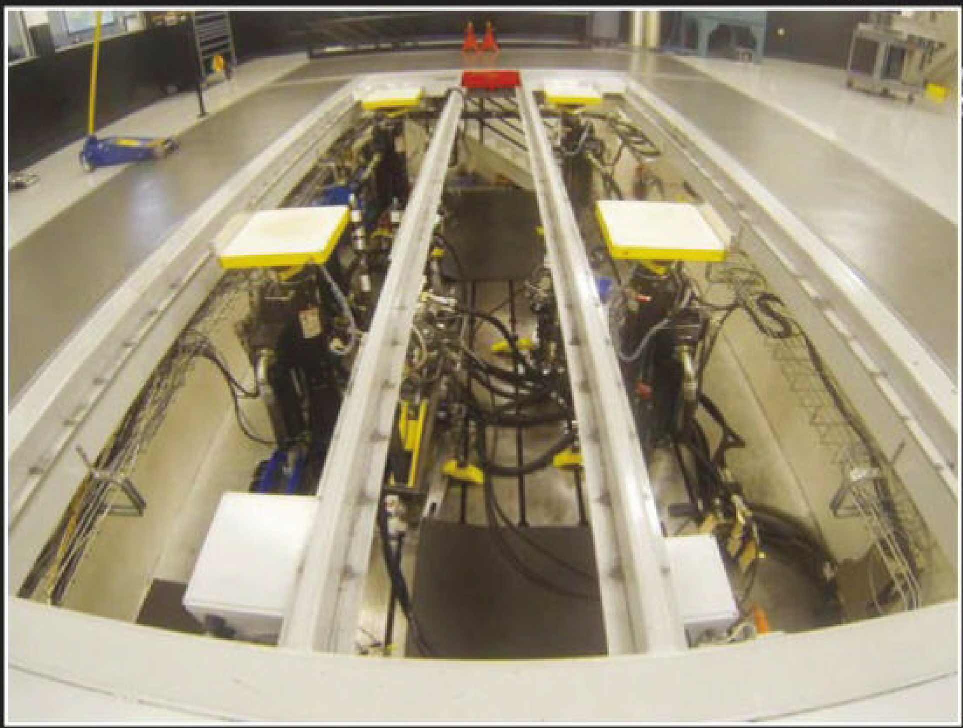
Researching how teams have handled these decisions in past races, and then seeing how these situations then played out for them, can take a lot of the guesswork out of making strategy calls during the race.

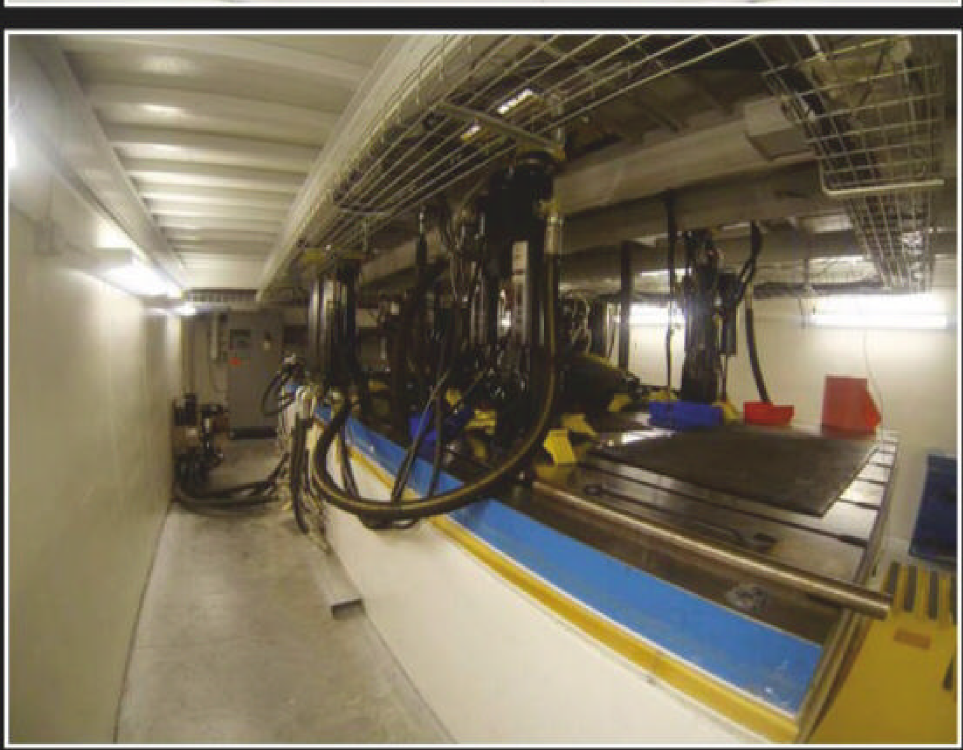
For taking traffic into account, a factor such as how hard it is to overtake at each track plays a role in strategy decisions. Electing for a three-

Every engineer has a story about 'going down the rabbit hole' on a set-up that didn't work out

Race engineer Peter Craik debriefs driver Ed Jones

The main consideration for a race strategy is how many pit stops do you plan to make and on what laps will they happen



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ULTRA

stop strategy and running flat out might not be the best choice if you are stuck behind someone running slower because they are two-stopping, and you are unable to overtake. At that point, you are effectively running two-stop pace but still making three pit stops.

Another situation where traffic comes into play is when deciding between pitting and going to the back of the field with fresh tyres or staying towards the front on tyres that are worn out. How difficult it is to get through traffic can help determine which option you would choose. While this is a hard metric to quantify, by going through past races at that same track we can see how teams in these situations have acted before, and how it worked for them.

Ed Carpenter embarks on a qualifying run at the Indy 500. A clear strategy for this needs to be devised during practice

Track types

One of the biggest challenges of competing in IndyCar from an engineer's perspective lies with the diversity amongst the tracks themselves. The existence of ovals and road/street courses on the calendar makes for radically different approaches depending on the type of track.

Different aero kits are used for road/street courses, short ovals, and superspeedways. Since ovals have much higher average and top speeds than road and street courses, aerodynamic configurations are a much larger consideration. For the majority of the road and street courses, teams will run with maximum possible downforce. However, on ovals, this is far from the case. The concept of trimming, that is removing downforce in exchange for drag reduction, is much more apparent (especially during qualifying). Teams will often go to extreme lengths in trimming their cars to try to eke out every last bit of speed on ovals.

Because of the increased speeds on ovals, cooling also becomes a bigger factor. Engineers have to balance the aerodynamic benefit of blocking up radiator inlets while ensuring the racecar does not overheat.

Gearing also differs massively between ovals and road/street courses. At road and street courses, the gearing is often dictated by corner entry speeds, minimum corner speeds, and where on the track the driver is able to shift gear. On ovals, the gearing is not dictated by the same criteria. The higher gears are called 'run gears' and are chosen to cover the spread of speeds encountered during race conditions, such as when leading or in the tow. Lower gears are based on launches from a pit stop or race restart speeds. Combined with the higher speeds seen on ovals, the difference in approach means that the gear ratios chosen for ovals and road/street courses differ massively.

Car set-ups are also extremely different between road/street courses and ovals. Put simply, the set-up for an oval is designed to do one thing: turn left. Oval set-ups are very asymmetrical compared to road and street course set-ups. Even the tyres are staggered to allow the car to naturally turn left. But finding an effective set-up for an oval can be extremely difficult. Thankfully, with Ed Carpenter behind the wheel, we have one of the most experienced oval drivers in the sport. His direction and feedback are always invaluable as we continually improve our oval package.

Find the gap

Not only do the cars themselves differ; so do some regulations and team procedures. On ovals there is only one tyre compound and no push-to-pass. Therefore, there's no need to spend practice time comparing compounds or calculating the additional lap time benefit and fuel consumption that comes with using push-to-pass. However, since ovals use single-car qualifying, we will dedicate practice time to running a mock qualifying run. This involves trying to find a gap where you can essentially run in isolation, so the tow doesn't skew your results or read on the handling.

Another key difference is how drivers save fuel on a road/street course versus an oval. Better fuel mileage is primarily achieved on road/street courses using a technique called lift and coast. On ovals, the tow is so powerful that driving in the slipstream of another car can save fuel. In both cases, we will usually dedicate practice time to quantifying how effective these fuel-saving techniques can be. However, while this can be done pretty much anywhere on a road course, it requires traffic to get a good read on an oval. Therefore, how the teams go about using their track time also differs between the different types of tracks used.

ECR race strategist Ben Siegel reviews the timing and scoring data

When the race weekend finally arrives there is still plenty to do before the green flag drops. We arrive on set-up day; this involves moving into the track for the weekend, unloading the car, finalising session plans for practice, pre-fitting adjustments that we want to try, and the track walk, of course. After set-up day we come back the next morning and finally get to go out on track for practice.

The primary focus of practice is to work on the car set-up for qualifying and the race.

Teams will often go to extreme lengths in trimming their racecars as they try to eke out every last bit of speed for the oval tracks

While tyre degradation sets in fairly early, due to tyre temps often the best lap to set a time during qualifying is two or three laps into a run

The track walk is a traditional part of the first day at the circuit for many teams

Honing pit stop drills. Races can be won or lost here and time must be set aside for practice

However, there is also so much more to be done. It's a chance for the drivers to learn or reacquaint themselves with the track so that they can push to the absolute maximum when it counts. It's also a chance for the engineers to acquire data on tyre degradation and fuel consumption in order to decide on a strategy for the race. And, for the team, it's a chance to scrub tyres while getting some valuable pit stop practice. So a lot of information needs to be gathered in a very short amount of time during practice.

On road and street courses, the teams run on two different tyre compounds throughout the weekend: the primary tyres (blacks) and the alternate tyres (reds). Teams are given a limited amount of each for a race weekend and must use both during the race. Thus, the strategy as to how best to use your allotment over the course of the race weekend is an important consideration. While teams are required to use both compounds at some point during the race, beyond that the decision is totally that of the teams. Deciding which tyres to qualify on, how many laps to do during qualifying, and which tyres to run during the race itself are very important decisions that are made based on the results from practice.

Qualifying plan

For qualifying we will often look at which lap during a run is the fastest during practice. While tyre degradation sets in fairly early, due to tyre temperature sometimes the best lap to set a time during qualifying is two or three laps into a run. We'll use data, along with some calculations about how long it takes to complete a lap and the duration of each qualifying session to come up with a plan for each round of qualifying.

To analyse race pace, we will often characterise each tyre as having an ultimate pace (best possible lap time) and a degradation slope (increase in lap time each lap due to tyre wear). Usually, the primary tyres will have a slower ultimate lap time but less degradation than the alternates. Therefore, there is often a crossover point, a certain number of laps into a stint, where the primaries will become quicker than the alternates. Additionally, there is another point later in a stint where the primary's initial time loss to the alternates is recuperated due to their degrading less. This data informs strategy decisions as teams decide which tyre they would prefer to spend the majority of the race on.

Pace *vs* fuel

The compromise between pace and fuel consumption also needs to be investigated quite thoroughly, often after qualifying during the morning warm up. While working on the set-up during practice, engineers will see what kind of fuel mileage the racecar will typically get when running hard. But it is vital to also see what the drop off in lap time is when running with a different fuel mixture, or lifting and coasting to save fuel. As mentioned earlier, stint lengths are sometimes shortened or stretched based on tyre life or cautions. This then dictates what kind of fuel economy the driver will need to achieve in order to make the strategy work. We will also dedicate time during practice to running in different fuel mixtures to see how much fuel we can save, that way we know what is reasonable to expect in terms of stint length before the race even begins.

Measuring the lap time deficit incurred by saving fuel is an important consideration too, as it makes no sense to save fuel in order to avoid making a pit stop if doing so means you will then lose more time than it would take to simply stop and refuel. All of this data and more has to be gathered over the course of practice in the days leading up to the race.

The ECR crew ready for the start of the IndyCar race at Long Beach

Then it's race day. By now you've got your best possible set-up, you've selected a tyre compound to start the race, you know where you've qualified, and you've got a general strategy in mind. While a lot of effort has gone into predicting the best strategy, the truth of the matter is that every engineer has to react in live time as the race plays out, just as the drivers do. Many plans have gone out the window after lap 1, turn 1; it's simply a part of motorsport.

The race itself is a pressure-cooker environment; crashes, passes, and even rain can seemingly come out of nowhere. By watching data as well as timing and scoring in real time, an engineer works with the driver over the course of the race to deliver the best result. But there is only ever one winner. All the hours spent testing, analysing data and practicing on track have helped one team cross the finish line before all the others. The race may have started two hours ago, but the hard work it took to win it started long before the green flag fell.

Final flourish

Toyota will face some very different challenges in the 2019/20 WEC but with a raft of aerodynamic updates and Le Mans winning pedigree its TS050 still goes into its final season as the car to beat

By ANDREW COTTON

The eighth season of the FIA WEC will be the last allowing the current breed of hybrid prototypes before new hypercar regulations arrive in 2020. It will bring to a close a golden era of endurance racing in which gasoline and diesel raced against each other with parity, while turbo and normally aspirated engines were also welcomed. But perhaps most significantly, a host of different hybrid solutions were tested, including battery, flywheel and super capacitors, while a range of energy recovery systems were also trialled in competition, including kinetic and heat recovery systems.

Toyota raced Audi, Porsche and Nissan during this era and, ultimately, all the cars converged to a similar concept; turbocharged engines with battery hybrid systems. But the Japanese car maker is now the last of these left standing. With the TS050, introduced in 2016, TMG and Toyota won Le Mans twice, in 2018 and 2019, as well as World Endurance Championship titles for manufacturers and drivers.

Closing the gap

Despite a new set of regulations that have introduced a balance of performance system on top of the Equivalence of Technology, with the specific intention of closing the gap between the fastest cars, Toyota has introduced a raft of aerodynamic upgrades for this final iteration of the TS050. This includes a new nose, revised location of mirrors and a smaller airbox as the most obvious changes to the naked eye. Under the skin, minor modifications have also taken place, with an emphasis on reliability.

The car will face some new challenges this year, including a balance of performance system that will be cumulative, meaning that throughout the season a successful car will be gradually slowed using a variety of devices, such as fuel flow, hybrid boost, weight and fuel energy per lap. The car has also started the season with a 14kg weight penalty compared to the end of last season, which Toyota calculated to be worth four tenths of a second around Barcelona and Silverstone. Therefore, efficiency was the main target for the upgrades, in order to mitigate any penalty either already applied or coming later in the year.

In the meantime, Toyota says that the developments made by the non-hybrid designs it races against since the start of 2018 have been significant. The non-hybrids raced with minimal testing at the start of the so-called super season (which encompassed two Le Mans 24 hour races

‘It is always good to keep developing and as development is allowed for non-hybrid cars then we had to anticipate that they would be quicker’

Toyota’s TS050, a car which has already won Le Mans twice, starts the new 2019/20 WEC season as the clear favourite and only concluded in June of this year) and development has been ongoing throughout that time. Also, a new Michelin tyre has been introduced this season with a view to closing the gap on the hybrid Toyotas, and so Toyota concluded that it could not stand still and wait for the BoP to balance things up.

With the first race having taken place at Silverstone at the start of September (after *Racecar* went to press) the season has now moved to a winter calendar, which has meant a great deal of adjustment for the teams.

Fewer contenders

The competition ranged against the Toyota has reduced in the WEC this year with the withdrawal from the top class of both the SMP cars and ByKolles. The former is the most keenly felt, having finished third at Le Mans with the AER-powered BR1 that was designed and built by Dallara. The Russian team felt that this result was the best that it could manage and it did not trust that the BoP would work effectively enough for it to justify the continuation of the programme for a further season. Toyota therefore faces the Rebellion team, with ORECA chassis that can trace their origin back to 2014, and Ginetta, which had its first truly competitive outing at Silverstone (see page 42).

The TS050 was introduced when Porsche and Audi were still competing. The regulations at the time, under cost-saving initiatives agreed with the other manufacturers, were that the chassis would be valid for two years, after which it could be upgraded. However, with both of its rivals pulling out by the end of the 2017 season and its budget accordingly reduced, Toyota had no reason to spend large amounts of money on a new chassis. This, therefore, is the fourth straight season with the same chassis design.

However, a new approach to the front of the car has seen it integrate a higher nose. This change has necessitated a new crash test, which was passed in the middle of the elongated 2018/19 WEC super season. 'You can see that the nose has changed a lot and that has affected the airflow over the car,' says TMG's project leader John Litjens. 'We are also channelling air through the car, so [airflow] is split [over and under the car]. That base concept is still there, the undercuts are still there, it was just other development and some help with the air over the car. The pure aero target is to gain efficiency, and that is the development [that we achieved]. That should not get worse, and that's a clear target for the design group.'


One of the more obvious changes to the TS050 is the higher nose

'You can see that the nose has changed a lot, and that has affected the airflow over the car'

Mirror image

One of the key design changes that has been introduced is the integration of the mirrors in the rear of the front wheel shroud, as Porsche had in the final version of its 919. Toyota did not believe that this was legal at the time, but as it was then declared to be so it has now done its own version of the design. That has cleaned up the airflow to the rear wing a little, and presumably reduced drag too. Rear vision is supported by the now-standard rear view cameras that takes care of the field of vision centrally behind the driver, although the mirrors are still required by regulation.

'The car from a mechanical point of view is not really different, and the rules haven't changed much,' says Litjens. 'The hardware underneath the car is not worth spending a huge amount of resource on, particularly with the new regulations coming up and it was mainly the aero people who were working, and we have finalised this.'

Another noticeable difference for the car is the reduced size of the air intake over the cockpit. The team has not made major changes to the cooling concept or efficiency though.


The Toyota is subject to a cumulative performance balancing system throughout the 2019/20 season

'The reduced air box was just one of the things that was not addressed before,' Litjens says. 'These are the aero things that in the wind tunnel you cannot really adjust because you have the fixing there. These are not massive things, but just things to fix.'

This is because wind tunnel models are normally attached to a vertical post, and then lowered onto a moving belt, which makes airbox design a little more challenging.

Secret testing

The new schedule has meant that the upgraded car had to be tested in secret mid-season, and early in 2019, in order to avoid interfering with the preparations for Le Mans. The car first ran at Paul Ricard in France in January, and then had another test at Aragon after Le Mans in preparation for the new season, which started with the Prologue in Barcelona at the end of July. In a way it has been fortunate that the car has had its development signed off so early, as the new hypercar regulations were finally confirmed at the Le Mans test day in June, and released to the wider world at the race.

Before then, the staff at TMG had stopped work on the new for 2020 car pending a positive outcome. Once Toyota and Aston Martin confirmed their hypercar programmes TMG has been flat out working on its new machine ready for the start of the 2020/21 season.

'The new regulations came quite late, so we had to keep our team busy,' says the team's technical director, Pascal Vasselon of the development of the TS050. 'They have been working with reduced budget and that has had an impact on the full car. It is always good to keep developing, and as development is allowed for non-hybrid cars, we had to anticipate that they would be quicker. If you do nothing, and the non-hybrid teams have done what they have done, we could have

The air intake over the cockpit has been reduced in size but the car's cooling concept has not changed

Toyota will target a new outright qualifying lap record at Le Mans, and a 3m12s lap is possible

been behind. In any case, it was not an option for us to stand still and count on the others not developing. We have seen some interesting progress on the non-hybrid side since Le Mans last year and this year so we kept going, and now we have the success handicap on top.'

Gripping stuff

The change to the tyre regulations is one that Toyota believes will help the privateers the most this season. Michelin introduced the 2018/19 tyre long before meaningful track testing had started with the new cars, and so took steps during the season to address the performance issue. 'It seems that the tyre issue was one of the main issues for them [the privateers] being caught out when conditions were changing, so we expect that Michelin has done a proper job,' says Vasselon. 'We do not expect a huge step in outright performance, but [that they are] better able to cope with changing conditions, and this we know from the work done with Michelin.'

How much of a performance advantage the new tyres will give will take time to assess, and Toyota was not able to predict their effect until after the first race of the season. 'Not all teams will benefit in the same way, and it is difficult to put maths behind it,' explained Vasselon. 'We know what the target was, and what were the problems, [but for] the exact result we don't have a picture.'

The Toyota began its final season at Silverstone running in its high-downforce configuration but there is a low drag kit that has been designed, and will likely debut at Spa in May, 2020. The team will no doubt target a new outright qualifying lap record at Le Mans, believing a 3m12s lap is possible. It would be a fitting way to close one of the great engineering exercises in racing history.

The view most of the privateer LMP1s will likely have of the TS050 this season. Note the mirror set into the rear of the front wheel shroud. This helps to clean up the airflow to the rear wing

A new hope


The Ginetta G60-LT-P1 is currently being run out of the factory but the company is looking for a partner team to race the car this season

Ginetta did not have a successful 2018/19 WEC campaign, contesting just two races, but its G60-LT-P1 is now back in the mix with a new powerplant plus a much improved performance potential. *Racecar* spoke to the team behind the car to find out more

By ANDREW COTTON

The 2019/20 WEC sees a return of one of the most eagerly anticipated challengers to Toyota in the shape of the Ginetta G60-LT-P1. Ginetta's full programme has yet to be revealed as *Racecar* went to press, but the team behind the development of the car is optimistic that it can show strongly in what is the final season for P1 before new regulations come in in 2020.

There is a likelihood that this generation of car will be grandfathered, but that depends on the number of manufacturers that will build hypercars. For now, Ginetta is concentrating on showing well this season.

The team ran the car at Silverstone, the opening round, at the beginning of September, but at the time of writing was looking for a partner team to run it in the remaining races. Ideally, it wants to sell the car and support the customer team, but at this stage it could be that the manufacturer has to run the car itself. 'We are a production facility, but we can race the cars,' said Ginetta's technical director Pete Smith at the Prologue, the pre-season test for the season held in Barcelona in July.

Full power

The biggest change for the Ginetta, compared to last season, is that it is now powered by the twin turbo V8 AER P65 engine which is producing the horsepower for which the car was originally designed. This was the engine that propelled SMP's Dallara-built BR1 to a third place at Le Mans in June, so it has the grunt and the reliability to perform well for Ginetta.

The G60-LT-P1 was originally designed to be able to take multiple engine choices, including Mecachrome, AER as well as the Gibson engine, to allow maximum choice for its customers. This meant that the gearbox casing and rear suspension was designed by Ginetta, while gearbox internals were done by specialist Xtrac. To do its own casing design was a decision taken by Ginetta in a bid to anticipate any potential changes that might arise, and ultimately it was right to do so.

'Right at the start there was definitely not going to be torque sensors,' says Smith. '[But] We did our own gearbox and we didn't want to get shot in the foot, so we package protected [ourselves] for this and before the design was even finished, it was then definitely on and we needed to have a torque sensor, so we were a bit wise to potential rule changes. We did that with engines too, package protection, not to compromise the base car. We had the CAD model [for various power units] but the first car had a Mecachrome engine.'

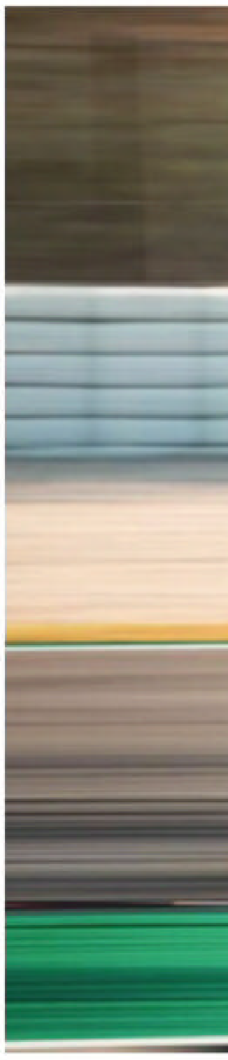
The car was first featured in *Racecar* V28N3 and the decision to run the Mecachrome engine in the first iteration was made in conjunction with the Manor team, that ran it for a Chinese investor. They had paid the entry fee and therefore owned the licence to race the car, but it was not a relationship that lasted the full season. The team took part in its first WEC meeting at Spa in May 2018 but the Ginetta only completed the minimum running time in qualifying and did not even start the race, due to issues that were not related to the car.

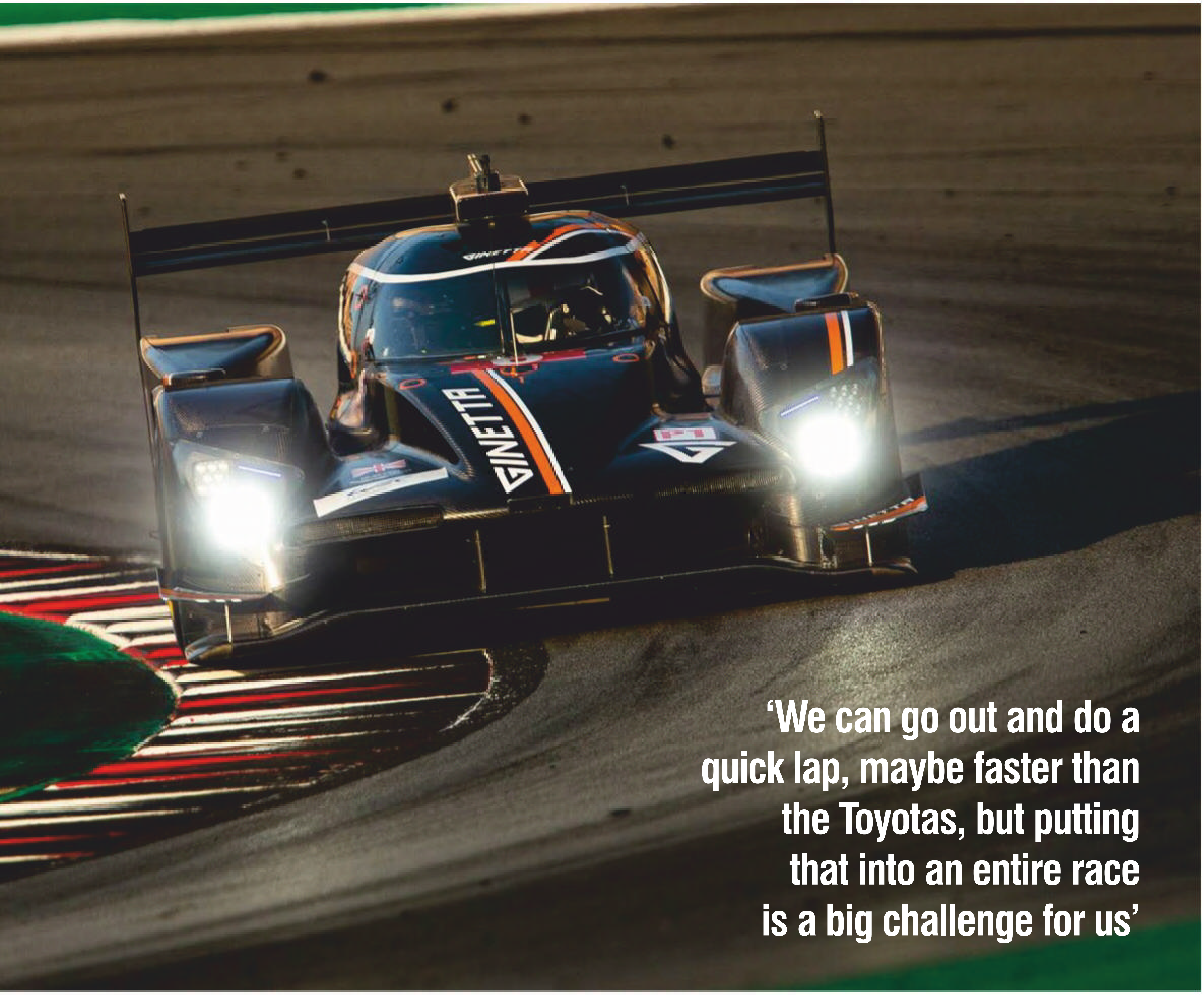
The team did compete at Le Mans in 2018, but the engine was noticeably down on power compared to others, and that started a downward spiral of performance that included a loss of downforce and subsequent tyre wear, as well as the slow lap times that were inevitable with the reduced power levels.

