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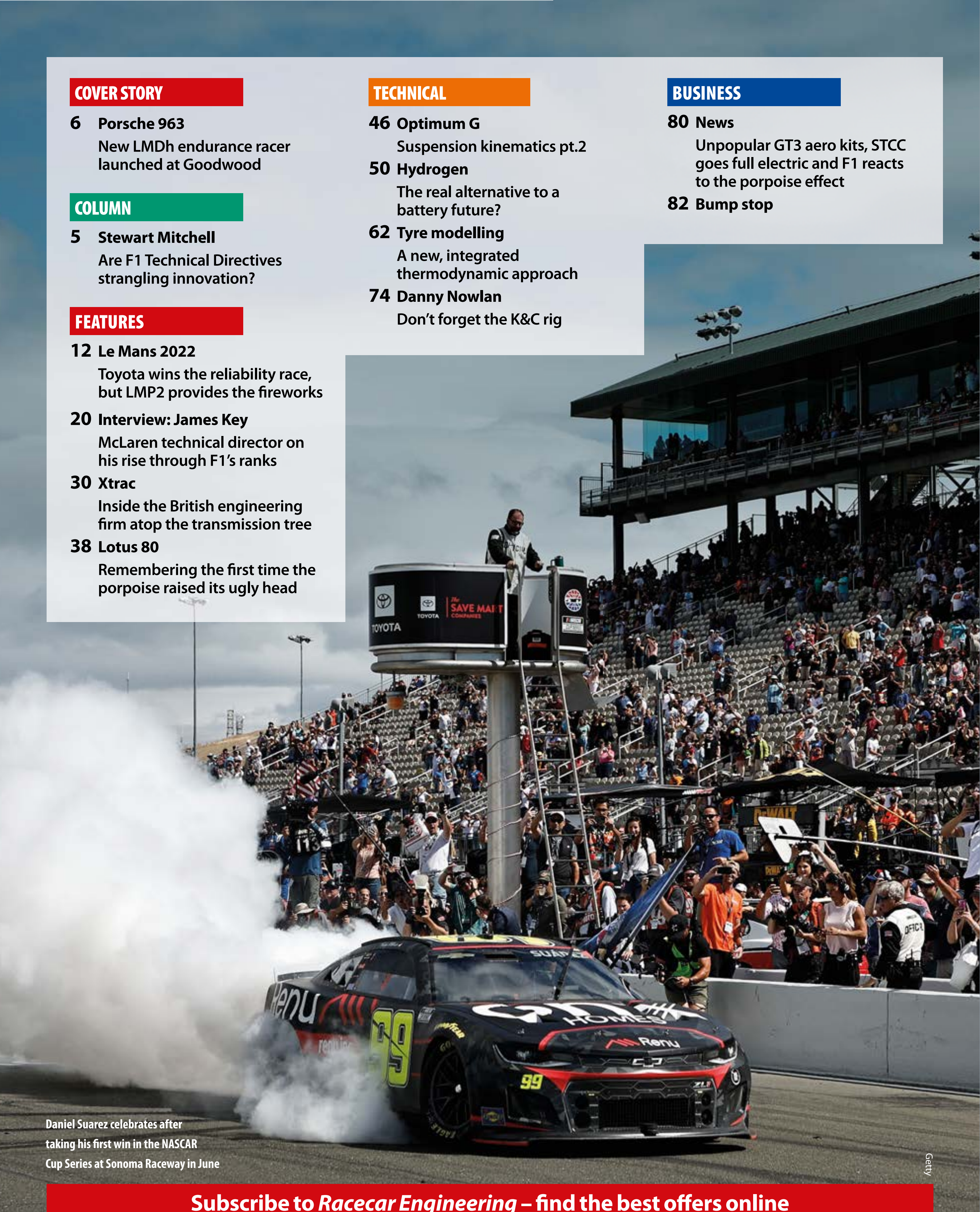

Daniel Suarez celebrates after taking his first win in the NASCAR Cup Series at Sonoma Raceway in June

Getty


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Advantage lost

Are Technical Directives reining in top F1 teams?

Technical directives (TDs) are publications used for directing the action and recording of modifications, re-positioning, operational improvement or an alteration in the characteristics of the equipment to which it applies.

TD changes are typically implemented outside of regular procedural review intervals within the industry in question and act as an update to them as a function of data collected during operation.

Motorsport sanctioning bodies reserve the right to implement TDs when they deem it appropriate to do so on reasonable grounds, such as safety. However, because the foundations around which a governing body can implement a TD affect the scope for performance in the concerned areas, there are often winners and losers after its delivery, shortly followed by leveraging of the new policy under the circumstances in which a Technical Directive is imposed.

The FIA has issued several Technical Directives in Formula 1 over recent years. In some cases, they have been to do with teams' interpretations of the Formula 1 rule book, mainly due to engineers jumping through so-called loopholes in its technical wording with their designs and implementation of on various aspects of their racecars.

À la mode

In 2020, from the Italian GP at Monza onwards, Formula 1 introduced Technical Directive 37, restricting Formula 1 teams to just one engine mode from qualifying to the end of the race. Previously, teams used as many as three modes in the qualifying and race sessions, with different settings of the internal combustion engine and energy recovery system, ranging from the highest possible output to the most conservative.

At the time, this TD looked to penalise the Mercedes F1 team, which was widely rumoured to be using a so-called 'party mode' aka STRAT 2 to extract the maximum out of its PU in a bid to obtain the highest track position in qualifying.

The threat of no longer being allowed to use a different engine mode for qualifying, unless it was also going to be used in the race, was supposed to even the playing field.

Mercedes looked set to lose, though the team's dominance at the time proved insurmountable by the end of the season.

In 2021 there was a TD tightening control areas concerning wing flexibility, sparked this time by the Red Bull RB16B. The team had introduced several iterations of its rear wing throughout 2021, though the one presented at the Spanish GP was by far the most famous. The wing was the subject of much debate during the practice sessions as the rearward-facing camera onboard the RB16B relayed it deforming on the straights, levering down and away from its static position, returning only when braking shed aerodynamic load before corners.

The rulebook allows for *some* deflection of this sort due to the materials used in their construction but, as the wing was twisting backwards at such a high displacement, the FIA put it under scrutiny on the basis that it *could* provide an aerodynamic advantage as it would reduce drag on the wing as it moved.

The FIA subsequently updated the testing template for the rear wing using Technical Directive 18/21, which addresses the 'pullback test' and the 'vertical load test' to check the rearward lean angle of rear wings.

In the first test, the rear wing is pulled back, while weights are placed on the support in the second test. The FIA almost doubled the amount of pressure exerted on the rear wing vertical supports, the idea being to ensure the pillars were stiffer, and therefore less flexible.

Red Bull looked to potentially suffer from the nth degree performance shaved off by the TD, though it still managed to remain competitive throughout the remainder of the season.

XPB

Red Bull Racing's form looks to be threatened by the FIA's proposed TD as it is one of the few teams who have managed to bring porpoising under control

Oscillation effect

The most recent TD came after round eight of the 2022 F1 championship in Baku, Azerbaijan. There, porpoising (the phenomenon of aerodynamic oscillations) and the effects of it during and after the race on drivers' physical condition, was clearly visible. The FIA therefore decided to implement a TD requiring teams make necessary adjustments to reduce, or eliminate the phenomenon in the interests of safety and driver health.

The TD guides the teams concerning the measures the FIA intends to take to tackle the problem. These include closer scrutiny of the planks and skids, both in terms of their design and the observed wear, and the definition of a metric, based on the car's vertical acceleration, that will give a quantitative limit for an acceptable level of vertical oscillation.

In addition to these short-term measures, the FIA will convene a technical meeting with the teams to define actions that will reduce the propensity of cars to exhibit any such phenomena in the medium term.

Here it looks like Red Bull, who appear to have a stability advantage compared to the rest of the 2022 field after nine rounds of the championship, is again set to potentially suffer from the introduction of this latest TD.

Formula 1 management is adamant it isn't implementing Technical Directives to 'improve the show', but the consensus amongst the top teams in any season where a TD has been introduced is it is damaging to their position.

Should, for example, the FIA dictate a set-up configuration for cars going forward, the team who seem to have best worked out how to deal with the porpoising issue will lose that advantage. Only time will tell.

Formula 1 management is adamant it isn't implementing Technical Directives to 'improve the show'

Leading the charge

Porsche has been pushing LMDh development hard, in an effort to ready itself and the spec hybrid system for the 24 Hours of Daytona in January 2023, but it continues to be a bumpy road

By ANDREW COTTON

Porsche has taken the wraps off its new LMDh challenger, which will carry the company's fortunes in endurance racing on both sides of the Atlantic. The 963 marks the return of the German manufacturer to endurance racing for the first time since the end of the 919 Hybrid LMP1 programme in 2017.

Then, Porsche pulled the plug on its project mid-way through its agreement with the FIA World Endurance Championship, but the company has been encouraged back to endurance racing by the new regulation set that allows it to build a hybrid Prototype for significantly less money than before.

The original plan was to return Porsche to its glory days of the 956s and 962s of the 1980s, with cars run in customer hands in endurance racing around the world. To that end, the LMDh platform was chosen as it was accepted in both the US IMSA WeatherTech Sportscar Championship and the FIA World Endurance Championship.

For the latter series, in order to accommodate LMDh cars, there have been some significant regulation changes, although these primarily concern the LMH manufacturers that have produced ground-up racecars, and take care of their own hybrid development. These include tyre sizes, hybrid deployment speeds and cockpit-adjustable anti-roll bars, as the governing bodies seek to give each car a chance to win.

Early starter

The Porsche will use a hybrid system that is standard across all the LMDh programmes, with battery from Williams Advanced Engineering, motor from Bosch and gearbox from Xtrac. So far, it has been the only one to hit the track, conducting much of the hybrid testing ready for introduction into other cars, notably Cadillac, Acura and BMW, in July.

Of the four options available, Porsche chose to partner with Multimatic on its LMDh project, a company it says it has a good working relationship with. Originally, it was thought Audi would benefit from the partnership too, but the VAG sister brand cancelled its LMDh programme earlier this year

What has changed for Porsche is that the LMDh platform will now not be used as the top class for the European or Asian Le Mans Series, which it had expected due to the lower cost of competition compared to the old LMP1 cars. The platform for the 963 was also *supposed* to have been shared with any other VAG brand, including Audi, Bentley and Lamborghini, which would have meant more cars and a shared development cost.

However, Bentley's ambitious programme to be a hydrogen partner has yet to get going, Audi cancelled its LMDh programme in March of this year, having previously confirmed it had two cars ready to start testing, while in May Lamborghini announced it will build its own car, partnered with Ligier, and is developing its own engine.

To have two other VAG manufacturers opt not to take the car has necessarily pushed the asking price up for customers, and the business case for the programme has had to adapt somewhat to the new challenge.

The platform for the 963 was also *supposed* to have been shared with any other VAG brand, including Audi, Bentley and Lamborghini

The car will now compete in both factory and customer hands, the factory team run by Porsche Penske Motorsport, the customer teams still to be announced.

Porsche is aiming to have the 963 make its debut race, a non-competitive outing, at the final round of the WEC in Bahrain, before a test in Sebring in December for IMSA to balance the car against its rivals for the 24 Hours of Daytona in January.

Styling cues

One of the key features of the LMDh platform is that the manufacturer provides the engine and the bodykit, which is finished using the brand's styling cues. Balance of Performance negates any advantage or disadvantage gained in either respect.

Porsche opted to delve into its history, and brought out a version of its 3.4-litre V8 that originally powered the RS Spyder in 2005. That engine was then bored out to 4.6-litres and used in the company's 918 hybrid road car.

For the LMDh project, the 4.6-litre capacity has been retained, but fitted with twin turbos to help achieve the power curves prescribed by the regulations.

The fact that Thomas Laudenbach, now Porsche's vice president of motorsport, was involved in the development of the engine in 2004 / '05 had nothing to do with the choice of engine for the LMDh programme.

'I would never make a decision just because I liked it, or that it was in my personal history,' insists Laudenbach. 'When you do something like [this project], you write down the main criteria of the rules you have to fulfil, the demands of the rules you have such as fuel consumption and whether or not that is important, minimum weight, are you allowed to mount it so that it carries load? You put everything on the table, and then [the regulations] give you a power curve. That is unusual for an engine designer because they are used to saying I want as much power as I can, so it is a different approach.

'Then you ask what is the best way to do it. You don't want to waste money because you have a certain budget per programme, and if you spend more money – for example on the engine – then you can't spend it on the rest of the car. So, you look to see where is the money spent well.

'In that case, it was very clear we didn't need an engine from scratch, so you look at what you have. It was obvious this was the best engine, in terms of fulfilling the demands of performance, weight, costs, packaging, all these criteria.

'It was standard work, tailored to special demands of LMDh. I didn't interfere with that. I know these guys, and I trusted them as they spent the time looking into the details.

'If we have two engines, both fulfilling all the technical demands so you don't carry a disadvantage, then you choose the cheapest one, for sure. That transfers into operation costs. We want to offer customer cars, and [it also makes sense] for our own budgets.

'There is a lot of carry over [from the RS Spyder engine]. I am not sure that we still had all the tooling, but then we got the go ahead to do it. Most of it was still there, and what was not in stock we could organise it.'

Easy option

Fitting the turbos to the engine was not that difficult, and this method was also the option chosen by BMW for its P55 engine that will be used in its LMDh car. While it is a favoured route taken by the LMDh manufacturers due to cost and availability options, it has been somewhat ridiculed by the LMH manufacturers. They have been outspoken about the fact they have developed their own engines, and hybrid systems, as well as battery design, in order to go racing, instead of taking an old V8 engine and fitting it to a commercially available chassis.

Supplementing engine power is a hybrid system. This will be used in all LMDh cars, from Cadillac to Lamborghini, and as the first car out on track, Porsche has been tasked with ensuring the system is tested properly. That, however, has not been straightforward.

Parts of the system have not performed as hoped and, while Porsche has put some 8000kms on its car since testing began earlier this year, the hybrid system has prevented it completing more. A 36-hour test at Aragon, for example, was curtailed by failures, much to the frustration of Porsche.

Problem solving

'We started testing on the track and that was good,' says Laudenbach. 'We did some kilometres with and without the hybrid, but not with the full potential. Then we went to Aragon for an endurance test, and we couldn't do it, which had a major impact. I am not happy about that, and it is something we have to solve.

'I don't want to see a situation where none of the LMDh cars can race at Daytona due to a part that we all use, so we have to solve that one. I just expect that the people who are responsible for that solve it because it costs us a lot of money.

'We wanted to have done an endurance run at this stage, and we haven't done it. We have been here before where, if things don't run as you expect, then you have to act with everything you have.

> **'We started testing on the track and that was good… [but] then we went to Aragon for an endurance test, and we couldn't do it, which had a major impact'**
>
> *Thomas Laudenbach, vice president of motorsport at Porsche*

'That is the only expectation I have from my own guys. If something comes up that doesn't work as we want it to work, put every effort into solving it as quickly as possible because we need to carry on with our programme.'

While many look at a spec system and say it should be easy to fit, a plug 'n' play, the system must be completely reliable, perform at the power outputs required by the regulations, and be built to a cost. This is not the work of a moment, and

Styling is a major part of the LMDh concept, manufacturers being able to incorporate recognisable elements from current road cars into the design, such as the full-width tail light seen on the 963 and also on regular production models

the decision to go with Multimatic, rather than Dallara, Ligier or ORECA, was an obvious one. As exclusive supplier to the VAG at the time the deal was signed, it was also to include Audi, and Porsche was able to be closely involved in the design stages of the project.

'With Multimatic we have a good partnership, and we did stick to what the idea of the rules are, and we were happy to bring in our knowledge,' says Laudenbach. 'You can't gain a big advantage from technology due to Balance of Performance, so what can you do? You can do handling well, make the car robust and stay within the framework of the weight. So a lot of things that we learned we contributed.'

As previously stated, the plan was to have LMDh cars fill out the national, as well as the international, series, but that was scuppered at Le Mans last year when the ACO and FIA confirmed their commitment to the LMP2 class. That left the four chassis manufacturers with a problem; how to turn the LMDh chassis back into a commercially cost-effective chassis for customers, fitted with a spec engine.

Porsche surely had memories of its dominant 956 and 962 (here in Group C guise) cars in mind when it started the LMDh programme

for now, Porsche is paying a price for it through testing delays caused by failures.

This is a worry not only for Porsche, but also all the other LMDh manufacturers, not least BMW, Acura and Cadillac, all of whom are scheduled to race for the first time at the 24 Hours of Daytona in January 2023. All expect the system to be working by then, but there is concern about the lack of testing time ahead of the race debut.

It gets worse. For a car to compete at Daytona, it must take part in IMSA's validation tests in December this year. Time is always the enemy in racing and, right now, it's a fierce one for the LMDh teams.

Chassis partner

Chassis options were limited to the four manufacturers selected to build LMP2 chassis for the 2017 season. For Porsche,

'There are a lot of things that need to be worked on for LMP2,' said Multimatic boss, Larry Holt, at Daytona in January. 'The tub we have worked on for Porsche has a great big battery cavity in it, and that drives cost. If you cut a section through the car, it is asymmetric. I have never built an asymmetric car before in my life!

'It has compromises in it to accommodate the battery and lines and so on. That has an on-cost and now you have to use it in LMP2, which seems weird.'

The ACO hinted at Le Mans that the future of LMP2 could be hybrid, and confirmed the LMDh chassis would be required to be available to teams for a fixed cost. That, however, is Multimatic's problem, not Porsche's.

Design cues

Balance of Performance allows the production car stylists to get involved in the racing programme, and they have done so with gusto. The 963 carries the styling cues of not only its 956 and 962 predecessors, but also current road cars, including a continuous strip of light at the rear that echoes the latest version of the 911, the 992.

However, the downside of the Balance of Performance system is that it is possible for manufacturers to hide performance, and this is a primary concern for Porsche. The BoP system is not yet operational for LMDh cars due to the issues in testing the hybrid system which has delayed the programmes of the other manufacturers.

Once they start running, the cars then have to be balanced against LMH, which itself has Peugeot as the outlier due to its rear wing-less concept and larger front tyre. LMDh carries the same size front and rear as the LMH cars from Toyota this year, and Ferrari next year, and already the arguments have started. Laudenbach already has experience of BoP arguments from the GTE category and knows what needs to be done.

'If I thought that the BoP would not be possible then we shouldn't participate, I would not have recommended to go to LMDh,' says Laudenbach. 'It is difficult, and even if they do it right, there will be tracks and conditions where one or the other will have an advantage. That is what I expect, but if the base balance is right, that is fine for me.

'If you come to the series you cannot expect to win five times in a row. That is something you have to accept before you sign to participate. But this is not the thing that worries me. What worries me most is how will the competitors act? If we expect from our governing bodies a good and fair BoP, so everyone has the chance to win if they do a perfect job, we must follow some rules, some code. If we don't do that, then I don't think they will have a chance to do it properly, and then we cannot blame them.

'If this is going to happen, it will kill the series, but we cannot blame the guys doing the BoP. Everyone has to show their performance.'

Playing the game

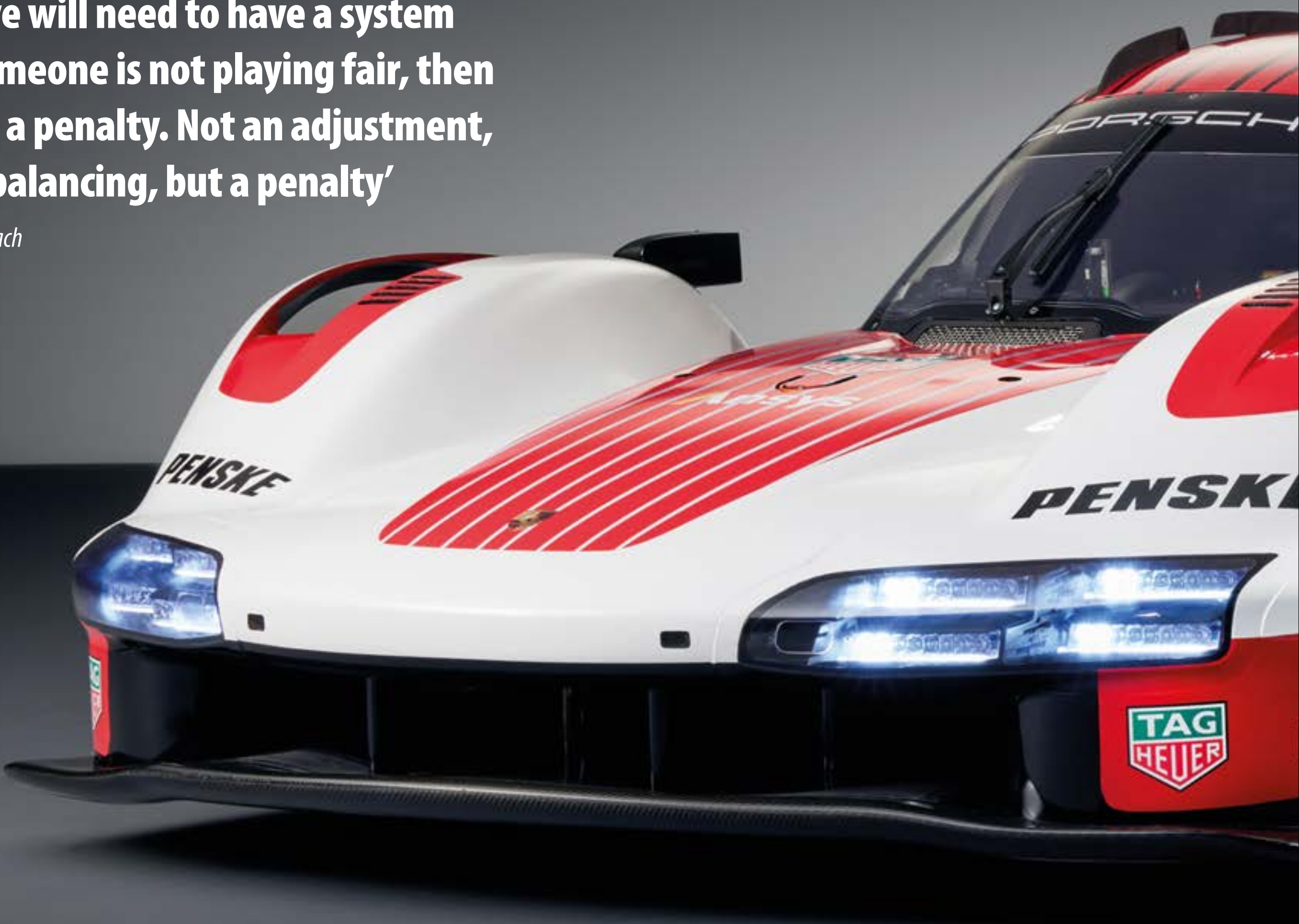
Next year features the golden carrot that is the overall win at the 2023 Le Mans 24 Hours, on the 100th anniversary of the race which has applied maximum pressure to the BoP engineers.

The governing bodies believe that, by prescribing performance windows into which the cars must fit aerodynamically, and in all conditions, as well as monitoring the power output through torque sensors on the driveshaft, they have enough at their disposal to be able to manage the performance and see what's actually happening in the car.

'If they take engine power from you, and they have torque sensors in the driveshaft, then it is difficult to react,' admits Laudenbach, when asked about the headroom naturally built into the cars when they are under

'I think we will need to have a system that if someone is not playing fair, then you need a penalty. Not an adjustment, not a re-balancing, but a penalty'

Thomas Laudenbach



Engine is based on the company's 3.4-litre V8 from 2005 (shown), which was later bored out to 4.6-litres for the 918 road car. For LMDh, it uses twin turbos to achieve the prescribed power curves

development. That headroom is released when the BoP changes are made, to maintain the same performance, even if there is a cut by the organisers.

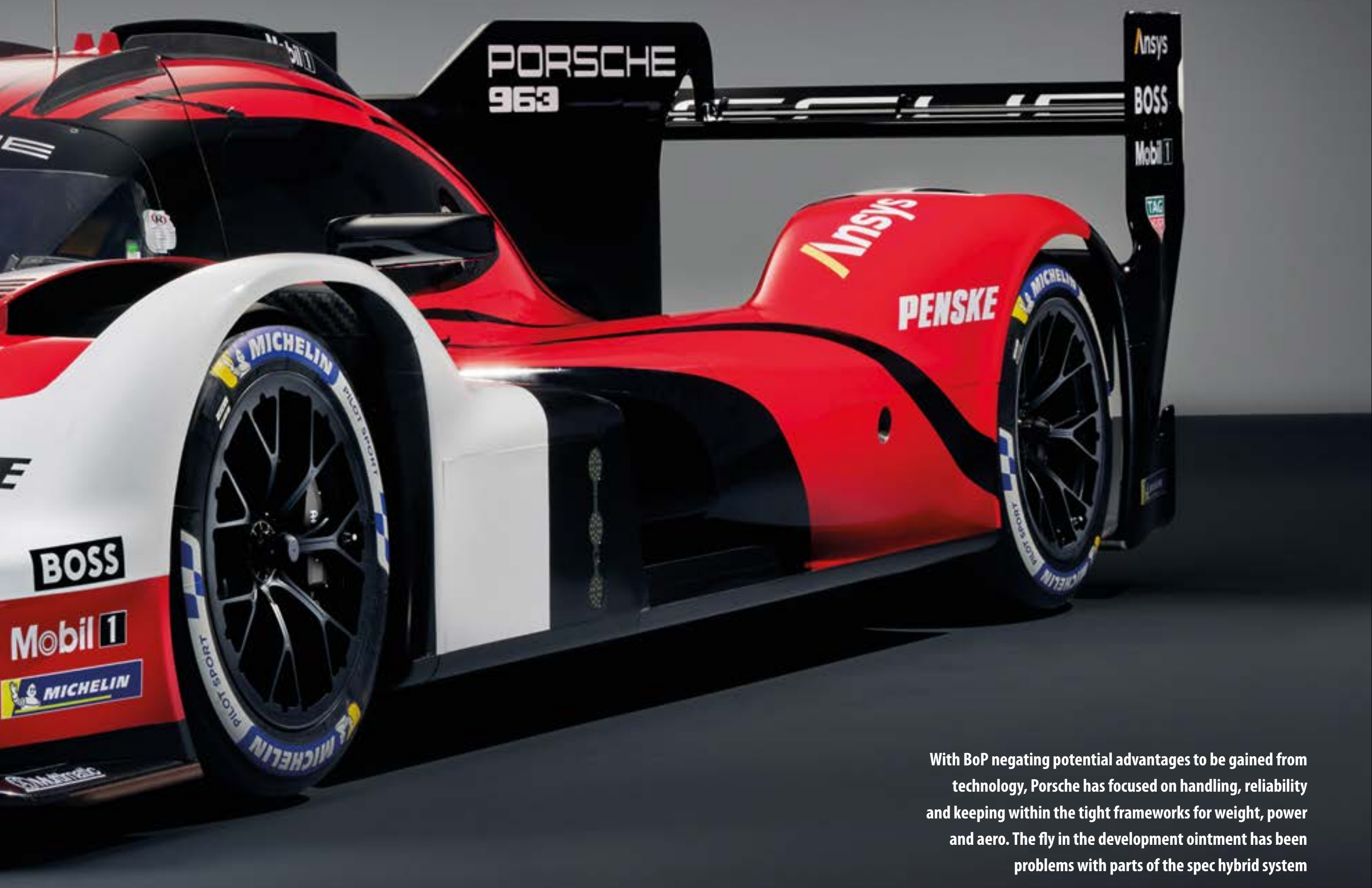
'From engine control it wouldn't be a problem. If they take off 10bhp, they can measure it. If they take something and you can compensate then that is fine, but that won't work in all areas. If they take off downforce because you are strong in grip restricted areas, like corners, then that is something you can measure. 'I think we will need a system that if someone is not playing fair, then you need a penalty. Not an adjustment, not a re-balancing, but a penalty.' This has been done by other series but not yet by the ACO or IMSA.

'Hopefully, we are coming to a stage where no one is playing that game, and get rid of this BoP discussion all the time, and we have series where we are close to that stage.'

For clarity, headroom is not the same as hiding performance. Once BoP is finalised, it is up to the manufacturers to show their full potential within that set of parameters.

'In the US, I see it works in the top class,' notes Laudenbach. 'I am not saying it is easy, but you have a choice to say I don't think it will work, so we step out, or that it is difficult but let's hope we get it right.'

'You can now race for overall victory in the US and Europe, which is really nice.'



With BoP negating potential advantages to be gained from technology, Porsche has focused on handling, reliability and keeping within the tight frameworks for weight, power and aero. The fly in the development ointment has been problems with parts of the spec hybrid system

Cruise control

Toyota, JOTA, Porsche and Aston Martin all took wins at this year's 24 Hours of Le Mans. Racecar *was on site to see the action*

By ANDREW COTTON

Toyota scored its fifth successive win at the 90th edition of the Le Mans 24 hours, with Brendon Hartley, Sebastien Buemi and Rio Hirakawa taking the victory ahead of their team mates, Mike Conway, Jose Maria Lopez and Kamui Kobayashi.

Glickenhaus, meanwhile, saw its two cars come home third and fourth, with Ryan Briscoe, Richard Westbrook and Franck Mailleux taking the final spot on the podium after a relatively trouble-free race.

Unsurprisingly, Balance of Performance was a hot topic ahead of the race, with Alpine penalised after qualifying within four tenths of the Toyotas after Thursday's Hyperpole session. As one observer put it, 'If ever you want an illustration of a Balance of Performance that doesn't work, this is it.'

Even if it had stayed reliable, there was no way the Alpine, winner at Sebring in March, could compete on pace.

In GTE Pro, BoP arguments raged behind the scenes, with at least one manufacturer threatening to end programmes completely unless cheating was exposed. This was a consequence of running the race outside the normal, automatically-generated Balance of Performance that governs the rest of the FIA WEC season, due to the nature of the circuit and length of the race.

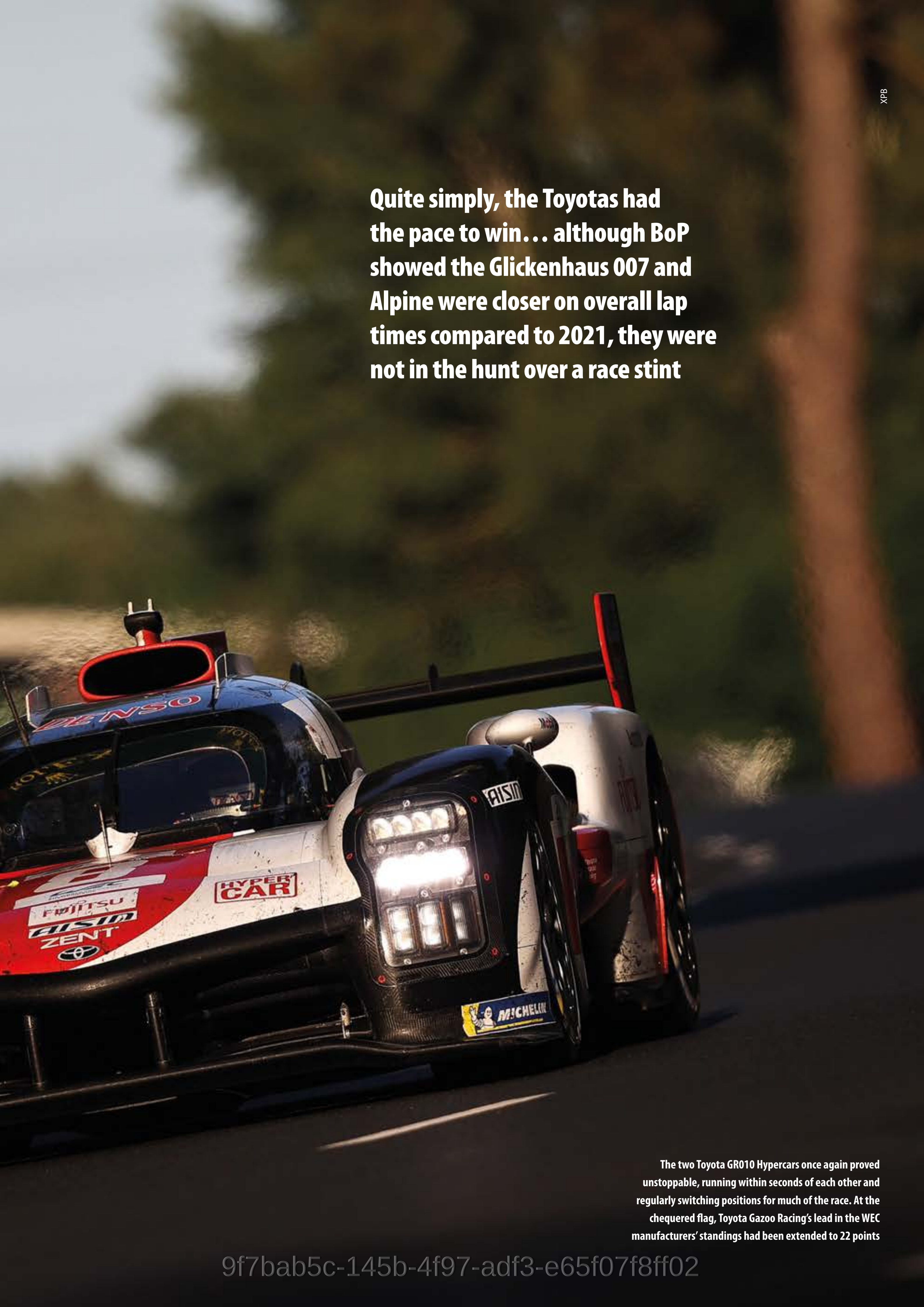
Eventually, it was resolved, but the rumblings about performance balancing will undoubtedly reach even noisier levels in the months to come as LMH and LMDh prepare to do battle in France in 2023.

For the future, there was a proposal to make a Le Mans-specific aero kit for the GT3 cars when they come in 2024, which will make balancing the GT cars even more complicated. With that in mind, there was further discussion about the kits being run throughout the year.

Consumable woes

One other topic of conversation was TotalEnergies' new fuel. It is supposed to be cleaner for the environment, but LMP2 teams have struggled to integrate it into their systems, due to its slightly different properties compared to the petrol used last year. Teams have also been working hard to find a suitable grade of oil that works with it.

Consequently, LMP2 teams were forced to run a different Motul oil for the race, switching from 5W30 to 5W50 grade to reduce the viscosity of the fuel. Teams then complained of higher oil consumption than last year, which rather negates its improvement in environmental impact, although there were no mechanical failures in the race due to this issue.



XPB

Quite simply, the Toyotas had the pace to win… although BoP showed the Glickenhaus 007 and Alpine were closer on overall lap times compared to 2021, they were not in the hunt over a race stint

The two Toyota GR010 Hypercars once again proved unstoppable, running within seconds of each other and regularly switching positions for much of the race. At the chequered flag, Toyota Gazoo Racing's lead in the WEC manufacturers' standings had been extended to 22 points

The durability of tyres was another concern. Michelin teams in the top class and GTE Pro, along with Goodyear in LMP2, all experienced problems that had to be resolved. Glickenhaus, notably, had to increase tyre pressure at the rear and therefore reduce performance in order to protect its inner shoulder.

