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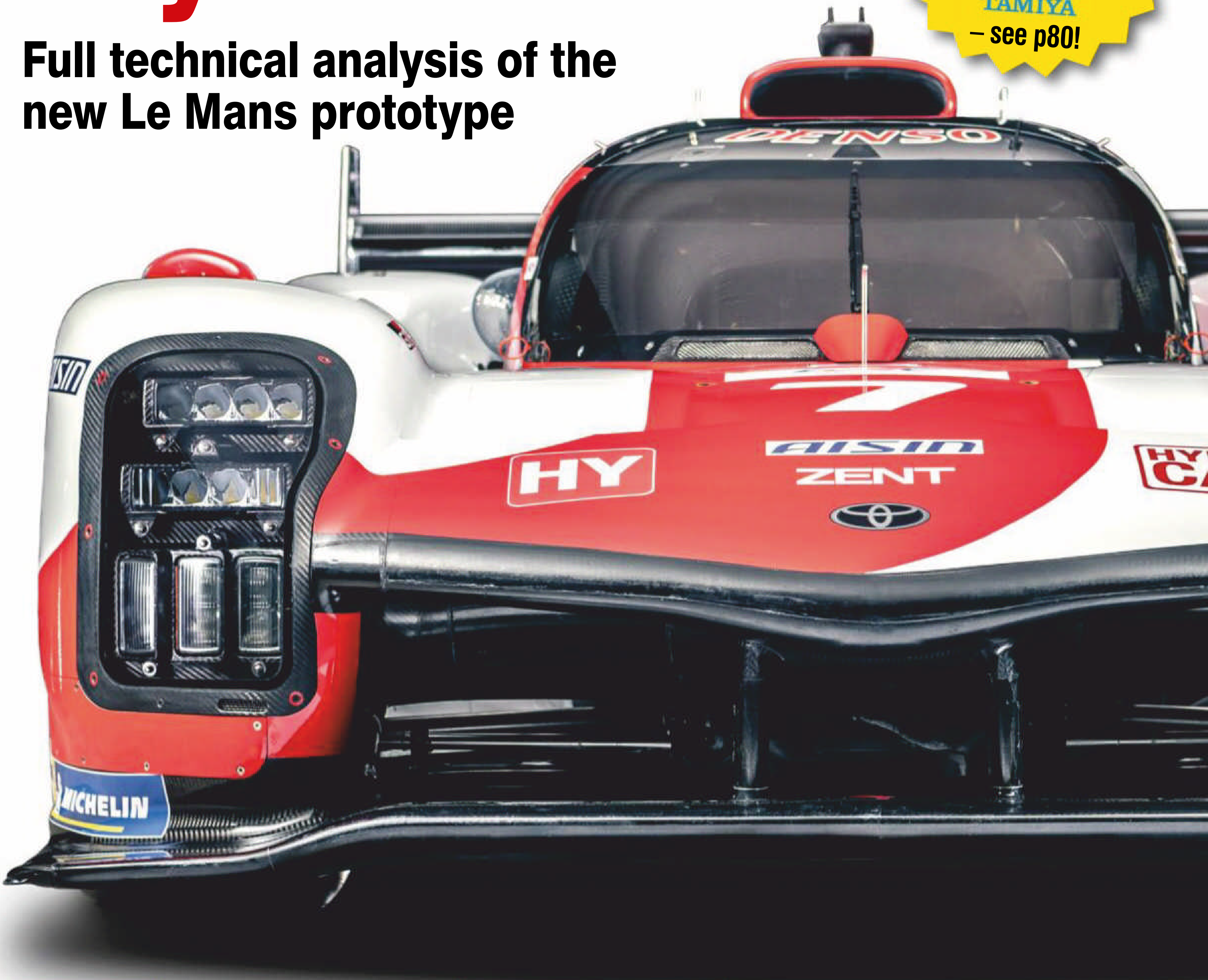

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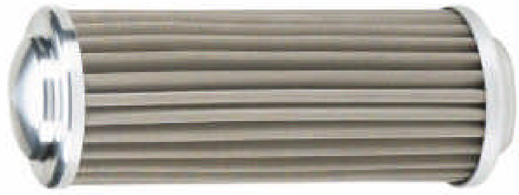

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Photo: Charly Lopez

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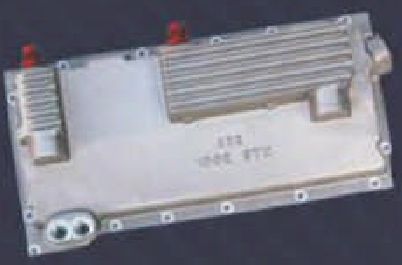

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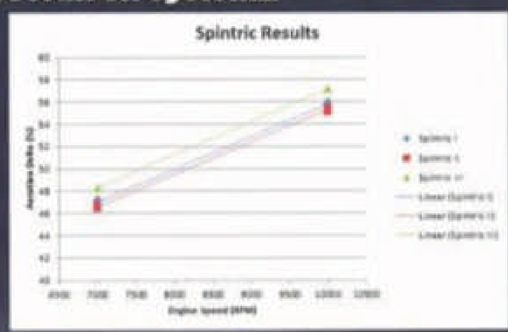

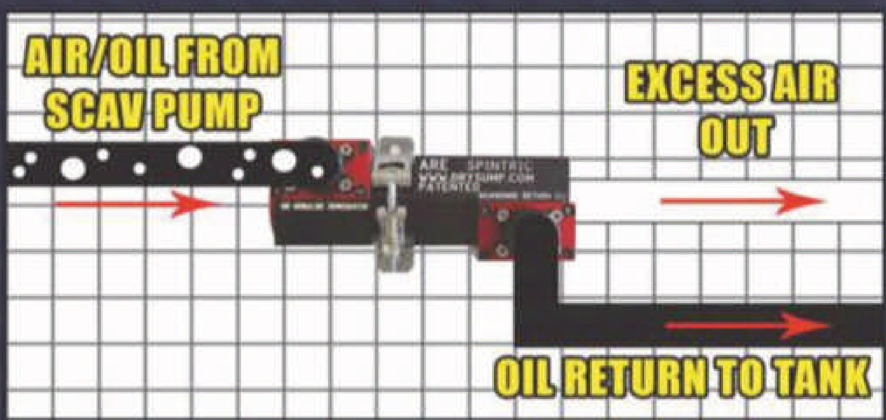

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Costed out

Lessons learned in 2020 could help further reduce the cost of racing

We spend a lot of time discussing cost saving measures, but perhaps there are some extreme examples we should be looking at. I am thinking here of track time at an event. Are there other options for a weekend schedule that makes racing cheaper and easier for the teams, while also improving the racing for the fans? I think there are.

Due to the tight scheduling, we lost a session from the weekend in last year's IMSA season, which meant less fuel burnt and fewer tyres used. That's the easy fix to save money, but there are other ways, too. Minimising running time before a qualifying session shifts some of the priority from qualifying simulation runs to race preparation, especially if the timing of sessions is the same as the race. If the first session is qualifying, that would require up front, offline simulation before hitting the track.

What do drivers learn from qualifying? Each track is individual and tyres need to be evaluated accordingly. Some preparation comes from simulation, but drivers learn about a track from their first laps on new tyres.

Mixed up

Maybe we should consider no practice sessions at all, then. Literally run what you brung. That could be entertaining, particularly for standalone events. Perhaps you have a half-hour session to sort yourself out at the start of the weekend, and then go straight to qualifying, and then the race. Fans would get to experience the excitement of a qualifying session, and the possibility of a mixed-up grid, rather than watching teams pushing the boundaries of science in practice sessions.

The flipside is you create a lot of pressure on preparation and simulation, because the team that arrives at the track better prepared is likely to win. That could increase cost down the line as you have to have the engineering capability to do that. So controls would need implementing, such as mandating set hours of simulation.

Modern racecars can be complex and there are lots of little areas you can interpret and develop further, which is why experienced resource is required. You have to look for the smallest margins to give yourself an advantage, especially in a BoP series. These give teams an edge and the ability to dominate a season.

Last year's schedule was, I hope, unique and there was a lot I didn't like about it. But at the same time there are things we can learn and take forward. The GT Commission last year monitored the state of the sport and likely outcomes of economic challenges. Although we've got a good idea of what is planned for 2022 and beyond, the challenges facing OEMs cannot be underestimated.

Richard Dole/LAT

Shortening race weekends, dropping practice sessions and reducing the 'glitz' could all help

For both OEMs and teams, reduction in expense to continue participation will be key, more so now than in previous seasons. Many teams rely on sponsors or paying drivers and their own economic challenges will force them to re-think their racing requirement. We're in changing times. When it comes down to it, the people that will stay in the business and help carry it forward are the ones that don't need to have those answers.

A typical IndyCar calendar is quite tough, even without a pandemic: racing on a short oval one weekend, the next weekend on a road course, the next at a street course. IndyCar teams have, over time, adapted to set up, race and pack down very efficiently, thus cramming multiple events into a short space of time. This has meant evolving their equipment, people and processes to move around quickly to maximise time on the cars, both at the track and back at the workshop. Sportscar racing is not quite as adaptable, due the complexity of the cars and type of racing. Some teams with experience in other disciplines have brought those elements to the sportscar paddock.

Show business

At the Sebring 12-hour race, as I walked through the paddock on set up day, I noticed the Corvette team putting up its awning between its trucks. I'd seen it assembled before, but not the process – it is quite the structure, and impressive. It required the use of forklifts to move beams into position and took time to set up but, once completed, it stands out. Tighter schedules would prevent this kind of preparation and would present a dilemma for manufacturers who need to think about the PR surrounding their racing, but a need for faster set up and tear down process may be a simple way of saving money.

Logistics for a race weekend can be challenging, carrying around bodywork, spare engines and gearboxes, tools and consumables. All this needs space, trailers and packing economically. Teams invest in infrastructure before adding the cost of the cars, fuel and tyres. Historically, the concept of customer GT racing with manufacturers selling cars, and then providing track support, has created healthy grids without losing the quality of racing. This concept is now being seen in future regulation changes, such as LMDh.

Last year, the pandemic forced us to do things slightly differently, but it also gave us an opportunity to see that things could be done differently, and *could* be done better.

Leena Gade is President of the FIA GT Commission

The pandemic forced us to do things slightly differently… but it also gave us an opportunity to see that things *could* be done differently

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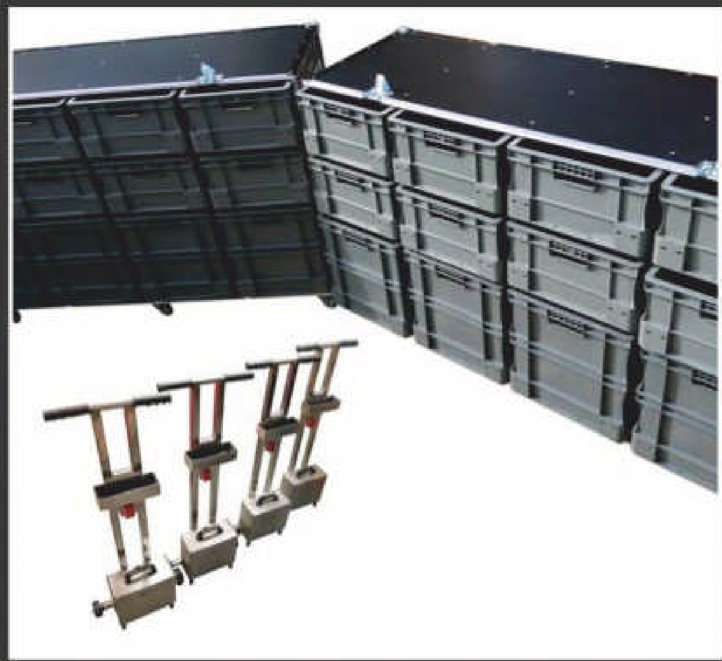

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Best wishes

No New Year resolutions from me, just a few things I wish I'd done differently

With my birthday following the start of the New Year, I should be making good resolutions. However, I figure if I haven't sorted my lifetime habits by now, it probably isn't going to happen in 2021. What came to mind instead, though, was a list of technical matters to which I wish I had paid more attention during my own race-driving career, such as it was.

Although racing has changed beyond imagination since then, and professional teams of any competence nowadays have a much more sophisticated handle on running a racecar, some of this may still strike a chord today, if only at historic, amateur or semi-professional level.

Example: I didn't make enough of being friends with my tyre supplier's engineers and pushing for advice and tips on pressures, wheel cambers, toe-ins / outs, finding the sweet spot etc. I might also have learned a little about what faster competitors were doing with regard to suspension set-up.

Three tools

If I was permitted only three simple trackside set-up tools, even now they would be tyre temperature and pressure gauges and a measuring device, which were basically what we used. Together with eyeballing the tyre condition and profile across the tread, they told me and the guys with whom I worked most of what we needed to know about the basic chassis set-up and what might need changing, even aero where appropriate.

This is something we did quite rigorously, but getting the most out of the rubber when new, whether in qualifying or during the first laps of the race, was not always sufficiently exploited. Tyre management in races wasn't much of an issue then – or maybe it was, I just didn't realise it (except when Bob Juggins and I shared a modified Sports 2000 Lola, under-tyred for its 250bhp engine, in Thundersports in the 1980s. Rear tread blisters the size of beer mats did concentrate our attention…).

I don't know why I and my helpers failed to experiment more with ride heights and weight distribution. Depending on the size of the individual being plugged in, driver position is the single biggest weight shift component that can be altered in the car without radical re-engineering. Despite being short, I saw a photo recently showing me sitting quite high in the cockpit. Good for placing the front wheels, bad for centre of gravity.

What if, at a circuit like Mallory Park, with only one real left-hand corner and three right, one of which is very fast, I could have tried different wheel cambers side to side, akin to an oval track?

Reducing friction in all moving parts was generally limited to engines, but rivals smarter than me included transmission, wheel bearings and so on. I so wish I had understood and explored dampers and their settings more, too. For a long time I favoured non-adjustable, gas-filled Bilsteins, just suitably valved for the spring rates being used, because their action was progressive and they didn't appear to go off when they became hot, unlike some cheaper products. It was easy to get confused otherwise.

It is often said hindsight is a wonderful thing, and it also allows one to indulge in a spot of what if? And I'm sure I could have been quicker if…

Perhaps it was because the tools for taking a more sophisticated approach just weren't readily available 30 years ago. Nonetheless, when making the switch to adjustable Konis I must have missed out on the subtle gains that were there for the taking, only largely touching on the more obvious damping effects regarding kerb hopping and pitch control.

Budget and time for testing were limiting factors, of course, but this should not have prevented far more focus on achieving minimum weight (instant performance gain) and beneficial placing of ballast, if below the limit.

And what about cooling? Achieving optimum specified temperatures for engine, transmission and brakes is important in extracting the maximum performance overall. I certainly always ensured engine temperatures were correct but, as oil and water are easier to balance with a correctly designed combined intercooler, this would have been better than separate coolers.

Brakes were about fitting the best pads for bite and pedal feel – something about which I was very picky – balancing front and rear and not overheating. But maybe I sometimes ran them below the optimum friction level? Having never had the opportunity of karting at a young age, I wasn't used to left-foot braking, but it's a technique I should have tried, to save fractions of a second, especially as I always insisted on a short throttle travel.

Care of the transmission was again mainly about avoiding overheating, but more use of thermo strips or paint could easily have monitored this, too. Too cool can be as bad as too hot and creates viscous lubricant drag. In cold conditions, particularly for short sprint races, running up the rear wheels in gear but on stands – hillclimb style – to warm the transmission oil could have been employed more often, as well as inserting an electric heating element into the oil tank.

The racers' friend, good old tank (duct) tape, wasn't the most efficient solution in partially blanking off radiators, albeit rapidly adjustable and cheap! Proper detachable bodywork parts reducing air inlet and exit would have been better aerodynamically as well.

All mostly small gains admittedly, but when combined, and with a very close grid typified then in FFord 1600, FF2000 and F3, surely these would have been worthwhile? But, whatever, one still has to drive the thing fast, and this was largely my focus back then.

I salvage some saving grace in looking at F1 cars of the same period. Oil tanks hung on the back of gearboxes, coolers of various sorts seemingly bunged anywhere, very basic cooling ducting, draggy aero devices… I could go on.

Hmmm. I suppose being 'Captain Hindsight' is useless really, unless it reveals benefits to those who follow on. Best wishes!

If I was permitted only three simple trackside set-up tools, even now they would be tyre temperature and pressure gauges and a measuring device

One step beyond

The Toyota is the first of the new breed of Hypercars to break cover, built to a completely new rule set that sees cars longer, wider, heavier, less powerful and supposedly cheaper to build and run than before

‘Probably the positive thing of the new regulations is that the aero is free’

John Litjens, project leader for Hypercar

Toyota launched its new Hypercar in January, and is set to defend its World Championship and Le Mans titles in the new era of endurance racing

By ANDREW COTTON

Toyota has taken the wraps off its new Le Mans challenger, the GR010 hybrid, with which it will compete in the FIA World Endurance Championship until at least 2025. Toyota is the first to reveal its new Hypercar, destined to make its race debut at the opening round of the FIA World Endurance Championship, scheduled for Portimao in April.

The GR010 is built to a totally new set of regulations and therefore is longer, wider, heavier and less powerful than the outgoing TS050. The car is expected to be around 10 seconds per lap slower at Le Mans than the TS050, and five seconds slower on a regular WEC circuit.

The GR010 is powered by a 3.5-litre V6 engine that produces a maximum power output of no more than 500kW by regulation, whether from solely the engine or a combination of engine and hybrid system, a loss of 33 per cent compared to the TS050.

The GR010 also carries less technology than its predecessor, making it cheaper to run. It features only one energy recovery system at the front, for example, and the interlinked suspension has gone, replaced by independent suspension on the four corners.

Reduced advantage

A new Balance of Performance system will govern the pace of the Hypercars, reducing the advantage for manufacturers. The development of this racecar will directly influence the roadgoing supercar Gazoo Racing and Toyota showed in concept at Le Mans in September.

The new regulations have targeted a reduction in costs, so fewer rare materials have been used in the construction of the car. The c of g for the gearbox, monocoque and engine have been defined by regulation, which for Toyota led to extensive re-design work and strengthening of parts for its 2021 challenger when compared to the TS050.

Aerodynamically, the GR010 is particularly striking, with large gaps between the front splitter and the bottom of the monocoque, and at the rear between the engine cover and diffuser. These are designed to ensure adequate cooling, while maintaining smooth airflow over the bodywork.

A further cost-cutting regulation is that there is no variant of the bodywork from race to race. So this is the body that will be used at Le Mans, as well as at shorter circuits such as Fuji. Cooling is therefore an important consideration as the car will also race in high temperatures without modification, and without overheating.

The regulations feature a set of performance windows into which each of the Hypercars, be they prototype or road car based, must fit. One of those is a point on the lift / drag graph that dictates the aerodynamics of the car and is not, according to Toyota, challenging to meet. With power limited and closely monitored by the FIA using standard telemetry and torque sensors on each of the driveshafts, this is a totally different animal to the team's former LMP1 car, and has been built with entirely new objectives.

All-new engine

The switch from the 2.4-litre engine to an all-new, 3.5-litre unit was largely driven by the fact it will be required to deliver more power than the old TS050. The increase in capacity is also to bring the engine in line with the planned production car, which would have struggled with the smaller capacity engine.

'The reason [for the change] is there is quite a significant change in powertrain regulation with the switch of power dominance from hybrid side to combustion engine,' says Gazoo Racing's technical director, Pascal Vasselon. 'We need to achieve a given power target, which is 500kW at the moment, and we know we can only temporarily use the 200kW of hybrid power, so this means the combustion engine has to be able to deliver 500kW.

'Considering that within the Balance of Performance category reliability is even more important than it was before, the decision to go to a bigger engine was quite logical. More power was needed, as were even higher reliability standards.'

The decision to stick to a V6 was also driven by the packaging requirements for the GR010. Even though the wheelbase is slightly longer than the car's predecessor, the cockpit has been moved back, further away from the centre line of the front wheels, and the mandated battery position is behind the driver. With the fuel cell located in a similar position, there was no option for Toyota to go for more cylinders.

'It was simpler when we started,' explains John Litjens, project leader for the Le Mans programmes including Hypercar. 'We had to do something with the road car and the clear goal from management was to share the main components between the two. So this is a totally new engine.'

One of the challenges for the engine will be the switch from full ICE power to combined power delivery from the hybrid system, which may only take place over 120kph in the dry, and between 140-160kph in the wet in order to protect the two-wheel drive competitors.

'The architecture is the most efficient one within the regulations, but we have to bear in mind that we are in Balance of Performance'

Pascal Vasselon, technical director at Gazoo Racing

At no point may the power output exceed 500kW, and so the control systems will need to be able to switch seamlessly between the two.

'The way to handle the hybrid system is totally different compared to LMP1,' says Vasselon. 'Now we are talking about a maximum combined power, while in LMP1 the power of the hybrid system was adding to the combustion engine. Now it is either or. It means that if we use 200kW from the hybrid, we can only use 300kW from the combustion engine.

With just one body kit allowed for the whole season, and the car designed with the roadgoing variant in mind, the rear fin was initially left off, but was later put back in as part of the car's development process. Rear wing end plates are noticeably smaller than before

TECH SPEC: Toyota GR010 Hypercar

Bodywork: Carbon fibre composite
Gearbox: Transverse with seven gears, sequential
Driveshafts: Constant velocity tripod plunge-joint
Clutch: Multidisc
Differential: Mechanical locking differential
Suspension: Independent front and rear double wishbone, pushrod system
Springs: Torsion bar
Anti-roll bars: Front and rear
Steering: Hydraulically assisted
Brakes: Akebono monoblock alloy calipers with carbon ventilated discs
Rims: RAYS magnesium alloy 13 x 18in
Tyres: Michelin radial 31/71-18
Length: 4900mm
Width: 2000mm
Height: 1150mm
Weight: 1040kg
Fuel capacity: 90 litres
Engine: V6 direct injection twin turbo
Valves: Four per cylinder
Engine capacity: 3.5 litres
Fuel: Petrol
Engine power: 500kW / 680ps
Hybrid power: 200kW / 272ps
Battery: High-powered Toyota lithium-ion
Front motor / inverter: Aisin AW / Denso

With more freedom by regulation, the above roof air intake is set much further back compared to the TS050

The regulations are a set of performance windows into which each of the five categories of car must fit

Only one adjustable aero device is now allowed, and Toyota chose to use the rear wing

'A hybrid system will remain more fuel efficient, and the hybrid system at the front allows four-wheel drive functionality. The architecture is the most efficient one within the regulations, but we have to bear in mind that we are in Balance of Performance, so these benefits will be compensated by other handicaps.'

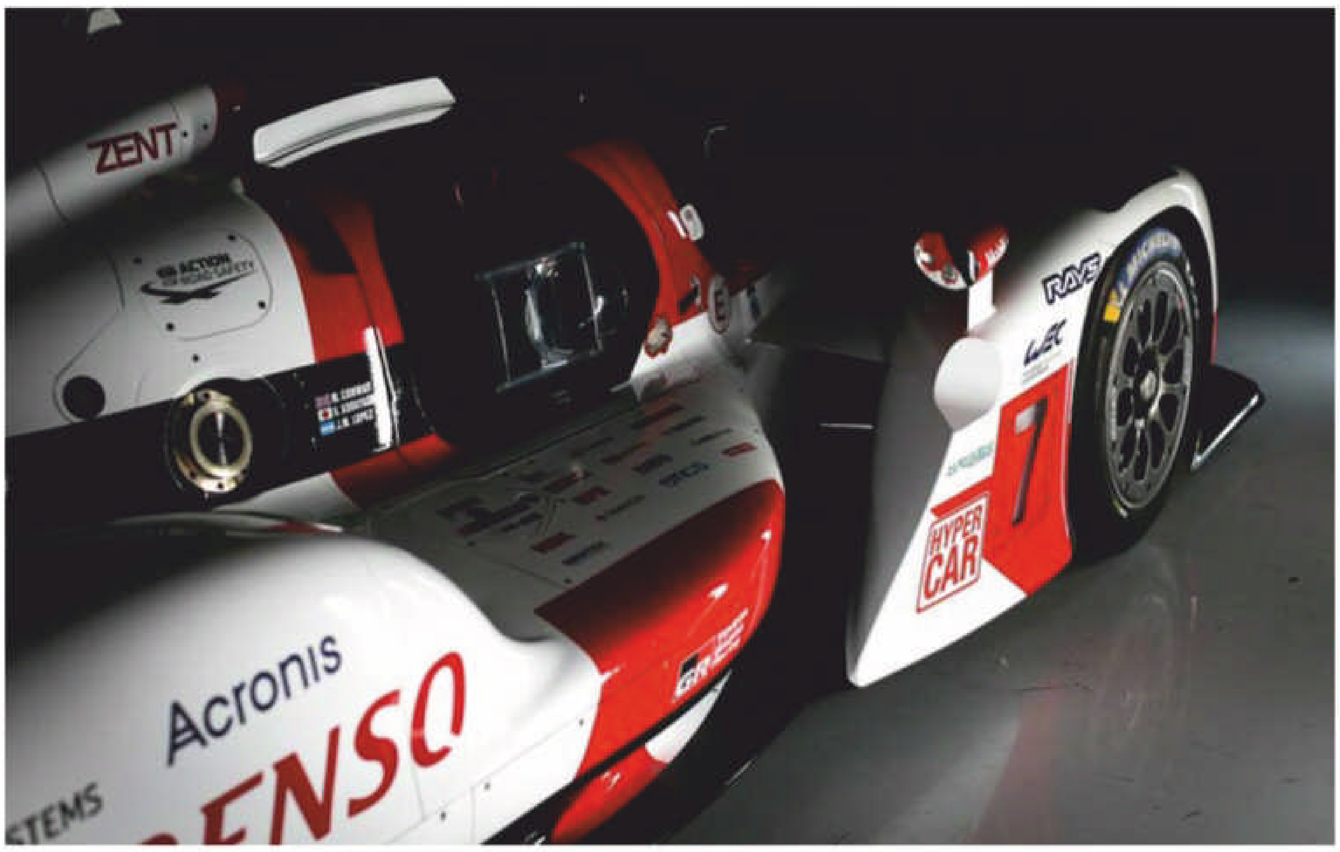
Hybrid system

The hybrid system is also new compared to the TS050, with different requirements compared to its predecessor. The MGU-K is still mounted in the footwell of the chassis, as it was before, but where the old hybrid system was limited to a maximum power output of 300kW, it was actually the recharging capability that drove the size of the battery.

'We were running much higher power in the recovery and boost in the LMP1,' confirms Vasselon. 'Now we are at 200kW for recovery and boost, so it is clearly a different battery. [The limit of 300kW of the TS050] was only for boost. We were going between 500-600kW in recovery [in the LMP1 era] and this was sizing the battery. It is a large reduction in the power requirement for the battery.'

In terms of power deployment, there are surprisingly few regulations and manufacturers will be largely free to decide where and by how much to boost. 'There is quite a lot of freedom in how to deploy the front motor, considering the main regulation is a catch-all regulation at 500kW, but within this we can do pretty much what we want,' says Vasselon. 'We can choose to boost continually throughout the lap at the front, or we can decide to boost at corner exit and use 200kW and nothing five seconds later. We have a lot of freedom, considering the main limitation is the maximum combined power.'

Airflow at the side of the car is directed through the radiators and into a Coke bottle effect, starting ahead of the rear wheels



Chassis re-think

The chassis for the GR010 is the first to be developed by the team since the start of the TS050 programme in 2016, and required a fundamental re-think due to the increase in weight and correlation to the road car. The racecar tips the scales at 1040kg by regulation. The engine, gearbox and monocoque are all heavier than the TS050, and the team has strengthened the more sensitive parts of the car accordingly.

'The gearbox increased in weight by quite a lot because there is a minimum weight by regulations, and there is a minimum centre of gravity, too,' says Litjens. 'The monocoque also has a minimum weight and centre of gravity, so you had to put weight on [there], and the rest of the weight went onto reliability and robustness in case of contact. We have load cases [design targets] and a safety factor [built into them], and we increased the safety factor.'

However, while the architecture was being finalised, the aero work was simpler than expected. 'Probably the positive thing of the new regulations is that the aero is free,' confirms Litjens. 'For sure, the aero numbers to meet the Balance of Performance boundaries are not that challenging if you compare to where we were with the LMP1 racecars, but we had the opportunity to create the link with the roadgoing Hypercars, and with the people in Japan working on these cars. From our side we put some positive things in, because for a roadgoing Hypercar you want some proper downforce.'

The gap between the front splitter and the bottom of the monocoque, for example, is large, and one of the challenges of the design team was to keep that area clear of driveshafts, suspension components and the motor generator unit.

'From an aero point of view, you are almost panicking about things not disturbing the airflow,' says Litjens. 'The aero efficiency and downforce numbers were not that

In addition to the reduction in the number of body kits, the new regulations also stipulate only one adjustable aerodynamic device can be used

challenging, so we worked on the suspension kinematics, and you have the packaging of the front motor and monocoque so that sets the driveshaft position.

'Also in play was the torque sensors, which are not small and are mandatory, and you need clearance, and so this all defined the aero. The numbers were not critical, though, so we didn't have an issue with that.'

Aero devices

In addition to the reduction in the number of body kits, the new regulations also stipulate only one adjustable aerodynamic device can be used. For Toyota, it was a tough call to decide between fixing the rear wing in place, or use a flap at the rear of the front diffuser to change aero balance, and that decision was not taken until after Christmas.

'Due to the regulations, you have to freeze all of your bodywork and have only one adjustable device, and this can be the front wing flap or the rear wing,' confirms Litjens. 'Our car will have the rear wing adjuster. In the end, we tried to get a clean aero, especially because of the importance of consistent aero. In LMP1, 2 and 3 you struggle

Driver's view, with Sebastien Buemi

Q: What is the GR010 like to drive?

A: It is different to what I was used to. The restriction of fuel per lap is gone, so it gives you the feeling that we are back to pure racing where you brake as late as you can, as hard as you can, and don't have to save fuel and recover as much as possible.

You still recover energy, but you don't have to adapt your driving style to maximise the effect of the hybrid system. It is a lot of pleasure because it is back to what it was years ago.

The car is heavier and less powerful, but nice to drive. There are many things we were able to improve over the last car.

Q: As a driver, what is it like with that added weight and less power?

A: The four-wheel drive is only useable above 120kph, so you don't feel that same acceleration out of a 50kph corner, but we maximise what we have. You feel the additional weight when you brake, but the downforce and mechanical grip in low-speed corners is impressive.

The car is two metres wide again, so it feels like a big car, and the mechanical grip is, if anything, better than the TS050. In Portimao the car feels big, but for Le Mans and Spa it will not be any issue at all.

We want to win Le Mans, so of course we want it to be good there and we have only one aero kit, so the car that you homologate, that's it. A few years ago, we had aero kits for pretty much every kind of track, then we had two for the year, and now we have only one for the whole year. It is going to feel much better on a track like Le Mans than a track like Portimao.

Q: Can you feel the difference on the brake pedal with an hydraulic and electronic system?

A: It is a bit of a different brake feel, but for a different reason. Before, we had end-of-straight recovery and we had to do some of that to go to 8MJ. Now you arrive flat out and brake hard, so that feels completely different. Before, there was a deceleration, not a big brake. Now you have slightly less assistance with one motor on the front and nothing on the rear, so you feel you need to press the brake harder, but it is not an issue. We are fine tuning it now.

Q: How does it work in traffic, will it be easier or more difficult?

A: You will not suffer the point where the GTs and LMP2 overtake you on the fuel cut as we used to have [at the end of the straight], but you also don't have the very strong boost. You could all of a sudden go from 500bhp to 1000bhp and you could overtake where you wanted. Now you have 600bhp from start to finish, but you don't have the fuel cut.

Driving in traffic will therefore be slightly easier because they don't have to look at your rear lights flashing to see if you are recovering energy, but sometimes you could see a GT entering Porsche Curves, and push a button to get it done. Now, if you can do it on the momentum then fine, but if not you are behind all the way through.

Q: How does the new suspension system affect driving?

A: The car is so different to how it used to be that it is very difficult to make a proper comparison. The car is heavier, limited four-wheel drive and has a limit on downforce. The interlinked suspension [on the old car] was to improve the aero. At slow speed, this car is amazing, and at high speed it is slower because you have less downforce and the car is heavier. For Le Mans, the downforce is pretty good compared to what we used to have. It will be very close to what we had there, and potentially better than before, but lower on other tracks because we don't have the other aero packages.

Q: How are the new tyres?