Works in progress

The car did not compete again during the so-called super season, despite attempts by Ginetta's owner Lawrence Tomlinson to take over the licence so as to race it. This new season, therefore, is the first opportunity that Ginetta has had to race the car competitively itself.

'At the Prologue last year, we realised that the Mecachrome wasn't giving the power that was promised,' says the team's designer Andy Lewis. 'From an aero point of view, I had developed the car with a certain drag target, because we knew it would have so much power. You get your aero balance and your downforce from that. Then you look at ways to reduce the drag, and when you develop a car you target an efficiency, the highest that you can.





‘We can go out and do a quick lap, maybe faster than the Toyotas, but putting that into an entire race is a big challenge for us’

With its new AER P65 twin turbo V8 engine overcoming the power deficiencies Ginetta struggled with last season the team has now been able to concentrate on sorting the car’s aerodynamic package

‘If you go down that curve to shed that drag off, you start to lose efficient downforce,’ Lewis adds. ‘That is where we were at Le Mans. Now we are able to put that downforce back on, and what you see here is that we are running high downforce, and we are making more rear wing options that we had homologated in the first instance but had never manufactured.’

Weighting game

Now that the power issue has been addressed and the aero on the car can be set up properly, the team can start to do some more advanced testing, including playing with the weight distribution, and it expects to be able to make good use of the new Michelin tyres that have been developed for this season.

‘One of the philosophies with the car, driven by the regulations, is that you have these huge tyres on the front,’ says Lewis. ‘The other LMP1 non-hybrid teams are using carry-over chassis [designs] from P2 and cannot [easily] turn the tyres on. They probably have a helping hand this year because the tyres are bespoke, but the whole philosophy of this racecar was one

‘The whole philosophy of this racecar was one of forward weight distribution, to bring the aero to the front and turn on the tyres’

of forward weight distribution, to bring the aero forward and turn on the tyres. If you are in a situation where you take all the drag off the car, you are also in a situation where you make compromises on where your aerodynamic balance is, and now we are not in that compromise. Now we can turn on the front tyres and get them to work.’

With changes to the pit stop rules the ability to use tyres over multiple stints might prove crucial this season

The long game

The Ginetta’s long-distance running was still a topic that had to be addressed ahead of the Prologue, but efforts in this area were being made, chiefly because the separation of refuelling and tyre changes in the pit stop has put the emphasis back on to saving time in the pits by using the tyres over multiple stints.

This feature will be especially important at the long-distance races, including Sebring in March and Le Mans next June. However, while the Ginetta development team expects good results over a single lap, putting together a strong race stint, or full race, that will rival Toyota is another matter entirely. ‘In terms of race pace it is going to be tough to beat a team with their resource,’ says Lewis. ‘With us, getting everything together [is the issue], we can go out and do a quick lap, maybe faster than the Toyotas, but putting that into a race is a big challenge for us. They can do consistent, quick lap times and that is the challenge for us.’

If Ginetta can put a full programme together this could be a surprise package for the series, but it needs experience of the different circuits to be able to challenge Toyota. That said, this could be the only season in which it might have a chance to compete for overall wins.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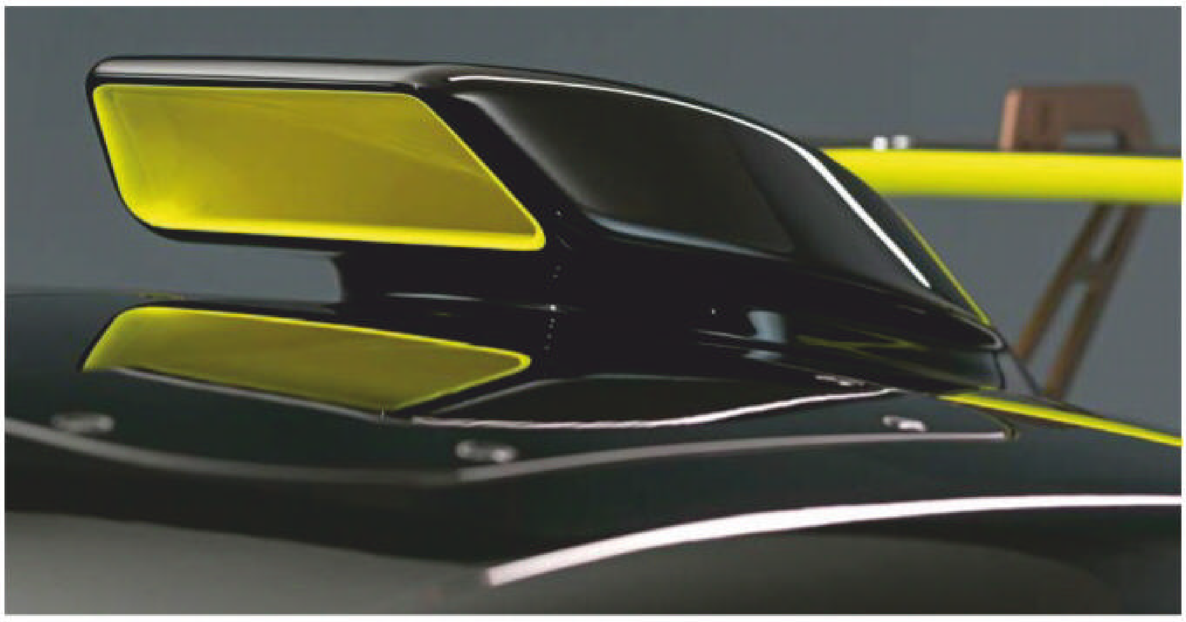
GR8 expectations

It packs almost 30 per cent more power than its GT3 sibling and it has been designed to be the perfect weapon for enthusiastic amateurs looking for a less full-on way in which to go GT racing. Say hello to the new Audi R8 LMS GT2

By ANDREW COTTON

‘The GT3 is a pure racing machine, but the GT2 is somewhere between a racing car and a collector’s piece’



The GT2's very distinctive periscope-style air inlet gives engine power a boost thanks to the ram-air effect

GT2 is a category that hosts GT racecars with more power and less aero than GT3

Something needs to be done about the nomenclature for GT racing. While series organiser Stephane Ratel says that now his house is completely built, with customer racing the foundation and manufacturer-supported customer racing as a penthouse suite, where each of the categories sits is rather confusing. And the introduction of GT2, a class that will allow amateur race drivers to compete against bone fide GT3 cars, and which features more power and less aero, has muddied the waters even further.

Ratel launched the GT1 class in the 1990s, and later added N-GT in 2001. N-GT quickly morphed into GT2, and raced alongside GT1 as the secondary class, which worked well and was understandable. Then GT1 ended in a world championship meltdown, GT2 became GTE in Europe, GTLM in the States and GT3 became the next class of customer racing cars.

Going for bronze

GT3 has become such a success that there are an estimated 1000 cars racing in this single class around the world. Yet with more aero and power the cars have evolved into something too quick for the bronze driver at which the class was originally aimed. GT4 was introduced to fill that gap, and is proving successful on national levels. But Ratel wanted something new.

Enter the new generation of GT2 car, a category that hosts GT cars with event more power but less aero than GT3. These are aimed purely at the amateur driver market and manufacturers are signing up to this new GT division. Porsche and Audi have already built cars, and many more are expected to join them.

The GTE and GT3 cars can share one base and many manufacturers are subscribing to this, including Ferrari. And now GT2 and GT4 can also share platforms, reducing the development costs for a manufacturer.

Audi launched its GT2 contender at the Goodwood Festival of Speed in early July, and then gave it its track debut at the Spa 24 hours at the end of that month. 'The intention was to have a car for gentlemen drivers that was easier to drive than the GT3, and in particular [with]

The 640bhp 5.2-litre V10 power unit is lifted from the road car and is not restricted, as it is in the company's GT3 racecar

The future of GT3

Despite the great success of GT3 racing all around the world, the FIA is working hard to make changes to the format and it has held manufacturer working groups to establish a new way forward. It issued a questionnaire to the manufacturers earlier this year to establish changes that they would like to make to the class, while it also attempted to split the category into one for pure sports cars, such as the Ferrari and Aston Martin, and one for platform cars, such as the BMW M6.

This plan fell flat, but the FIA is persisting, and it now appears to have gone to another level in its efforts by establishing the working groups without the category's founder Stephane Ratel involved. Under new proposals for 2022, the FIA has also put forward a proposal for a new front structure, wheelbase, width and roof height, also freeing up engine development. The new width restriction will mean more than just a reduction in floor area and therefore downforce levels; it will also mean that the exhausts cannot run down the side of the car, a particular problem for cars that pack a V8 engine.

'Freeing up the engines makes the costs go crazy,' said a representative of one of the manufacturers, who did not want to be named. 'The hot vee engines that have the turbo inside the vee, you can run the exhaust up and out, but with the V8 you need a side pipe and either you run it through the car like DTM, or you run it through the side. Nissan, Mercedes and Bentley need that.'

By proposing new GT3 homologation rules based on all the waivers granted to date to all the manufacturers, the FIA seems to be aiming to simplify its workload. However, one observer says that the proposal in its current form will open a Pandora's box for upgrades and will push costs beyond the customer teams. These discussions will no doubt continue.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the downforce,' says Armin Plietsch, Audi Sport Customer Racing head of development. 'In a GT3 car you need the confidence in the corners. Stephane Ratel's wish was to find somewhere between GT3 and GT4 in terms of downforce but we want to have a powerful and attractive car for the gentlemen which accelerates quickly, so they go slower through the corners and faster on the straights. That is the reason why this regulation makes the car closer to the road car, although it might not look like that.'

Indeed, the car has a monstrous air intake over the roof, plus a front air intake that could swallow a dog. It is based on the convertible version of the R8, with a hard top built to cover the cockpit. The Audi Space Frame forms the basic structure of the car, comprising a mix of aluminium and CFRP, while a steel roll cage is fitted inside. Particular attention has been paid to the aerodynamics, making the car both easy to set up and to drive for the customers.

'The underfloor of the car is exactly the shape of the road car, so there is no diffuser like the GT3 car to generate the downforce from the underfloor,' says Plietsch. 'You have flicks [front diveplanes that are homologated and permanently fitted], front splitter and rear wing, and the advantage of this is that they are very stable so are not sensitive to pitch and roll, so it is easier for the gentlemen to feel. If you create downforce from the underfloor it is very sensitive, so you have to be smooth through the corners and that makes it even more difficult.'

The steering wheel is more complex than the one in the GT4 and is adjustable for traction control, ABS and ESC stability

The GT2 has a monstrous air intake over the roof, plus one at the front that could swallow a dog

Power up

The car features the same engine as the GT3, which is the 5.2-litre V10 taken from the road car. While the GT3 is heavily restricted down to around 470bhp on the Nordschleife for the VLN, the GT2 car will be far more powerful. 'This car has 640bhp which is the maximum capacity of the road car engine due to the ram-air effect from the roof, where we put emphasis on the roof and we gain 25mb ram-air effect that increases the power by 25-30bhp,' Plietsch says. 'You are pressing the air into the engine, so the engine needs less effort to pump the air through and it has more air in the combustion chambers, and more fuel in the combustion chambers, and then you get more energy out of it.'

This means that the new car has around 2.1kg/hp and as the GT3 is so heavily restricted, according to Audi's press material, the engine fitted to the GT2 car puts out some 28 per cent more power than its more professional sibling.

The cooling systems on the car have given it a rather distinctive look, and no doubt this will make a great Lego model in future. The R8 features a huge radiator at the front which cools the engine oil and feeds an oil/water intercooler at the back of the car. There are no fans at the front, and air is guided out of the vents in the bonnet via fins to either side of the car. That leaves cool, fresh air for the intake over the roof.

The suspension is very close to GT3, but with less expensive materials. The road car already features a double wishbone suspension, so the mounting points were built into the chassis. While the road car has aluminium wishbones, the GT2 version has smaller, lighter bars. The number of options for spring rates has not yet been decided for the category, as the rules are still being finalised but there will be adjustability in the set-up according to the different circuits on which the car will race. The dampers are the same as on the GT3 car and so there is adjustability in there, too.

The car sits around 30mm higher than the GT3 R8. The calipers and steel brake discs are supplied by Brembo

High rider

The GT2 car runs with a higher ride-height compared to the GT3, up to 30mm more, which makes the car less vulnerable to wear. The height is adjusted through the kinematics rather than adjusting the mounting points.

The brakes are from Brembo with steel discs at the front and rear. The brake calipers at the front are from the GT3 car – as are the hub


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The road car-derived gearbox has paddle shifting, but the software has been updated so that the shift times are faster

carriers and wishbones – while the rear calipers come from Audi's GT4 machine.

The R8 LMS GT2 is two metres wide and runs the same size rear tyres as the GT3 car. The extra width over the road car was achieved with longer suspension arms, but required an all-new design for the bodywork to envelope the wheels. 'We knew with the road car bodywork we could not package bigger tyres,' says Plietsch. 'We asked if we could do two-metre wide cars like the GT3, and Stephane Ratel gave us the feedback that two metres was okay for him. That was okay for us to package the tyres and that was important. For the GT3 car, when we went to the 680 at the front, we couldn't load them, so we had more potential than load. With the GT3 upgrade package, we could do that, but with the GT2 car we have the [smaller] 660. This car is heavier at the back because of the road car gearbox. The load distribution compared to the tyre size is more natural than it was for the GT3.'

That road car-derived gearbox has paddle shifting, but the software has been updated so that the shift times are faster. 'It's the same gearbox as is in the GT4 car, so it is really reliable,' says Plietsch. 'The engine has a small check after 10,000km and a bigger check after 20,000, so the same as the GT3. The gearbox will last for sure 15,000km, but we don't know [what the limit is] because we haven't had one break yet.'

Safety measures

As is now standard in GT racing, the seat is bolted to the floor and the steering column and pedals are moveable. This keeps the driver protected by the A-pillar and allows access for safety crews through the roof hatch, should there be a need to do so. Side impact protection comes from encased foam that is also designed to protect a driver from small debris intrusion.

'The steering wheel is much more complex than on the GT4 car, so adjustable TC, ABS and ESC stability control,' says Plietsch. 'The drivers will still feel like they are making a difference. In GT4 we have on and off, high and low, but here you have different positions that you can adjust the TC to the conditions.

'Due to the intake, there was no opportunity to use a rear-view mirror so we installed a camera there and that transmits the pictures,' Plietsch adds. 'It's from the LMP1 car. It is quite easy to get a camera, easier than a mirror, and you can programme some tools in it. We put a lot of effort into the interior to have it like a collector's piece. The GT3 is a pure racing machine, this is somewhere between a racing machine and a collector's piece.'

Aero tuning

The main aerodynamic tuning device is the rear wing, which has rear-mounted swan neck supports in order to keep the airflow disturbed as little as possible to the leading edge.

'If you need a lot of front downforce you need rake, and if you need less rear downforce you need less front, so you go down on the rake and go flat,' says Plietsch. 'With these two methods you keep the car always in balance.

'The important thing is that the underside of the wing is not disturbed, and the easiest way to achieve that is from the back and over the top,' Plietsch adds. 'You are not destroying the airflow through the support. It is very clear and there is a disturbance only at the back.'

The new GT2 cars are due to run in races that are no longer than 60 minutes, but the Audi is fitted with a Krontec refuelling nozzle, and so mid-race refuelling is possible at races in the future. GT3 did start in exactly this way, as a low-cost, sprint race series, but rapidly evolved to take in 24-hour races. It is impossible not to imagine that the new GT2 class will do exactly the same thing. The first customer R8 GT2s will be delivered by the end of the year.

TECH SPEC: Audi R8 LMS GT2 (2019)

Body
Audi Space Frame (ASF) featuring an aluminium-CFRP hybrid design with steel roll cage.

Engine
V10, 90-degree cylinder angle, four valves per cylinder, DOHC, gasoline direct injection, emission control system using two exhaust gas catalytic converters for racing; engine management via two Bosch MED 17 (master slave concept); dry sump lubrication (adopted from production); power output 470kW (640bhp); Torque, more than 550Nm.

Drivetrain/transmission
Rear-wheel drive; traction control (ASR); ESP; two electro-hydraulically operated multi-plate clutches in an oil bath; S-tronic 7-speed double-clutch transmission with paddle shifters; mechanical limited-slip differential; constant velocity joint driveshafts.

Suspension
Double wishbones front and rear; struts with coil springs and adjustable dampers, plus adjustable stabilisers front and rear.

Steering
Electro-hydraulic rack and pinion steering; multi-functional steering wheel.

Brakes
Hydraulic dual-circuit braking system; Brembo steel brake discs front (380 x 34mm) and rear (350 x 32mm).

Wheels
ABS forged aluminium rims; front 12 x 18in, 40 offset; rear 13 x 18in, 43 offset.

Tyres
Front, 325-660/18, rear 325-710/18.

Fuel cell
FT3 safety fuel tank; 110-litre capacity.

Dimensions
Length, 4568mm; width, 1995mm; height, 1280mm.

Weight
1350kg (dry).

The main tool for aerodynamic tuning is the swan neck mounted rear wing


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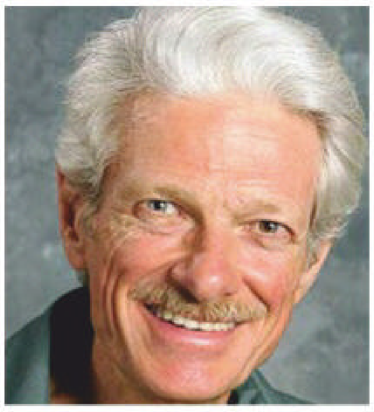

Formula 1 spin doctor

Could a flurry of off-track excursions during the British Grand Prix weekend be down to some basic errors in suspension geometry?

By MARK ORTIZ

Antonio Giovinazzi heads into the gravel at the British GP. Many F1 cars left the track at Silverstone and our questioner thinks driver feel might have been sacrificed for aero benefits

Q Watching Formula 1 at Silverstone during the British Grand Prix weekend I saw many cars just fly sideways off the road. With this in mind, what compromises can a designer make that takes road feel away from the driver?

I was taught a simple rule long ago that the lower arm outer ball joint pivot needed to be about half an inch above the inner pivot so the side force had to travel in a line that brings the spring into play (non-jacking). I've been on the grid and seen cars that go against this rule and it gave me confidence I could attack them in the race. So are the Formula 1 teams breaking this rule to get aerodynamic benefits?

THE CONSULTANT

A Rules regarding lower control arm angles in independent suspensions have been a fixture in racer mythology for decades. The one I mainly encounter in the US is that the lower control arm needs to be level.

The truth is that the control arms only matter with respect to what they make the wheels do. Any control arm angles that make the wheels do what we want are okay. What angles those will be will depend, among other things, on the height of the control arms, which in turn depends on the design of the uprights and the frame or tub. Additionally, each arm's angle depends on the other arm's angle.

The truth is that the control arms only matter with respect to what they make the wheels do

In terms of front-view geometry, we want two main things. We want some, but not an excessive, amount of jacking in an anti-roll direction, and we want camber change properties that prevent large amounts of camber change in either ride (two-wheel heave) or roll. We have a fairly wide range of values for these things that will work acceptably, so the game is often one of satisfying other requirements – packaging, load paths, bump steer characteristics, aerodynamics, use of existing components, compliance with rules – without having any really bad geometric characteristics.

Ordinarily, we want camber to go toward negative as the suspension compresses and toward positive as it extends, at a rate of 0.6 to 0.9 degrees per inch of wheel travel (about .24 to .36 degrees per centimetre). This is commonly called camber gain. I like to call it camber velocity, although that's not widely accepted terminology. We can live with values all the way down to zero if necessary.

When the front view projected control arms are parallel, camber velocity is zero. Most current F1 cars are like this, or close. With zero camber velocity, camber does not change with heave displacement, whether due to road irregularities or variation in downforce. The wheels lean with the car in roll. This is dealt with by not letting the car roll much.

Jacking coefficient

We would like the suspension to generate some geometric anti-roll, although again we can live with a value of zero. We do this by having the contact patch move outboard as the suspension compresses and inboard as the suspension extends. We want the contact patch to move laterally no more than 0.15 times as much as it moves vertically. This ratio will be the jacking coefficient; the ratio of jacking force to lateral ground plane force.

If it's 0.10, then each 100 pounds of lateral force induces 10 pounds of jacking force. This would correspond to a front view instant centre that is 10 times as far from the contact patch centre horizontally as it is above ground; a force line slope of one in 10.

Current Formula 1 racecar suspensions are constrained by the need to keep the control arms very high for aerodynamic reasons. That is not really great from the standpoint of ball joint and control arm loads, but designers accept that to get the aero benefit.

On the level

This year's Formula 1 cars appear to be running more nearly level front control arms than in the past. Previously, designers were trying to keep the ball joints inside the wheel rim, in order to get a small front-view steering offset (ISO) / scrub radius (SAE). This required sloping the control arms upward toward the elevated front portion of the tub at about a 0.15 slope. That meant that the arms had to be parallel or nearly so, to keep the jacking coefficient from becoming excessive. With the even more severely raised ball joints being used now, the arms can have a little convergence, so the car can have a little camber recovery in roll.

Even better geometry could be had by raising the ball joints still further, running the lower control arm slightly downhill to the tub, and the upper control arm a bit more downhill to the tub. We may see this if the current trend continues. However, to keep the front of the tub at current height, that would involve having the lower ball joint at about the height of the top of the wheel rim and the upper ball joint at about the height of the top of the tyre! That would really put big loads on the ball joints and control arms in cornering and braking. Then again, we are almost there right now. The upper ball joints on this year's Mercedes Formula 1 car is about midway between the top of the rim and the top of the tyre. The parts can be made strong enough. There's just a weight penalty.

This would look pretty freakish, but the designers in F1 don't seem to be daunted by that these days

If we totally disregarded ball joint and control arm loads, we might want to put the ball joints even higher, and run the control arms really steeply downhill to the tub. We'd like to have a front view swing arm (FVSA) length between 60 and 100in (1500-2500mm) and a front view instant centre height about a tenth of the FVSA length. Not only would the loads get pretty severe, but the driver might have problems seeing past the suspension!

If desired, steering offset in a layout with really high control arms could be reduced by using double ball joints. I haven't checked the rules to see if this is still legal, but I certainly see no reason it shouldn't be. Or, if both ball joints are above the tyre, we could curve the upright around the top of the tyre. That would look pretty freakish, but Formula 1 designers don't seem to be daunted by that these days.

I don't see any reason that driver feel should be affected by this, except perhaps that large steering offset might require more boost for the steering, and/or possibly designers might try reducing trail to reduce steering effort.

Slide rules

The questioner mentions cars sliding off sideways, as opposed to nose first or tail first. That suggests cars that are set up for very neutral handling; little understeer or oversteer. It has been recognised for a long time that a car is generally fastest when set up that way, because at the limit of adhesion it's making full use of both front and rear tyre pairs. However, the car gives less warning of impending breakaway. It is also hard to catch when it lets go, because both ends let go, and we can't catch the car by redistributing grip. If the car has some understeer, the driver is warned of impending breakaway by the need to steer further, and can recover some front grip by lifting a bit. If the car is dead neutral, there is less warning, and the rear has no reserve grip so we can't lift without spinning the car – or at least it's trickier to. There's nothing new about this, though, and I think it's a separate issue from front control arm angles.

At sixes and sevens with Late Model fuel weight

Last issue (September, V29N9) I said gasoline weighs about seven pounds per gallon. A number of readers have pointed out that it's actually closer to six, at least assuming we're using US gallons and considering pump gas. Seven pounds per US gallon is a whole number approximation that people often are taught to remember even though it's a little on the high side, because using seven rather than six will keep you from underestimating fuel weight if you're doing mental arithmetic. One accepted international standard is 6.073 pounds per US gallon. That's the lowest figure I've encountered so far: www.aquacalc.com says 6.25 pounds. One reader said he uses 6.3. The actual density varies considerably depending on the blend, the temperature, and the pressure.

Racing gasoline generally contains a lot of aromatic compounds, which make it denser. One common one is toluene, which is around 7.25 pounds per gallon. Commercial race gas can contain as much as 30 per cent toluene. If the remainder of the blend is 6.073lb/gal, that would be 6.43lb/gal – still a little closer to six than to seven, but significantly more than six. If the remainder of the blend is 6.25lb/gal, that would be 6.55lb/gal – a little closer to seven than to six. The really exotic blends of the Formula 1 turbo era in the 1980s reached over 80 per cent toluene. That would push the blend above seven pounds per gallon, although of course that's not representative of race gasoline most of us are likely to see.

According to the US EPA (Environmental Protection Agency), methanol is 6.59lb/gal and ethanol is 6.57. In any case, a hundred pounds of fuel burn-off during a run is a reasonable round figure for an illustrative calculation when discussing effects on weight distribution and brake bias in a pavement Late Model stock car.

Cars like the Brabham BT52, pictured at a recent track display, would use fuel that was over 80 per cent toluene in the 1980s

CONTACT

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Time's winged chariot

In a brand new series we embrace some old school aero with our wind tunnel study of a Reynard SF79 FF2000 historic racer

By SIMON MCBEATH

This month's new project features the lovely Reynard SF79 of Paul Allen, a regular visitor to the podium in the UK's Historic FF2000 race series. For younger readers who might need an introduction to these cars, the Formula Ford 2000 category was introduced in the mid-1970s to bridge the large gap between Formula Ford 1600 and F3. Powered by the Ford 2-litre Pinto engine and running on slick tyres the regulations also permitted downforce-generating devices. The category continued as a national series until the late 1980s when it was supplanted by Formula Vauxhall. Nowadays various popular historic FF2000 series provide relatively low budget slicks and wings racing for club competitors. From our viewpoint an FF2000 study provides not just a glimpse into the aerodynamic thinking of its time, but also the opportunity to re-learn some old aero lessons.