With such stiff competition in LMP2, it was to be expected that teams would run higher camber and lower pressures in a bid to make a difference, but debris on the circuit, and the sharp stones the ACO introduced into the gravel traps more than 20 years ago caused tyres to be cut, and in some cases to burst. Teams also reported damage to certain kerbs, which contributed to punctures.

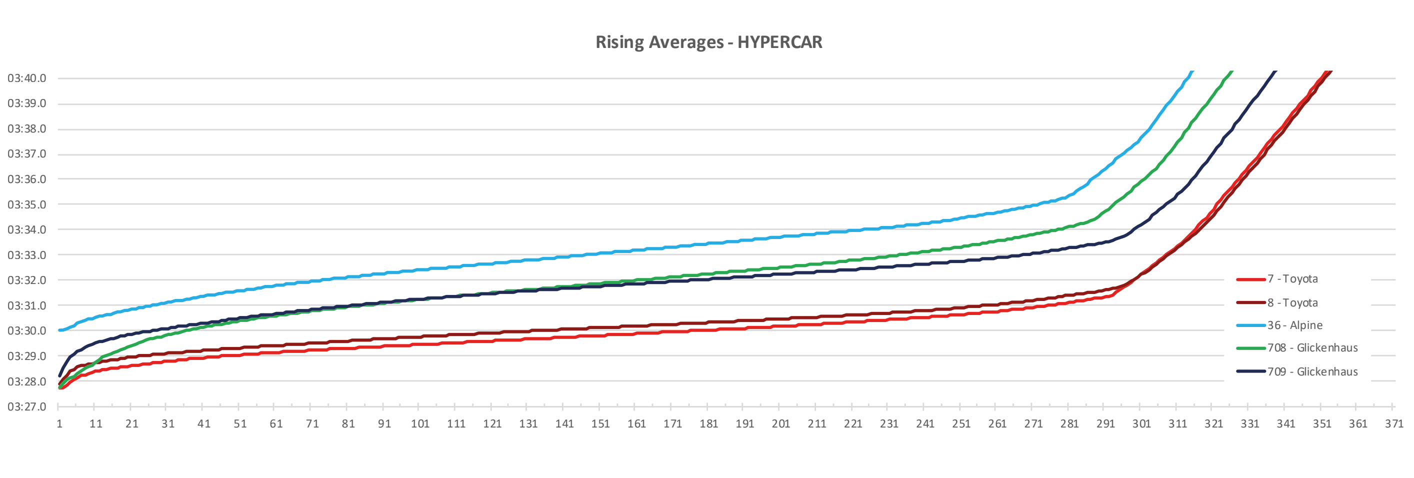
Reliability run

The race for the overall win was, as expected, a reliability run, and it was only a momentary lapse of reliability for one of the two Toyotas that ultimately decided the race. Quite simply, the Toyotas had the pace to win and, although Balance of Performance showed the Glickenhaus 007 and Alpine were closer on overall lap times compared to 2021, they were not in the hunt over a race stint.

That lack of outright speed over 12 laps of the 13.6km circuit was made worse by reliability issues, particularly from the Alpine, while a driving mistake cost the crew of the 708 Glickenhaus dearly, it finishing 10 laps behind the winning Toyota.

It was Alpine, however, that was hardest hit by BoP. The A480 Gibson was just not fast enough to compete with Toyota, having been given a 33kW reduction in engine power ahead of the race. It had already been given a 20kW power reduction after winning the Sebring 1000 miles in March, though half of that was returned for the test day, and a

LMDh rising averages



Best lap, and best average over 50 laps, Hypercar and LMP2, *sorted by finishing order*

Pos	No.	Team	Car	Laps	Best lap	Per cent	Ave best 50 laps	Per cent	No of pit stops	Total time in pit
1	7	Toyota Gazoo Racing	Toyota GR010 HYBRID	380	03:27.906	0.08%	03:29.329	0.13%	31	39:47.802
2	8	Toyota Gazoo Racing	Toyota GR010 HYBRID	380	03:27.749	0.00%	03:29.050	0.00%	32	41:45.782
3	708	Glickenhaus Racing	Glickenhaus 007 LMH	375	03:28.227	0.23%	03:30.492	0.69%	31	44:20.837
4	709	Glickenhaus Racing	Glickenhaus 007 LMH	370	03:27.765	0.01%	03:30.374	0.63%	33	53:44.798
5	36	Alpine Elf Matmut	Alpine A480 - Gibson	362	03:30.030	1.10%	03:31.573	1.21%	34	1:24:31.411
1	38	JOTA	Oreca 07 - Gibson	369	03:31.721	0.00%	03:33.654	0.10%	41	53:29.683
2	9	Prema Orlen Team	Oreca 07 - Gibson	369	03:32.335	0.29%	03:34.009	0.26%	42	53:59.187
3	28	JOTA	Oreca 07 - Gibson	368	03:32.750	0.49%	03:34.226	0.37%	42	51:43.111
4	13	TDS Racing x Vaillante	Oreca 07 - Gibson	368	03:31.728	0.00%	03:33.446	0.00%	42	54:22.088
5	5	Team Penske	Oreca 07 - Gibson	368	03:31.910	0.09%	03:34.001	0.26%	41	54:27.376
6	23	United Autosports USA	Oreca 07 - Gibson	368	03:32.436	0.34%	03:33.913	0.22%	49	57:27.613

Best lap, and best average over 25 laps, Hypercar and LMP2, *sorted by best average lap*

Final class pos	No.	Team	Laps	Best lap	Best 25 lap average	Pit stops	Total time in pit
8	48	IDEC Sport	366	3:31.601	3:32.557	43	1:00:11.550
17	41	Realteam by WRT	362	3:30.918	3:32.613	43	1:05:23.498
11	32	Team WRT	366	3:30.946	3:32.765	43	58:43.205
4	13	TDS Racing x Vaillante	368	3:31.728	3:32.912	42	54:22.088
7	37	COOL Racing	367	3:31.421	3:32.935	44	58:30.872
22	10	Vector Sport	357	3:31.115	3:33.098	42	1:26:07.160
27	31	WRT	285	3:32.136	3:33.204	35	44:49.438
1	38	JOTA	369	3:31.721	3:33.252	41	53:29.683

further 7kW increase given for the Hyperpole. But a subsequent 10kW reduction for the race meant, as Nicolas Lapierre lamented, 'We are struggling to even overtake the LMP2 cars in a straight line.'

The car was certainly better matched against the Glickenhaus on overall lap times, but both cars were far away from Toyota on overall pace (see rising averages chart on p14).

Evenly matched

As expected, the two Toyotas were evenly matched throughout the race. It was only on Sunday morning when a problem with the front hybrid motor stopped Lopez in the no.7 car out on track, and a subsequent lengthy pit stop to reset the system, decided the result in favour of the no.8 car.

In fairness, it had been anticipated that at least one of the cars would have the mechanical issue as it has happened before in testing, and at the WEC race at Spa.

The rumblings about performance balancing will undoubtedly reach even noisier levels in the months to come as LMH and LMDh prepare to do battle in France in 2023

'From my side, it is hard to take to be in the car when these things happen,' said Lopez after the race. 'We knew it *could* happen, we have had it in testing, and we had procedures that took 30-40 seconds to fix it. But this time it took longer.

'In the pit, we tried new procedures and we look at the positives: we were able to keep fighting, we were nearly a lap down, and came back by nearly a minute, and so we showed we had a car good enough to win.'

Toyota's technical director, Pascal Vasselon, confirms this: 'The set-ups were slightly different, but the pace of the two cars was extremely close, and the leader was changing nearly every stint at some point, so we cannot say that one car was better at night.

'At the beginning, Seb [Buemi] was pushing [hard] in the first stint and paid for it in terms of degradation. Later, he took a bit more care of the tyres and then the two cars were close. Because the two cars were so close, a small problem decided the hierarchy.'

Sensor humour failure

The two Glickenhaus cars that had run so reliably in 2021 had a less successful 2022 event. The first issue hit the no.709 car of Briscoe, Westbrook and Mailleux on Saturday afternoon when an engine sensor failed. Each bank of cylinders has a sensor to monitor power output and one showed the engine was using too much power. The team made an alteration to the system so one sensor covered both banks and continued without problems, but then the same issue also affected the sister car.

Olivier Pla made a mistake on Saturday night in the no.708 car and spun at Tertre Rouge. The Frenchman, who shared the driving with Pipo Derani and Romain Dumas, damaged the left rear of the car against the barriers and picked up a puncture, too.

However, a bigger problem for the team was the state of the tyres, with a series of rubber-related problems on Saturday. Posting slower lap times, and with the aforementioned sensor issues, the team elected to sacrifice further performance by increasing the pressure of the rear tyres to make them more secure.

Alpine also had far from a perfect run. A problem with the electronics controlling the clutch dropped the car down early on Saturday, and an engine issue cost more time. Pushing hard to recover, Matthieu Vaxiviere then crashed on Sunday morning while lapping traffic in the Porsche Curves, ending the team's hopes of a podium.

The grandfathered LMP1 car was granted a stay of execution for 2021 as the series needed cars in the top group, and that was extended through to 2022. However, the series will not need it next year and team owner, Philippe Signault, was clear that this was the last time the car would race at Le Mans.

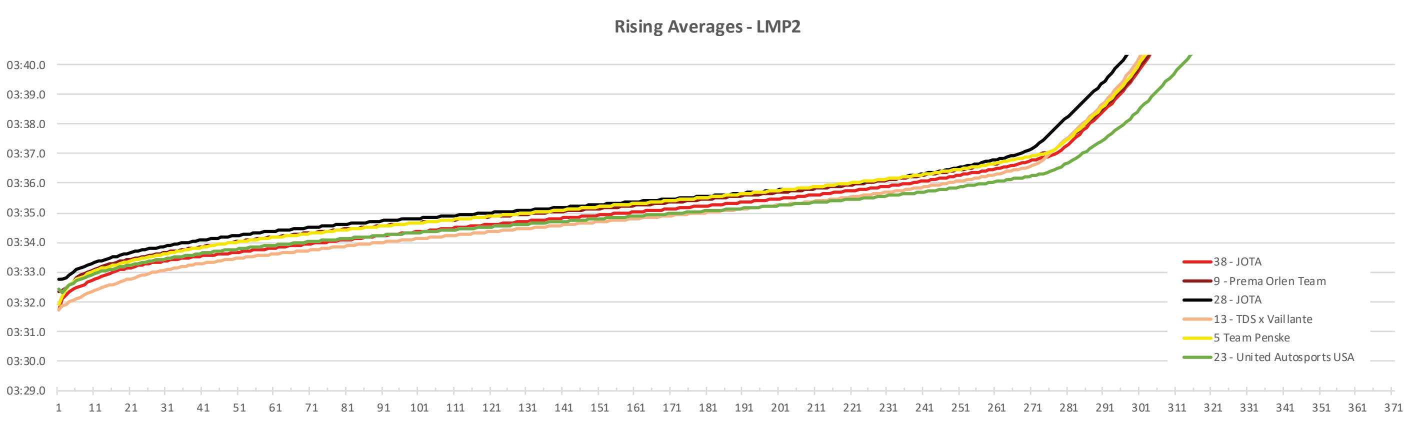
Next year, new cars will come from Ferrari, Peugeot, Porsche and Cadillac, while Jim Glickenhaus still has to confirm plans after what was set out to be a two-year programme.

Other privateer cars are also waiting in the wings, so it is unlikely the old LMP1 car will continue to race in the series.

XPB

Pre-race, the Toyotas had been suffering intermittent problems with the front hybrid units and the issue occurred again on the no.7 car during the race, deciding the finishing positions of two otherwise very evenly matched cars

LMP2 rising averages



Things were slightly different in the LMP2 class. The race got off to an incredible start when Rene Rast, driving one of WRT's three cars, moved to the left on the run to the first corner, hitting the United Autosport car of Will Owen, who was pushed into another of the WRT cars driven by Ferdinand Habsburg.

Owen lost a lap being pulled out of the gravel at the first corner, Rast received a stop and go penalty and Habsburg had to complete a slow lap back to the pits with rear-end bodywork damage. That wiped out three of the leading contenders for the race win on the very first lap.

Mighty impressive

With just one Ligier in the group and the other 26 cars all ORECAs, the difference between the LMP2s was negligible on paper. However, during the race it was Team JOTA's mighty no.38 car that produced an incredible display, taking the win by more than two minutes, leading a total of 354 laps, including the last 259 to the chequered flag.

That said, its opponents pressed the self-destruct button early on, with accidents, punctures and penalties taking out some of the other fancied runners before it even got dark. Nevertheless, Antonio Felix da Costa, Roberto Gonzalez and Will Stevens performed faultlessly on track, building a gap on Saturday afternoon, while the team made full use of its strategy options to extend the advantage, running an F1-style virtual garage to help get the big calls right. The JOTA team was also strong in the pit, so the LMP2 class also became a reliability on Sunday.

'My age-old adage is that if you finish with the same nose and tail that you start, you will be on the podium,' said JOTA team manager, Sam Hignett. 'That still rings true. But Antonio and Will's stint at night, they were really impressive, the pair of them.'

Competition came from the Prema team of Robert Kubica, Luis Deletraz and Lorenzo Colombo, which led in the opening stages thanks to a great start from Kubica, but things went downhill from there.

Team JOTA's mighty no.38 [LMP2] produced an incredible display, taking the win by more than two minutes, leading a total of 354 laps, including the last 259 to the chequered flag

'We had some oversteer on Saturday so lost time with that, then I picked up a puncture at Dunlop and had to drive around with a flat tyre,' admitted Deletraz. By Sunday, they were the only ones able to challenge the pace of the JOTA team despite overheating problems. They were followed over the line by the second JOTA car of Rasmussen, Jones and Aberdein.

XPB

LMP2 was where the real action was to found. After a first lap incident took out three contenders, Team JOTA proved unassailable, crossing the line convincingly ahead of the field

Drew Gibson

The GTE race was tough, with Corvette putting in a strong performance, but forced out with mechanical issues and an unfortunate race incident, leaving Porsche to take the chequered flag

Best lap, and best average over 50 laps, GTE, *sorted by best average lap*

Pos	No.	Team	Car	Laps	Best lap	Percent	Ave best 50 laps	Per cent	No of pit stops	Total time in pit
1	91	Porsche GT Team	Porsche	350	03:49.060	0.31%	03:50.605	0.33%	24	32:44.388
2	51	AF Corse	Ferrari	350	03:49.109	0.33%	03:50.733	0.39%	26	34:52.914
3	52	AF Corse	Ferrari	349	03:49.196	0.37%	03:50.860	0.44%	24	32:43.219
4	92	Porsche GT Team	Porsche	348	03:48.356	0.00%	03:49.848	0.00%	23	39:23.237
5	74	Riley Motorsports	Ferrari	347	03:49.391	0.45%	03:51.157	0.57%	26	35:18.727
6	64	Corvette Racing	Chevrolet	260	03:48.771	0.18%	03:50.082	0.10%	N/A	N/A
		GTE-Am								
1	33	TF Sport	Aston Martin	343	03:53.266	2.15%	03:54.174	1.88%	24	36:07.294

Looking at the LMP2 rising averages, it is of course close competition; hard to differentiate when the tyres, engine, chassis and aero are the same for everyone. It comes down to race preparation and drivers, as well as some quick work in the pits. Ultimately, the goal is to finish reliably, and then see where you are in the overall scheme of things.

The TDS car dropped its bronze driver after he was excluded from the event following a series of incidents, and replaced him with Toyota reserve driver, Nyck de Vries. That meant the car was moved out of the Pro-Am category of LMP2 and was competing for the class win. It also improved the average lap times of the car, and many had it tipped to be a potential race winner.

The no.38 car was certainly fast, but not as consistent as the TDS car. From a driving perspective, De Vries was fastest in 15 per cent of lap times, with a 3m32.803s average, compared to no.48, Patrick Pilet's, 3m32.867s.

Notable too was the performance of Yifei Ye and Norman Nato, both gold drivers and faster than the platinum drivers, including Mirko Bortolotti, da Costa, Robin Frijns and Felipe Albuquerque. Clearly, the race is won and lost by the quality and speed of the Gold and Silver drivers, and the old adage of 'fast, reliable, rich; pick two…' is being challenged.

GTE battle

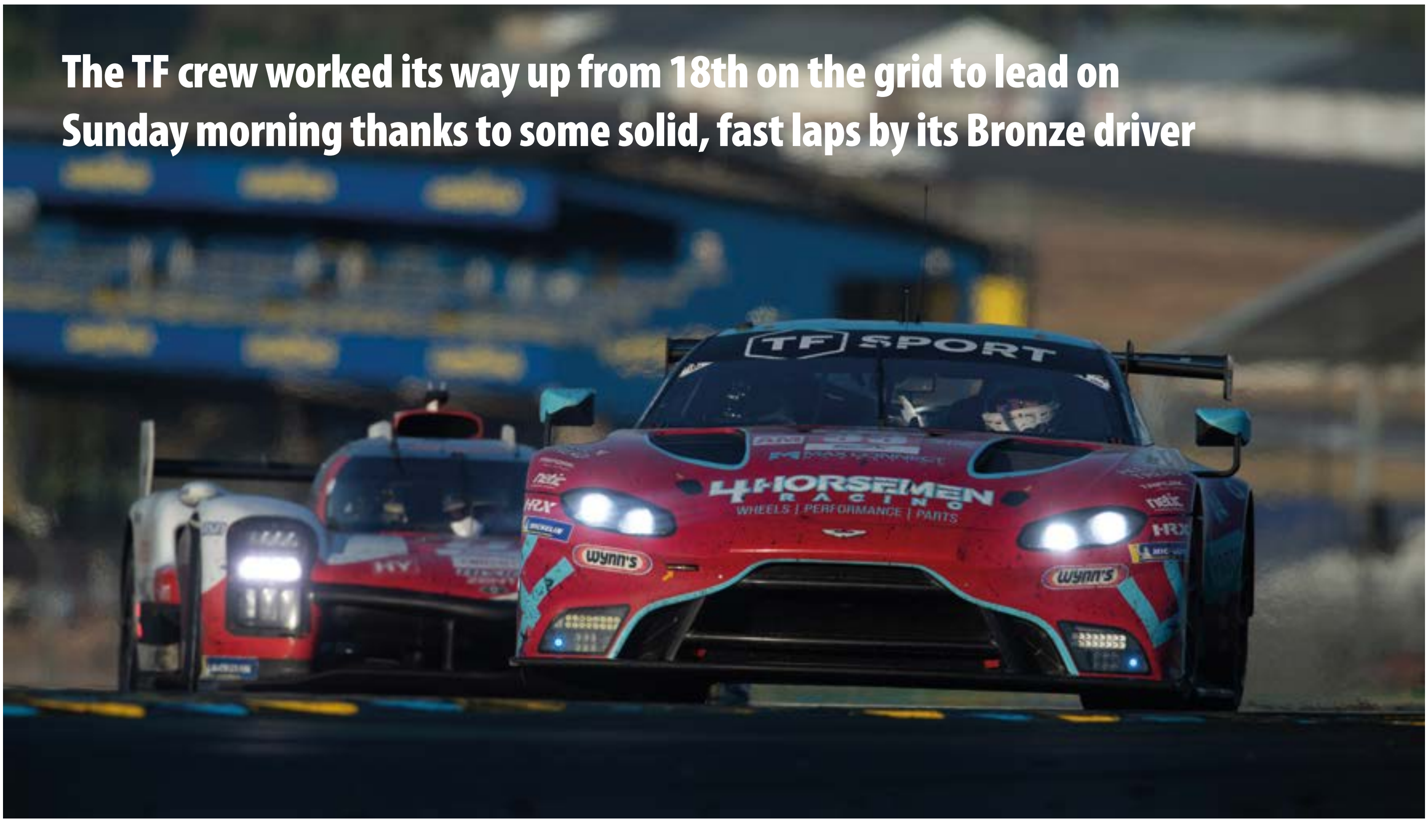
Porsche took victory in the GTE Pro class, thanks to a great drive by Fred Makowiecki, Gimmi Bruni and Richard Lietz. They benefited from problems that hit their main competitors, notably Corvette, and crossed the finish line 42 seconds ahead of the Ferrari

The [LMP2 Pro-Am] race is won and lost by the quality and speed of the amateur drivers

488 GTE of Alessandro Pier Guidi, James Calado and Daniel Serra.

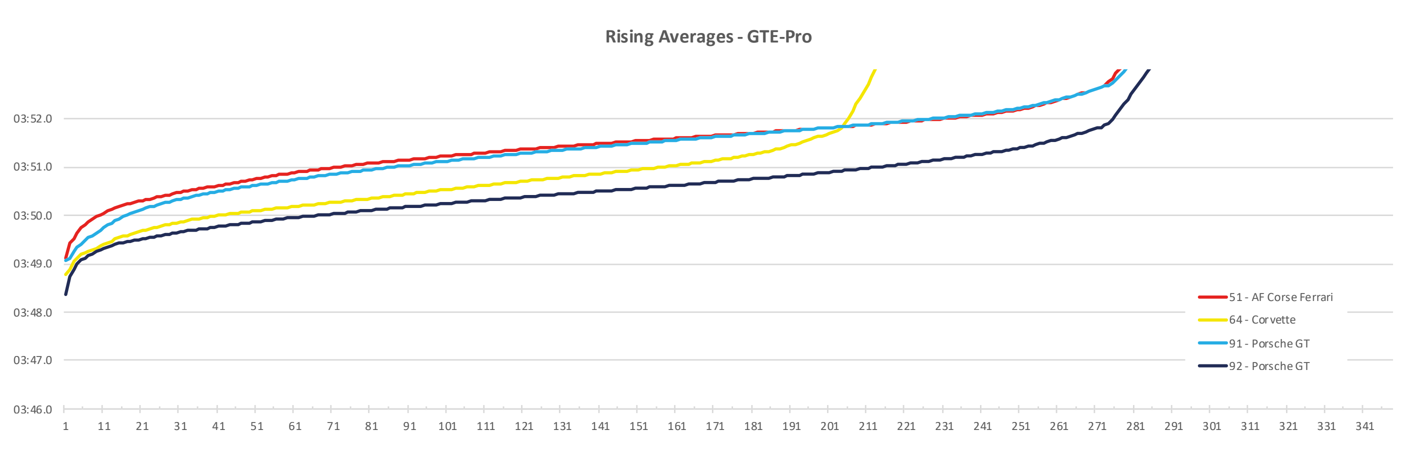
However, that's not to say the Corvettes didn't have their time in the sun. Both took their turn at the head of the field, before one dropped out with a rear suspension failure that the team were unable to trace to a root cause, so it was retired as a matter of precaution. The second was chasing the lead

XPB



The BoP arguments extended into the GTE-Am class. With no pro category entrant, rivals expected the Aston Martin to be strong and it was, taking the class win after some strategic thinking

GTE Pro rising averages



of the class hard when Alexander Sims was hit by another competitor and crashed out on the Mulsanne Straight. Game over.

That left Porsche at the head of the pack, but a front puncture with Michael Christensen at the wheel led to a lengthy pit stop that prevented them going for the win. Instead, it was their team mates in the no.91 Porsche that took the honours.

For Pier Guidi, second was the best he could have expected after a week of political wrangling around the BoP. Having scored two wins and two second places in the last four years, Ferrari clearly didn't have much to complain about. Except they did. The Italian manufacturer had power taken from it before the race, and paid the penalty during the race. Some believed they were playing a game but, when the flag drops, the bullshit stops.

Not only was the Ferrari struggling for pace but, shown in the rising averages above, the Ferrari drivers also had the highest lap times.

The surprise is that Corvette was not the fastest of the GTE Pro cars, but that is due to it doing fewer laps, so the pool of quick laps to compare is rather shallower than others.

Talking of the Corvettes, no.63 was slower than its sister car, but the no.92 Porsche was quick and would almost certainly have given it a good run for its money.

In the GTE Am class, the TF Sport Aston Martin team of Ben Keating, Hugo Chaves and Marco Sorensen took the win, a mere 44 seconds ahead of the WeatherTech Porsche of Cooper Macneil, Julian Andlauer and Thomas Merrill. The TF crew worked its way up from 18th on the grid to take the lead on Sunday morning, thanks in part to some

Some believed [Ferrari] were playing a game but, when the flag drops, the bullshit stops

solid, fast laps put in by its Bronze driver, Keating. The team also took advantage of the only safety car period of the race in the 18th hour to establish a gap to the second-placed Porsche, though the WeatherTech crew threw away its chance of victory after an off-track excursion on Sunday morning.

Also on the podium after the race was the Northwest AMR team of Paul Dalla Lana, Nicki Thiim and David Pittard.

Key differences

McLaren technical director, James Key, shares some of his experiences of a career spent in racecar engineering

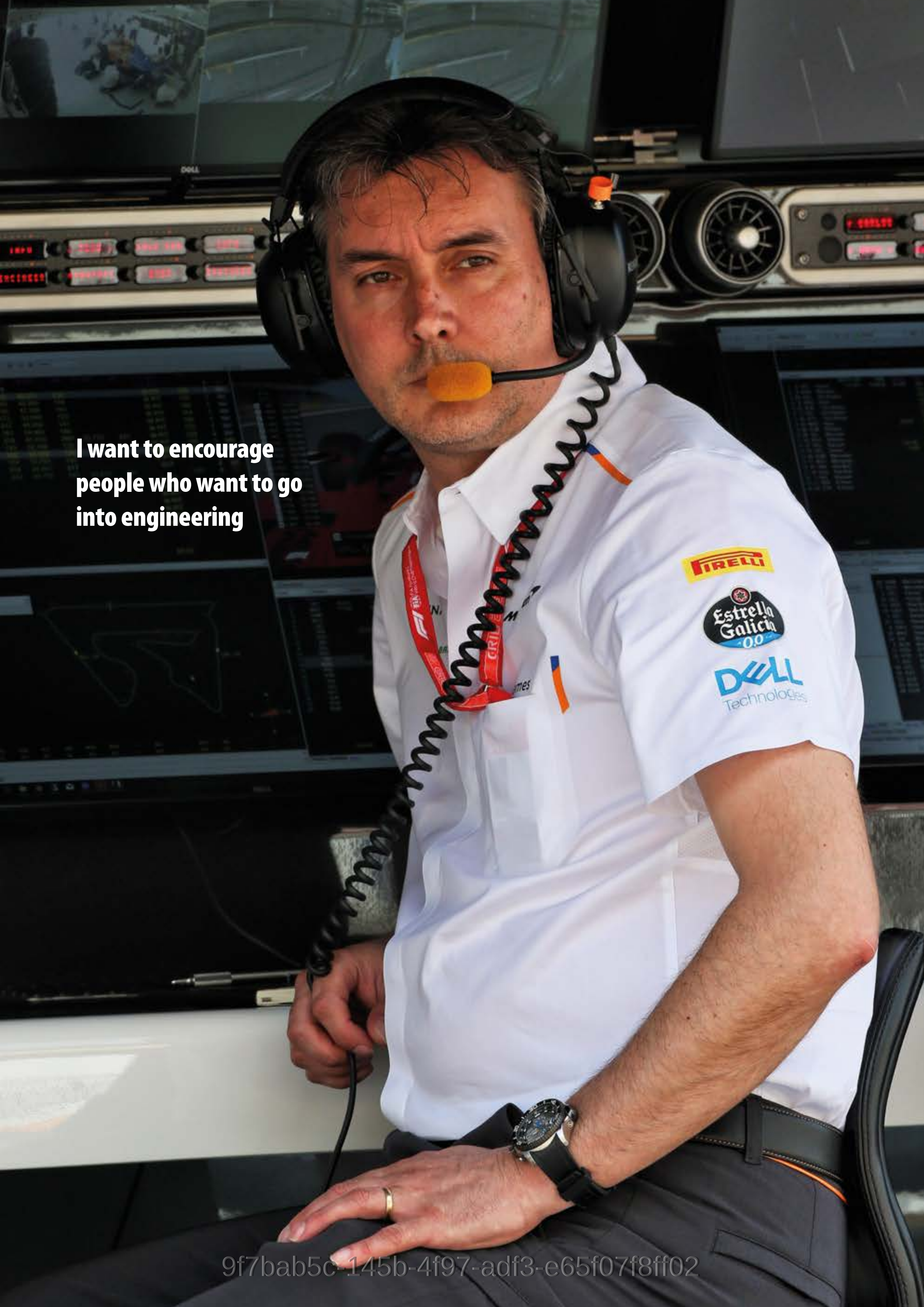
By DIETER RENCKEN

In July 1984, a 12-year-old English lad was so enthralled as he watched Niki Lauda win the 1984 British Grand Prix in the McLaren-TAG MP4/2 that he vowed to not only work in Formula 1 as an engineer but, ultimately, to do so by joining McLaren.

Via a somewhat circuitous route that saw him take up an apprenticeship with Lotus before graduating as a mechanical engineer, he realised his ambition in 2019.

Photos: XPB

The design of the 2022 car was helped by modelling data from the FIA that meant teams were not starting from a blank sheet of paper. The MCL36 Mercedes has since scored a podium at Imola



I want to encourage people who want to go into engineering

That youngster was James Key, now technical director at McLaren, who led the design of the 2021 MCL35M (M for Mercedes), an evolution of the Renault-powered MCL35. In September last year, the MCL35M scored a one-two in Monza, a momentous day for Key and vindication for his chosen career path, although the now 50-year old modestly credits his entire team. It was he, though, that set the design direction.

In this exclusive interview for *Racecar Engineering*, Key provides valuable pointers for budding engineers and technical directors. The conversation may be liberally sprinkled with words such as 'luck' and 'fortune', but, as this interviews underscores, 'luck' can be created…

***RE*: How did you get into Formula 1?**

JK: When I was very young, my father, a very successful engineer and car enthusiast, would open the bonnet of his car and I'd be fascinated by all these boxes and wires and pipes and stuff. He influenced me by explaining how things work and sharing his enthusiasm and passion for how important engineering is. It changes the way we live. It doesn't come out of the brown of a tree.

I believe we don't talk enough about it, but how the way we lead our lives, and how societies live, is heavily influenced by innovations out of science and engineering.

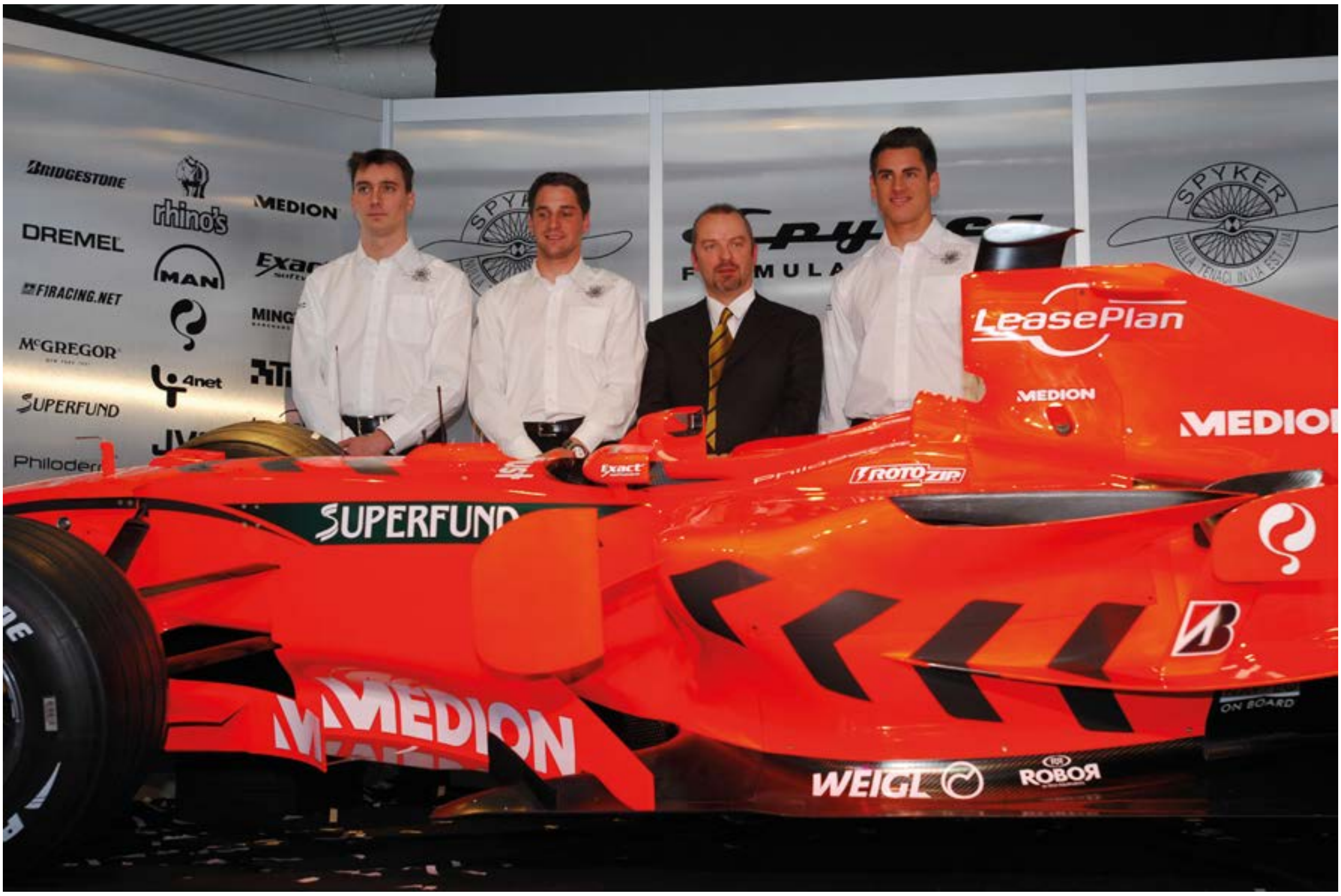
The way we lead our lives, and how societies live, is heavily influenced by innovations out of science and engineering

Formula 1 I picked up when I was about 12, and was immediately hooked, not least by the wonderful commentary by Murray Walker and James Hunt, who made the world of Formula 1 sound like a magical thing. I decided that's what I'll do if I'm lucky enough to get the opportunity.

I was fortunate to have a plan at a young age, and left school and home at 16 to go and pursue it. I know drivers do that, but not many engineers do. I joined Lotus Engineering, who were not very well known at the time. It was mainly road car stuff, but they had some big clients with big projects like active suspension. I got into chassis simulation – incredibly important at the time – and we did a Le Mans project.

Plus, Team Lotus [F1] was situated just down the road, which was very exciting.