A: You would be surprised the good work [Michelin] have done. They need to find the right compromise between durability and not be too risky, but they have lots of experience and know what to do.

The tyres are a bit heavier, but that might come from the fact the car is heavier and they want to be sure it is safe.

Though the new car is heavier and less powerful, and has a limit on downforce, drivers report it is highly competent and exciting to drive, and will especially suit a track like Le Mans

‘Our philosophy was to get as clean as possible car’

John Litjens, project leader for Hypercar

Nose of the car remains high, though the driver’s legs are actually lower in the chassis than they were in the previous TS050

for this, so you have a lot of flaps, turning vanes and winglets that on long runs take tyre marbles and so your aero degrades. Our philosophy was to get as clean as possible car.’

The nose of the car remains high, although in comparison with the TS050 the driver’s legs are actually lower than before. The discussions about more upright seating positions ended early on when the plans for new regulations for 2018 were shelved following the withdrawal of Porsche. A change in seating position like that would have had a knock-on effect on the height of the car, which was not what the regulators wanted to see.

With clean airflow through the nose of the car and channelled around the monocoque, it then feeds through the radiators mounted at the side of the car before following a Coke bottle effect, starting ahead of the rear wheels and ending between them.

‘The floor is cut back because the air goes above the splitter, between the chassis and the floor, and then into the radiator duct and underneath into the Coke shape. And the floor has a curved foot ahead of the rear wheels,’ confirms Litjens.

While blanking plates are allowed to help with brake temperatures in cooler conditions, that is the only permissible change to the bodywork, so the whole cooling concept has to be geared for the hotter races.

Moving back through the car, the air intake above the roof is significantly set back compared to the TS050, and the fin on the engine cover is of totally different design. ‘The regulations in LMP1 said you had to start [the air intake] a few millimetres behind the windscreen, but it is not there any more so you are more free to work around,’ says Litjens. ‘The air inlet feeds the engine and the gearbox cooler, as well as our cooling to the exhaust.

‘The fin is not mandatory any more. You have the downforce and drag levels to respect to be in the [performance] window and then, because of the stability of the cars, there are some regulations set up with a reference car in CFD. They have to find certain ride heights and yaw angles, and you then have to make sure your car is better than the reference car.

‘We started off without any fin, and therefore have a double-pillar rear wing, but to fulfil the criteria, we know from LMP the shark fin is a big step. That is why we added a big part of it back in by development.’

The decision to try to build the car without the fin was again driven by the road car design. ‘We didn’t know what the road car would look like with the fin, so that’s why we started without, but we realised after the first check that it would not be clever [to leave it out],’ notes Litjens.

Noticeably, and significantly, the rear wing end plates are smaller than might be expected and the team did experiment with them, making them larger initially to compensate for the loss of the fin and there is still an option to adopt this concept within the homologation period if the design team can make it work.

‘Your homologation is for five years, but each manufacturer within these five years has the chance to do an update,’ confirms Litjens. ‘The good thing is that it was not planned to allow anything like that, but it depends which manufacturers come with their own programme. They kept it flexible with their newcomers and work with people’s road car programmes.’

Development path

With a view to reducing costs, the new era of endurance racing’s top class will feature simpler cars, and with that has gone the interlinked suspension that was a feature of the old LMP1s. Designed to create a stable aero platform, the complicated and expensive system has been replaced with a traditional independent system on the four corners.

Also different is the braking system, which by regulation features a brake-by-wire system for the MGU-K at the front and, for the first time in Toyota’s WEC programme, a hydraulic system at the rear. The brake

The area with possibly the biggest development path is the electronics that will need to cope with the ever-changing demands on the brake pedal

sizes on the TS050 were led by the amount of hybrid regen’ that could be harvested, but with this more conventional layout the brakes are of more traditional size.

The area with possibly the biggest development path is the electronics that will need to cope with the ever-changing demands on the brake pedal. While the car is charging up the battery using kinetic energy under braking, the force on the pedal would be lighter than when the battery is fully charged and more braking requirement is needed.

‘It is a nice exercise for our people,’ says Litjens. ‘Either it is full conventional on both axles or not, so now we really have to find a way to control it in a smooth way.’

At time of writing, the car has completed three tests, including the roll out and two endurance runs with both cars. Snow has negatively affected the pre-season test plan, but the first race in Europe in April means more time will be available to the team before final sign off. The European season continues at Spa in May and Le Mans in June although Covid restrictions may change that plan.

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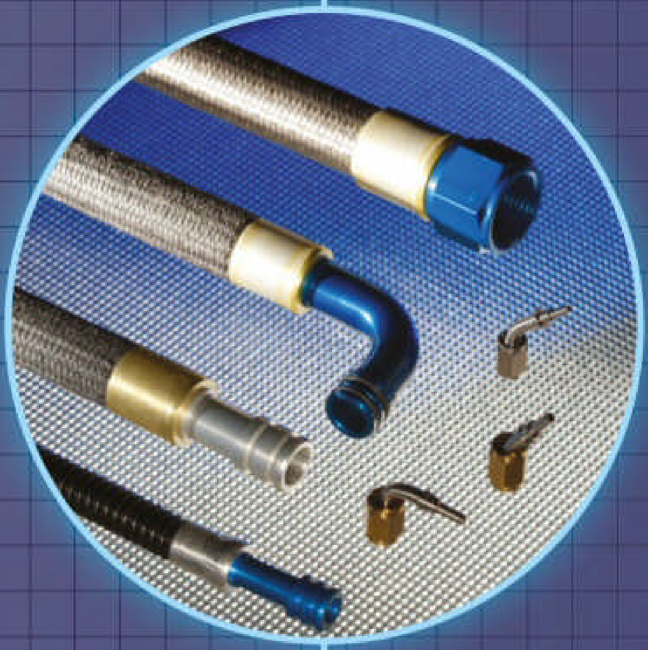

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The layout of the LMH cars is tightly controlled. A minimum weight for the engine and gearbox is prescribed, as is the centre of gravity in order to keep cars within the performance windows. Pictured is the Glickenhaus in build

Small torque

The FIA and ACO are looking to balance totally different concepts with their top class for the WEC and Le Mans. The FIA's technical director, Gilles Simon, runs us through the process

By ANDREW COTTON

The new era of Prototype racing at Le Mans and in the World Endurance Championship will begin this year, with the Le Mans Hypercar (LMH) class governed by an ambitious performance balancing system devised using the latest technology.

This is a change in concept from the LMP1 era, where equivalence of technology balanced the cars. The issue with this was each car had to perform at its maximum capability in order to achieve the efficiency needed to be competitive. That was expensive and so, for the Hypercar era, a more invasive and prescriptive performance balancing system has been devised by the technical teams at the ACO and FIA. Designed to allow for different concepts to race on an equal basis, it also aims to remove the incentive to develop any part of the car for performance gain.

Evaluation process

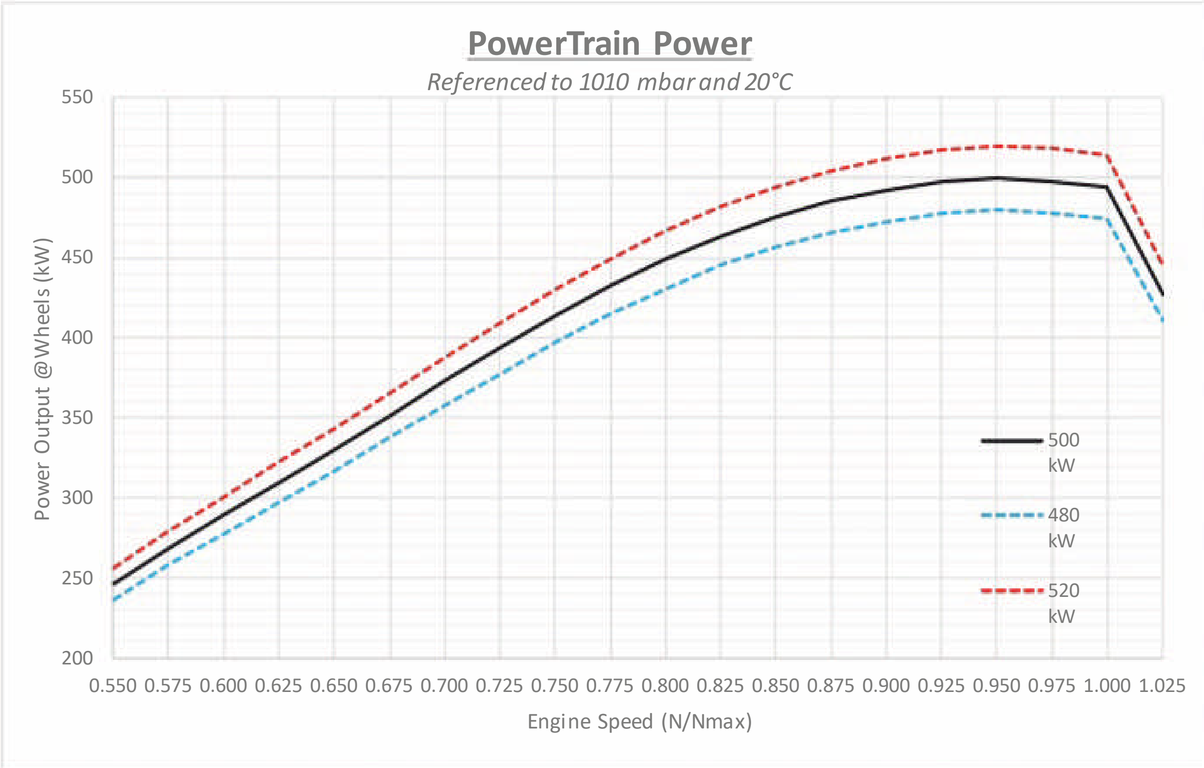
Following a long evaluation process, the LMH class will comprise five different routes into the Le Mans Hypercar category: hybrid Prototypes; non-hybrid Prototypes; hybrid road cars; non-hybrid road cars, and LMDh, which is based on an homologated LMP2 chassis with a standard hybrid system and engines and aero kits chosen by the manufacturer.

In order to bring these different concepts into the same performance bracket, parameters have been set to govern power, weight and aerodynamic efficiency, and manufacturers have to design their cars to meet these targets. They are designed against a virtual 'reference' car that has been created by the FIA and ACO technical teams in CAD and meshing to test and develop the new aerodynamic regulations.

The manufacturers do not necessarily measure themselves against this car, but can use it as a calibration reference to re-scale their development tools, especially CFD. It is against this reference car that Toyota measured its yaw stability without the fin

Power struggle

Cars must be designed to target the following total maximum power curve (Sum of the 4 wheels power measured by driveshaft torque sensors) with low and high margins to be adjusted for BoP reasons as follows:



Engine speed (N/Nmax)	POWER (kW)	ADJUSTMENT (kW)	
	500	LOW	HIGH
0.550	**246**	236	256
0.575	**269**	258	279
0.600	**289**	277	300
0.625	**309**	297	322
0.650	**330**	317	343
0.675	**351**	337	365
0.700	**372**	358	387
0.725	**393**	378	409
0.750	**413**	397	430
0.775	**432**	415	449
0.800	**449**	431	467
0.825	**464**	445	482
0.850	**475**	456	494
0.875	**485**	466	505
0.900	**492**	472	512
0.925	**497**	477	517
0.950	**500**	**480**	**520**
0.975	**498**	478	518
1.000	**495**	475	514
1.025	**427**	410	444

Details:

The PU performance may be checked on a dyno, and homologated. It will include:

- Power vs rpm. It is expected that power below 0.55xNmax is lower than 246 kW.
- Maximum rpm.

The maximum power is given for reference conditions: 1010 mbar 20°C and 0 % Relative Humidity.

If the ambient conditions naturally reduce performance, the maximum power curve will be corrected, at the beginning of each event, to the ambient conditions using the following correction factor:

Pref = 1010 mbar, *Tref* = 20°C

Patmo (Atmospheric Pressure in mbar), *Tatmo* (Atmospheric Temperature in °C), *Hatmo* (Atmospheric relative Humidity in %)

$$min\left[1;\frac{1}{\left\{\left[\frac{Pref}{\left(Patmo\quad\left[6.1121*exp\left\{\left(18.678\quad\frac{Tatmo}{234.5}\right)*\frac{Tatmo}{(257.14+Tatmo)}\right\}*\frac{Hatmo}{100}\right]\right)}\right]^{1.169}*\frac{(Tatmo+273)}{(Tref+273)}\right\}}\right]$$

Power Unit usage is free (settings, modes) as far as the total power stays below the maximum power limit allocated by the BoP.

The shape of power delivery is also strictly controlled. There is a maximum peak power figure of 500kW, with penalties issued during the race if that target is exceeded

on the engine cover, for example, and when it was unable to meet the technical team's requirements, it reverted back to the fin.

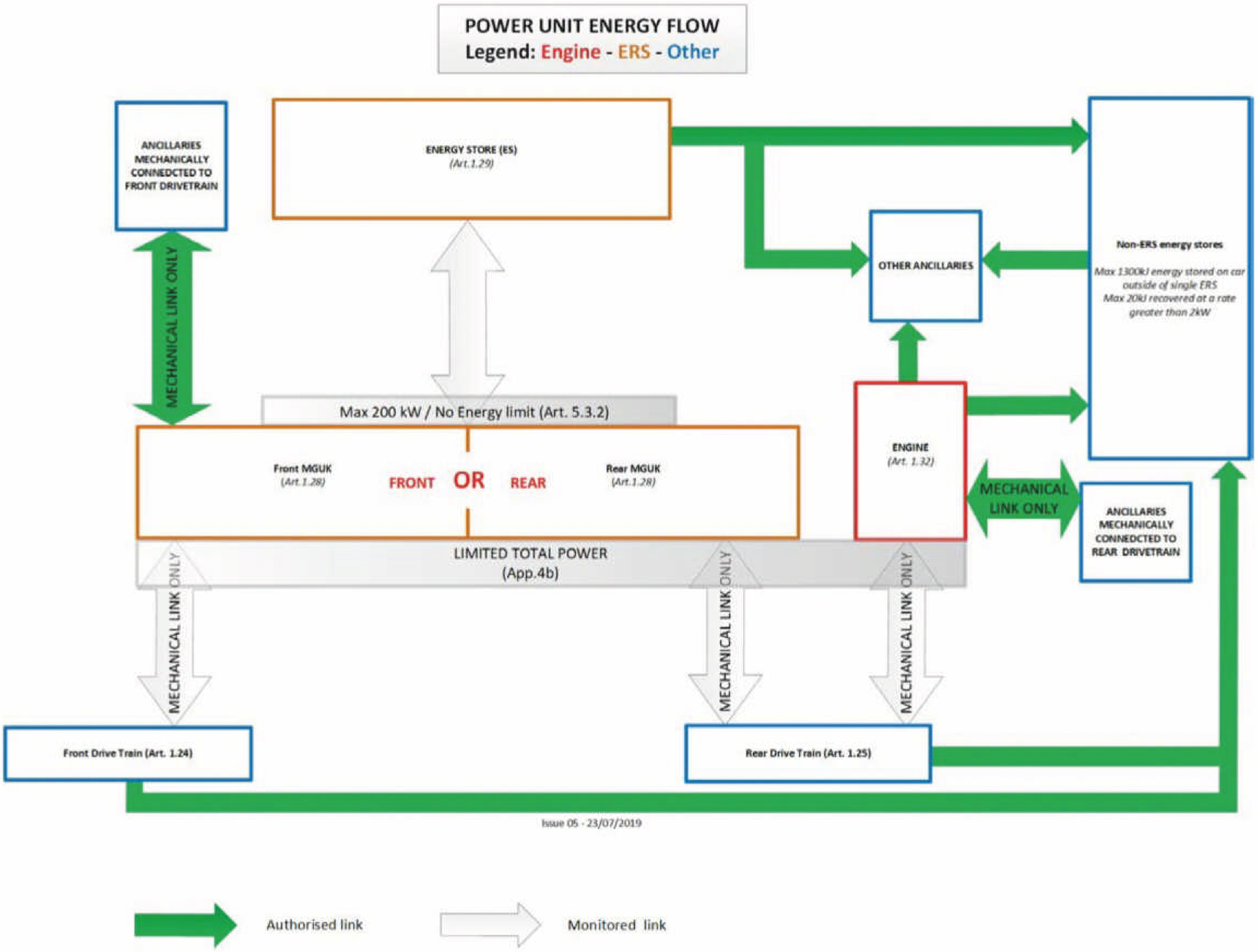
Philosophy changes

The LMH category has had to make some significant changes to its philosophy in order to achieve the desired performance balance, one of which is to specify a single tyre supplier, Michelin. However, the French company is able to develop tyres specific to two-wheel-drive cars (29/71-18 front, 34/71-18 rear with narrower front wheels) and four-wheel drive cars (31/71-18 front and 31/17-18 rears).

In order to meet the performance targets, the FIA has had to be extremely prescriptive with its design parameters for the LMH cars (the LMDh cars follow different design rules), including a minimum weight and c of g for the engine (165kg and no less than 220mm above the reference plane) and gearbox (75kg and 150mm above the reference plane). Weight distribution is homologated for each car with a small tolerance, which will avoid manufacturers playing with extreme weight distribution change between events.

'The application of the principle of 'performance windows' is a completely new regulatory approach by the FIA and the ACO to the top class of the FIA World Endurance Championship,' says the FIA's technical director, Gilles Simon. 'This way we're ensuring sporting equality and preventing cost escalation. It has been made possible by the application of a precise and modern methodology for measuring first order performance parameters, combined with the experience of efficient data acquisition and analyses processes.'

Weight distribution is homologated for each car with a small tolerance, which will avoid manufacturers playing with extreme changes between events



The mechanism for power delivery is also prescribed, and the front wheel hybrid unit will only be able to replace power from the engine, not add to it

Order of play

The first order parameters are the targets for the car designers but, traditionally, the trouble starts with second and third order consequences. Topics such as tyre wear, pitch sensitivity and cornering are only able to be studied in track conditions, and for these to be made accurate, mileage needs to be accumulated. Already, with Toyota targeting four stints at Le Mans and double stinting tyres in a regular WEC race, Glickenhaus believes it is at a major disadvantage as it has yet to run its car and will probably only be able to manage two or three stints at Le Mans, and will similarly struggle in a typical WEC race.

ByKolles and Peugeot, meanwhile, are not due to release their cars until 2022 or 2023, and LMDh cars are still in the design phase, with their introduction date yet to be confirmed.

However, the definitive answer to questions over such issues as tyre longevity is not yet made, and with testing disrupted or delayed due to weather (Toyota's test at Aragon in January was disrupted by snow) and Covid-related travel restrictions, they probably won't be until the tail end of the 2021 season.

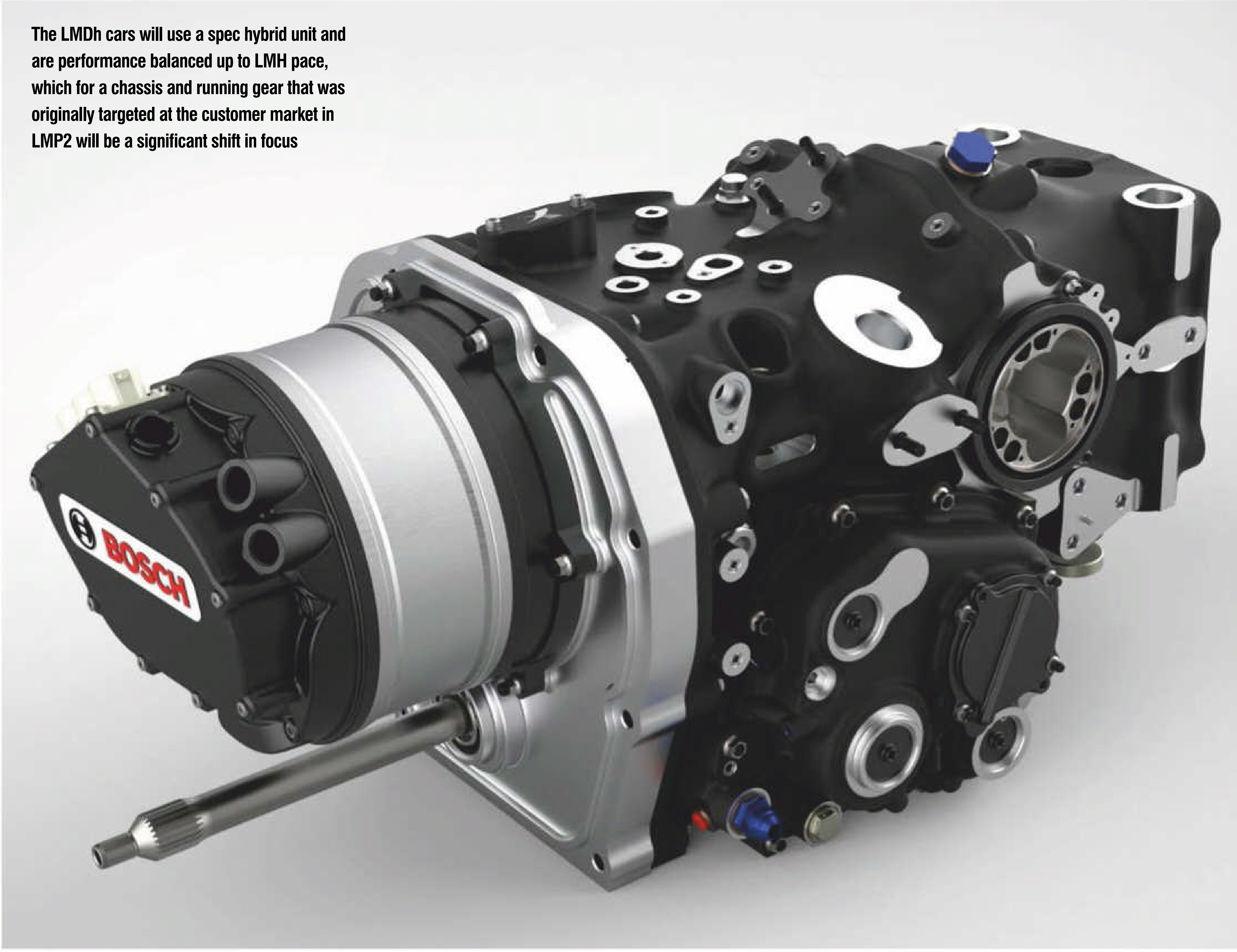
With the start of the season just months away, the need to test has become more critical as the homologation period for the cars has been set at five years, with no performance development allowed in that time. The only changes allowed are for reliability, and only with the advanced permission of the FIA. This is one of the reasons Glickenhaus stated it would not bring its car to Sebring, although it will run in Portimao, ensuring that it has taken the time to test and prove the speed and reliability of the car before signing it off until 2025.

Performance target

'The targets of BoP are to make sure every car has the chance to win a race,' says Simon. 'Hypercar has a much closer starting point than the LM GTE class, yet we managed to balance out different LM GTE cars and have extremely close level of competition. They all had the chance to compete on equal terms.

'In the Hypercar category, all the cars are designed for racing. Overall race performance, stint length and refuelling time are part of the BoP process and therefore equalised.'

Traditionally, over time BoP racing reduces the performance differential between the cars. Development costs drop due to long homologation periods and penalties for



The LMDh cars will use a spec hybrid unit and are performance balanced up to LMH pace, which for a chassis and running gear that was originally targeted at the customer market in LMP2 will be a significant shift in focus

improving performance, though costs start to escalate again as car designers delve deeper into the systems available to extract any small advantage. However, live telemetry readings and detailed lap analysis attempt to stave off that threat.

'We are constantly developing the BoP, measuring more parameters and ensuring it's tailor made to the requirements of each category,' says Simon. 'The FIA and the ACO have a wealth of experience to lean on as BoP has been in use since the mid-2000s, and each year there are over 40 FIA-regulated events where BoP is employed, varying from cross-country to Touring Cars and GTs.'

GTE experience

The system is a variation on that used for the GTE category which, in the World Endurance Championship, is governed autonomously. The category allows manufacturers to race production-based cars with different layouts, but was decided by humans using available data. After years of arguments, an automated system was developed in association with the manufacturers.

This takes the performance of the cars in a given circumstance, with a sustained and measured period of dry running in the previous race, and then balances them for the next event. Only Le Mans sits outside the automated system due to its unique circuit layout and 24-hour duration.

For the rest of the WEC season the arguments have now stopped, partly due to the involvement of manufacturers in the process, which left them little room to criticise their own system, but also because it has produced close and competitive racing. Manufacturers have also found they cannot rely on the system to make up for performance deficiency, as Aston Martin found following the 2018 / '19 season with its rear tyre wear issue.

Entry point

As satisfactory as the GTE system is, the entry point into the automated BoP was key to its success or failure. Given the length of time between races, and the fact that the majority of them feature at least some wet weather running, if a car went in with the wrong initial settings, it could take the rest of the season to correct it.

For the Hypercar category, with overall wins at stake, that entry point will be even

The FIA and the ACO have a wealth of experience to lean on as BoP has been in use since the mid-2000s

more crucial, but the FIA is confident it will have enough knowledge of the cars to be able to balance them. 'LM GTE was an important experience for us,' confirms Simon. 'However, the Hypercar BoP will be different, owing to narrow aero performance windows and the introduction of a brand new torque meter sensor, developed specifically for the Hypercar category.

'The three first-order performance parameters: weight, power and aero, are the same for all the cars. The entry point [into the BoP system] will be defined automatically, based on homologation data including wind tunnel data, weight, propulsion type, two

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and four-wheel drive and fuel consumption. This is new compared to LM GTE, but the homologation procedure is now gathering more performance data to achieve a narrower performance estimation target, owing to the introduction of the new tools.'

Unlike GTE, there is only one body kit homologated for the season, which will reduce the downforce on many of the circuits as the traditionally low-drag Le Mans kit is likely to take priority. Only blanking for the brakes are allowed as a safety measure.

'As there's now only one aerodynamic bodywork, no sprint and Le Mans kit any more, the Le Mans Hypercars will stay the same in all types of races, so consistency will be better on all tracks,' confirms Simon.

Torque meters

Torque meters at the driveshaft are nothing new. Indeed, GT3 looked to bring them in as part of its performance balancing process, but discounted the idea as too expensive for a customer-based programme. They also generate a huge amount of data that needs to be considered in real time, which is not cheap, and their physical size means it is not a question of simply bolting them on.

'Three types of data will be used to control the performance,' says Simon. 'We will have homologation data, which is the measurements coming from the wind tunnel, tyre data, weight and hybrid specification. We will also have timing, which includes split times and GPS, and we have the data from car sensors connected to the FIA / ACO data logger. They will include the torque meter, fuel flow meter, speed, attitude of the car and driver commands, including braking, steering and acceleration.

'The FIA and the ACO have developed specific tools able to manage these three types of data, all of which will be correlated and augmented with simulation tools.' As the data will be recorded live, the technical team is confident there will be no delay in analysis that might cause a race result to be compromised.

In the regulations there is a list of penalties that may be applied should any car breach the performance targets mid-race. Any such penalties will be served during the race.

Everything that has an absolute limit causes teams a headache as they have to get as close to that limit as possible without breaching it. It's a different philosophy to the old LMP1 era, and the WEC technical team also understands that racecars have a habit of being unpredictable. Power is limited to 500kW, for example, but there may be occasions when the software is milliseconds too slow to react and that limit is exceeded. So how stringent are these regulations and penalties?

Zero tolerance

'The aerodynamic performance window is set for homologation only,' confirms Simon. 'It's fixed, and to be homologated a car must be in the performance window when measured in the wind tunnel. No tolerance is allowed. Basically, the car will race in that exact configuration, and bodywork scanning will be performed to check this.

The three first-order performance parameters: weight, power and aero, are the same for all the cars

'During the event, the BoP is enforced with ballast and power fixed. There is no tolerance on minimum weight, as with other categories. There's no tolerance on maximum power, which is controlled live by the torque meters, and there is an appendix in the Sporting Regulations that provide for some of the BoP abuse penalties.'

Aero measurements take place at the Sauber wind tunnel in Switzerland, where much of the GTE aero is measured. The information is solely for the FIA and ACO technical teams, and is not shared with Sauber personnel or with other teams and manufacturers.

'We have defined a process to compute the exact position in the performance window [CdA/ClA],' says Simon. 'Once the car is in that window, the bodywork, including blanking and all movable aero devices, is frozen, 3D scanned at the FIA and homologated.

'During an event, we check that the bodywork, and any other elements that

Peugeot will join Toyota and Glickenhaus in Hypercar as will ByKolles. Audi, Porsche and Acura are coming with LMDh-specification cars. Others are expected to announce programmes, with Ferrari and Hyundai favourites to do so

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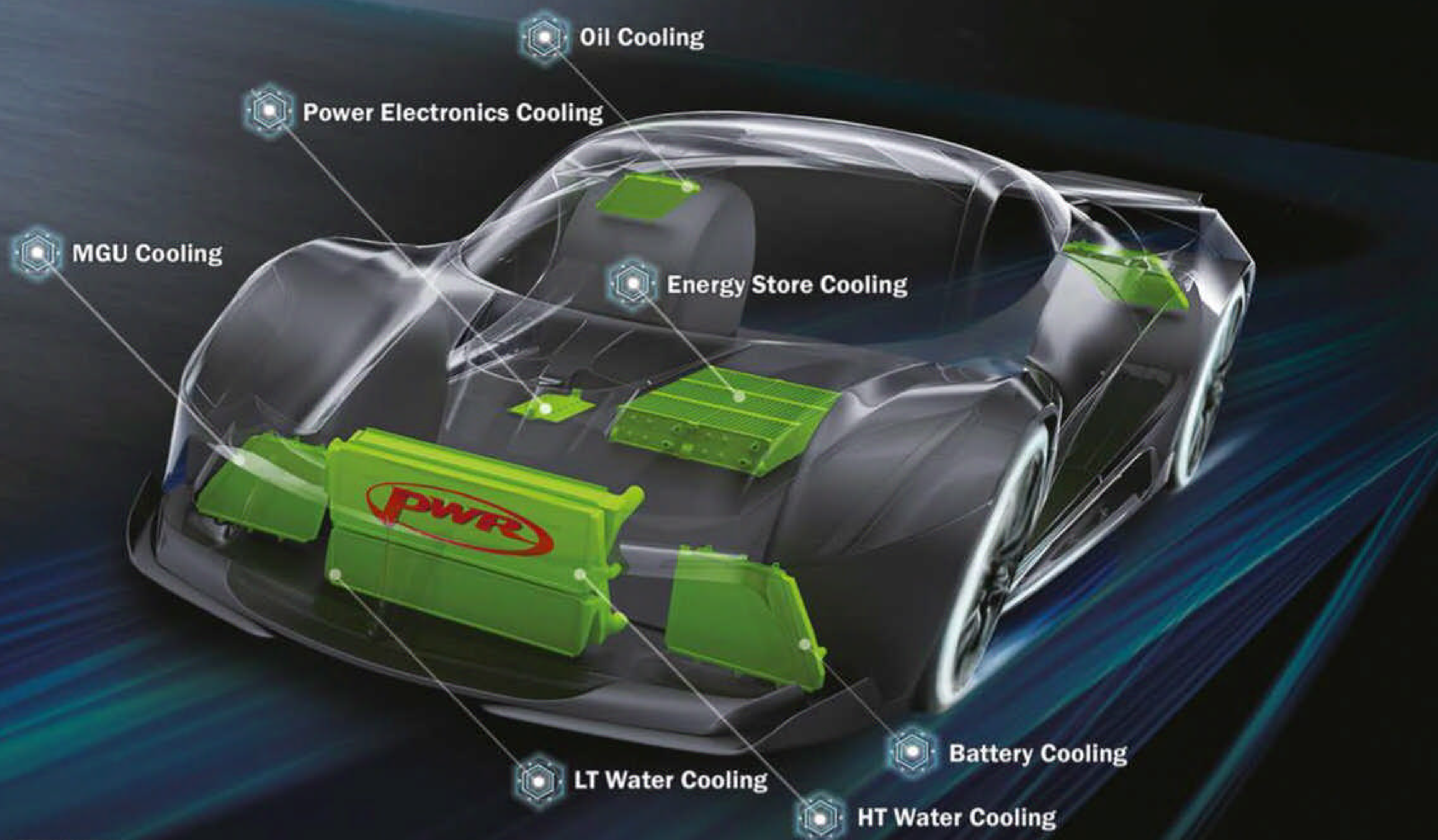

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Toyota introduced a first version of its Hypercar at Le Mans. This is the roadgoing model on which the Prototype will be based. Toyota Gazoo Europe is developing the car in line with the Le Mans variant

influence aerodynamic performance, is exactly the same as the one measured in the wind tunnel as there is a scanning process at scrutineering.