Uncomplicated aero

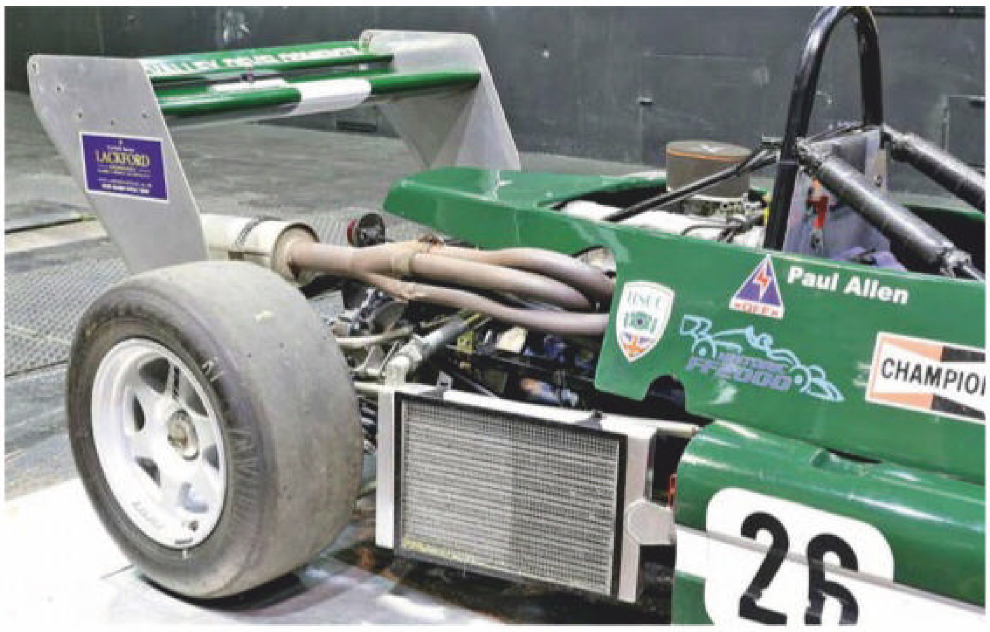
A quick tour of the Reynard SF79, an example of which Adrian Reynard himself took to the European FF2000 Championship in 1979, reveals an uncomplicated aerodynamic package. At the front a wide, shallow nose just within the permitted 1350mm width featured an adjustable splitter but was hollow underneath. Various simple tabs and Gurneys were available for aerodynamic adjustments at the front – one contemporary competitor chassis, the Van Diemen, featured a narrow nose with single element wings at the front, but there did not seem to be a strong indication one way or the other as to which set-up was best. The rear wing was an adjustable, modestly cambered dual-element device, 1030mm wide and in this case was cross-tube mounted via tall end plates. There were no sidepods, and the air/water radiators were mounted on either side of the engine bay at a shallow angle to the airflow. Apart from the panelling under the chassis and engine bay there was no aerodynamic underbody as such.

A key mission was to address an end-of-straight speed deficit to other cars

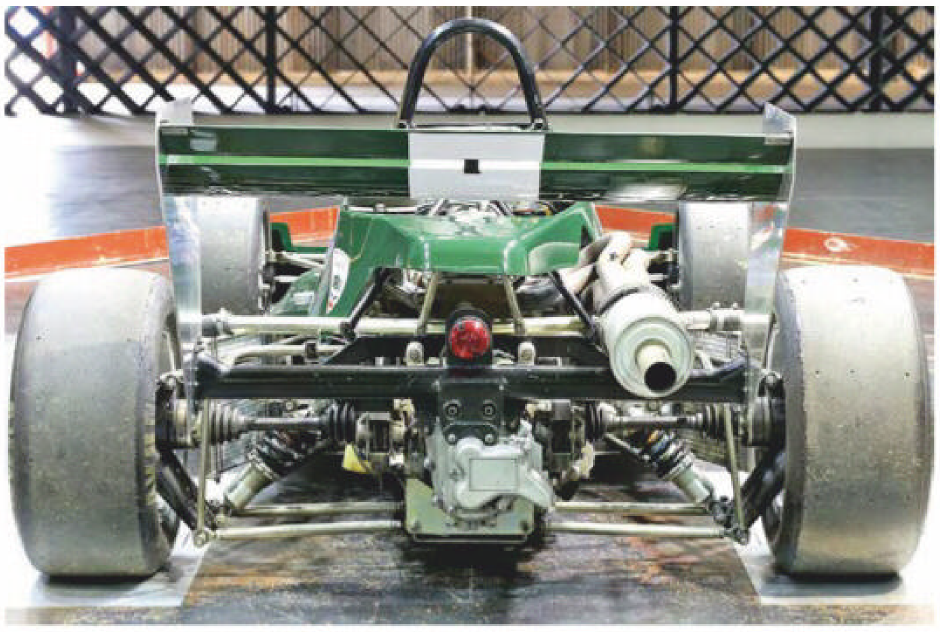
Illustrations: Simon McBeath

Top and above: The Reynard SF79 is a Formula Ford 2000 racecar, a category which was a driver's likely first slicks and wings experience from the mid-1970s to the late 1980s. This particular example is currently competing in Historic FF2000

Wide, shallow nose with adjustable splitter. Narrow noses with single-plane wings were used on some other FF2000 racers



The Reynard SF79 features exposed side-mounted radiators and a minimalist engine cover


Classic rear end with beam-mounted rear wing the only downforce-inducing component

As ever, extensive preparations had been made by the owner and his support crew for a range of configurations to be tested during our four-hour session in MIRA's full-scale wind tunnel. There was also a key mission; to address an end-of-straight speed deficit to other cars by looking for drag reductions. The session was also the usual opportunity to obtain hard data and log the responses of the car to the kinds of changes that are made at the track. And with the car coming from strong showings in recent races, would the numbers back up the driver's assertion of a reasonable balance?

Table 1 confirms that the baseline results showed the car, which has a 38 per cent front/62 per cent rear static weight distribution with driver, was reasonably well balanced, if short of ideal on %front value. To put the other numbers into context let's compare them to other cars in categories either side of FF2000.

Comparison site

To make direct comparisons between different cars' aerodynamic data we need to multiply the coefficients by the frontal area in each case. These values then relate to the forces measured in the wind tunnel. **Table 2** compares with CD.A and CL.A ranges for two different Formula Fords and two successive Dallara F3 cars tested during our MIRA sessions. The Reynard FF2000 falls in between FF and F3 on drag and lift/downforce, but as shown in the right hand column the Formula Ford 1600s generated positive lift while the FF2000, and of course the F3s, generated negative lift, or downforce. The downforce generated by the FF2000 may be modest, but it also represents the eradication of the positive lift that occurs with wingless single seaters as well as the generation of real downforce.

The benefit that downforce brings to grip is relative to the vehicle's weight (more correctly the benefit is relative to the dynamic weight on the wheels at any particular moment, but it's simpler to think about the static situation as a rough guide). So what vertical forces were being generated by the Reynard FF2000 front and rear, and what proportion of the axle weights did these forces represent?

Table 1: Aerodynamic coefficients on the Reynard SF79 in baseline configuration

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.509	0.407	0.140	0.268	34.3%	0.800

Table 2: Comparative data

	CD.A	CL.A
Swift SC92 FF (1992)	0.456 to 0.498	+0.160 to +0.177
Spectrum 011 FF (2006)	0.400 to 0.450	+0.201 to +0.282
Reynard SF79 FF2000	0.563 to 0.648	-0.370 to -0.596
2008-11 Dallara F3	0.664 to 0.801	-1.324 to -1.916
2012 Dallara F3	0.640 to 0.801	-1.420 to -2.091

Table 3: Power absorbed by aerodynamic drag in different configurations

	CD.A min	CD.A baseline	CD.A max
100mph	41.0bhp	44.5bhp	47.2bhp
125mph	79.9bhp	86.6bhp	91.9bhp

The car with the driver on board weighs around 5250N (535kg), split 38 per cent front (1995N) and 62 per cent rear (3255N). In highest downforce, balanced (38%front) configuration we saw 657N of downforce at 100mph (using the writer's usual ill-disciplined mix of SI and Imperial units) and 490N in low downforce balanced configuration. Thus, at 100mph downforce represented between 9.3 per cent and 12.5 per cent of the car's weight, and alters with the square of the relative speed, e.g. rising 69 per cent more at 130mph to 15.8 – 21.1 per cent of car weight. At typical UK circuit cornering speeds, then, this is not insignificant in terms of increased grip potential, but the range available from 'high' to 'low' downforce was not particularly large.

Looking now at aerodynamic drag, a useful way to regard this is in terms of power absorbed to overcome it, using the formula:

$$BHPabsorbed = (CD.A \times v^3)/1225$$

Where: v is speed in m/s

Using this formula **Table 3** shows the range of power absorption figures at two speeds for the minimum, baseline and maximum drag values found during our session. Given that these racecars produce a modest 135bhp or thereabouts, it would appear that aerodynamic drag is a significant performance-sensitive parameter at higher speeds, with increasingly large gains in the power left available to accelerate the racecar (and overcome other forms of resistance) at higher speeds from the lower drag configurations.

Without the luxury of lap time simulation it's impossible to say exactly what the relative merits of high and low downforce and drag would be, but from these numbers taken in isolation, it looks as though drag could be the more sensitive parameter.

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Class of the field

This year's Formula Student UK event at Silverstone threw up some interesting technical solutions, as always, but there was no amount of tech trickery that could deny MoRe Modena Racing (MMR) of its well-deserved victory. *Racecar* took a close look at the Italian team's clever little M-19L racer

By JAHEE CAMPBELL-BRENNAN

The 2019 FSUK winner, MoRe Modena Racing (MMR), took the competition by storm, with a 119-point advantage over its closest rival, Oxford Brookes.

MMR is based at the University of Modena and Reggio Emilia and its Formula Student journey began back in 2003, when it was run out of a small workshop at a car showroom. Today, the team fields three cars out of a dedicated university workshop and comprises approximately 80 mechanical, mechatronics, electrical and management students.

The 2019 FSUK winning car, the M-19L featured a carbon fibre monocoque for the fifth year running, a longitudinally mounted gearbox and a full aero package. 'The main focus for 2019 was to optimise concepts and solutions from the 2018 car,' says Gianmarco Carbonieri, team leader at MMR. 'There were some components that had reliability issues, for example the DRS system in 2018 did not work correctly, so we made sure that was fixed this year.'

The MMR team has worked hard to eradicate an aero imbalance it had with last year's car while also improving the cooling

That's a MoRe

Weight was also a strong focus and by optimising component development the team managed to lighten the car significantly, contributing to its dynamic performance targets. 'We had a design objective to reduce individual component weight over the whole car by six per cent from last year, and actually we overachieved this and lost nearly 10 per cent of weight from last year's car – we're currently weighing in at 196kg,' Carbonieri says.

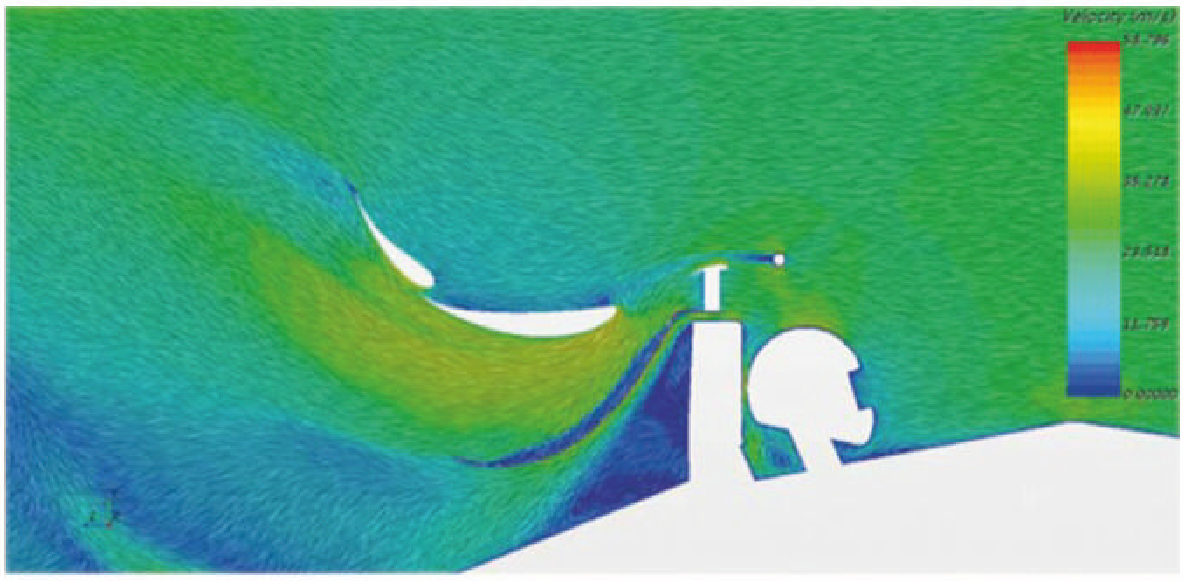
The Formula Student regulations recently changed to allow an increased maximum displacement of 710cc. MMR took full advantage of this and therefore up-sized this year's engine to a 708cc Suzuki GSXR, something it predicted would generate more power over a wider speed range than the previous 600cc GSXR unit. 'The original idea was to use a 708cc Suzuki GSXR engine derived from a 750cc stock unit,' Carbonieri says. 'We modified the crankshaft and connecting rods to reduce displacement to 708cc, but unfortunately on the bench we had a crankshaft failure due to a manufacturing defect. We lost that engine and so had to revert back to the standard 600cc engine. We lost around 7bhp by using this, but we're still managing around 99bhp, so we reached our specific power target of 2kg per bhp.'

The engine is mounted longitudinally, which is an unusual approach for a Formula Student team, as they usually opt for transverse. 'We are one of the only teams to use the longitudinal engine mounting,' says Carbonieri. 'This brings advantages in terms of space for accessories, it also moves the heat from the exhaust further away from the driver, fuel tank and electronic components. The bevel gear transmission we are now able to use is more efficient in the driveline. We only used gears two to five in this gearbox, so we removed ratios one and six. This saves us some space and weight that we take advantage of with a custom gearbox casing.'

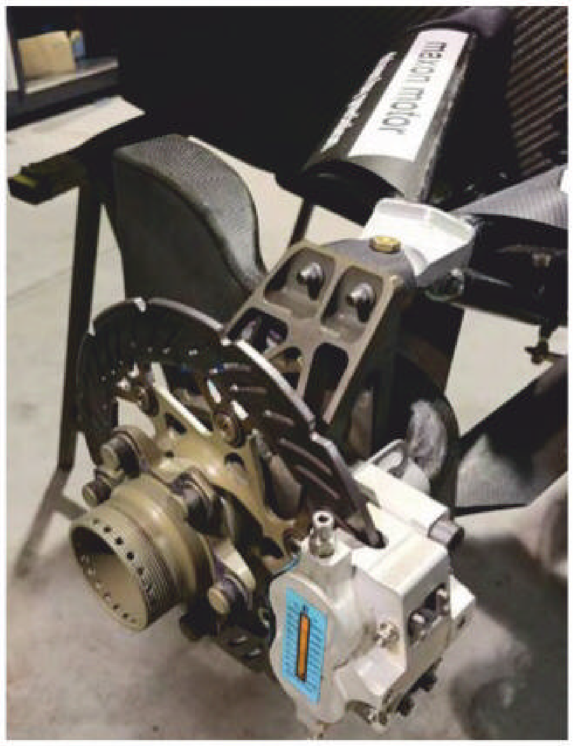
MMR's carbon fibre chassis concept is an evolution on previous years' cars and is a slightly different approach to the fully moulded monocoques more regularly seen amongst the winning teams. 'We are using the cut and fold technique without moulds for our monocoque, primarily to reduce costs,' explains Carbonieri. 'Traditional carbon fibre monocoques were costing around €50,000 for the mould and another €10-15,000 for the part. Finished, our chassis is around €10-12,000 total.'

Using this method, carbon fibre and aluminium honeycomb panels are constructed in 2D and 'cut and folded' to form 3D shapes, creating a somewhat geometric appearance to the monocoque. Panels are then bonded

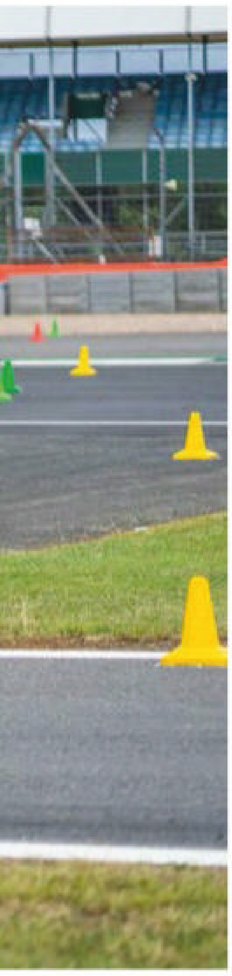
'We are using the cut and fold technique without moulds for our monocoque, this is primarily to reduce the costs'



CFD plot taken along the longitudinal centreline showing the velocity distribution around the car's rear wing



The M-19L's very neat brake and upright assembly



to form the finished part (see V28N9 for the full method). The final chassis is lightweight, weighing under 17kg, and has a high torsional rigidity, which improves vehicle dynamics.

One interesting feature of the MMR car is the driver operated DRS (Drag Reduction System). Used in F1, the concept behind this technology is to reduce the angle of attack of the uppermost wing element (with the largest frontal area), reducing drag significantly where downforce is not needed. 'We use a motor and wire operated element, all the wires are integrated into the main-plane and endplates so it is a neat solution,' says Carbonieri. 'Packaging the wiring was a little difficult initially as we had some problems with the flap cutting the wire, but we have addressed those now. The motors and associated hardware are weighing nearly 500g and are mounted quite high [1m] on the car, but we made the judgement that the effect on CoG was negated by advantages on the straight section of the track.'

One of MMR's key objectives for 2019 was to reduce unsprung mass as much as possible. This is why it aimed to bring new 10in carbon fibre wheels to FSUK. 'We made a prototype but unfortunately we had a problem with the supplier for this part so we only made one wheel. With each wheel weighing just over 1kg this is a 3kg saving across the whole car so we're certainly aiming to implement this design in the future,' says Carbonieri. 'We use M46J CF and unidirectional reinforcements around the centre. It's a 10in diameter with three spokes, of hollow construction. We are using aluminium inserts to be certain that there is an evenly distributed load from the hub into the wheel as carbon fibre is quite fragile in that respect.'

For 2019 MMR had two main aims which drove the design of the car's aero package. The first was to solve the aerodynamic balance which was too rear biased on the 2018 car, and the second was to improve the cooling efficiency, which meant modifying the sidepods. 'We developed the aero package this year to address an understeer issue we had with the 2018 car, so we looked at more aggressive aero on the front wing to solve this,' says Carbonieri. 'A lot of work went into our end plates and we got to a 58 per cent front balance which works better for us. Last year we had separate radiators for our water and oil but this year we implemented a single air-water heat exchanger for the water and used a water-oil heat exchanger to cool the engine oil.

'Last year the radiators were fairly big so we have reduced the dimensions of the radiators by 40 to 50 per cent. We have two coolers in parallel and a larger pump with PWM [pulse width modulation],' Carbonieri adds. 'We found this to be more efficient in terms of thermal exchange. This configuration also gained us about 2-3kg of weight saving with smaller radiators, less water and smaller sidepods, with the latter also allowing us to rework the aerodynamic performance and reduce drag.'

Test of time

Testing and verification is an interesting challenge within FS. With only one year for design and manufacture as well as limited resources, development work continues right up until very close to the event. In FS terms, MMR actually had a fairly significant amount of test resource, both analytical and physical, which played a key role in its success. With the powertrain, MMR used analytical tools for the majority of its development and calibration. 'We ran powertrain simulations using 1D sim tools such as Simulink and used a dyno to gather measured data,' Carbonieri says. 'We would correlate all of the 1D sim outputs on the bench to ensure they were producing accurate data which allowed us to trust what we were doing.' Using this approach saves both time and money, allowing iterative concepts to be proven and verified in a short time frame.

Physical testing is not always possible, and definitely not to the extent that teams would like. This is particularly true with aerodynamics, where testing in controlled environments such as wind tunnels is often not available. Therefore, to correlate its CFD data, MMR used a different strategy. 'For our aero package we relied largely on CFD as we had no access to a wind tunnel, but we did try to correlate our CFD using a method of attaching string to the aerodynamic surfaces during track testing to monitor the airflow patterns, and we had quite good success with that,' says Carbonieri. 'We also had displacement sensors on our dampers so we used the data from those during track testing to monitor compression of our springs due to aerodynamic load, this gave us a little correlation to the CFD simulations. We also used this to fine tune the aerodynamic balance.'

Vehicle dynamics simulation was another crucial aspect of the car's development as it allowed the defining of suspension geometries and critical dimensions. It also enables the optimisation of parameters such as spring and damper rates, anti-roll bar stiffnesses as well as understanding the influence and sensitivity of the car to CoG location with regards to weight transfer and the moments generated on track.

'We used ADAMS to design our suspension layout and kinematics and then used VI Grade to run lap time simulations to figure out where last year's car was and where we could improve on this,' says Carbonieri. 'For example, modifying the CoG to see if we had any performance advantages or simulating a lighter car to see how the lap times improved. This was very useful for our development process. We also used MatLab to understand the brake power requirements and the heat produced during simulated braking events, we used this to design the brake ducts and the discs. Last year we had overheating in our brake fluid which led the driver to lose confidence in the car, so we wanted to get that under control this year.'

In terms of physical testing, the team had access to three test tracks encompassing areas for acceleration and brake tests, plus a skid-pad and an autocross track to replicate what it would face in the competition. MMR managed around 150km of testing in the months leading up to the FSUK event, using the time to optimise the aero and vehicle dynamics set-up.

Overall, MMR built on previous experience, and with a solid approach it designed, produced and raced a car that was very worthy of its impressive victory at FSUK in 2019 .

Schools of thought

Formula Student UK and Formula Student Germany were once again hotbeds of innovation this year with inspiring and intriguing solutions on show at both. Here's our review of the most fascinating technology and trends to come out of the 2019 competitions

By JAHEE CAMPBELL-BRENNAN

With concepts ranging from single-cylinder combustion cars to 4WD electric drivetrains, this year's Formula Student UK (FSUK) and Formula Student Germany (FSG) events were once again great adverts for the ability and ingenuity of student engineers, and there was very much of interest on show at both Silverstone and Hockenheim.

Starting with the suspension, in general the overall design approach to this across the paddock has more or less converged to a common format. Springs and dampers are positioned inboard of the wheels and the chassis is actuated via pushrod and bell-crank assemblies. This year's UCL car, however, featured an innovative and novel approach to suspension design in the form of flexures. In the context of control arms, flexures are an alternative mounting technology to the traditional spherical bearing configuration. Traditionally, control arms are fastened to the chassis via bolts in double-shear with articulation to allow for wheel displacement provided by spherical bearings. The idea of a flexure is that the control arm is mounted to the chassis without a spherical bearing and instead uses a flexible section of material bonded and fastened to the arm. The benefits of this arrangement include reduced weight and friction in wheel articulation, as well as a finer control of kinematic and compliance effects within the system.

Flexible approach

It was at first a little surprising to see flexures on a Formula Student car due to the fairly large wheel travel requirement (a combined 50mm of bump and droop), whilst the control arms are relatively short so there is a typically large range of angle required for wheel articulation.

'The entire approach to this FS car was towards mechanical grip rather than that of aerodynamic grip,' says Pete Weston, who played a key role in the development of this feature. 'With the suspension we saw the opportunity to try something a little different and so have used flexures on the control arms. We initially began the project with the intention of using torsion springs to reduce the friction and stiction of the system, although that idea didn't make it on to the finished car.'

The car featured no downforce generating bodywork; the entirety of grip generated was mechanical and so the team at UCL focused on creating a chassis that worked the tyres efficiently, generating heat and maximising grip. 'We initially performed a study into which suspension parameters had the largest influence on tyre temperature and incorporated

Flexures, seen here on the UCL control arms, are an alternative to the traditional spherical bearing approach

Metz competed with an aero package for the first time this year the results from that study into our design,' Weston says. 'We did extensive FEA on the flexures. The solution was driven through a combination of [using] x-section and the length, and is designed to be flat at static ride height so the nominal deflection is defined by a maximum of 25mm of travel at the wheel either side of this to equally load it in bump and droop. Material selection was a big factor in defining a safe flexure and we settled on SAE 4130, which is a high UTS steel with a good fatigue life.'

Aero smiths

Despite aerodynamic appendages now being a common sight in FS, the philosophies around the paddock are far from converged. Depending on the resources available to each team some opt for wingless configurations with simple fairings to reduce drag while the more well-resourced teams have developed complex and extremely aggressive aero packages in the search for downforce, with large chord and high camber wings, dual tier rear wings with two or three elements and high gradient diffusers.

Despite the low speeds of the competition's dynamic events with maximum speeds only around 75mph/120km/h, the overall results do suggest that the additional weight and drag penalties of an aerodynamic package are outweighed by performance gain.

Just two students were responsible for designing the Metz aero package and the team has only nine members

Metz arrived at FSUK this year with its first attempt at an aero package, despite competing in FS for the last nine years. FS aero packages tend to be very aggressive in design due to the low speeds that result from the design of the track and Metz's package wasn't any different in this respect. But the really impressive thing about it was its complexity, despite there being just nine members in the team. In fact, just two students developed the entire aerodynamic package from a blank sheet of paper.

'Our aim with the aerodynamics of the car was to build a solid and efficient foundation,'

The more well-resourced teams have developed complex and extremely aggressive aero packages in the search for downforce

says Alexandre Leys, team manager at Metz. 'We didn't initially search for ultimate downforce figures but we wanted to be safe and incorporate adjustability from which to create an aerodynamically balanced platform. We wanted our centre of pressure just behind the centre of gravity and we accomplished this with a 53 per cent rearward aerodynamic balance to our 50:50 weight split, generating a total of around 45kg of downforce at 60km/h.'

This was achieved using a relatively simple tiered front wing which directs the air over the front wheels to reduce lift and subsequent downstream turbulence, with an outer dual element tier and vertical end plates. The rear wing was again not revolutionary but of a sound and concise design; featuring three elements along with an upper tier. The lowermost aerofoil of the three-element assembly featured a very long chord length. Presumably this is aimed at maximising the potential of the extremely turbulent and low energy air that has travelled over the driver, main roll-hoop and engine intake. This results in a more efficient flow on to the upper tier, which also featured a neat Gurney flap to aid flow attachment.

'The entire approach to this car was towards mechanical grip rather than aerodynamic grip'

The ingenious use of gas struts on the Strathclyde FSUK entry allowed the front wing to run in ground effect

Go with the flow

The underbody aero also featured a high gradient diffuser to promote mass flow. 'Our two aerodynamicists worked for the first six months solely on design and simulation and often had simulations running 24 hours a day,' says Leys. 'Our sponsors, Safran, assisted with the manufacture of the wings, with a foam core used for the aerofoil sections. The profiles were cut by us with a wire-cutter but without the experience and help of Safran we wouldn't have been able to manufacture them in time.'

Metz's implementation of sound aerodynamic theory coupled with its maturity in not attempting the unachievable was impressive and should be commended, especially when achieved with relatively small resource. Often it's better to keep things simple and do them well, rather than overcomplicating the task and running into issues.

Another neat aero innovation was the front wing design of the Strathclyde car. Regulations necessitate a jacking point at the rear of the car which when used will rotate the front wing into contact with the ground and therefore damage it. This usually means that the teams design wings that are mounted relatively high and therefore are clear of any potential ground effect performance gains. However, to work around this, Strathclyde installed gas struts and a pivot point where the front wing is mounted to the nose. So as the rear of the car is jacked up, the front wing contacts the ground, compressing the gas struts which consequently prevents any damage. 'Mounting the front wing in this way meant we could utilise ground effect; reducing our drag and increasing the downforce,' says Iain Lowther, the team's technical director. 'This then allowed us to use a more aggressive rear wing package and consequently increase the car's overall downforce numbers.'