Key spent 12 years at Jordan, through the team's transition to Midland, which was when he held his first technical director's role, aged 33



In a convoluted series of events, Jordan became Midland became Spyker (briefly), and eventually settled as Force India. It was a turbulent period but Key says it taught him some valuable lessons

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Key remembers his time spent at Sauber, and then Toro Rosso fondly, not least because it gave him the opportunity to work overseas with a number of very talented European engineers

Lotus [Engineering] sponsored me through university, and I tuned my degree to topics that were relevant to motor racing. I said to my professors, 'This is what I want to do, how can you help me achieve it?' And not just for my CV, but to learn the topics I needed to know, such as fluid dynamics, mechanics and vehicle dynamics. I was also able to work for them during the vacations and afterwards.

So, three years out [of university] I found myself in F1 with Jordan Grand Prix.

RE: What university did you attend, and what did you study?
JK: University of Nottingham, studying a Bachelor of Engineering degree, mainly mechanical, which comprised a whole range of engineering disciplines, including mechanics.

My third-year project was to design, build and test a performance acquisition system for competition cars, which was really tuned to what F1 was doing at the time. I've since set up a scholarship at that university (see sidebar on p29).

Then I went back to Lotus for two years, and then started at Jordan just before the 1998 season as a data engineer; what is now called a performance engineer. We were about five people doing the job of what is about 45 now.

It was at the transition of going from when you'd have someone who basically designed the car and had some help, to the sort of structure we've got now, where you've got a huge number of specialists all over the place who coalesce to design a car because it's so complex nowadays. I was lucky I caught that transition.

RE: Within Jordan, which variously changed identities, you became technical director in 2005. At 33, you were amongst the youngest to hold that position in the sport.
JK: I was there for 12 years. I saw [the team] through the period going from Jordan to Midland, which is when I became the technical director of the team, just before the Midland buyout, which was the same time really.

Then the team became Spyker for a year, so it was a bit of a turbulent period with ownership changes and budgets and so on. It was quite a tough time. Then it became Force India [in October 2007] and everything began to settle down again.

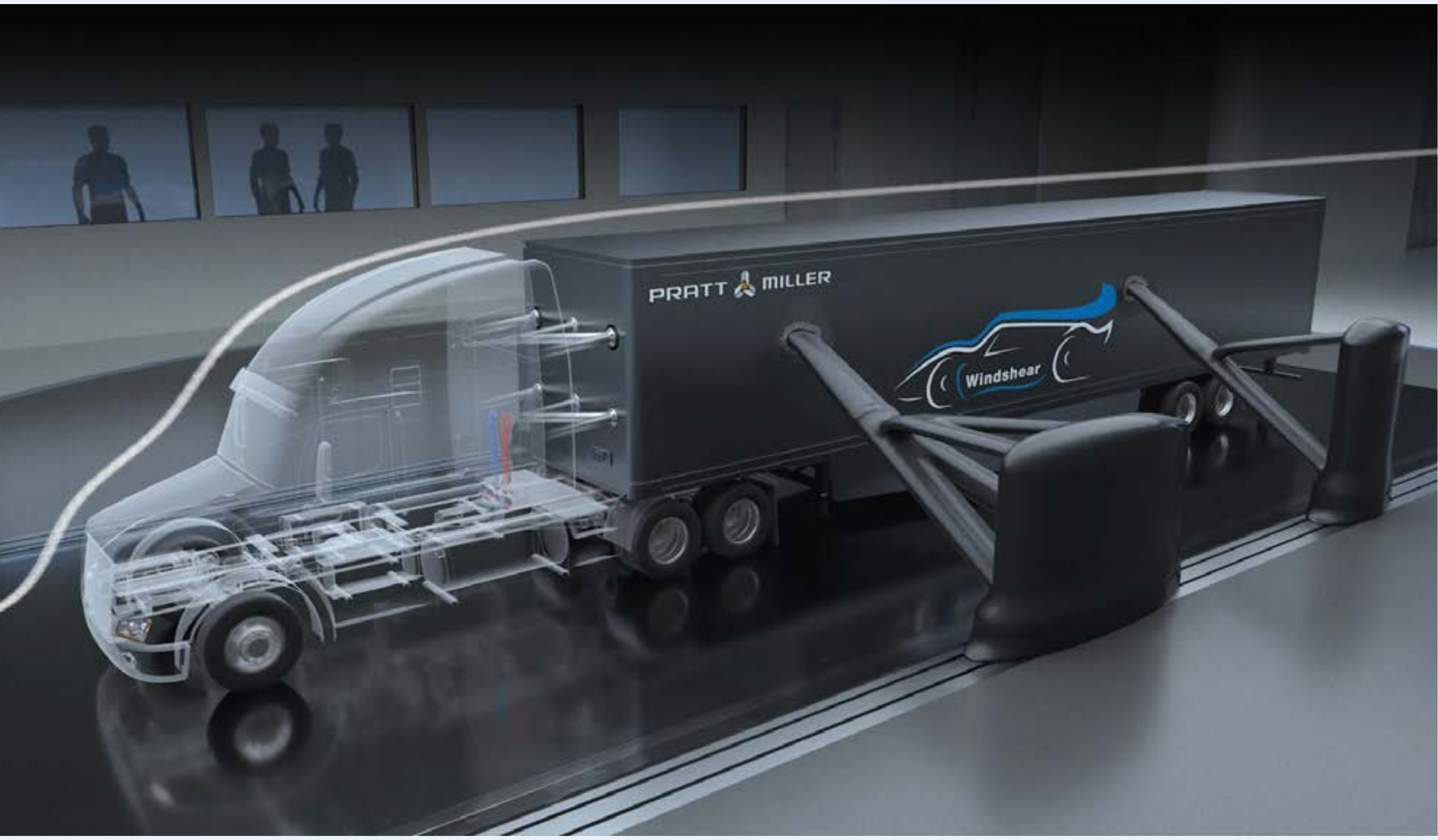
I was incredibly lucky to be surrounded by some very good people at Jordan. It was a team that punched well above its weight, having some successful years.

I suppose the biggest thing it taught me was how a small team – it wasn't really a small team, but it wasn't as big as McLaren or Ferrari – can operate very successfully. The way in which that happens, the efficiencies involved in it, the sacrifices you have to make to make up for the fact you haven't got so many people doing your job. Above all, how much difference *people* could make.

It was at the transition of going from when you'd have someone who basically designed the car and had some help, to the sort of structure we've got now

I learned so much from Gary [Anderson, former technical director], a huge amount from [colleague] Sam Michael and aerodynamicist Dino Toso, who so sadly passed away some time ago. All of these characters were just brilliant, and I was lucky [that word again…] to learn from them.

RE: Then in 2010 you joined Sauber in Switzerland, with all the challenges of moving countries.
JK: Sauber was another really good team, very similar to the way the Jordan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operated, with lots of experienced, good people. So it felt very familiar.

You'd have a group of four who did a whole suspension system, seven to do all the composites. It was impressive how much throughput there was. Everyone would quietly beaver away, and it was a really good, very efficient place to work.

But it was clearly going to be short of money, and because I joined just as BMW pulled out, there'd been such an awful period of uncertainty. It was also nice going in there to grab the bull by the horns and try and get away from that sort of difficult period.

***RE*: Then you had an offer from Toro Rosso.**
JK: That came out of the blue, to a certain extent, but what was attractive was that they had more stability, really strong ownership. It also meant that I worked in another country that's got a Formula 1 team, so I did the rounds in Europe a little bit!

Toro Rosso was also fantastic to work in. I signed off [drawings] in a Portacabin next to the old Minardi factory, and the team was growing all the time. New facilities were being built – we needed a much bigger aero department, we needed a bigger, more structured design group. We had a really strong design team, we just needed more boots on the ground.

I caught it at a time when it wasn't performing particularly well, so there was a lot of work to do. It was another great challenge. I'd been through it a bit with Jordan, so I thought there was some familiar ground, even though the team was unfamiliar, and the language was definitely unfamiliar, although they did a great job of speaking English.

In terms of the challenges, it was familiar, and I thoroughly enjoyed working with the Italian engineers. Very skilful guys and girls, and a pleasure to work with. That was a fantastic time.

***RE*: That came to an end when you received the McLaren offer, the realisation of a dream. You came in ahead of a regulation change that was pushed back a year due to Covid, which meant rolling over the MCL35 for a season and entailed a change of power unit from Renault to Mercedes. How did your team manage to dovetail the two?**
JK: New regulations are always a great challenge for engineers. We like new regs – I certainly do – because it gives you an opportunity to step back and re-think everything, rather than just the detail of what you're doing now.

New regulations are always a great challenge for engineers

Engine-eering

***RE*: During your time in F1, you've worked with virtually every power unit supplier, and almost every configuration: V10, V8, with and without hybrid units, Ferrari, Renault, Ford, Cosworth, Mercedes…**
JK: You can add Toyota to that list.

***RE*: What are the major differences in approach and *modus operandi*?**
JK: They were all very different. Not only do they have different architectures and so on, but their facilities, the approach, that sort of thing. There wasn't a set formula. It was all done differently, depending on the supplier you're working with.

The way the data is formatted and presented is different, so are the details, the electrical installations and systems and voltages, their cooling systems… *Everything* is totally different.

When it came to installing another power unit in the car after a change, there was very little carryover, you really did have to start again.

One of the most difficult things with engines is heat rejection, to get your cooling correct. It's a very difficult thing to measure and quantify as you don't really have any references. So, you really do have to start from scratch when you've got to design and integrate a totally different cooling system.

In fact, you have seven cooling systems on these cars, and must invent a package to fit into a space that you want to try to reserve for it. They're all very different, and they've all got their pros and cons.

In March 2019, Key received an offer to work for McLaren, the team that had inspired him to forge a career in F1 as a child. With a new rule set and then Covid, it was in many ways a baptism of fire

Last year's car regulations had been around for a while. It was maybe the fifth season of both [sporting and technical] sets of the regulations. With the new regs, we could look at an entire car in a very innovative, fresh way, particularly when they're so different.

RE: What was the next step once you'd grasped the overall direction?
JK: You start off a set of projects based around relatively robust regulations that changed a lot, and they continue to do so. You have the bones of what a 2022 car should look like, then everything else is applied to that.

We also had this very good process of developing the regs, which meant we had [modelling data] from F1 and the FIA in terms of aero surfaces. So you weren't really starting completely from scratch, there were reference points and aero data around from the white paper.

It was kind of a fuzzy beginning, because we weren't picking up the regs for the first time and reading them, they gradually introduced themselves.

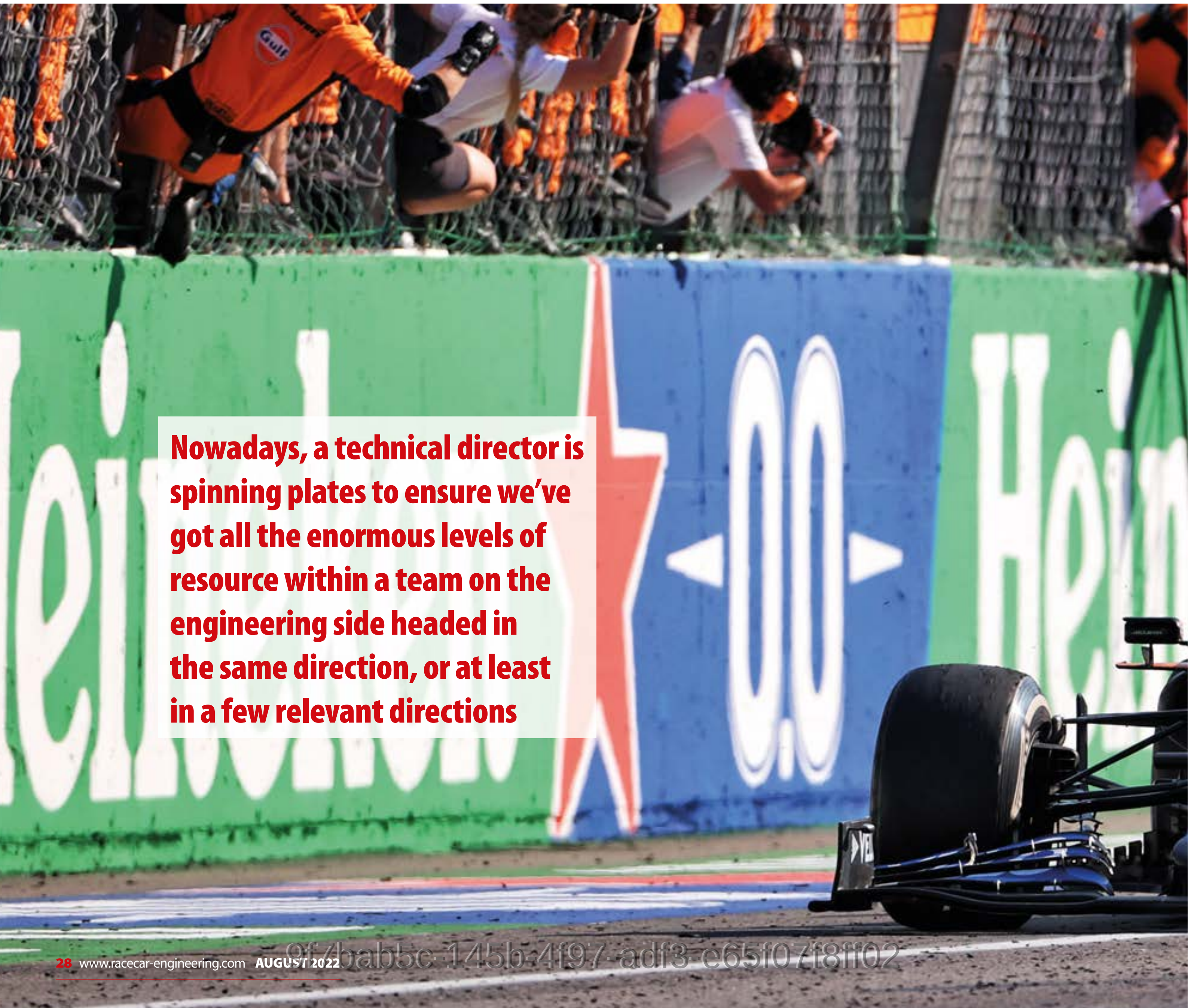
RE: And the next step after that?
JK: It was really a case of allocating resource and coming up with some ground rules on how you're going to approach it. You don't want to commit to things too early because there's so much to learn, but you don't want to be be sitting there waiting for things either. So we left our options open, assessed how much potential performance there was, because in some way we've got to know what sort of lap times makes a good 2022 car.

It's a whole range of things. A lot of simulation, a lot of understanding of tyres, because these factors are balanced and the set of balances will govern what you do with your suspension design, your front wing and so on.

It's an iterative process. We were constantly circling around all those things and gradually a direction and architecture emerges, which tries to complement everything you've learned. Then you really start getting into the details of setting out your platform based around that architecture and hitting your CFD and wind tunnel with finer detail of things like suspension geometries, until finally you end up with something. Then you're iterating a car around what you've established and fixed.

RE: How many decisions did you have to take almost on a daily basis, because obviously you've got all sorts of compromises to make that affect cooling, drag and so on?
JK: I couldn't tell you on a daily basis because I took decisions all the time, but the big ones – I suppose once, or maybe twice, a week you'd end up with, what are we actually going to do about this or that major component? What should we prioritise? Something that can change the direction totally.

It shouldn't be just down to me, so I tend to discuss it, to look for data or simulations, the trade offs. So there's



Nowadays, a technical director is spinning plates to ensure we've got all the enormous levels of resource within a team on the engineering side headed in the same direction, or at least in a few relevant directions

ways of making those decisions, which isn't just an executive decision.

***RE*: The way F1 has developed, there is no longer such a thing as a 'James Key car', but how much concept input did you have into any of the cars that were designed under your leadership?**

JK: That's changed over time because teams have got bigger and bigger, and more and more complex, and the need to specialise has increased.

Nowadays, a technical director is spinning plates to ensure we've got all the enormous levels of resource within a team on the engineering side headed in the same direction, or at least in a few relevant directions, because all of them complement each other and join together down the line.

So, you're kind of managing the process. I wouldn't say it's *more* managerial, or more technical, because it's also about meeting heavy budgets, HR matters, and many other factors.

I think a lot of [the job] nowadays is influencing the direction you're going in. You're outlining what the priorities are, then monitoring them, then discussing it, all the while making decisions as you go along.

You've got experts to then go away and really get into the details.

The 2006 Midland was the first car I did, but it's all changed since.

***RE*: Do you own one of 'your' cars?**

JK: No, but it would be nice to actually own one. I've got a special space put aside for one, should the opportunity arise…

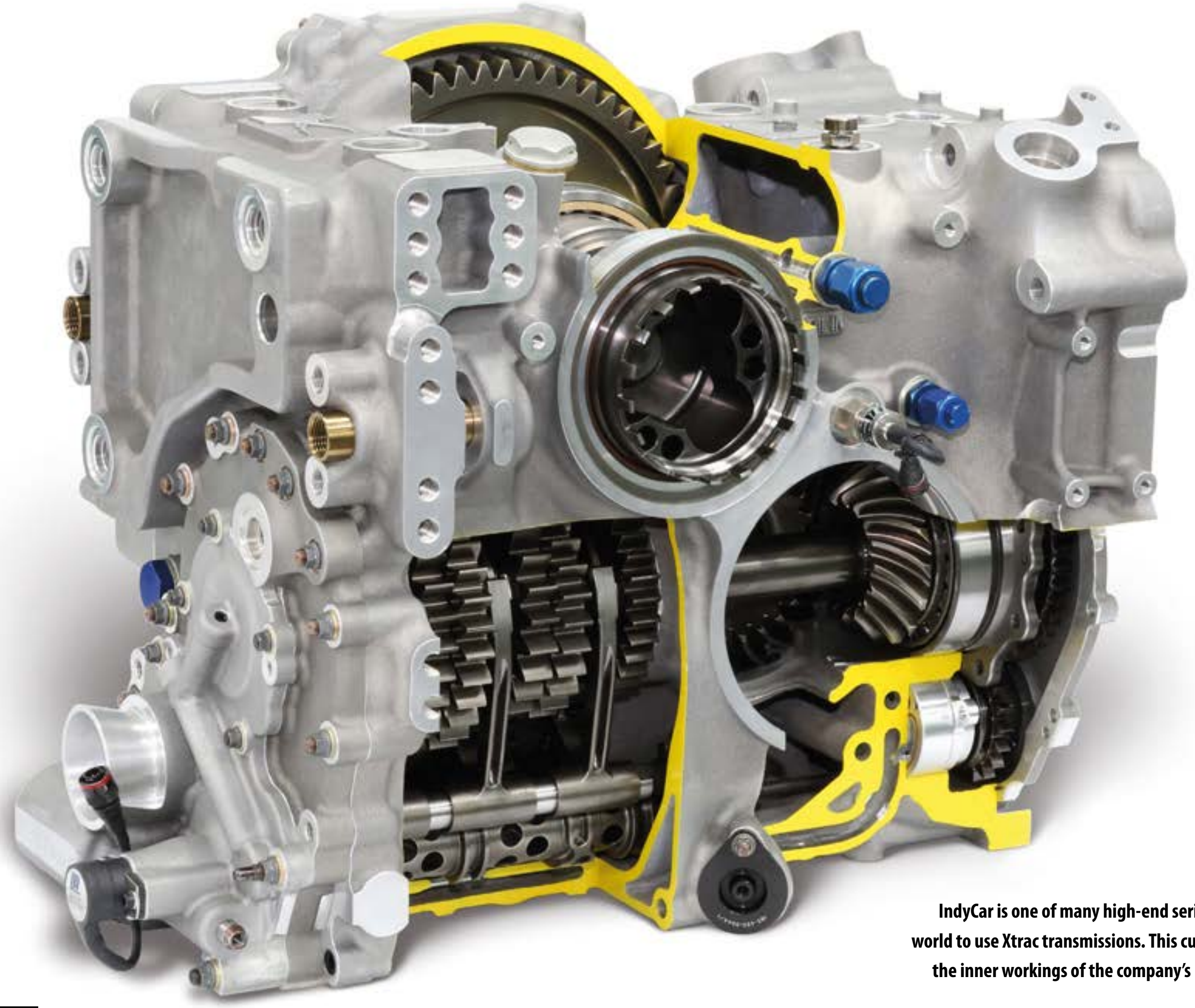
Nottingham University scholarship

***RE*: You seem to have really enjoyed your time at Nottingham University, so much so that you've founded a scholarship for engineering students whose annual household income is under £35,000 (approx. $43,000)**

JK: Yes, I had a brilliant time at university. It was a really special time in my life, although maybe it should have been weighted a bit more toward the academic side, rather than the 50 / 50 studies and enjoying myself it was!

I've since set up a scholarship there to help engineers from disadvantaged backgrounds to go through it, because it was a great place to be and I wanted to give something back.

I want to encourage people who want to go into engineering so, as well as the scholarship there, I've also provided support for their Formula Student team. I wish it had been there when I was at university because I love the concept.



IndyCar is one of many high-end series across the world to use Xtrac transmissions. This cutaway shows the inner workings of the company's Indy gearbox

Top gears

UK-based Xtrac dominates the high-end motorsport transmission market with control gearbox deals in NASCAR, IndyCar and LMDh. **Racecar** ***discovers the secrets to its success***

By MIKE BRESLIN

We're halfway through the year and cars packing Xtrac gearboxes have already won three of the biggest events in motorsport: the Daytona 500, the Indianapolis 500 and Le Mans. In some ways, this is down to circumstances, as the company's 'boxes are mandatory in NASCAR and IndyCar, while the vast majority of the WEC grid also uses its kit. But, to twist a well-known phrase, in this business you make your own circumstances.

And Xtrac has been doing just that for as long as it has been making transmissions, which is close to 40 years now.

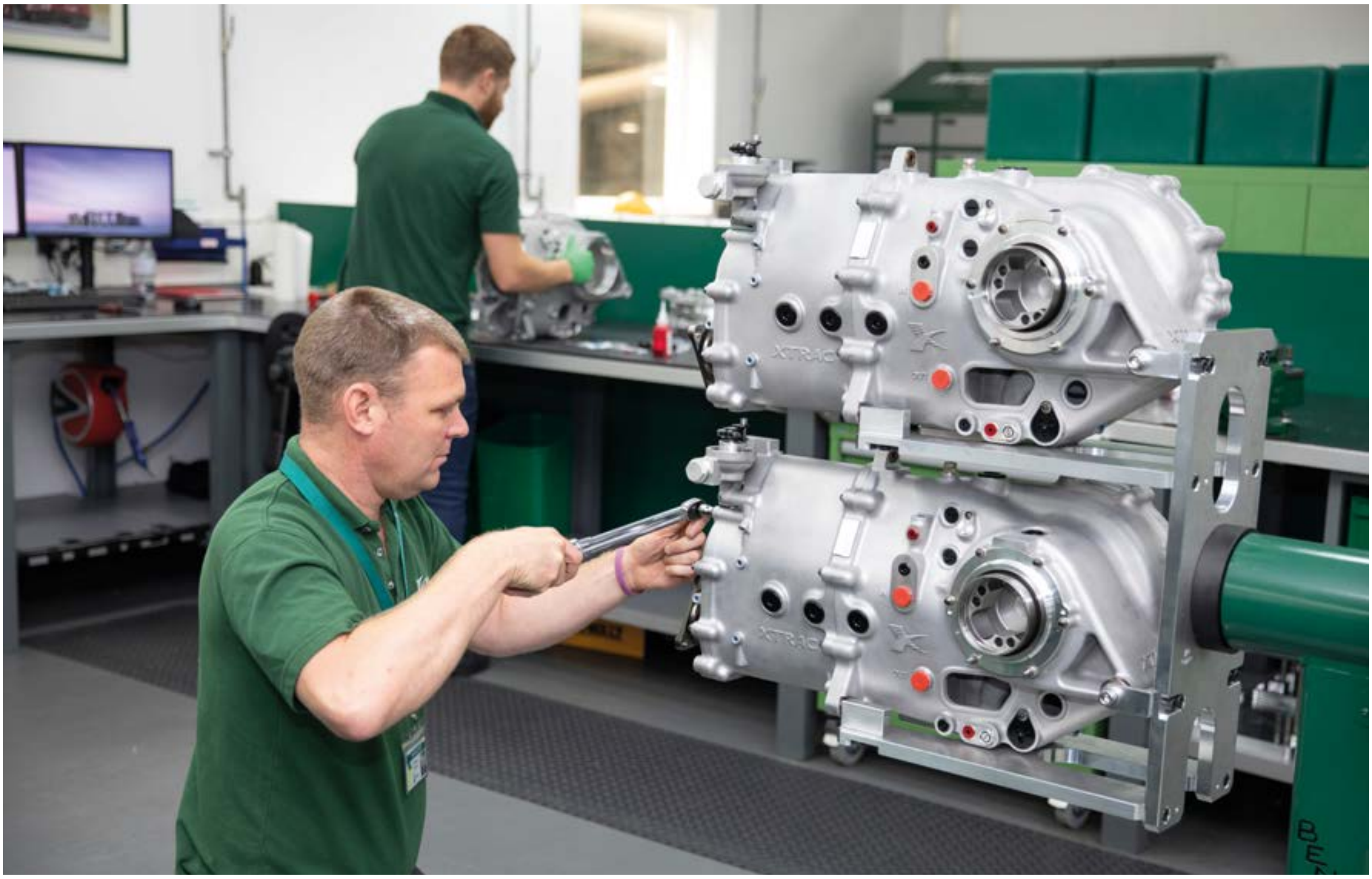
It all started with former Hewland engineer, Mike Endean, in 1984, and a clever, changeable bias, hydraulic 4x4 system that was fitted to a Ford Escort Rallycross car. Since then, the company has produced over 1200 unique gearbox designs, in the process cementing itself as one of the world's go-to high-end motorsport transmission specialists.

Peter Digby has led the company since the mid-1980s and is now its president, with CEO, Adrian Moore, in charge of day-to-day business. Moore first came to Xtrac in 1992 as a design engineer, then returned as technical director in 1999, after a three-year spell in Formula 1, at both Ferrari and McLaren.

Steady growth

'In the '90s, when I first joined, it was 60 people,' remembers Moore. 'Mike Endean was still designing gearboxes on a drawing board, and I was one of the first in the company to use CAD. We had a very small engineering team, which has grown a lot since then, as the whole company has.'

Xtrac CEO, Adrian Moore, has been an integral part of the company since 1992, except for a three-year spell when he worked with Ferrari and McLaren in Formula 1



Xtrac now has the spec gearbox deal for the new NASCAR Next Generation Cup car, which means it has to supply, and maintain, 36 racecars over 38 races this season

Indeed, today it employs close to 400 people in the UK and US, with around 100 of those working in the engineering team, while it moved from its original base in Wokingham to Finchampstead in 1986, and then to its present 125,000ft. sq hi-tech facility in Thatcham in 2000.

But the biggest change in that time has really been within the industry itself, specifically the proliferation of spec series with identical cars and, of course, identical gearboxes.

Xtrac's first control gearbox supply was for IRL – one of the two series that ultimately merged to become IndyCar – in 2000, and Moore says this represented a major change in the way the company went about its business.

'That was one of the first motor racing series that really attacked cost across the car. And that's a big difference from how it would have been in '92 when I started with the company. Back then, racing was different, in that there was a lot of freedom in terms of technical regulations, and we didn't think about cost so much.'

The company has gone on to provide control transmissions to many other series since, including IndyCar, LMP2, LMP3 and the BTCC, while it also supplies LM Hypercar, WRC, Rallycross, motorcycle racing (including MotoGP), Formula E, Rally Raid and many others.

Xtrac's first control gearbox supply was for IRL – one of the two series that ultimately merged to become IndyCar

US presence

Perhaps its biggest coup in more recent time, though, is landing the deal to provide gearboxes and driveshafts for NASCAR's Next Generation Cup car, which hit the track in competition earlier this year.

Xtrac already had a very strong presence in the US, 25 per cent of its business is there, with a facility in Indiana that looks after IndyCar and Sportscars, and in North Carolina, which is dedicated to NASCAR.

'Our North Carolina facility has been open for over 10 years,' confirms Moore, 'because we've been doing NASCAR for a long time. But NASCAR was then free in terms of supply. We had some gearbox products that were used by some people in NASCAR, but certainly not universally. We specialised in rear-end gears – the bevel gears – as well as some gearboxes and parts.

'But then, when the single supply NASCAR contract was put out to tender, we tried very hard to win it, and we did.'

At time of writing, Xtrac had delivered over 300 gearboxes to NASCAR teams. 'We supply every car in every race, at least 36 cars, at least 38 races. Not only that, it's also a gearbox that's sealed and only maintained by us,' Moore says.

Those 38 races also take in a wide range of tracks, from superspeedway to intermediate and short oval, road courses and even the dirt track at Bristol. And from this year that's using just the one spec of racecar, and gearbox, which is converted to suit the different types of track by splitting the 'box, swapping the rear portion and changing drop gears.

Hybrid future

Xtrac also ensured there was a certain amount of package protection in the design, in the expectation that NASCAR will progress to a hybrid unit in the future. This is something that the company already has plenty of experience with, as it supplies the spec gearbox for the new BTCC formula for both front and rear-wheel drive cars, and is heavily involved in WRC, which has also switched to hybrids this season.

Xtrac is also the chosen transmission provider for the new LMDh category, where it teams up with Bosch (electric motor) and Williams Advanced Engineering (batteries) to provide a common set of components to be installed in manufacturer chassis from Ligier, Dallara, Multimatic and ORECA.

Xtrac is providing the transmission for the new LMDh category (pictured), working closely with Williams Advanced Engineering (battery) and Bosch (electric motor)

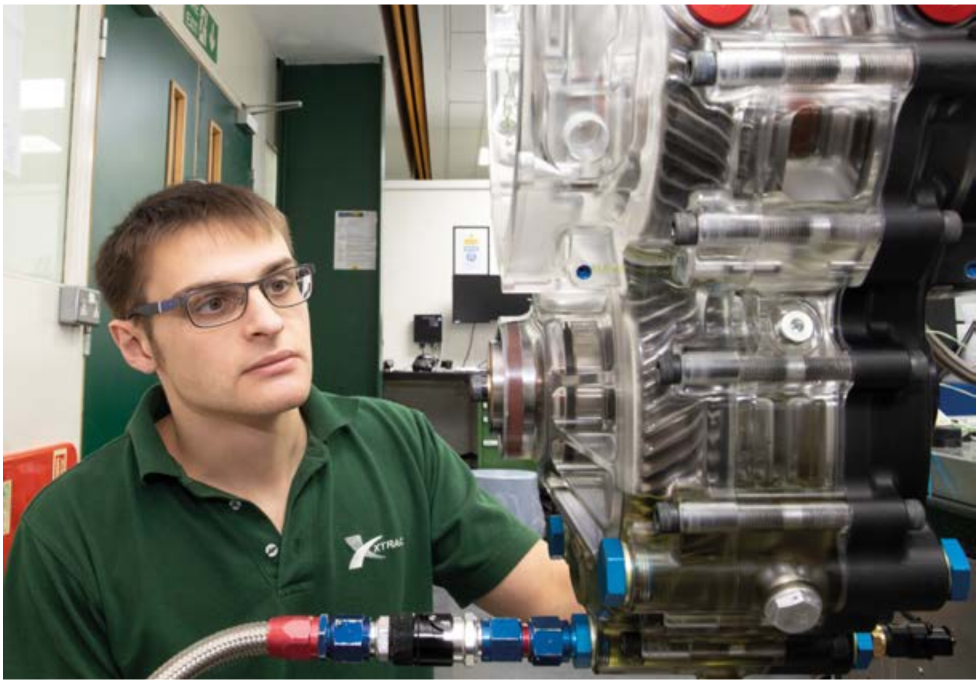
But Xtrac brings more than just its gearboxes to the table in the LMDh project, largely because of the tremendous experience it has in packaging its products for motorsport applications.

'The whole transmission and motor package is highly integrated into the vehicle,' says Moore. 'And that's to suit four different chassis manufacturers and multiple engine manufacturers. So, there's a lot of packaging constraints around that, and when it's a consortium programme like this, we take the lead in that vehicle package because we're familiar with all the parts of it.

'We're very familiar with vehicle suspension packaging, for example, while electric machine manufacturers, they're naturally, and rightly, focused on the electric machine and its performance.'

Porsche is currently testing the first LMDh car with the Xtrac transmission, while gearboxes are on the dynos right now for other manufacturers, all of which will be ready for the category's debut at the 24 Hours of Daytona at the start of next year. This is what Moore calls 'an immovable date', a feature of the motorsport business sector, but also something which very much drives the process at Xtrac.

'The time-sensitive nature of racing is a really strong ethos in this business,' Moore says. 'Le Mans is always that middle weekend in June. It's *always* there. And to get a customer with a new car to Le Mans, there's a whole series of steps you've got to go through, starting the year before, in terms of design, analysis, calculation, and manufacturer prototype testing in the car. And you have to go through those steps in the right time scale so that on that middle weekend in June, they're there, on the grid, with a reliable, proven product. That date doesn't change.'



The way lubricants interact with the gears and surfaces is critical. Here oil is being tested in a gearbox with a clear casing

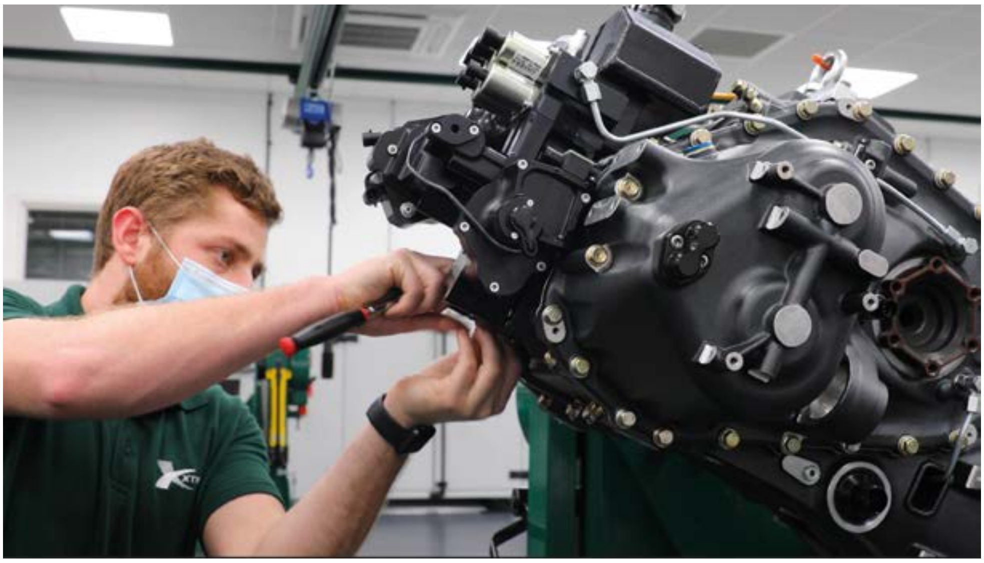
Formula 1

Beyond the control gearbox supply work, Xtrac is still 'heavily' involved in Formula 1, though the nature of its business in the

'The challenge now, which we've massively embraced and are absolutely loving, is the whole transition from ICE to hybrid to EV'

Adrian Moore, CEO at Xtrac

EV transmissions are a large and ever-growing part of the business. This is Xtrac's Integrated Lightweight Electric Vehicle gearbox



Xtrac's High-Performance Automotive road car division accounts for 35 per cent of the company's business. This 'box is for a Pagani

series has changed and it's not at liberty to disclose which teams it supplies.