'Aerodynamic performance will also be monitored on track with top speed correlation and suspension sensors. But this is more for understanding and knowledge to improve the process in the next years.'

Although there will be a five-year homologation cycle, there will be an opportunity to update a Hypercar when new manufacturers join. However, this is not the same as a 'joker' package that is permitted in LMP2. There, any manufacturer with a performance deficit, or with a need to make a change, is permitted to do so in order to close the gap. 'No 'joker' package is needed here because the championship is ruled by a BoP,' insists the Frenchman. 'Any possible difference will be compensated by a different combination of ballast, power and any other necessary measures.'

Bumpy road

From the manufacturers' point of view, the BoP windows are a design target, but even within them there is an issue that needs to be considered. With the four categories stipulated by the FIA and ACO, there is also the LMDh route into the series. This is the homologated LMP2 chassis and running gear, including the gearbox from Xtrac and standard hybrid system, but with engine and bodywork stipulated by the manufacturer.

The chassis meets all the safety standards required by the FIA but, performance-wise, it has to serve two different functions. In the WEC it also runs in the amateur driver-targeted LMP2 class, with a standard Gibson engine, spec aero and without the hybrid system. In the European Le Mans Series it runs as the top class against LMP3 cars.

As LMDh is essentially an updated version of the current Daytona Prototype International (DPi) cars, after their introduction in 2023 they will also race in IMSA against the current DPi cars. That said, they may arrive mid-season, late in 2022, and have to be performance balanced down to DPi speeds in order not to disrupt the championship.

'A significant job has been achieved to allow competition between LMH and LMDh,' says Simon. 'Aerodynamic performance window, minimum weight and maximum power are identical. That was the key target to achieve convergence between the two types of cars. It was in the interest of all parties, and especially the manufacturers, to achieve this global target for endurance racing.

'Furthermore, all the homologation process will be identical and done in a transparent collaboration manner.

'It's also important to note that LMH can choose between two different

It is now up to the race and technical teams to turn it into a competitive and fair system

dimensions of tyres, and use the most suitable option [linked to car architecture and weight distribution]. In LMDh, all the cars will be in the same window of weight distribution and will be allowed to use only one tyre dimension option.'

Clearly, the FIA and ACO technical teams have thought through the process and spent years fine-tuning the concept throughout the discussion phase. However, in practice balancing the different cars is not going to be easy or straightforward. Given the different characteristics each will display, coupled with driving styles and team management, it will undoubtedly take a number of races to iron out the performance differences between the cars.

However, to have achieved a system by which manufacturers are able to commit to Le Mans' top category is commendable. It is now up to the race and technical teams to turn it into a competitive and fair system.


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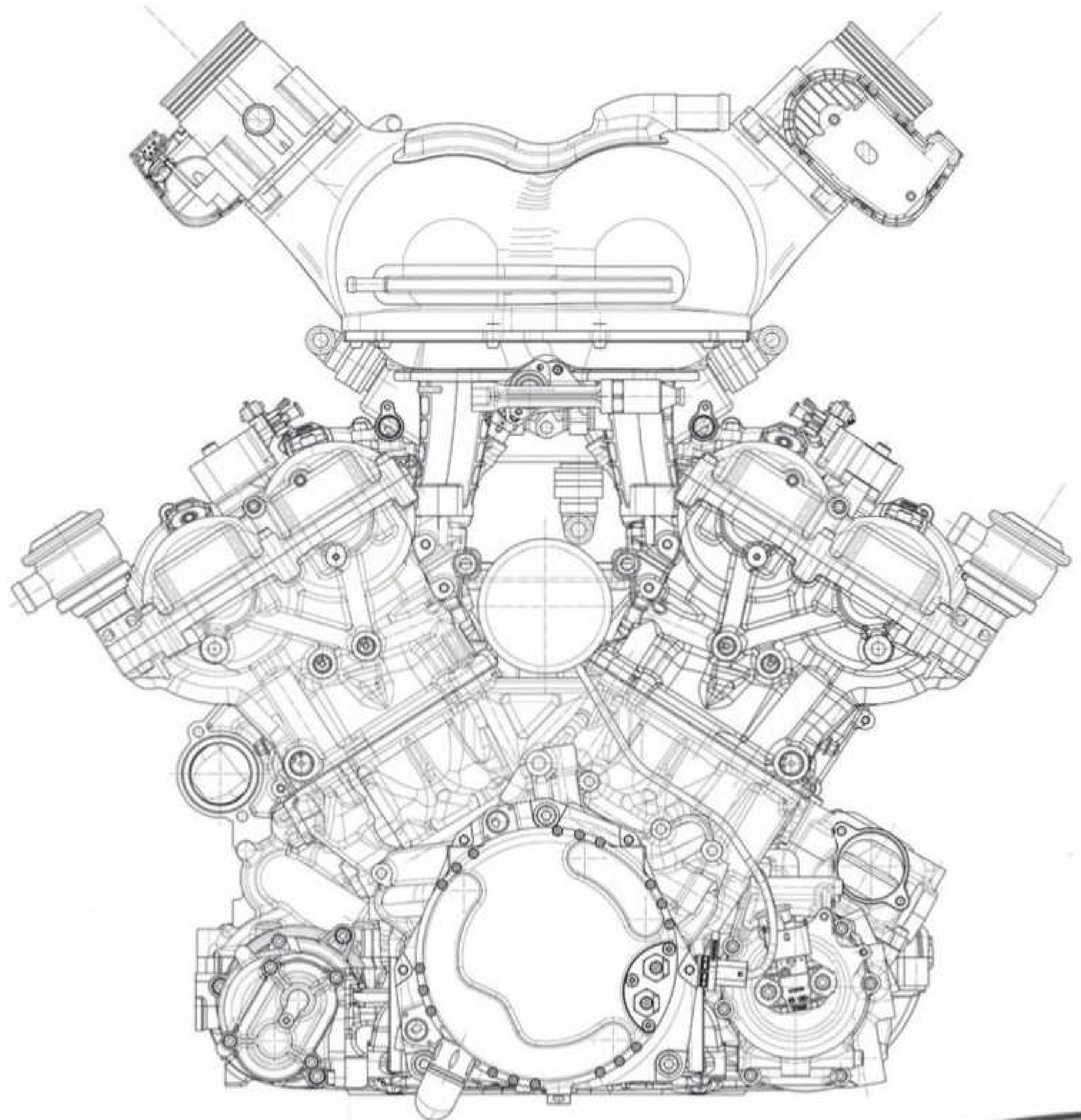
When Gordon Murray set out to build the ultimate driver's car, he was insistent it have a high-revving V12 engine. Enter Cosworth

By LAWRENCE BUTCHER

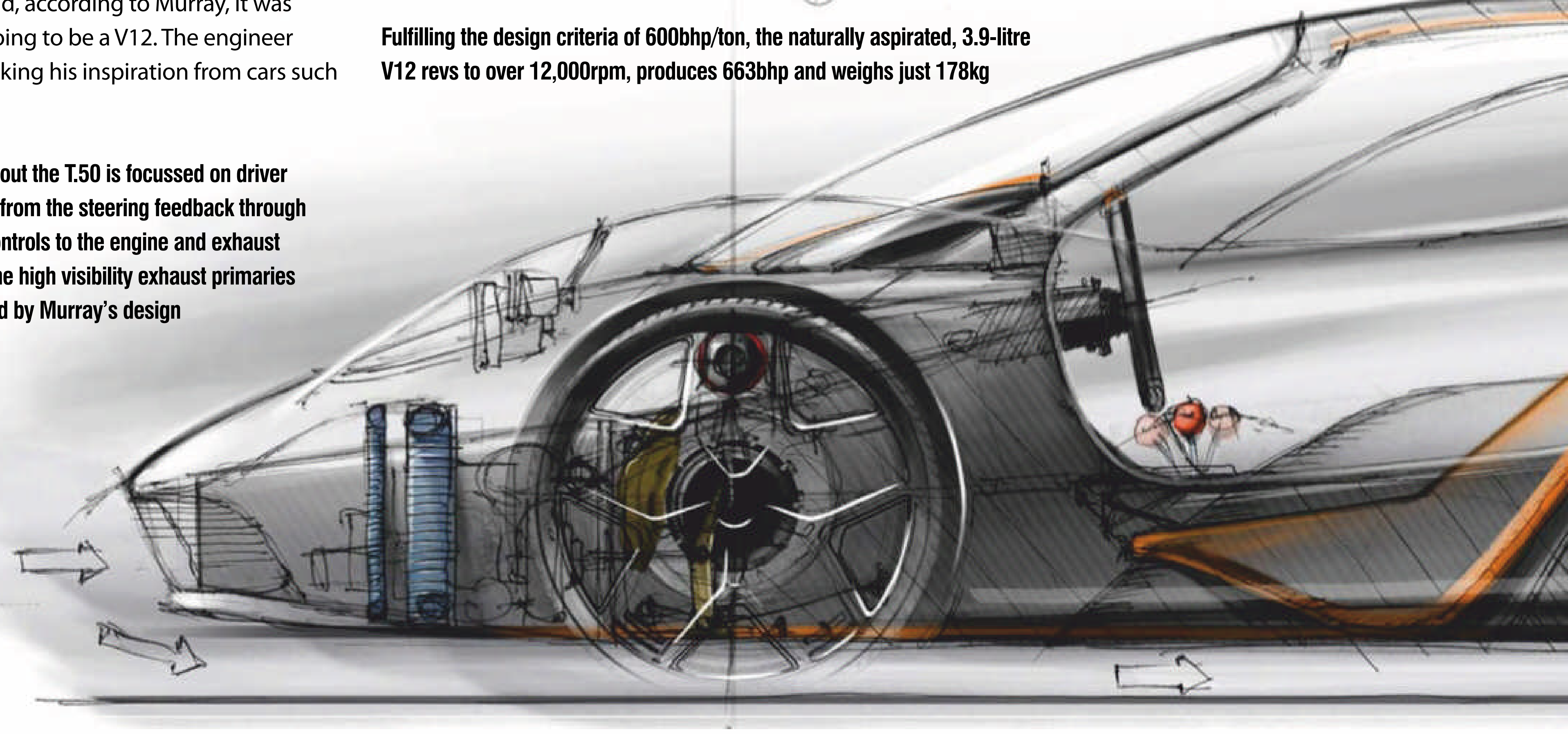
The last time Gordon Murray penned a supercar (we'll ignore the Mercedes McLaren SLR, which he was less than enamoured with), it won Le Mans. That car was, of course, the McLaren F1 and, while his latest creation, the T.50, is being built primarily as a road car, there will be a limited run of track-only specials.

His concept for the T.50 was straightforward – create the ultimate driver's car. However, the execution of this aim is considerably more complex. Murray set his sights on ensuring every element of the driving experience is optimised to provide maximum driver engagement, from the steering weight and feedback to the engine note and even the tactility of the cockpit controls. To this end, the T.50 is both beguilingly simple, yet replete with some very advanced engineering concepts, such as the fan-assisted aerodynamic package (see sidebar on p32). It is also almost entirely bereft of the trinkets one has come to expect of a modern supercar. There is a stereo, but no all-singing digital HMI and, thanks to weekly weight watchers meetings during the design and development process, the overall weight has been kept to a hair under 1000kg.

At its heart is an engine with true racing pedigree and, according to Murray, it was only ever going to be a V12. The engineer admits to taking his inspiration from cars such



Fulfilling the design criteria of 600bhp/ton, the naturally aspirated, 3.9-litre V12 revs to over 12,000rpm, produces 663bhp and weighs just 178kg



Everything about the T.50 is focussed on driver engagement, from the steering feedback through the cockpit controls to the engine and exhaust notes. Even the high visibility exhaust primaries were specified by Murray's design

as the Lamborghini Miura and Ferraris of the 1960s, which were fitted with the Gioacchino Colombo-designed, 60-degree, 3.0-litre V12.

Logical choice

Developed and built by Cosworth, the T.50's powerplant is dubbed the GMA V12, and the numbers seem out of kilter with a road car spec sheet. Displacing 3.9-litres, it will rev to more than 12,000rpm and produces 663bhp, in a package that weighs just 178kg, making it the lightest roadgoing V12 ever released.

Murray says Cosworth was always the logical choice of engine partner on the T.50 project, and admits he had a demanding set of requirements for it to meet. Not only did the engine need to be capable of out-revving the Light Car Company Rocket (a previous design of his that held the record as the highest revving road car), it was to be more responsive than the V12 fitted in the McLaren F1, while also hitting a power requirement of 600bhp/ton. Additionally, it had to be both visually and aurally appealing.

Given the brief, turbocharging was never going to make the grade, so the GMA V12 is naturally aspirated and also features port injection (the reasons for this we will address later). Fortunately, this wouldn't be Cosworth's first foray into producing such an engine for the road, as at around the time the approach came from Murray's team, it was in the late development stages of the 6.5-litre V12 for the Aston Martin Valkyrie. Though that engine is quite different from the GMA – not least because the Aston has a full hybrid system – it is still an emissions-compliant V12 capable of 10,500rpm, and its development meant Cosworth was not approaching the project blind.

Best compromise

In terms of basic architecture, the 48-valve engine, with four gear-driven overhead cams, has an aluminium block with a 65-degree bank angle. This layout, according to Bruce Wood, managing director powertrain at Cosworth, represented the best compromise between packaging the exhaust headers (Murray was insistent on individual primaries, visible from above) and the components that had to be located within the vee.

When it comes to the reciprocating components, the engine's racing heritage is clear. Notably, Cosworth has chosen to use a metal matrix material for the piston construction (which would not be allowed under most current racing regulations). This, says Wood, is a result of the engine speed and its power density (approx. 62bhp/l), which would have pushed a standard monolithic aluminium piston, with what is a relatively heavy ring pack, uncomfortably close to reliability limits.

While the GMA is Cosworth's first production engine to use the material, Wood notes that Cosworth has been working for several years with MMC supplier, Materion, on highly stressed components and it felt using the material would bring a useful reliability buffer.

The pistons run in plasma-coated bores, a process undertaken in house at Cosworth, and one which it has used on all its racing engines since the CA V8 F1 unit produced in 2006. Though initially the preserve of race engines, Wood says it has seen increasing use on its roadgoing products. The rest of the components are relatively standard in racing terms, but still unusual for a road car, not least the titanium connecting rods.

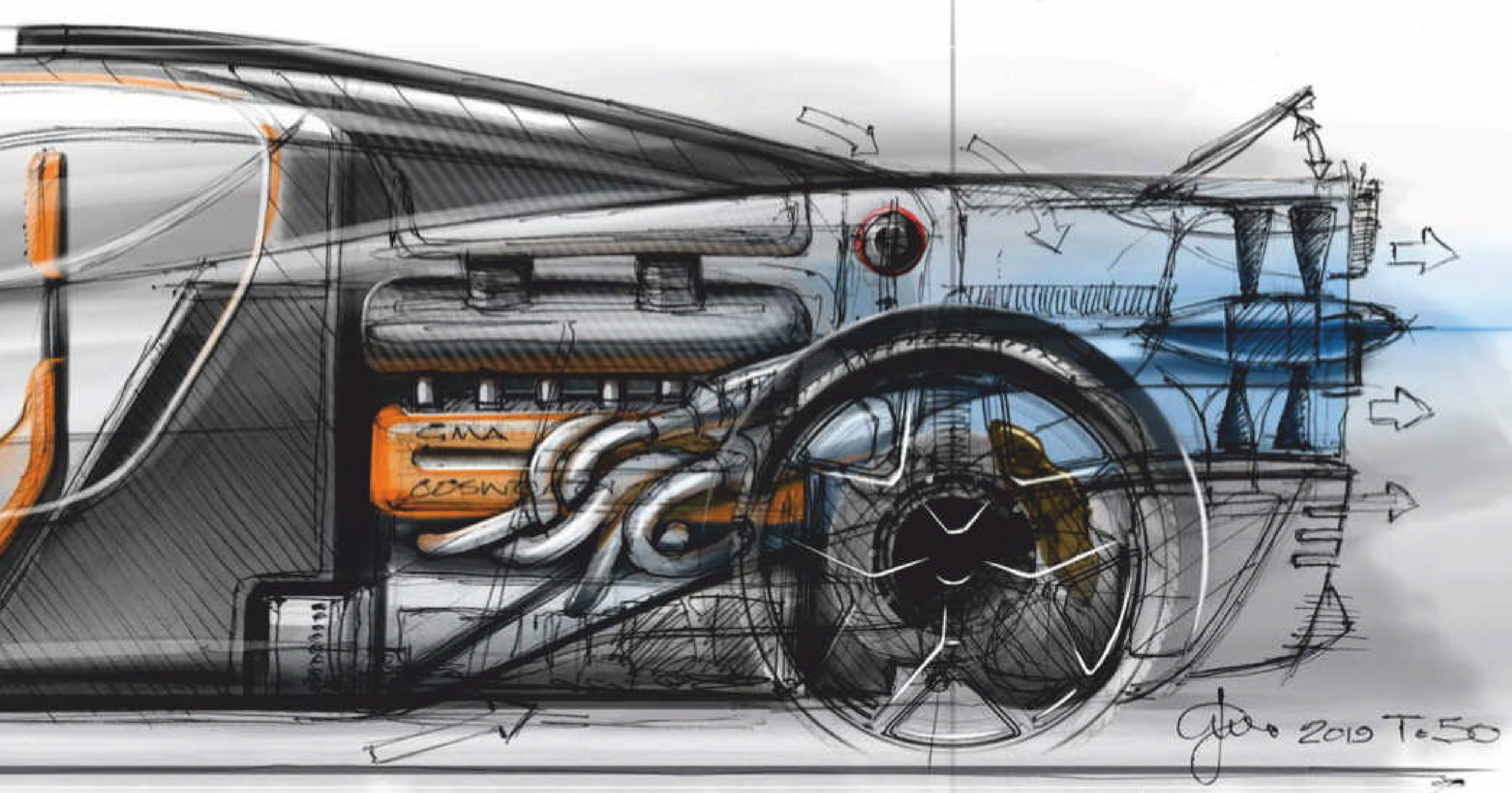
Valvetrain durability is evidently a prime consideration in an engine capable of such heady rpm, and considerable effort has been invested in both materials – for example, the valve springs are triple vacuum melted steel productions from a supplier in Japan – and refining the dynamics of the cam train. Wood says the most important element to ensuring valve spring reliability is the cam profile, with fine tuning of the ramp on and off the spring key to longevity. And as these engines are expected to have a service life between rebuilds of 80,000km, that's no mean feat, given the spec would make some recent race engines blush.

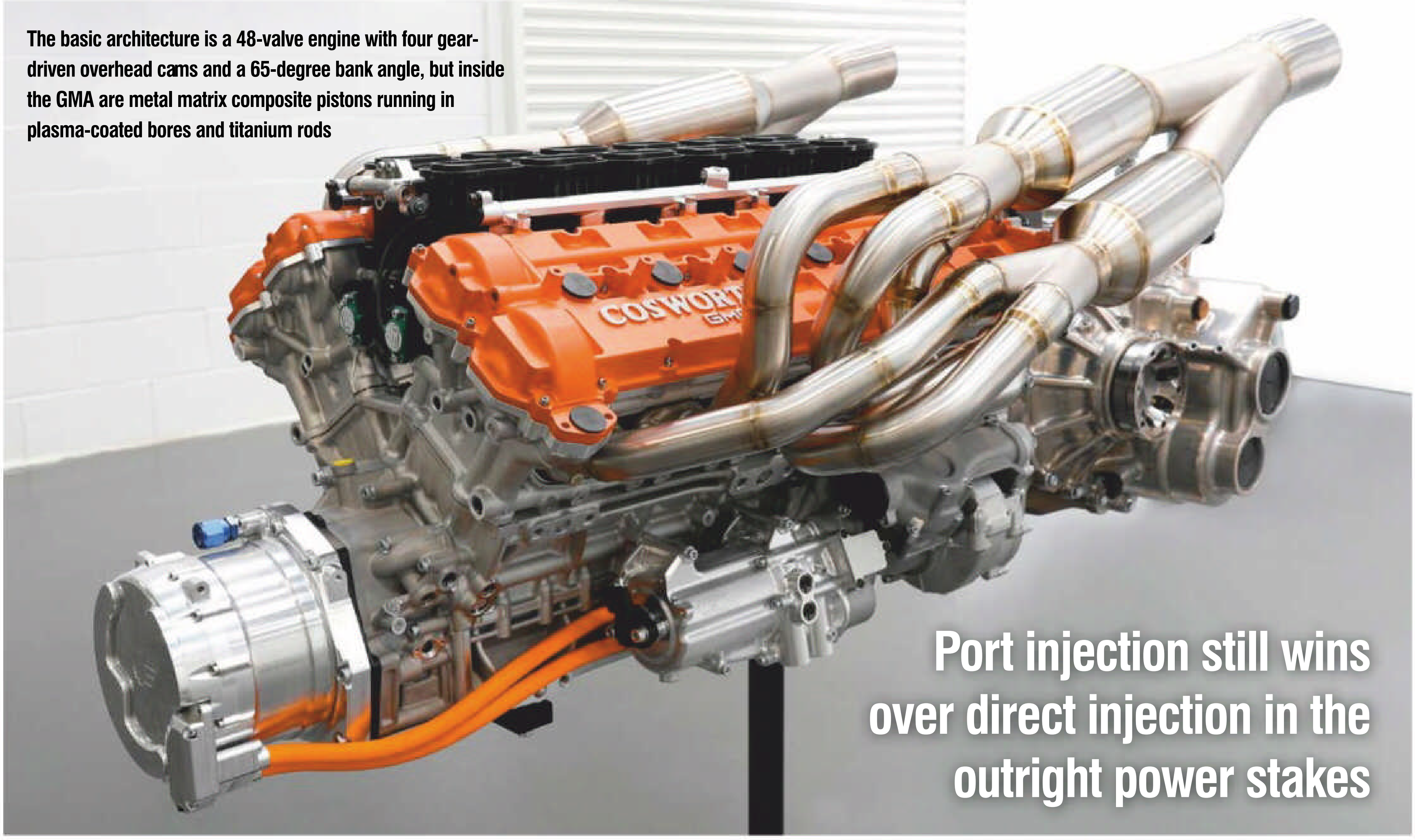
Port for power

Wood explains that the use of port, rather than direct, injection was driven by two main factors. The first, surprisingly, was emissions. Passing current particulate

'We've thrown everything at pushing this car beyond the levels of anything that's been done before. It's a celebration of British engineering and our team's extensive motorsport experience'

Gordon Murray, Gordon Murray Design





The basic architecture is a 48-valve engine with four gear-driven overhead cams and a 65-degree bank angle, but inside the GMA are metal matrix composite pistons running in plasma-coated bores and titanium rods

Port injection still wins over direct injection in the outright power stakes

emissions regulations using direction injection without the use of a particulate filter in the exhaust is apparently nigh-on impossible, and there was little chance of Murray being happy to accommodate a pair of heavy filters in the featherweight T.50.

The second factor, says Wood, is port injection still wins over direct injection in the outright power stakes. Firstly, the fuel is suspended in the inlet charge for longer than if it is simply squirted straight into the cylinder. Secondly, the presence of an injector within the combustion chamber robs valuable space. Wood notes there is a choice between side or central location of the injector, with the majority of road cars now trending towards a central injector. However, on a four-valve head, the injector takes up space that could be occupied by valves, which limits the power potential unless turbocharging is used. While a side injector could have been made to work, there is little tier one support for such systems. In other words, port injection was the only logical choice, though it didn't make the task easy.

The ideal flow conditions for power, which Wood describes as laminar with barrel turbulence in the combustion chamber, are almost the exact opposite of those needed for emissions, where as much turbulence as possible is desirable within the combustion chamber to speed up combustion, which in turn helps bring the catalytic converters to the ideal temperature. Experience from the Valkyrie project, coupled with an extensive single-cylinder test programme,

Considering the spec, and the engine's capability, suggested service / rebuild intervals of 80,000kms are quite extraordinary

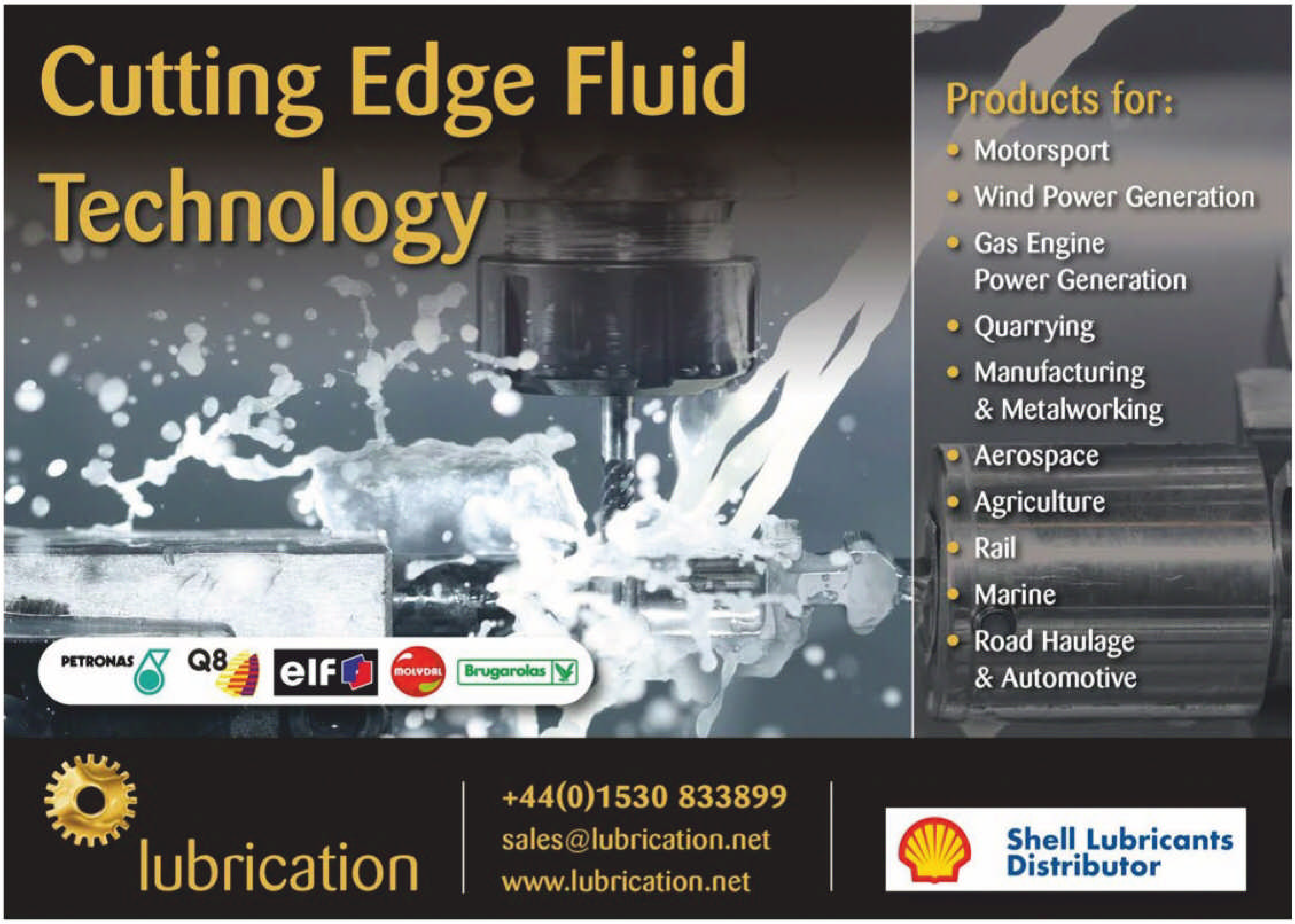
meant that from relatively early on in the project, Cosworth was confident it could hit both the emissions and power targets.

Tractable torque

But Murray's demands weren't over yet. He also wanted the engine to be as tractable as possible, something not normally associated with a 12,000rpm V12. Impressively, through the development of a variable valve timing (VVT) system, Cosworth has managed to ensure that 71 per cent of the engine's 467Nm of torque is produced from just 2500rpm. Again, the company had already developed a VVT system for the Valkyrie engine that can survive at nearly 11,000rpm, and Wood describes it as an iterative step to make that reliable at 12,000rpm.

The VVT is hydraulically actuated and runs on a separate oil circuit to the main engine lubricant, operating at a much higher pressure.

The engine runs a dry sump, and here Wood points out that Cosworth has used the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same bottom end architecture for nearly two decades, and the experience gained over that time in terms of crank bay geometry, pump sizing and other elements means it was able to avoid most pitfalls. Its engineers also had the luxury of having more packaging space available than they necessarily needed to achieve its performance targets in this area. Though Murray wanted a low crank centre height, the diameter of the clutch, which is sizeable compared to a racing application, dictated the lower most extent of the engine, rather than the internal details of the sump.

The transmission is just as finely honed as the engine. Manufactured by Xtrac, it has more in common with a racing transmission than one destined for the road. It also provides a strong hint towards the analogue nature of the car, featuring an H-pattern manual shift and just six speeds; five close ratio and a tall sixth for cruising.

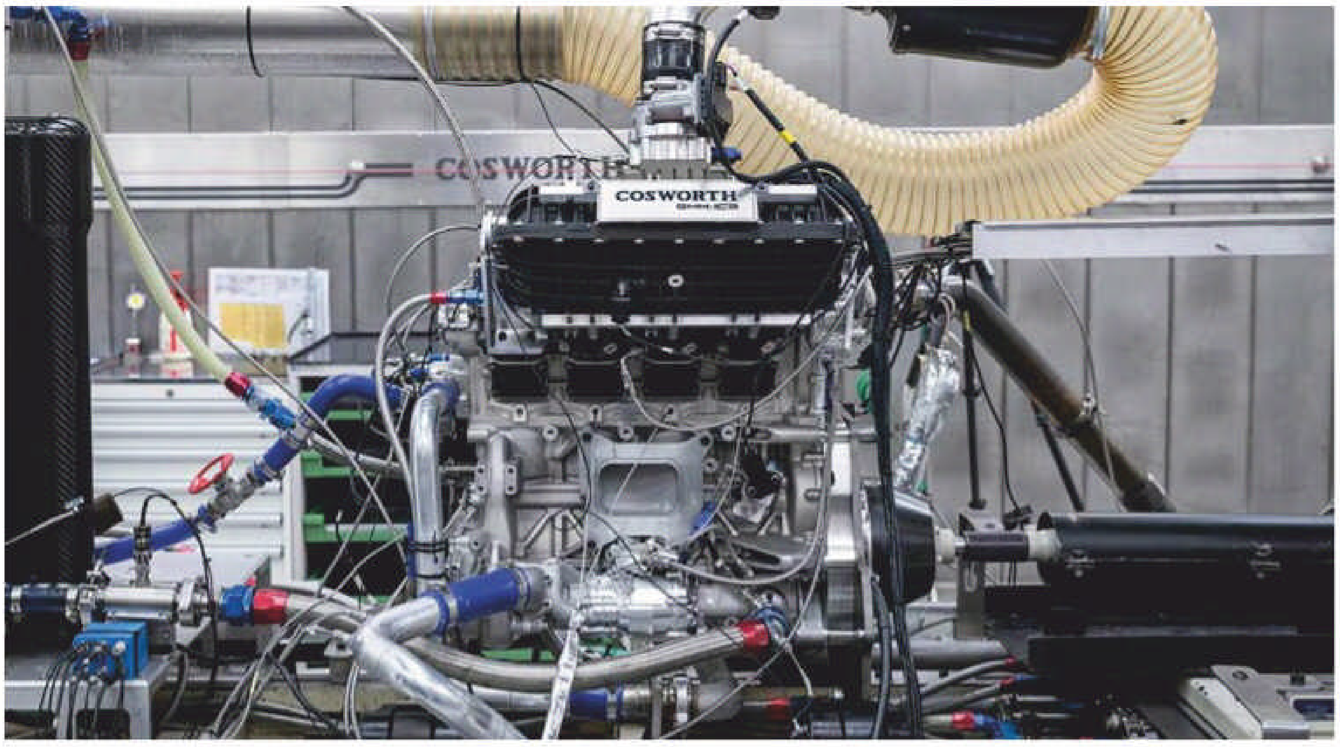
The gear cluster and differential are housed within a thin wall aluminium casing, just 2.4mm thick. During early testing, the gearchange motion and weighting was honed using adjustable actuators fitted to all parts of the gear linkage. According to Murray, his target gearshift feel was that of a 1960's Ford Cortina GT.