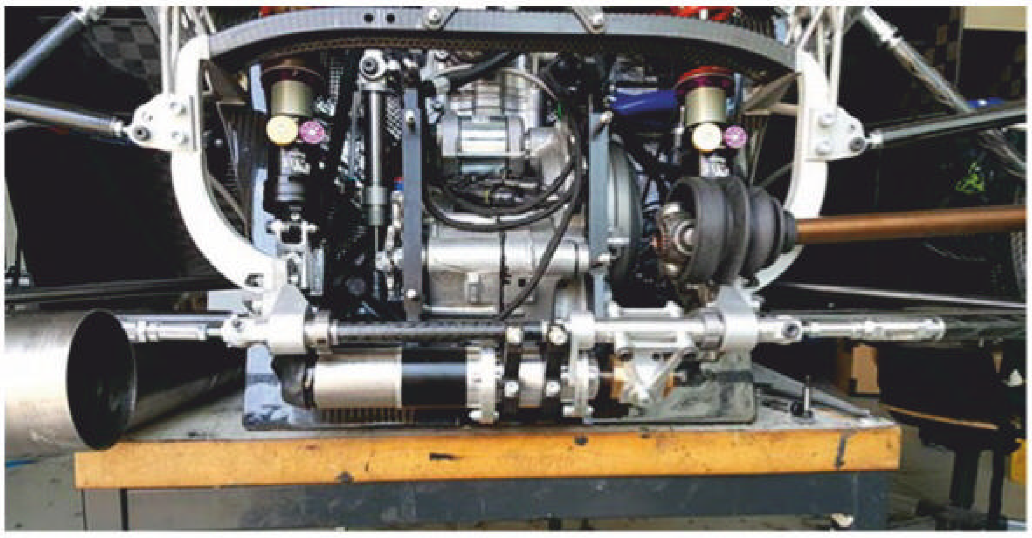
To make its aero package Strathclyde used a simplistic but effective carbon fibre lay-up technique. 'We have a pretty simple lay-up technique which means we could manufacture the entire aero package within two weeks but it's also pretty lightweight, at only 7kg,' says Lowther. 'We had to stretch the limits on what we could technically get away with, but it resulted in the second lightest aero package of the [FSUK] competition, so we are proud of that.'

Joint effort

Occasionally, universities work with each other to develop an FS car and one such collaboration for 2019 was that of Ain Shams University in Egypt and the University of Sussex in the UK. In all forms of motorsport, technical collaborations are prominent, teams outsource engineering solutions due to time, budget and expertise limitations. In this collaboration Ain Shams produced the chassis, suspension and bodywork whilst the University of Sussex developed the electric powertrain and other electrical systems.

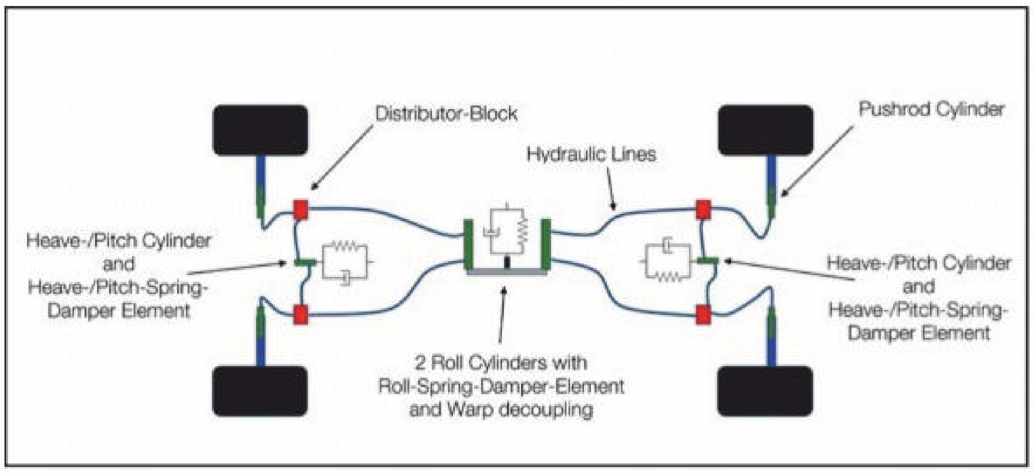
'From the start of the project, anticipating future complications, both teams agreed that we would keep the car as simple as possible for our first venture, with reliability at the forefront,' says Serdar Cicek, team leader of the project. 'As ever, there were plenty of obstacles to overcome. For example, the chassis was manufactured in Egypt so when we received it, we found there were some tolerances in the manufacture that were larger than expected, which resulted in some issues which we had to overcome, so we learnt valuable lessons there. The chassis didn't arrive until early May for various reasons so we only had around five

Imperial's car features a largely self-designed electric powertrain



TU Graz rear wheel steering system; the toe control arms are actuated by the motor assembly

TU Graz's main focus has been on its switch to smaller tyres



AMZ's mode decoupling suspension is similar to the FRIC system on the Porsche 919 LMP1 car

The remarkably light AMZ car features four 37kW wheel-mounted electric motors

weeks before our car launch to prepare the car and mate all the systems together. Therefore, we effectively only had nine weeks to complete a running car, but never the less we managed to get our car ready for competition.'

Imperial measured

Imperial University entered FSUK with its first Class 1 entry, having previously only entered the competition in Class 2, which is where teams are judged on their designs alone. The team developed a car with an electric powertrain but the ingenuity with this project was its battery solution. The battery was designed and manufactured entirely in house and is air cooled. While that may not be revolutionary in itself (see page 72), the battery is cooled using passive airflow travelling underneath the car, rather than the more conventional method of active air cooling which utilises fans.

A team of four students worked on the battery and used cells from an external supplier. These were then used to build up the battery modules, which were mounted underneath the chassis rather than in the more common location of behind the driver. This is not only a clever way of reducing complexity and cost, but it also has further dynamic benefits such as lower weight and improved weight distribution. 'Some of our challenges were with the manufacture, in order to fit the cell packs in the tight space under the chassis as opposed to in the sidepods or behind the driver,' says Harry Thompson, who developed the batteries at the Imperial team. 'We had to employ some very tight packaging tolerances so tolerancing and machining were our main hurdles.'

TU Graz achieved one of the lightest cars seen at FSG, weighing in at an impressive 150kg

Many forms of electric vehicle battery packs require liquid cooling to keep the lithium-ion cells within a very narrow temperature window, sensitive to +/-1degC, to optimise performance. But with this solution the rate of cooling is dependent on vehicle speed and therefore the level of heat rejection. 'With our cooling solution, the positive is that when the car is moving slowly and there is low air speed, we don't need to reject a large amount of heat,' explains Thompson. 'At the times where the cells are generating a lot of heat under acceleration, the air speed is high, so it works well in that sense. We have also done some analysis in terms of both computer simulation and within a battery oven at our expected worst case conditions, and while there is always the possibility that the cells get a little too hot in unexpected conditions we have safety measures that will shut the car down to avoid unsafe conditions escalating. Our battery can release the full 80kW limited by regulations and the pack has a capacity of 7kWh which will last the whole endurance event, so we feel we have produced a successful design.'

Graz routes

TU Graz entered the 2019 FS season with an impressive history; three world records and two overall wins in recent years. Its main objective for this year was therefore to continue this success by evolving the technology and designs of the car. Much of the 2019 car comprises of incremental changes compared to previous years, with particular focus on weight reduction; it achieved one of the lightest FS cars seen at FSG, weighing in at an impressive 150kg.

One of the most substantial changes this year was the switch to a smaller diameter tyre developed by Hoosier. 'We noticed that a lot of the teams were putting substantial work into their aerodynamic development and seeing positive results. So this year our main focus has been on the smaller tyres and how to optimise the car's behaviour with those, whilst also increasing our aerodynamic performance,' explains team leader Jodok Hammerle.

Dropping from 18in to 16in outer diameter tyres, the smaller tyre not only reduces weight, but also the polar moment of the car and rotational mass, complimenting vehicle dynamics. This change also required some modifications to the kinematics of the suspension to capitalise on these advantages, allowing the team to feature some additional aerodynamic elements around the wheel to improve aerodynamic efficiency.

A new rear wheel steering (RWS) developed by the students also featured on the TU Graz car this year. RWS systems are used to influence the yaw responses of a vehicle through actively controlling toe at the rear wheels during cornering to reach optimum slip angles and maximum cornering grip. TU Graz's system uses

inputs from steering wheel angle, vehicle speed and a gyroscope to create a map of steering input to the rear wheels for best performance. 'In testing we were showing to be one to two seconds faster around the circuit with the system enabled, even gaining 0.3 of a second in one hairpin alone, so it's a great addition for us,' Hammerle says. 'We currently use it for all events aside from the skid-pad as our drivers reported it was very difficult to drive [with it] on that particular course layout. The total weight for the system is 1.4kg so we are not incurring much of a weight penalty with this.'

Going TU Fast

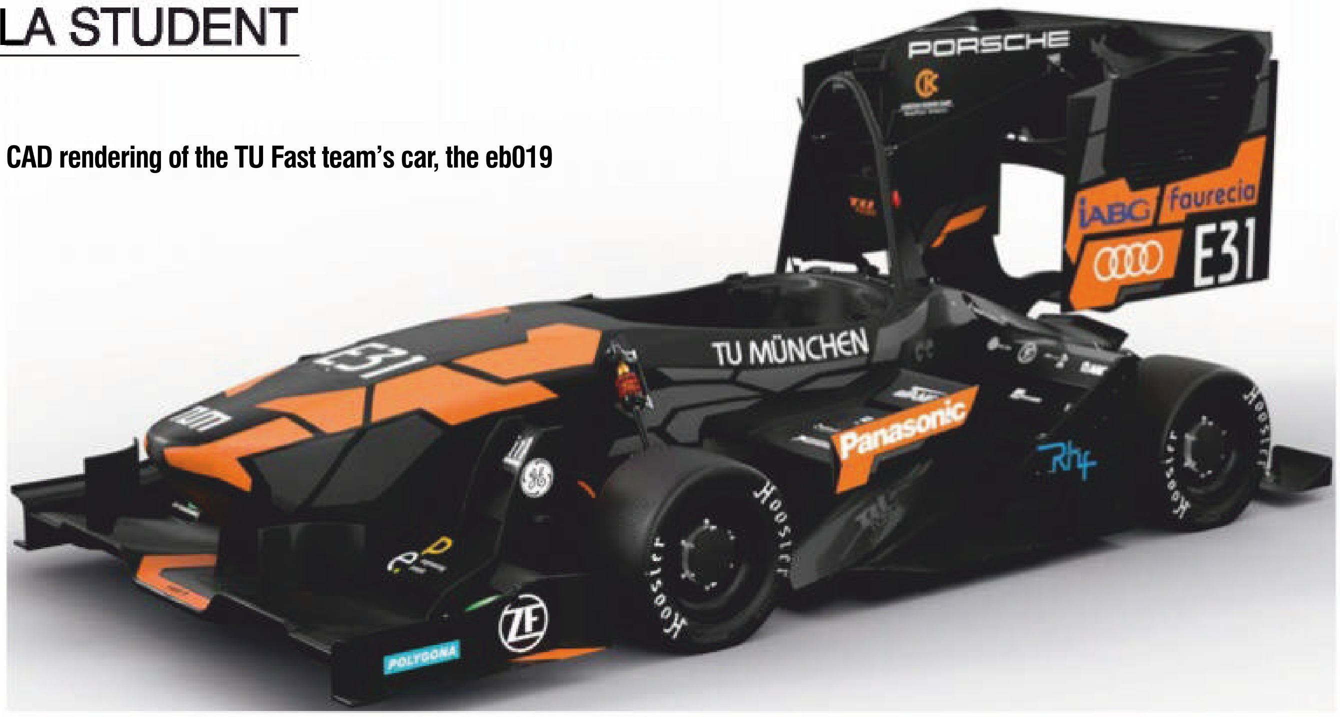
Another one of the best German heavyweight teams is that of TU Fast from the Munich Technical University. Having unfortunately been disqualified for a software issue after effectively winning the FSG competition last year, it was determined to set the record straight this year. So, having already identified the formula to build a competition winning car, the 2019 entry was an evolution of the 2018 racer, with incremental changes and updates, but largely the same technical package.

That said, aerodynamics were a focus for improvement for this year's TU Fast car, with the new aero package being 10 per cent more efficient than last year. 'Our extra aero efficiency was due to a larger rear diffuser and underbody modifications,' says Gregoriy Garyuk, technical director at the team. 'Most of the effort was focused there and this then meant we had to make adjustments to our front wing to maintain the correct aerodynamic balance, so we added additional flaps to help this.'

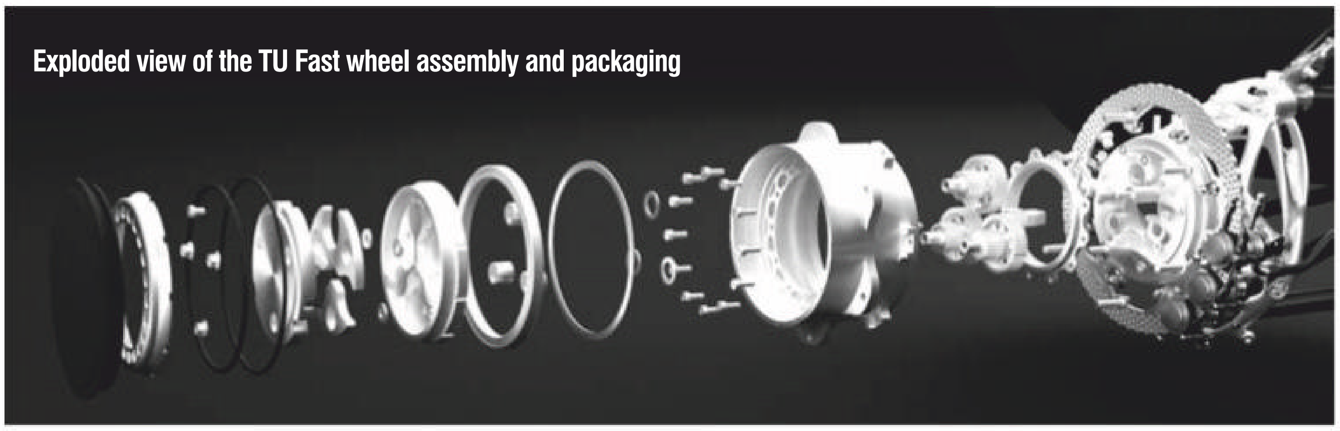
Speaking to various Formula Student teams, it seems the vast majority of those running a 10inch wheel have this year moved to the newly available Hoosier 16in tyre. TU Fast also took this opportunity, leading to a revision of its suspension kinematics, which is a pretty standard change. However, it also chose to take this opportunity further and it has downsized its reduction gearboxes too, with the new configuration now reducing the torque reacted in the gearbox, while this alteration also gave it a small weight advantage.

TU Fast also attributes some of its speed on track to a completely (aside from the motors, that is) in-house powertrain design. 'We have developed the ECU, accumulator and inverter in house,' Garyuk explains. 'This year we also changed our communication protocols between the ECU and the inverter which required a little work, but we have a great inverter solution and none of the issues with EMI [electro-magnetic interference] that we have seen other teams have. The combination of ECU, inverter and accumulator is very well adapted to the requirements of our car.'

Electromagnetic interference can occur from components like power inverters when they are not correctly shielded from the behaviour of



CAD rendering of the TU Fast team's car, the eb019


Exploded view of the TU Fast wheel assembly and packaging

The vast majority of the teams running a 10in wheel have moved to the new Hoosier 16in tyre

the electromagnetic field. If not under control it can affect CANBUS communications creating malfunctions of the control systems on the car and can also damage the inverter itself.

Swiss watch

Powertrain development was also a theme at AMZ Racing, the Zurich team. Its 2019 contender is an evolution of last year's car, with the same basic concept. This features four 37kW wheel mounted electric motors delivering wheel torque to a remarkably light 158kg body and a well-developed aerodynamic package and suspension system. Where the 2019 powertrain differs to last year on the Zurich car is the switch from two electrical accumulators to one. This consequently changed the aero concept around and necessitated a smaller rear air diffuser due to package redistribution behind the driver. This allowed the sidepod area to be used for aerodynamics rather than pump and electrical equipment packaging.

Development of its in-house inverters has also continued. The current design is half of the weight of last year's design and was achieved through moving from four single inverters to two double inverters, allowing further packaging and weight distribution freedom.

The tech that really shone on this car, though, was that of the suspension system which featured active wheel control. 'Last year we had a hydraulic active suspension concept actuating each wheel individually, but we ran into major issues which meant we had to run the system passively, which was not ideal,' says Oliver Haselbach, chief technical officer of the mechanical aspects of the car. 'This year we simplified the suspension system to utilise three spring and damper elements with one element at each of the front and rear axles acting to decouple heave/pitch modes, plus one central element for roll and warp mode decoupling.'

This system is an evolution of an initial concept introduced at AMZ three years ago and from a vehicle dynamics perspective it gives a great amount of control and precision of reaction to input in multiple degrees of freedom, ensuring an optimal dynamic response in a range of conditions. This ultimately leads to a reduction in the variation of contact pressure between tyre and track surface and a set-up that produces maximum mechanical grip. This is similar to systems that have been used in high level motorsport, such as the Porsche 919 LMP1 car's FRIC system, and it will always benefit the car's performance throughout dynamic events, which AMZ has always excelled at anyway.

Lastly, there is also a new wheel upright and motor assembly packaging that was influenced by a move to smaller wheels this year. 'We have a new smaller tyre from Hoosier which meant a change to the wheel packaging,' says Haselbach. 'We are now using SLM 3D printed aluminium uprights which have integrated water-cooling channels for the motors, so it's very complex and we are proud of that. In total we saved 6kg with this packaging update.'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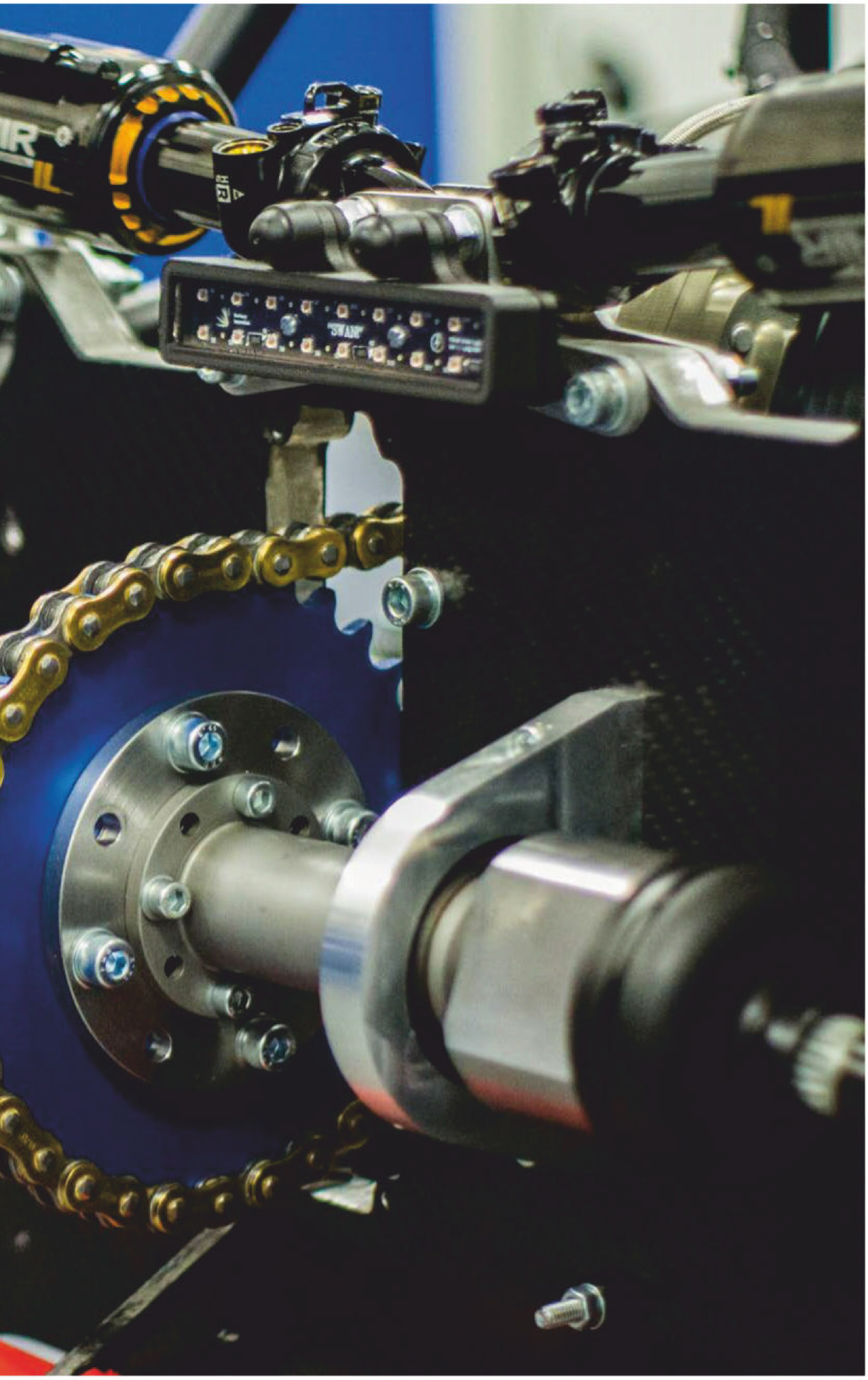
Taking charge

Electric racecars competed at FSUK way back in 2007 – four years before Formula E was even conceived

The Team Bath Racing car makes use of a chain drive solid spool axle, which is a common approach on Formula Student designs that are running with a single electric motor

A large and ever-increasing number of Formula Student cars are now electrically-motivated but, as *Racecar* discovered, developing such a machine presents teams with a whole host of complications and technical challenges

By GEMMA HATTON



Formula Student may be an engineering competition for universities, but the innovations showcased by these racecars are often a step ahead of the motorsport industry. For example, autonomous cars are now fully integrated into the competition and the first electric racecars competed at FSUK way back in 2007 – four years before Formula E was even conceived.

In fact, in 2016 the electric FS car from AMZ racing set a world record for the fastest-accelerating electric vehicle, achieving 0-100km/h in just 1.513s, which still stands today. In comparison the new generation of Formula E cars accelerate from 0-100km/h in 2.8s. Although this is not an entirely fair comparison as Formula E and electric FS are designed to a completely different rule set, it does highlight the incredible standard of engineering within these FS cars.

Today, over 32 per cent of FSUK teams are now electric, with 39 teams also competing in the electric category of Formula Student Germany. It is no longer just the well-resourced outfits that are taking on the electric challenge, but the smaller teams are too.

Plugging in

As with any racecar, the first port of call is the rulebook, and for electric Formula Student cars complying with the rules is extremely tough. 'One of the most important things to realise when competing in electric FS is that you have to go through two sets of entirely different scrutineering at competition,' says Ben Carretta, technical manager at Team Bath Racing Electric. 'As well as the standard scrutineering you also have to go through an accumulator [battery] scrutineering and a full electrical scrutineering. It feels like the rules are trying to make you jump through a lot of unnecessary hoops, but when you start building the car, the rules are actually quite a sensible guidebook on how to design a safe electric racecar.

'For an electric FS team starting up I would say that the most fundamental thing is to have a simple and reliable system, one that you know is going to work, and then pay close attention to the rules,' Carretta adds.

With this in mind, most teams opt for a two-year approach when starting an electric project. The first year is spent designing, with the final versions of the virtual car submitted into Class 2 of the competition. Judges then analyse their progress throughout the Design, Cost and Business Plan events. The second year is then used to build and test the real car, ready to compete in Class 1. To help further kick-start the electric team, many universities will continue to run their combustion car, which aids the transfer of mechanical know-how to the electric team. This was the strategy that Oxford Brookes took with its new electric team, competing in Class 2 this year.

'Aside from our accumulator lead engineer, pretty much everyone in the team is new to electric vehicles and the challenges that they bring,' says Deepak Selvan, chief engineer of Oxford Brookes Racing Electric. 'So having the Class 2 and then Class 1 structure has been probably the most important aspect for making the switch to electric achievable. The biggest challenge so far has been moving decisions forward in such an open and unknown problem space. With an electric car there is a big phase of research and learning and what we struggled with most was defining where we cut that off and actually start making decisions. It wasn't actually an electrical challenge but more a project management one.'

Skills audit

A team also needs to decide which components will be developed in-house and which will be bought in and this depends on the expertise within the team. 'It's about looking at who you've got within the team and what knowledge you have within the university and figuring out what you are capable of doing,' says Carretta. 'It's easy to look at individual systems

'With regards to the batteries and motors, we are not a road car and we are not a racecar'

and say "this is feasible" but it's bringing all those systems together to create a reliable package which is most difficult. We had people who were interested in battery technology, so that has been an area that we've dived into ourselves, with the help of our sponsors. It wasn't necessarily an area that we decided we could make a massive improvement on. Formula Student is a learning experience and if you had people in your team who loved motor design then that might be what you try and develop.'

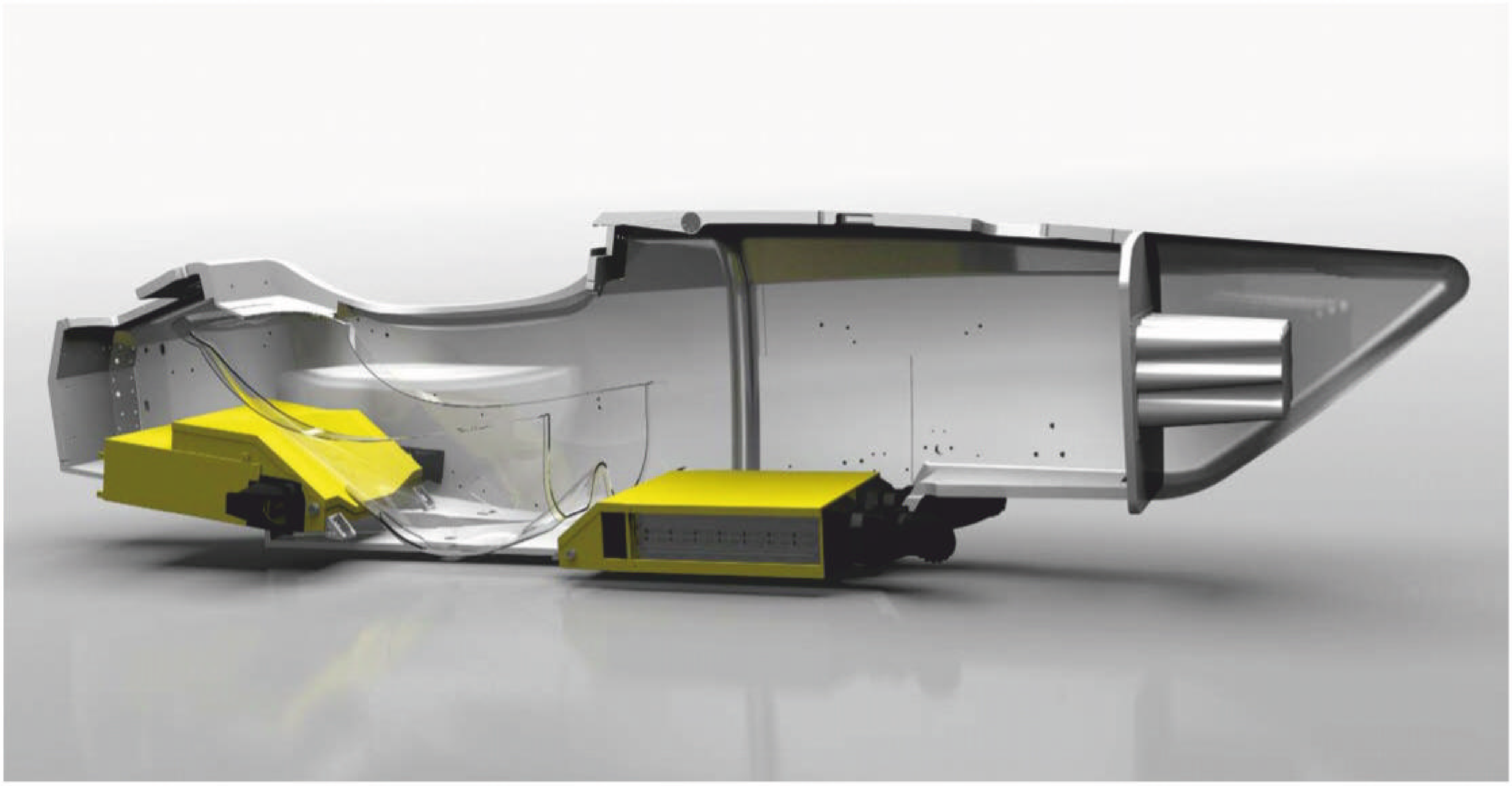
'At the end of the day Formula Student is an engineering competition and in general you have to ask yourself whether it is sensible to take the time and resource to develop something, or are you trying to reinvent the wheel, in which case it may be better to buy something in,' says Natalie Kyprianou, the accumulator lead at Team Bath Racing Electric. 'We're building a prototype car and the requirements are very different to what you can buy off the shelf. With regards to the batteries and motors, we are not a road car and we are not a racecar. We don't race the distances they do in Formula 3 or Formula E and we don't have the speed requirement that these series have either. Also, we need to consider the rules. We could buy or produce an extremely powerful motor but that would be unnecessary mass as the electric Formula Student cars are power limited. Furthermore, as the power increases the struggle of putting that power down to the wheels would be greater due to the limit of traction. We decided to build our own battery because we wanted to fully understand what was inside it.'