'Formula 1 was once a big part of our businesses, but it has become less so as a percentage for two reasons,' explains Moore. 'Firstly, because the rest of the business has grown. And secondly, because the number of gearboxes per car has significantly reduced in F1.

'The last time we did a whole Formula 1 gearbox was for the previous generation pre-hybrid [2013], but the way it is now is that the teams have a very high in-house capability. So, we will manufacture internal parts for Formula 1 gearboxes, with Xtrac materials and heat treatment, and some gear forms, those sorts of things.

'But if we go back 15 years, it was very different,' Moore adds. 'We would even make qualifying gear kits for people. They would put thin gears in to qualify, and then put standard gears in for the race. It was very wasteful. So, the eight fixed, homologated ratios in they have for a season in Formula 1 now is a sensible idea because teams used to have 60 or 70 gear ratios.'

Electric transition

Large-scale F1 work may be a thing of the past for Xtrac, but this is a company with its eyes firmly locked on the future. And that, Moore believes, will be electric.

'There will be two types of cars: EVs and classic cars,' he says. Interestingly, he also reveals that a new variant of a GT3 'box Xtrac has just designed is likely to be the last ICE-only gearbox the company ever does.

'The challenge now, which we've massively embraced and are absolutely loving, is the whole transition from ICE to hybrid to EV,' Moore says. 'And that transition is a once-in-a-generation technology change across automotive and motor racing.

'We don't know how long it will take, nor do we know how quickly it will go from ICE to hybrid to EV.'

But Xtrac is certainly not waiting for the future to arrive. It already provides transmissions for Formula E and, from this year, eWRX (electric Rallycross).

'They're two quite different products because Formula E is a really high technology product,' says Moore. 'But most of the car in formula E can't be changed, it's a standard car, so the bits you *can* change [such as the gearbox], obviously have a lot of focus on them. That means there are a lot of technical challenges around Formula E from a gearbox perspective.

'Of course, it's entirely different from a Formula 1 gearbox but, in terms of technology, in terms of materials, efficiencies, coatings and oil systems, it's exactly in line with Formula 1.

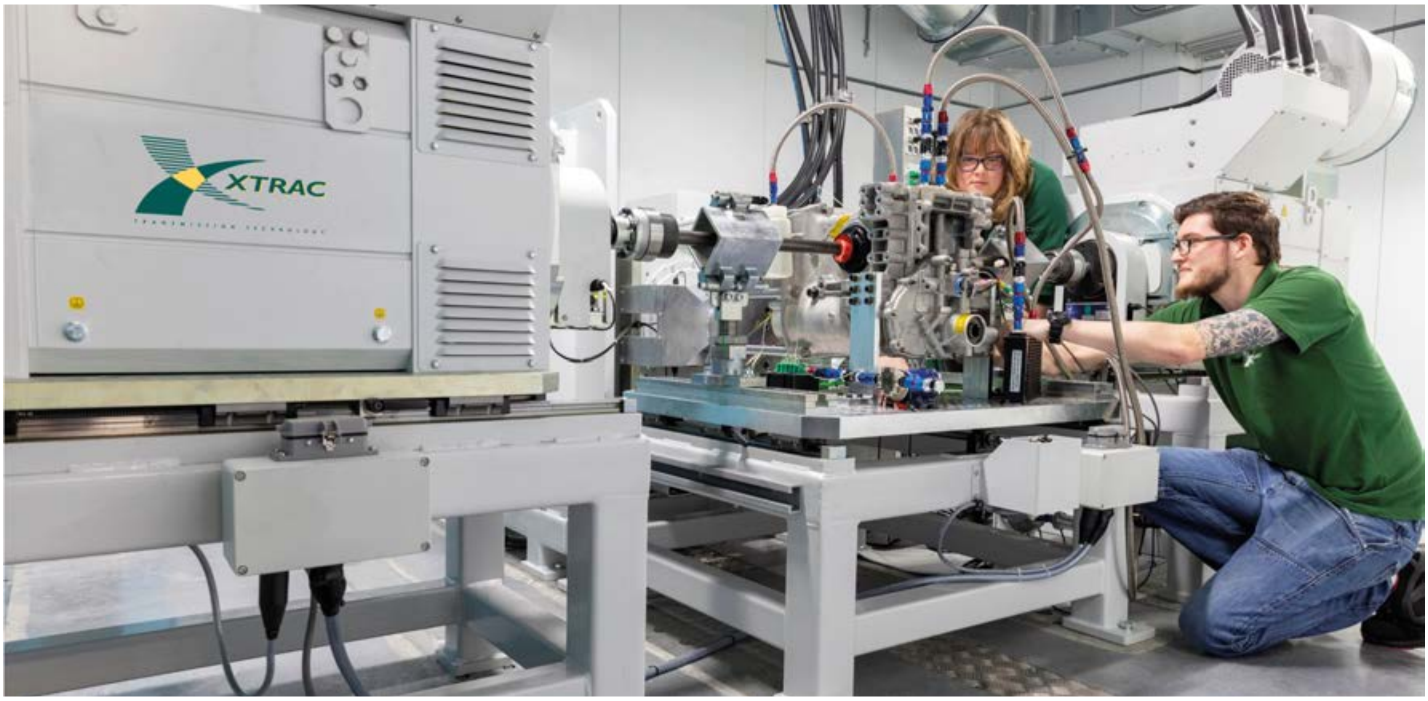
'And then you've got eWRX, with a standard gearbox in every car. So, it has a cost-controlled approach, where it's got to be reliable, while also performing well for the series.'

Agnostic front

Xtrac is clearly not fazed by fundamental changes in power unit technology, so much so Moore likes to say, 'we're entirely power source agnostic'.

That goes for its road car projects, too, through its High-Performance Automotive (HPA) arm, which amounts to 35 per cent of its business and, as the name suggests, is largely restricted to sports and Hypercars. Xtrac can't name all the companies it works with, though it's no secret that Pagani is one of them, while it also developed the H-pattern, manual, six-speed 'box for Gordon Murray's T.50 project.

Back to the EV theme, it's also been working with Lotus on the new Evija electric sports car.



Xtrac employs a wide range of gearbox testing equipment, including recently acquired loaded EV rigs, which allow the company to run entire test and development processes in house

'The Evija is four motors, so four gearboxes. It's a gearbox on each corner, basically,' explains Moore. 'It's an epicyclic reduction gearbox, and we've done some clever things with the oil system.

'We did all the development in house, as we've got some really good oil simulation tools, which we developed for use in motorsport to chase efficiency, but which apply just as well to any other gearbox. We did a lot of oil system simulation in the virtual space, and then a lot of validation by running the EV gearbox on our test rigs. And that gearbox runs with no oil pump, it's very high speed. I'm very proud of what a clever oil system it is.'

Oil industry

Oil, and the way it works in a transmission, is a big part of the design process at Xtrac, both for HPA and for motorsport, and the company sometimes also helps to develop gearbox oils.

'Formula E is probably the most recent where we've done oil development,' Moore says. 'The challenge is the coating: what coating is on the gear, and how that interacts with the oil. And you're trying to get that balance of the oil and the coating working together. How does the coating adhere to the gear, and what surface finishing is needed on the gear for the coating to adhere?'

To this end, Xtrac has a special test machine, called a four-square rig, with which it can test how oils work in a gearbox.

'The idea is that you run a pair of gear coupons at a fixed speed, temperature and load, and you try different oils, and you see how the coupons pit or how they fail. This way, you build up a picture of the fatigue life of those gears with different oils,' says Moore. 'As a way of evaluating the performance of an oil, it's an unbelievably powerful tool.'

The four-square rig is just one of many test machines at Thatcham, the most impressive of which are probably the loaded transient test rigs.

'Because of the transition from ICE to hybrid to EV, we've invested about £2m in two loaded transient test rigs,' says Moore. 'We never had an internal combustion engine test rig because of the cost and the complexity. Then there were a lot of these electric-driven test rigs, the rigs Formula 1 teams have, but they are so expensive because they emulate how internal combustion engines operate, so they're very unrealistic for a company like us to invest in.

'But once you're into pure EV, it's a £2m investment. While that's still a significant amount for us, it's within reach.

'The eWRX gearbox, the entire programme was done here; all the endurance testing, everything. We ran full endurance cycles on the rig, all in house.'

There are also four other test cells at the factory, three of which currently contain non-loaded test rigs (the fourth will be filled soon), plus three rigs in North Carolina (which is a measure of the amount of work involved with the NASCAR programme), and two in Indianapolis. And every single gearbox or differential built at the Thatcham facility is put through end-of-line tests on the rigs.

Heavy industry

However, stringent quality control begins well before the test rig stage, at the steel store at the very beginning of the process where material is stamped for traceability. This way, in the unlikely event there is a problem with a component, Xtrac will know what batch of steel it came from, as well as who worked on it, and with what machine, at every stage of the process.

Oil, and the way it works in a transmission, is a big part of the design process at Xtrac

Incidentally, the steel used by Xtrac for its gears is a case-hardened carbonised material, specially developed in conjunction with Liberty Steel.

The factory where that steel is shaped into gears is almost on the cusp of heavy industry, what with its substantial machinery and sheer scale. It's pretty much a one-stop shop when it comes to gearbox manufacturer too, as everything is done here except the coatings, although aluminium and magnesium casings are cast at approved foundries. Those parts are still designed at Xtrac and CNC machined there, as well as at a number of approved suppliers, with over 5000 casings worked on each year.

The large design office is also impressive, and here three groups – one for HPA and two for motorsport – work with Siemens NX (CAD / CAM / CAE), with a very high level of design capability.

Another area Xtrac has recently invested heavily in is the latest gear cutting and grinding technology, and it had five full form, ground gear grinding machines installed in 2019. It also has three bevel machines, including a Klingelnberg G30 CNC spiral bevel gear grinder, the first of this type in the UK, which was purchased in 2016.

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'It's designed for road cars and NVH. That's really what these machines are about,' says Moore. 'Bevel machines are mostly used to make road car bevels, and for them you want a quiet gear. But we can use it to make a gear that is particularly efficient, or particularly power dense. And then we can tweak it until we've complete control over the topographical shape of the gear tooth.

'The clever thing is it's a closed-loop process,' Moore adds, 'from design to manufacturer to inspection, so you have complete control over the gear profile.

'So, it's not just the investment in the machinery, it's also an investment in all the systems and the design tools that go with it. You can design a bevel, and you can simulate the load that it sees on the car in the design space, and then see how it's going to deflect, including the deflection of the casing etc., and then you can design to allow for that.'

Highly skilled

There has also been significant investment in heat treatment capabilities at Xtrac. 'We've got five furnaces, three of the older type, and now two of the latest IPSEN vacuum temper furnaces,' confirms Moore.

Meanwhile, shot peening is handled by several robots and rumble machines, including the latest computer-controlled, three-axis Vacublast machine. After that, every part is hand finished by highly skilled artisans before it's sent to the assembly bays, where equally skilled technicians piece together the finished gearboxes.

'Highly skilled' is the key phrase here, and it applies to people working throughout the factory. This, Moore believes, is one of the crucial ingredients to Xtrac's success.

Masters and apprentices

When *Racecar* arrived at Xtrac's impressive facility in Thatcham, we were greeted with exuberant floral displays in the company's corporate colours of green and yellow, all lovingly arranged for our visit…

Well, perhaps not just us, as earlier that day the Princess Royal had been there to meet Xtrac apprentices, the company being a recipient of the Princess Royal Training Award.

Xtrac apprentice manager, Warren Page, discusses NASCAR bevel gears with apprentices Alfie Gibbons and Faye Cook

It's not the first time Xtrac, or its apprentices, have picked up training awards, and it won't be the last, as providing opportunities for youngsters is central to the company's philosophy.

'We have a really strong undergraduate programme, and a really strong apprentice programme,' says Xtrac CEO, Adrian Moore. 'We normally take on around five or six apprentices, and five or six undergraduates a year,' adding that demand for these positions is very high, with 'hundreds' of applications.

Providing opportunities for youngsters is central to the company's philosophy

The company took on its first apprentice in 1991, and a remarkable 14 per cent of employees currently working at Thatcham started their careers as apprentices at the firm.

Recently, it has also opened its Xtrac Academy, which provides a dedicated space for practical and classroom-based learning, featuring CAE facilities and workshops, while its apprentices are also given the chance to work in up to 16 departments across the company (for more information on this go to: www.xtrac.com/xtrac-academy/).

They also get some excellent opportunities to further their education. 'We've taken some of the apprentices right through to master's degrees, and quite a few are now doing degree apprenticeships,' says Moore enthusiastically. 'The brilliant thing about degree apprenticeships is that maybe they'll end up with a degree a couple of years after somebody who's left school and gone straight to university, but they will have no student debt and they've worked since they were 18, so they've got all that experience of the workplace.

'I absolutely love to see apprentices going on and doing degrees, and we fully support anyone who wants to do it.'

The factory floor is close to heavy industry, with millions invested into machinery, such as these bevel gear grinders

It's investing in the people you've got, and in the equipment you want them to use, with a clear focus

Adrian Moore, CEO at Xtrac

'It's the people in the business, 100 per cent. And it's investing in the people you've got, and in the equipment you want them to use, with a clear focus on the direction you're trying to go.

'Also, absolute focus on customer service. The customer wants the products they asked for when they want them, to the specification they need. If you put all this together, you get the result.'

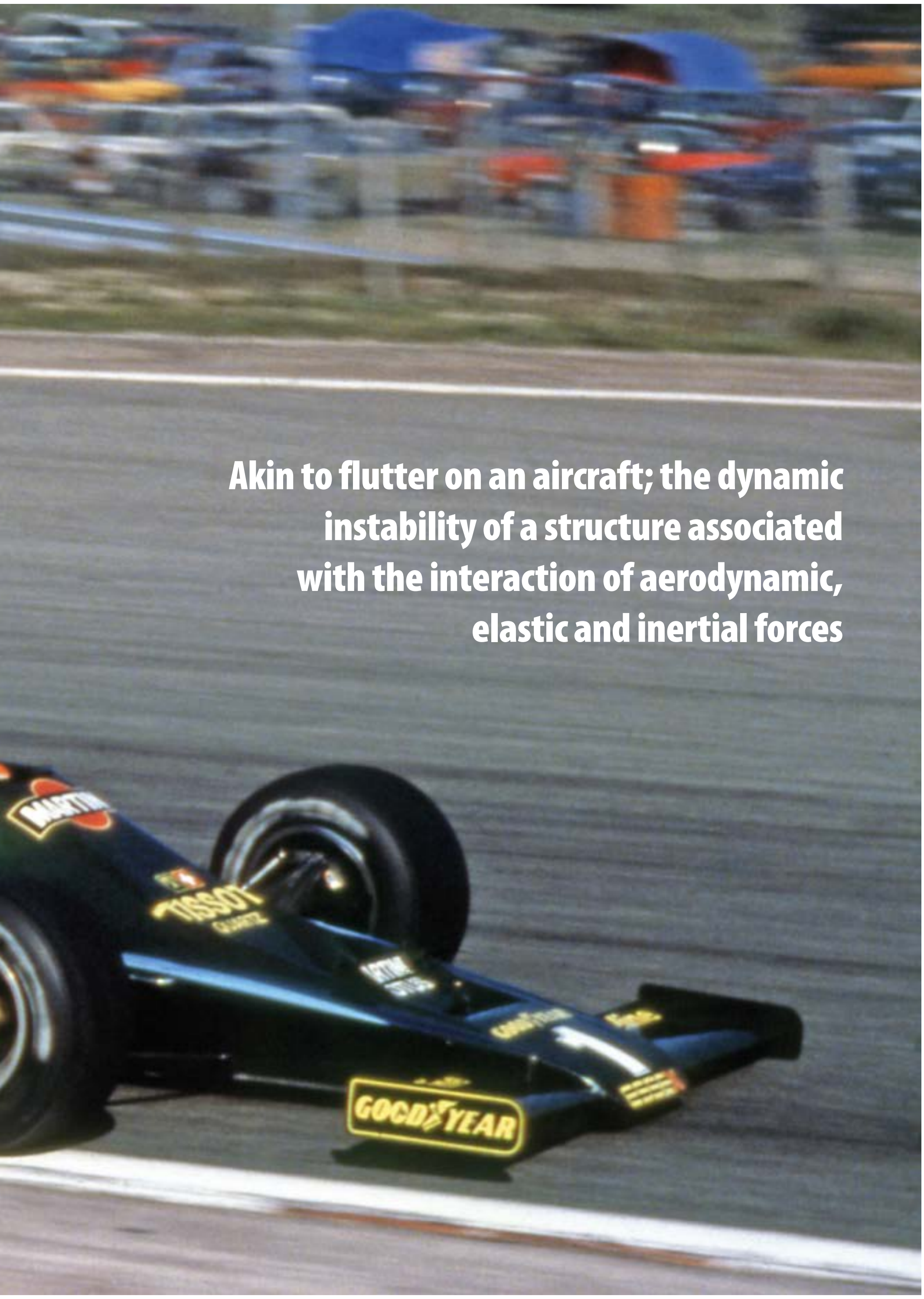
And that result is winning at Daytona, Indianapolis, Le Mans and pretty much every other notable track or rally stage in the world. Whatever the circumstances.

Mario Andretti finished a creditable third at the wheel of the Cosworth V8-powered Lotus 80 in the 1979 Spanish Grand Prix at Jarama, but the car had yet to show its nasty side

History repeating

Racecar examines the Lotus T80 of 1979, the first Formula 1 car to exhibit the supposedly 'new' phenomenon of porpoising

By PETER WRIGHT



Akin to flutter on an aircraft; the dynamic instability of a structure associated with the interaction of aerodynamic, elastic and inertial forces

Following the first 2022 F1 test at Barcelona in March, the paddock was forced to dig into the archive and produce a term that has been gathering dust for over 40 years, 'porpoising'. In the late 1970s, Team Lotus was deeply into the development of ground effect: T78, the original, skirted ground-effect car had lots of downforce, good; T79, more downforce, better still; T80, even more downforce, yet almost undriveable…

As Lewis Hamilton has commented with reference to his Mercedes W13, 'Whatever we do makes no difference.'

Those words brought memories flooding back of the desperate days of Mario Andretti trying to tame the porpoising T80, to no avail. I recall well that test day at Silverstone where we equipped him with a tape recorder to give us a running commentary, and when we played it back, his strained voice noted, 'I can see daylight under the front wheels!' as he ran down Hangar Straight at speed.

Initially, the car had flattered when Mario finished third at the Spanish GP in Jarama with its short straights and many slow corners. But by mid-season, the car was abandoned in favour of the older T79s.

XPB

XPB

The term porpoising is everywhere in contemporary F1, and some teams are struggling more than others to deal with it, yet it was a well-known phenomenon in 1979…

The T80 was designed to exploit the underneath of an F1 car to the maximum. From the radiator intakes to the extreme rear of the car was shaped as a venturi, terminated by a large flap. No rear wing was fitted. The under surface of the wide nose was another venturi, and no front wings were planned. Both the nose and main undertray were fitted with sliding skirts, the main skirts being curved to pass between the rear wheels.

Quite early on, front and rear wings were added to generate a contribution to downforce that was independent of the car's attitude relative to the ground, and which was unaffected by skirt performance.

Hot skirts

The previous T79 was designed with all-enclosing sidepods housing the radiators and exhausts, and forming the venturi and diffusers. The skirts were mounted to the outer edges and the cars suffered overheating of the exhausts, which then cracked. The drivers lost power, but still won.

The following year, Williams built its first ground-effect car, and made the sidepods in a simpler way with the skirt boxes forming the sides, supported on frames, with top and bottom skins. These could not only be quickly removed for access, but easily re-designed as aerodynamic development progressed.

The T80, by coincidence, followed the same design philosophy based on the experience with the T79. The car was launched with fabricated titanium suspension, which was quickly changed to steel following cracking in early testing.

Before too many parallels are drawn between the porpoising T80 and the current porpoising F1 cars, it should be noted that the cars in the late 1970s were fully skirted, and the tyres were Goodyear crossplys that grew in diameter with speed, raising the car. Also, suspension rates were of the order of 300lb/in ie 50+N/mm – way down on today's rates. Finally, top speed was significantly lower at under 300km/h compared to 350km/h today.

To help develop the T78 and T79, Team Lotus commissioned a chassis data system from Cranfield's flight instrumentation department. Based on a system developed for a Neil Williams aerobatic aircraft, it stored data on a cassette tape, sometimes. We knew we needed such data to enable correlation between track and wind tunnel, and to monitor the performance of the skirts, in particular the effects of wear.

By the time the T80 came along, it had become routine to fit the data system for tests, although the mechanics didn't really like the wires and sensors all over their cars. David Williams, head of the flight instrumentation department, brought his aeronautical experience to bear on the T80's problem and advised that the phenomenon was akin to flutter on an aircraft: the dynamic instability of a structure associated with the interaction of aerodynamic, elastic and inertial forces. In other words, an aeroelastic issue.

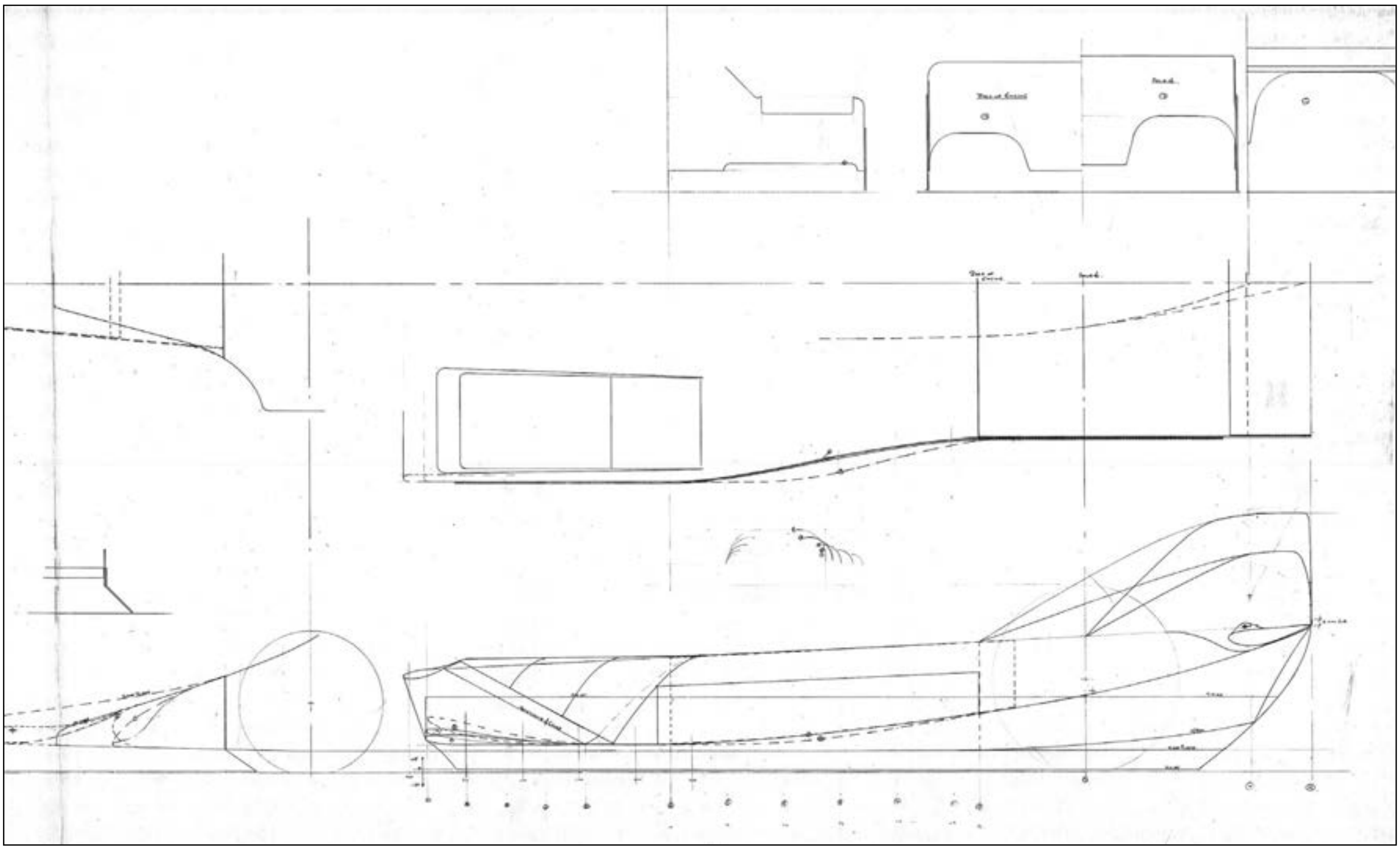
Flutter affects aircraft structures, especially wings, but also bridges and tall chimneys, and often results in structural failure. The T80 was heaving and pitching on its springs and tyres, excited by changing aerodynamic forces as it moved relative to the ground. At higher speeds this caused resonance in a mode involving both heave and pitch.

On aircraft, this is limited by imposing a VNE (velocity never exceed), but that's clearly not a suitable solution for a racecar!

Extreme modifications

So, at the end of 1979, we took a T80 to Ricard for a winter test, and Stephen South drove the car with some extreme modifications to see if we could better understand it. The amazing thing about working for Colin Chapman was that if something failed to work as expected, he didn't just dump it; he could recognise a technical barrier and wanted to overcome it to hopefully achieve technical supremacy. There were not many like Chapman.

The T80 was heaving and pitching on its springs, excited by changing aerodynamic forces as it moved relative to the ground



Classic Team Lotus

Colin Chapman and Team Lotus recognised the answer to the porpoising problem was to separate the two main functions of a racecar suspension, giving each its own set of characteristics

Imagine a room full of hopeful Engineers who have worked relentlessly around the clock to meet the project deadline. Some of them are pondering the last time they were able to leave their desk on time at the end of the day. They have had sleepless nights, restlessly thinking about optimal design, tolerances, the parts functioning in a demanding environment...

It's time. Time that they test the long-awaited parts from their supplier. Just as they begin to put the first of the components through their initial basic testing process... SNAP. The part fails. The whole room lets out a painful sigh. Not only have hundreds of hours gone into getting these designs perfect, but they're now behind on the project if they can't fix this fast.

This is the extremely frustrating reality for many Engineers and Designers.

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Once we had initiated Stephen with a porpoising T80, we fitted it with the stiffest springs we could, some three times the normal rates. Ricard is pretty smooth and Stephen reported that the car was not porpoising, was pretty nice to drive and had plenty of grip, but he had trouble keeping his feet on the pedals. That set us thinking.

Isolation approach

What the car's aerodynamics wanted was the minimum attitude change relative to the road, but what the main masses of the car wanted was isolation from road disturbances. In technical terms, the two main functions of a racecar suspension needed separating, each given its own set of characteristics.

The forces due to inertia – cornering, acceleration, braking – along with aerodynamic downforce and fuel mass changes should be reacted according to the vehicle dynamic needs, and the road disturbances minimised in terms of sprung and unsprung mass modes. To do this completely requires an active suspension, where the different inputs to the suspension are sensed using accelerometers, load cells, displacement transducers, air speed etc, and the hydraulic suspension reacts according to algorithms and control loop gains.

This was more than Team Lotus was capable of in 1980, though work started on such a system in 1981. In the meantime, a car with two chassis and two suspension systems was developed: the T86 mule car, which was then followed by the T88.

Twin systems

The approach taken with the T88 was to give the body its own suspension system, such that the aerodynamic downforce it and the wings generated was reacted by its own suspension, attached to the wheel hubs.

As speed increased, the body lowered until it was virtually directly connected to the wheels. As speed reduced below that of racing speeds, the body slowly rose (high rebound damping) to a legal height, as measured with the car stationary.

The T86 ran successfully in testing in the autumn of 1980, in great secrecy. Ferrari, however, got wind of it and stimulated a rule change that banned cars with no suspension. That rule still survives today!

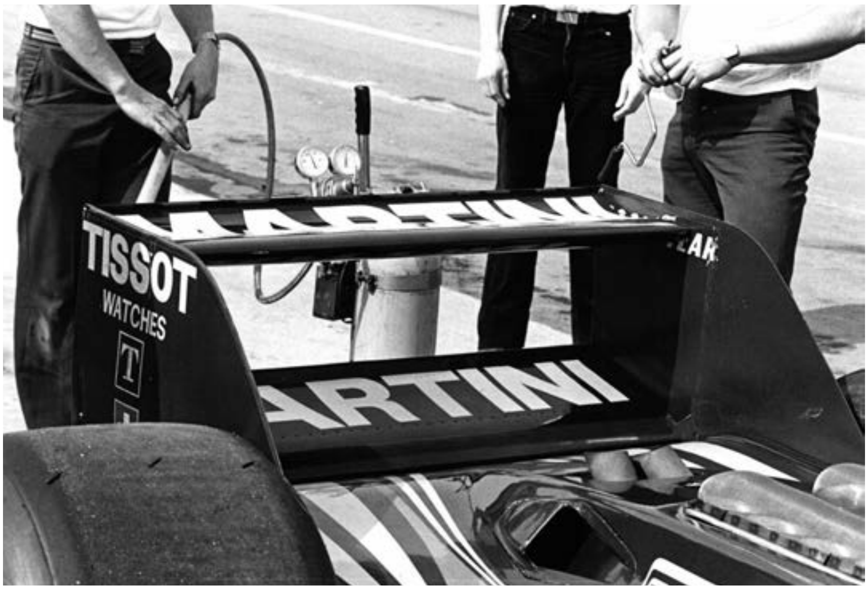
At around the same time, the FIA decided to ban sliding skirts, and we realised we had a concept that was perfect for this new regulation, so proceeded to the T88.

When it appeared at Long Beach, our competitors realised what we had done and made sure it was never allowed to run in anger. Would it have worked? We never had the chance to find out, but it didn't porpoise!

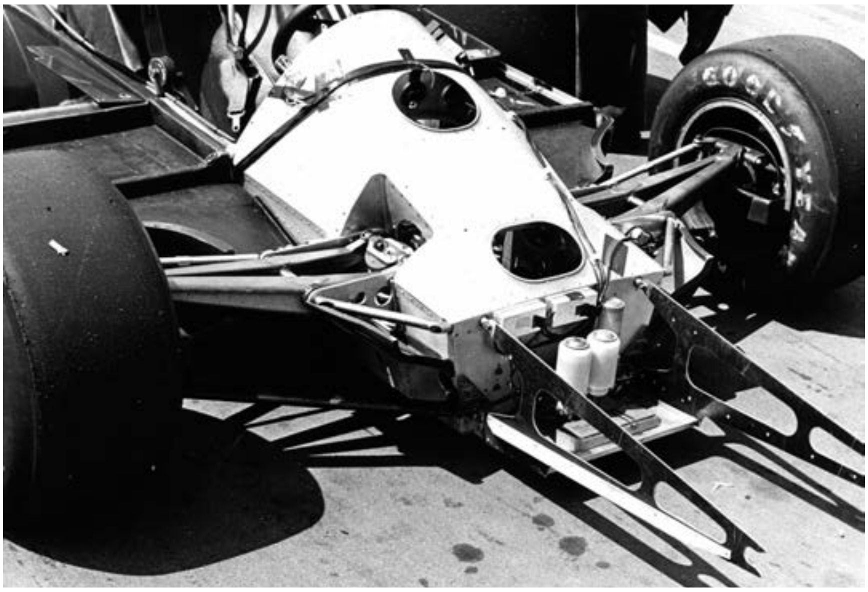
While Chapman licked his wounds, he okay'd a move to plan b – active suspension.

Photos: Peter Ritches

The Lotus T80 at its launch, shown here with no front wing fitted



The porpoising effect was traced to an aeroelastic issue, similar to that experienced by wing profiles in aeronautics


When the T80 was launched it had fabricated titanium uprights, but these were dropped as they fractured during use

'I can see daylight under the front wheels' commented Andretti during a fraught test session at Silverstone in 1979

Front wings were added to the T80 to try to solve the porpoising issue but more work was needed to fix it properly

The monocoque used in the T80, T81 and T87, was the last time Team Lotus used aluminium construction

For 2022, with the good intent of reducing the wake of the cars to facilitate overtaking, the regulations defining bodywork were re-written

This completed the job of separating the functions of the suspension, and also proved a solution to porpoising, but was also banned at the end of 1993.

Same, but different

So how come, 30 years later, porpoising has become a buzzword in F1 and has brought World Champions, Mercedes, temporarily, and unexpectedly, almost to its knees?

Since 1983, Formula 1 cars have been mandated with flat-bottom undertrays with a short diffuser. The aerodynamics that control the flow under the car evolved to the amazingly complex detail of bargeboards, vanes and vortex control devices that culminated in the 2021 cars.

To control the way the cars move relative to the road, sophisticated front and rear suspensions have been developed, banned, and re-developed, incorporating ride height control systems and inertial dampers.

As a result, the cars remained stable and did not porpoise. But for 2022, with the good intent of reducing the wake of the cars to facilitate overtaking, the regulations defining bodywork were re-written following major CFD and wind tunnel programmes by FOM. Each team then took the new regulations and performed their own safety and wind tunnel development programmes to find out how to get the most out of these regulations.

Part of the new concept was to reintroduce a degree of venturi shaping to the underside of the cars, 'powered' by a large diffuser. Why, then, did the threat of porpoising not make itself apparent during all these hours of wind tunnel testing and teraflops of CFD analysis? Or did it?

Compounding the problem of the whole vehicle becoming unstable in heave and pitch are some other changes to the regulations: 18in wheels and low profile tyres, and a ban on all forms of 'tricky' suspensions, including ride height control devices and inertial dampers.

Both wind tunnels and CFD generally assess static or quasi-static characteristics. To assess how these characteristics interact with the inertias of the sprung and unsprung

XPB

The Adrian Newey-designed Williams FW15C had semi-active suspension and dominated in 1993. It is perhaps no coincidence then that Red Bull appear to better understand the porpoising issue

masses, and all the springs and dampers in the suspension and tyres, requires extremely complex dynamic modelling.

Degrees of freedom

To just model heave and pitch requires a four-degree of freedom model. But add bodywork and wing flexibility and the number of degrees of freedom goes up. Then add non-linear and dynamic aerodynamics, and even the best model will only be as good as the input of aero and tyre data.

Once a model with all the above characteristics and inputs that influence porpoising is developed, it requires validating. This can be done by comparing the model outputs with data from sensors mounted on the car during testing, but is only possible once the car is available.

Alternatively, a seven-post shaker rig could be introduced. For this, a previous year car could be used as only the inertias, suspension and tyres need be representative, and the proposed aerodynamic characteristics are input to the two aero force and moment 'posts'. Most seven posters apply aero, downforce and pitching moment loads by two low-rate springs, the preloads of which are controlled by actuators. However these actuators are usually slow response, simply used to set the aero loads for a given test.