Racing ambitions

Unsurprisingly, there is due to be a motorsport variant of the T.50, currently known simply as the T.50s. When this version was announced, Murray's enthusiasm for it was clear: 'With an unwavering focus on performance, and free from roadgoing legislation and maintenance considerations, the T.50s will achieve astonishing performance on track, demonstrating the full extent of the car's capabilities.

'We've thrown everything at pushing this car beyond the levels of anything that's been done before. It's a celebration of British engineering and our team's extensive motorsport experience.'

In addition to being subject to further weight saving efforts, one of the most significant modifications to the T.50s will be



Hydraulically-actuated variable valve timing means the engine makes around 331 of its 467Nm of torque at just 2500rpm

a 1758mm wide delta wing mounted to the rear of the car, which echoes the design of the front wing on Murray's 1983 Brabham BT52. The visually striking wing works in conjunction with a revised underbody, featuring a more aggressive front splitter and adjustable diffusers. When coupled with the car's fan system, the aero package is predicted to generate more than 1500kg of downforce – 170 per cent of the racecar's 890kg weight.

Where the road car has six different aero modes, the T.50s will operate in high-downforce mode at all times, with its underbody diffusor ducts fully open and the fan running permanently at 7000rpm.

From the perspective of the engine, Wood says there was always intended to be a track-focussed variant and, as such, a specification has been devised using a revised cylinder head design, increased compression ratio, more extreme cam timing and a freer flowing exhaust system. These, combined with revised calibration, will push the power output to over 700bhp.

The question of whether the T50s will remain purely a track day special or, as Murray has expressed a desire for, actually compete, currently remains an open question. However, on the announcement of the track version,

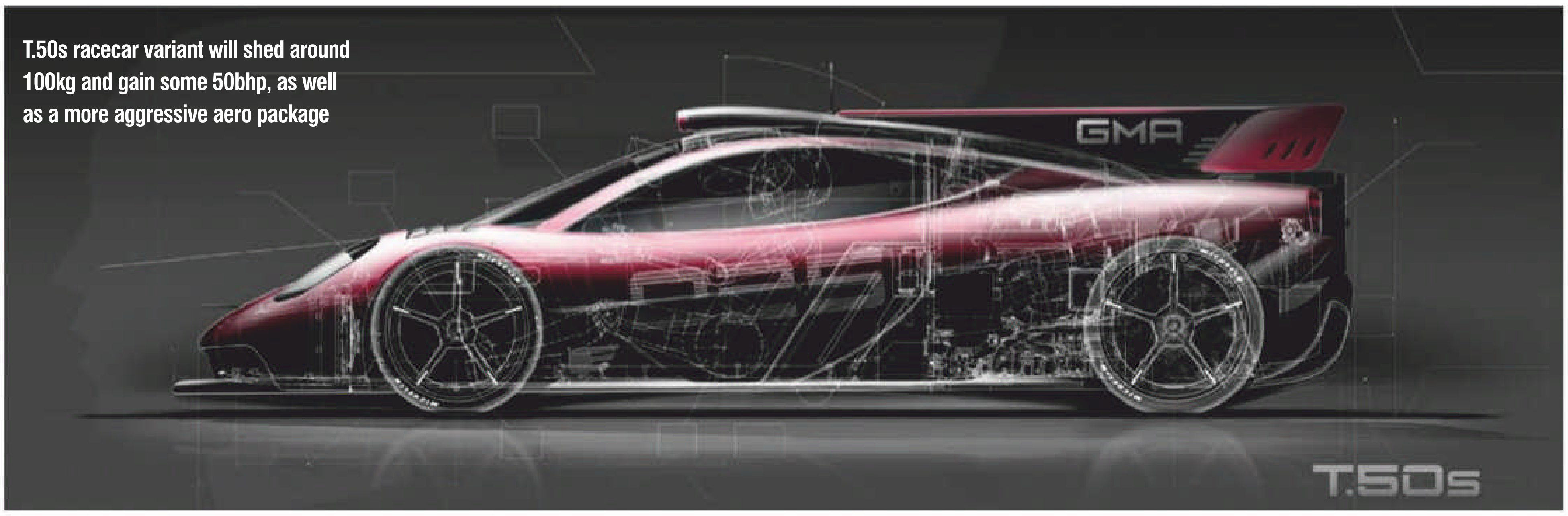
A track-focussed variant… will push the power output to over 700bhp

he stated: 'I'd like to organise a series of racing events as part of our Trackspeed package to ensure the T.50s is driven regularly by owners. There will be nothing like the experience of driving this car. And hearing it…well, that will be something else!

'I'd also like each of the 25 cars to be unique, from set-up to paint finish.'

Murray has also been in discussion with Stéphane Ratel of SRO regarding the potential for a series encompassing similar supercars.

In terms of regulations, it is hard to see where the car could slot in. With a target weight of just 890kg, it doesn't fit the ACO's Hypercar rule set without its whole *raison d'être* being compromised, and the idea of competing in a BoP formula is likely anathema to Murray. We can only hope a regulatory body somewhere sees sense and allows what may be the last true V12 to turn its wheels in competition.



T.50s racecar variant will shed around 100kg and gain some 50bhp, as well as a more aggressive aero package

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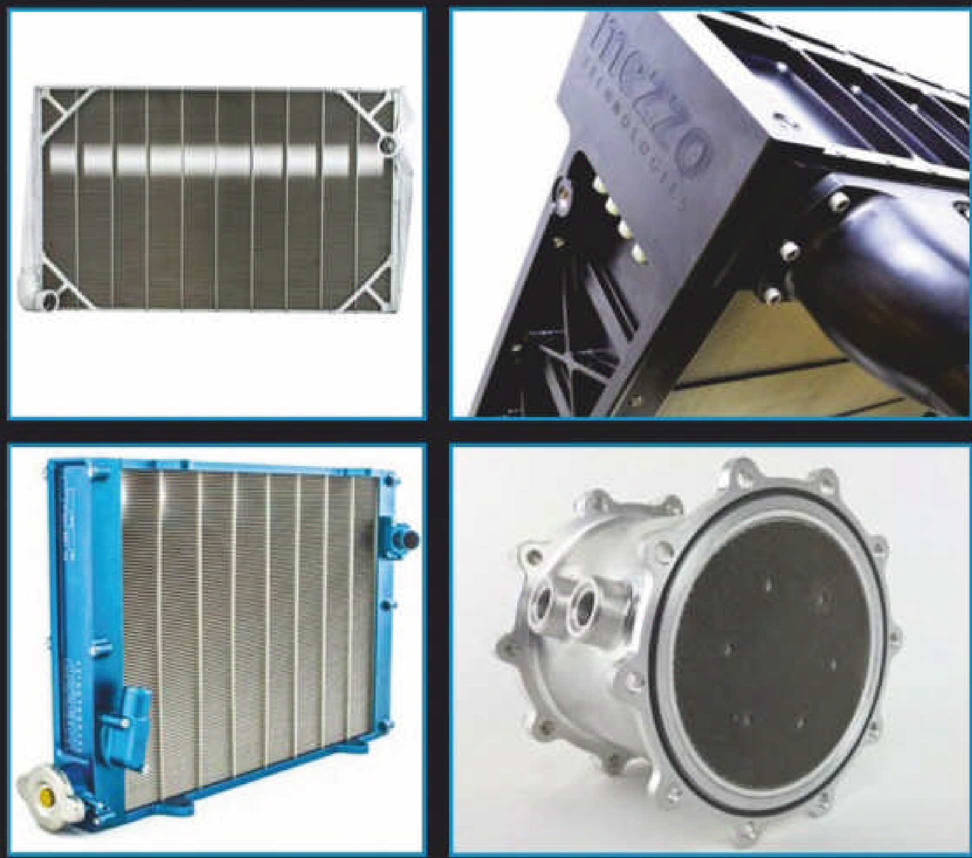

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Aerodynamic concept

Being a road car, the T.50 is not constrained by tiresome regulations governing aspects such as moveable aerodynamic devices and, consequently, Murray has drawn on several of his previous concepts in order to create an efficient, yet benign aerodynamic package.

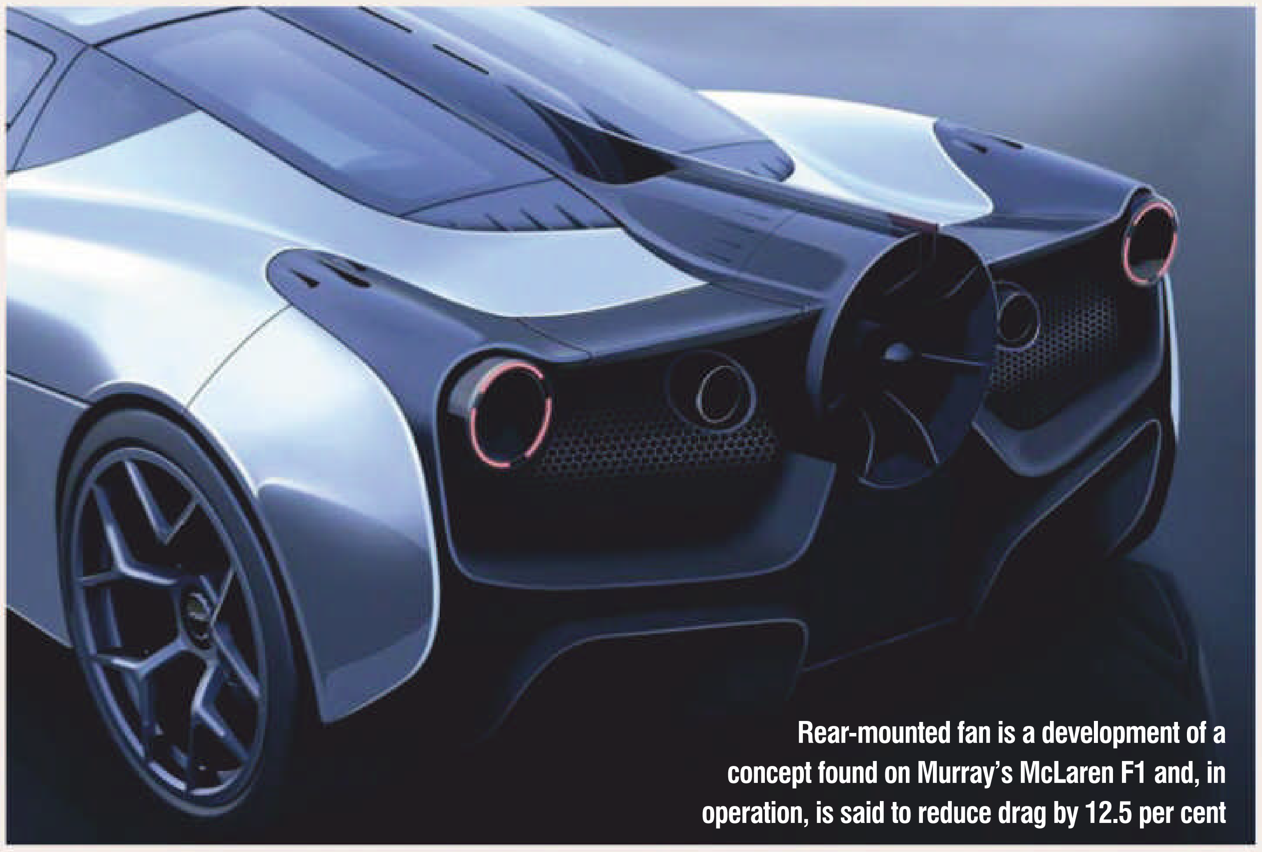
The centrepiece is of course the rear-mounted, 400mm diameter fan, provided with power by an engine-mounted, 48V Integrated Starter Generator (ISG). However, unlike Murray's infamous Brabham BT46b, where the rear-mounted fan was intended to literally suck the car to the floor, the T.50's concept is far more nuanced.

'The Brabham was a really crude, simple device. It was just a vacuum cleaner,' explained Murray while documenting the car's aero development. 'You can't do that on a road car. With this [the T.50] it actually borrows far more from the [McLaren] F1, where we had two 140mm diameter fans pulling air from a very steep section of the diffuser, and we got about five per cent more downforce.'

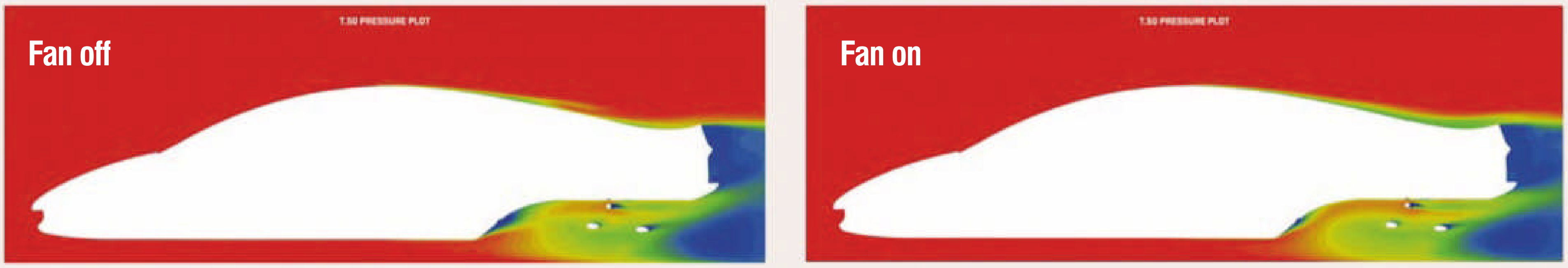
For the T.50, he has taken that concept and expanded it to the full length and width of the diffuser, greatly improving the L/D ratio of the car. When in high-downforce mode, ducts open in the roof of the diffuser, and the fan extracts air running at its maximum operating speed.

In 'streamline' mode, the direct link between downforce and speed can be mitigated, achieved by the two small, adjustable rear spoilers being set to -10 degrees (these are also raised in high-downforce mode), reducing the base suction at the rear of the car. At the same time, the ducts between the fan and diffuser are shut, shedding around a third of its downforce, and the fan is used to pull air from the upper surface of the car, helping to clean the airflow over the rear duct.

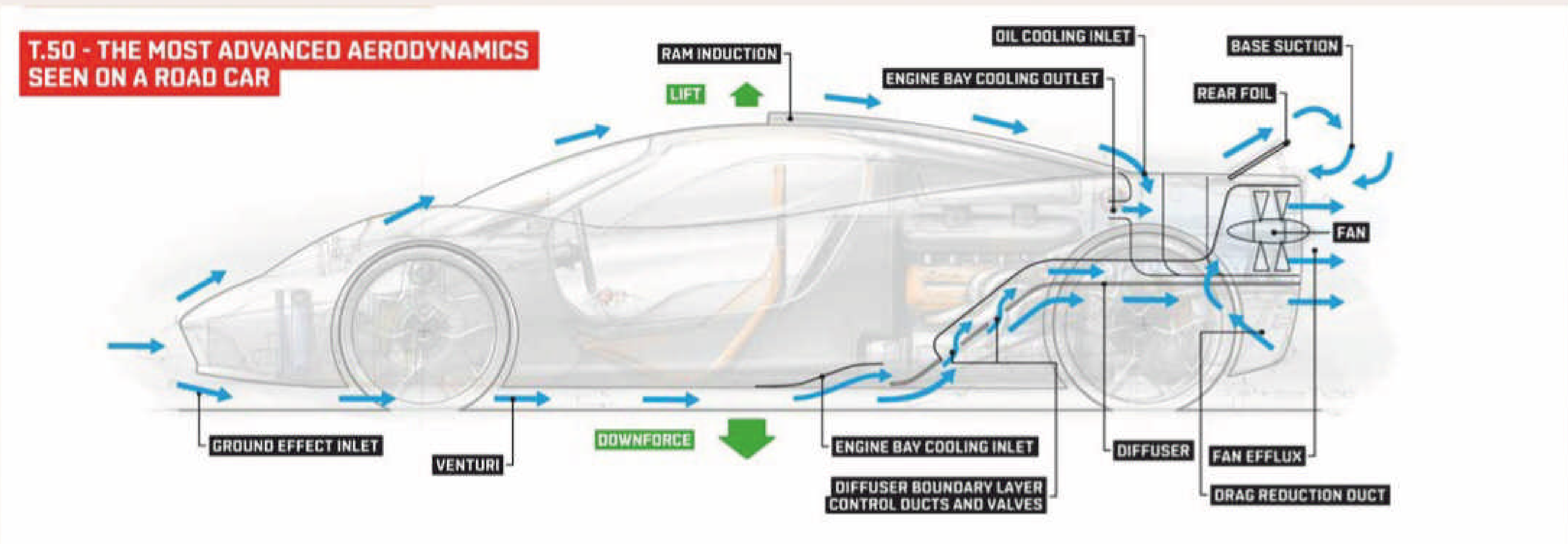
The efflux from the fan further helps 'fill in' the low-pressure area at the rear. Murray says the measures reduce drag by 12.5 per cent.



Rear-mounted fan is a development of a concept found on Murray's McLaren F1 and, in operation, is said to reduce drag by 12.5 per cent



Total pressure plot of a cross section of the T.50 through the left hand diffuser tunnel at 150mph



- Fan is multi-purpose - cooling / downforce enhancement / efficiency enhancement / drag reduction
- Fan is active and interactive with top surface of car aerofoil
- Fan control is automatic for cooling and braking
- Driver control of High Downforce / Streamline / Vmax / Test mode
- Developed with Racing Point Formula One Team in their large scale / rolling road wind tunnel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Sand scorcher

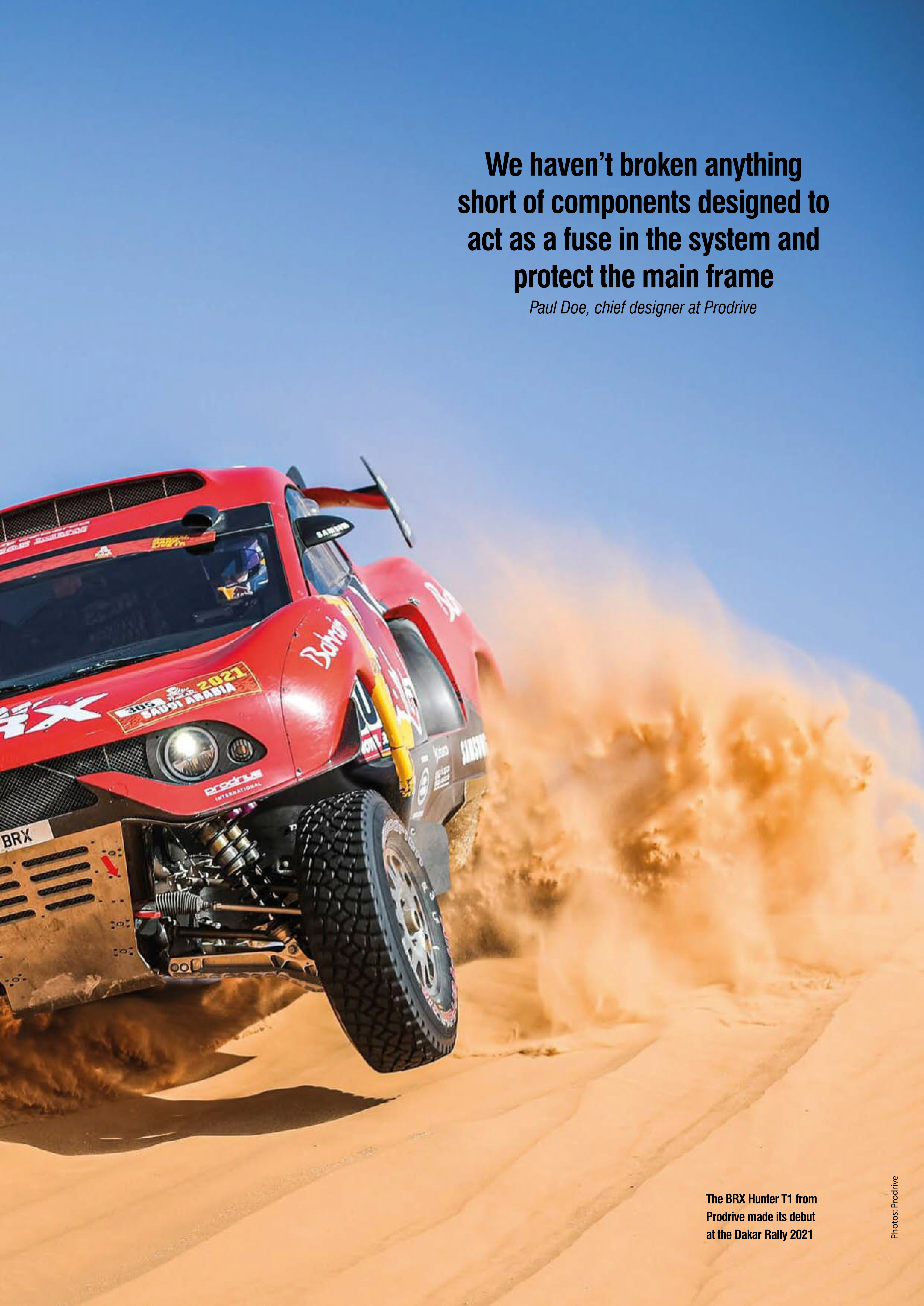
A joint vision between chairman of Prodrive, David Richards, and the Crown Prince of Bahrain, the BRX Hunter T1 represents a whole new challenge for the British constructor

By STEWART MITCHELL

The Cross-Country Rally World Cup's flagship race event, the Dakar Rally, is the pinnacle for those who take part in off-road Rally Raid competition. The Dakar Rally first ran in 1978, from Paris, France to Dakar in Senegal, West Africa. However, owing to concerns about terrorist attacks in the Sahara region, from 2009-2019 South America hosted the event. In 2020, the event moved to Saudi Arabia, where it remains for 2021.

The Dakar Rally is known as a marathon event, primarily owing to its length, typically between 7000 and 10,000km, but the Rally Raid format is the same as conventional rallying, with each event broken up into point-to-point stages. The length of each stage on the Dakar varies from short sprints to distances of up to 800-900km.

The top class of cars allowed to compete in the Dakar Rally is called T1. According to engine type (petrol or diesel) and driveline (two or four-wheel drive), these prototype off-road racing machines subdivide. The regulations also set the weight of the car according to engine type and capacity.



We haven't broken anything short of components designed to act as a fuse in the system and protect the main frame

Paul Doe, chief designer at Prodrive

The BRX Hunter T1 from Prodrive made its debut at the Dakar Rally 2021

Photos: Prodrive

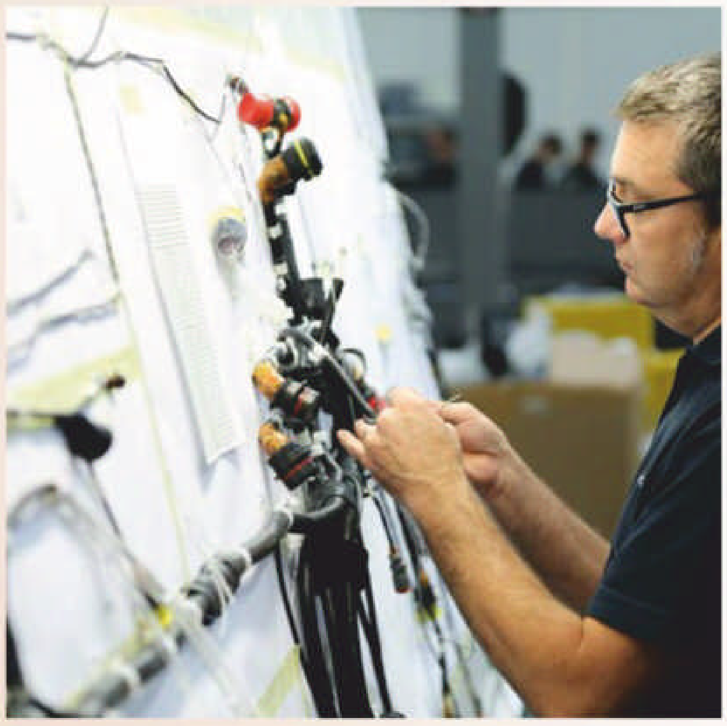
Where the majority of T1 vehicles bear a passing resemblance to the manufacturer from which the powertrain has been sourced, the Hunter BRX was free from any such constraints, and represents a true clean sheet of paper design

Frédéric Le Floc'h/DPPI

BRX Hunter T1 chassis in build. Note the narrow front and rear cross sections to enable the desired suspension geometry

KEY SUPPLIERS: Hunter Dakar T1

Spaceframe: Prodrive
Composites: majority Prodrive
ECU and electronics: Bosch Motorsport
Wiring harnesses: Prodrive
Dampers: Reiger
Springs: H&R
Brake calipers and discs: AP Racing
Exhaust: Akrapovic
Transmission: Sadev
Differentials: Sadev
Driveshafts: GKN
CFD provider: TotalSim
Fuel tank: Proflex
Seats: Sparco
Fire suppression system: Lifeline
Intercom: Stilo
Lights: Wipac
Wheels: EvoCorse
Tyres: BF Goodrich



Electronics for BRX Hunter being laid out. Robustness is key here

TECH SPEC: Hunter Dakar T1

Engine: Front-mid; 3.5-litre, twin turbo V6; single plenum / throttle; dry sump oiling
Power: 400bhp
Torque: 700Nm
Transmission: Four-wheel drive; six-speed sequential shift gearbox; front, centre and rear differentials
Chassis: High strength steel tubular structure; carbon and natural fibre composite bodywork; built-in hydraulic jacks
Suspension: Double wishbone front and rear; two fully adjustable dampers per wheel
Interior: Carbon fibre seats; six-point safety harness; dual fire extinguisher system; lightweight lithium-ion battery; navigation system
Fuel system: 500 litre in FIA-spec safety cell
Brakes: Six-piston front and rear calipers; vented discs
Wheels and tyres: 16 x 7; BF Goodrich All Terrain
Dimensions: Length – 4500mm
Width – 2000mm
Height – 1800mm
Wheelbase – 2900mm
Dry weight – 1850kg

Most of the T1 cars have a tubular spaceframe chassis with bodywork representing the manufacturer from which the powertrain has been selected. Several manufacturers have been represented in T1 over the years including Peugeot, Volkswagen, BMW, Ford and Toyota. New for 2021, however, is a T1 entry from Prodrive International – The BRX Hunter.

Prodrive's chief designer, Paul Doe, explains the philosophy behind the project: 'We've been looking at Dakar for a long time. In fact, even as long ago as the end of the Mini WRC programme [2013] we were evaluating concepts. It's been a long-term ambition, and we hope the BRX Hunter T1 is a long-term programme with a customer side to it in the future.'

Design decision

T1 Dakar car design is dictated in part by the driveline configuration the team has chosen, be it two-wheel drive or four. This has a significant influence on the layout of the engine, drivetrain and ancillaries.

For four-wheel-drive vehicles, the rules state the engine must be installed on the car's centreline and longitudinally in the chassis. The maximum distance between the crankshaft central axis and the front axle centreline is 190mm, and the crankshaft must be at least 110mm from the floor of the car.

We hope the BRX Hunter T1 is a long-term programme with a customer side to it in the future

For two-wheel-drive cars, the regulations are less restrictive. The crankshaft height rule remains, but the engine's position on the car's central longitudinal axis is free. Because of this freedom, many two-wheel drive T1s have the engine mounted towards the car's centre, just behind the driver cell.

'We did a comprehensive look into both two-wheel drive and four-wheel drive formats,' remarks Doe. 'We figured two-wheel-drive cars were not as easy to drive and easier to get stuck in. However, they have a much lower weight limit [around 300kg less], and virtually all they are missing is the front diff and a couple of driveshafts. That's probably simplifying a little bit, but the main point is that it's tough to reach the weight limit for a two-wheel-drive car, whereas the four-wheel-drive car is relatively comfortable.

'What that means is if you're going to do a two-wheel-drive car, you have to nail everything in terms of cutting-edge design, and every single component has to be on the edge, weight-wise, to get there. Then you're into potential reliability issues with parts.'

Performance is relatively balanced between the two configurations, but there are some advantages for selecting two-wheel drive. 'If you have a very sandy event, maybe the two-wheel-drive vehicles have an advantage because they're allowed tyre pressure management live onboard, whereas that is not allowed in the four-wheel-drive cars,' explains Doe. 'Additionally, the two-wheel-drive cars have unlimited suspension travel, which means they're able to take obstacles without slowing down as much, so their minimum speeds on some sections are usually higher. But on technical, twisty stages, the four-wheel-drive cars prevail.

'All things considered, we decided four-wheel drive was the best option here.'

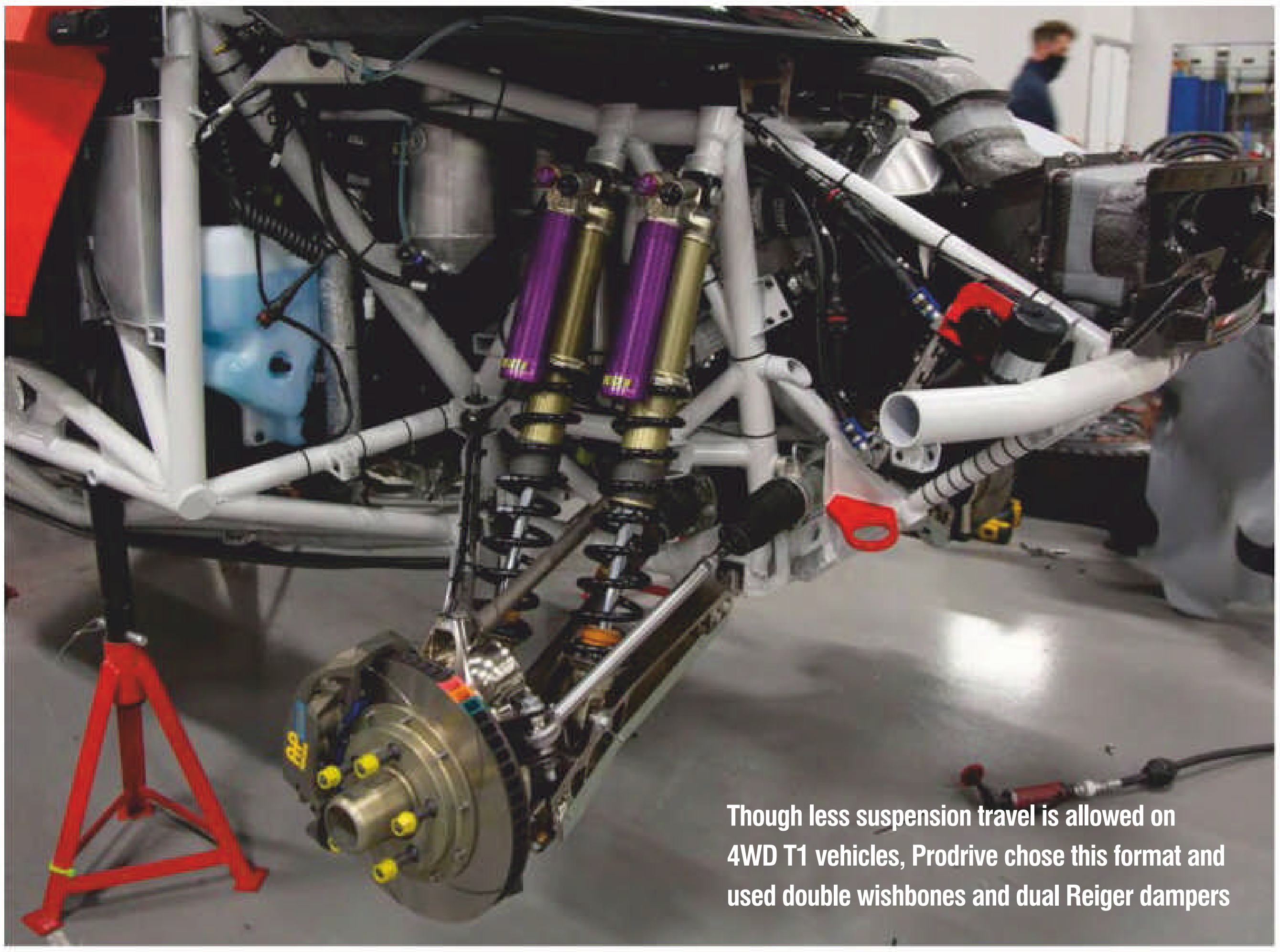
Shapes of things

Serious work on the project commenced at the end of the third quarter of 2019. Unlike most of Prodrive's other race car builds, there is no manufacturer association with the BRX Hunter T1. As such, the car didn't have a vehicle silhouette to adhere to, it could have looked like anything, which enabled it to take on the best design elements Prodrive saw fit to implement within the T1 framework.