Batteries included

With off-the-shelf batteries often heavy and not customised for Formula Student, this is an area where teams can make significant performance gains. 'In our 2017 car the battery weighed approximately 120kg; 2018 was the first time we developed a truly custom design which dropped the weight down to 67kg,' says Carretta. 'We continued developing the BMS [Battery Monitoring System] and other battery ancillaries and dropped the weight down again to 48kg for this year's car. Compared to off-the-shelf solutions which can be around 70 to 75kg, this is a huge weight saving.'

Once the overall approach has been defined the next stage is to develop a concept, and again there are several schools of thought here. There are two parts to a car's electrical system. Firstly there is the high voltage, which is all the components with an electrical connection to the accumulator (effectively the powertrain).

'Having the Class 2 and Class 1 structure has probably been the most important aspect for making the switch to electric achievable'



The location of the battery modules within the chassis can affect the weight distribution and CoG, which can change the vehicle's dynamic behaviour. AMZ Racing's design pictured

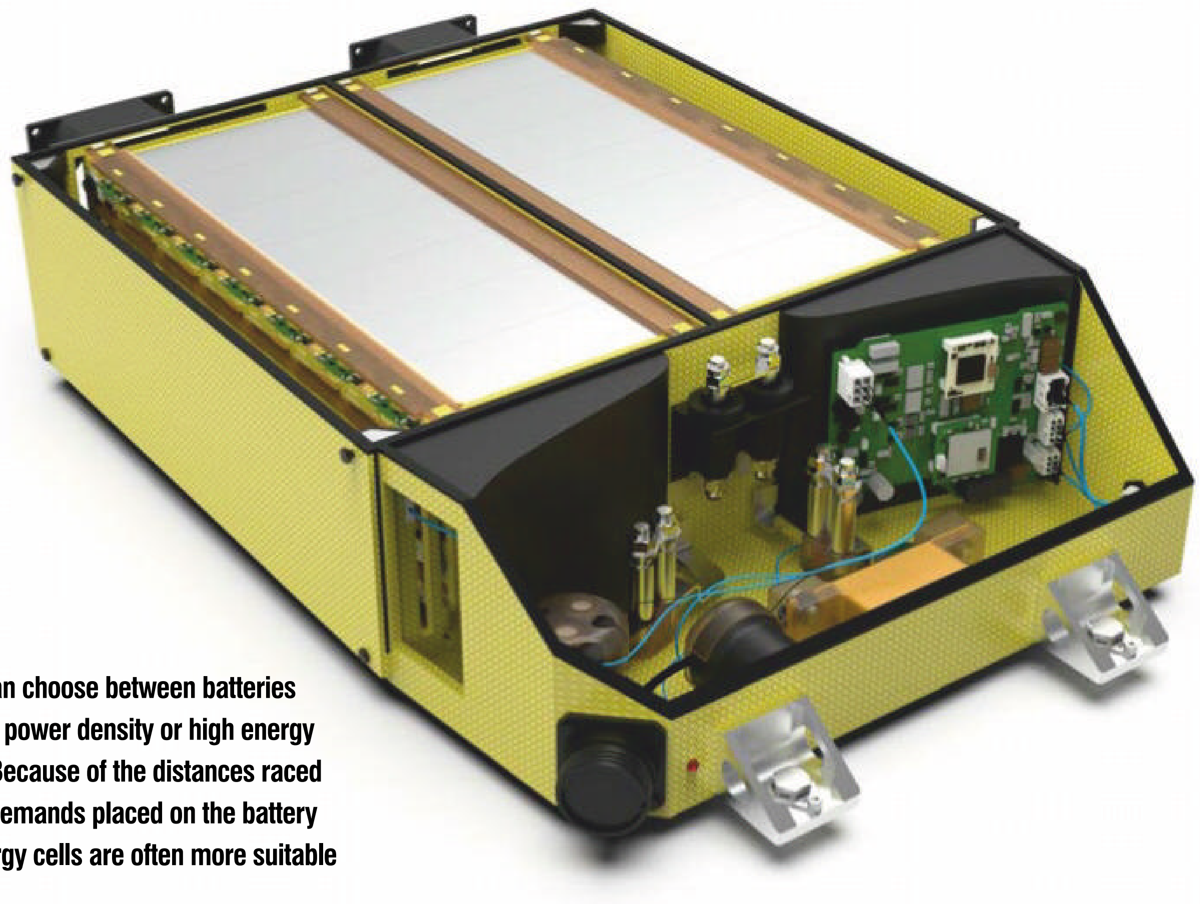
Secondly there is low voltage, which is all the safety and data logging systems.

An electric car works through an accumulator or battery providing power, but this is often in the form of direct current (DC). An inverter then uses a transistor switching arrangement to convert this to three phase alternating current (AC). This then powers a motor which essentially rotates a magnet (rotor) surrounded by copper coils (stator) and the resulting oscillating magnetic field is used to generate rotational motion which is then mechanically coupled to the wheels.

Current thinking

The most simplistic concept is a single motor on a fixed rear axle and to increase traction during cornering a mechanical differential or a chain driven solid spool axle can also be incorporated. To achieve further control of the vehicle dynamics, a second motor can be added to drive the two rear wheels separately, along with a chain drive single gear reduction or a planetary gearbox. However, the most effective method to maximise traction and dynamic control is to have independent motors driving each wheel. This four-wheel drive approach is costly, but it does give the teams using it the opportunity to explore the benefits of technologies such as torque vectoring.

There are many different approaches to designing an electric powertrain. But for FS usually the first stage is to decide between 2WD and 4WD and whether the motors are inboard or outboard, which then determines the maximum power requirement. This is dictated by the rules which stipulate a maximum power of 80kW for 2WD and 60kW for 4WD. The motors



Teams can choose between batteries with high power density or high energy density. Because of the distances raced and the demands placed on the battery high energy cells are often more suitable

can then be selected, with teams aiming to match the torque and speed characteristics of the motor to suit Formula Student style competition. The operational voltage of the chosen motors and inverters then dictates the maximum voltage required from the battery.

'We started with having a target voltage that we wanted to be at, based on the motor package we are running on to try and keep it in the efficiency band we wanted,' explains Selvan. 'From there we looked at a range of cells with different voltages and capacities along with data from our lap time sims on what our energy needs were for endurance.

'We did also look at how much of a buffer we would need if we don't get regenerative braking working or aren't able to keep the motors in their efficiency band,' Selvan adds. 'We ended up working down from about 26 different battery configurations to a short-list of three before deciding on our final battery design.'

Energy limits

'You are only allowed a specific amount of energy in every compartment, so this limits the maximum number of cells of each module,' explains Andreas Horat, chief technical officer at AMZ Racing. 'The maximum voltage of the

The most effective method to maximise traction and dynamic control is to have independent motors driving each wheel

Putting more cells in series increases battery voltage, while putting more cells in parallel increases current. Batteries need to be designed to meet specific current and voltage targets

accumulator is on one side limited by rules, which allow a maximum of 600V, but in our case it was also driven from the inverter. The inverter used in previous years specified the maximum battery voltage which then leads to the number of cells in series. Together with the estimated necessary energy, the number of cells in parallel is fixed. We have 130 cells in series. We then look at the current draw at maximum as well as the maximum charging current when recuperating [energy]. In the end the number of cells is adjusted to fit them in a convenient way within the box. The cooling is also considered during the cell placement.'

Motor specs

An alternative approach to determine the motor spec is to focus on the desired tyre performance. 'Calculations including mass transfer, speed-sensitive aerodynamic loads and tyre data in combination with our self-developed lap time simulation as well as mass sensitivities derived from post-season tests were used to find the event-point optimal key parameters for the motor design,' says Horat. 'A top speed of 115km/h and a maximum wheel torque of 395Nm yield the highest score prediction. Briefly said, the motor design is driven from the tyre side so we can reach the optimum performance of the tyres and the accumulator is driven from the capacity side to ensure we have enough energy for the whole endurance.'

The next stage is to determine the amount of energy and therefore the capacity that the battery must carry throughout one single discharge to complete endurance. For this, often a Matlab script called Lapsim is used. This programme takes an aerial-view image of a track with a known pixel-to-physical-distance ratio and then runs a theoretical vehicle through a lap of the circuit. The physical characteristics of the vehicle (weight and gravity etc) as well as vehicle dynamic parameters (downforce, roll, pitch etc.) are considered along with safety factors, an aggressive set-up and all parasitic losses at 100 per cent to simulate the worst case scenario. This model identifies the energy required from the accumulator during one lap, and therefore the energy that is required for the entire endurance race as well as all the other dynamic events at competition.

The accuracy of this simulation can be further developed by incorporating more reliable data such as that from tyre tests. Also, the script itself can be extended to calculate the performance of different powertrain concepts to determine the potential number of points each concept could achieve at competition.

'We only have to complete 22km for the endurance and we are limited to a max of 80kW for rear-wheel drive cars and 60kW for four-wheel drive cars, so this already creates your window of both power and energy,' says Carretta. 'We looked at the average power and speeds of previous cars to get an energy requirement in kWh and size our battery. We then identified the power draw at each individual point to see how much we would stress our batteries which then gave us an ideal power and energy requirement so we could look for cells that matched that and start building up the battery pack from there.'

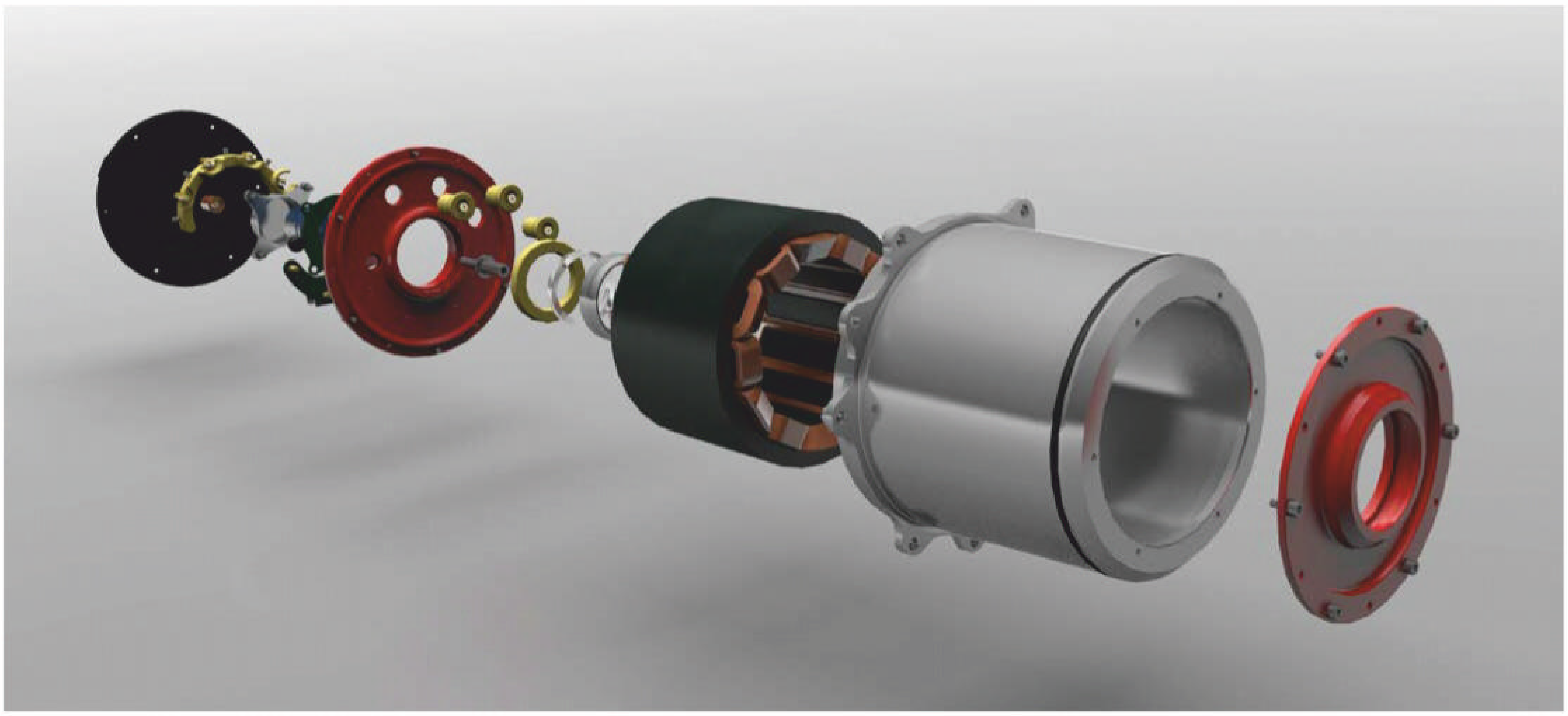
Choosing the 'perfect' cells for the battery is by no means an easy task. Not only are there different chemistries, but there are also different types to consider, such as pouches or cylindricals, with each cell offering different power and energy density combinations.

Perfect chemistry

Most motorsport batteries are lithium ion chemistries, with different cathode (positive electrode) materials. Selecting the optimum chemistry is a balancing act between achieving the desired energy and power densities whilst maximising safety. 'Li-ion cells with iron phosphate or manganese-based cathodes are intrinsically safer than any of the primarily cobalt based lithium ion cells,' says Dr Dennis Doerffel, chief technology officer at REAP Systems, which supplies battery components to Formula Student teams. 'This is because their cathode spinel structure doesn't collapse if it is completely depleted at the end of charging and the anode cannot be overcharged because li-ions from the cathode are depleted. The spinel structure does not collapse and the cells do not provide oxygen in case of thermal runaway. So they are safer but often heavier.

'Most cathodes are a mix of nickel, cobalt and manganese these days in order to balance the advantages and disadvantages,' Doerffel adds. 'Cells which have a high manganese content – similar to li-ion phosphate cells – can't produce [their] own oxygen, if the cells overheat. So, they can be more easily extinguished with C02. These manganese-based cells have higher voltages than iron phosphates which is why they have a higher energy density and the current is a little lower so power densities are quite similar. If you want higher

'Battery packs must be designed in such a way that a thermal runaway in one of the cells cannot propagate to the next one'



The AMZ car uses four 37kW motors with a refined rotor and stator design; these drive a wheel each and give it good traction out of the many tight turns that are typical on FS events

power and energy densities then you can go for more cobalt content and less manganese, but the higher cobalt and nickel content means that if the cell catches fire it will be virtually impossible to extinguish. Battery packs must be designed in such a way that a thermal runaway in one cell cannot propagate to the next.'

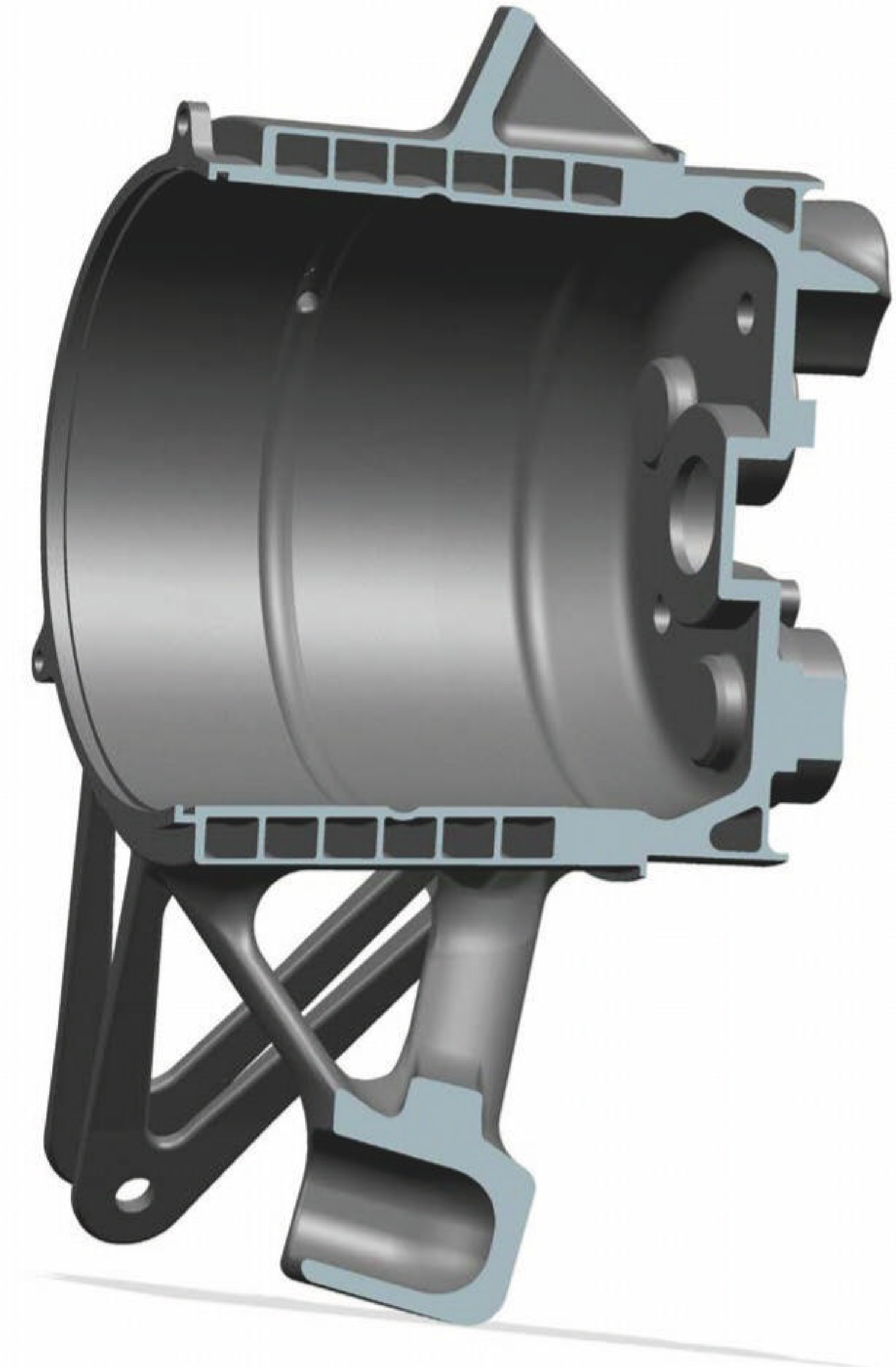
To get our heads around these power and energy densities let's look at other high voltage motorsport batteries. In F1, the ERS (Energy Recovery System) battery is discharged and recharged multiple times per lap as the energy from braking is stored in the battery which can then be utilised later as additional boost. Therefore, to achieve the power required for that boost within the smallest F1-style package available, these cells have high power densities of approximately 10-17kW/kg, with lower energy densities of around 90-120Wh/kg.

On the opposite end of the spectrum is Formula E, where the battery has one single discharge over the entire race and teams only have a fixed number of joules of energy to play with. Therefore, the batteries are designed to contain as much stored energy as possible, whilst the car is optimised to use this energy efficiently. This is why Formula E batteries have lower power densities of roughly 2.2kW/kg but much higher energy densities of around 232Wh/kg, compared to Formula 1.

High energy

'The longest race in Formula Student is endurance which is usually half an hour or so which requires high energy cells, rather than high power cells,' says Doerffel. 'A high energy cell can fully discharge in about 20 minutes, whereas a high power cell can discharge in six minutes with ultra high power cells discharging within three minutes or faster. The problem is that in a high energy cell there is more internal resistance, so although it may have a higher amp hour capacity rating, the watt hour rating may significantly reduce if you discharge with higher current. Also, regenerative braking with high energy cells can be difficult as usually they charge at 1C [coulomb, a unit of electrical charge] so you can't push as much power back into the battery when compared to a high power cell.

'Another interesting consideration is the cell manufacturer's data sheet,' Doerffel adds. 'As manufacturers have to ensure their cells can provide the life cycles they specify, you can usually push the cells more than what the data sheets say because racing usually doesn't require the stated cycle life of 3000 or so cycles. However, it is difficult to find out how much more you can push them safely because manufacturers won't tell you. This is why FS is so interesting, because the teams can choose either high energy or high power cells but they really need to identify the overall benefits and that is a question that can't be answered without developing accurate simulation tools or without testing cells and packs.'



AMZ Racing cools its motors by using water-cooling channels that are integrated within its 3D printed aluminium uprights

Cell selection also depends on how the cells are packaged within the battery box as this can affect the overall performance characteristics. The number of cells in series determines the voltage, while the number of cells in parallel determines the current and capacity. Therefore, the more cells in parallel, the higher the current and the more cells in series, the higher the voltage. High voltages results in low currents which is beneficial for the motors and inverters, but not the battery. Furthermore, the rules stipulate that the battery has to be split into isolated modules, each limited to 120V, 6MJ of energy and a maximum weight of 12kg. Therefore, a high voltage battery would have to be split into several modules, each accompanied by a positive and negative high current connection, BMS, fuse, contactors and other ancillaries – all adding weight to the overall battery box. Alternatively, teams can choose lower voltage batteries and save weight but take the hit on motor and inverter performance.

'The Formula Student rules require you to take the battery out of the car when charging for safety reasons, which is a big design limitation as it means we can't make the battery structural like you can on other electric racecars,'

'The Formula Student rules require you to take the battery out of the car when charging for safety reasons, which is a big design limitation'

The cells need to be arranged in such a way that the air can effectively flow in between them and through the battery

says Kyprianou. 'So then you think "we will split the battery in two", but the rules specify that each module has to be identical so not only does it double the electronics, switches and mass, but also the risk of failure as you're effectively building two batteries.'

Cool running

Cooling the cells is another vital consideration that needs to be thought about early on in the design process. Most Formula Student batteries are air cooled, with a fan circulating the air. Therefore, the cells need to be arranged in such a way that this air can effectively flow in between the cells and through the battery.

'Our research showed that for what an FS car has to endure, with the hottest and longest cycle being the endurance, active air cooling was suitable,' says Kyprianou. 'We have fans inside the battery and pass air though the cells rather than liquid. Liquid cooling adds a lot of risk and there's a lot more work involved.'

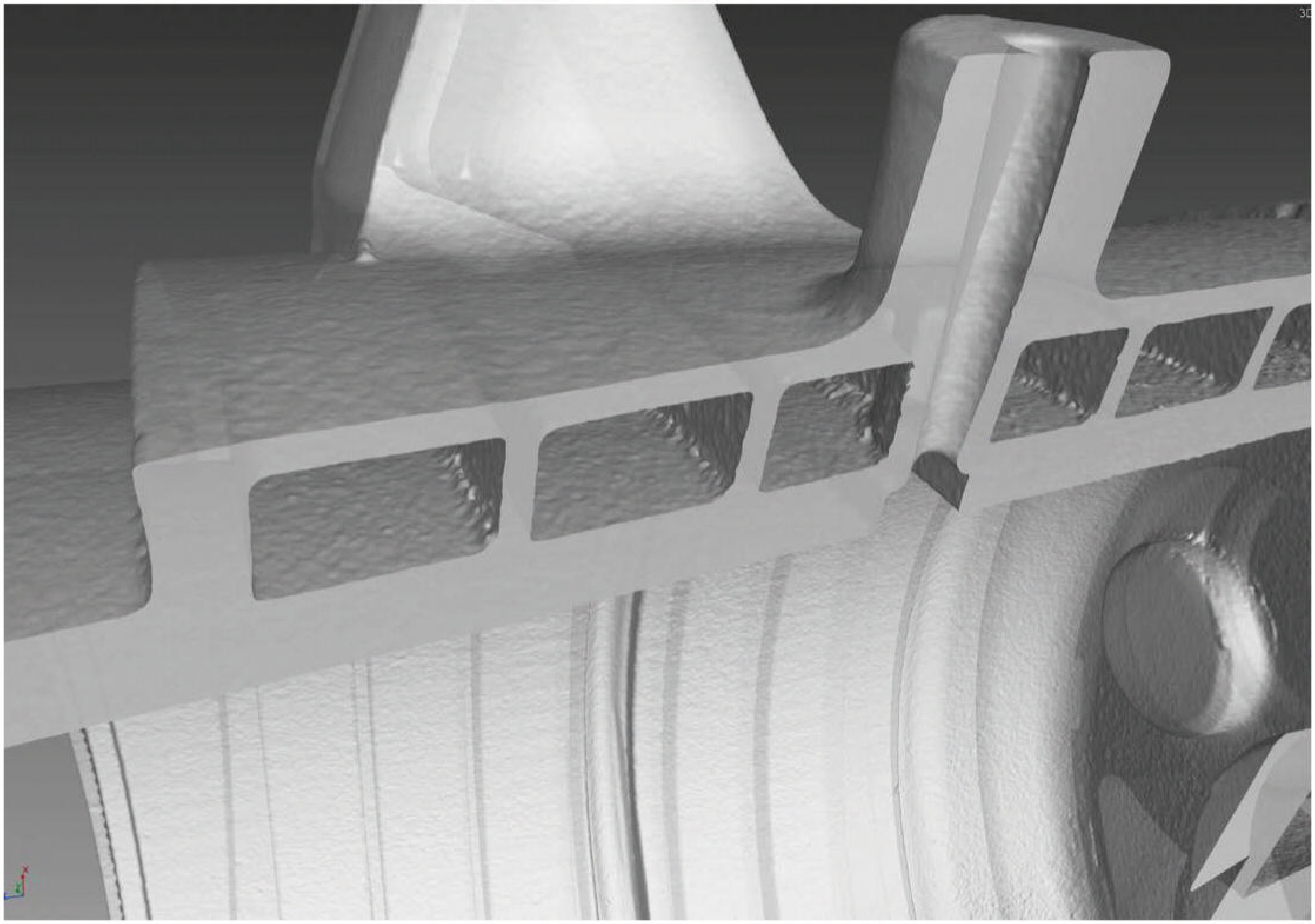
It's not just the battery that requires cooling, often the motors do too, as is the case with AMZ Racing's car. 'We started nine years ago to design our motors ourselves and although we have continued to optimise the rotor and stator design, the main design concept remained the same for the past few years which allowed us to continuously improve our motor every iteration, reaching 22Nm and 38kW at a weight of 2kg in the 2019 season,' says Horat. 'Cooling of the motors is really important, so for this year's car we have integrated the motor cooling inside the upright so that the motor needs no additional cooling casing. So we effectively cool our upright which in turn cools the motors. This allowed us to design a lighter and stiffer upright.'