To validate the dynamic changes to the aero load as the car moves in heave and pitch requires high response actuators with load feedback. Such a facility may not be available.

Given all this, it can be better understood why porpoising was perhaps not anticipated in 2022, unless a senior and suitably experienced engineer foresaw it. It is interesting to note that Red Bull with Adrian Newey, and Ferrari with Rory Byrne, seem to suffer less from porpoising, and also display the most performance.

In F1 racing terms, the T80 can only be described as a failure. In spite of its one podium finish in the hands of Mario Andretti, it was stood down from Team Lotus' championship challenge mid-season. And yet it was an essential part of the intense aerodynamic development that started in the 1960s, gained momentum with ground effect in the 1970s, and continues to this day.

Having found out how to exploit ground effect, Team Lotus reached the limits of how much conventional suspension systems could control it. The T80 showed the target was no longer simply more downforce, but an integrated vehicle that generated downforce *and* managed it throughout the speed range. At the same time, the FIA set out to limit the magnitude of available downforce, firstly banning moveable skirts, then setting a minimum gap to the edge of the body, and finally, in 1983, mandating flat bottoms.

Active development

What emerged from all this was an aero configuration that didn't generate so much downforce that there were safety issues, nor did the cars porpoise, but where the flat bottom was critical to the attitude relative to the road, resulting in the need for very stiff suspension. This incentivised the development of full active suspension (Team Lotus) and semi-active suspension (Williams).

If Peter Warr, team principle of Team Lotus following Chapman's death in 1982, had continued to fund the team's development of active suspension beyond the first races of '83, it could have been way ahead of the field.

The T80 showed the target was no longer simply more downforce, but an integrated vehicle that… managed it throughout the speed range

Instead, by the time Gerard Ducarouge and Ayrton Senna requested it for the T99T in 1987, Williams had commenced work on its own semi-active system based on Automotive Products' road car suspension.

Peter Warr again dropped the Team Lotus system for 1988, while Williams continued to develop its system to dominate in 1993, after which the FIA banned it.

The basis on which all active suspensions were banned was they influenced aerodynamics. The next decade saw some very clever passive suspension systems that served everything from the high-rake Red Bull to the low-rake Mercedes. All banned for 2022, just as a new aerodynamic configuration was introduce that really *needed* these sophisticated systems.

Surely now would be a good time to consider allowing a limited form of active suspension. It could be semi-active, and have both physical and algorithm limitations. With hydraulic systems already fitted to F1 cars, cost could be kept under control, and the issues that have re-emerged eliminated.

The T80 will never go down in history as a successful Formula 1 car, but its influence on the sport was far from insignificant.

Optimal thinking

Theory and good practices on suspension kinematics design part 2: corner weight variation in steering

BY CLAUDE ROUELLE

Let's start with a little story. A few years ago, I was invited to attend a demonstration of a high-end simulator, and asked a driver, a multiple winner of the Spa 24 Hours, to accompany me.

The simulator engineers asked me if I could sit in the car and give my impressions. I told them that I thought I was a decent driver on public roads, but did not think of myself as a good racing driver. Nevertheless, they insisted, and I went so I sat in the car.

The car was in the virtual pit lane, and an idea crossed my mind. I asked the engineers if all systems were recording. When they said yes, I turned the steering wheel 90 degrees to the left, and then 180 degrees to the right, before returning it to the initial position with a last movement of 90 degrees to the left. To the surprise of those around me, I then got out of the car and went to the control room, where I asked to be shown each tyre vertical load and front ride height *variations*.

There were none! After the control room engineers confirmed that every virtual sensor and / or simulation inputs and outputs were properly recorded, I exchanged glances with the driver I came with, and decided to leave.

Now, maybe the simulator hardware was good, but I had real doubts about the relevance of the vehicle dynamics software going with it. If the outputs from a steering wheel cannot be seen with a car at rest, I have all the reasons I need to doubt the outputs of a car at speed. In other words, if the picture is already wrong, how can I trust the movie?

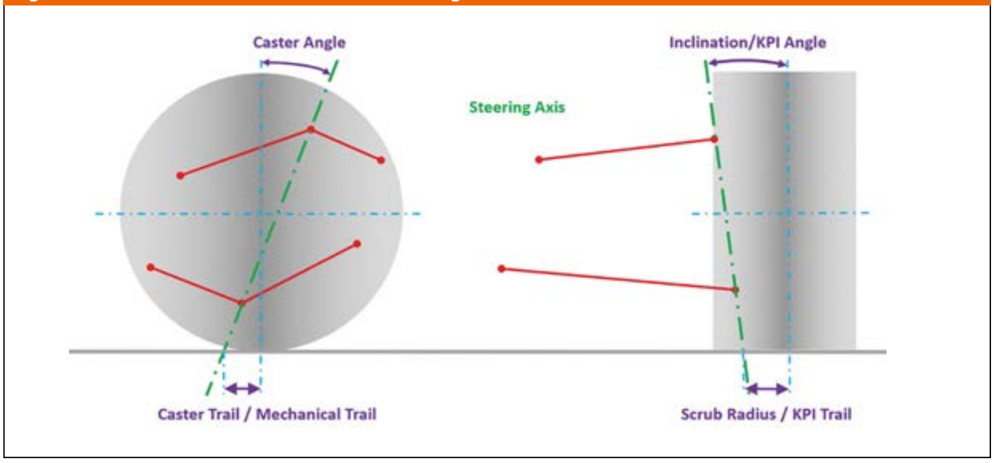
Four factors

Let me explain. For a given steering wheel input, the design of the front upright will influence four major factors of car performance. Here they are, not presented in order of importance, because that order could be different from one car to another.

1. Corner weights variation in steering (what will be discussed in this article).
2. Camber variation in steering.
3. Ride height variation.
4. Steering torque variation.

The four design variables that will influence the car outputs are the king pin inclination (KPI), caster angles, the mechanical trail (sometimes called the caster trail) and the scrub radius (sometimes referred to as the KPI trail). The majority of this magazine's readers know those definitions but, for the sake of comprehension and visualisation, they are shown in **Figure 1**.

Fig 1: Quick reminder of the caster and KPI angles and trails definitions



Due to space constraints, I am not able to display all the graphs and equations in this article as I do in some university masters engineering courses, but there are some basic principles to explain, or at least be reminded of.

As a design judge in Formula Student competitions, I often pose this question: imagine that your car is on a set-up pad, each wheel on one scale. You are in the workshop, so no speed, no downforce, no longitudinal or lateral acceleration. You turn the steering wheel 90 degrees to the left, what variation do you notice on the left front (LF) scale?

There are only three answers: the LF corner weight goes up, down or stays unchanged. Additional questions to consider: if the corner weights change, do they change by 0.1, 1.0 or 10kg? Are any of the other corner weights changing at the same time? If so, which one, and by how much? Now, why is it important to know the answer to these questions?

Wrong answer

Worryingly, about 70 per cent of the students give me the wrong answers. If that is the case, I ask them how they are going to answer the following question: How, during the suspension concept phase, did you choose the caster and KPI angles and trails?

Let's not only blame the students here. Except in a few high-end professional racing series, I have spoken with many so-called racecar engineers over the years who could not answer these questions either.

So, let us start to answer those questions with the simple analogy of a car with each wheel on a scale and a table (**Figure 2**).

When you sit at a table and one leg is too short or too long, or the ground is not flat (**Figure 2b**), the table will stand on three legs. As soon as one guest puts their elbows on the table, the load shifts onto the three other legs. Unpleasant. One of the guests will invariably then take a paper napkin, fold it, and put it under the leg not in contact with the ground. Problem solved.

Cylinders and cones

On any car, if the KPI axis of one front wheel is perpendicular to the ground (no caster or KPI angle), when the steering wheel is turned, there will be a slight wheelbase and front half-track variation. In themselves, these will create wheel load variations, but no camber variation, nor any variations of the altitude of the wheel centre. With no initial camber, the wheel planes will stay perpendicular to the ground. Their movements will follow the envelope of a cylinder.

However, if there is a KPI, and a caster angle, the wheel plane will follow the envelope of a cone. When the steering wheel is turned to the left, the RF wheel will go up vs the car frame and acquire more negative camber. At the same time, the LF wheel will go down vs the car frame and have less negative camber. This can be easily demonstrated by

Fig 2: illustration a **shows a table on flat ground;** b **a variation of the diagonal loads if one table leg is longer;** c **a closer similarity with a racecar as there are springs between the 'leg' lower side and the ground (tyre springs) and the 'leg' top side and the table lower surface (suspension springs)**

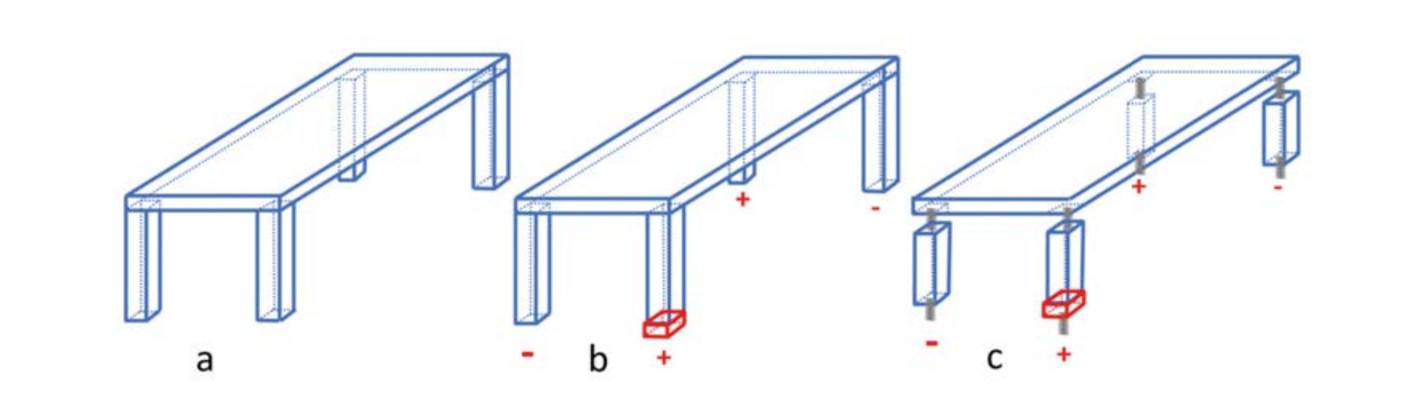
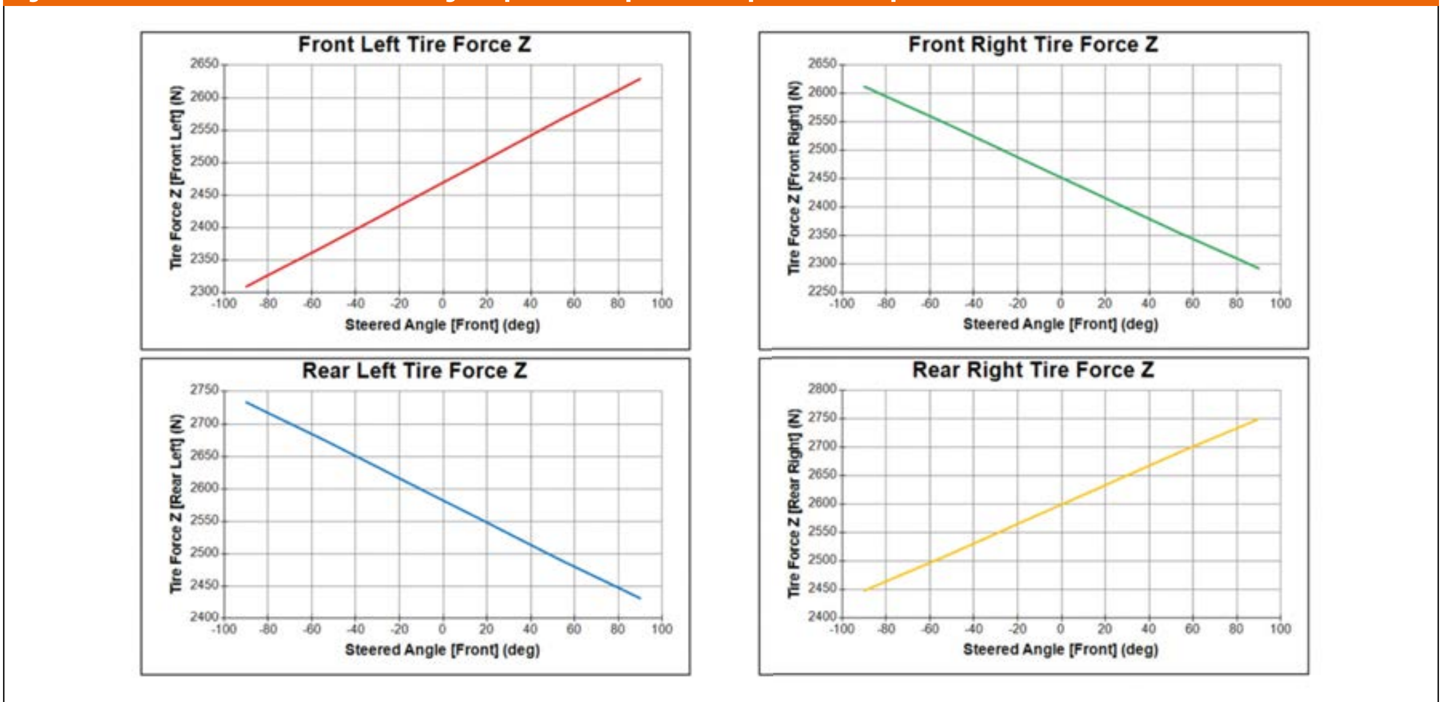


Fig 3: Vertical wheel load variation in steering. Simplified example with no speed (workshop measurements)



For a given steering wheel input, the design of the front upright will influence four major factors of car performance

turning the steering wheel of a Go Kart on stands and observing the movement of the wheels and variations in camber.

On any car, if you turn the steering wheel to the left, because of the KPI and caster angles and trails, the LF wheel will 'want to go into the ground'. We know this is not possible. The LF wheel load will increase, and the LF ride height will increase, too. Also, the LF wheel will get less negative camber and the distance between the wheel centre and the ground will increase. It is as if we had a shorter 'RF leg' and a longer 'LF leg'.

As with the table example, if one leg (here, the LF) becomes longer, necessarily the table will stand on three legs. Necessarily, RR 'leg' load will increase, too.
There will also be more load on the LF – RR diagonal. If you know where the c of g is, you will know which two remaining legs, RF or LR, will be off the ground.

At the same time the RF wheel goes up, its wheel centre will go lower as it acquires more negative camber. Less load on the RF will inevitably mean less load on the LR.

So, if we follow the table example, if we turn the steering wheel, will one of the four wheels be off the ground? That will be the case if you have dummy (rigid) suspensions and wheels, and the frame is 100 per cent rigid.

On a real car, however, we have eight springs: four between the bottom of each leg and the ground (the tyres' vertical spring) and four between the top of each leg and the table (the suspensions between non-suspended and suspended masses). See **Figure 2c**. That is why, even with a very rigid frame, all wheels stay on the ground when the steering wheel is turned.

Wheel loads

Figure 3 shows an example of each of the four wheels vertical load variation in steering. This simulation has mostly been validated by workshop measurements. I use the word mostly here because the chassis frame is not necessarily perfectly rigid, and there are always some residual frictions in suspension (mostly dampers) and tyres. Also, the slight longitudinal, lateral and steering movements of the contact patch vs the scale centre could induce a vertical load measurement variation.

KPI and caster angles and trails create an anti-front load transfer and a pro-load transfer

One good sanity check here is to add all four wheels' loads. The total must remain the same. You can maybe tolerate an error of one or two kilos, but certainly not 10!

Figure 3 is a simplified example because there is no speed. We are in the workshop, or in the pit lane, as I was on the simulator at speed zero. The steering wheel angle is defined as positive when turned to the left.

We can see that the LF load increases from about 2470N to 2630N for a 90-degree steering wheel angle to the left. That is 160N, or about 16kg. If you know the tyre forces and moment sensitivity to the vertical load, you know that is not negligible. The same increase will occur on the right rear (RR). While on the LF and RR diagonal, the load increases by 2 x 160N = 320N, while the right front (RF) and left rear (LR) diagonal load decreases by 2 x 160N = 320N. That is what we sometimes call the diagonal load transfer.

How does that affect car handling?

Lateral load transfer

Let us first look at a theoretical example of a lateral load transfer, as shown in **Figure 4**.

The two front wheel static loads are different. Same for the two rear wheel static loads. These loads were measured on a real car where there is often a bit of asymmetry. There is no braking or acceleration, nor any downforce, and the total vertical load remains the same: 10,110N. The load distribution (48.66 per cent front) is also unchanged.

A lateral acceleration of about 1.8g will create a front load transfer of 1950N and a rear load transfer of 2050N. The total lateral load transfer distribution (TLLTD), or 'magic number' (this concept has been explained in previous articles) is 1950 / (1950 + 2050) = 48.75 per cent. The diagonal load LF + RR is 51.14 per cent, the opposite diagonal load is 48.86 per cent.

Of course, this is a very theoretical calculation. If we have lateral acceleration, we must be in a corner and, if we are in a corner, there must be some steering…

Figure 5 shows the effect of the diagonal load transfer induced by the steering. The car is at rest, with no lateral or load transfer, no speed, no downforce, just a steering wheel input of 90 degrees to the left. 320N (2 x 160N) are added to the LF – RR diagonal and are removed from the RF – LR diagonal. It is interesting to note that the change in diagonal load percentage is significantly bigger that the one due to the lateral load transfer. We now start to understand how the design of the front upright can change car behaviour as much, if not more, than springs and ARBs, especially on tight corners with a lot of steering wheel input.

To conclude, let us now look at **Figure 6**, which is the composite of **Figures 4** and **5**, combining the effect of both steering and lateral load transfer.

The front load transfer is 1950N - 160N due to the steering. That is 1790N. The new rear load transfer is 2050N + 160N = 2110N. The total load transfer without steering was 1950N + 2050N = 4000N. It has not changed, as 1790N + 2210N is still 4000N. The new magic number is therefore 1790 / (1790 + 2210) = 44.75 per cent. Compared to the previous magic number of 48.75 per cent, that is a very significant change.

A very simple way to summarise **Figure 6** is as follows: KPI and caster angles and trails create an anti-front load transfer and a pro-load transfer. Knowing the influence that 10N of vertical tyre load variation can make on the car balance, it should now be clear that the design of the front uprights has to be very carefully considered.

Fig 4: Theoretical load transfer calculation with no steering (all loads expressed in Newtons (N))

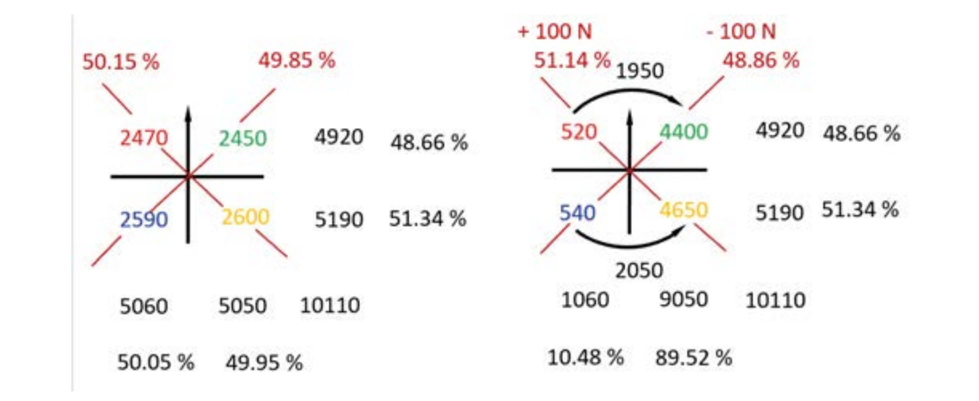


Fig 5: Theoretical load transfer only induced by steering (all loads expressed in Newtons (N))

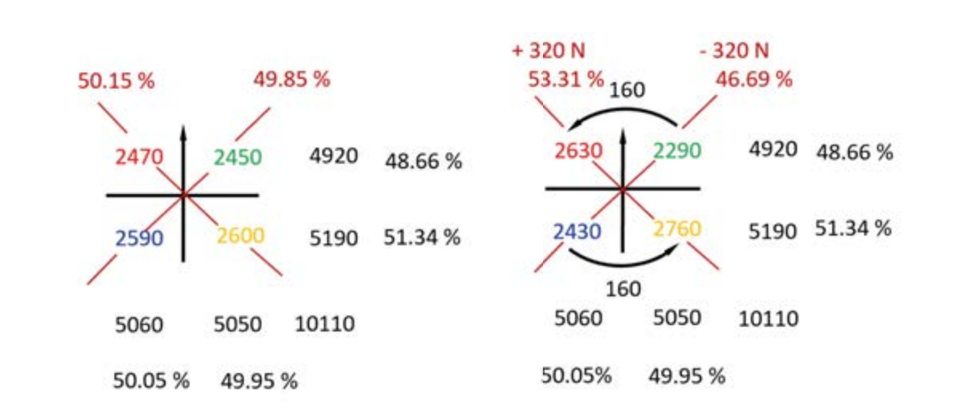
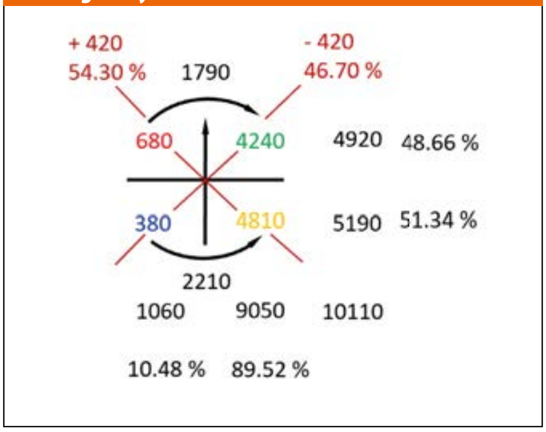


Fig 6. Combined effect of lateral load transfer and steering on dynamic wheel load



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

Public, on site, and online OptimumG seminars are held worldwide throughout the year. The Advanced Vehicle Dynamics and the Data Driven Performance Engineering seminars present several theories and best practices that can be used by engineers when making decisions on how to improve vehicle performance. OptimumG engineers can also be found around the world working as consultants for top level teams.

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Beyond BEV

As OEMs and racing bodies look for an alternative to pure battery electric, hydrogen propulsion concepts are developing fast.* Racecar *looks at the current state of play

By LAWRENCE BUTCHER

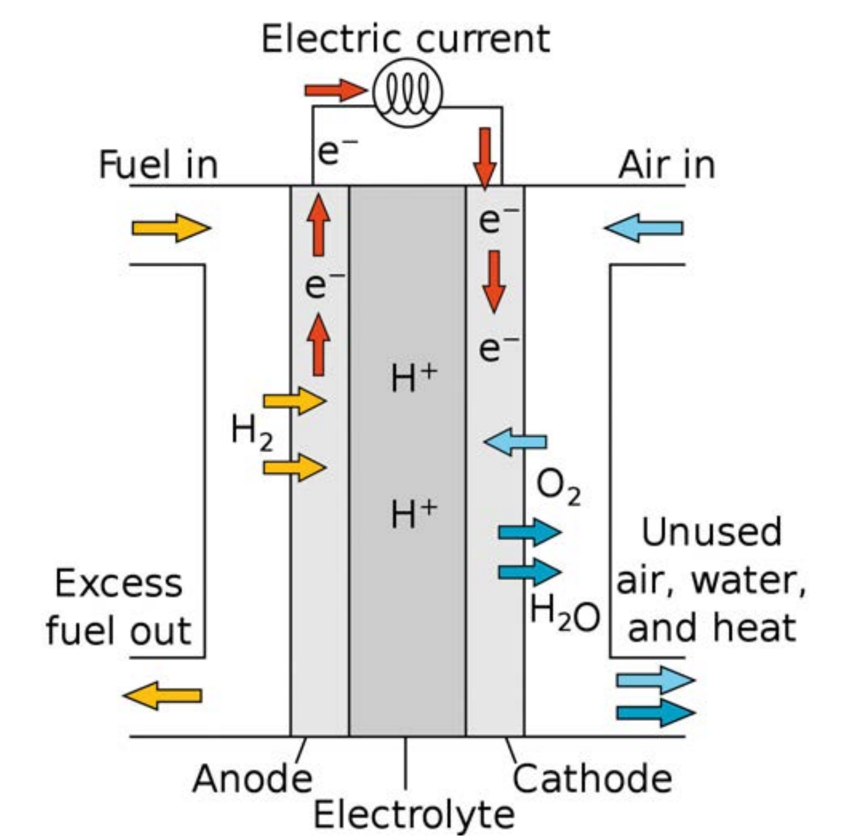
Battery-powered electric vehicles (BEVs) may be the *enfant gâté* as the world transitions to low-carbon propulsion, but talk to most experts with a realistic view on decarbonisation and they will assert that BEVs are far from a catch-all solution. The raft of issues surrounding everything from sourcing materials such as lithium and cobalt, through the sticky subject of what to do with batteries at end of life – not to mention the sheer size of packs needed to extract reasonable range from vehicles – mean that adding batteries to everything from scooters to boats and 'planes is simply not a sustainable option.

The reality is that (notwithstanding simpleton politicians being unable to understand more than one solution) BEVs will be *part* of a wider range of low-carbon solutions, incorporating both synthetic fuels and, the subject of this article, hydrogen.

The development of what is referred to as the 'hydrogen economy' is already well underway, though admittedly at different rates across the world. In some places such as Japan, the implementation of widespread hydrogen infrastructure is progressing at pace. For Europe, progress is slower, but gathering momentum with most countries, and the EU, having now developed hydrogen roadmaps.

The benefit of hydrogen from an emissions perspective is that when combusted (in an ICE) or reacted (in a fuel cell), the only significant by product is water (though NO_x can be an issue when used in combustion engines).

Diagrammatic representation of a proton exchange hydrogen fuel cell



The principle of operation is similar to that of a battery, featuring an anode and an cathode and utilising the inherent chemical energy of the hydrogen

The benefit of hydrogen from an emissions perspective is that when combusted (in an ICE) or reacted (in a fuel cell), the only significant by product is water

GCK Motorsport's e-Blast racer has an electric battery and hydrogen fuel cell on board and was showcased at the 2021 Dakar Rally to demonstrate the application of fuel cell technology in racing. The French company's updated version, e-Blast H2, was presented in prototype form at this year's event, and will race competitively in 2024

The first hydrogen-powered entry on the Dakar Rally was the H2 built by Gaussin of France. It featured a 380kW fuel cell, 82kWh battery and twin 300kW motors. It completed the 2022 event

However, despite hydrogen being the most prevalent element in the universe, it tends to be fixed in compounds and needs to be separated out. The two most common methods used for this are steam-methane reforming (SMR) and electrolysis, both of which require considerable amounts of energy. Depending on the source of that energy determines how 'clean' hydrogen is in an emissions sense.

Grey, Blue and Green

Where good old non-renewable energy is used for SMR (think coal or gas power stations), one obtains Grey hydrogen. If the SMR process uses carbon-capture techniques, the resulting gas is called Blue hydrogen. Lastly, if electrolysis powered by carbon-neutral, renewable energy is used, Green hydrogen is the result.

Currently, most of the world's hydrogen is Grey, but considerable efforts are underway to transition to Blue and Green production methods. Of course, using energy to refine hydrogen is less efficient than simply putting it directly into a battery (SMR is around 65 per cent efficient, the latest electrolysis plants around 80 per cent), but the benefits of having a relatively easily transported energy storage medium are considerable. Not least because many of the best locations for renewable energy generation are not in parts of the globe where that energy is most needed. The coastline of South America, for example, for wind generation, or the deserts of Africa for solar. Convert that energy into hydrogen, or a carrier medium such as ammonia (which is easier to liquefy at just -33degC and contains 1.7 times more hydrogen per cubic metre than liquefied hydrogen) and it can be shipped around the world in bulk carriers.

Pound for pound, hydrogen also has higher energy density than even the latest battery technology, 35,000W/kg compared to the lithium-ion technologies at around 4-500W/kg. So, if you can compress it enough (or store it as liquid), greater range can be extracted from a hydrogen-powered vehicle at a lower weight than a BEV. Hydrogen-fuelled vehicles can also be refuelled at a much faster rate than a BEV can be charged.

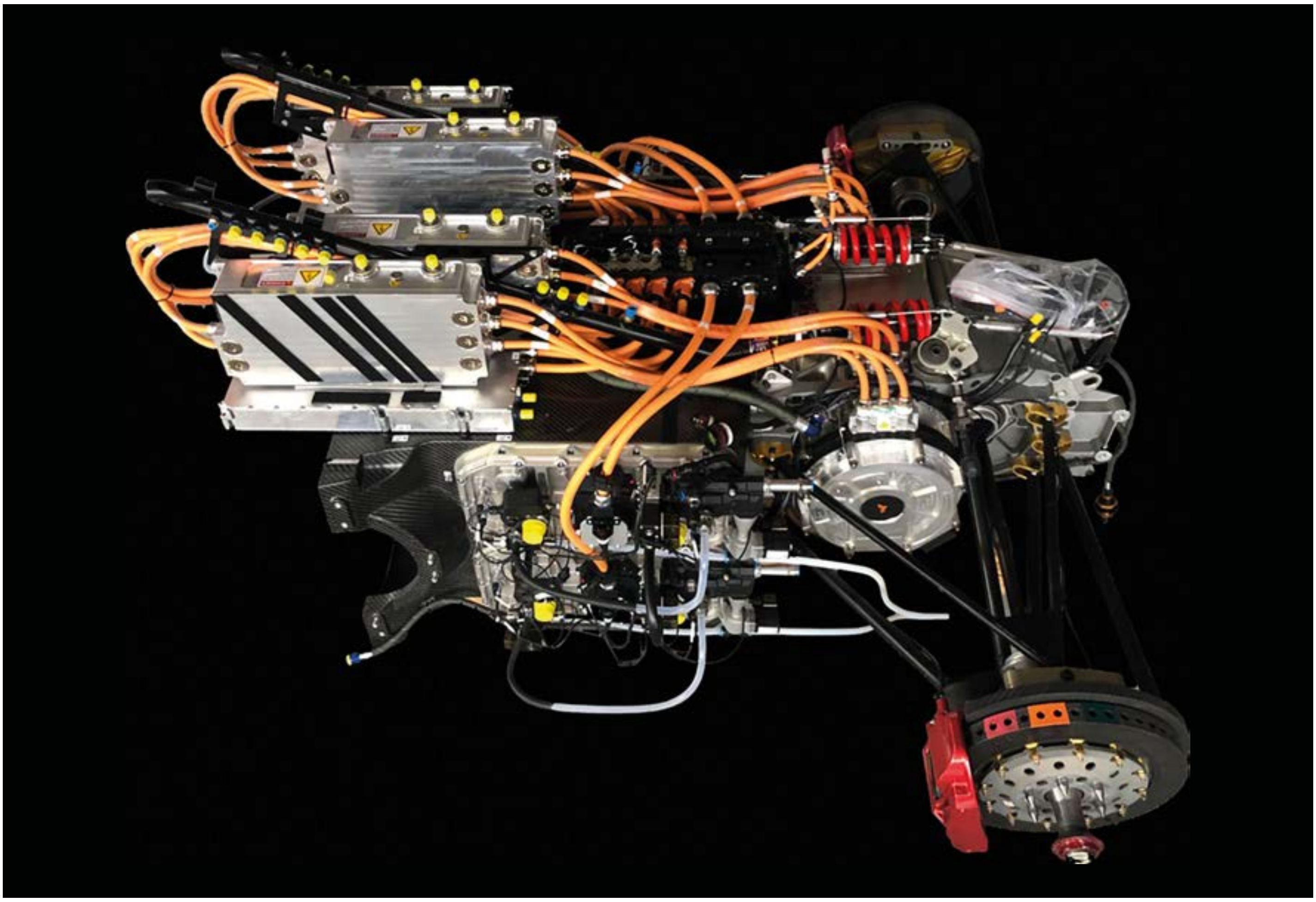
Hydrogen in motorsport

Thanks to these advantages, hydrogen is firmly in the sights of a number of OEM vehicle manufacturers, with even greater interest being shown for freight vehicles and aviation. Inevitably too, various hydrogen-fuelled motorsport endeavours are currently underway as well.

The forms of hydrogen propulsion relevant to motorsport can be broken down into two classes: hydrogen fuel cell-powered EV (FCEVs) and hydrogen-fuelled ICE. Both approaches are being deployed in racing currently but, for the purposes of this article, we will focus on the former. One can already buy FCEV road cars in the form of the Toyota Mirai and Honda Clarity, and FCEVs have competed in a number of racing disciplines.

With trucks the area of transport where fuel cells are being adopted more widely, it was fitting that the first hydrogen entry on the Dakar Rally be a truck produced by French specialist vehicle manufacturer, Gaussin. Its H2 Racing Truck finished the 2022 Rally and features a 380kW fuel cell coupled to an 82kWh battery and a pair of 300kW motors, all housed within a lightweight 'skateboard' chassis developed specifically for hydrogen-based electrification.

The forms of hydrogen propulsion relevant to motorsport can be broken down into two classes: hydrogen fuel cell-powered EVs and hydrogen-fuelled ICE



Franco Swiss outfit, GreenGT, has been working to develop a hydrogen fuel cell-powered racecar for several years. In this early iteration, the fuel cell was linked directly to the traction motors

Also set to compete on the Dakar in 2024 is a fuel cell-powered car under development by GreenKorp Connection (GCK), headed by French Rally driver and skier, Guerlain Chicherit. The e-Blast H2 is being developed with input from advanced powertrain design specialist, FEV, and will feature a bespoke fuel cell and storage tank system.

Scuderia Cameron Glickenhaus is also in the midst of developing a fuel cell power entry for the Baja 1000.

Currently competing in a more traditional track setting is Franco Swiss firm GreenGT, running a FCEV Prototype with the Michelin Le Mans Cup as a test bed for the ACO and FIA's future H2 hydrogen class at Le Mans, which we will return to in greater detail shortly.

Fuel cell technology

First, though, it is worth looking at what a fuel cell is, and how it works. Invented in 1839 by Welsh scientist, William Robert Grove, the principle of operation for a fuel cell is much like that of a battery, featuring an anode and a cathode and utilising the chemical energy of, in this case, hydrogen.

In a hydrogen fuel cell, the anode and cathode are surrounded by electrolyte and a catalyst at the anode separates hydrogen molecules into protons and electrons. The protons move through the electrolyte to the cathode, while the electrons pass through an external circuit, creating a flow of electricity. Once the protons have reached the cathode, they combine with oxygen, creating water and heat as by-products of the process.

There are a variety of different fuel cell types available, but those of greatest interest for automotive, and motorsport, rely on Proton Exchange Membrane (PEM) technology. PEMFCs have a number of desirable attributes. For example, they operate at relatively low temperature (under 100degC), have high efficiency and can be started up and shut down rapidly.