The result is a narrow front and rear section with double wishbone suspension and a sports car-type body design penned by Ian Callum, ex-chief designer for Jaguar and Aston Martin. 'The engineering team had to give the designer an idea of what the bare vehicle would look like, as there are a few things you can't get away from,' notes Doe. 'These include the safety cell's main hoop position relative to the wheelbase, the wheelbase and the track width, all of which the regulations prescribe. After fixing those, the engineers built a shape that Ian [Callum] had to clothe, and he applied his style direction on top of that.'

From the engineering side of things, Prodrive started with a small team. 'At the beginning, we had one engineer working on the total architecture of the car, one studying suspension layouts, one on powertrain layouts and a structural engineer working on solving the load cases. That's about it,' recalls Doe. 'We start to try and put the architecture of the car together quite carefully because that kind of thing you can't so easily change.

'If you get down the road and realise you have the wrong sort of architecture, you can't go back. So we spent as long as possible defining that, and the targets for the complete project, with a relatively small number of people before we threw resource at it.'



Though less suspension travel is allowed on 4WD T1 vehicles, Prodrive chose this format and used double wishbones and dual Reiger dampers

Engines for T1 cars must derive from a production car model homologated in FIA Group N production car-based racing classes

With variable, and enforced, speed limits on road sections of the course an electronically-controlled speed limiter is vital equipment

Power unit

Engines for T1 cars must derive from a vehicle homologated in FIA Group N production car-based racing classes – that is, produced in quantities of more than 2500 units in 12 consecutive months. Rally Raid engines are not thoroughbred racing units. All the internal components, including pistons, connecting rods and valvetrain, as well as block material and geometry, cylinder heads and so on must be the production versions.

Consequently, a vast range of engine types and configurations are used in modern Dakar T1 racecars. The BRX Hunter engine, however, is the most notable difference between it and the competition, being the only turbo petrol currently competing in Dakar. The FIA allowed turbo petrol power units for the first time for 2021 as it tries to align the regulations with road cars to make the class more relevant to manufacturers developing production vehicles.

The engine of choice is the 60-degree V6 Ford Ecoboost, which in road car trim displaces 3495cc from a bore and stroke combination of 92.5mm x 86.6mm. It is of fully aluminium construction, with a 10.5:1 compression ratio. For Dakar, the FIA implemented a boost curve limit for the BRX Hunter, bringing its output in line with the naturally aspirated petrol engines in the field. As such, it produces a peak output of 400bhp and 700Nm of torque.

Prodrive has a lot of experience with off-road race engines, given its rally and Rallycross programmes, so forging a new path here wasn't a big deal. 'Knowing what we know, it's quite easy to make a flexible engine with a petrol turbo,' comments Doe. 'Comparing it to the diesel and naturally aspirated petrol engines, we knew we could create a smaller package with the turbo petrol than with the other options, and that would help with overall packaging.

'We considered quite a few configurations, even a four-cylinder engine for a tiny packaging envelope. However, in that circumstance, we calculated the engine would be a bit too stressed and, as Dakar is an endurance event, reliability is critical.'

Free elements

Some machining and modification for setting up mounting supports are allowed by regulation, as is mechanically deleting standard engine variable functions such as valvetrain, camshafts and inlet. Choice of flywheel is free too, as is the cylinder head cover, provided it weighs at least as much as the production cover.

Also free are the choice of intake and exhaust manifolds, spark plugs, coil and HT cables, electronic ignition components, engine wiring loom, sensors, ECU, alternator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and starter, provided the latter originates from a series production vehicle. Its location inside the engine compartment is open, too. Teams can also change the throttle valve, though it cannot be bigger than the standard engine. Fitting fuel coolers is authorised only on the return circuit to the tank.

Prodrive took advantage of all the free elements in the powertrain rules and implemented a dry sump oiling system, a new belt drive system on the front of the engine and a new flywheel on the back, new exhaust manifolds to manage the high load case and aid flow to the turbos, and the turbochargers themselves. 'We changed them for new ones, which are production-based, but higher performance,' confirms Doe.

The BRX Hunter's chassis design with a narrow front and rear end mean the engine actually protrudes into the cockpit structure between the driver and co-driver's legs and is enveloped in carbon. A 500-litre fuel cell sits behind the occupants.

'We didn't want to put the engine any further towards the rear as it's already in a position where the car's inertia is quite low in terms of yaw inertia,' highlights Doe. 'Additionally, looking at mass distributions front and rear, we don't want any more mass rearward, so there's how we located the engine in its position.'

Much of the primary performance factors such as torque curve and vehicle mass are prescribed in the Dakar rules. A target power curve from the FIA matches the output characteristics of a naturally aspirated engine. 'The FIA hooked the car up to a logger measuring lambdas and boost and various other parameters to be confident we will have the power we should have on the event,' says Doe, before going on to explain how things like radiators, intakes, exhausts and other engine ancillaries are all housed within the structure. 'We didn't want to DNF the car from a minor incident where something as simple as the intake track gets damaged, and you end up taking dust into the engine. For this reason, we positioned the airbox and air filters up underneath the dash and within the car's main structure.'

The BRX Hunter cockpit is a busy place, and note how far the engine protrudes into the passenger compartment


A brace of BRX Hunter T1s during assembly at Prodrive in the UK, one chassis in white and one car almost fully assembled

Suspension

Given the nature of Rally Raid, a lot of the design effort has gone into the suspension. The car features double wishbones on each corner with two fully adjustable dampers and 280mm travel per wheel. 'We've mounted the dampers onto the lower wishbone as the lower is stronger, and that's where much of the suspension loads go through,' notes Doe. 'It enables us to keep the upper wishbone very simple and light. It also allows us to keep the dampers very low in the car and have a low sweep to the windscreen to get the visibility the drivers need.'

The longer the wishbones, the more manageable the suspension angles and stress on the system, including control of track width changes. For this reason, Prodrive designed both ends of the car to have a very narrow cross section, similar to a side-by-side chassis design. The suspension is the same front to rear and left to right, and many parts are transferable. This simplifies production and minimises the number of spare parts the team needs to carry.

'It was challenging implementing like components front and rear, while also creating the different geometries you want in terms of anti-squat and so on,' says Doe. 'It's not first time we've done this sort of thing though. If you look at the Mini WRC there was a lot component sharing around that car, too.'

There are no regulations on suspension type in the Dakar T1 class. Teams can build cars with a live axle, and the rules allow more wheel travel if you choose this path. Prodrive did consider it, but opted for a double wishbone design as it's the lightest way of achieving control over the wheels.

We didn't want to put the engine any further towards the rear as it's already in a position where the car's inertia is quite low in terms of yaw inertia

'I can't reiterate enough the challenge of carrying the vertical loads from the dampers through the wheel,' says Doe insistently. 'It's such a big vertical load. With our design, we can't locate the dampers to the upright where it's fairly easy to control the loads, so we have to go via the wishbone.'

To help with this, Prodrive designed and implemented a custom lower bearing on

With Ian Callum, ex-chief designer at Jaguar and Aston Martin on board, it's no coincidence the rear body shape recalls the Jaguar F-Type sports car

E Vargiolu/DPPI

the lower wishbone's outboard end, which, says Doe, is a unique design. 'That took a lot of analysis to survive in FEA, and for us to be happy it'll survive on the event itself. That was the one bit I started testing with a certain amount of nervousness because it wasn't a straightforward solution. The methodology was existing, but not for something quite like this, and I wanted to be sure it was bulletproof in our testing.'

Load cases

When it came to understanding the loads experienced on Dakar, the team came at it from several different directions, some based on WRC experience, with load cases extrapolated from the Mini scaled up to the BRX Hunter's weight, grip level and vehicle speed. One area designed from this study was the independent wheel bearing units. Prodrive calculated that because the load cases are so immense, building the bearings straight into the aluminium upright would not survive the loads.

'We had some early consultancy from someone who has worked on Dakar vehicles in the past,' admits Doe. 'That work gave us a few points that helped us find our load cases and perhaps pick up one or two that we wouldn't have considered.'

Even then, Prodrive learned some load cases from its own testing regime. 'We designed one particular part of the suspension to bend in an extreme case, and we bent one in testing. From this result, we believe our load cases can't be a million miles off because we haven't broken anything short of components designed to act as a fuse in the system and protect the main frame.'

The car's driving dynamics were designed to be neutral, with a little bit of natural oversteer to make it easy to drive. Differentials are relatively conventional and supply a 50 / 50 torque split to the front and rear wheels respectively. The centre diff' is relatively well locked, so the drive very much goes to the wheels with traction. There is nothing in the way of torque vectoring.

'Fundamentally, we set out to make a car that is easy to drive so we haven't gone very aggressive with anti-geometries such as anti-squat and anti-dive,' explains Doe. 'We have tried to keep the car quite dependable and predictable in any circumstance. The driver must have confidence with these vehicles, and this design – keeping the car quite pointy at low speed – means the driver has authority over the car in rotation, which is ideal for this kind of challenge.'

Aerodynamically, the car was designed for stability above all else. 'These cars have big front wheelarches, which create a lot of lift at high speed,' remarks Doe, 'so we spent quite a lot of time and effort reducing the frontal lift with subtle design elements and also implemented a rear wing on the car, which is a stability aid at high speed.'

Rear suspension mimics the front with interchangeable double wishbones. Note the radiator mounted in the back

To avoid potential damage, the air intake to the engine is located within the spaceframe chassis structure

As for Vmax, the top speed of T1 cars is capped at 180kph (112mph), so obviously teams want to be at 179.9 and running reliably at that speed as much of the time as possible, as well as getting to that speed as quickly as they can. 'You want to be able to hit Vmax on almost every kind of surface and, ideally, have the car behave the same on every surface,' notes Doe. 'To get the software to cope with all of that has been a challenge.

Kind of intelligence

'Various speed limits are set in the road sections that you have to adhere to, and we have a lot of kind of intelligence in the software to do that as well.

'I believe Dakar is up there with Le Mans and so on in terms of races that are hard to win,' concludes Doe. 'We still have a lot to learn, and we're under no illusion that we can just turn up and win. We are competing against teams that have been doing it for decades, and know this stuff inside and out. We're still on the learning curve here.'

Fundamentally, we set out to make a car that is easy to drive so we haven't gone very aggressive with anti-geometries

After a gruelling two weeks, Bahrain Raid Xtreme driver, Nani Roma, consolidated fifth place in class, while during stage eight Sebastien Loeb suffered two punctures. Without the required number of spare tyres onboard to be able to continue, he was forced to retire from the stage, and subsequently this year's Dakar Rally. The team noted that despite the challenges they faced, this is all good learning for the future.


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Rare breed

Hayden Paddon, the best-known name in New Zealand for the modern rallying era, has just designed and built the world's first electric WRC car

By DR CHARLES CLARKE

Paddon says the car has been designed to hit the engineering sweet spot and can be driven just like a combustion-engined World Rally Car, only one with instantaneous power delivery and a perfect 50/50 weight balance

Based on the Hyundai Kona platform, and with full support from Hyundai New Zealand, the car looks like a traditional ICE World Rally Car, but the design ethos was entirely new

'The idea was originally mentioned to me in a 'phone call in 2017,' remembers Hayden Paddon, principal at Paddon Rallysport. 'At which point I laughed at the concept, but the idea stuck in my head over the course of a year or so, during which time I sounded people out and checked with various others in the industry to try and figure out whether or not it was possible.'

In 2018, Paddon Rallysport started putting plans together for what an electric WRC car might look like, and how it could work. The build itself started at the beginning of 2019.

'The project started as an idea,' continues Paddon, 'and we had the support of Hyundai New Zealand throughout. We started designing in March 2019, based around a Hyundai Kona platform.'

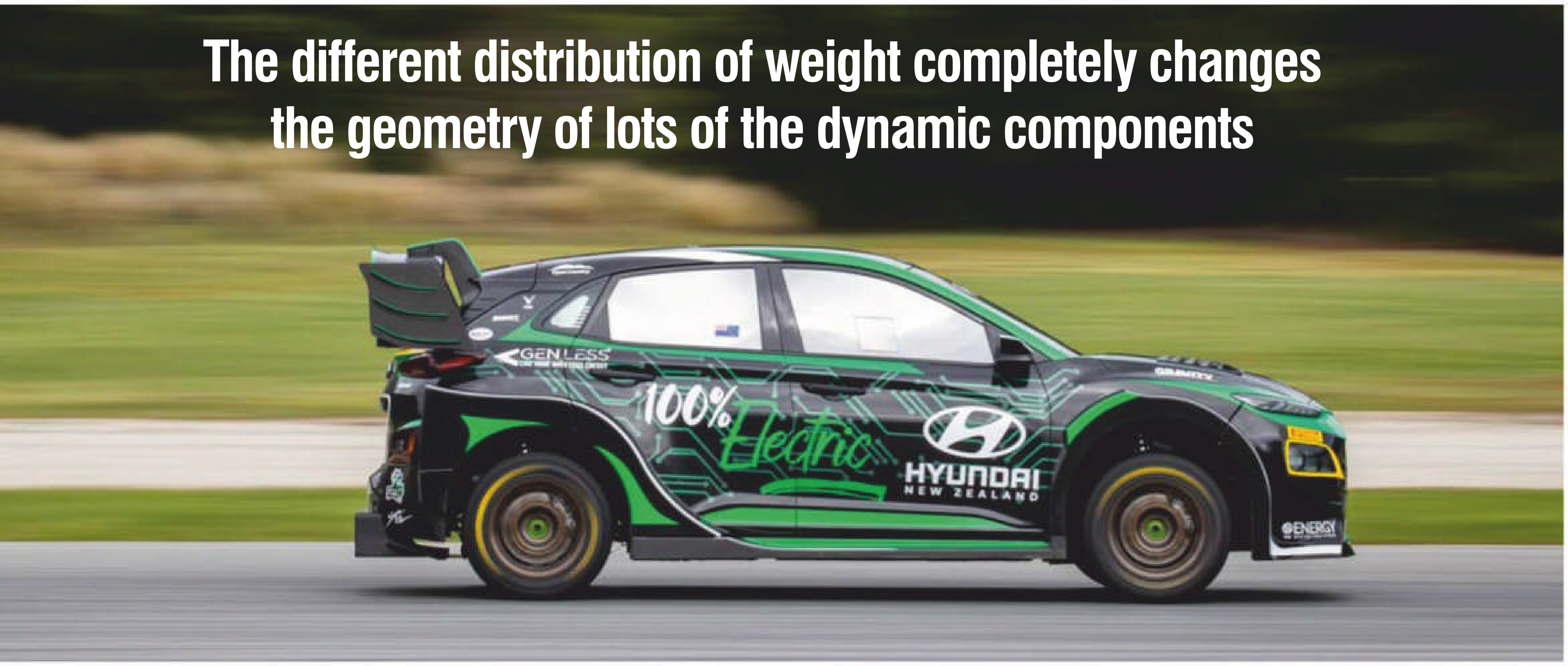
Paddon Motorsport did all the usual preparation work in much the same way as with any rally car, stripping out the bodyshell, seam welding, chassis lightening and fitting a rollcage. 'We took out every piece of unnecessary metal to remove as much weight from the standard bodyshell as possible because of the extra weight of the batteries in an EV,' he says. 'The rollcage is quite extensive and, because the batteries are in the floor of the car, it gives a lot more support to the floor.'

We had to do all this from scratch as there was nothing close to what we were trying to build that we could learn from

Over engineered

From an FIA rules perspective, the rollcage is a separate structure, but it had to be designed in such a way as to provide significant support to the battery box and make sure the whole structure of the car was adequate for the extra weight very low down in the body. The basic design was conditioned by the FIA rules and recommendations for WRC.

The different distribution of weight completely changes the geometry of lots of the dynamic components



The additional weight, mass and positioning of the battery pack forced a fundamental re-think of the car's chassis design, but the resultant lower c of g worked in its favour

'In this situation, because of the significant weight of the batteries, safety is paramount and so the rollcage is over engineered,' admits Paddon. 'But we were keen to err on the side of caution as we were doing something which hadn't been done before. Also, as the rollcage adds to the torsional stiffness, any over engineering improves the dynamics of the car.'

Enough of the main chassis was left to locate the body panels, most of which are steel. 'The tubs and body panels are all steel at the moment, from both a durability and budget standpoint. We were keen to prove the concept rather than spend lots of money on carbon and Kevlar from the outset. Things are easier to repair if they are steel, too.'

Step by step

The process was to make it strong, stiff and heavy initially, then step by step go through and lighten it up. 'This way you end up with the car that actually works,' says Paddon. 'If you work the other way round and make it as light as possible as early as possible, you end up having to do a lot more work to make it strong enough. Making it light and then strengthening it is a much more costly way of doing the development and, although that is the more normal method with bigger teams, we have budget restrictions to think about.'

Also, when you try to stiffen a car up later, it's more difficult to pinpoint critical areas that need further attention.

The chassis and basic geometry are based around a tried and tested Paddon Rallysport concept using data from WRC and R5 specs for car and chassis ergonomics.

'We basically tried to take all the best parts of all the cars I'd driven from a driver's perspective. From that, we managed to establish a benchmark for what we wanted to do, and how we wanted the car to work. Then we just had to work through that, the design of the chassis, the geometry and the pick-up points to get to our target numbers.

'We had to simulate the hugely different roll centre and weight distribution of the car to help us establish this benchmark. This was done by calculation rather than real-life data.'

Weight distribution

All the work was specific to this car because of the additional battery weight and its influence on the centre of gravity. 'The different distribution of weight completely changes the geometry of lots of the dynamic components,' notes Paddon. 'We had to do all this from scratch as there was nothing close to what we were trying to build that we could learn from. We also had to ensure the car was completely adaptable and adjustable, so we have some interesting innovations throughout the car where we can make adjustments over and above what you would normally do for a traditional 'combustion' car.'

One of the things that the team was able to introduce was moveable pick-up points for squat and dive. 'When you're starting from a blank piece of paper, while in theory the computer tells you it's okay, often when you build things physically, they work slightly differently. So having the ability to change things considerably is a significant advantage. Not just one or two options either, there are many different set-up options on various parts of this car. This kind of flexibility is key to developing something that's never been done before.'

No consensus

The car is built as a Hyundai Kona, but the sport is in its infancy at the moment when it comes to EV technology and homologation.

'We are making our best efforts, working closely with Motorsport New Zealand locally, so the car is eligible for competition here in the next year or two. The rules for homologation are very unclear. And there is no consensus in terms of EV in motorsport yet. Yes, we have Formula E, but there is nothing in rallying.

'We have been working with STARD in Austria as our technical supplier for things like the batteries, motors and inverters. These are common parts used in Rallycross in Europe, but they all meet different rules and regulations. In terms of how you make it work in a rally car, how you make the safety work, whilst working on the parity with combustion cars – that is uncharted territory.'

To clarify those comments, there are EV Rallycross cars, and there are a couple of Dakar-style EV trucks (Extreme E) that have their own series, but there are currently no other EV Rally cars.

'With EV trucks it's a different environment to what we are doing,' continues Paddon. They're not really interested in high power, they're more concerned with long range, and they are also huge vehicles, so they're not necessarily worried about the extra weight and mass that comes with a smaller EV design.'

The process was to make it strong, stiff and heavy initially, then step by step go through and lighten it up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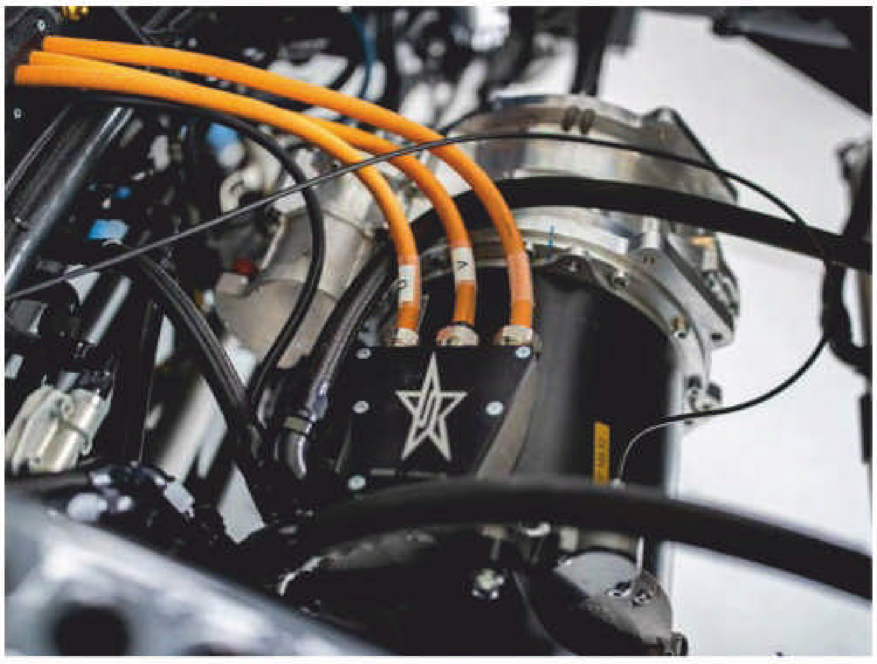
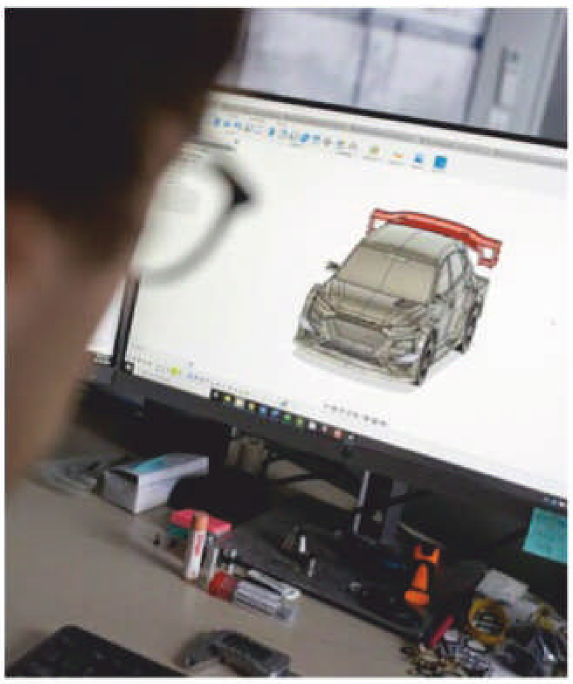
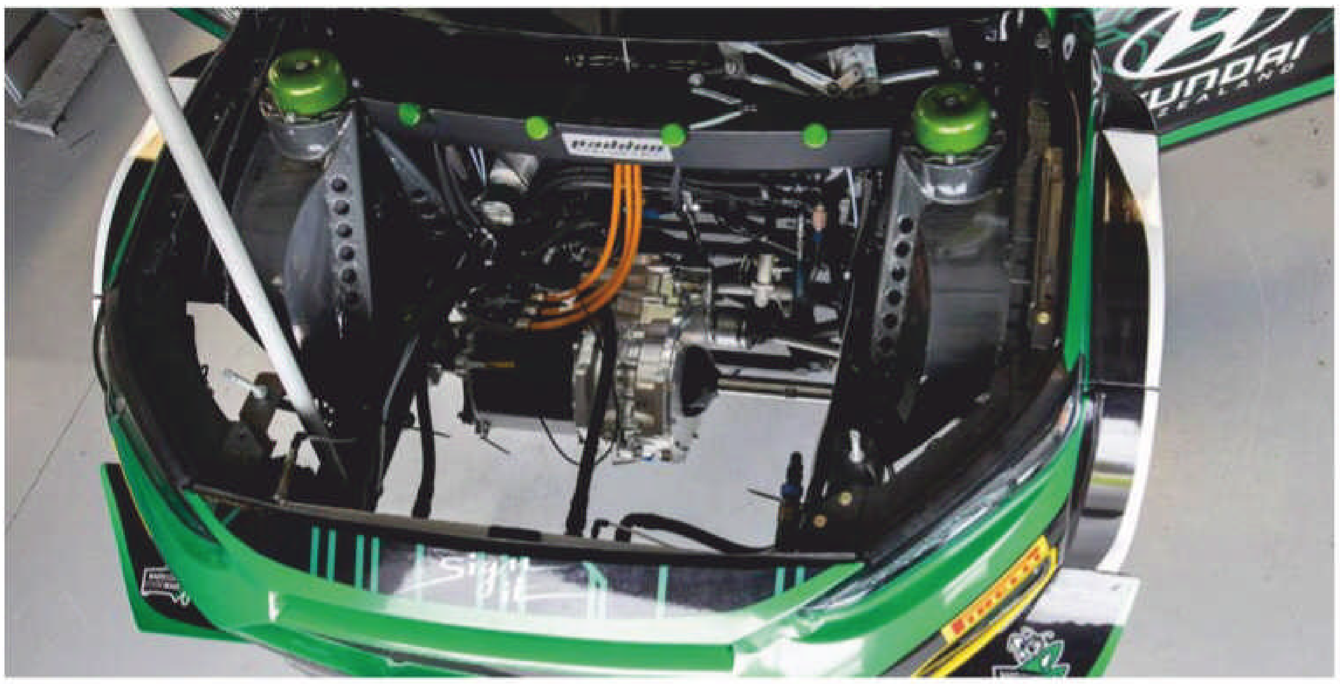


Motors, inverters and batteries are all sourced from Austrian company STARD, which has extensive EV experience in European Rallycross series

Rollcage structure is deliberately over engineered, with the safety of occupants and marshals in the event of a rollover incident in particular a paramount concern



Design process took its initial cues from data gained from Paddon's previous WRC and R5-spec cars



Power comes from two 200kW motors, one on each axle, both with its own transmission. This gives it significantly more available power than an ICE WRC already, but with the capacity to accept four motors for double that total power output

The car is currently running with a prototype battery. It represents the exact size of the eventual battery needed for the rally spec, and that will be coming within the next 12 months.

'In terms of the motors, they have a peak power performance of 200kW each,' says Paddon. 'It's running on two motors, one on each axle, with two transmissions. The transmissions are two speed, so we effectively have a high and a low ratio, which is working quite well.'

The downside of the gearbox is the availability of a lot more energy, but it gives more flexibility for the changeable conditions that are always encountered in rallying. The transmissions are specials supplied through Bruiser.

Software development

'We are running MoTeC electronics throughout the car, with some generic software we've been working on. From here, we need to develop the software to work in the rally context, with customised torque vectoring and brake regeneration so we can optimise the battery range.

'We currently have 400kW of peak power, but have to optimise how we use that for rallying. It's great to have instant torque, but it has to be managed much more sensitively when you have variable surfaces.'

It has also been important to develop the car to conform from a parity point of view with conventional combustion WRC equipment. 'Current WRC cars are producing between 300 and 320kW, and that's probably the range we need to be targeting.

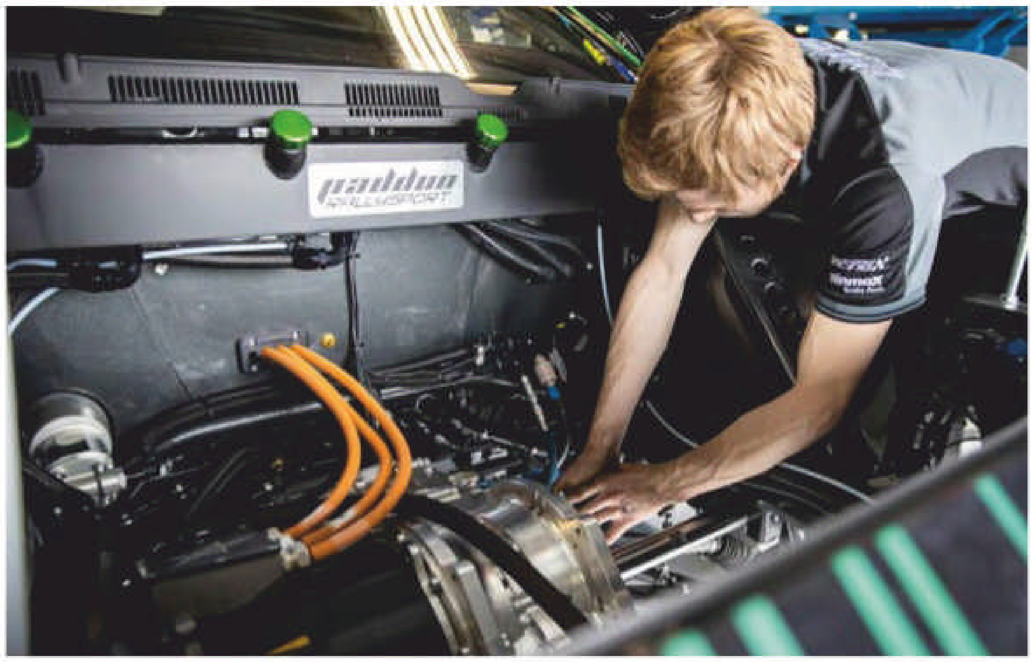
'But the beauty of this technology is that if we want to go to something like a hillclimb, we can easily attach another two motors to the transmissions. It has the capacity to accommodate four motors, so potentially we can have a platform capable of handling 800kW. That's when it gets really interesting!'

The car is running Brembo brakes and EXT suspension. 'We've got about 300mm of suspension travel,' highlights Paddon. 'We designed the car to have a lot of suspension travel like a WRC car, to help with traction and grip, but it's also got to support a lot more weight. The car currently weighs 1400kg, but that's with a small prototype battery. With a full-size rally battery it's going to be heavier still. We can compensate for that by making the car itself lighter using composite and lightweight panels, so the suspension is probably optimum.'

Unique challenges

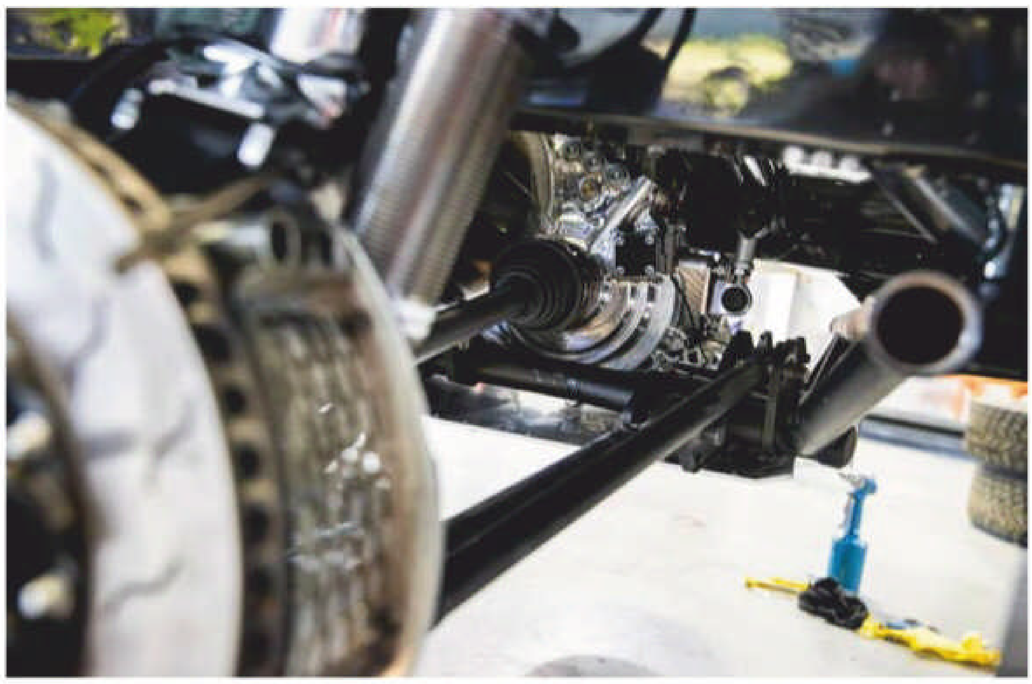
The cooling side has also presented some unique challenges. 'We had to design the cooling system from scratch. We are currently running more cooling than with

It has the capacity to accommodate four motors, so potentially we can have a platform capable of handling 800kW. That's when it gets really interesting!



Twin two-speed transmissions rob some of the available power, but give the car greater flexibility for the changeable conditions encountered in rallying

The next big hurdle is configuring the management software so it recognises the different surface conditions and adjusts things like brake regen' accordingly



As it is charting new territory, a great deal of additional adjustability was built into the chassis. This will prove useful as the car will be demonstrated at a variety of motorsport events

Electronics are all by MoTeC and currently the team are working with generic software to get the car up and running, but will develop from there

The software needs to be able to recognise the kind of surface and adjust the brake regen' accordingly

an equivalent combustion car, and so far in testing it's been within all our target numbers.