Safety systems

Once the motors, inverters and cells have been selected and the battery configuration has been optimised, the next challenge is to integrate the BMS and other safety systems. 'We have our predominant shutdown system which is a single loop that goes around the car and it has various systems such as emergency stop buttons, [in] the BMS or the ECU that can break that electrical line which then causes the car to shut down,' says Kyprianou. 'So, if anything goes wrong the shutdown line is broken and therefore the battery isolates itself completely, so you have a really robust and simple safety system.'

Although some teams develop their own BMS, the majority buy off-the-shelf tried and tested systems. However, this still requires some level of engineering from the teams. 'Our BMS is not specifically designed for Formula Student, so the teams still have to understand how it works and do a lot of engineering,' says Doerffel. 'There is a lot of electro-chemistry inside batteries that engineers are still understanding and I think one of the biggest concerns is that batteries are very quiet. They sit there and they look quite peaceful, and students can underestimate the safety risks of them.'

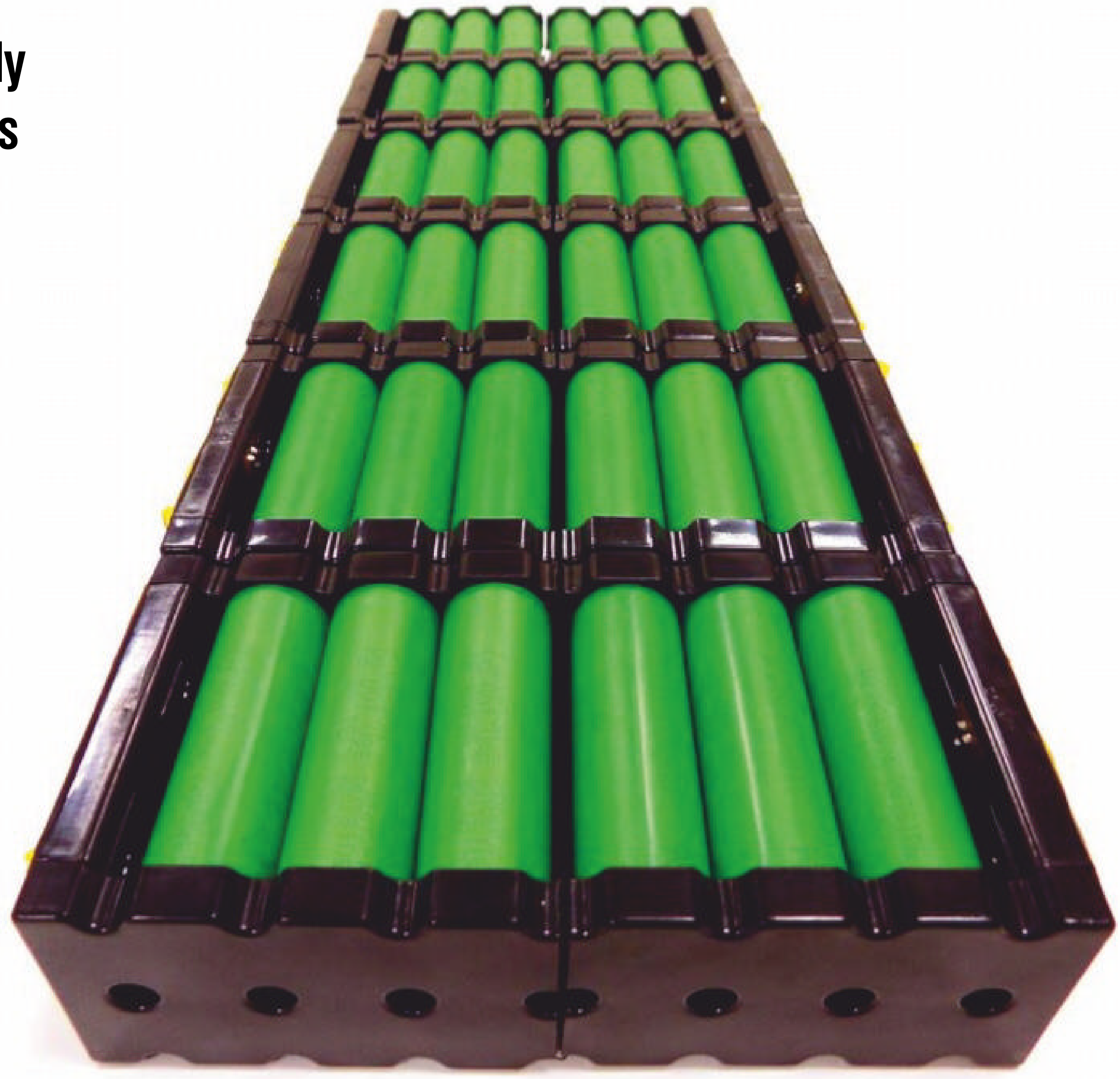
Overall, there are a huge number of factors to consider when developing an electric powertrain, and a whole host of additional factors to design a high performance one. But with competitions such as Formula Student encouraging students to face these challenges early in their careers, the next generation of engineers will be able to solve the mysteries of electric technology much faster.



The geometry of the water cooling channels on the AMZ Racing uprights can be seen here in this CT scan. This approach had a knock-on effect of improving the upright's design

Build your battery in hours, not months

Everything is taken care of, fully complies with FSAE regulations



Li2x3p module with six cells in parallel

This Li-ion building block was developed specifically for Formula Student competition with simplicity and safety in mind. Using 18650 lithium-ion technology, these offer the most modern and energy-dense solution in an easy to use package. The 18650 is a very well established and time-tested battery cell standard, especially common in consumer devices. These cells are designed to withstand normal consumer use, while offering the best in class energy density.

Various options of 18650 cell are available: SAMSUNG 25R, SONY VTC6, LG HE4 and almost any other genuine cell.

EXCEPTIONAL SAFETY

In addition to internal protection techniques, the module includes two fuses for each cell, and there are16 for a complete 8-cell module. These act as a second level protection devices in case of cell failure and in case the internal safety mechanisms are not enough.

In case of cell venting, released gas travels through dedicated channels to avoid pressure buildup.

UNMATCHED FLEXIBILITY

Due to the simple nature of these building blocks, desired battery pack configuration can be built in minutes, connecting them in series and parallel using bolt connections. Even MWh-scale batteries can be assembled with ease.

Left are examples of the Li1x4p modules

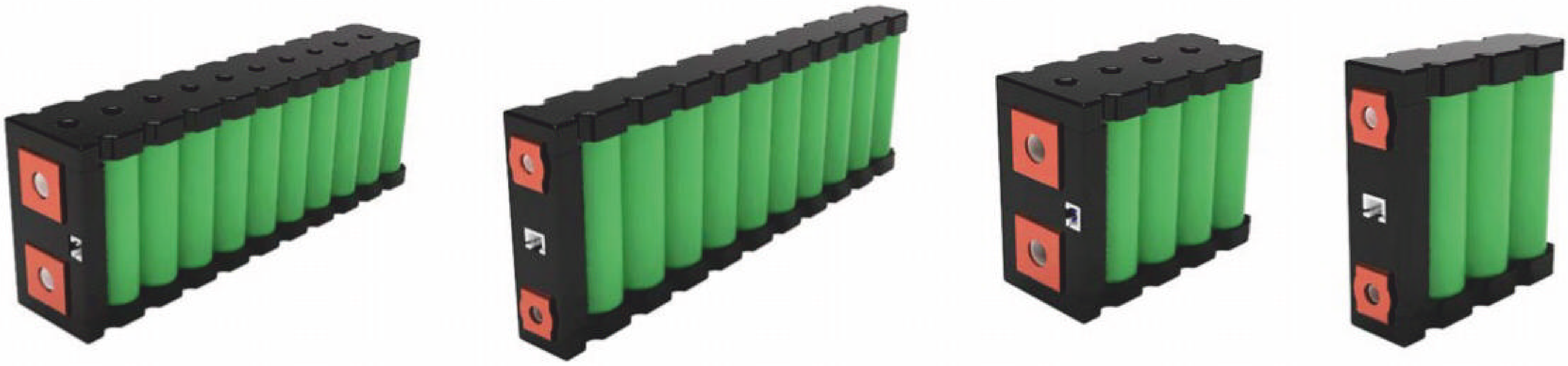
TECH SPEC: [Battery]

Features

- Specially designed for FSAE traction systems
- 271Wh per litre
- 172 Wh per kg
- Individually fuse-protected cells; no parallel fusing is required
- Ultra low self-discharge
- No initial balancing required
- Rapid prototyping of the battery pack
- Convenient thermal control
- Built onlly from 18650 type cells
- Low flammability: UL 94 V-0 rated
- Built-in multi point temperature sensor

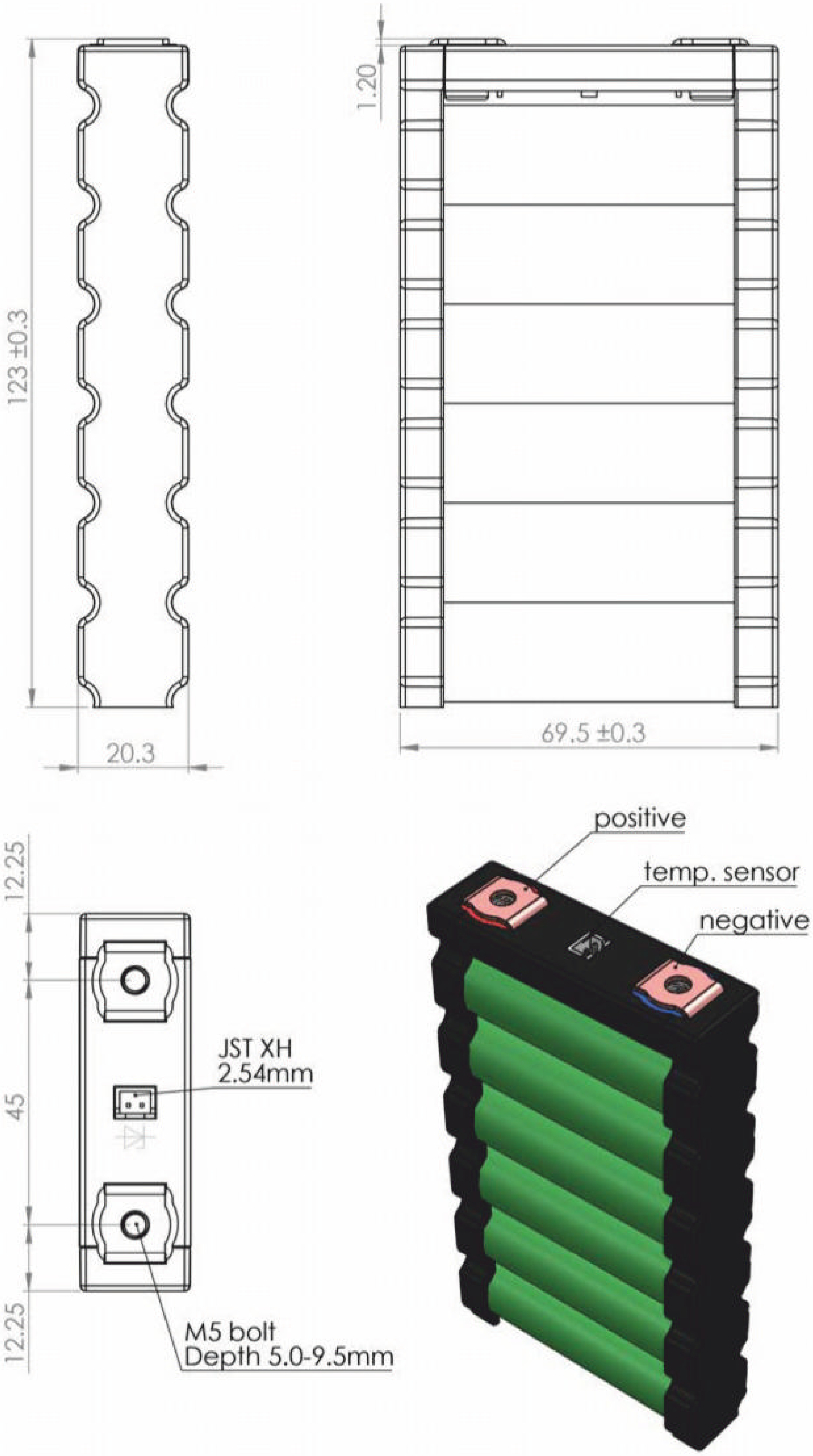
Specifications

- Nominal capacity: 3Ah to 70Ah per module
- Peak discharge current: Up to 18 C
- Average discharge current: 10 C max
- Nominal voltage: 3.60 V (2.50-4.20 V)



Modules can come in packs of 20 (above) or ten (right)

Your battery is as good as BMS allows it to be



An example of the Li1x6p module

TECH SPEC: [BMS]

Features

- Very small dimensionally
- Flexibility: 4 to 16 cells of any kind, including Li-ion, LiPo, LiFePO4, Li-Titanate and Li-sulphur chemistries
- Current measurement and SOC calculation.
- Firmware updates, new feature releases and improvements for free
- Bluetooth connection (good for USB replacement)
- Event logs and live data view: easy to debug the system, check what happened and when
- External contactor support for charger and load
- External current sensor support up to 750A
- Faster balancing due to "early balancing", which saves charging time
- Ignition/enable input. BMS will switch off the output and go to low power mode when no signal on certain pin (if enabled)
- Temperature measurement in multiple points of the battery - for safety, to prevent overheating and charging in cold

Specifications

- Series cells: 4 to 16
- Cell voltage: 0.80 to 4.50 V
- Cell balancing: 150 mA, dissipative
- Discharge/Regen current peak: 150 A**
- Discharge/Regen current sustained: 60 A**
- Charge current peak: 100 A**
- Charge current sustained: 30 A**
- Discharge/Charge/Regen current: 750 A*
- Interface: UART (USB / Bluetooth / CAN)
- Up to 64 channel temperature sensors (available in Energus Cell Modules)

* - with external relays and current sensor
** - given that BMS is mounted on cool metal surface.

ENERGUS
BATTERY SOLUTIONS

Trace engineering

Our resident simulation expert runs through some of the more advanced channels available for design and structural analysis

By **DANNY NOWLAN**

Sometimes I get suggestions from some of my customers for articles, and often they are very clever ideas indeed. As a case in point, one ChassisSim customer – Adelaide, Australia-based damper company Supashock – suggested I write a piece on ChassisSim's advanced data logging channels, and how this pertains to racecar design and structural analysis. Given that this, and the use of in-depth data analysis, is one of ChassisSim's unsung strengths, I agreed this was a subject that deserves to be explored in some depth.

ChassisSim boasts a fully transient nature combined with a plethora of data channels. If you combine all this with the fact that it also uses a full multi-body vehicle dynamic model you will understand that you can get an excellent snapshot of what the car is doing, so you can then make some very informed calls on what you are doing with the racecar.

As an example of how this all works, let's consider suspension geometry by doing a force analysis so you can see what you need to take into account. To start, take a look at the simulated lap trace shown in **Figure 1**.

The data examined in this piece is based on a traditional Formula 3 chassis, such as this Dallara pictured at Macau last year

Going through the traces briefly; the first trace is speed, second is engine RPM, third is steer/neutral steer, fourth is throttle and fifth is front tyre contact patch lateral forces in kgf. The sixth trace is the rear tyre contact patch lateral forces in kgf and seventh is the roll centres.

The first thing you will take away from **Figure 1** is the lateral forces that are returned.

Figure 1: Plot of lateral forces and force-based roll centres for a simulated F3 car

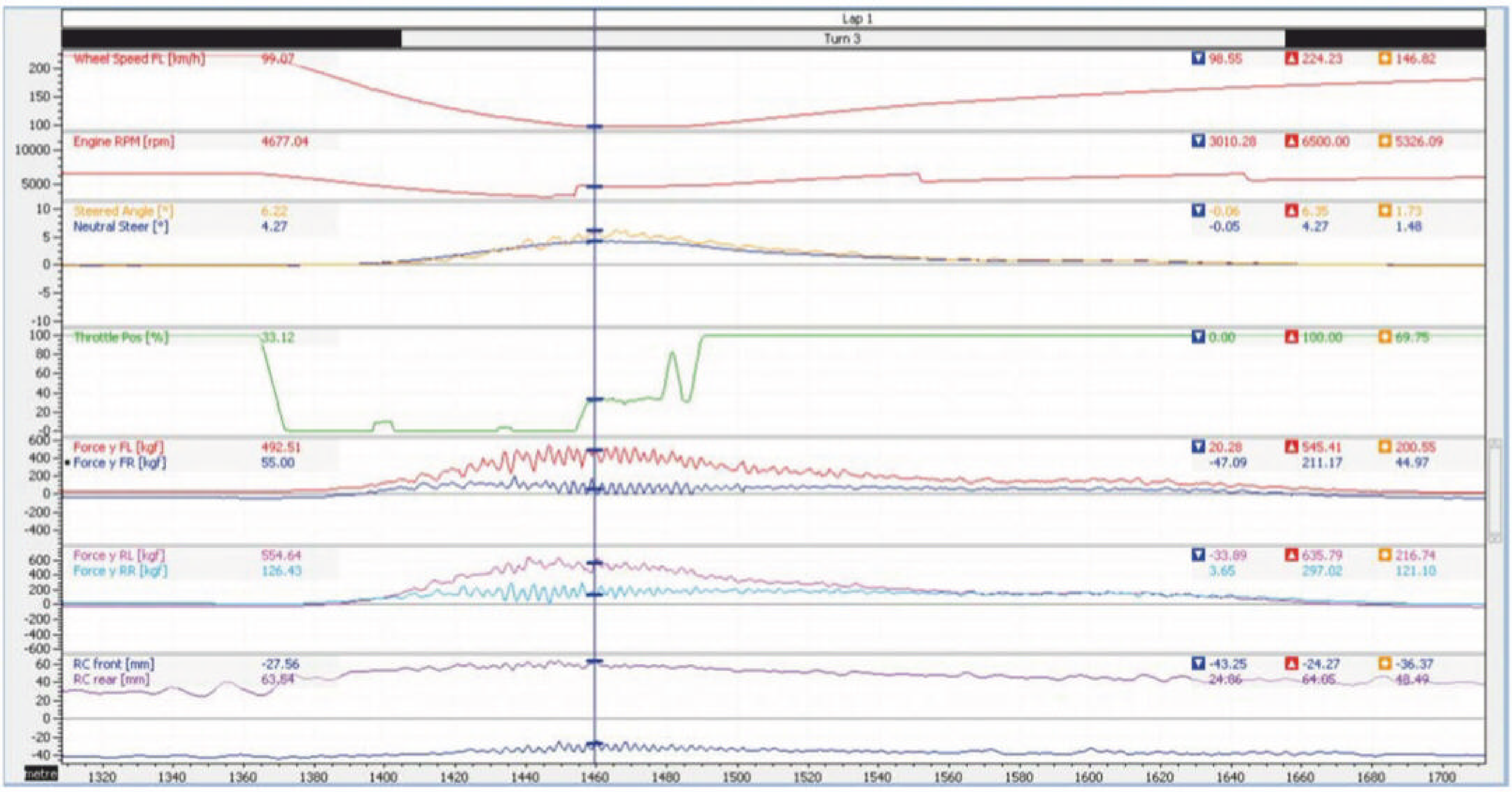


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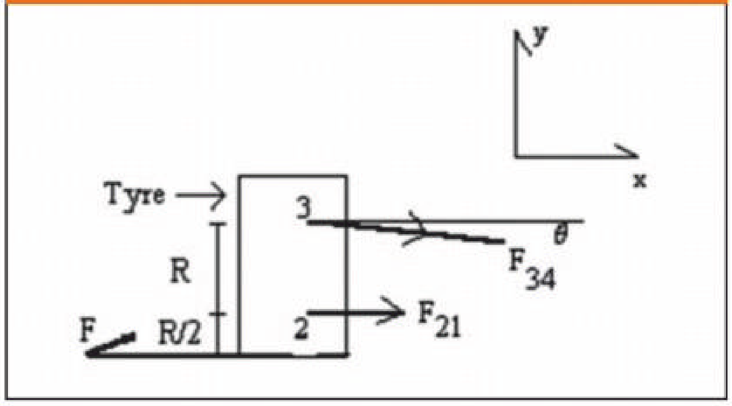
Figure 2: Double wishbone suspension analysis



In any structural analysis one of your most vexing questions is; what are the loads and what do you design to? The great thing about a correlated and representative simulation model is now you are no longer guessing. You have this in full Technicolor and we can see from **Figure 1** that the peak front contact patch lateral force is 514kgf and the rear peak lateral contact patch lateral force is 606kgf.

Back to basics

This data has several uses. For instance, if you need something quick and simple you can combine it with the roll centres to determine the loads of your individual elements. The way you accomplish this is by going back to basics. Let's consider a simple force analysis of a typical double wishbone suspension arm. This is shown in **Figure 2**. Going through and doing the force analysis you get **Equation 1** (the terms for both are below the equation).

EQUATIONS

EQUATION 1

$$\sum F_x = 0$$

$$F = F_{21} \cdot \frac{R}{2} - F_{34}\cos(\theta)$$

$$\sum M_0 = 0$$

$$0 = F_{21} \cdot \frac{R}{2} - \frac{3}{2}F_{34}\cos(\theta)$$

$$F_{34}\cos(\theta) = \frac{1}{3}F_{21}$$

$$F_{21} = \frac{3}{2}F$$

Where:

Fx = sum of all the forces in the x axis
M_o = sum of all the moments about the contact patch
F_{21} = force on the lower wishbone
F_{34} = force on the upper wishbone
F = applied lateral force on the contact patch
R = tyre radius
$R/2$ = tyre radius divided by two

The significance of **Equation 1** is that you now have the tools at your disposal to figure out the total lateral forces applied to each wishbone element. All you need to do to tie this up to your suspension is re-do the analysis in **Figure 2** and **Equation 1** and re-apply it to your suspension geometry. You can then cross reference it to the roll centres presented in **Figure 1** and, hey presto, you have your wishbone loads. This allows you to calculate these load cases with excellent accuracy.

Also, the process for the longitudinal forces is nearly identical to their lateral counterparts. The only thing that makes this just a little bit trickier for independent suspensions is how the pitch centres change when you go from braking to accelerating.

Where you can really make all this work to your advantage is if you have access to finite element analysis (FEA) software. The applied lateral and longitudinal forces give you the contact patch load forces for the entire lap. Looking at the ride height data both in pitch and roll you know how the body is moving. You can then do some very accurate fatigue analysis testing, not just of the suspension arms but of the chassis too.

The other really cool thing about the ChassisSim advanced data logging channels is that they allow you to quantify the spring forces. ChassisSim will return all the spring forces zeroed in the air as wheel forces, and this is illustrated in **Figure 3**.

For a damper manufacturer, like Supashock for instance, this is very useful on so many

Figure 3: Illustration of spring and roll bar forces for a simulated F3 car

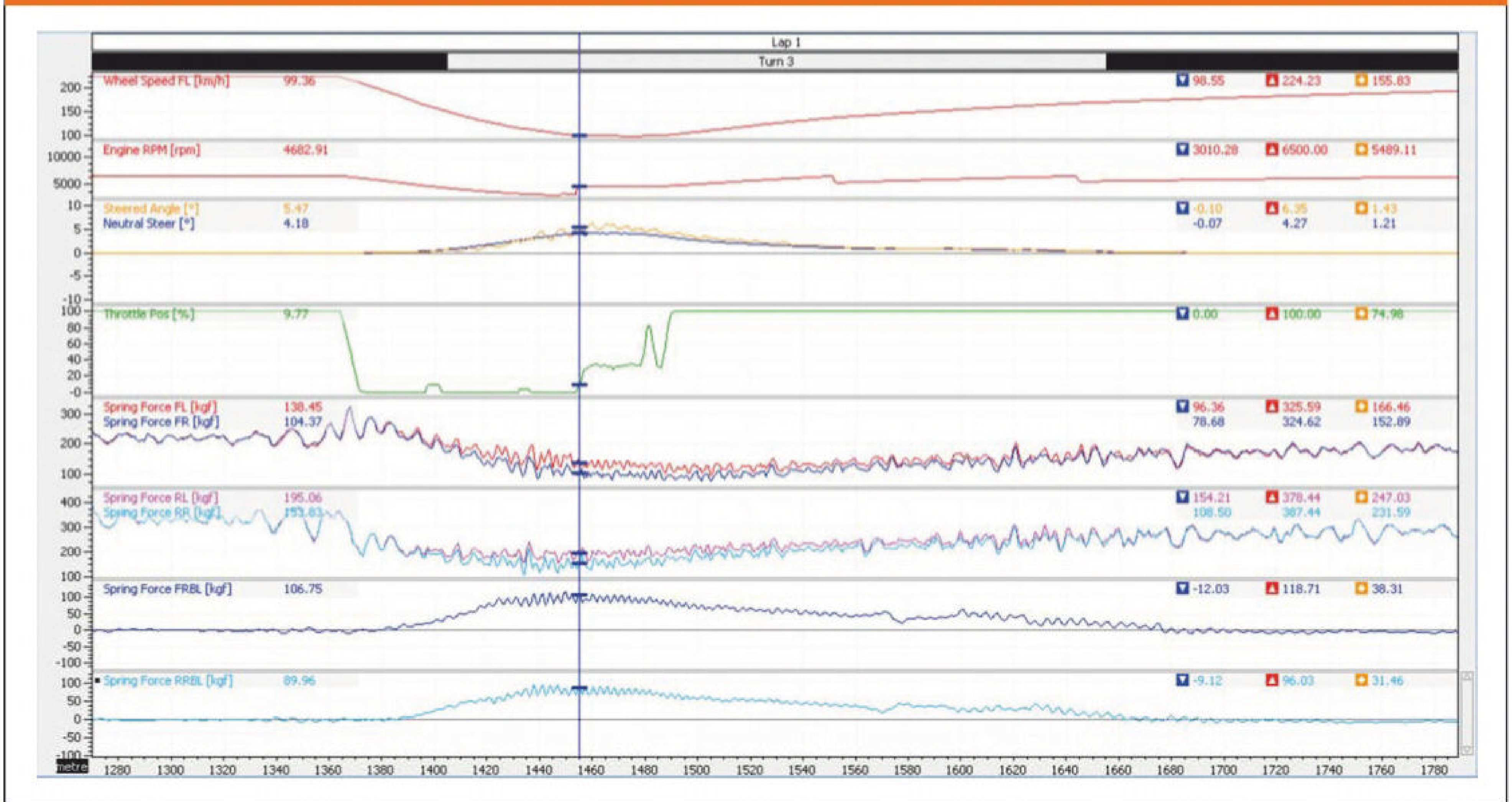
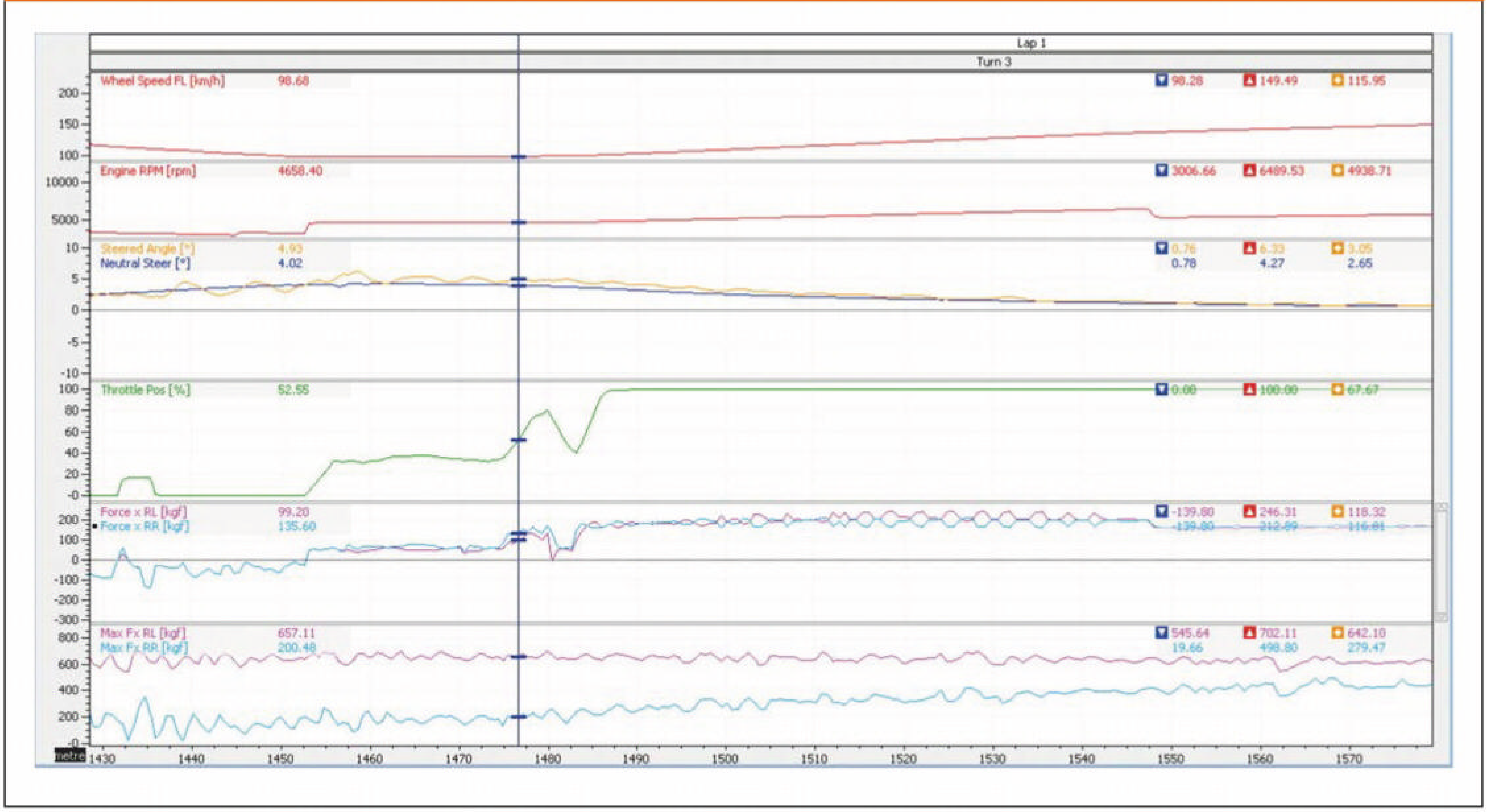


Figure 4: Channels that can be used for differential tuning with a simulated F3 car



levels. Since this is at the wheel, if you have a pushrod, bell crank suspension you can do your pushrod and damper forces in one hit. Also, knowing what the roll bar forces are you can also get a clear picture of the forces going into the roll bar, so you can then size the bar elements appropriately.