A PEMFC uses a polymer electrolyte for conducting the protons, such as perfluorosulfonic acid, in the form of a membrane, onto which is painted the catalysing anode and cathode material (normally platinum particles in a carbon support). This assembly is sandwiched between gas diffusion layers (GDL), which facilitate the transport of reactants to the catalyst layers and the removal of water.

The resulting layered component is known as a membrane electrode assembly (MEA). Multiple MEAs are assembled in series using bipolar plates, increasing the output voltage to a useful level, and creating a fuel

One thing fuel cells tend not to be so good at is transient performance, therefore most FCEVs rely on a high power density buffer battery

cell stack ranging in power from one to over 100kW. These stacks then tend to be bundled together to increase system power.

A variety of ancillary systems are needed in addition to the cell stack, including an air compressor, which pushes air through the stack supplying oxygen for the cathode reaction. Thermal management and cooling systems, as well as a DC-DC converter are also used and, of course, high pressure storage tanks for the hydrogen.

Transient performance

One thing fuel cells tend not to be so good at is transient performance. Therefore most FCEVs rely on a high power density buffer battery, facilitating rapid changes in power deployment as well as energy recuperation under braking.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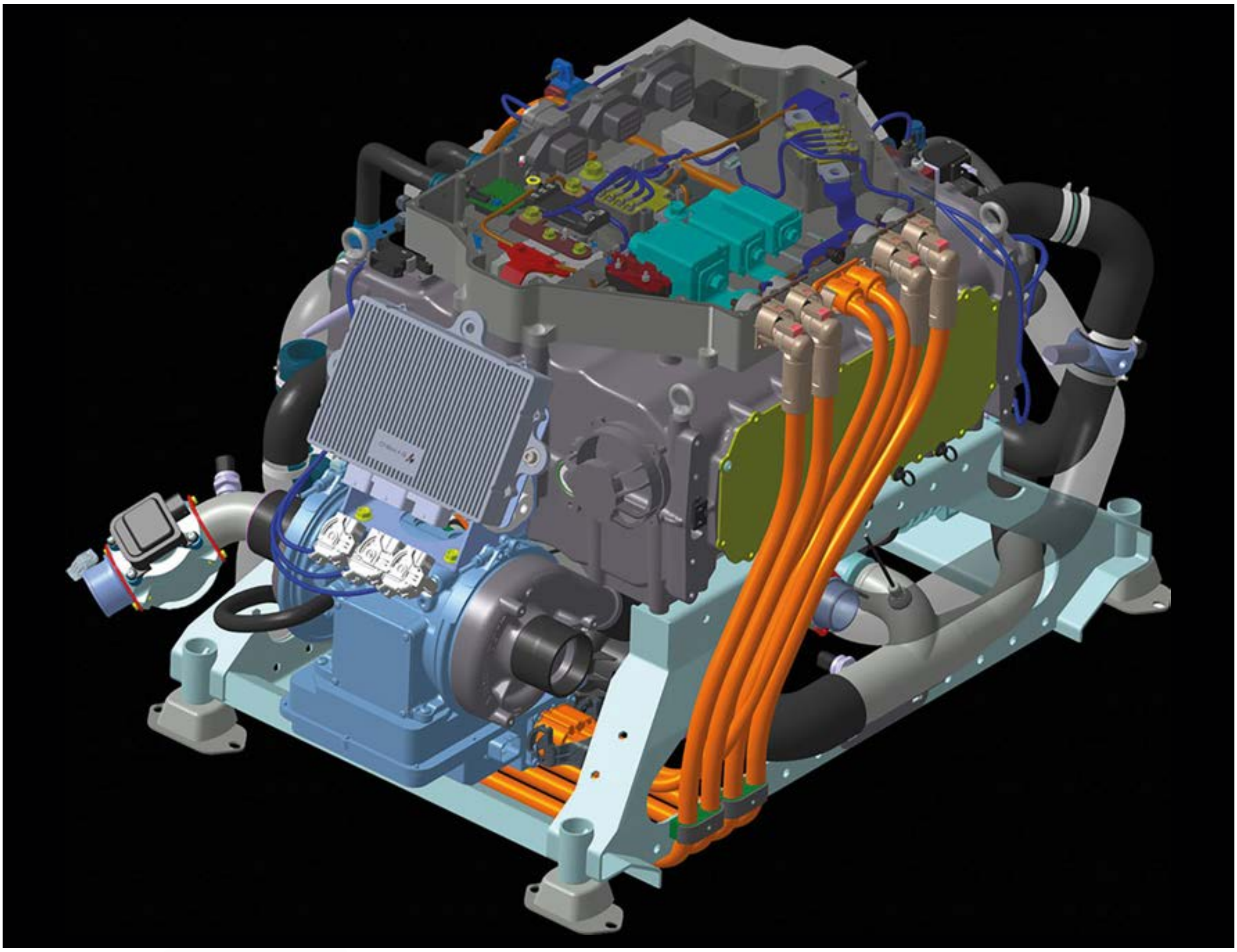


GreenGT has been steadily developing its fuel cell package, both increasing power and reducing size and weight, down from 400kg to 133kg in this current iteration. Power output is 250kW

Competition ready, the car fielded by Green GT in the Michelin Le Mans Cup is a good example of the current state of the art for high-power fuel cell integration. The ACO has set its sights on establishing a class for hydrogen fuel cell cars at Le Mans in 2025, and part of its plan to achieve this is via a partnership with GreenGT, which has been working on the development of a hydrogen fuel cell racer for many years. The company's test mules have evolved considerably from the rather wild-looking H2, which was intended for a Garage 56 entry in 2013, and it now has a fully operational racecar based on an ADESS LMP3 chassis.

Over the last decade, the company has steadily increased the potency of its fuel cell package, both upping the power and reducing its size and weight. The first iterations used a road car-derived fuel cell with 18 stacks, while the current system uses a more active surface chemistry on the fuel cell membrane and only features four stacks, with an output of 250kW. While versions of the old cell were higher power, developing up to 320kW, weight has been reduced from 400kg to the current cell's 133kg.

The fuel cell is fed air via a high efficiency compressor and a buffer battery between the cell, while the four electric traction motors allow for regenerative braking and storage of energy from the cell when it is not immediately required. The car is fuelled with gaseous hydrogen, rather than liquid.

The company's early cars had the fuel cell linked directly to the traction motors. But by adding a battery into the system, it was possible to double the energy available for the motors at peak demand. The 2.4kWh battery can deliver 300kW over 20 seconds.

The company worked with a Formula 1 battery supplier on the development of the buffer and, with power rather than energy density the priority, was able to achieve an astounding 150 C-rate.

Packaging and weight

'The main target we have at the moment is to reduce the weight of the system, which is critical. We are not touching the fuel cell itself, because over the last four years it has proved very stable,' explained Jean-François Weber, MD and head of R&D at GreenGT, speaking at Le Mans this year.

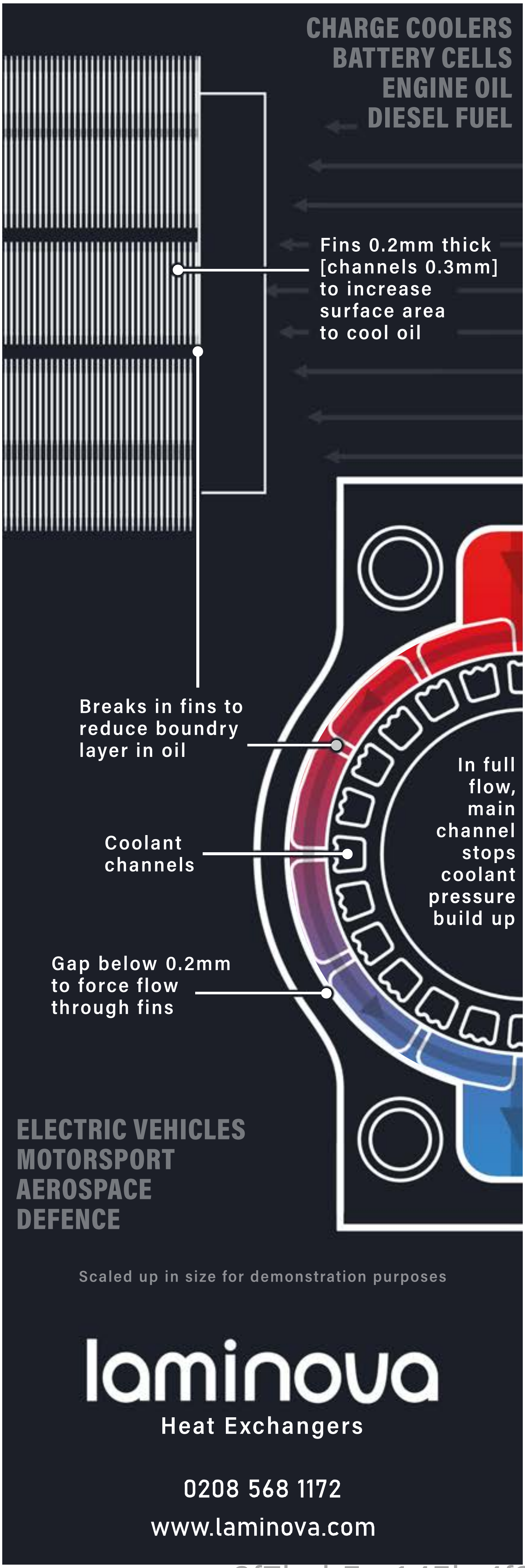
The ACO has set its sights on establishing a class for hydrogen fuel cell cars at Le Mans in 2025

'We have focused our work on the accessories – things like the compressor, the cooling – and the aerodynamics of the car.'

It is notable that the fuel cell element of the GreenGT is considered adequate in terms of performance, with the main challenges now being keeping other components cool and packaging everything within the constraints of a Sports Prototype chassis.

Let's be clear though, the cooling demand of the battery and motors at full power is considerable.

'When we combine the fuel cells and battery, we are near 500-520kW,' says Weber. That's why the car features a somewhat unusual, roof-mounted scoop for supplying cooling air to the motors and battery.



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Due to the sidepods being occupied by a pair of hydrogen tanks, there is only space in the sides for the fuel cell cooling circuit, hence the need for the additional roof scoop. 'We need to re-think the definition of the cars and where we put the various components,' suggests Weber.

The fuel cell is due for further development, both to cut its weight and increase performance. 'We started four years ago on [the development] of composite bipolar plates, and on the MEA we have some developments to improve the active surface, but we cannot give more details on that yet,' says Weber. 'We hope to reduce the volume by 30 per cent and improve the weight by efficiency. We are at the point where we can compete with IC engines and the curve for development is very steep.'

Currently, the team is limited in how far it can go with overall vehicle architecture changes as the existing fuel tank design is the only one homologated for racing.

'With the regulations, we cannot do everything we hoped we could,' muses Weber.

Emerging technology

Looking to the future, though, there are several promising options that should make packaging hydrogen tanks less burdensome.

'We need to re-think the definition of the cars and where we put the various components'

Jean-François Weber, MD and head of R&D at GreenGT

GreenGT had this FCEV Sports Prototype running at Le Mans this year as a test mule for the ACO and FIA's proposed H2 hydrogen class, which is currently scheduled for Le Mans competition in 2025


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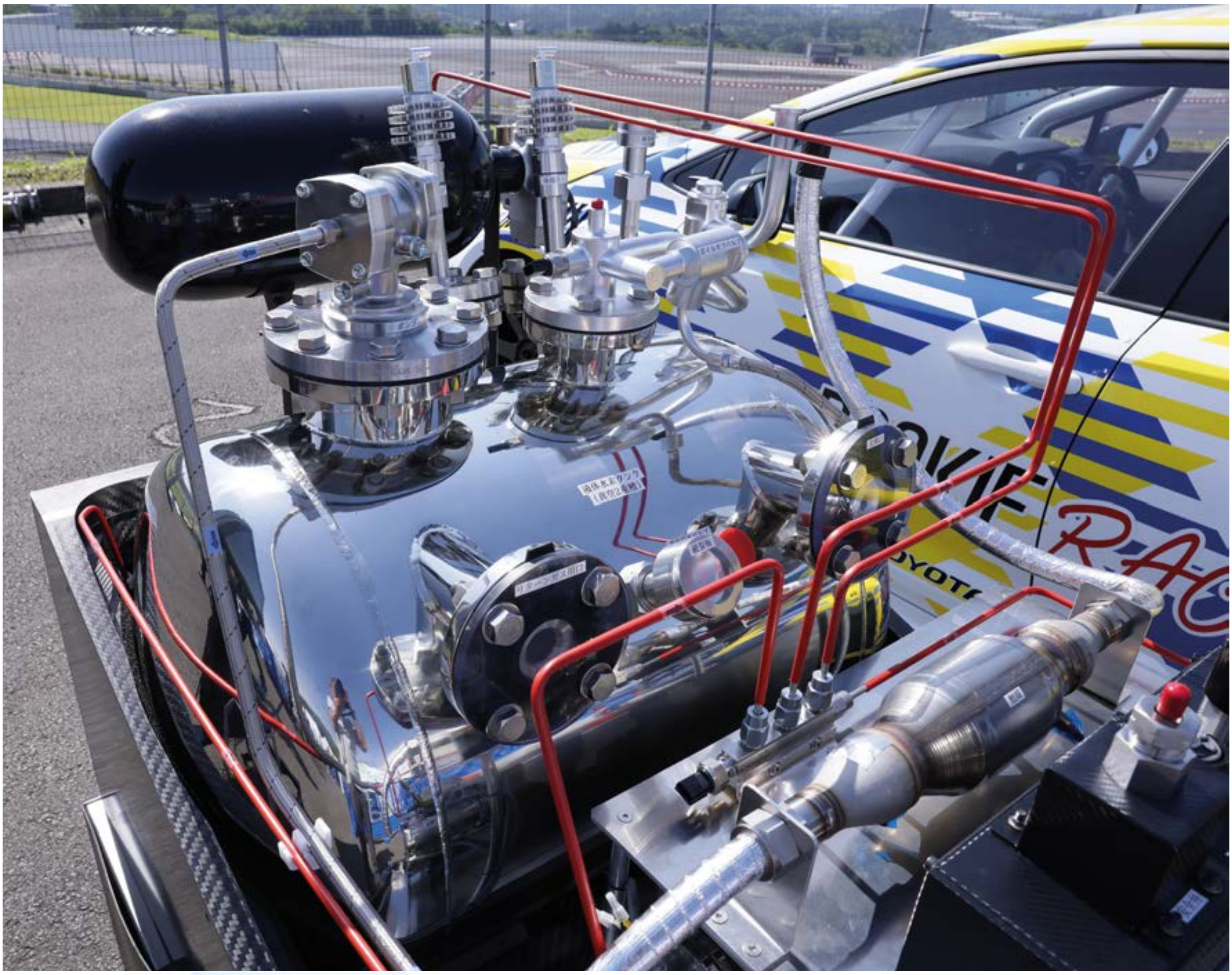


Toyota has been pushing ahead with its hydrogen project, competing with a hydrogen-fuelled ICE Corolla in the Super Taikyu series, as well as developing this mobile liquid refuelling station

For example, a UK-based company called Viritech, with former F1 engineer, Mat Faulks, as its CTO, has patented a design for structural tanks. Produced from a graphene composite, the tanks are intended to act as stressed members, allowing for better integration into a vehicle and a considerable weight reduction.

A move to cryogenic-cooled liquid fuel would also greatly reduce the tank size needed to achieve representative stint lengths at a track like Le Mans. 'The volume would go down three to five times,' observes Weber.

Thanks to liquid hydrogen being stored at much lower pressure, the need for cylindrical tanks is also removed, adding further packaging flexibility. Though the industry standard for automotive currently centres around gaseous hydrogen, moves are afoot, particularly in the freight sector, to develop liquid fuel systems and infrastructure.

It is notable too that in Japan, Toyota is progressing with work on a mobile liquid refuelling system for its hydrogen-fuelled ICE Corolla, currently racing in the Super Taikyu series.

The Japanese company has also been pushing the capabilities of gaseous refuelling. For example, by increasing the size of the car's fuel port and nozzle, coupled with a rise in pressure from 40MPa to60MPa, it can now fill the car's twin tanks in around one and a half minutes, compared to five minutes when the project commenced in 2021.

Development rate

The efforts of GreenGT in Sportscar racing and others across different motorsport genres will, it is hoped, accelerate the development rate of hydrogen fuel cell systems. However, suitable regulation and the infrastructure to make it work on a larger scale lags behind the currently available technology (as, of course, was the case when EVs first started racing).

Regulation constraints have already slowed the development of innovative storage solutions for GreenGT, while trackside infrastructure needs considerable investment if hydrogen-fuelled cars are to compete in significant numbers. Taking Le Mans as an example, the bunkering required to provide petrol for a grid of 60+ cars is huge, and even just the installation of hydrogen tanks and supply lines for five cars would be a major undertaking, let alone a full grid. But, if 2025 remains the target for an H2 class, such work will need to begin soon.

Regulators and race series organisers need to remain flexible for the technology to prove its potential

Hydrogen almost certainly has a future in motorsport, but regulators and race series organisers need to remain flexible for the technology to prove its potential.

The heat is on

In the third of a series of three articles,* Racecar *offers a revised approach to tyre modelling that integrates critical thermodynamic quantities into the model

By ANDREA QUINTERELLI

Photos: XPB

Knowledge of the optimal temerature range for a tyre compound is critical in motorsport because racing tyres are particularly affected by the tread's thermal conditions and the carcass structure

The two previous articles in this mini series (see *RE* V31N11 and V32N1) have provided an overview of the most common tyre testing and modelling methods. They have highlighted how dominant factors like temperature, pressure and wear have, historically, been challenging to incorporate into a formulation that would work in real-time, and how both could be used as an input and an output.

In this third and final article, a new approach to tyre testing and modelling will be introduced, one whose main innovation is the ability to consider the aforementioned thermodynamic parameters during the testing and modelling phase.

Using outdoor testing performed with a car used as a moving laboratory, and without the need for expensive, tailored equipment, non-destructive measurements performed directly on tyres show a new way of modelling them.

As previously mentioned, a young Italian start-up illustrated a more comprehensive methodology to understanding and describing tyre behaviour. In this article, we will focus on how critical thermodynamic quantities can be measured and integrated into a tyre model, how that affects the force and moments exchanged with the road, and how those changes depend on tyre characteristics and external factor inputs.

The goal of the model is to describe tyre thermal behaviour, including the interaction with the external environment and internal wheel chamber

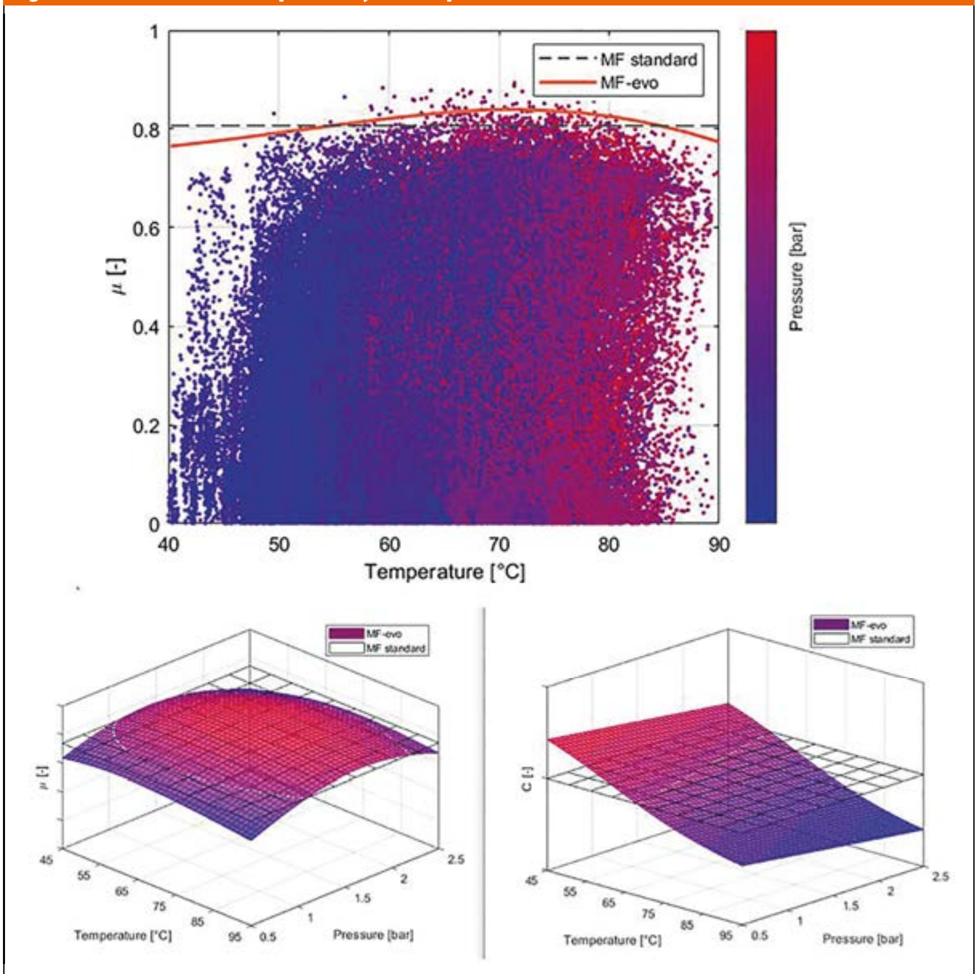
Thermodynamic model

The goal of the model is to describe tyre thermal behaviour, including the interaction with the external environment and internal wheel chamber (inner air, rims, brakes etc).

As touched upon in the previous two articles, tyre behaviour and performance are influenced by many factors, and not all phenomena are fully understood yet. They are among the most complex systems in a racecar and one of the most influential in terms of performance.

Tyre temperature is undoubtedly one factor influencing some of the most critical parameters of a racecar, like peak grip, braking and cornering stiffness and durability.

Fig 1: Friction coefficient dependency on temperature



Knowledge of the optimal temperature range for a tyre compound is particularly significant in motorsport because racing tyres are highly affected by the tread's thermal conditions and the carcass structure.

The external surface is one of the few areas of a tyre where temperature can be measured dynamically while the car runs on track, thanks to infrared sensors. In recent years, advances in sensor technology have also allowed measurements of the inner carcass temperature to be taken using multi-function devices able to collect tyre inflating pressure and internal temperature at up to five different points. These sensors are generally still identified as a tyre pressure monitoring system (TPMS).

Still, between tyre inner liner and tread, there is a significant amount of material where measurements are complex to perform, at least dynamically. Experimental data show how tyre external surface temperature varies very quickly when a car is driven at the limit on the track. This usually correlates in a relatively wrong way with grip variation, which indicates that surface temperature cannot modify the whole tread's mechanical characteristics.

'Grip shows an excellent correlation with the compound internal temperature,' Aleksandr Sakhnevych, CTO of the Italian start-up, MegaRide, explains. 'Tyre frictional behaviour can be more directly associated with tread core layer temperature, which we can only evaluate using a specific tyre thermal model,' he adds.

The relationship between the temperature of the bulk of the tread layer and friction is usually described by a bell-shaped curve, an example of which is shown in **Figure 1**.

Tyre discretisation

As briefly described in the last article, the most effective approach seems to be discretising the tyre structure. Since they are non-homogenous components, slightly different methods must be employed for the other layers. Sakhnevych notes that a tyre is an extremely complex and integrated system, whose structure can be divided into three layers, each serving different functions:

- Tread compound, accountable for the generation of tangential interaction forces within the contact patch.
- Body plies, belts, and sidewalls, which determine the carcass shape and contact patch configuration and dimensions.
- Inner liner layer that maintains the inflation pressure.

We can achieve a good compromise between accuracy and computational efficiency by dividing the complex structure of a tyre radially into two parts: the tread,

Fig 2: The two-layer discretisation proposed by MegaRide seems to be a good compromise between accuracy and computational efficiency

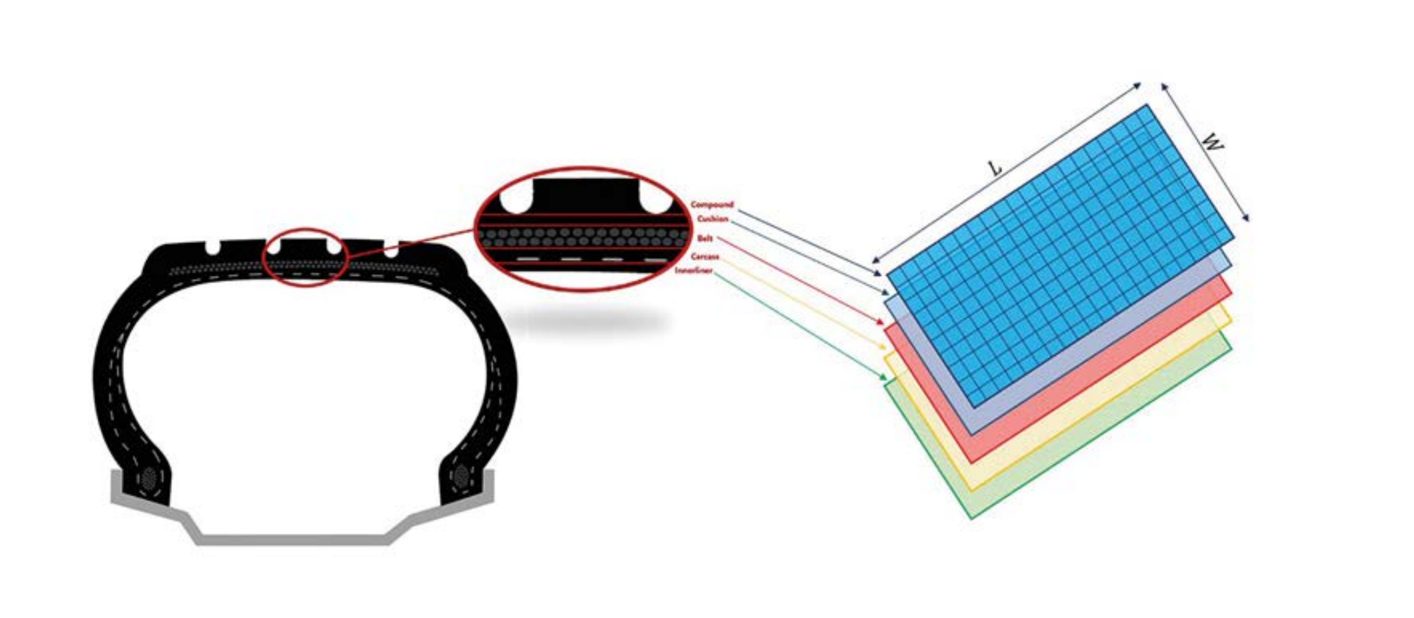


Fig 3: Tyre reduced discretisation of the inner layers

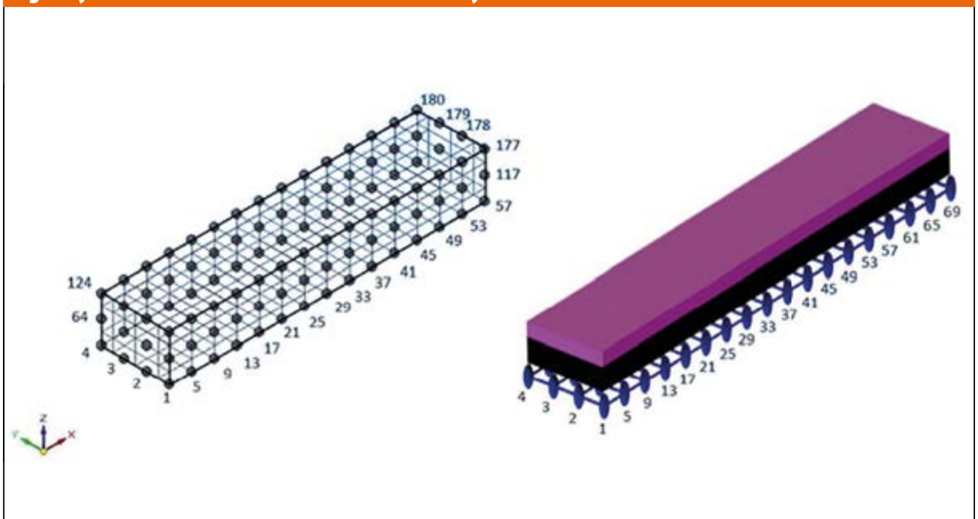
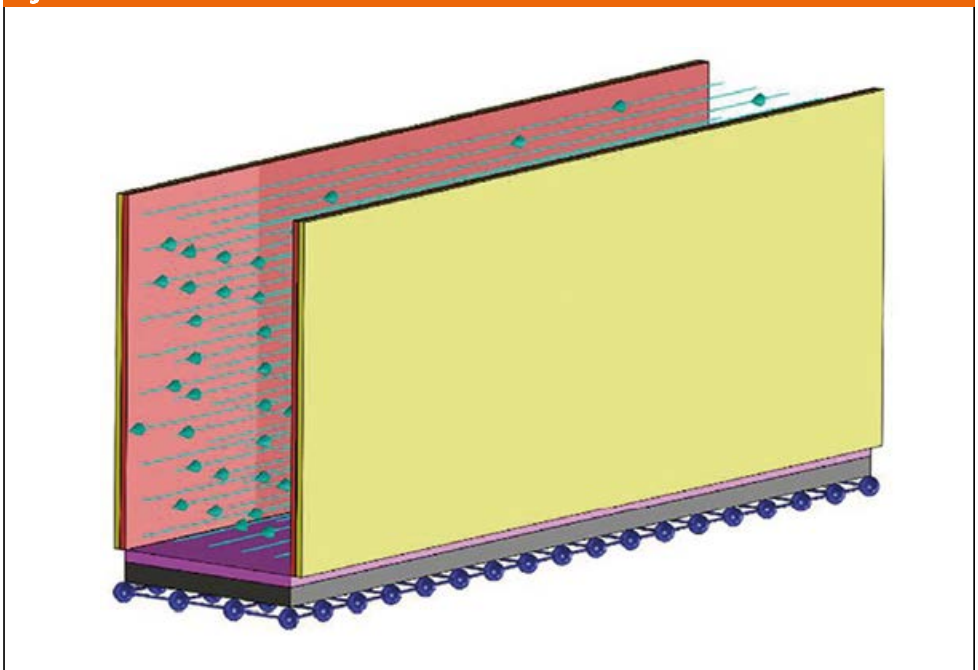


Fig 4: Sidewall discretisation



Racing tyres are extremely complex and integrated systems, whose structure can be divided into three layers: tread compounds; body, belts and sidewalls and an inner liner constituting only the rubber compound, and the composite carcass structure, including belt and inner liner.

The road can then be represented as a homogeneous, even plane in direct contact with the contact patch.

'Each layer is discretised using a grid of nodes,' explains Sakhnevych. 'Each has its thermal inertia, analytically linked to the volume of the parallelepiped, including radially and transversally between two nodes.'

To further increase computational efficiency, and to use this approach for real-time applications like DIL simulators, a simplification could be considered, substituting the node grid of the inner layers with a singular node configuration. This seems to be a sensible approximation because the thermal inertia of inner layers, even in highly dynamic applications like racecar tyres, is too high to induce significant circumferential temperature gradients.

'Thanks to the reduced computational effort ensured by this simplification, our model can also consider the sidewalls and a further discretisation along the circumferential direction within the external layer to more accurately simulate the fast thermal dynamics of tyre external surface without undermining real-time simulation requirement,' specifies Sakhnevych.

'Consequently, internal tyre nodes tangential heat exchange has been neglected, and only radial conduction has been considered.' **Figure 3** shows the switch from a full discretisation to a 'reduced' one. **Figure 4** depicts how we can include the sidewall into the mesh.

Thermal results

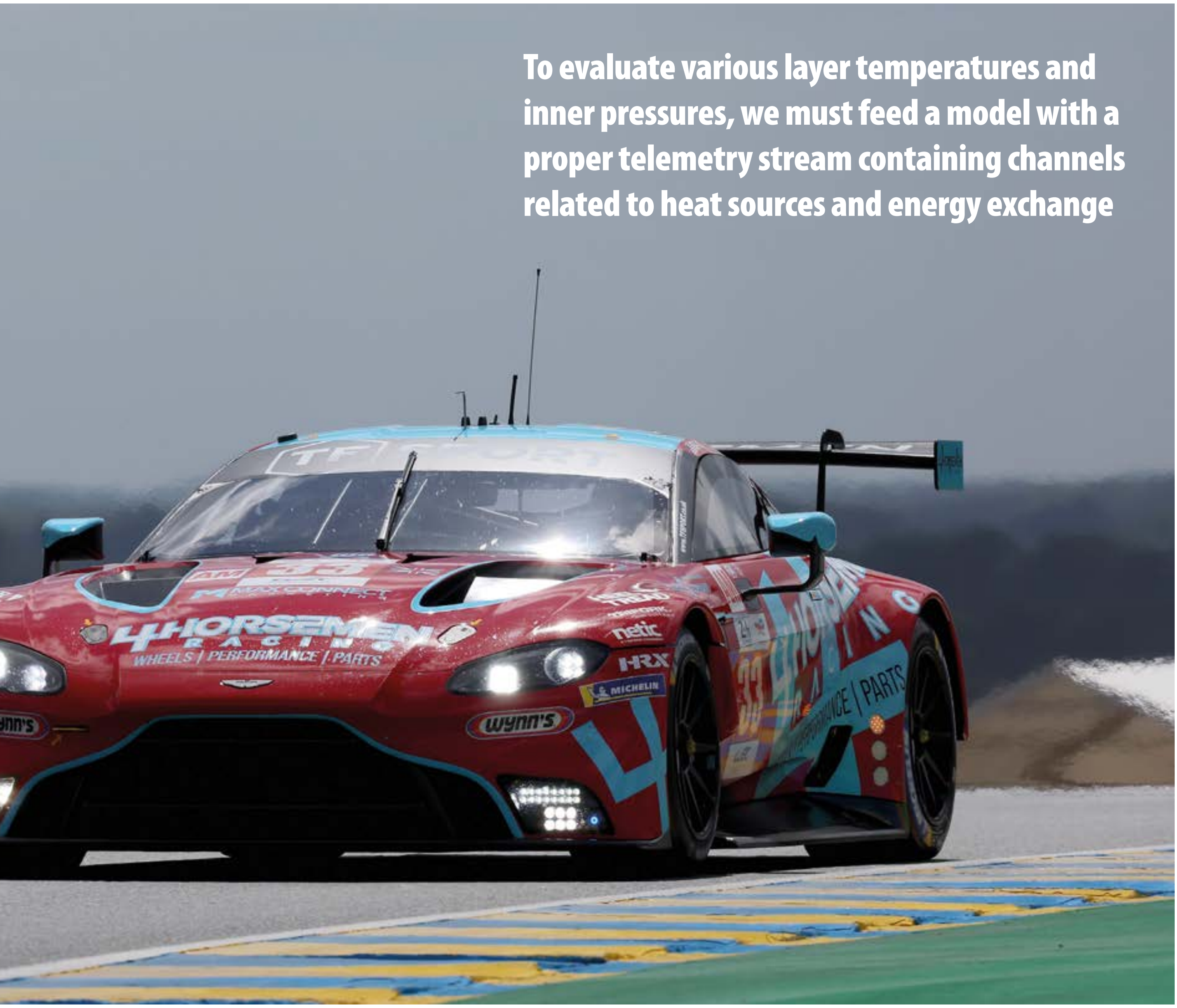
The thermodynamic evolution of the tyre system can be described by the Fourier diffusion equation, applied to a three-dimensional domain. Sakhnevych explains:

'The model needs to consider several physical phenomena, including heat generation due to friction and strain energy loss. Heat exchange with the external environment must also be considered. This is linked to thermal conduction between the tyre tread and the road surface, thermal convection between tread surface and external air and thermal convection of the inner liner surface with the inner air.