'We have three independent coolers on the front, one for the battery and two for the inverters. It's all running on separate auxiliary power. All the power circuits are separate from each other, so the water pumps are all running independently, as are the power steering motor systems. All the normal car operations such as lights and normal electronic functions are in another loom again.'

The braking system is one area that remains conventional. All hydraulic with Brembo calipers front and rear and an hydraulic handbrake in the middle. 'The only change on the braking side will be the software for brake regeneration to recover some of the braking energy to recharge the batteries. But even that's not as straightforward as it is in a normal racecar. We have to condition the regen' to accommodate all kinds of surfaces. If you have too much brake regen' on loose surfaces you can unsettle the car, and in rallying surfaces can change almost from corner to corner, so the software needs to be able to recognise the kind of surface and adjust the brake regen' accordingly. It's a little bit complicated, but we think we are on the right track and we're confident we can get it working.'

Next steps

Hyundai New Zealand has been a massive support for Paddon Motorsport in this and all the outfit's previous rally projects, but it's the collaboration with STARD that has really paid additional dividends. 'Working with STARD as a technical supplier has been a real bonus,' says Paddon. 'This is a really good partnership as they've done so much ground work in EV Rallycross, and it's helped us to hit the ground running with this project. The programme is fully funded in New Zealand.'

With the car now up and running, the next 12 months will be focussed almost exclusively on development.

'The difference is that it will be done in public. We will be attending a lot of demonstration events, like hillclimbs or sprints to promote the development and the EV Rally concept. This also helps us collect as much information and data as we can, which we feed back into the development.

'Over the 12-month period we will also be developing the big rally battery, which will go into the car at various points and be tested at the demonstration events. In 2022, we will be ready for the car to compete in rallies. In line with that, we will be working with Motorsport New Zealand to make sure the safety aspects and the rules appropriate to Rally New Zealand will allow our car to comply, so that we can compete alongside combustion cars.'

Design for safety

The biggest hurdle to be overcome is the fact the componentry in this car is not like normal EV road cars, with OEM batteries and components. 'This car is bespoke, and throughout the design process safety of the

Opportunitites for testing have been limited so far, but the car has already shown great promise. 'It's a lot of fun to drive,' says Paddon, 'and produces an enormous grin on your face, which seems to last forever'

EV components has been a primary concern. So when we are competing in a rally, the car should be no different to a combustion car. If it happens to flip and land on its roof, the safety of the driver and any attendant marshals has already been taken care of.'

The battery case is very strong, and has cooling systems built into it and technology to detect whether there is 'thermal runaway'. Systems can be shut down automatically if they are outside 'normal' parameters.

'There are a lot of things happening in EV rally cars that don't necessarily happen in normal OEM EV vehicles. It's the same as formula E in many respects. Formula E has been running for a number of years and there have been a number of spectacular accidents, but none where they caught fire or otherwise threaten the public or the race marshals.'

Things have moved on since the early days of EVs, and the potential availability of huge energy shocks from the battery packs is no longer an issue. 'We work on the EV car in the workshop as if it was an ordinary combustion car,' confirms Paddon. 'The only reason we might have a problem is if there is a short in the system. We have sensors throughout the car and a bank of safety lights in the cockpit that give us the status of every component so, if there is an issue, it is sensed and flagged instantly and remedial action can be taken, or the system can be shut down automatically.'

Within the safety systems, there is also an alarm circuit that warns personnel to keep clear until the appropriate system is shut down. 'This is an extremely rare case, and it hasn't happened yet,' confirms Paddon. 'We do take precautions in that we understand the EV car is a slightly different animal, but we have learned to deal with it, and it hasn't presented any problems throughout the development.'

Hot seat

'As the driver, I don't feel any more nervous driving the EV than I would a combustion car. In fact, the EV is probably safer, as there are no volatile liquids to catch fire. We've been rallying long enough to appreciate all the potential pitfalls and hazards, and we've designed all the componentry of the car so it would be safe, irrespective of its resting or terminal orientation in an event.

'It's a lot of fun to drive. We have been a little bit limited in terms of real testing so far, but in all the testing we've done it's turned out really well. I must say it surprised me straight out of the box. Mechanically, we've had zero issues, we haven't even broken anything, and on gravel it handles really well.

'Obviously, there are inherent advantages with the centre of gravity being so low because of the batteries. The weight is very central in the car, and we've got a perfect 50 / 50 weight distribution, which almost never happens in internal combustion engine cars, at least not without a great deal of work. From a driver perspective, the balance of the car is far superior to any combustion car I've driven. It's as controllable with the seat of your pants as any other combustion car, too.

'It has been designed to meet the engineering sweet spot, and I can drive it in exactly the same way I would drive a

From a driver perspective, the balance of the car is far superior to any combustion car I've driven

combustion car. I can unsettle it in the same kind of way, and it responds in the same kind of way to all normal driver inputs.

'The only thing different is the throttle. In a combustion car you always have a little lag, whether it's naturally aspirated or turbocharged, but with the EV there is torque from zero, which makes for an incredible instantaneous response. You have 100 per cent torque at 10 per cent throttle or 100 per cent throttle, which takes some getting used to.

'So with this car you are using the throttle as a direct driver input, rather than a request for motive power, so it's a lot more controllable in the EV context. You can play with the throttle a lot more to help control the chassis behaviour whatever's going on. That's quite a difference, and it usually produces an enormous grin on your face, which seems to last forever.

'This car has the potential to be a lot faster than a corresponding combustion car purely because you have so much more control over the power,' concludes Paddon. 'We just have to get on top of the software and the torque vectoring to make it work perfectly and efficiently.'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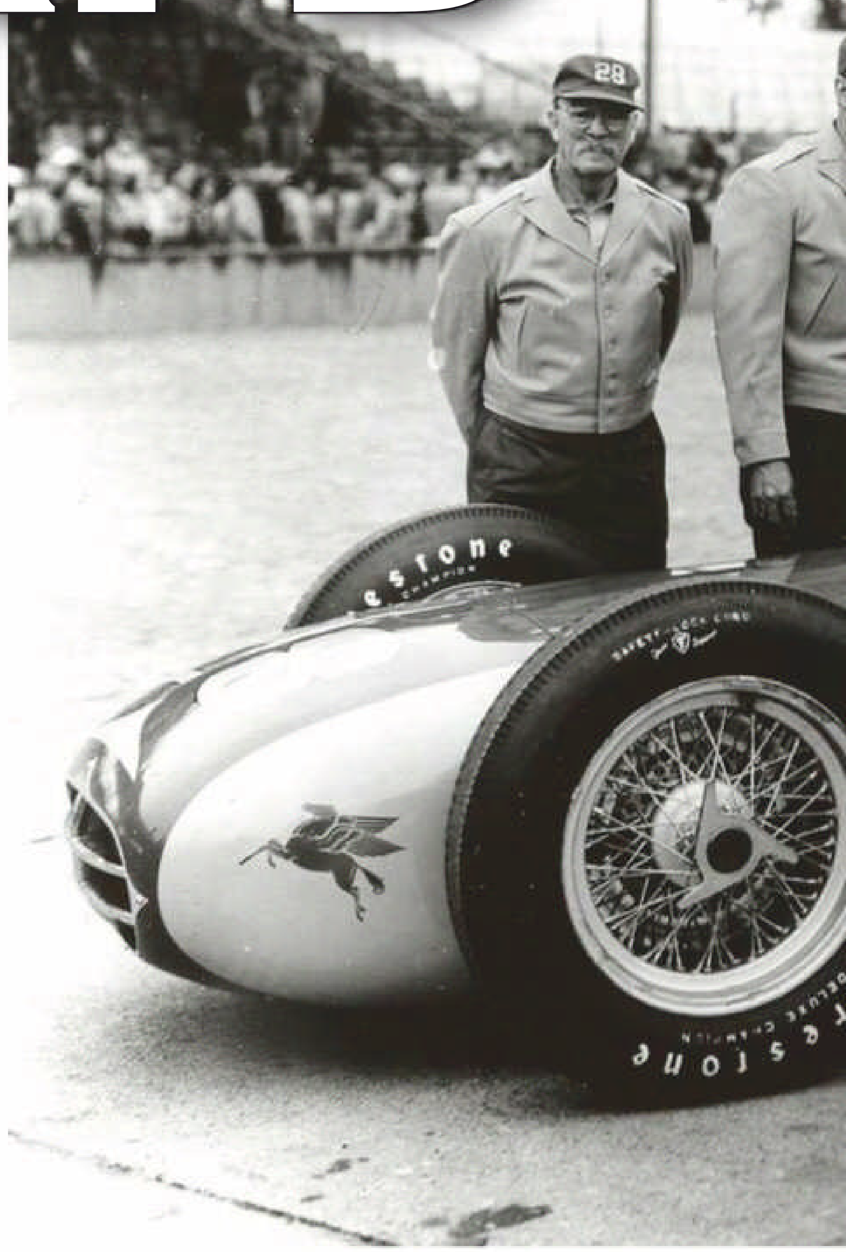


IMS Photo

Diesel racecars are nothing new, *Racecar* investigates the inspiring legacy of the Cummins Diesel Specials

By WOUTER MELISSEN

At the 1952 Indy 500, Freddy Agabashian scored a historic pole position during qualifying. The Cummins Diesel Special he drove represented a number of firsts for the race. The car is remembered best for being the first, and to date only, diesel-engined car to claim pole position at the Brickyard. But a closer look at the bright yellow and orange no.28 machine reveals there is much more to it than just its engine. As it turned out, it would be a hugely influential racecar, with all of its innovations eventually becoming common place in IndyCar racing. Ironically, with the exception of its diesel engine.

Clessie Cummins was a self-taught engineer. His first appearance at Indy was at the inaugural 1911 edition, where he served on the pit crew of eventual winner, Ray Harroun. Later that decade, Cummins acquired the patent to produce diesel engines and set up his eponymous business in Columbus, Indiana.

Combining his efforts to introduce diesel to the mainstream with his interest in racing, he planned an entry in the 1931 Indy 500. Fitted to a Duesenberg chassis was a mighty Cummins four-cylinder engine. The car could not match the pace of its petrol-powered rivals, but did underline one of the advantages of the diesel engine as it became the first car to complete the Indy 500 without needing to stop for fuel.

In the following years, several other cars powered by Cummins engines raced in the Indy 500. For Cummins himself, competing at Indy was more than just a marketing ploy, it was used as an incentive to inspire the company's engineers to push the envelope.

In 1934, two Cummins-engined cars were run side by side, one using a four-stroke and the other a two-stroke engine. The main reason for this was to see if a properly developed two-stroke diesel would be a viable alternative.

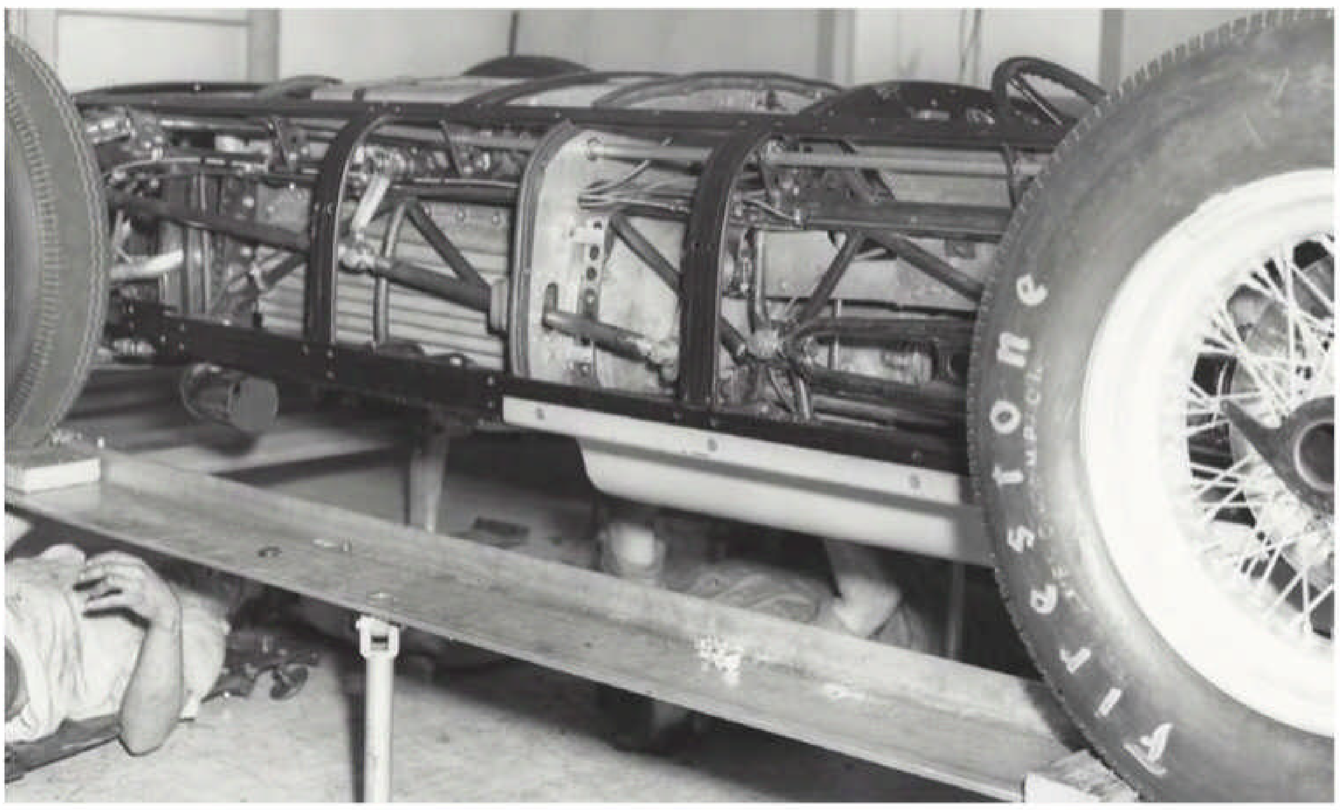
Cummins' 1950 entry was one of the first cars to race at Indy with disc brakes, and its JBS-600 straight-six engine featured a proprietary direct injection system.

While all very interesting, the first four Cummins diesel-powered cars were not particularly competitive. By its very nature, the diesel engine was frugal and had an abundance of low-end torque. But it was also considerably heavier than a conventional engine and, despite more lenient regulations, lacked top-end power. This did make the diesel engine perfectly suited for use in commercial vehicles, though, which is the arena in which Cummins eventually excelled. By the late 1940s, his business was thriving.

Balancing performance

Going back to Indy now only made sense if a car could be fielded that operated at the same performance level as the rest of the field. To do just that at the 1952 edition, a team was created in 1951, headed by Clessie's brother, Donald, who was a talented engineer in his own right. He was joined by Nev Reiners as the chief engineer. The rest of the team were Cummins staff, who volunteered their own time to the project.

While outright performance was obviously now the main objective, Donald Cummins was adamant the engine used would be of the same basic design, and built on the same line as the regular production units. This ensured any advances made during the



Cummins Archive

A major re-think was needed to be competitive. The straight six was retained, but lightened and laid over at 85 degrees

For the 1952 Indy 500 effort, a dedicated team was put together, led by Donald Cummins, with Nev Reiners as chief engineer. The rest were Cummins staff, working on their own time

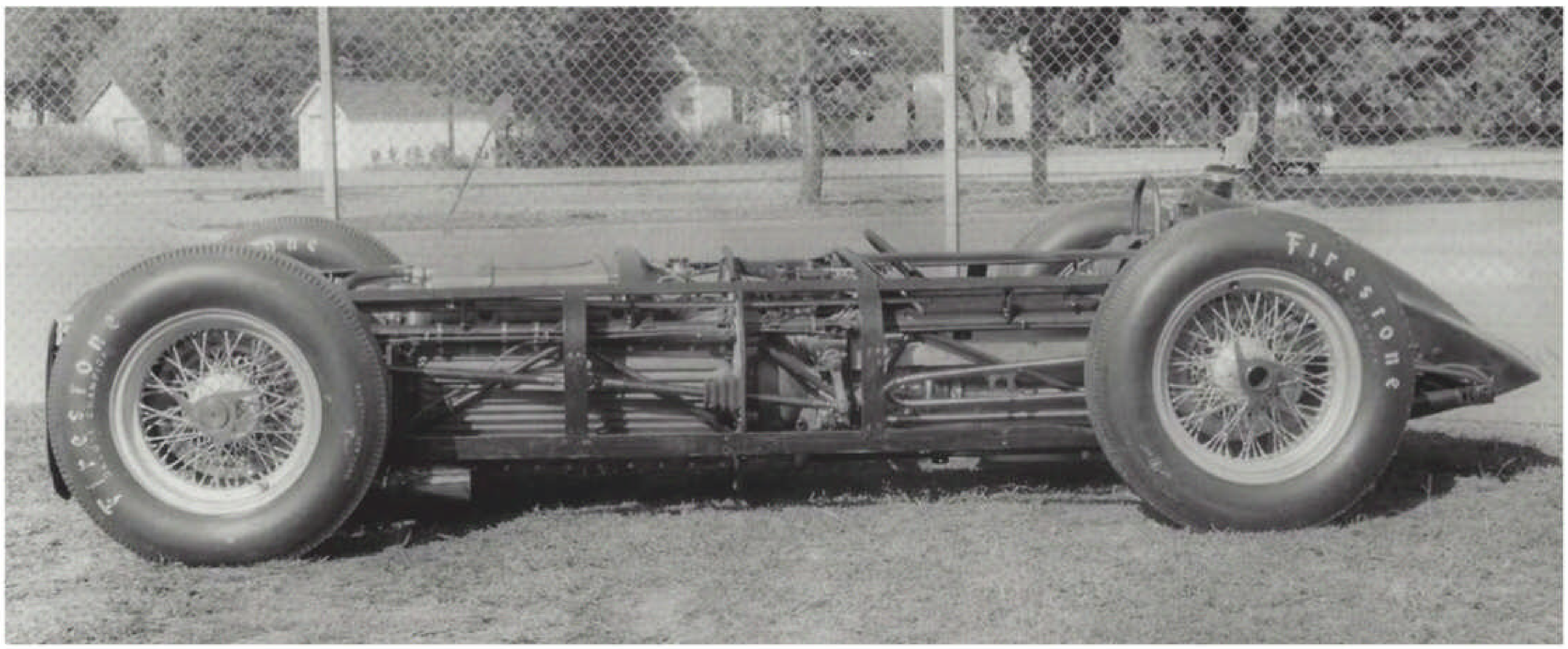
The 4-cyl unit set a record of 100.755mph in 1931

Photos: Wouter Melissen, except where stated

Cummins' 1931 entry used a four-cylinder motor in a Duesenberg chassis. It lacked outright pace, but was the first car ever to finish the race without refuelling

The firm's 1950 entry had innovative disc brakes and direct injection, but still lacked top-end power

Competing at Indy was more than just a marketing ploy, it was used as an incentive to inspire the company's engineers to push the envelope



Cummins Archive

For the first time, Cummins employed a chassis builder, Kurtis Kraft in California, and offset the heavy components to the left. The result was a streamlined racer perfect for oval tracks

While competitors were still using crank-driven superchargers, Cummins used an exhaust-driven turbosupercharger, which gave the diesel engine the top-end power it was lacking

development process had a wider benefit than just the competition programme.

As in 1950, the base engine of choice was the JBS-600 straight six. Usually fitted in commercial trucks, it had a displacement of 6.6-litres, making it about one-and-a-half times bigger than the naturally aspirated, four-cylinder Offenhausers used by most other teams. So not only was the Cummins engine heavier, but also considerably larger in every dimension. Undaunted, Donald Cummins addressed this problem with a revolutionary solution: instead of mounting the engine upright, he decided to lay the straight six on its side at an 85-degree angle.

This would only be possible thanks to a new partnership with specialist racecar chassis builder, Kurtis Kraft, out in California. For the first time, a dedicated car would be built specifically for the Cummins engine, instead of having to adopt an existing chassis to house it. Mounting the engine on its side had all sorts of advantages, particularly on an oval circuit like the Indianapolis Motor Speedway where a perfect left-to-right weight balance is of no use. Obviously, this unusual layout dramatically reduced the frontal area, too. It also allowed the driveshaft to run alongside the driver, not beneath, significantly lowering the driver's seat.

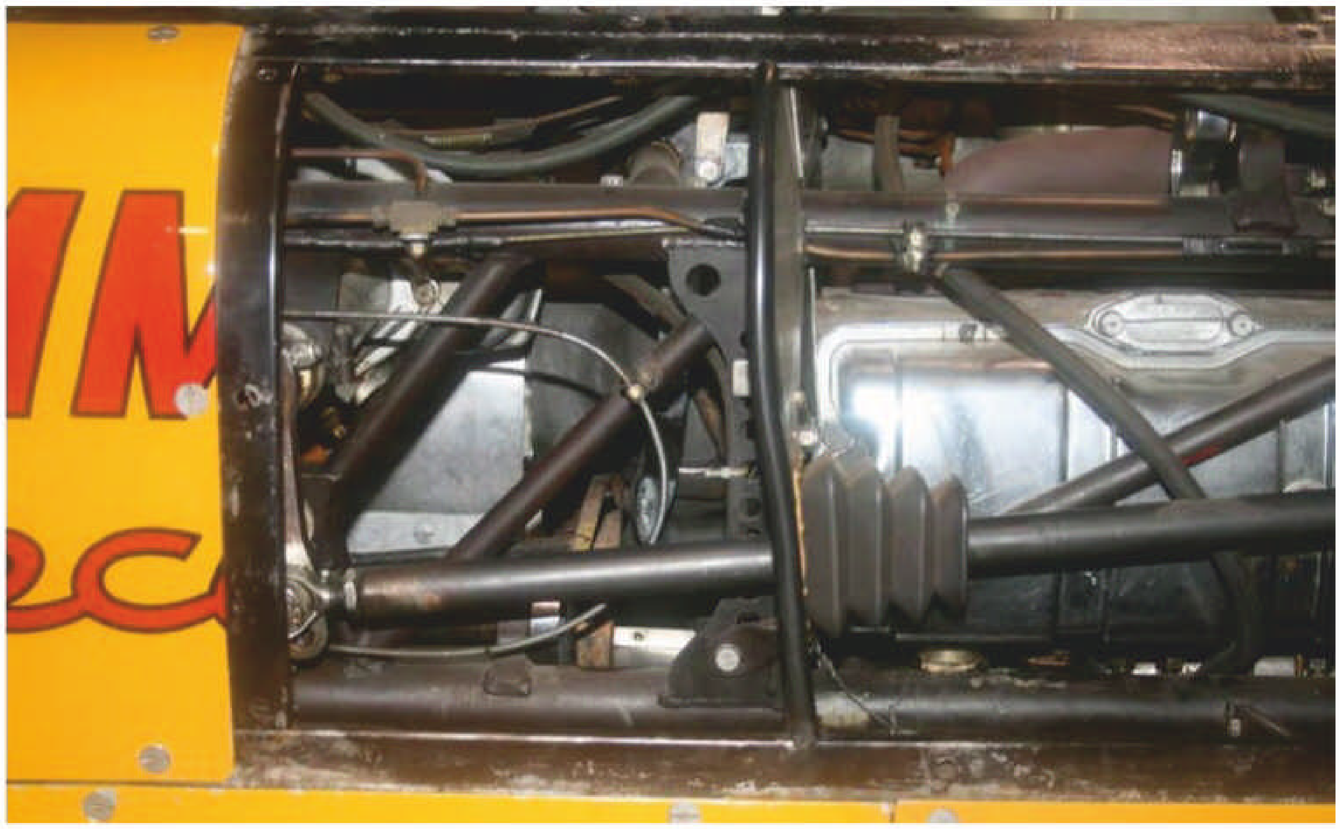
By placing the heavy sump and gearbox on the left side as well, the car would also have a better weight balance on the ovals.

Weight reduction

In attempt to further reduce the weight of the engine, the Cummins engineers experimented with a variety of aluminium and magnesium alloys. Using the production dies, several new blocks were cast with the lightweight materials and built into complete engines for testing. The engine eventually earmarked for the 1952 Indy 500 effort used magnesium for the crankcase and aluminium for the cylinder block and head.

IMS Photo

The car was tested in the wind tunnel at full scale and at full speed, complete with the driver sat in the cockpit throughout! Many innovations were taken forward, but not that one.


Bruce Watson

Mounting the sump, gearbox and driveshaft on the left side of the car aided weight distribution, and the driver sat lower, too


Bruce Watson

Cummins engineers experimented with alloys for weight reduction. The racing block was magnesium, the head aluminium

The first time a device referred to at the time as a turbosupercharger was used at Indy

The engine featured four valves per cylinder, which were actuated by pushrods and a single camshaft mounted in the block.

The induction system fitted was also revolutionary, as it was the first time a device referred to at the time as a turbosupercharger was used at Indy. The preferred method of forced induction until then was through blowers driven by the crankshaft. Conventional superchargers were most effective at lower revolutions, where the diesel engine already excelled. Conversely, by harnessing the energy of the exhaust stream, a turbo worked better at higher revolutions – exactly where the diesel engine had been lacking power. The turbo was mounted ahead of the engine and fed fresh air by a ram intake mounted to the right of the radiator.

As in 1950, the engine employed what would come to be known as the Cummins PT (pressure time) fuel system. The direct injection system used a regular fuel pump that fed fuel to a common rail. From here it was injected at high pressure into individual cylinders at the end of the compression stroke. Thanks to this precise method of fuel distribution, the engine could rev higher than most diesel engines of the time.

More power

All this development work made a considerable difference. The JBS-600 of 1950, which also used a Roots-type supercharger, produced 340bhp at 4000rpm. The new

The first Indy car to be submitted to a full-scale wind tunnel test

turbocharged engine could rev to 4500rpm, at which it produced an impressive 430bhp.

Aiding the dramatic hike in power output, the engine was also 50kg lighter, though still tipped the scales at 340kg. Much of that weight could be mounted on the left-hand side of the chassis, which helped distribute the mass of the car more evenly on a course with only left-hand corners.

Before Cummins had completed the racing engine, a wooden mock up was made and shipped to the Kurtis Kraft shop in Glendale, California. There, a relatively wide, tubular frame was under construction. Either side of the chassis featured a pair of longitudinal steel tubes, cross braced to improve rigidity. The height of the chassis just about matched the height of the engine laying on its side. The front suspension was through double wishbones and a live axle with trailing arms was fitted at the rear.

A conventional steering column could not be fitted to the car as there simply was no space left in the engine bay, so instead the steering box was mounted behind the engine. This actuated tie rods that ran the length of the engine between upper and lower chassis members.

As in 1950, the Cummins Diesel Special was fitted with disc brakes on all four corners.

The rolling chassis was tightly wrapped in a steel frame, on which the aluminium body panels were mounted. Thanks to the unique engine configuration, the body was wider than it was tall, at a time when most Indy racecars was the other way around. Where the Cummins diesel had towered well over the top of the tyres in 1950, the scuttle of the 1952 car sat considerably lower than the tyres.

Tunnel testing

With the bodywork still in bare aluminium, the car was shipped to Wichita, Kansas, where the new Cummins Diesel Special became the first Indy car to be submitted to a full-scale wind tunnel test. The facility even allowed the test to be conducted at what would be the speeds achieved in the race. Also on hand was Freddie Agabashian, who had been drafted in to race the car at Indy that year. To further validate the test results, he was in the seat himself during the wind tunnel tests.

Following the tests, the bodywork was further refined and then painted in a striking colour scheme at the Kurtis Kraft facility.

Once the work was completed, the car was flown from California to Columbus, Indiana, where a team of regular Cummins mechanics, who had all volunteered for the job, tore the car apart. The mock-up engine was removed and, where possible, the chassis drilled to further reduce the weight.

At the same time, the engine due to be used in the race was carefully assembled. Leaving nothing to chance, all components were measured and honed before assembly. Once the engine was complete, it was mounted in the rebuilt Kurtis Kraft chassis.

The complete car weighed in at around 1400kg, still about a third heavier than its petrol-engined rivals.

Sandbagging

The completed car was then displayed, by an understandably proud Cummins company, on the main street of Colombus for all the residents to admire. A few weeks before qualifying was due to start, the Cummins Diesel Special was shipped 80km north to the Indianapolis Motor Speedway for testing. Agabashian, who sat barely 10 centimetres off the ground in the driving seat, quickly realised the all-new machine worked very well, and reportedly never completed a lap at maximum throttle in order not to scare the rivals into demanding the car be slowed down. Sandbagging is, apparently, nothing new either.

In the weeks running up to qualifying, a number of subtle changes were made to refine the car's handling characteristics.

The first and only diesel car to win the pole position at the Indy 500

With a startling 70 cars entered, 1952 was to be the fastest and most competitive field in Indy 500 history. The Cummins Diesel Special immediately grabbed a lot of attention. Sleek and very low, it made the other cars around it on the grid look big for a change.

Thread shredder

Agabashian was one of the last cars to enter the track for his four timed laps. On his first lap he smashed the existing record by clocking 139.104mph. He then continued at virtually the same speed for the remaining three laps, shredding the tread of the front right tyre as he pressed on with a vengeance. He would go on to record an average 138.010mph for his four timed laps.

It is difficult to imagine that it ran faster than the other entries with what was effectively an engine from a commercial vehicle, burning commercial grade fuel instead of the exotic concoctions fed to the Offenhauser 'fours'. While two other drivers would go on to set faster times over a single lap, Agabashian's four-lap average remained fast enough to clinch a historic pole position for the no.28 Cummins Diesel Special.

During the opening stages of the race, Agabashian ran at a relatively conservative pace. The Cummins Diesel Special was not quite as fast out of the corners as the other cars, but was able to run in the top ten without straining the car too much. By lap 71, though, the car hit trouble due to discarded rubber from the tyres clogging the intake of the turbosupercharger. While the car still ran, it was determined by the team that the turbo had been damaged and the pole sitter was retired from the race. At that point, Agabashian had run at a 131.5mph average, with the eventual winner recording just under 131mph at the end of the race, underlining how competitive the car really was.

Not raced again, the Cummins Diesel Special was brought back to the Cummins factory and displayed in the lobby of the company headquarters for many years. It would be the final Cummins-engined car to race at Indy. Undoubtedly not taking into account the monumental effort made behind the scenes, the Cummins Diesel Special was deemed too competitive by the race regulators, who changed the rules for diesel engines ahead of the 1953 season, making it even more difficult for oil burners to compete in later runnings of the Indy 500.

But for the crack

To take part in the company's 50th anniversary celebrations in 1969, the 1952 Indy 500 veteran was rebuilt. In the process, a crack was discovered that ran the full length of the crankshaft and would have almost certainly caused the engine to fail had the turbo damage not prompted its retirement. Following the rebuild, it was regularly demonstrated until 1999.

In 2016, the car was prepared to full running order again by a team led by former Cummins engineer, Bruce Watson. The company's 100th anniversary was then marked with a parade lap by all five Cummins-engined Indy cars ahead of the 2019 running of the Indy 500.

While the 1952 Cummins Diesel Special will be remembered as the first and only diesel car to win the pole position at the Indy 500, its significance reaches beyond the realm of motorsport. By the end of the decade, most front-running Indy 'Roadsters' featured an engine mounted on its side, and the turbochargers which eventually became commonplace are still used to this day.

The lessons learned were incorporated in future Cummins products. The engine orientation would prove useful in powering buses, and the common rail injection system gave Cummins the edge for decades.

Special thanks to former Cummins Diesel engineers, Bruce Watson and Tom Dollmeyer, for their help with this article.