Tuning diffs

Another great thing you can do with the advanced simulation channels is differential tuning, as is illustrated in **Figure 4**. Walking through the channels, those of most interest are the fifth trace, which shows the applied longitudinal forces at the contact patch, and the sixth trace which shows the maximum possible longitudinal forces.

What you might find especially interesting about **Figure 4** is that for this low-speed corner it shows we are caught in a compromise. The locking ratio on this differential is 20 per cent. Right at the mid-corner condition we have the condition that is shown in **Table 1**.

What **Table 1** illustrates is that in the mid-corner condition we have over-locked the diff, but later on the diff setting kicks in. The great news is you can now look at this and get a much better gauge of where your compromises are. This means that when you play with the differential settings this will take out an awful lot of the guess work.

Table 1: Longitudinal forces through a low-speed corner

Forces	Mid-corner	Corner exit
Force x FL (kgf)	107.64	228.05
Force x FR (kgf)	138.83	163.97
Force x max FL (kgf)	662.18	606.23
Force x max FR (kgf)	196.14	276.07

Table 2: Longitudinal forces through a high-speed corner

Forces	Mid-corner
Force x FL (kgf)	151.49
Force x FR (kgf)	101.00
Force x max FL (kgf)	776.32
Force x max FR (kgf)	309.22

But to illustrate the compromises involved in differential selection let's review this for a high-speed corner on the very same lap. This is illustrated in **Figure 5** (next page). Here the situation is very different. This time around the differential settings work very well and just after corner exit the numbers look quite good, as illustrated in **Table 2**. As can be seen the differential in this corner is working very well.

What is quite interesting in high-speed corners is that your speed isn't just a function of grip, but it's also a function of drag and how much engine force you can put down, and minimising your drag. Given how distinctly underpowered Formula 3 cars are you need all the help you can get. So, in this case we might have to live with the differential being over-locked in the low speed corners. But the important thing is that these channels give us the numerical tools to quantify all this.

Another thing we can look at is using simulated yaw rate to quantify the control power of the steering. For reasons that are largely driven by technophobia most regulatory bodies have seen fit to ban yaw rate sensors. However, if you have a well correlated simulation model the yaw rate pops out in the wash. That is, if you plot yaw rate *vs* steer angle you can plot the control power of the vehicle. This is illustrated in **Figure 6**.

Yaw rate sensors are banned by most regulatory bodies but if you have a well correlated simulation model the yaw rate pops out in the wash

Figure 5: Longitudinal forces through a high-speed corner for a simulated F3 car

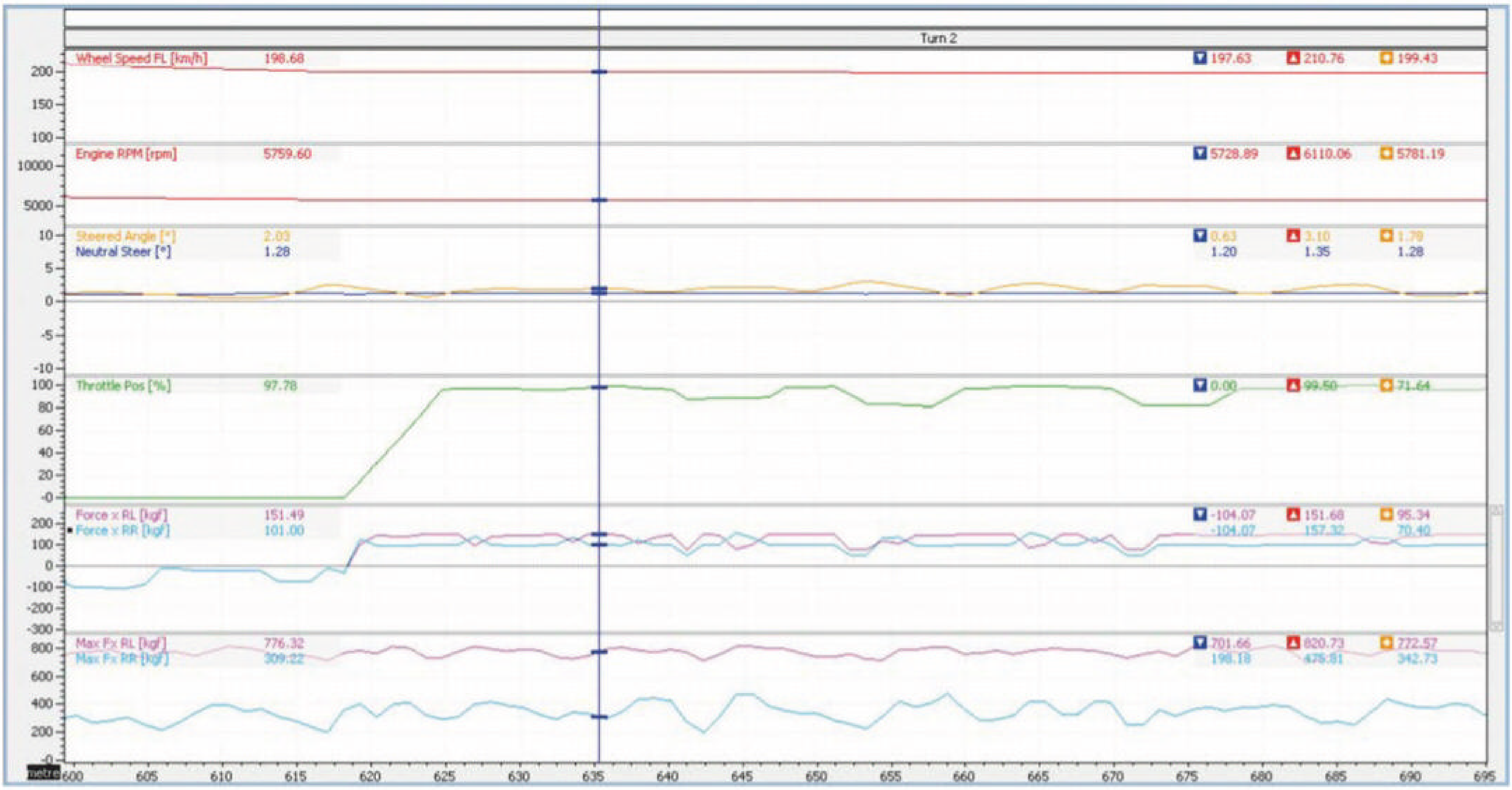
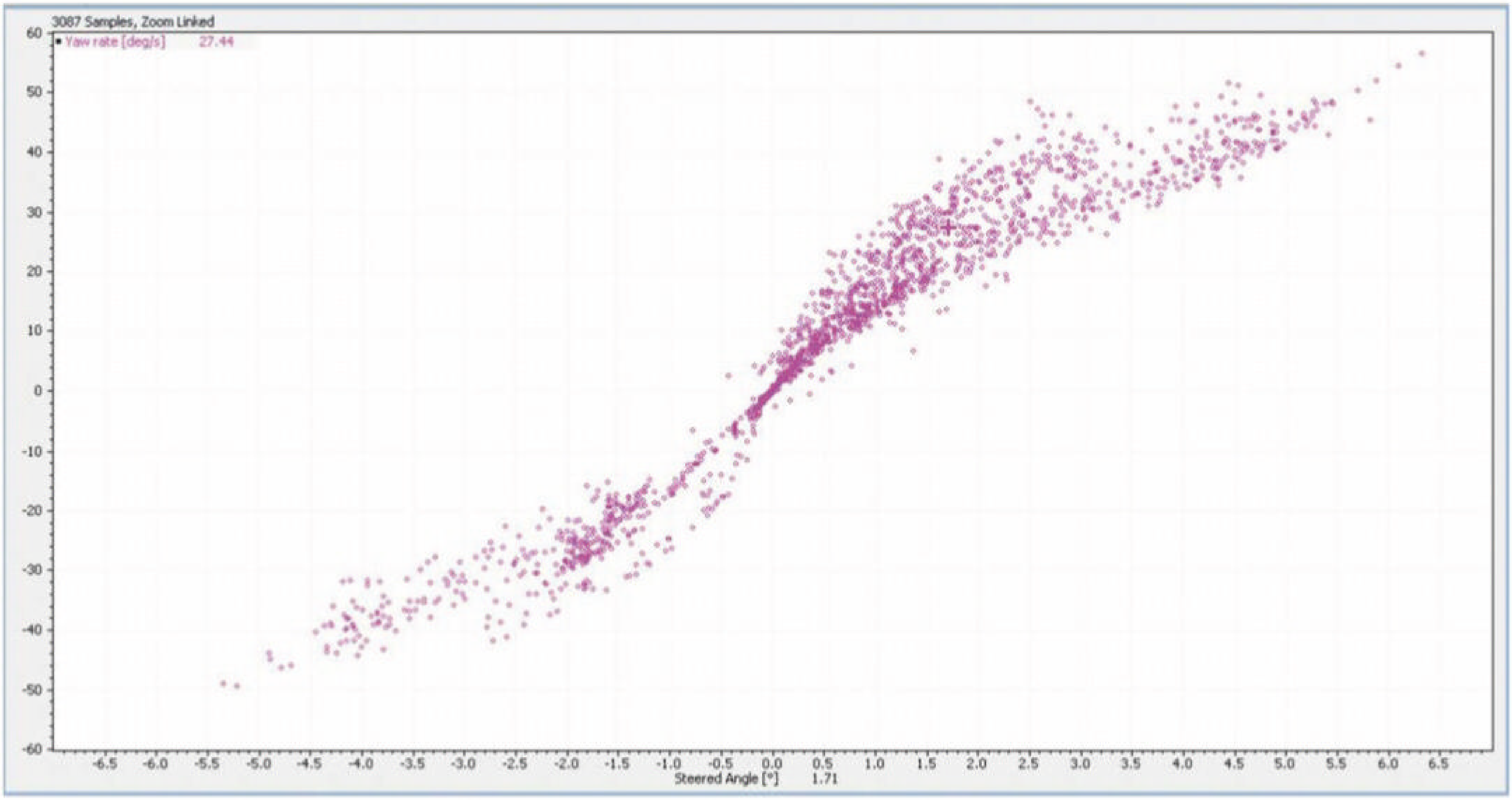


Figure 6: Yaw rate *vs* steered angle for a simulated F3 car

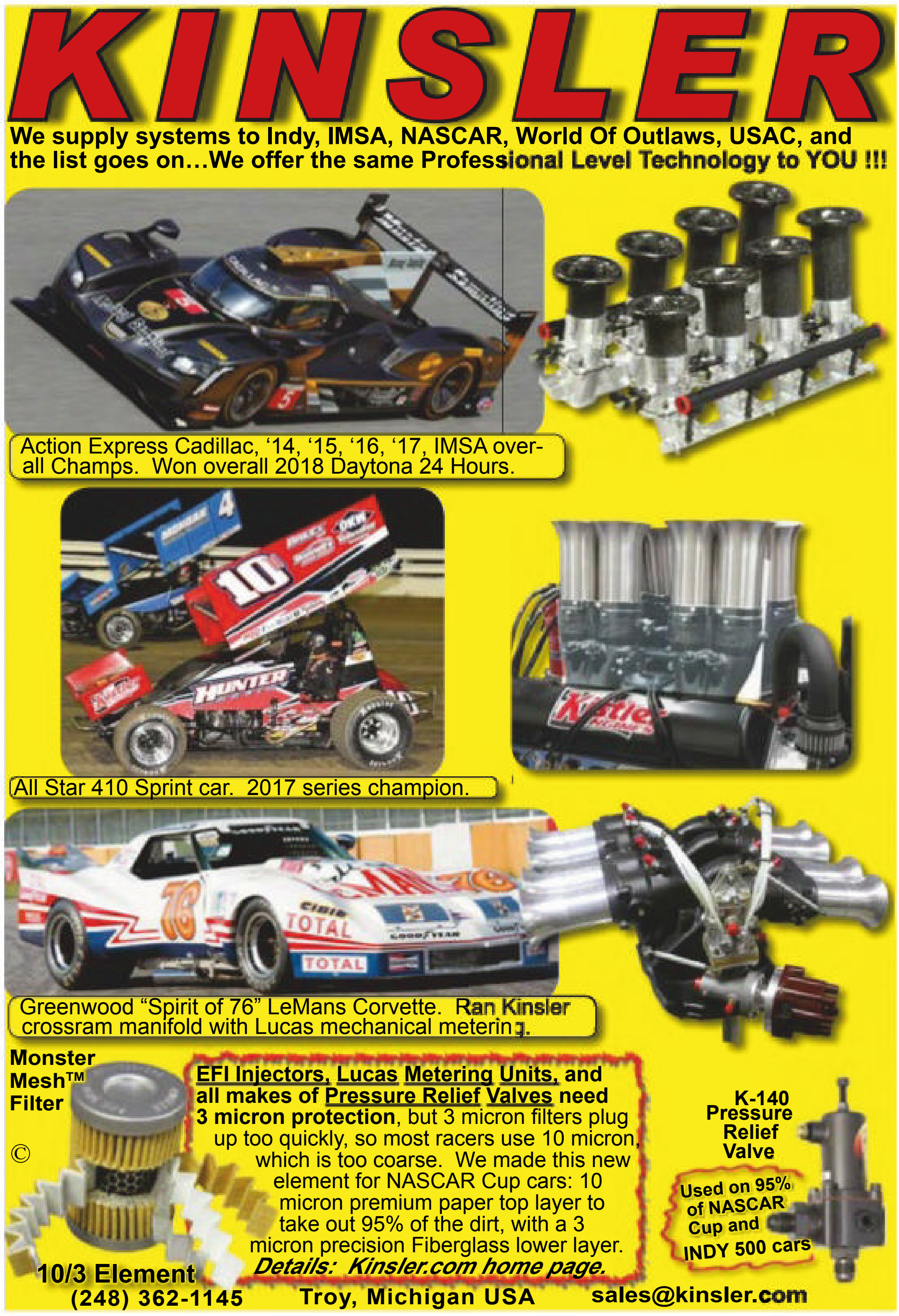


The important thing in **Figure 6** is that the slope of this curve determines the control power. The steeper the slope the more effective the steering is. So, if you have a driver complaining that the steering isn't responsive you now have the tools to start exploring this.

Please note that what I have presented here is merely the tip of the iceberg. I can't speak for the other simulation packages that are available but ChassisSim now has well over 150 logged channels that cover both chassis and powertrain. It gives you plenty of options to really drill in to what the racecar is doing, then.

In closing, the case studies presented here represent a small slice of a multitude of in-depth analysis you can do with advanced simulation channels. The simulated contact patch loads have a wealth of application to feed structural analysis so you can quantify the loads going into the racecar.

Also, the returned tyre forces, both applied and maximum, give you key insights into differential tuning and other useful things like steering control power are an added bonus. But perhaps the most exciting thing about all this is that what we have presented here has merely scratched the surface.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F1 races into the unknown the season after next with some sweeping changes to the technical regulations that are aimed at improving the quality of the show and reducing costs

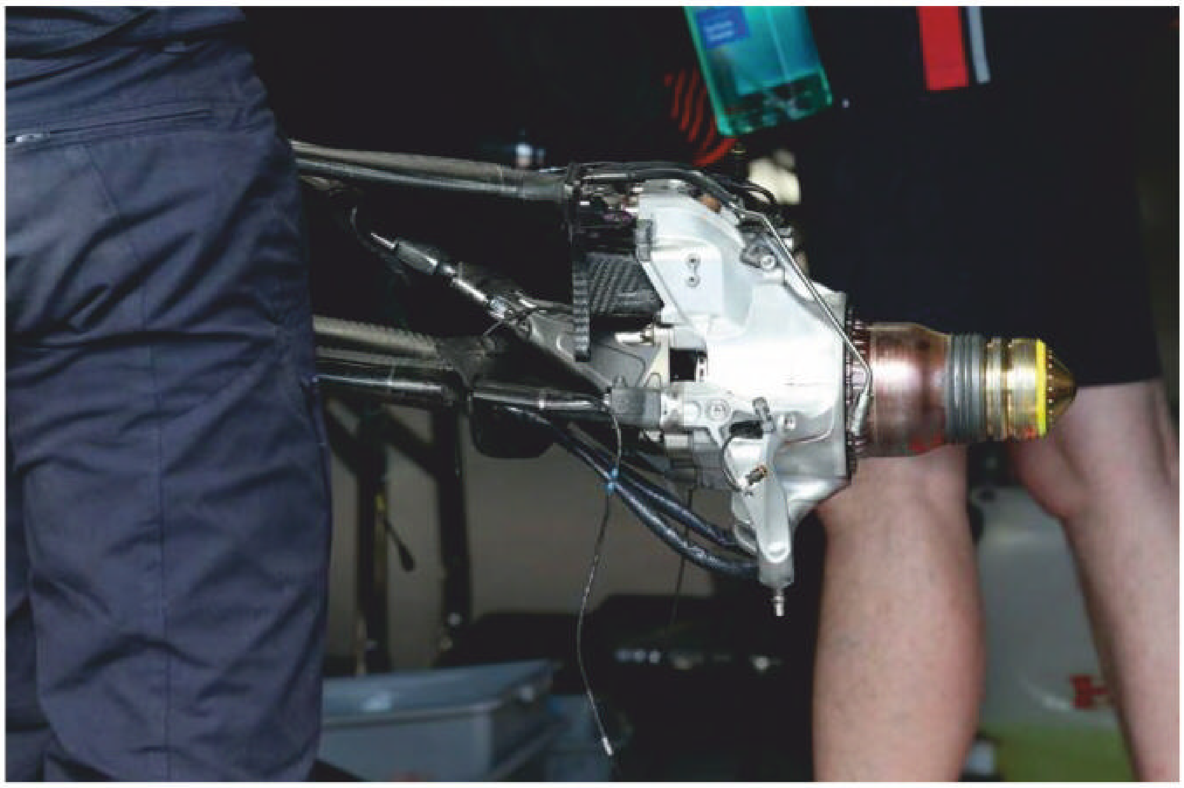
Formula '21

In 2021 Formula 1 will see wholesale changes to its technical regulations based upon a completely new approach to framing them. At the British Grand Prix the men in charge of devising the new rules package, Ross Brawn and Nikolas Tombazis, outlined this radical philosophy

By SAM COLLINS

Better racing, more spectacular cars and lower costs are all part of a 'new' Formula 1 being introduced in 2021. Under the ownership of Liberty Media the sport has set about a fundamental re-evaluation of its present and its future, with the aim of creating a completely new set of regulations. Previously, a number of details as to the form these new rules will take have emerged, such as the outline aero concept, the move to larger single spec wheel rims and the introduction of low profile tyres.

Some further details were then revealed during a briefing at the British Grand Prix, hosted by Ross Brawn, F1's managing director of motorsports and technical director, and Nikolas Tombazis, the FIA's head of single seater technical matters. At this meeting Brawn stated: 'We have arrived with the current cars without a lot of structure. The decisions and directions to create the rules have evolved mainly due to political pressures or whatever. At no point has there been a serious look at where F1 should sit, but that is what we are doing now. I have heard some comments from the teams about the things we are doing but I have to ask why is it that where we are today is this holy position that should not be changed? I think that is wrong for many reasons, and what we are doing is putting it into a much better place.'



One controversial aspect of the 2021 rules is the use of spec parts, which will include hubs and wheel nuts

Pit equipment, such as the wheel guns, is also set to be standardised as part of the cost cutting measures

'At no point has there ever been a serious look at where Formula 1 should really sit, but that is what we are doing now'

The first and most urgent area to be tackled by Brawn and his team was the overall aero package. However, with the publication of the new rules now delayed to October the rule makers are taking the opportunity this extra time gives them to fine-tune the aero package. 'There are some areas where work on the rules is still going on, for example we are not completely pleased about the front wing, both from an aerodynamic point of view and an aesthetic one,' Tombazis says. 'There is good reason that it is very wide but aesthetically we realise that it is not the best result.'

Insider knowledge

Unlike previous attempts to come up with new regulations the process with the 2021 rules has seen Brawn's team of 'poachers turned gamekeepers' return to their old ways, at least temporarily. 'Currently there is a lot of work going on to break the rules!' Tombazis says. 'We are trying to push them to the extreme to identify any loopholes or unintended consequences. So right now the aerodynamic department have put on a different hat, not that of a rule maker but more like one of an aerodynamic department at a team. For example, they are seeing how they can stretch the rules; can they for instance come up with a front wing that meets the rules, creates more downforce and is more efficient but at the same time [does not] negate some of the good things that have been achieved for the following car performance. If such cases are found then clearly we will react to avoid such issues.'

This work is likely to result in a number of detail changes to the regulations before they are issued and, according to Brawn, further

'We are trying to push the rules to the extreme to identify any loopholes or unintended consequences'

changes are entirely possible after the rules are published, too. 'The group we have at FOM will not stop working when the rules are issued,' he says. 'As we see the teams solutions evolve we will analyse them and start to understand if they are starting to negate the objectives, then we can steer it back again. This is not a one-stop shop where you just issue a set of solutions and leave it alone. We are going to monitor, develop and tune the solutions constantly to make sure we maintain the objectives.'

Cost cutting

While the new aerodynamic package is aimed at improving the show in F1 by making it easier for cars to follow and overtake, other moves are being made to try to close up the field by levelling the playing field and reducing costs for teams through both rule changes and the introduction of a $175m per season cost cap.

Part of this process will involve the standardisation of a lot more components, with fuel pumps, rear impact structures, the steering wheel, steering column, driveshafts, pedals and DRS mechanism all thought to be under consideration. The hubs, wheel nuts and the wheel guns are all set to be spec components too, as the FIA feels that teams are spending too much money on trying to gain 0.1 second in a pit stop.

The process had already started, with a standard gear cluster considered and a tender issued, but this concept was later dropped. However, a move to simplify the transmission still seems to be a certainty.

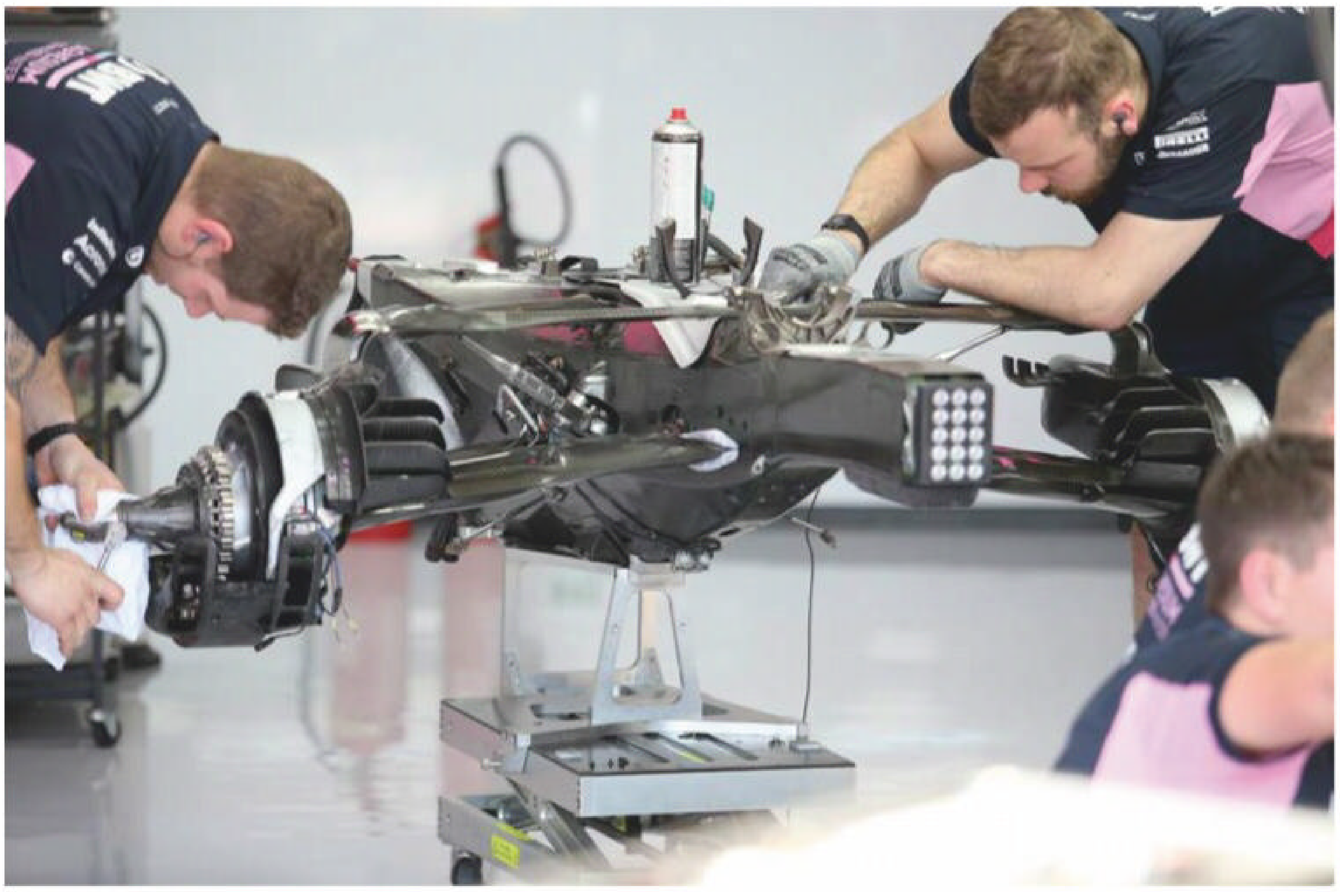
'Following the gearbox tender which was cancelled, we have decided to introduce a far more frozen specification of the gearbox to ensure that there isn't really any performance differentiation between gearboxes,' Tombazis says. 'There will be a reduction in R&D costs as a result of keeping certain parameters of the gearbox frozen and to a fixed specification.'