'Heat conduction between the tyre nodes due to the temperature gradients must also be accounted for.'

To evaluate various layer temperatures and inner pressures, we must feed a model with a proper telemetry stream containing channels related to heat sources and energy exchange. Particularly relevant are the forces (longitudinal, lateral and vertical) the tyres exchange with the road, their slip (longitudinal and lateral) and velocities, tyre rotational frequencies, inclination angles and speed.

To evaluate various layer temperatures and inner pressures, we must feed a model with a proper telemetry stream containing channels related to heat sources and energy exchange



The output is the circumferential and lateral temperature distribution across the different tyre layers, discretised in the radial direction as follows:

- Compound surface, the outermost part in contact with the tarmac and external air.
- Compound core, compound material layer, strictly connected to tyre grip.
- Compound base, the deepest part of the compound layer, linked to tyre stiffness.
- Belt and carcass, the main contributors to the structural behaviour of the tyre.
- Inner liner, the layer in contact with the air inflating the tyre.

Compound core and compound base layer temperatures are particularly interesting because these cannot be measured with any currently existing sensor and are closely correlated to global tyre stiffness and the hysteretic tread phenomena.

'Our model has been validated with different vehicles like trucks, motorsport and passenger cars and motorcycles, with temperatures acquired via multi-array IR pyrometers, which are usually pointed to several points of the tyre outer layer (tread surface) and inner liner, and from the internal pressure channel acquired by using TPMS,' explains Sakhnevych.

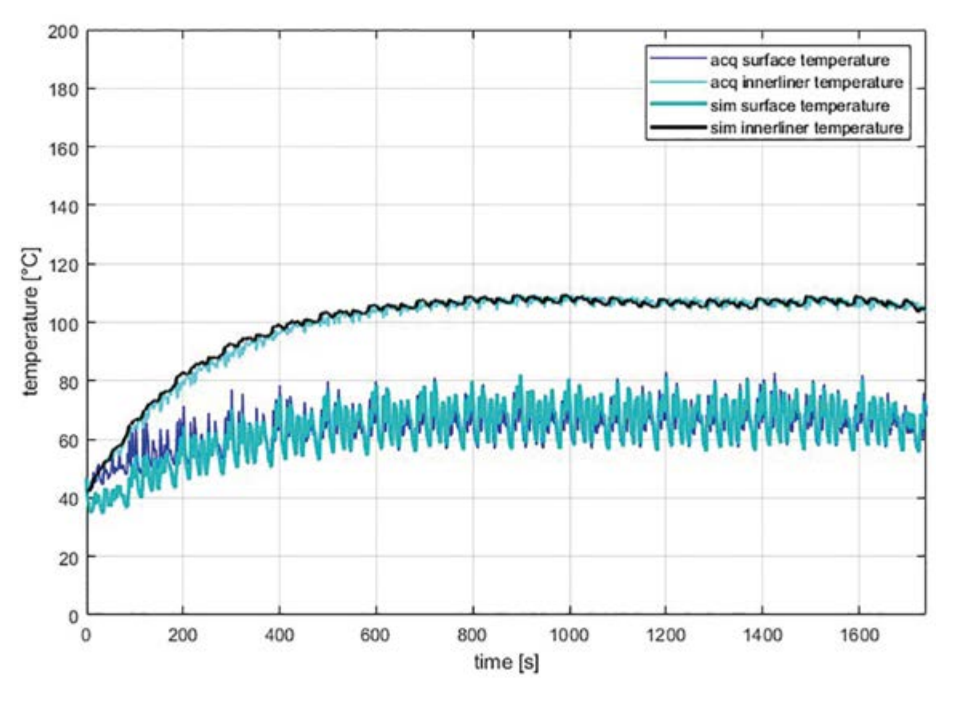
The main advantage of this approach is that, thanks to the radial discretisation, it is possible to evaluate the temperature distribution in all the internal layers that most affect tyre performance, especially in terms of grip and stiffness.

'With the availability of internal tyre layer temperature data, the optimal thermal range and the expected bell-shaped curve can be identified with a much better correlation to logged data,' notes Sakhnevych.

In particular, the temperature shown along the horizontal axis of **Figure 1** can be considered a mix of the temperatures of different layers, with a significant weighting toward the tread core.

'The reason tread core temperatures offer better results is that tread surface temperature is very dynamic, and so the

Fig 5: Comparison of estimated tyre temperatures with measured ones



The main advantage of this approach is that… it is possible to evaluate the temperature distribution in all the internal layers that most affect tyre performance

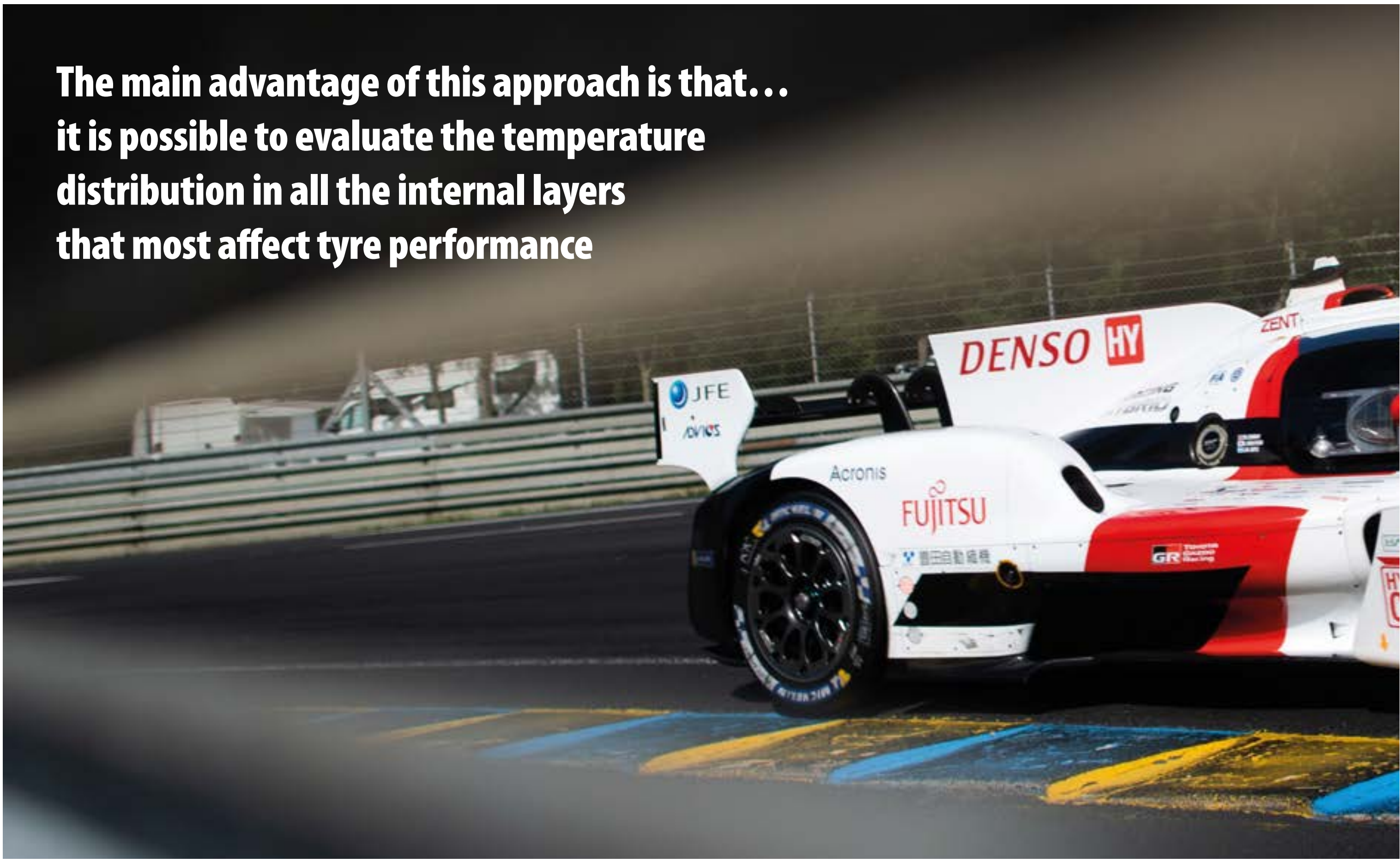
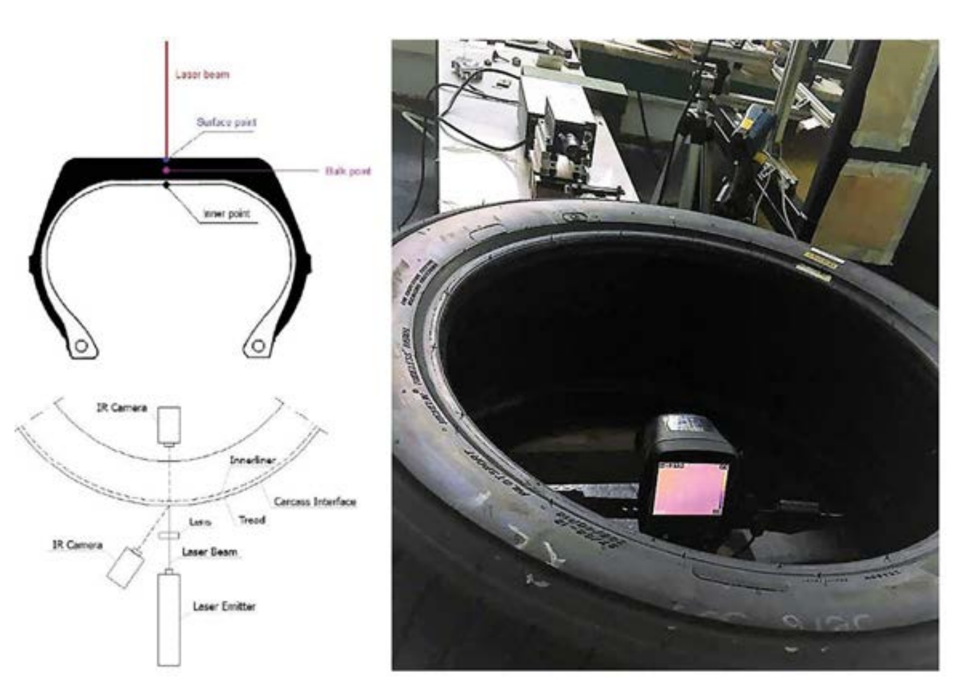


Fig 6: Schematic representation of the test set up used to characterise tyre thermal properties



‘The reason tread core temperatures offer better results is that tread surface temperature is very dynamic’

polymer characteristics do not change quickly enough to influence the whole tyre’s frictional behaviour,’ continues Sakhnevych. ‘Tread core temperature is less prone to fast variations because of its intrinsic inertia and can be easily linked to viscoelastic rubber states.’

Figure 5 is an example of results obtained with this approach, compared to logged data.

A similar model must be preliminarily characterised using a specific ‘lab’ version to identify thermal (density, conductivity, and specific heat) and structural characteristics.

Characterising tyres

‘We do this using non-destructive methodology,’ says Sakhnevych. The easiest way to gather the data required to feed the model from a thermal standpoint is to measure how the tyre reacts to a heating source.

‘The goal is to isolate physical parameters, like density, specific heat and thermal conductivity, in specific thermal conditions in a different zone of composite tyre structure and translate this to a non-linear physical model,’ explains Sakhnevych.

Such a test can be performed using a laser emitter, pointing to the tread whose beam is directed using a lens that seats between the laser and the tyre. Two infrared cameras, one facing the inner surface, the other pointing to the outer surface of the tyre, are responsible for temperature measuring. The temperature of the deeper strata at the interface between tread layers and carcass can be measured by a thermocouple.

This measurement is critical because it allows quantifying of the thermal conductivity of tyres’ internal layers, and the equipment can acquire the complete temperature distribution in a radial direction. A schematic of this testing set up is shown in **Figure 6**.

The goal of this approach is to isolate physical parameters in specific thermal conditions in the different zones of composite tyre structure, and then translate that to a non-linear physical model

A standard test can be performed in three phases, says Sakhnevych: 'Initially, the laser is switched off. In this first step, identified as idle, testing equipment's correct functioning is verified. The laser is then switched on in a second phase (heating), and heat propagation is measured. The emitter is switched off when the temperatures stabilise.

'Transient temperature trends are significant because they provide previous information about internal layers' physical properties. The third phase (cooling) sees no more action from the laser, so the tyre starts to cool down.' An example of this process is illustrated in **Figure 7**.

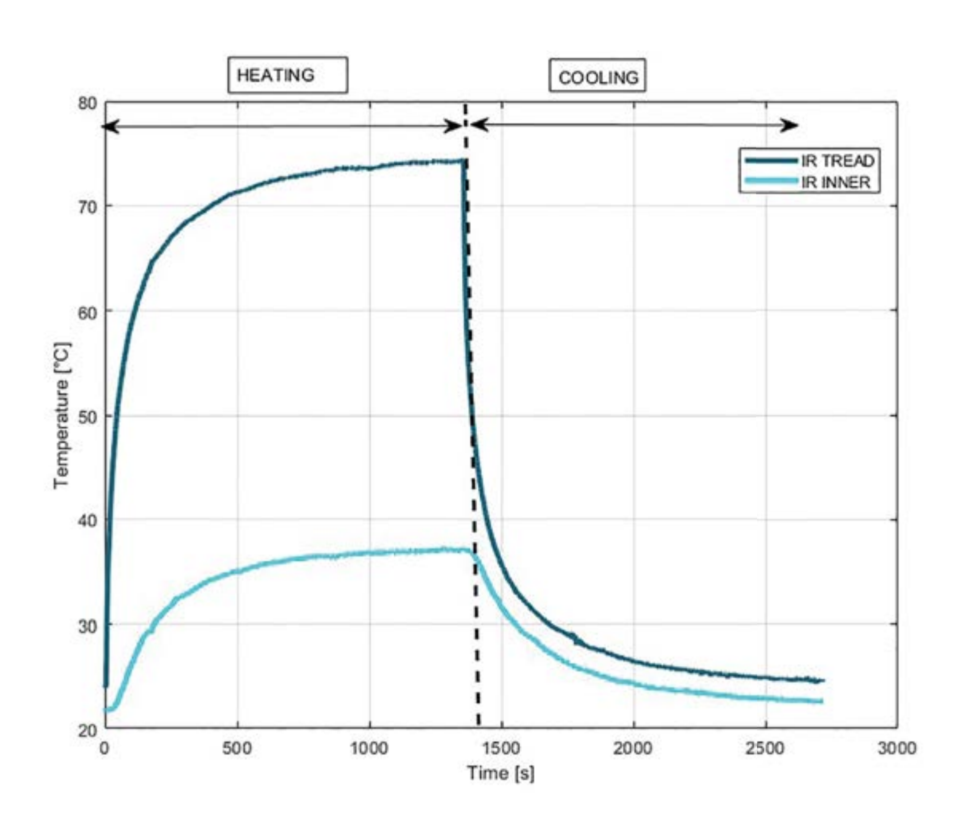
Such a test procedure is repeated using different laser powers to characterise both steady-state and transient thermal phenomena better, and more completely understand each layer's thermal inertia.

'The acquired data is used to feed a 'lab' version of the thermodynamic model and its parameterisation is performed with an optimisation process.

'The newly obtained parameter values can then be employed in real-time simulations.'

Figure 8 compares the acquired and simulated temperature evolution during a test.

Fig 7: Tyre thermal characterisation procedure



Evo Magic Formula

As discussed in the last article, Pacejka's Magic Formula is still a standard in motorsport, and in the general vehicle dynamics field, to model tyre behaviour for simulation purposes. This is a semi-empirical model, providing curves that fit the experimental results for the given testing conditions well.

Pacejka standard formulations output the forces and moments of tyre exchanges with the road as a function of vertical load, longitudinal and lateral slip and inclination (or camber) angle. Still, it doesn't consider other factors, as Sakhnevych explains:

'While the standard Magic Formula ensures a high level of accuracy and reliability for the response of the tyre to kinematic quantities, such as longitudinal and lateral slip, camber angle and vertical load, it does not contemplate several physical concurring aspects affecting frictional tyre behaviour, such as the tyre temperature distribution, inner air pressure, tread wear, road roughness and compound viscoelastic characteristics.

'Enriching the model with the tyre multiphysics, and introducing into the simulation loop additional variables

Transient temperature trends are significant because they provide previous information about internal layers' physical properties

Fig 8: Comparison between simulated and measured temperatures in a different zone of a tyre

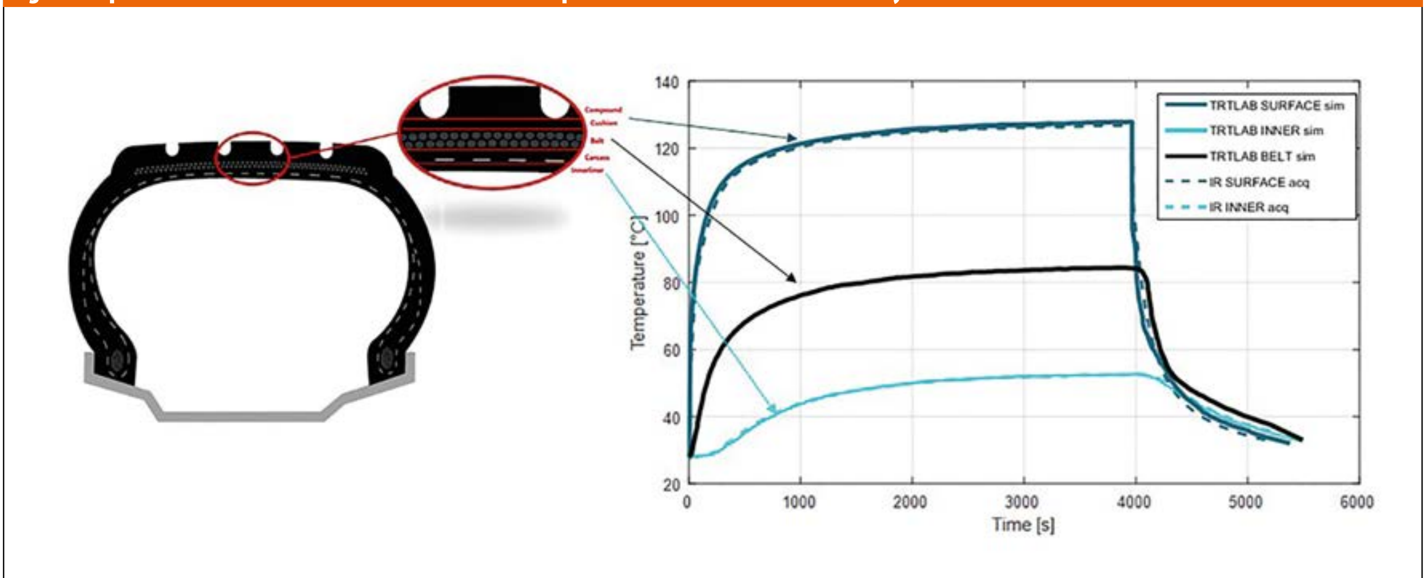


Fig 9: How different modules work together to build up the advanced MF formulation

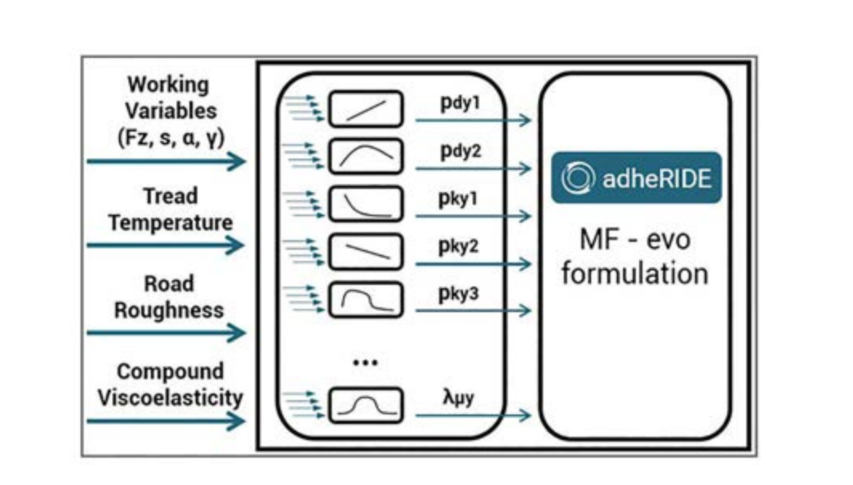
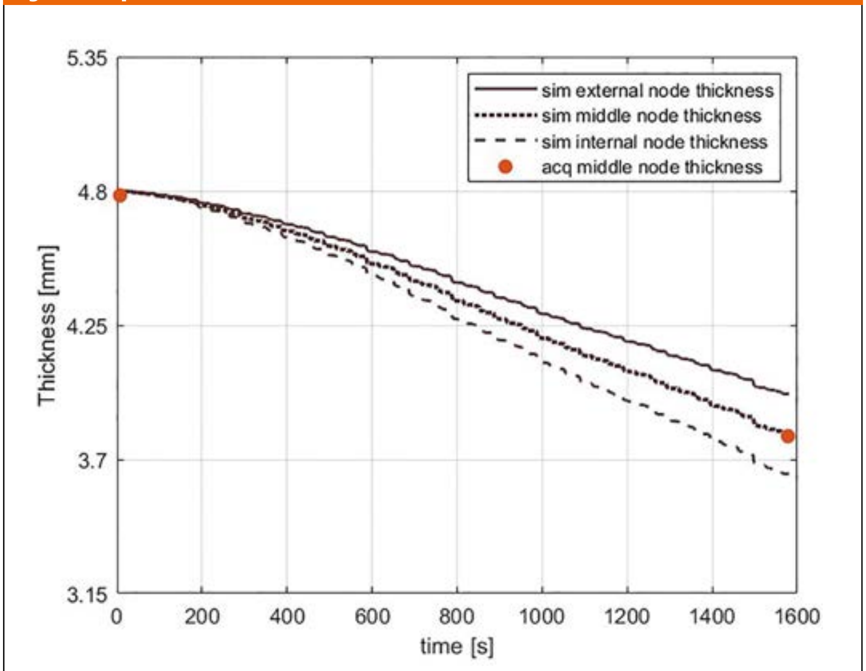


Fig 10: Comparison between estimated and measured thread thickness



concurring to tyre-road interaction means improving the accuracy of simulations for all the possible operating conditions of the tyre.'

From here, the idea of adapting Pacejka's original formulation incorporates how these parameters affect tyre forces and moments. This is enabled by integrating several tools to dynamically change the value of each Pacejka Magic Formula coefficient to reflect the influence of external factors on tyre performance. A schematic representation of a similar process is shown in **Figure 9**.

'Tyre properties, as incorporated in Pacejka Magic Formula, are no longer constant, but change point by point in a multi-dimensional space depending on temperature, pressure and wear,' explains Sakhnevych. 'We can easily appreciate the thermal effects on real tyre behaviour regarding maximum exploitable grip and stiffness.

'As a consequence, the additional functions embedded in such a model act on the corresponding Magic Formula micro coefficients, ensuring the surfaces resulting from the envelope of forces for each combination of temperature, pressure and wear show the characteristics provided by experimental data.'

Optimal window

'For a specific wear level of tyre compound, there is an optimal window concerning temperature and inflation pressure where we can exploit the maximum amount of friction, while the cornering stiffness exhibits a decreasing trend concerning these parameters. Moreover, the amount of grip available decreases due to wear, and the tyre tends to become stiffer.'

Wear is a critical part of this modelling approach then because it affects tread mass, rubber characteristics and thermodynamic properties of a tyre, all of which have an impact on grip and dynamic behaviour.

Temperature and pressure variations induced by the thinning of the tyre… form the core of tyre management strategy

'Wear modelling is based on two mechanisms: the mechanical abrasion of the compound due to interaction with track asperities, and the chemical degradation of the rubber,' says Sakhnevych. 'The latter is due to the continuation of the vulcanisation process from sustained thermal and stress cycling, which leads to a gradual hardening of the compound and a reduction in peak friction capability.'

The causes considered are:

- Forces and sliding velocities to evaluate friction power contribution, which is available within telemetry data sets.
- Tyre temperatures and pressure evaluated by employing the thermal model.
- The Storage Modulus, derived with previously described non-destructive tests.
- Contact patch data helps consider the local stress distribution variation.

The first output of wear modelling predicts how much tread thickness reduces over a particular time or distance. An example of which is shown in **Figure 10**. The tyre is divided into three ribs whose different wear is related to dynamic camber and pressure.

A second, equally important output of the wear model is its impact on whole tyre thermodynamics, and on temperature and pressure profiles. 'After a long stint, average tyre temperature tends to decrease due to wear effect, which determines a tread thickness reduction that leads to the tyre having a lower volume for the generation of heat for strain energy loss,' says Sakhnevych.

'Temperature and pressure variations induced by the thinning of the tyre are significant in the context of overall vehicle dynamics and form the core of tyre management strategy.'

Conclusions

Analysing the common tyre modelling methods, it is clear how important a complete understanding and representation of tyre thermodynamics, and its integration into a simulation environment is. Talking to MegaRide offered an opportunity to take a closer look at how the industry is changing, how these new technologies are implemented and why they can help you gain an advantage on track.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Action Express Cadillac, '14, '15, '16, '17, IMSA Champs. '18, '21 Won driver & Mfr. Champs, overall '20 Daytona 24 Hrs.
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A sensor occasion

How Alsense Motorsport tyre and brake temperature sensors can help you optimise the set-up of your racecar and improve lap times

At just under €500/corner, the ALS Tire Pro provides excellent value for money

Given GP Elite's remarkable success in the Porsche Supercup, and other championships, we're always looking for ways to be ahead of the competition. Collecting new data, especially tyre and brake temperature information, proved critical in our success throughout 2021.

Measuring the temperature across the tread is critical as engineers can see whether the tyre is being used optimally or not, assess different suspension set-ups and coach drivers in techniques for extracting the most out of the tyres at various stages in the lap.

Just measuring temperatures with pyrometers in the pit lane, however, gives a distorted picture as tyres cool down unevenly, with large deltas between channels, especially on cars running significant camber. This makes any set-up changes done using such data imprecise at best. Tyres also have a 'short memory', so measurements only show what happened in the last couple of corners, and provide little information on earlier parts of the lap and stint.

Simple solution

Assessing existing solutions in the market, none were found to be as easy to install and remove as the wireless ALS Tire Pro sensors from Alsense. These compact sensors (60mm x 40mm x 14mm) can be attached quickly and easily to virtually any surface. The lack of wiring means no bodywork to remove or drill, and an optional protective lens negates potential damage from debris.

When Porsche introduced a new Cup car for 2021, the 992 GT3, with a new Michelin tyre, understanding the operation of the tyres in conjunction with the car was critical. With only a handful of set-up variables we are allowed to influence, tyre performance is one of the most important. So, we collected as much tyre and brake data as possible during the test days, with the goal of understanding how tyre pressure, tread temperature and suspension set-up interact with each other, in order to correctly set up the brake cooling and pad performance on the car. Using Alsense ALS Tire Pro sensors, we were able to quickly and precisely determine the correct tyre pressures, toe and camber settings for the 992.

2021 also marked the year GP Elite increased its presence in endurance racing. We decided to participate in the Dubai 24h at the beginning of January 2022. Since that competition mandates Hankook tyres, we embarked on another set of test sessions, again using the Alsense tyre temperature sensors. As the Hankook has a different construction and compound to the Michelin, the information obtained was crucial to making the proper setup adjustments for a fast, consistent car in the race.

Tactical advantage

It's not only set-up that is important, though. Tactics are of enormous value in endurance racing. We used an ALS Brake Pro to measure brake temperatures on each disc, enabling us to compare several different cooling set-ups, and the differences were visible. The data collected helped us develop the entire brake cooling architecture in house and make the final decision on brake pads.

Because of this, team GP Elite only needed one front brake pad change during the whole 24-hour race, while the rear brake pads lasted the entire race.

How many times have you heard a driver saying they're on the limit, only to notice they've actually lapped slower? Although many modern racecars are equipped with tyre pressure and temperature monitoring systems located inside the tyre, they only measure air temperature. That data is of limited use as it doesn't tell us much about how the tyre surface interacts with the track. Using the ALS Tire Pro Wired system allows us insight into how much of the tyre is used in various phases of the corner and how the balance of the car changes, meaning we can determine the percentage of the lap / stint where we benefit from maximum tyre grip.

If a driver is going slower, it might be because their tyres went outside their optimum temperature window, so the car was sliding and harder to control. The scatter plot shown in **Figure 1** represents data from one of our test sessions with the Porsche 992 Cup car in Jeddah, Saudi Arabia. It's clear that the best grip was obtained when tyre temperature was between 90-110degC.

From this data we were able to determine what percentage of the lap / stint was spent with the tyres in that optimum temperature range. From there, we can go one step further and diagnose set-up problems.

Using the ALS Brake Tire Pro to measure tyre temperatures enabled us to perfect optimal setups for all conditions

ALS Tire Wired can read up to 16 channels of tyre data

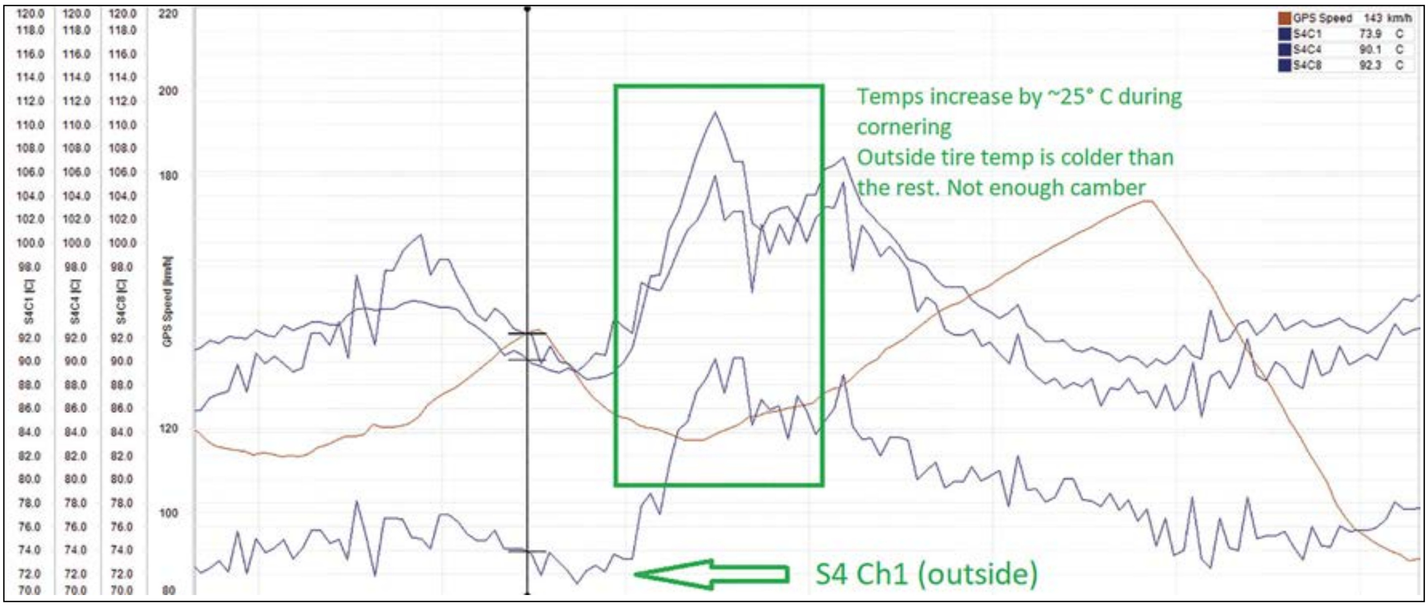

Fig 2: Rear left tyre data in a mid-speed right-hand corner

For our Porsche 992 Cup car, we estimate to have gained around 0.7s / lap using the data provided by Alsense tyre and brake temperature sensors

Using the benefits of real-time temperature monitoring, we can determine if various handling problems across the track are caused by tyres going outside their working window. For example, an understeering car can be due to the outside front tyre overloading on corner entry. This will be shown by a sharp increase in that tyre's average temperature during that phase of the corner. One solution might be to soften the anti-roll bar to decrease the load transfer to the outside wheel and send more cornering load to the other tyre.

Tuning set-up

Being able to tune set-up is just one of the critical functions of multi-channel tyre temperature systems. The ALS Tire Wired can read up to 16 channels of tyre data, while the ALS Tire Pro can read up to eight. For most applications, however, we only want to focus on three main channels: inside, centre and outside the tyre surface. We're looking for a maximum of 15degC difference between those channels.

We'll see normal, straight-line driving produces very close temperatures on the inside and center channels, while the outside will be significantly lower, with less load upon it due to camber. But as the car moves through the various corner phases, we're looking for the three temperatures to be as close to each other as possible, signalling that the energy generated is being evenly distributed across the surface, and so achieving maximum grip.

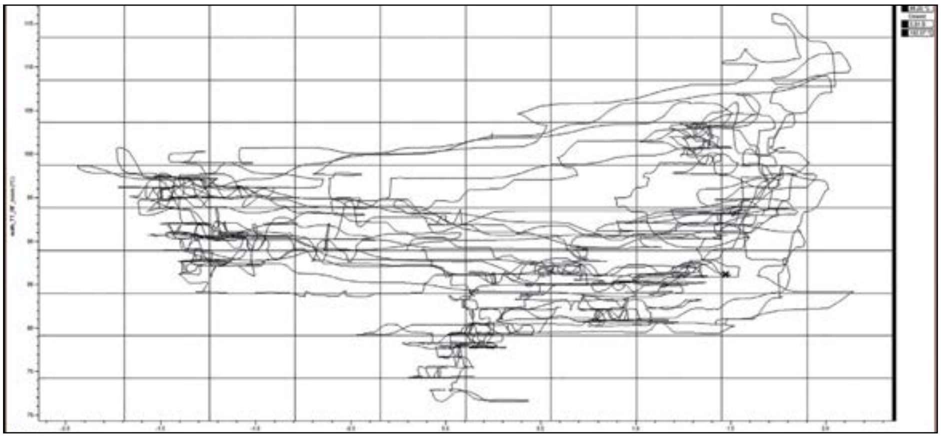

Fig 1: tyre temperature plotted against lateral acceleration for the GP Elite Porsche 992 Cup car in Jeddah

This will also depend on tyre position. It's not unusual to see rear tyres with the outside colder than the inside and middle during braking, due to less load on them under braking, only for the channels to equalise when they're put under cornering load. Our main concern always is obtaining the most grip while cornering.