The car clinched pole in '52 and ran in the top ten at the start of the race, but was then retired. The car never raced again, but ran up the hill at the Goodwood Festival of Speed in 2017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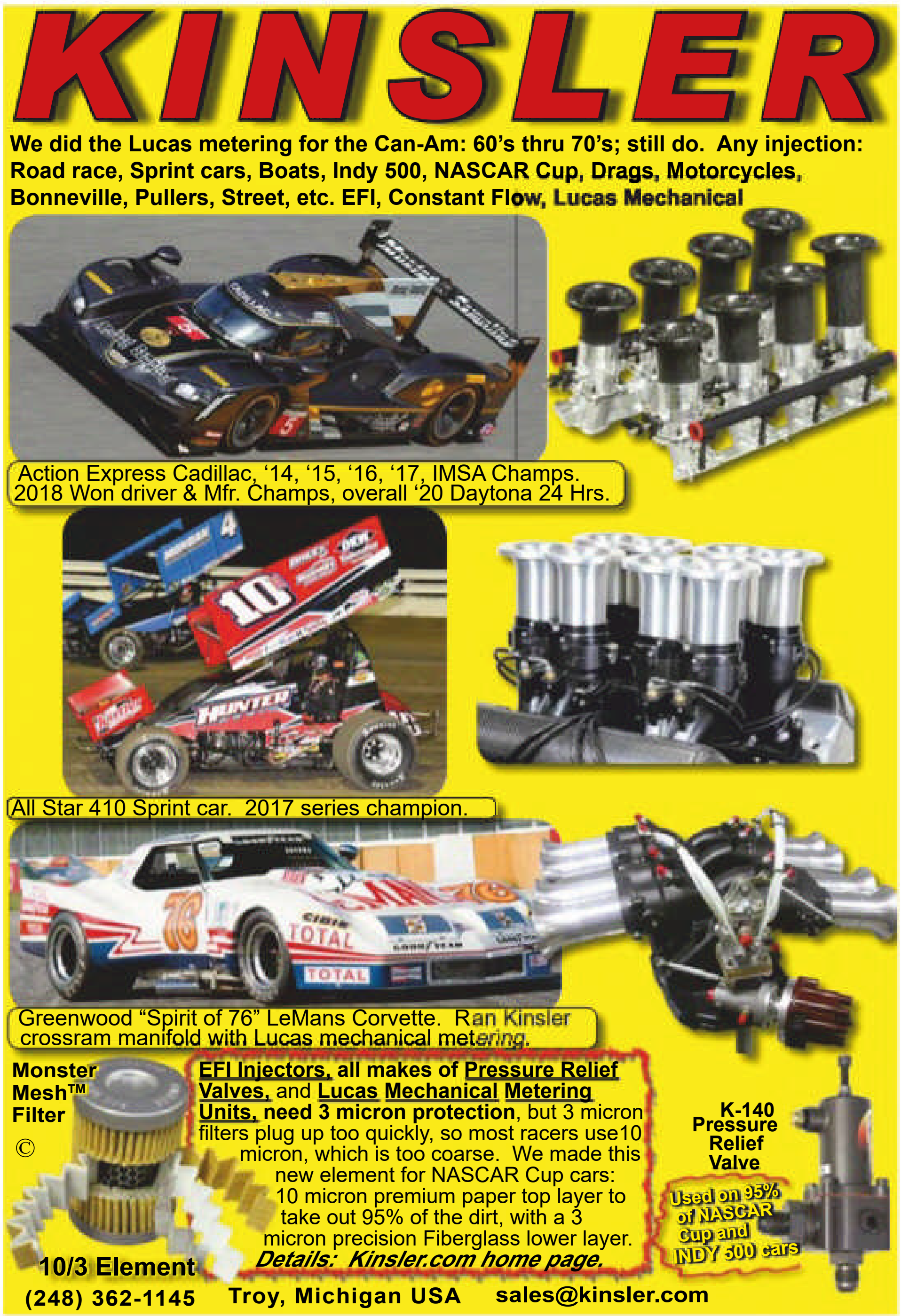
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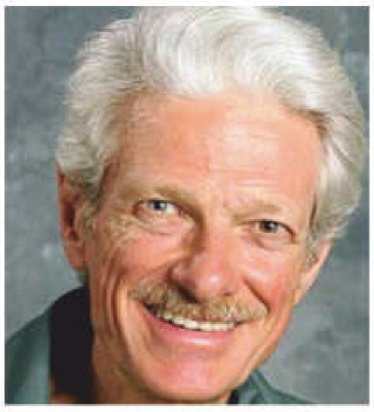


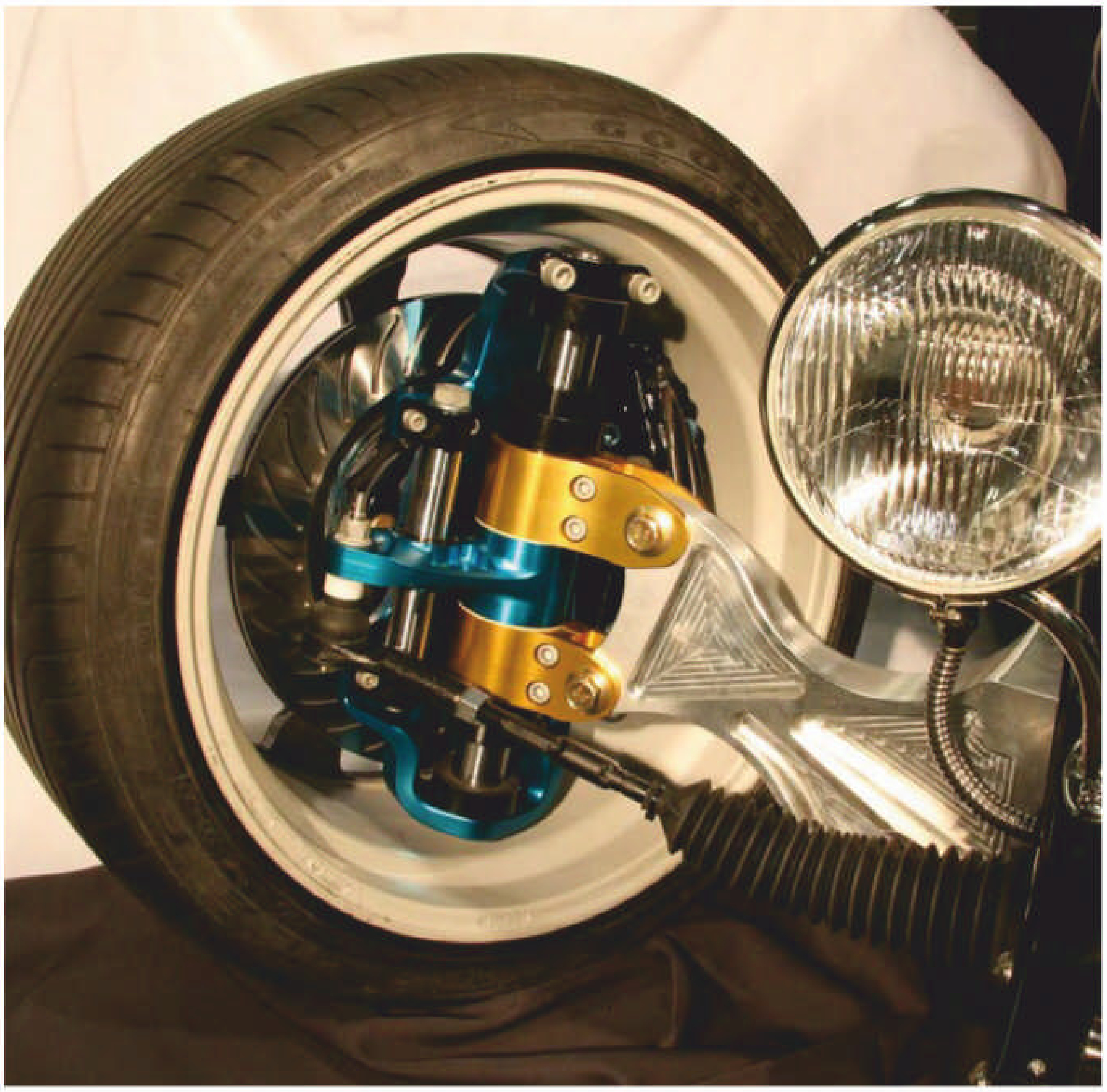
Of pillars and ovals

Further thoughts on sliding pillar suspension, and a free reign wheelbase request

By MARK ORTIZ

I've received some correspondence about the article on sliding pillar suspension in the last issue [*RE* V31N2], with some further thoughts and resources.

This from Doug Milliken: **'Related to your recent article on sliding pillar suspension is Multimatic's in-wheel suspension. Larry Holt explains in the video on this page: www.fluxauto.com/?p=6368 or you can see the system in action in the video here: www.youtube.com/watch?v=0w7_N9Aenn8**



Multimatic's ingenious in-wheel sliding pillar suspension. In response to The Consultant's comment about bump steer, Larry Holt, executive VP Multimatic Special Vehicle Operations, notes: 'The observation [on bump steer] is incorrect. The tie rod end does not move with the suspension at all.'

THE CONSULTANT

This [pictured right] is a sliding pillar system intended for the street rod market. Unlike other sliding pillar systems, it is compact enough to fit inside a 17 or 18in wheel rim, rather than needing to be inboard of the wheel, as in a Lancia or Morgan. This makes the system useable with modern tyres and wheels without a large steering offset or scrub radius resulting.

According to Mr. Holt of Multimatic, the system permits about 4.5in (115 mm) total travel. This is reasonable by street rod standards, but a bit skimpy for most roadgoing applications.

The combination of travel and vertically compact dimensions is achieved by not having the springing and damping in, or alongside, the pillar assembly. Instead, the pillar assembly just incorporates a hydraulic cylinder that connects to a remote spring / damper unit, which can be mounted on the firewall, or elsewhere.

The system has most of the advantages and also the limitations of other sliding pillar systems. That is to say:

- No camber change in ride / heave (good)
- No camber recovery in roll (not good)
- No geometric anti-roll, ordinarily slight pro-roll (roll centre below ground)
- No geometric anti-dive, ordinarily slight pro-dive
- Absence of caster and camber adjustment, except by shimming, bending or incorporation of additional elements
- Heavily loaded sliding contacts
- Difficulty of completely eliminating undesirable bump steer

I don't think I mentioned it previously but, in addition to having slight pro-roll, a sliding pillar suspension has a Mitchell index of zero. This means that the point people call the kinematic roll centre doesn't move with respect to the ground plane in ride / heave, but migrates wildly in roll, especially laterally. Long-time *Racecar Engineering* readers will know I don't think this is a problem, but there remain some people who think it is.

The vertical compactness of the system requires the sliding contacts to be more closely spaced than in other sliding pillar systems or strut suspensions. The lower bushing, in particular, will see large radial loads in cornering.

The street rod in the video also obviously has severe bump steer. A better design could greatly reduce that although, as I have noted, eliminating it entirely is problematic.

In my view, the most interesting part is not the system in the form shown, but the hardware used: the hydraulic cylinders for individual wheels and the remote spring / damper units. These could have potential for interconnected suspension systems.

In my view, the most interesting part is… the hardware used. These could have potential for interconnected suspension systems

Q Hi Mark, can I pick your brain on wheelbase? There is talk here in Michigan about a new series that runs Sprint Cars, Supermodifieds, roadsters and rear-engine (RE) cars all together. Crate engines and smaller, harder tyres are targets to keep costs down, but what will be entirely 'open' is chassis design.

Many that have expressed interest are excited about building and running a RE car, myself included. My question is, since you would be competing against 88-90in Sprint Cars and existing Supermodifieds, can a much longer wheelbase car (because of the need to fit everything between the driver and rear axle) be made to turn as well as a highly developed pavement Sprint car or Supermodified?

THE CONSULTANT

A There shouldn't be any problem getting adequate 'dartability', or quickness of yaw response. Oval track racing doesn't demand that nearly as much as, say, Autocross, or road racing on a street circuit with chicanes. Turning circle is generally not any worry.

If all layouts are allowed exactly the same tyres and wings, it's going to be hard to beat a radically offset Supermodified on a short oval. Left percentage will be worth more than anything else.

They've been running Sprints and Supers together at Madera, California lately, and the Sprints are allowed bigger wings. Without that advantage, I don't think they could compete. However, this example illustrates that you can make almost any type of car competitive against almost any other type by adjusting the rules.

The thing to remember when you have different types of car competing against each other is lobbying is at least as important as engineering because the promoter always has an interest in filling fields and having close racing. This can mean that putting big efforts into a world-beating, innovative car can be an exercise in futility, even if the car itself succeeds. But it sure is fun to think about what you'd do.

Off centre

So, rules permitting, if I were going to design a car for this kind of series, I think I'd put the engine behind the driver, and put both the driver and the engine between the left wheels, not near the centreline of the car. This precludes having a transaxle and independent suspension like a formula car or IndyCar.

ACME Racing

The Consultant's ideal oval track racer would be a development of the Supermodified concept, but with the driver also situated between the left side wheels, ahead of the engine, and with the fluid tanks behind it

The engine is most conveniently mounted backwards, with a gear train behind the driver to take the power to a driveshaft running to the right of the engine. This drives a quickchange axle with a built in, in-and-out dog clutch.

Fuel and oil tanks might be behind the left rear wheel, if suitably protected. That would be best for aero and left percentage, but rear percentage would change a lot with fuel usage. The tanks could also be to the driver's right, which would protect them better and reduce rear percentage change. Or the tanks could be behind the driver, ahead of the engine, as has become well accepted in prototype and formula cars. That would entail a really long wheelbase if the pedals are behind the left front wheel, and further distance the driver from the rear wheels.

There would be very little in the right two thirds of the car, which opens up a lot of interesting aerodynamic possibilities. You could have a really effective under-car tunnel right down the middle of the vehicle, for example.

Another aero device that generally shows up on a short oval with no rules is a huge Lexan fence down the left side of the car. That works. It *really* works if you skew the axles and deliberately make the car run in aerodynamic yaw, even when it's travelling straight.

Returning to the matter of wheelbase, a short wheelbase does promote rearward load transfer under power. Assuming rear drive, this benefits forward acceleration, up to the point where the car is limited by wheelstand. Sprint Cars can be limited by wheelstand even on dirt, if it's tacky enough. On pavement, quite a lot depends on banking angle as steeper banking helps keep the front planted.

So, although a longer wheelbase is probably not a problem in terms of manoeuvrability, it may be an advantage or disadvantage for acceleration off the turns and down the straights, depending on the tyres, the track, and the rules.

CONTACT

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

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The thing to remember when you have different types of car competing against each other is lobbying is at least as important as engineering


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Magic numbers

Determining anti-roll bar stiffness using delta values

By CLAUDE ROUELLE

In the last few articles we have reviewed the art and science that help us to define our targets of spring stiffness and dampers force vs velocity curves. The next logical step then is to explain how to determine anti-roll bars stiffness. But to do so we will have to first make a little detour in the world of magic numbers.

The best way to predict the future is to look at the past. Sometimes the best simulation, the best performance prediction, is provided by the exploitation of previous data collected on track or in lab tests.

When your car satisfies some objective and subjective performance criteria, there are in the analysed test data and simulation outputs some key performance indicators (KPI), or 'magic numbers'. Call them best references if you want. If you get lost during another test or race, these references will allow you to quickly and accurately get back to the level of performance you had when you had good lap time, lap time consistency, decent tyre wear and fuel consumption and 'happy' drivers. It works. It is magic.

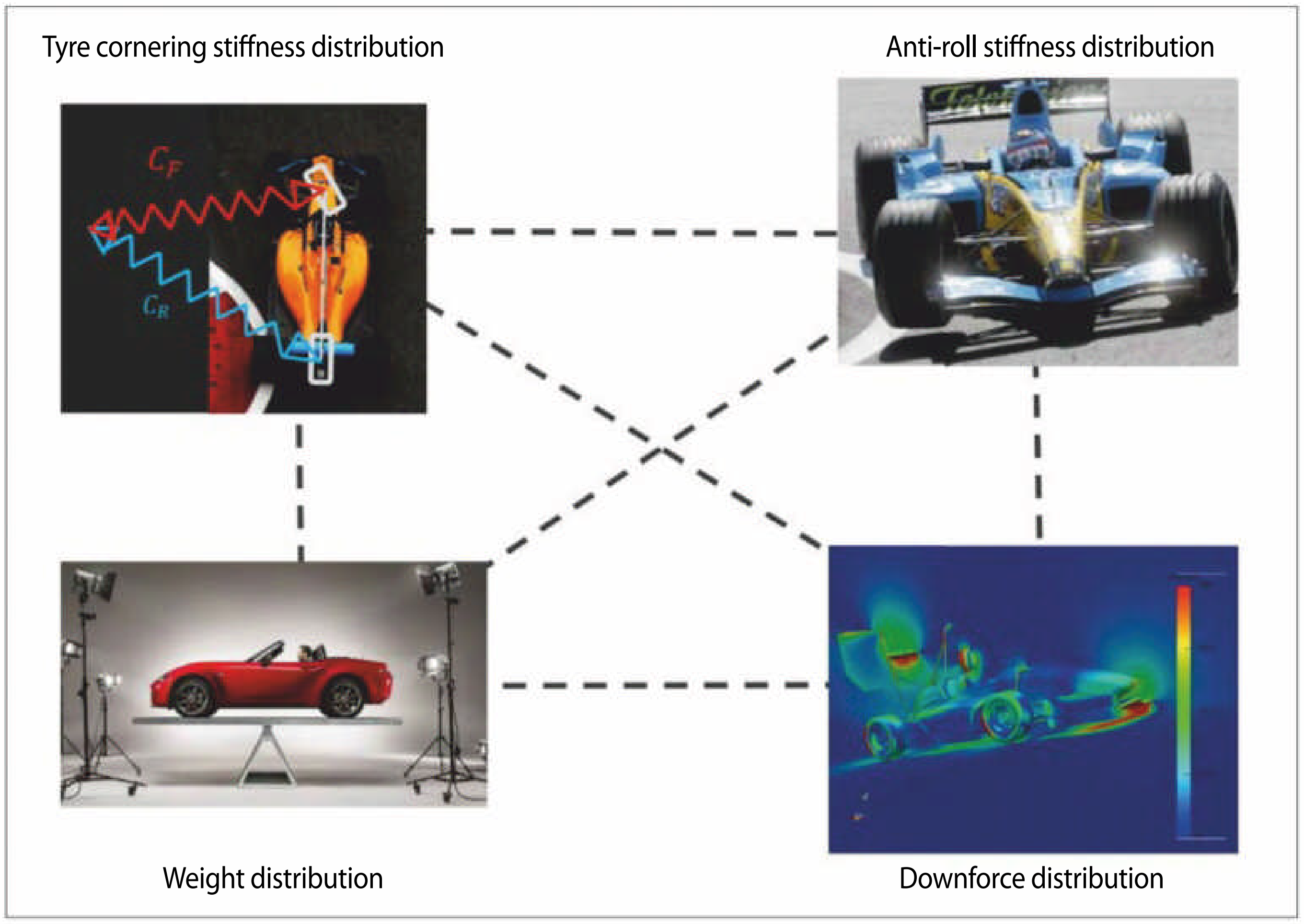
These objective KPIs can be correlated with subjective qualification and quantification of car behaviour by drivers' notes written in organised debriefing sheets.

There are several magic numbers, but here are the four most important:

- Weight distribution
- Front and rear tyre cornering stiffness distribution
- Downforce distribution (often called aero balance)
- Anti-roll stiffness distribution

As you can guess, the latter is a reference that will help the race engineer decide front and rear anti-roll bar stiffness for the racecar.

Anti-roll stiffness distribution can be adjusted with springs, but most engineers try to avoid changing springs once they achieve a good ride as that affects the tyre mechanical grip and grip consistency.



The most important factors in determining the magic numbers for *your* racecar. These numbers are not the same for *all* cars

And good ride height control, on high-downforce, ground-effect cars, affects downforce (therefore total grip) and downforce distribution (therefore balance).

If you can understand how these magic numbers, and their interconnection, influence a racecar's performance, you will already have mastered 50 per cent of the racecar engineering challenges. Here are a few things to note:

1. These numbers are all expressed in percentage of the front value related to the total one. For example, front weight distribution is 48.5 per cent of the total weight.
2. Good racing drivers (and some good passenger car test drivers) will feel a difference of a fraction of a per cent of any of these four magic numbers in a change of car set-up.
3. When cars and tyres are all the same in a given race (which means the same weight distribution and tyre cornering stiffness distribution), such as the Indianapolis 500, expect the other two magic numbers (anti-roll stiffness distribution and aero balance) to be with one per cent for the whole field. That shows how tiny the window between first and second position could be.
4. During the car design process, good racecar designers will look carefully at both weight distribution and front and rear tyre grip (quantified by cornering stiffness) distribution. On a passenger car, the front weight percentage is often bigger than the tyre cornering stiff percentage. The majority of today's passenger cars are front engine and front-wheel drive, with a weight distribution of about 55-60 per cent front, if not more,

If you can understand how these magic numbers, and their interconnection, influence a racecar's performance, you will already have mastered 50 per cent of the racecar engineering challenges

Front engine, front-wheel drive cars have a natural tendency to understeer. This can be tuned out for racing

On ground effect cars, good ride height control affects both downforce and downforce distribution

Ideally, on a racecar you want the front / rear weight distribution to be approximately the same

but with the same front and rear tyres. These cars will naturally understeer and that is what most non racing drivers want.

For a racecar, however, you want both numbers to be quite close. If during the season the designer changes the weight distribution but keep the same tyres, there will be serious balance issues. The problems can be solved with different anti-roll stiffness distribution and / or different aero balance but, by introducing another imbalance to compensate the first one, you can get back to the targeted balance but will pay for it in a loss of total grip.

5. The magic numbers can be accurately determined by simulation if, and only if, we have accurate inputs. Remember the old adage; garbage in, garbage out. If weight distribution can easily be measured with four scales, the knowledge of downforce distribution will depend on accurate aeromaps defined by CFD and wind tunnel tests, and then validated by on-track measurements.

   The front vs total tyre forces and moments distribution will require accurate and relevant tyre models that also have to be validated on track. The anti-roll stiffness distribution might seem to be easily calculated with a spreadsheet and knowledge of springs and anti-roll bars stiffnesses, their motion ratios, the front and rear tyre vertical stiffnesses and the front and the rear track width. However, lab kinematics and compliance (K&C) tests will also take into account compliance of the chassis, the stiffness of all suspension elements, their attachments on the chassis (what we sometimes call installation stiffness) and chassis torsion stiffness distribution. And that is without even considering the non-linearity of these stiffnesses and motion ratios or the fact tyre stiffness is speed, camber, pressure, temperature, vertical load, slip angle and slip ratio sensitive.

6. You do not need to be perfect to be efficient. There is no reason to be discouraged if you do not have access to all these accurate inputs and / or ultra-performant simulation software. The wise engineers will tell you there are too many inputs and too many inaccuracies in those inputs to be able to work in precise and absolute value. You progress thanks to relative comparisons, experience and successive approaches. You work in delta values.

   Example (simplified, I insist): when your driver was happy at a previous race or test, balance was quantified as neutral in a subjective appreciation on a debriefing sheet by a zero on a scale of -10 (big understeer) to +10 (big oversteer). The anti-roll stiffness you calculated with your simplified spreadsheet in this instance was 47.8 per cent. That is a reference, make a note of it. Maybe the 'crystal ball' perfect simulation, with perfect inputs, will tell you the real anti-roll stiffness distribution was 46.9 per cent, but you do not know that, and so you decide to ignore that possibility.

   So, 47.8 per cent of anti-roll stiffness distribution is now one of the four magic numbers. Two weeks later, on another track, your driver complains about oversteer, quantifying the balance this time as three on the same scale. The new track is smoother than the previous one, and your driver likes a responsive car with stiff anti-roll bars, so you increased the total roll stiffness. But, by doing so, you changed the anti-roll stiffness distribution, and your magic number is now 47.1 per cent.

Remember, you goal is to get back to your magic number of 47.8 per cent that made your car, your tyres and your driver happy. By playing with your spreadsheet, you will know by how much you need to increase your front anti-roll bar to get back to that same front anti-roll stiffness distribution.

It is not always going to be accurate, and you will not always reach the desired balance at the first set-up adjustment, but it will not take too many tests for you to master the correlations between the driver subjective balance description (on the -10 to +10 scale) and an objective measurement of the anti-roll stiffness distribution target.

By accepting you do not have full and accurate knowledge of all car characteristics (in the example here, an absence of tyre models and aeromaps), you have decided to work in relative, not absolute value. It works, good enough!

7. On the same circuit, with the same car, and the same tyres, magic number targets can be different from one driver to another, but only by a few tenths of one per cent. Some drivers like cars with a bit of overseer, some with a bit of understeer, but the difference between magic numbers should be quite small. In fact, experience has shown that in a team of four Formula 3 or formula cars, if the magic numbers are more than one per cent apart, there is a high chance the cars are not the same. There could be a difference in chassis torsion stiffness, or stiffness distribution due to a crash repair, or because the repair and mounting of underwings on the cars have not been accurately described and policed. There may have been a slight change in the shape of the underwing or diffuser and the aerobalance is not what you think it is. And a different aero balance will require a different anti-roll stiffness distribution.
8. A racecar aero balance is front and rear ride height, yaw, steering and roll angles sensitive (usually in this order of importance). It changes a few per cent during a lap. As a reference, take the aero balance in a straight line at an average speed that corresponds to most critical corner speeds. It is a number. Remember, you work in delta.
9. Ideal magic numbers could be slightly different from one circuit to another. Usually, street circuits require a slightly higher anti-roll stiffness distribution than circuits with high-speed corners.
10. Ideal magic numbers could have to be changed significantly, by as much three per cent or more, if front and rear tyres are changed. That usually happens when a team, or a whole racing series, switches from one race tyre manufacturer to another. The teams that have access to comparative tyre models will cope with such changes in an easier and faster way.
11. Weight distribution is nearly fixed during the car design process, but can change with the amount of fuel onboard. A GT car with a central fuel tank will not get any significant weight distribution difference from a full to an empty tank, while that number can change as much as 1.6 per cent on a NASCAR that has a rear fuel tank. All other things being equal, that will give the engineers and the driver a challenge in terms of balance variation from the beginning to the end of a stint. And all other things won't be, or stay, equal. Consider the unequal loss of grip through front and rear tyre wear as an example.
12. Your anti-roll stiffness distribution target could also change with tyre wear, especially if you have different front and rear wear and / or if the same front and rear tyre wear correspond to a significant tyre grip variation. That is why adjustable front and rear anti-roll bars from the cockpit help a driver cope with balance change during a race.
13. Weight distribution and aero balance are interconnected. Usually, the aero balance is one to three per cent smaller than the weight distribution. An aerodynamic centre of pressure behind the c of g helps with aerodynamic stability. On slow circuits, the difference between the weight distribution and aero balance percentages is typically smaller than on fast circuits. In some specific cases, like Formula Student, an aero balance bigger than the weight distribution could be beneficial because with good drivers on the typical low-speed corners of Formula Student competitions, stability is a lesser problem. But again, that consideration cannot be made without paying attention to front and rear tyre grip distribution and anti-roll distribution.


This shot beautifully illustrates how three similar cars can be set up differently for the same circuit

Ideal magic numbers could be slightly different from one circuit to another

There are other magic numbers such as heave, roll and pitch damping stiffness and damping ratio, percentage of time spent by the dampers at low and high speed, to name but a few. We will further develop those in future articles, but for the next one we will return to our suspension stiffness definition, when talking about anti-roll bars.

Slip Angle is a summary of Claude Rouelle's OptimumG seminars, which are held worldwide throughout the year.

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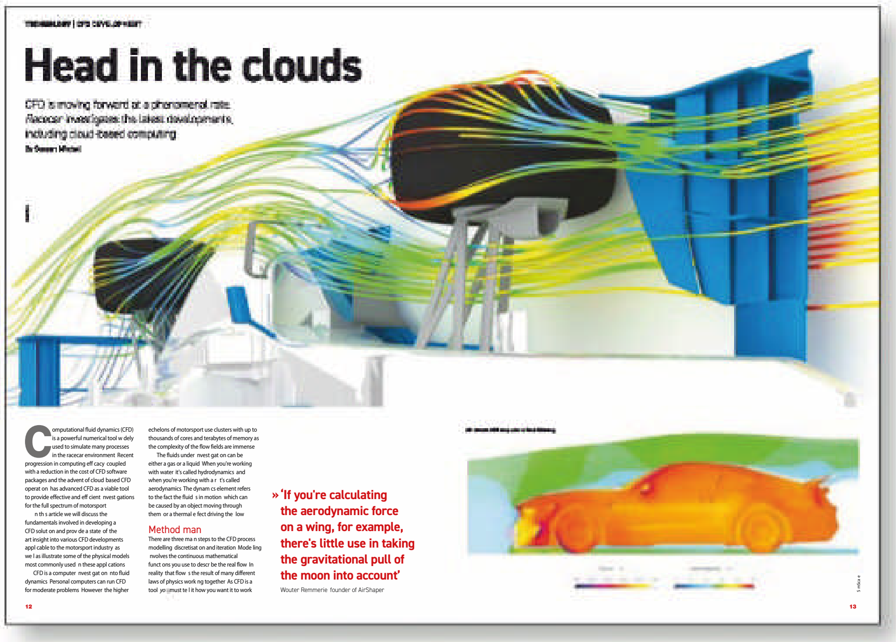

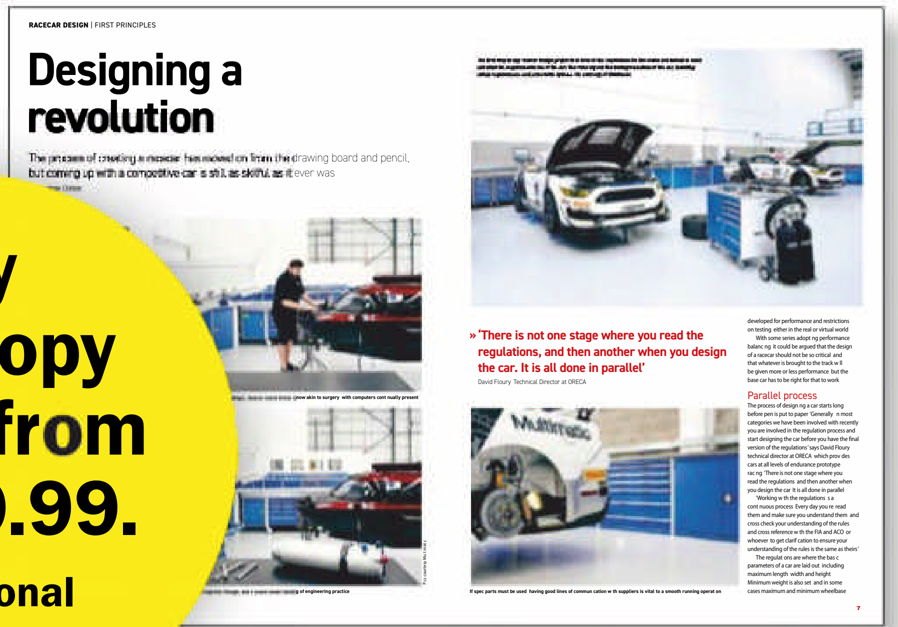

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Mutually inclusive

Understanding the challenge, and necessity, of data correlation

By STEWART MITCHELL

By definition, the word correlation means the process of establishing a relationship or connection between two or more things. In motorsport, the correlation between elements of racecars designed in CAD, tested in CFD, refined in the wind tunnel and then raced at the track is critical, especially with so many series imposing limits on track testing in today's world. Yet, even with all the technology available in the upper echelons of motorsport, the correlation between CFD, wind tunnel and on-track performance still, in many cases, leaves something to be desired.

The correlation between CFD, wind tunnel and on-track performance still leaves something to be desired

Aerodynamics is one of the largest differentiators in the top classes of modern racing. Teams that make the most of the scope within the regulations to develop their aerodynamics using CFD, wind tunnel and track testing typically better understand how the car works, and are therefore able to develop it further.

However, even top teams experience challenges validating what they see in simulation and testing and how the car behaves on track. In this article we will discuss the challenges of correlation in the field of aerodynamics in motorsport.

Function of CFD

CFD is a powerful numerical tool used to simulate most fluid-dynamic physics in the racecar environment. Modelled areas of the car that require investigation in CFD use continuous mathematical functions to represent the real flow around them. Said flow is the result of many different laws of physics working together.

CFD is used to confirm the car's calculated aerodynamic behaviour and sometimes refine detailed areas of aerodynamic devices to ensure, for example, there are no separations anywhere, and that no elements are overloaded. CFD is used as a proof of concept and provides evidence that any changes have the desired effect before those changes progress to the build stage.