There will also be changes to the suspension systems. 'We are banning hydraulic suspension which is used by some teams, and limiting the type of mechanical components used to more simple solutions,' Tombazis adds. 'For example, things like inerters which don't add anything to the show, they just add complexity and have no road relevance, these are things that we don't think should stay in the future of Formula 1.'

Areas where complexity has increased over recent Formula 1 seasons have been a particular focus for the cost saving efforts

With Mercedes and Racing Point, representing both ends of the 2019 grid, known to have developed fully hydraulic rear suspension systems, this is something of an unexpected move. Indeed, the additional reduction in freedom in terms of suspension design is perhaps even more of a surprise considering that F1 had been contemplating the re-introduction of active suspension.

'We did evaluate active suspension as, compared to the very complicated hydraulic systems currently in use, an active system would be potentially cheaper than the current systems,' Tombazis says. 'It was rejected as we felt that if cars were developed to work in a very specific optimised window like ride height or whatever, then the aerodynamic characteristics would mean that the following car would be much more sensitive to the wake and would as a result suffer bigger losses than now.'



Hydraulic suspension, as used on the Racing Point, could be banned while gearboxes will be simplified and homologated

Reducing complexity

Areas where complexity has increased over recent seasons have been a particular focus for cost saving efforts, and as with the suspension these will be significantly restricted. 'The radiators, for example, will be simplified by regulation as this is an area of huge expenditure by some teams,' Tombazis says. 'They are very flimsy and have to be changed very frequently, they have extremely complex shapes.'

This is an area which has seen some significant differences between teams in recent seasons with the introduction of centreline cooling and various approaches to charge air cooling. Any tight restriction or standardisation of coolers, or even just the cores, could have a substantial impact on the wider car design.

Notably, the aerodynamic model of the 2021 car shows a small airbox and longer sidepods than found on 2019 cars, suggesting that centreline cooling will not be a feature in F1 from 2021, and that the low side impact structure approach used by all teams bar Mercedes may also be outlawed.

Changes to the chassis construction itself are also on the horizon, as the rules strive to make the cars a little more rugged. 'We are looking at simplifying the lower part of the chassis, and having structures under the chassis that protect it from kerbs and damage,' Tombazis says. 'It's also an area which is quite difficult to regulate in terms of the permitted deflection, so we are working on that. There will be a realignment of some of the materials regulations to stop some of the more exotic materials, but there will still be allowance for some innovation. We also want to continue with the modern industrial trend of additive manufacturing, but we want to regulate that more, which is missing from the current Formula 1 regulations.'

Under the bodywork there could be further changes with tighter limits placed on the electronics used on the car, in an attempt to force the drivers 'to drive the car unaided'. The last time this was attempted (in 2015) in the form of a ban of those on the pit wall from telling the drivers what they can do to adjust the car, it was widely criticised and ultimately dropped part way through the season.

'We are still looking at the electronics of the car and removing some driver aids. That of course is a sensitive subject, but we are working to avoid any unwanted consequences,' Tombazis says. 'We are discussing a reduction in pit to car telemetry, we would really like to leave the drivers alone during the race to handle all of the technical aspects of the car. There would still be radio communication for strategy or safety, but there would not be communications about temperatures, or telling the drivers to do certain things. We would prefer the car and driver to have responsibility for that and not have the continual help from the pit.'

Game of clones

It's fair to say there are some big changes on the way in Formula 1 then, and it's clear that the rule makers are expecting some severe criticism. And indeed, one team's technical director told us: 'These rules are not very good, it is not IndyCar, there will be nothing for you to write about as all the cars will be the same.'

But Brawn is ready for and expecting such criticism and has clearly heard similar sentiments in meetings with the teams. 'I think we need to understand that there will be push-back on some of these things, but the teams have different objectives. Our objective is to make Formula 1 more entertaining, more accessible and more sustainable, and this is the first time in the history of the sport that there has been such a deep study into what is needed,' he says. 'We are going to be very proscriptive to begin with because if we are not we won't achieve the objectives.

'Regarding the complaints we have heard that the cars will all look the same, there is an exercise that Pat Symonds has done, by taking the paintwork off all of the [current] cars and putting them up on the wall, you cannot tell them apart,' Brawn adds. 'You need to be an extreme geek to pick them out, and even within our office we could only pick out two or three. We know that even with these very proscriptive regulations the fertile minds in Formula 1 will still come up with new solutions. Compared to the current regulations the teams will probably find it frustrating, but if the teams take the approach that it is the same for everyone, and by doing a better job than the rest they will find that they are two tenths faster, not two seconds, that is what we want.'

Between now and October many more details on the specifications of one-make parts will likely be released and many debates will be had about the pros and indeed the cons of these new rules. Ultimately, it will not be clear if they achieve what they set out to do until the 2021 season is well underway, but it is clear that it will be a very different Formula 1.

Interview – Brian Gush

Life of Brian

Bentley's recently retired motorsport director recalls some of the highlights of his 20 years with the famous marque

By MIKE BRESLIN

'We came back to Le Mans in 2001 and nobody knew what to expect of us, then we pulled third place out of the bag, and that was fantastic'

If one thing encapsulates Brian Gush's time at Bentley it would be the signing off of a limousine designed for the Queen at Millbrook, and then driving on to Snetteron for the roll out of the EXP Speed 8 Le Mans car. Gush, who has recently retired, was so much more than a motorsport director, you see. In fact, while he was masterminding the marque's triumphant return to La Sarthe he was also designing a large chunk of the Bentley Continental GT road car, wearing his other hat as the firm's director of chassis and powertrain.

The early 2000s were a very busy time for Gush, then, who was actually just the second motorsport director at Bentley, the first being founder WO Bentley himself. The reason for this was because Bentley was not really that interested in motorsport after the halcyon years of the Bentley Boys in the 1920s, and even though its cars had often worn badges like 'Mulsanne' and 'Arnage' it had not been to Le Mans for 70 years when it rolled up in 2001, with Gush at the helm.

Bentley went on to score a famous one-two finish in the great race in 2003, yet it's actually that comeback year that is Gush's proudest moment of his 20 years in charge of the company's motorsport activities. 'We came back and nobody knew what to expect of us, and we pulled third place out of the bag, and that was fantastic. Because it was unexpected,' Gush says. 'In 2003 there was a lot of expectation because we'd put a lot into it and there was the feeling that we had to do it then. But in 2001 nobody knew what to expect.'

Bentley boy

Gush had come to Bentley in 1999, after working with parent company Volkswagen in his native South Africa and then in Germany for some years, and he quickly looked for a way to get the marque back to Le Mans. 'There was that feeling that Bentley belonged at Le Mans, for sure, but there was not a clear path to get back,' he says. 'But then with the Racing Technology Norfolk project that had stalled I saw the opportunity to get it together. It was the right thing to do for the brand at the time, as we were trying to establish ourselves to a younger audience, and there's no better business marketing tool than motorsport.'

The rtn project mentioned above refers to a stillborn Volkswagen racecar. 'rtn started out with an Audi project, that was the R8C, which then was dropped,' Gush says. 'And then VW picked up the organisation and designed a complete new car, that they had on the drawing board for their W12 engine; and then that got dropped. I then saw that there was an opportunity to pick up where they had stopped and negotiated a deal with Audi for some 3.6-litre engines.'

Bentley's win in 2003 is now a part of Le Mans folklore, but if there is one thing that rankles with Gush it is that some of the company's glory often seems to be, at least partly, attributed to Audi. 'Because we were using an Audi engine there was a touch of Audi about it, yet the project had nothing to do with Audi. The car was completely, uniquely designed,' Gush says. 'Nobody calls the McLaren a Renault, do they?

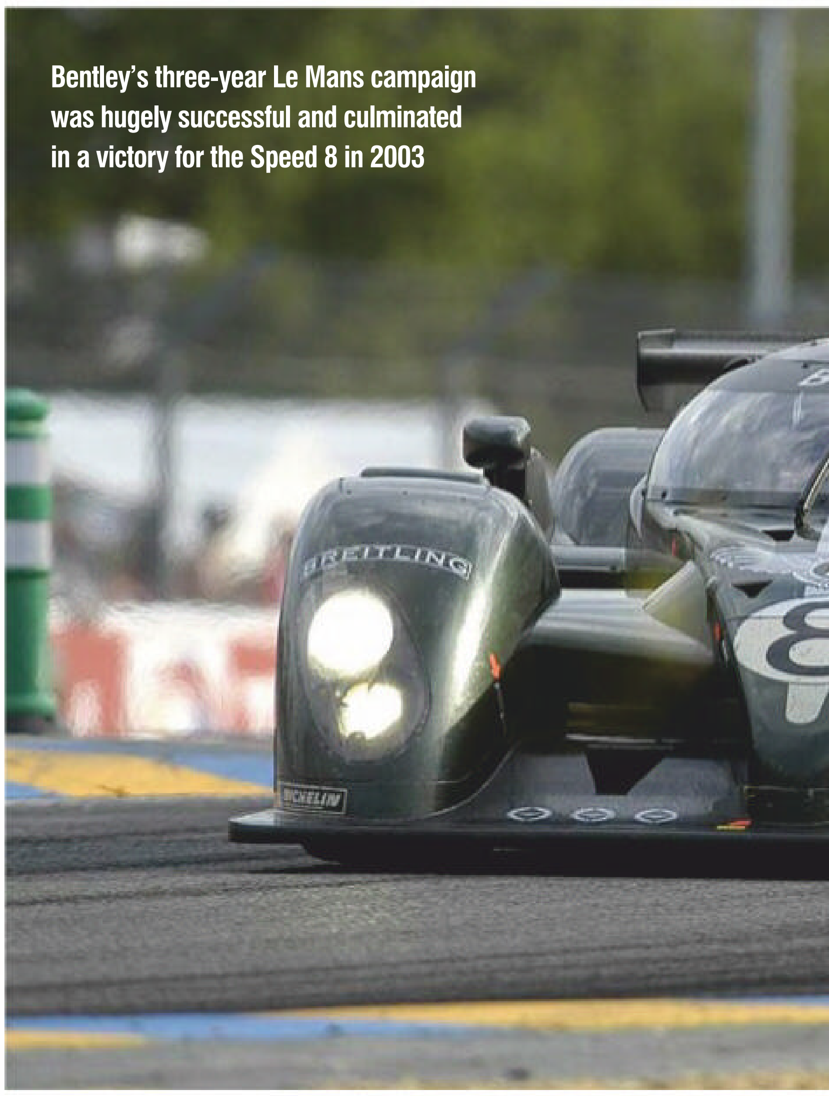
'And Audi didn't do much to dispel it, they were quite happy to just let it run,' Gush adds. 'And that's, a bit, what prompted us in 2002 to make something different. So I commissioned [engine designer Ulrich] Baretzky to do a complete new engine for us, which was a 4-litre direct injection. This then separated us from the Audi engine; the block, the crank, the heart of the engine was different. That was a bespoke Bentley engine, but the perception persisted, probably through lack of clear PR on our side, and Audi not doing much to dispel it.'

After its success at Le Mans motorsport took a backseat at Bentley for some years, but it was never wholly forgotten. 'Then it was road car work, we'd closed rtn, the facility, and I ramped down the team to just a very small number of guys that I had around me, and then we did things like the high speed record in 2007, we were aiming for 200mph [on ice!] and didn't quite get it, so we went back in 2011 and got it,' Gush says.

Second coming

But Bentley was always looking for an opportunity to return to racing and there was even the chance of a Le Mans comeback in the late 2000s 'We came close to going back in 2008, when we started looking at the P1 class again,' Gush says. 'It would have been a similar engine and we were talking to Lola at the time, but the financial crisis just stopped that in its tracks.'

The car that Lola made became an Aston Martin, in name at least, and Bentley had to wait a further five years before its motorsport return, this time in GT3 – a category that has a customer sport philosophy at its heart, so in some ways it echoes the era of the Bentley Boys.



Bentley's three-year Le Mans campaign was hugely successful and culminated in a victory for the Speed 8 in 2003

'At that stage the P1 rules were so expensive, with hybridisation, you could no longer do LMP1 as a small manufacturer; Toyota, Audi, and Porsche were spending research budgets on it,' says Gush. 'And then, racing the Continental, the only set of regulations open to us was GT3, because of the four-wheel drive, all our cars are permanent four-wheel drive and that's the only regulation that allowed you to remove the four-wheel drive. The GTE regulations do not allow you to do that. So then GT3 was the obvious choice. There was a lot of scepticism, the FIA just basically said to us, you can't do it, you will never get within the guidelines, you will never get it within the performance windows. And it was quite satisfying to show that we could.'

In fact, Bentley has gone on to use the size of the Continental as a plus-point. 'What you do is you take what you have and you use it to your advantage,' Gush says. 'So you have got a good footprint, and pressure times area equals force. So, if you have got a big area and you create some low-pressure areas then you have got good downforce.'

Gushing praise

Of course, any real advantage is negated by the Balance of Performance, so how frustrating is that for a pure engineer like Gush? 'That's always a challenge, but if you are a competitive engineer and there's a rulebook, then off you go,' he says. 'The GT3 Balance of Performance is there to create close racing, and I think the SRO have done a great job in that. They have got it right, they have 12 manufacturers involved in GT3, and there is no other race series in the world, wherever you look, that has got 12 OEMs that are building cars… [And] You then make a difference where you can, which is in pit stops, in reliability, and in creating a stable racecar.'

Gush's last race as Bentley boss was at this year's Spa 24 hours at the end of July – which was sadly not a success for the marque – but he is not quite done with motorsport and as well as a 1966 Lotus Elan and a collection of old British motorcycles to look after in his retirement he also has a Ford Escort rally car – which he has built himself – that he intends to use in historic competition. He will keep himself busy then, just not quite busy as he was in the early 2000s.

RACE MOVES

XPB

Alain Prost has taken on the role of non-executive director at the company that's behind the Renault Formula 1 operation, Renault Sport Racing Ltd. Four-time F1 world champion Prost replaces Renault Group executive **Thierry Bollore** on the board; the latter is no longer involved with the F1 team after taking on extra responsibilities as Renault Group CEO.

Former driver **Gil de Ferran** is to head up the management team of the new McLaren IndyCar programme, which the organisation is to undertake in partnership with established outfit Arrow Schmidt Peterson Motorsports next season. Arrow SPM co-founders **Sam Schmidt** and **Ric Peterson** will continue in their current roles within the team.

Petronas has announced its second global hunt for a trackside fluid engineer to work with the Mercedes team during the 2020 Formula 1 season. To apply for the role, interested candidates can visit Petronas Lubricants International LinkedIn page or email ptfe2020@pli-petronas.com by September 25.

Cliff Daniels is now crew chief on the Hendrick Motorsports No.48 NASCAR Cup Chevrolet driven by seven-time champion **Jimmie Johnson**. Daniels was previously Johnson's race engineer during the 2016 Cup season and last year he joined Hendrick's competition systems group, before re-joining Johnson as his race engineer earlier this season.

Paul Williams has been appointed director of motorsport at Bentley, replacing **Brian Gush** (see interview, left). Williams, who has been at Bentley since 2008, moves from his current role as director of powertrain, where he has overseen the design and development of the all-new 6-litre W12 engine that powers the Bentayga, Continental GT and the new Flying Spur models.

Alberto Blanco, the race strategy engineer at Mahindra Racing, has won Formula E's Modis Engineer of the Year Award for the 2018/19 season. The award was instigated to celebrate the unsung heroes of the FE paddock and to recognise outstanding engineering. Blanco, who first worked in FE as a reporter, was chosen 'for his outstanding contribution to the sport and his team, with a special focus on innovation'.

John Borghetti, a former boss of Virgin Australia, has joined the board of Supercars as an independent director. Borghetti joins Supercars CEO **Sean Seamer**, Archer Capital's **Peter Wiggs** and team owners **Brad Jones** and **Rod Nash** on the board.

Matt Breeden is now the president of the Sportscar Vintage Racing Association (SVRA) in the United States. Breeden has held executive positions in motorsport companies for over 15 years, including spells at IndyCar and Champ Car, while most recently he served as chief financial officer for Indianapolis-based Racetrack Engineering.

Dick Jordan, who was the PR man for US racing sanctioning body USAC for over 50 years, has died at the age of 74. Jordan, who started working for USAC in 1968, was inducted into both the National Sprint Car Hall of Fame and the National Midget Auto Racing Hall of Fame, while more recently he received the Jim Chapman Award for excellence in motorsport public relations.

Markus Schafer and **Frank Markus Weber** have joined the board of Mercedes-Benz Grand Prix Ltd. This follows the departure of **Ola Kallenius**, who has stepped down after assuming the role of chairman of the board of Daimler AG – the Formula 1 team's parent company – and **Bodo Uebber**, who has left his position as Daimler's chief financial officer. Schafer now takes on the role of non-executive chairman, replacing the late **Niki Lauda**.

NASCAR Cup operation Front Row Motorsports has swapped the crew chiefs on its No.36 and No.38 cars. **Seth Barbour** has now taken over running No.36, while **Mike Kelley** goes in the other direction to tend the No.38 car. Kelley is in his first year with Front Row Motorsports, having moved from Roush Fenway Racing for this season.

Monchaux replaces Resta as Alfa Romeo's F1 tech boss

Jan Monchaux is now technical director at the Alfa Romeo F1 team, replacing Simone Resta, who has returned to Ferrari after fulfilling his short-term deployment at the Swiss-based operation, which was previously known as Sauber.

Monchaux, who has been promoted from the role of head of aerodynamics, was at Ferrari himself from 2010 until 2012, working in the aero department, before moving to Audi Sport as its head of aerodynamics. He then joined Sauber in the same role.

At the time of writing it was not known what position Resta was to take at Ferrari but it has been reported that he will concentrate on the Scuderia's 2021 car.

'I am very excited about this new challenge and I am looking forward to starting in my new position,' Monchaux said. 'The owners, board and team principal are sending a simple but strong message to the whole company – they value continuity and believe in the existing team and the work we have been doing. It is now up to us to prove them right.'

Simone Resta has left Alfa Romeo to return to Ferrari

Meanwhile, Ferrari man Alessandro Cinelli has been hired as the new head of aero at Alfa to replace Monchaux. Cinelli has worked at Ferrari for 17 years, having started in F1 at Tyrrell in 1997 then going on to Williams two years later before joining the Scuderia at the height of the Michael Schumacher era in 2002. He became head of the aero experimental group at Ferrari in September 2015.

'I join this young team with the mission to build on the solid foundations that have already been laid and to help produce results on track,' Cinelli said 'I am confident we can continue in the right direction and bring more success to the team.'

RACE MOVES – continued

Dave Greenwood, who was **Kimi Raikkonen's** race engineer at Ferrari in F1, is now the technical director at the United Autosports sportscar squad, where he will work with its LMP2 and LMP3 teams in the WEC, the European Le Mans Series and the Le Mans Cup championship. Greenwood was with the short-lived CEFC TRSM (Manor) programme for a time after leaving Ferrari at the start of 2018.

NASCAR Xfinity Series crew chief **Nick Harrison** has died at the age of 37. Harrison had been working on **Justin Haley's** Kaulig Racing No.11 Chevrolet this season, after spending the last five years at Richard Childress Racing.

NASCAR suspended Truck Series crew chief **Jeff Stankiewicz**, truck chief **Austin Pollak** and engineer **Jonathan Stewart** for three races after the No.2 truck they work on suffered a 'loss or separation' of ballast during the Eldora dirt track round of the series.

A Renault Formula 1 team member was taken to hospital after a road accident involving one of the team's trucks on the day after the German Grand Prix, while it was travelling between Hockenheim to the next race at the Hungaroring. The truck's driver was taken to hospital but he suffered no serious injuries and was discharged three days later. The accident happened on the M1 motorway close to the city of Gyor in Hungary.

NASCAR officials fined **Chris Gabehart**, the crew chief on the Joe Gibbs Racing No. 11 Toyota, and **Chad Johnston**, the crew chief on the Chip Ganassi Racing No. 42 Chevrolet, $10,000 each after both cars were found to be running with a lug nut that was not safely secured at the Pocono round of the Cup Series.

IndyCar team co-owner **Richard Marshall** suffered an injury at Eldora Speedway when he fell from the top of his team's transporter during the Kings Royal World of Outlaws event. At the time of writing Marshall was said to be 'on the mend'.

Nick Leventis, the founder of the Strakka Racing GT team, and also one of its drivers, has been banned from motorsport for four years by the FIA for an anti-doping offence. Leventis has said the violation was unintentional and that the drugs concerned were prescribed by a doctor and supplied by a personal trainer, but because he has now retired from racing he will not be appealing the decision.

William Storey is no longer associated with controversial Haas F1 sponsor Rich Energy. The flamboyant former boss of the energy drink concern has had his appointment as a director terminated, according to information filed at Companies House in the UK. Storey had been in dispute with shareholders of the company since just before the British GP, when he wrongly announced on Twitter that the sponsorship deal with Haas had been terminated.

Former Benetton and Renault F1 boss **Flavio Briatore** is to enter politics in his native Italy, where he has formed a party called *Il Movimento del Fare*, which he says is 'totally independent of any current political party' and 'at the complete service of the citizens'.

OBITUARY – Jean-Paul Driot

Jean-Paul Driot, the founder of the hugely successful DAMS single seater outfit and its e.dams Formula E offshoot, has died at the age of 68.

Driot set up his team to run in Formula 3000 at the end of 1988 and it became known as DAMS, standing for Driot Associes Motor Sport, in 1989.

Described by those who worked with and for him as hands-on but savvy enough not to get involved with the technical side of things, Driot was never in racing for the money – he was a successful crude oil trader – and hence he could employ drivers on their ability rather than the backing they brought. Because of this DAMS became a springboard for talent, with pilots of the calibre of Olivier Panis, Romain Grosjean and Sebastien Bourdais driving for DAMS during their career. But it's not just drivers who have honed their craft at DAMS, and Eric Boullier and Vincent Beaumesnil are among the many engineers and managers who have worked for the firm. Indeed, it's been said that one of Driot's strengths as a team boss was to always find the right people for the job.

DAMS took its first major title in Formula 3000 in 1990, with Eric Comas at the wheel, and it went on to win 147 races in professional-level single seater racing, including F3000, GP2, F2, F3.5, GP3 and Formula E. DAMS also won races in sportscars in the late 1990s and early 2000s.

Renault, which worked with DAMS in Formula E (with the e.dams operation), said in a statement: 'We are deeply saddened to hear of the passing of our friend, Jean-Paul Driot. The sport has lost a spirited man, one who identified and nurtured its future champions. He was a pragmatic racer, driven by passion, ready to take risks and relish every moment. His enthusiasm was absolutely and inspiringly refreshing.'

Jean-Paul Driot 1950-2019

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Turn of the century

This month I chalk up a century of editions that I have edited. While I am not one prone to celebrating milestones of any sort, of this one I am proud. The last eight years have been some of the most exciting in terms of technical development in motorsport, and they have seen some of the biggest changes since the Lotus 79 revolutionised the world of aerodynamics in racing. In this era, rather than aero, we have witnessed a massive evolution in terms of powertrain. Top categories have adopted hybrid technology and the tech appears to be spreading to other categories, including IMSA's DPi and IndyCar, while at Le Mans NASCAR's Ed Bennett confirmed that the US stock car series was also looking hard at ways of introducing it. F1 power units have hit 50 per cent thermal efficiency, a true milestone.

One of the mysteries of this era is how Formula 1 and sportscar racing managed to have separate hybrid systems. The plan was to have a crossover of the technology between the two, reducing the development costs and increasing return. There has always been suspicion between them, that sportscar racing can become too big as this is where manufacturers want to race, but the category has always fallen into the trap of having only one valuable race, Le Mans, and the rest is a way of off-setting this profit. It still confuses me why manufacturers say that they have to race in China and Bahrain, when grandstands sit empty. But this, like big development curves and expense seems logical to manufacturers and organisers.

There is no doubt that the Equivalence of Technology worked, and manufacturers with vastly different concepts were able to race within fractions of a second of each other. The rule was pretty much perfect, and was attractive, but wasn't for Formula 1. F1 has its own problems in terms of the ratio between development, funding and racing, but the series is robust enough to survive while it finds a solution.

By contrast, the WEC schedule this season has a vastly increased travel budget due to flying the cars rather than shipping them and this has caught many privateers out. They are therefore now under undue and unexpected financial pressure. There are other series that they can choose, and more are appearing every year. The US endurance racing scene is more stable, but even there it appears that there is no agreement on what hybrid system should be used, and the manufacturers are pulling in different directions.

Whatever the often-repeated mistakes that sportscar racing makes, not having a powertrain that could be shared between Formula 1 and Le Mans has cost both of the categories, although one far more than the other.

Not having a powertrain that could be shared between F1 and Le Mans has cost both categories

Another aspect of the time since I took over at the helm in 2011 is the uncertainty surrounding the future of fuels. We have talked about diesel, petrol and hybrid, and now electric is in the mix with Formula E attracting huge manufacturer interest, but there is no clear guidance which will be the dominant fuel in the medium-term future. Governments seem hell-bent on it being electric without considering the environmental impact of the technology, only the air quality issue, and the manufacturers know that a change of government could easily bring about a different direction. This is the first time in history that there has been such doubt and at a time where we need cheap short-term solutions, organisations are gambling on taking long-term decisions and hoping for the best.

Even in the last eight years there have been wildly different philosophies. When I started at *Racecar*, one was to go small capacity engines, turbocharged. There was a plan for a Global Race Engine, a 4-cylinder 1.6 or 2-litre that was turbocharged and used in all areas of racing from grassroots (smaller capacity) to world championships (larger). The logic was that all manufacturers have them already in their production fleet, and by creating a racing version, given the car conglomerates that are now in existence, it would be easy to bring multiple brands to racing for little money. After that, it was the diesel era. Although this had already started in anger in 2006, and we had already had some wonderful competition between Audi and Peugeot. Audi was continuing to press ahead with the tech believing it to be the ultimate solution. Then dieselgate happened …

After that it was hybrid, and we have cycled through that quickly. The ACO wants to introduce hydrogen fuels alongside gasoline, hybrid and electric. When the diesel scandal has finally been swept up, no doubt that will again emerge as a viable option.

Tyres have already gone through their cycle, and will continue to do so. Materials are pretty much out due to cost restrictions, and so weight is not going to feature. I do wonder what the next eight years will bring, but by the time my time as editor of this magazine is up I hope that we have finally got some clear direction on powertrain and fuels, while I also hope the next revolution will bring even more great racing.

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