During braking and corner entry, the three areas of the tyre are within our 15degC target, but mid-corner, the outside temperature rises significantly above the others. This suggests we're not running enough camber.

Using the telemetry in **Figure 2** as an example, we're in a left-hand corner scenario and monitoring the front right tyre. S4 is the sensor covering the left tyre in the short braking area before and during a mid-speed, right-hand corner. The channel order starts with channel one on the outside of the tyre and goes to channel eight on the inside. The data gathered for this corner shows we're not running enough rear camber to work the outside of that tyre.

For another example, Alsense Motorsport sensors might tell us the outside and inside of a tyre is running at 78degC, while the middle is at 58degC. This suggests tyre pressure is too low. Conversely, if the middle of the tyre is significantly hotter than the outside and inside, tyre pressure is too high. Both cases will likely be accompanied by a driver complaining the car is sliding around too much!

We hope we've managed to at least pique your curiosity regarding the many benefits *accurate* tyre and brake temperature data can have on set-up, driver training and, ultimately, gaining valuable tenths per lap. For our Porsche 992 Cup car, we estimate to have gained around 0.7s / lap using the data provided by Alsense tyre and brake temperature sensors.

If you would like more information on our products, or have questions about tyre and brake management using temperature sensors, please get in touch or subscribe to the newsletter on our home page for more information on how to get the most out of the data gathered with our sensors.

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The forgotten one

An explanation of the benefits of the kinematics and compliance rig

By **DANNY NOWLAN**

Fig 1: The Morse Measurements kinematics and compliance rig

When we talk about rigs in motor racing, we hear an awful lot of mention of four, seven and eight-post shaker rigs, and even more discussion on the benefits of wind tunnels. However, the great forgotten test measurement device in motor racing – and I'm just as guilty of this as anybody else – is the kinematics and compliance rig, K&C for short.

Over the last couple of years, I've had a few customers use the MIRA rig in the UK and the Morse Measurements rig in the US. To say both of these rigs have made my life infinitely easier when it comes to vehicle modelling is a massive understatement, and what we'll be discussing in this article is what such rigs offer and why, if you are running in the mid-levels and above, you'd be crazy not to use one.

But first, a couple of housekeeping points. Firstly, due to the highly sensitive nature of the data, I am presenting road car results for the K&C samples, courtesy of Bob Simmons at Morse Measurements. In all other cases, the sensitive results have been necessarily redacted.

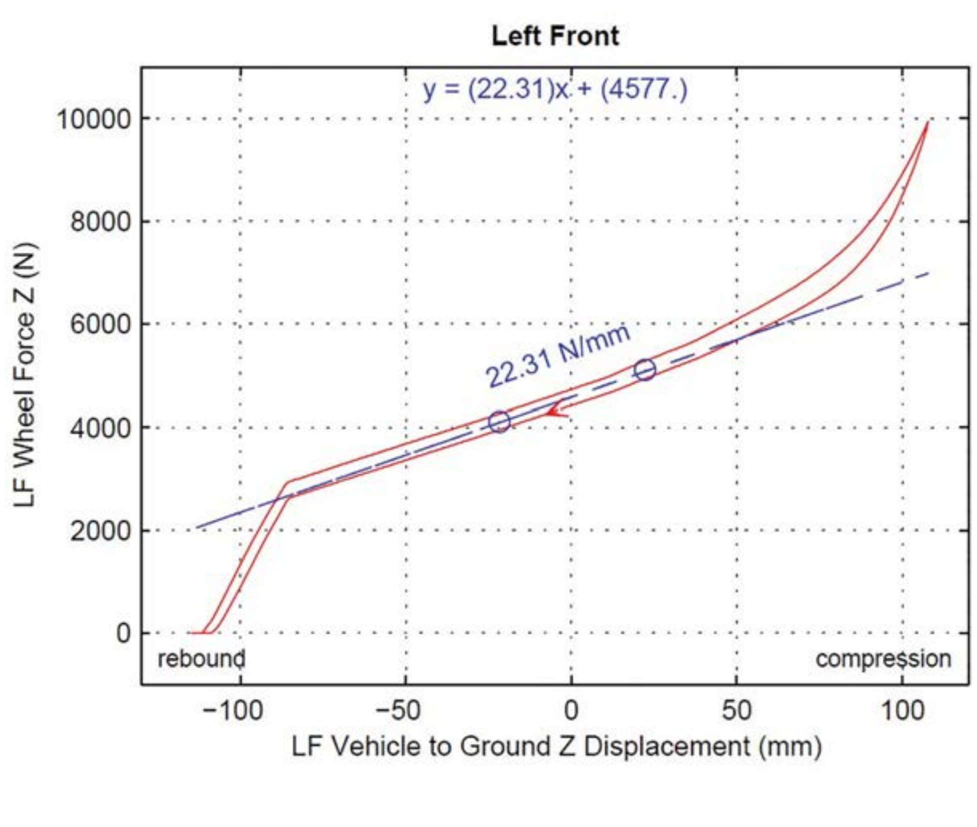
Secondly, I will reiterate how much easier these rigs have made my job of ChassisSim modelling, and I apologise here if this sounds like an infomercial. It isn't.

Know the rig

So, to kick this discussion off, a simplified explanation: kinematics and compliance is a measurement of all your deflections

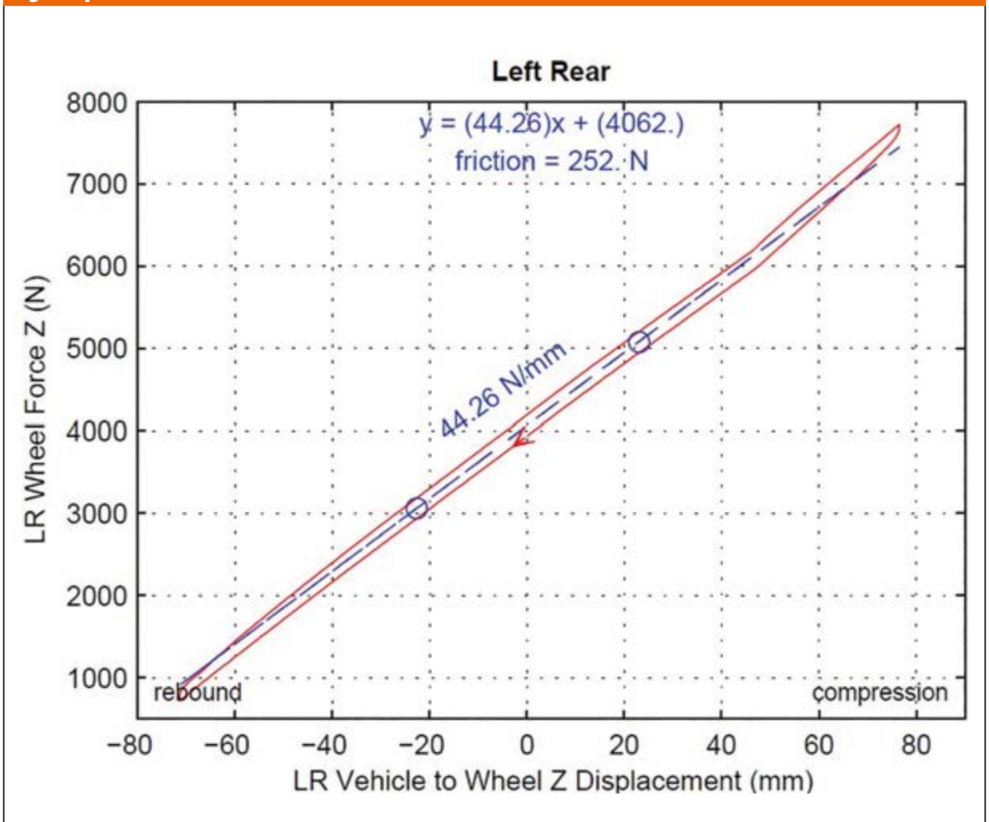
If you are running in the mid-levels and above, you'd be crazy not to use one

Fig 2: A plot of wheel force vs ride displacement



A K&C rig will answer a lot of questions about the car that you were either too afraid to ask, or those a racecar manufacturer can't tell you

Fig 3: A plot of differential force vs differential movements



and compliances on a car. To illustrate, **Figure 1** shows what the K&C rig at Morse Measurement looks like.

What this device does is measure everything from your suspension geometry and compliance, nailing down all of the car deflections as a function of force. As such, a K&C rig will answer a lot of questions about the car that you were either too afraid to ask, or those a racecar manufacturer can't tell you.

While not strictly a by product of a K&C rig, another thing Morse Measurements now offers is a Faro arm measurement service. Having spent many hours working under cars and hoists, this is a revelation. Typically, this is what you'll get back:

- All your inbound and outer suspension pick-up points.
- Spring and bar mounting points.

In other words, everything you will need to figure out your geometry and motion ratio using either SusProg, OptimumK, ChassisSim or any such analogue system. Don't get me wrong, you can still get good results by doing this part of the operation yourself, but it saves a truck load of hassle.

Force vs deflection

Where the K&C rig really shines, however, is when you start running force vs deflection tests. This is the point where you start getting down on your hands and knees and start thanking your appropriate religious deity for the results.

The first takeaway you get is the force vs wheel movements, and a sample of these results are shown in **Figure 2**.

The big piece of information you get from this is your wheel rates. More importantly, you can see if there are any non-linearities that need to be dealt with. One might contend you could just as easily see this from a kinematics program, and that certainly points you in the right direction. Enough that in 80-85 per cent of the cases you are likely to be dealing with, it will get you by, but the big difference is the K&C rig gives you that answer definitively, in 100 per cent of the cases you will come across.

Where the K&C rig really starts to pull away from the rest of the field is that it gives you the bar rates in absolute black and white. On paper, figuring out a bar rate at the wheel and the appropriate motion ratio is straightforward. Any second-year engineering student can figure out a bar rate, and the motion ratios pop out in the wash. But in the real world, what tends to happen is you get all sort of compliance issues as load is applied to the car that can send the paper results a bit silly. With a K&C result, it is black and white.

To say this greatly aids your knowledge of the car's set-up is grossly underselling its value

With plots like that shown in **Figure 3**, you can quickly determine what the actual bar rates are. To say this greatly aids your knowledge of the car's set-up is grossly underselling its value.

The other thing that pops out with K&C rig results is the suspension geometry. An example of this is shown in **Figure 4**.

Again, one could contend you can easily get this from a kinematics program. True, but the rig gives you two things. Firstly, a confirmation of what you already thought. Secondly, and more importantly, this can be extended to force-based roll centres, which is something you cannot do with a kinematics program.

Compliance effects

Where the K&C rig starts to display its worth further still is in showing you where the compliance effects start to kick in. A key item here is how camber varies with lateral force, as illustrated in **Figure 5**.

For well-built racecars, this variation will be small, typically in the order of 0.1deg/1000N. However, for Touring Cars and road cars, these numbers are typically about 0.4deg/1000lbf. When you are at these numbers, this will make its presence felt, particularly if the tyre is camber sensitive. There are exceptions to this rule, but these can be discussed another time.

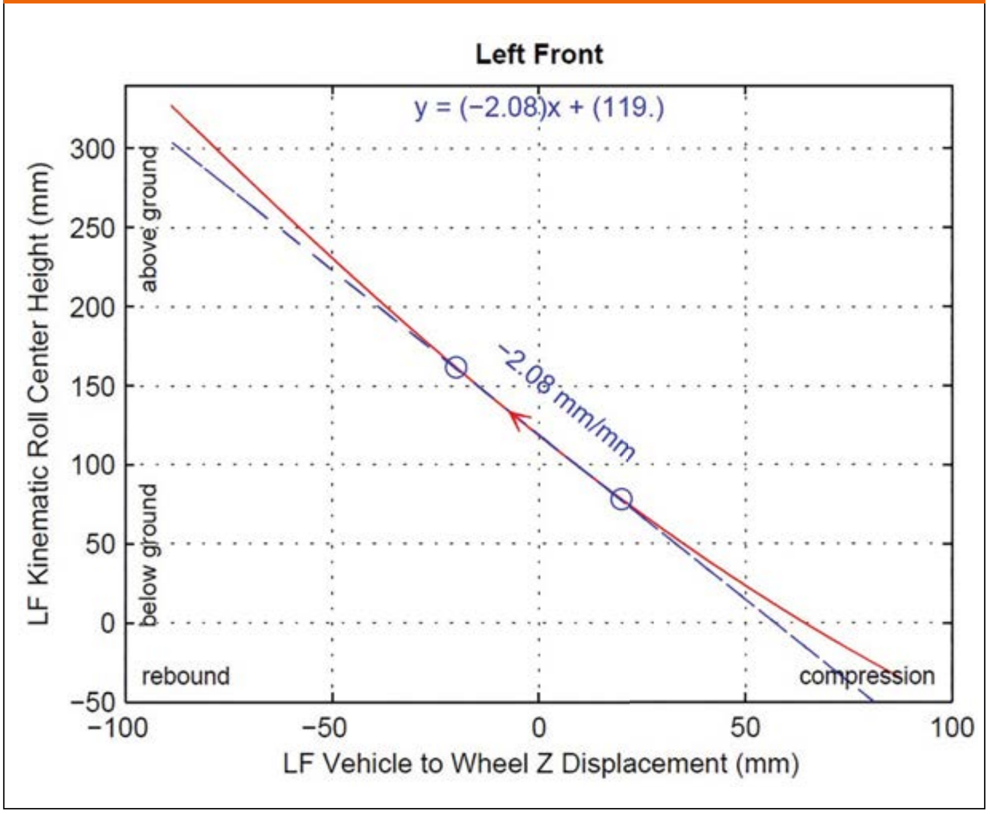
The next thing you'll discover with a K&C rig is your installation stiffness, and any other chassis compliance issues you need to be aware of. As a case in point, one of the worst kept secrets in the open wheeler community is how you have to watch bellhousing and tub compliance like a hawk. This is particularly apparent as a chassis gets older. The K&C rig answers these questions very quickly.

Then there's tyre spring rates, an example of which is shown in **Figure 6**. This sort of information is gold dust, particular if you are running any sort of downforce.

First cut

The real pay-off in all this, though, is what it delivers in terms of being able to predict what the car is going to do *before* you go out on the racetrack.

Fig 4: A plot of roll centre height vs wheel displacement



The real pay-off is what it delivers in terms of being able to predict what the car is going to do *before* you go out on the racetrack

Fig 5: A plot of camber vs lateral force

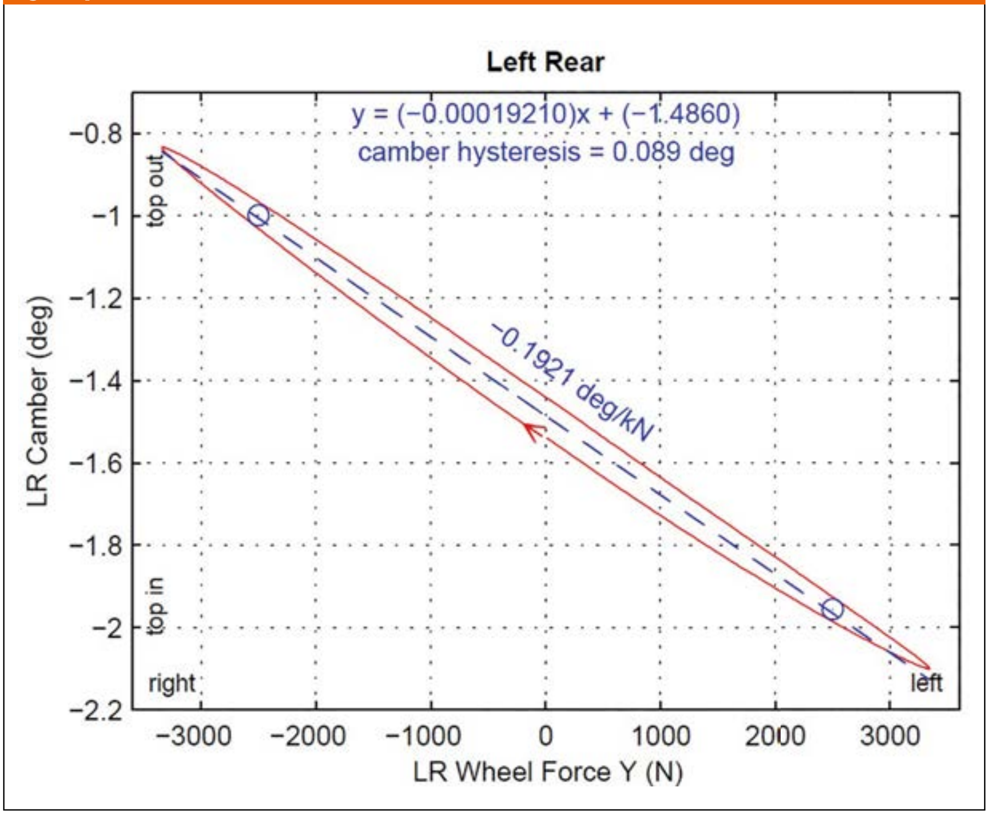


Figure 7 is an example of some customer work I did when I had access to a K&C rig. As always, actual data is coloured and simulated data is shown in black.

A couple of things to note with this supplied data, aside from the obvious fact I can't tell you where it's from.

While this simulation is a first cut (consequently, it is not perfect) I would draw your attention to the third and fourth traces, which are the front and rear dampers respectively, and to the last two traces that are the front and rear rolls (the differentials between the front and rear dampers respectively). Look at how close they are. Not bad for a first cut, huh? This is the end result of all the information derived from a session on the K&C rig.

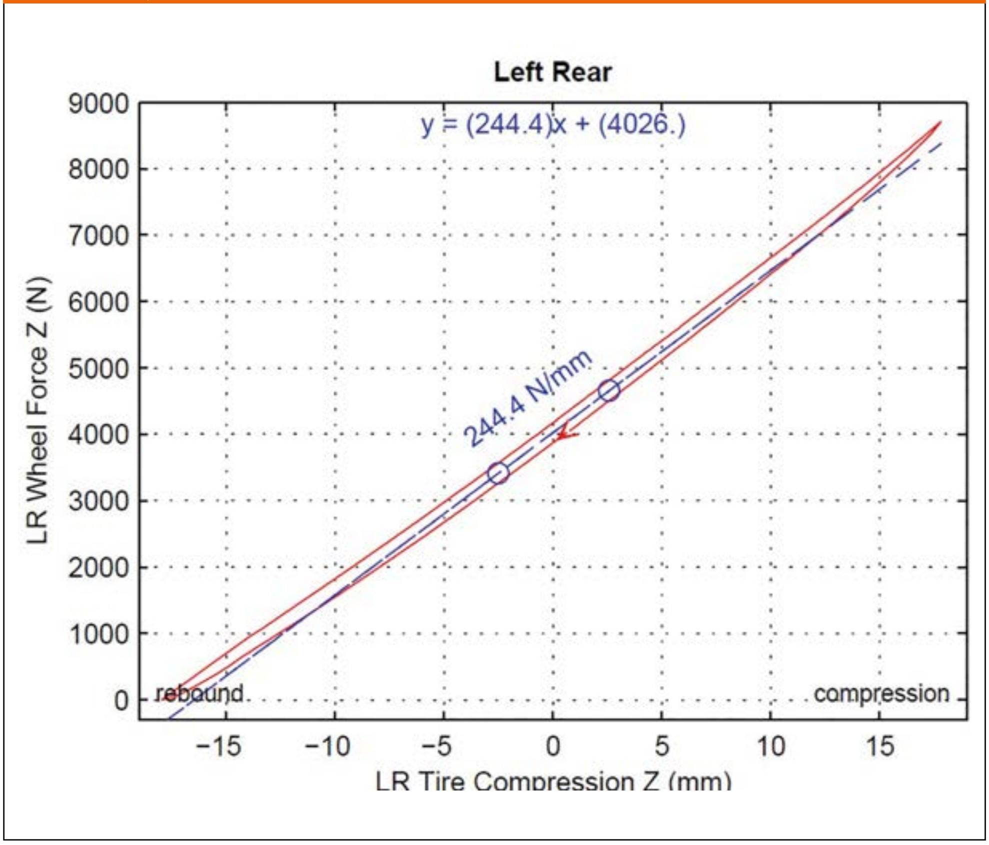
Valuable information

If all this has been enough to make you want to book a K&C session, either the MIRA rig in the UK or Bob Simmons at Morse Measurements in North Carolina, USA can help you. Both rig operators have current motor racing experience and a wealth of expertise at their disposal.

In closing then, while the K&C rig tends to be the largely forgotten measurement rig, it offers a wealth of valuable information that will assist you in optimising the set-up of your racecar.

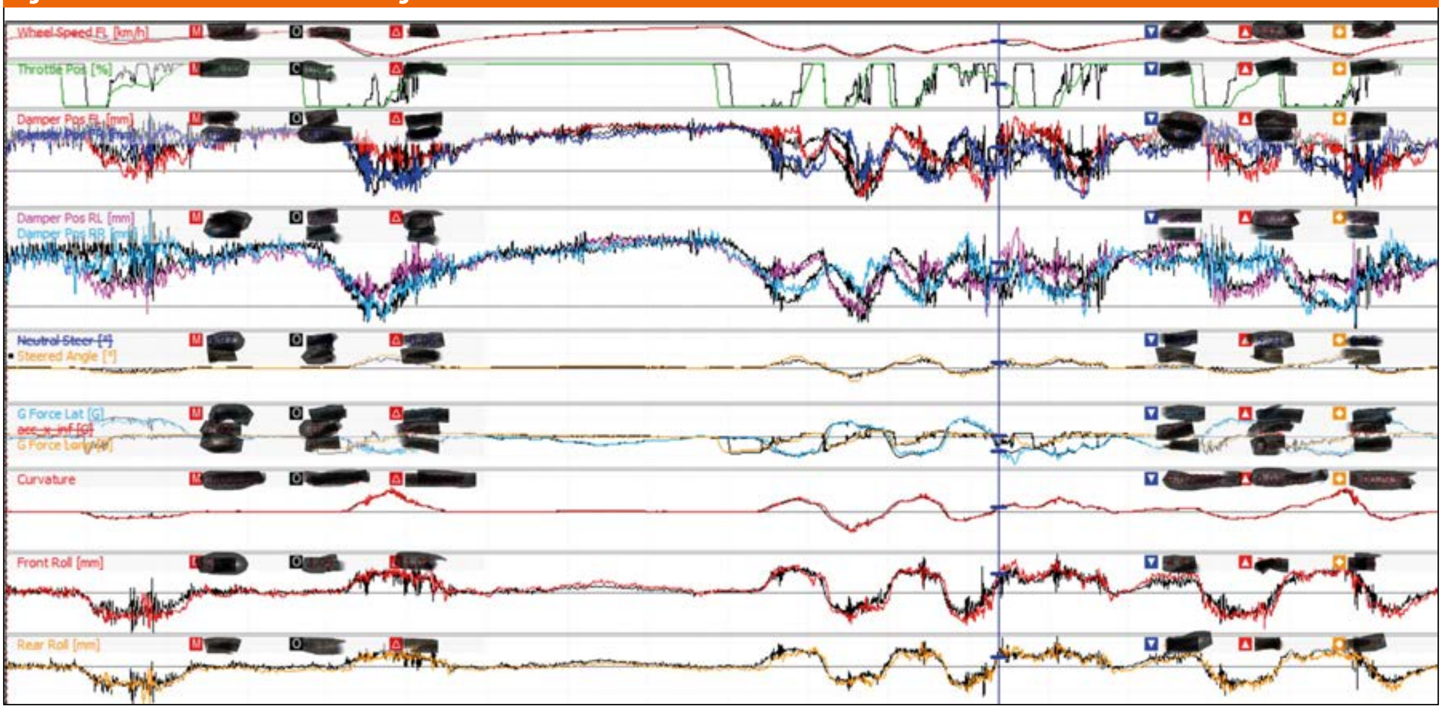
In addition to the data you would usually expect, like suspension geometry and all the vehicle compliances, it gives you a plethora of additional information to draw upon, all of which translates to usable information so when you get to the track, you already know exactly what you are doing.

Fig 6: Plot of tyre spring rates



In addition to the data you would usually expect, like suspension geometry and all the vehicle compliances, it gives you a plethora of additional information to draw on

Fig 7: Simulation correlation with K&C rig data



GT3 aero kits proposed

The ACO used its Friday press conference at Le Mans to confirm it will welcome GT3 cars to Le Mans from 2024 with a Pro-Am line up, and it intends to run aero kits to provide the cars with a unique identity compared to other GT3 races around the world.

Manufacturers and teams were united against the idea, as all feel it adds unnecessary cost to an otherwise cheaper alternative to the current GTE cars, but Stéphane Ratel was supportive of the move: 'Le Mans is special, and deserves special cars,' said the Frenchman. 'Some manufacturers will moan, but they will do it because they always do what the ACO want them to do, and the clients will pay because they want to race at Le Mans, because they have the money and will save a lot when compared to running their current GTE cars, and because they will be happy to have special Le Mans cars that appreciate in value.'

By making the Le Mans kits unique, it also protects the identity of the Spa 24 hours, which is the largest international single-category race of GT3 cars anywhere in the world.

In order to mitigate the cost of the Le Mans kit to teams, which is scheduled to be between €50,000-100,000 (approx. $52,650-105,350) and which, says the ACO, should not change the aerodynamic characteristics of the car. Consideration is being given to a proposal to run the kits for the full FIA WEC season.

XPB

The idea of Le Mans-specific aero kits for GT3 was met with universal displeasure by manufacturers, who all feel it will add unnecessary cost to the series

IN BRIEF

The **FIA** has announced **Tanya Kutsenko** as its first ever equality, diversity and inclusion advisor dedicated to motorsport. She will be responsible for developing a new EDI strategy in line with the FIA's new course of promoting greater diversity, inclusion and doubling motorsport participation.

The **ACO** became the first motorsport event to encourage spectators to use low-carbon forms of transport to get to the race by offering 20 per cent off eco-friendly products in the museum, a donation to a low-carbon project near the track and a free eco cup.

The organisation also reduced the number of vehicles in the circuit and aims to reduce that further by 2023, encouraging more bicycles be used.

Ligier Automotive and **Parella Motorsport Holdings** have extended their contract to support the Formula Regional Americas series, and Formula 4 United States Championship. The multi-year agreement brings a new chassis for F4 and new Honda engines for both series.

The **Virtual Le Mans Series** is set to comprise five rounds in 2022 / '23, ending with the Virtual 24 Hours of Le Mans on the weekend of January 14-15 2023. Prize money for the event is $250,000.

The 2023 **Acura Integra** made its motorsport debut at the 100th running of the Pikes Peak Hillclimb at the end of June. The car appeared in Integra's traditional red, grey and white livery and was driven by rookie, **Paul Hubers**.

Lubricant supplier, **Motul**, has appointed **Hasanaat Tahier** as Motul UK technical specialist. 'Has' previously worked as a product engineer at TotalEnergies and, before that, at JTEKT Group's Koyo Bearings.

3D printing company, **CRP Technology** and **CRP USA**, has signed an investment agreement with ITT Inc, a leading manufacturer of highly engineered critical components and customised technology solutions.

2022 Motorsport Games applications open

Motorsport UK has announced the first eight entrants selected to represent Team UK at the second edition of the Motorsport Games in October.

Seventeen disciplines are represented across a broad spectrum of the sport, including Auto Slalom and Crosscar, as well as Drifting, Rallying, circuit racing and historics.

Applications are open to represent the country in Formula 4, Esports, Karting and Touring Cars.

The 2022 edition of the FIA Motorsport Games will be held across three sites at the Circuit Paul Ricard.

France's Circuit Paul Ricard will host the second edition of the Motorsport Games in October this year

Supercars on track

Supercars continued to test its new Gen3 models at Toowoomba's Wellcamp Airport near Brisbane with straight line testing for the new Ford Mustang and Chevrolet Camaro.

'We're very much encouraged with where the two cars are,' says Supercars' head of motorsport, Adrian Burgess. 'The cars were in different configurations, but the numbers are backing that up.

'We're here to refresh all our processes, software and calculations. It's about putting our technical staff and the homologation teams into a co-operative space.

'We're also sharing our data with D2H Advanced Technologies in the UK. They're supporting us in real-time, checking through the data.'

F1 steps in to tame the porpoise

Formula 1 has recently issued a Technical Directive to F1 teams regarding measures it intends to take to address the issue of porpoising that has arisen this year. The governing body has reacted to complaints from drivers, and the clear adverse physical condition of drivers after the Baku Grand Prix in June.

The two-point plan from the FIA includes closer scrutiny of the planks and skid blocks under the car, which help to maintain ride height throughout the race, and the definition of a metric based on the car's vertical acceleration, that will give a quantitative limit for acceptable oscillations.

XPB

Drivers have been complaining of back pain and excessive fatigue after recent races

According to the FIA press release, the mathematical formula for this metric is still being analysed, and all F1 teams have been invited to contribute to the process.

The FIA also called a technical meeting with the teams to define measures that would reduce the porpoising phenomenon in the medium term.

'The FIA has decided to intervene following consultation with its doctors in the interests of safety of the drivers,' read the FIA release.

'In a sport where competitors are routinely driving at speeds in excess of 300km/h, it is considered that all of a driver's concentration needs to be focussed on that task, and that excessive fatigue or pain experienced by a driver could have significant consequences, should it result in a loss of concentration.

'In addition, the FIA has concerns in relation to the immediate physical impact on the health of the drivers, a number of whom have reported back pain following recent events.'

The issue was first evidenced at pre-season testing when teams ran their cars at full speed for the first time. While some teams have managed to reduce the phenomenon, others are still struggling to overcome it and drivers have publicly called for intervention.

For more on porpoising, see our feature on the Lotus T80, p40.

STCC goes fully electric for 2023

Not just fully electric, but the most powerful Touring Cars yet seen, and with the added benefit of returning the series to street circuits in 2023, which will help further raise the profile of the STCC

The Scandinavian Touring Car Championship will feature 100 per cent electric cars in 2023, with the most powerful cars ever produced for the series.

Built by Swedish company EPWR, the new cars will produce 550bhp and are based on production cars available to the general public.

The cars are then modified for racing in terms of safety equipment, brakes and dampers.

The 550bhp comes from a combination of an electric motor and a 45kWh, 800V battery.

The first model to be revealed is based on the Tesla 3, with others to be announced later this year.

The first production batch of 12 cars have been booked by teams.

'The power available and the low c of g that the batteries entail makes the driving experience as close to single seaters as you can get, but with the amazing racing of Touring Cars still there,' says test driver, Mikaela Ahlin-Kottulinsky.

The existing petrol-powered TCR cars will continue to race in 2023 during selected race weekends, but electrification has allowed the series to return to street circuits for the first time in five years, including Helsingborg, where a new street track will be created in the central harbour.

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The (not so) Great Race

Searching for positivity amongst the predictable

There is no denying the 2022 edition of the Le Mans 24 hours was hardly a classic. On the 90th running of the great race, it was again a contest of pure reliability in the top class. If the Toyotas ran well, they would finish first and second. They did. If Glickenhaus ran well, its cars would come third and fourth. They did. If Alpine ran well, it would be fifth in class. It was.

That's pretty much what happened, except that one driving mistake lost Glickenhaus time, while the Alpine crashed, and had an engine coil and a clutch control unit fail too. It was therefore easy to be disappointed in the race. I personally found it challenging to find the motivation to continue watching, but then I am notoriously hard to please. Sat out in the fading sunshine on Saturday night, it was the LMP2s that provided the most entertainment but there was very little in the way of actual overtaking. Still, it *looked* like a good race, with plenty of nose-to-tail action, but this was a 24-hour race, not a 10-lap sprint.

Five on it

At the chequered flag, Toyota secured its fifth overall win at Le Mans. While that in itself is an achievement, it should also be noted that following a spectacularly well-supported race in 1999, Audi pretty much carried the race through to 2007, when the Peugeots arrived to take on the challenge.

Before that, Audi faced a Pescarolo, Dome and Zytek, hardly cars that could have matched the outright spending power of a manufacturer. And Bentley, which won in 2003, yet we look back on those days with fond memories.

Tom Kristensen lodged nine Le Mans wins, an incredible achievement (not least because one of those wins was with Bentley, *against* the Audis), and Audi wrote its own chapter in Le Mans history. Toyota has since done the same.

All that said, there were a few moments of drama pre-race. The ACO held its press conference on the Friday and confirmed its intention to run with GT3 cars in 2024 as its main GT category. Only to make it special, it also stated it should run Le Mans kits just for these cars.

The manufacturers were shocked, as GT3 racing is only for customers and they don't want to be paying for a new kit. The manufacturers don't want to design and develop one either. Consequently, there was a general air of grumpiness in the paddock, and part of the challenge was trying to find out whose idea this was.

Enter Stéphane Ratel. He believes manufacturers will do it because the ACO asked them to, that teams would be happy because they would have something unique and would be saving themselves a lot of money by not running GTE cars. And lastly, their cars would appreciate in value with a Le Mans start under their belts.

However, the argument that they will park the car and then sell it doesn't necessarily ring true. Nor does the idea that teams will switch from GTE to GT3. They might leave the WEC altogether and be replaced with existing GT3 teams, for example. Even if they do switch machinery and save money, they will surely want to continue to race, and won't invest in a new car to do so.

Conversely, there was a lot of positive energy around the new Prototypes, and the manufacturers responded brilliantly. Acura teased everyone with an image that showed a camouflaged car against a camouflage background. Ferrari essentially launched a picture of two headlights, while Cadillac presented its new car online, without giving any details. There was more information in the accompanying press release; that the car will have an all-new, 5.5-litre V8 engine in it.

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BMW's was probably the coolest livery, with nods to its previous racing successes. The WRT team, which was about to campaign the Audi LMDh programme before that was cancelled, is likely to take on that contract, although not until 2024. Before then, it will be the RLL team conducting the testing and first races in 2023. Provided they sort the Bosch motor in the spec hybrid system first, of course.

Village people

One of the most popular displays in the Village was the Peugeot 9X8 show car. Even the Peugeot personnel were surprised at the volume of people that showed up to look at it. It was like the Place de la Republique on Friday night.

That was the key. Spectators, young and old, came back to Le Mans to enjoy a weekend of racing and parties. Despite the backdrop of a European vote that sought to ban the sale of ICE passenger vehicles by 2035, it was clear people loved being back to enjoy racing.

Despite the lack of competition at the front of the field, the race was, like the Nurburgring 24 Hours, well attended and next year will be even better. Reducing CO_2 emissions per the European vote is critical, but there are other ways of doing so than focusing solely on pure electric. Hydrogen is an option worth further investigation, for example, and Le Mans is leading the way in this area. Let's see where it leads.

ANDREW COTTON Editor


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