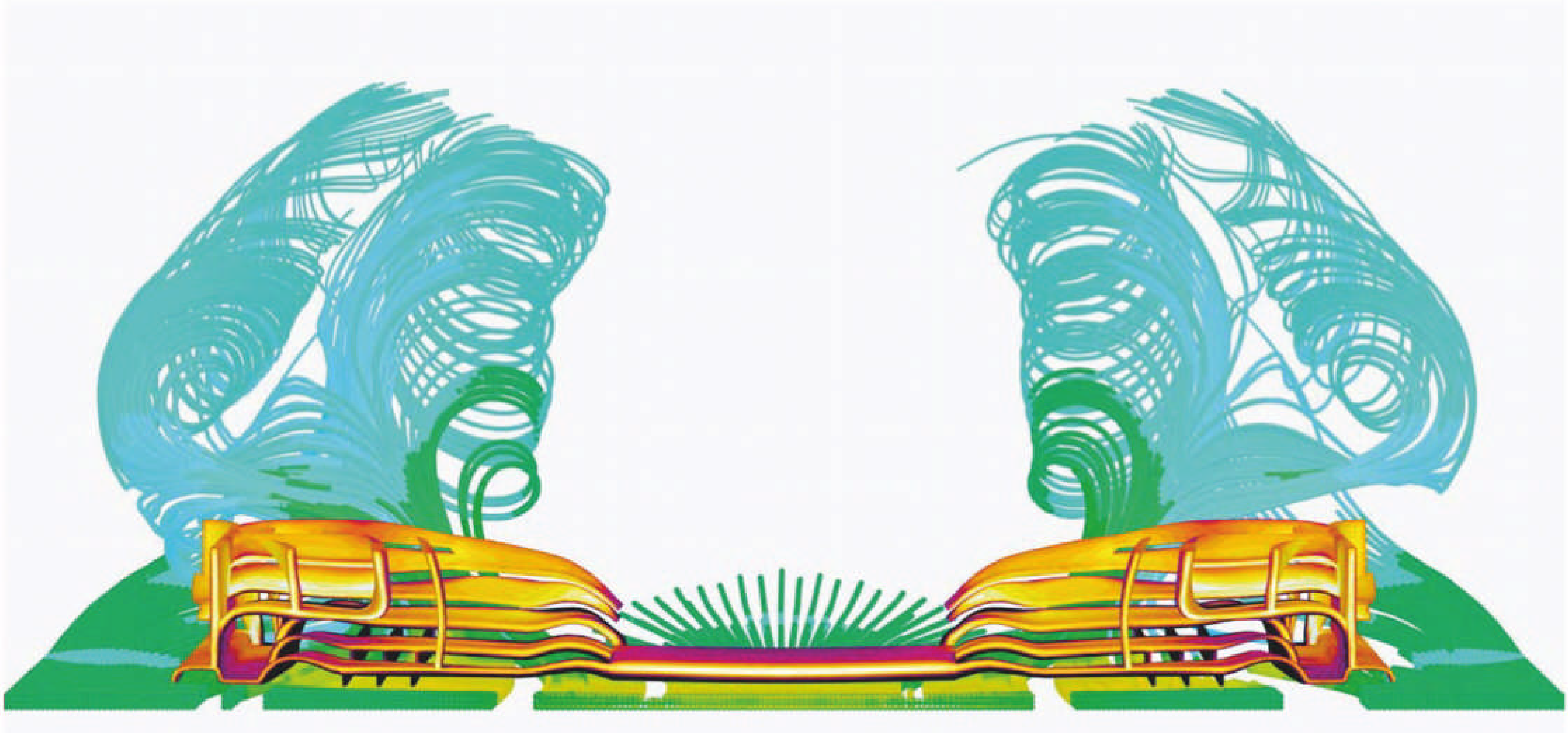
Since its introduction into the motorsport environment, the amount of CFD a team could do was purely a function of its budget, and how big its computer cluster was, leading to a massive disparity across grids. So, in a bid to level the playing field, as well as reduce costs and make the sport more sustainable, motorsport rule makers have placed limitations on CFD resources.

By restricting CFD time, the way in which teams use the technology has evolved as they've been forced to work smarter with it.

Only once a team is confident in a given design of an aerodynamic component will it take the next step to build it and test it in the wind tunnel. Rarely are parts sent from CFD straight to the racecar.

Tunnel testing

The wind tunnel's role in contemporary motorsport is much more than a real-world confirmation of what was simulated in CFD. The wind tunnel is a vastly more detailed test of concept than what can be gathered from CFD testing.



Simscale

Example of complex aerodynamic phenomenon such as the Y250 vortices, which can be visualised and studied in contemporary CFD

Sebastian Vettel picks up the front wing from his car following a crash at the 2020 Russian GP. Clearly marked on its underside are the locations of the pressure taps Ferrari was using to gather information

Getty

Engineers run through whole corner trajectories, ride height scans, pitch and roll scans or anything else they can think of, as long as they have the wind tunnel capacity to do it.

Typically, the process for development of external aerodynamic elements goes through the wind tunnel. Exceptions might be the internal flow of cooling devices or brake ducts. Sometimes, that's because it is not feasible to properly model such elements in a series such as Formula 1, where teams are limited to 60 per cent scale wind tunnel models.

Additionally, items such as load cells, active tyre pressure systems and dynamic suspensions aren't possible to model. In such situations, CFD is the final sign off before the parts are put on the car.

CFD is used as a proof of concept and provides evidence that any changes have the desired effect before those changes progress to the build stage

Track testing

After the wind tunnel, teams go to the racetrack. The amount of data that can be collected in real-world testing is significantly less than can be gathered in the wind tunnel as the car is affected by external variables such as crosswinds, tyre and track conditions and temperature. Essentially, there is far less control at the racetrack, so it's used more as a way to understand if the updates have influenced performance in the right direction.

At the track, engineers try to spot if the car is behaving in the same way it was calculated in CFD and wind tunnel tests, despite the measurement and repeatability being significantly worse.

Sometimes updates measured in CFD, or the wind tunnel, go to the track and there is no measurable difference in the car's performance. For example, a Formula 1 car produces a downforce coefficient (CZ) value of around 5.0 (engineers often discuss aerodynamic development in 'points', one point being 0.01 of a CZ). If 5.0 is the amount of downforce a car produces, 10 per cent of that is 0.5, which is 50 points. So, one per cent of that is five points, and 0.2 per cent of that is one point.

To put that into context, when a team says its update package brings three or four points, it's not very much. Any team in the paddock would be ecstatic with a 10-point update package, however, as that equates to two per cent of the overall downforce.

Max Verstappen's Red Bull Racing RB14 with sensor equipment fitted during pre-season testing to measure airflow coming off the front wheels

XPB Images

It would have to be something pretty spectacular to achieve that though. Aerodynamic updates more commonly bring a one or two-point gain in aerodynamic efficiency, and the racetrack environment typically sees a five-point variation run on run. As such, engineers are never going to see a one-point gain at the track.

Greater detail

In the wind tunnel and in CFD, though, engineers can see these units in far greater detail, as fine as 0.1-point variation. So, in the wind tunnel engineers might see a three or four-unit variation in overall downforce but, when they go to the racetrack with the exact same set-up across two cars, it can yield a 10-point variation.

Generally speaking, a small, mid-season update package in Formula 1 could be worth two points in overall downforce, while a big update might yield eight or nine points. Even then, it can be tough to take that to the track and see that in the results. Not least because of the sensitivity of aerodynamics.

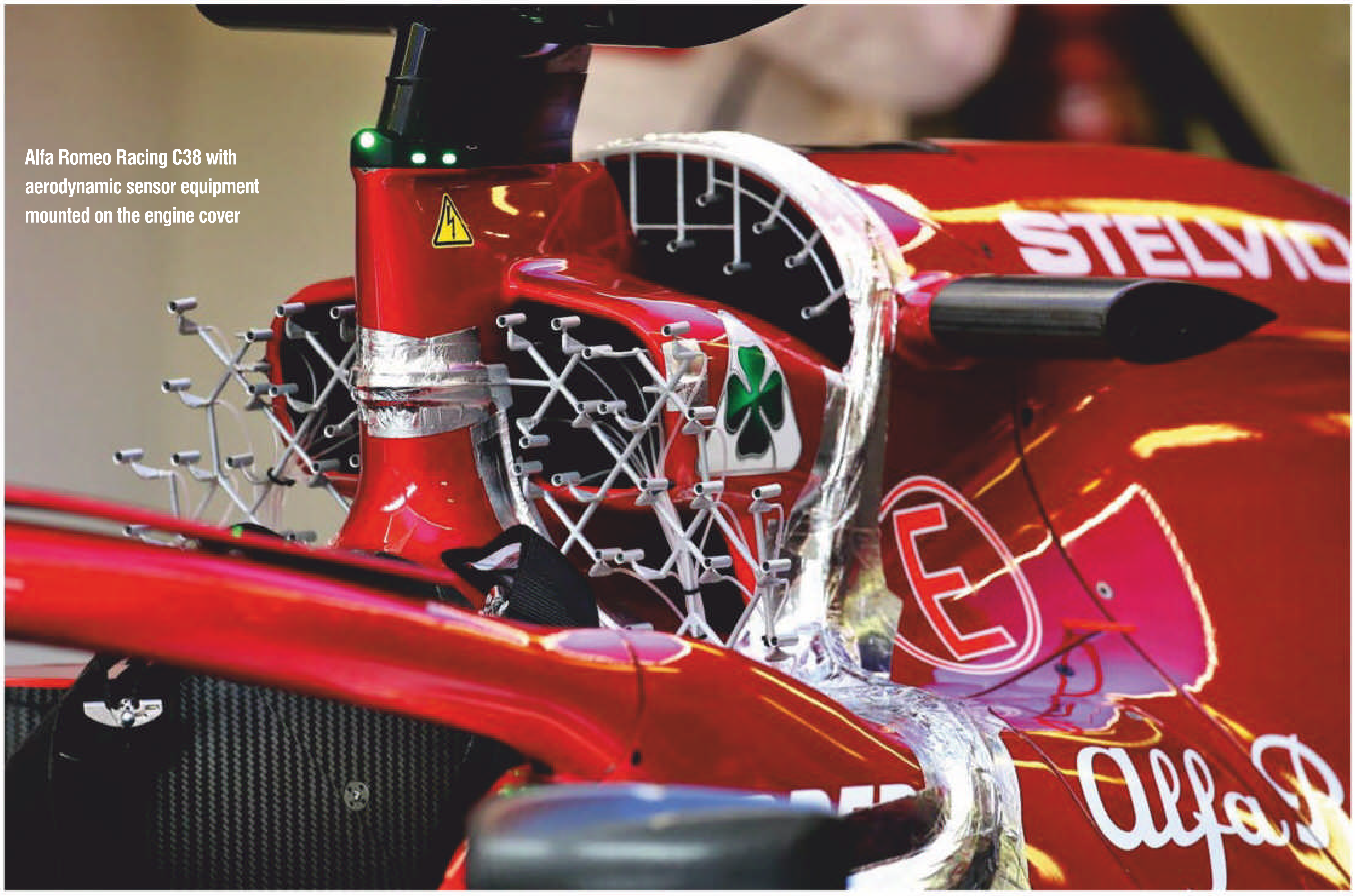
Suppose two cars collide and the front wheel of one hits the mid-section of floor on the other and rips out the side area (similar in area to what is lost in the 2021 floor rules), or a bit of a turning vein, that impact will potentially lose the car 70 to 100 points in overall aerodynamic efficiency just from a bit breaking off.

XPB Images

Many series are limited to scale model wind tunnel testing only. This is a highly detailed NASCAR model of a Chevrolet

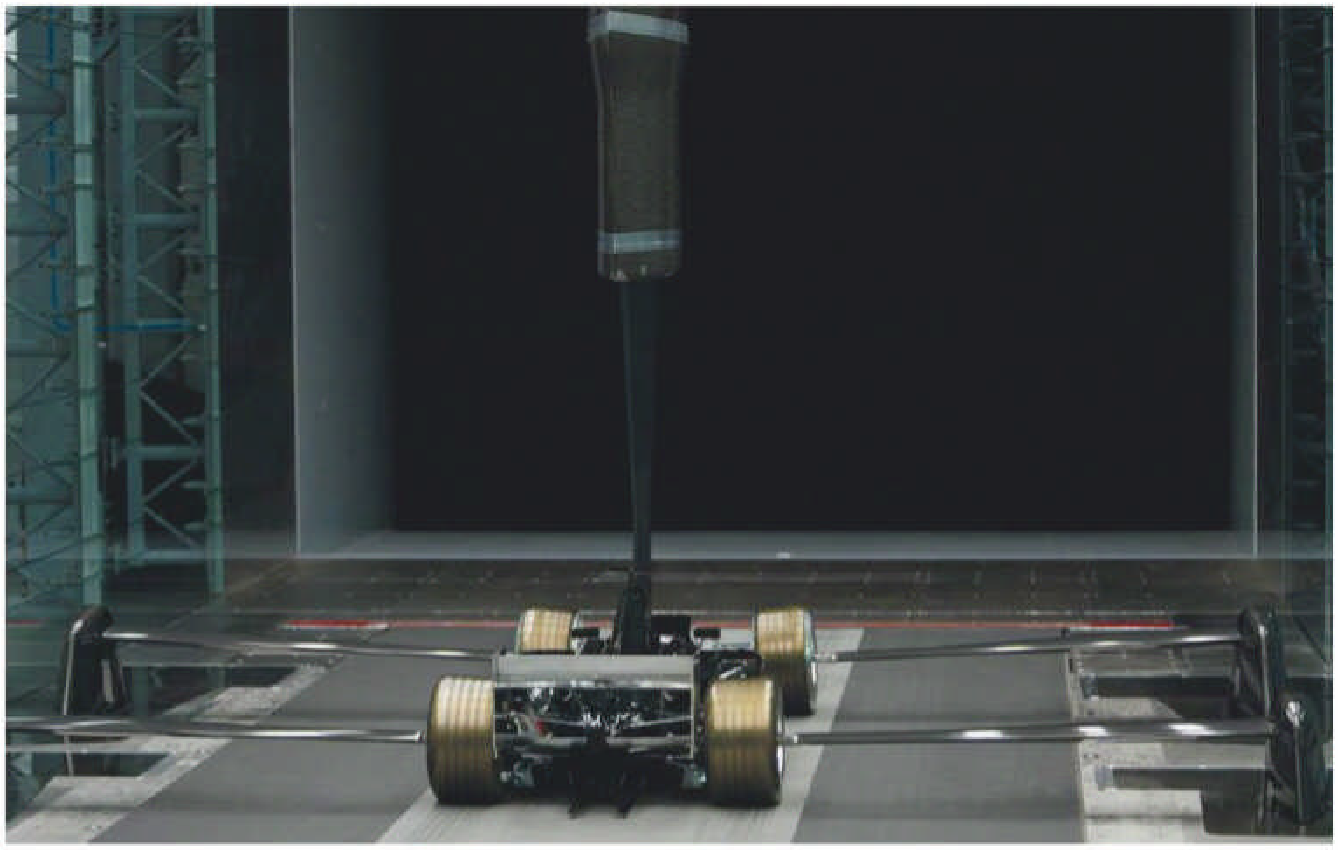
As characterising car behaviour in cornering is vastly more complex than in a straight line, teams carry out a straight-line test with load cells on the racecar and measure the aerodynamic load. The measuring devices used are pressure taps throughout the racecar, located on the surfaces of areas such as floor and wings. These give a snapshot of the pressure on the part's surface, but nowhere else. Engineers take these individual pin prick points and then triangulate the values, taking the average load between them, assuming nothing crazy is going on between the points. They can then derive a load from that average force because downforce is just suction over an area. The more suction produced over a given area, the more downforce that element produces.

Many different things can affect that pressure value, and the amount of downforce the car is producing. The largest influencers



Alfa Romeo Racing C38 with aerodynamic sensor equipment mounted on the engine cover

XPB Images



XPB Images

Formula 1, for example, is limited to 60 per cent scale model testing only. This is the Toyota Motorsport GmbH wind tunnel

are air pressure, temperature and the direction and force of any wind. For this reason, pitot tube arrays are also used to measure the airflow over various sections of the car. Any crosswind, headwind or tailwind will be measured as well. If there is a 10mph headwind, the air going over or under the car is effectively 10mph faster. If the car turns the other way because the track turns 180 degrees, there is now a 10mph tailwind, and the air going 'through' the car is 10mph slower, which means there's a 20mph differential in the amount of effective downforce, just on one lap.

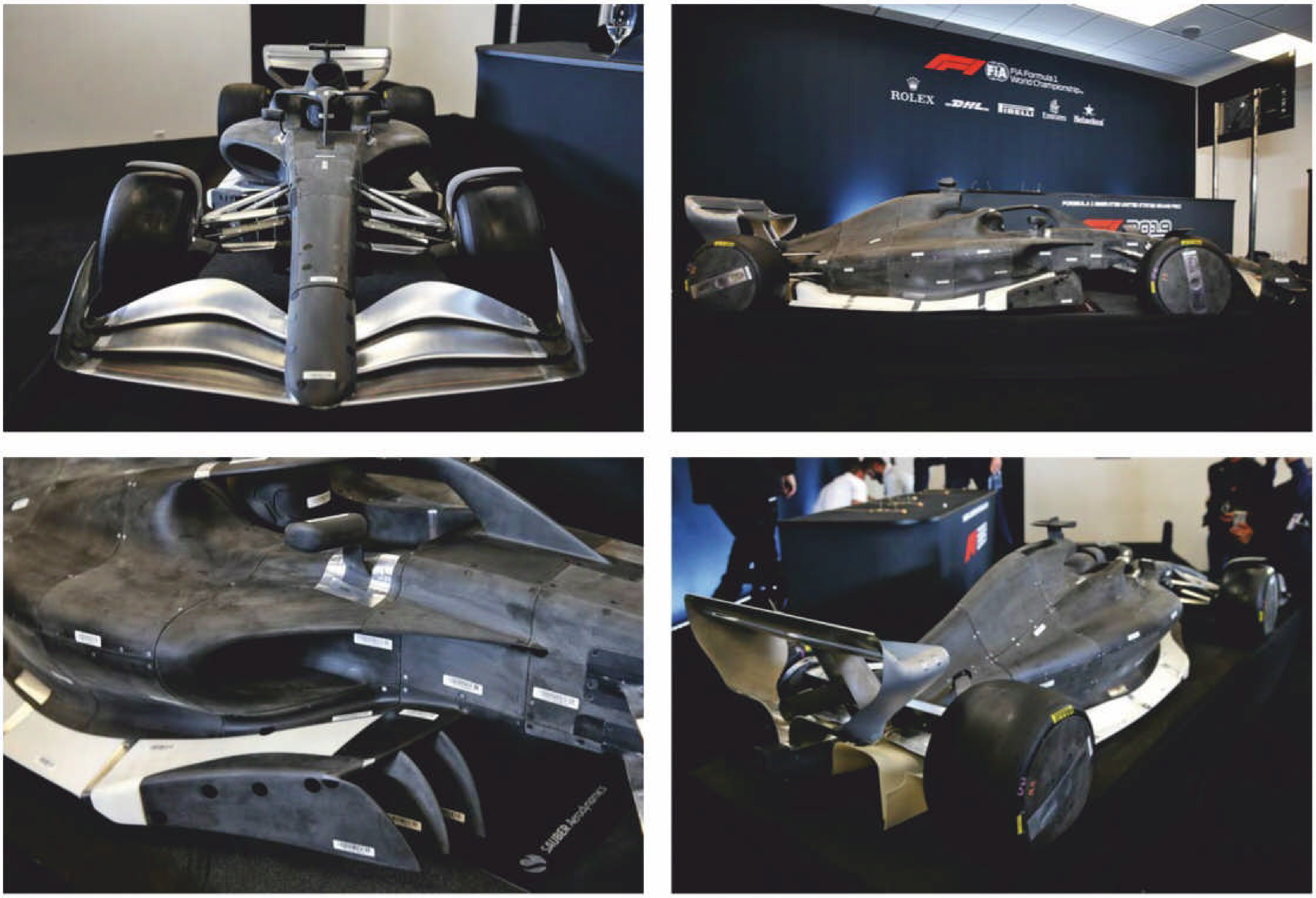
And, of course, wind doesn't always behave quite as neatly as that. During a single test, it can switch to the opposite direction between sessions and sending the car back out again can register a massive difference in overall downforce when actually it's just a change of wind direction. A car driving at the same speed can effectively be going slower, or faster, in terms of the amount of downforce it produces in this scenario.

The amount of downforce and drag also increases with the square of the speed. So, if the speed doubles, the amount of force produced quadruples. As such, small differences in speed can have a significant effect on force.

Suspension load

Another technique is measuring load cells in all the suspension linkages, which calculate the amount of downforce produced as a function of the amount of load on the suspension. The cars are weighed in the pits, taking the load values on each corner as the car's weight. That is considered the datum, or zero value, for the load cells. Taking the same measurements when the racecar is at terminal velocity provides a delta between the two equal to the amount of downforce it produces.

The problem with relying on this method is that racecars rarely reach terminal velocity. There's almost always acceleration, which means there's also a pitching moment into the car. That means that some of that force difference is not downforce, it's from an acceleration vector on the back axle. Therefore, a great many different maps need to be taken into account to make these values before using aerodynamic load calculations. They're always useful for tyre contact



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In order that data gained in a wind tunnel correlates with CFD and the real car, the models have to be extremely accurate. This is the wind tunnel model of the 2022 Formula 1 chassis

loads and such like, but there's a law of compensation that needs to be used for aero calculation. As a result, it's not a particularly useful measurement of downforce.

On a racecar, these two fundamental ways of calculating the amount of downforce a car is producing are both fundamentally flawed, but for different reasons. Some discretion is therefore required but, if both methods show a trend in one direction, the engineers would have cause to believe it.

Driver input

On some occasions following an update, the car goes out on track and engineers see nothing adverse on measurement devices. It all seems to work as desired. However, the driver comes in for the debrief and says it feels awful, unstable in corners, like the back end wants to come around, or it's pushing the front on. The engineers are then left scratching their heads as they can't see any of that in the data and think it should have been a better car, and it should have more downforce in the right areas. That happens regularly.

That's because the car's behaviour is tuned by a complex combination of things, including suspension, chassis, tyre and aerodynamic set-up, and they all have to work together. Often a driver will tell an engineer there's not enough downforce in a given condition when what they actually mean is the tyres aren't up to the right temperature in that corner. It's therefore the job of the trackside engineers to translate driver feedback into engineered changes they can make to the car.

Track correlation is constantly improving because the quality of the measurement devices is getting better, but it still leaves much to be desired.

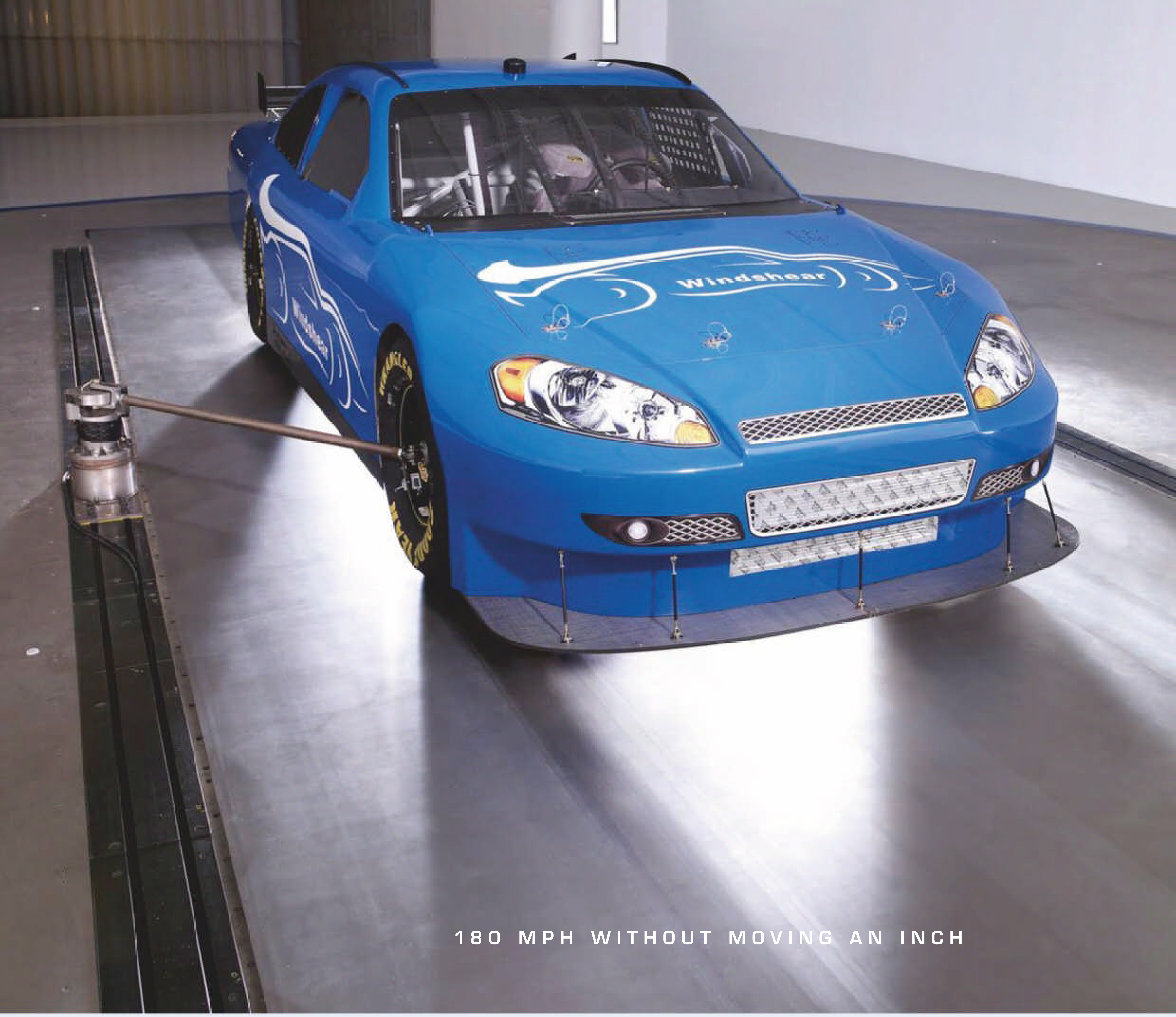
The latest CFD software allows teams to take a snapshot of the pressure of a plane of air and transpose that to show, for example, the effect of wheel wake across the car in sections. There are also devices used in the wind tunnel that effectively scan that same plane of air to show effects of changes in wheel wake as a function of aero rake. The same thing is repeated with pitot sensor arrays fixed to the car when it goes out on track.

These three measurements of the car's performance are run with the same spec ride height, the same roll set-up and all other parameters equal in order to compare as closely as possible what the delta in correlation is. When a car is instrumented up for track tests of this nature, it will be fitted with pitot arrays in various locations to collect information on things like the Y250 vortex exposition, which can be directly compared with CFD and wind tunnel scans.

The car's behaviour is tuned by a complex combination of things, including suspension, chassis, tyre and aerodynamic set-up, and they all have to work together

Reliable sources

A decade ago, Formula 1 wind tunnel capability and CFD was basic. Neither were very accurate, and the amount of useful information that could be extrapolated and correlated between them was minimal.



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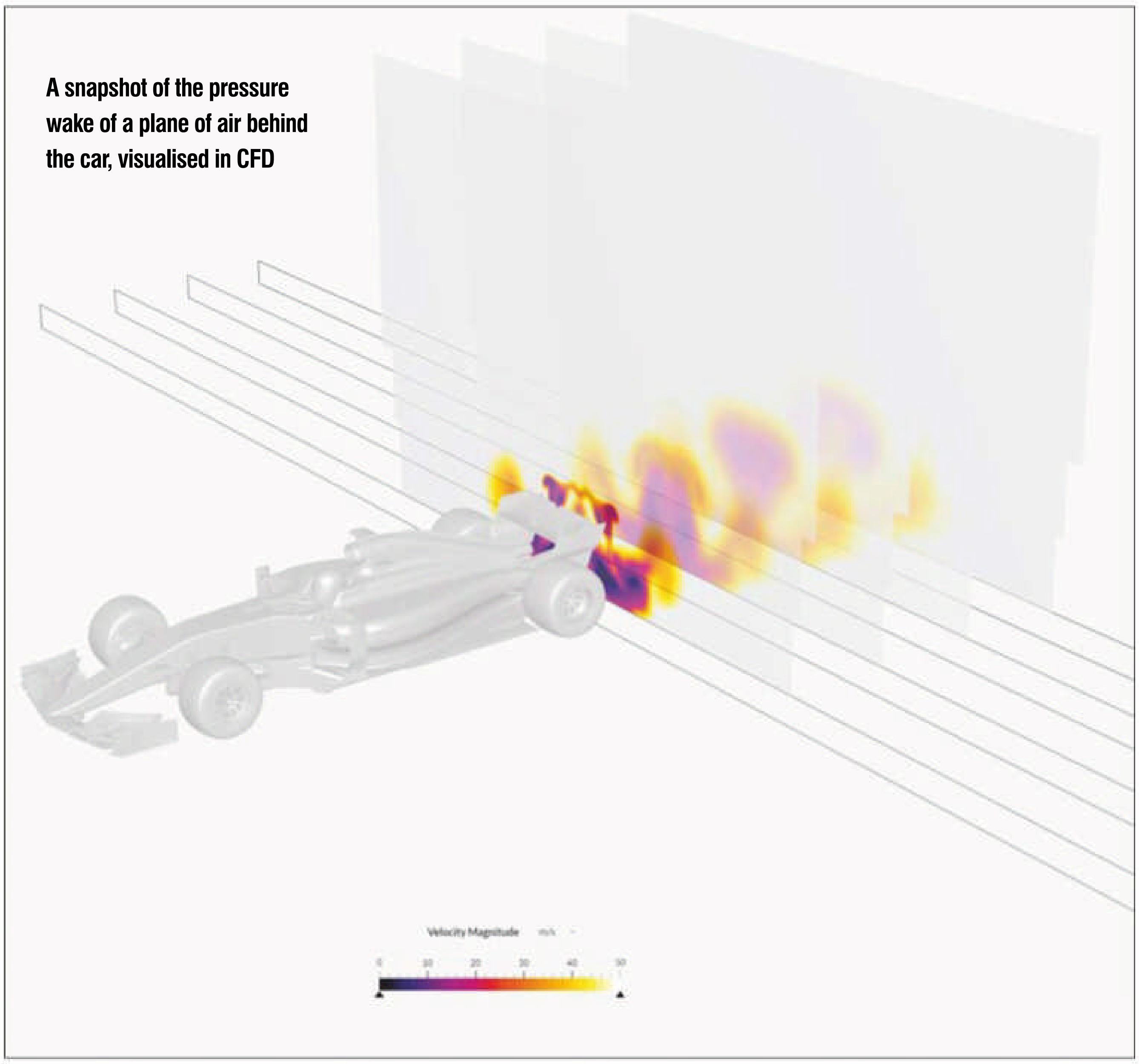
However, there was plenty of data from the racecar, but there was little reliable data to compare it to CFD and wind tunnel testing. Engineers would therefore hope the racecar repeated the wind tunnel's behavioural trends, but they didn't honestly know. These days teams have all three tools at their disposal, and they're becoming increasingly accurate all the time, allowing engineers to make a much better judgement of whether they are correlating or not.

Due to a significant reduction in size and weight, teams are now able to put more pressure taps on a race car during a track test. Where once one kilo of pressure scanners delivered 16 measurement points, now it's about 130.

All Formula 1 teams run pressure scanners in the front wing in the centre section and several places in the floor. To each one, weighing as little as 100g, engineers may connect as many as eight tubes to scan an area, the data collected via a single wire output to the CAN. Ten years ago, a single pin 16 scanner weighed around 500g and had a whole section of loom going to it.

There are many reasons why a team might choose to run such a complex array of pressure scanners within the body of the car during qualifying, or even a race session. It could be they have a problem with the car and are trying to capture as much information as possible. Another assumption would be they're light enough that a team is happy to run the sensors regardless, accepting the additional weight as a pay off against the value of the data they give. Other teams just run them on Friday and take the weight reduction gain on Saturday or Sunday.



A snapshot of the pressure wake of a plane of air behind the car, visualised in CFD

Simscale

Miscorrelation can be the difference between holding up a trophy or being seconds off the pace

Conclusion

Even for teams that are far down the field, having good correlation is critical. If the correlation is right, the development or simulation environment is good and can be used to develop the car. When everything correlates, engineers can trust the simulation environment, which is cheaper to run than track testing and more efficient in the development process. Trustworthy gains shown here will then translate directly to the real car.

A lack of correlation, however, can cause major issues for a team. It can be difficult to understand and costly on resources. In such an instance, a team would be better off pouring resource into understanding the correlation issue rather than the car.

There's a whole host of experimentation teams must go through to understand what is wrong, and it typically involves dragging countless data sets off the real car and the simulation environment and comparing the two. Eventually, when the engineers see where the miscorrelation comes from, they must either correct the real car or the simulation environment, neither of which is simple to do. Miscorrelation can be the difference between holding up a trophy or being seconds off the pace, and is arguably one of the most challenging aspects of motorsport today.

The real sting, however, is that miscorrelation can lead to a team dropping behind on development as rival teams with correct correlation add performance.

XPB Images

Ferrari SF1000 fitted with sensor equipment at practice day in Barcelona before the Spanish Grand Prix

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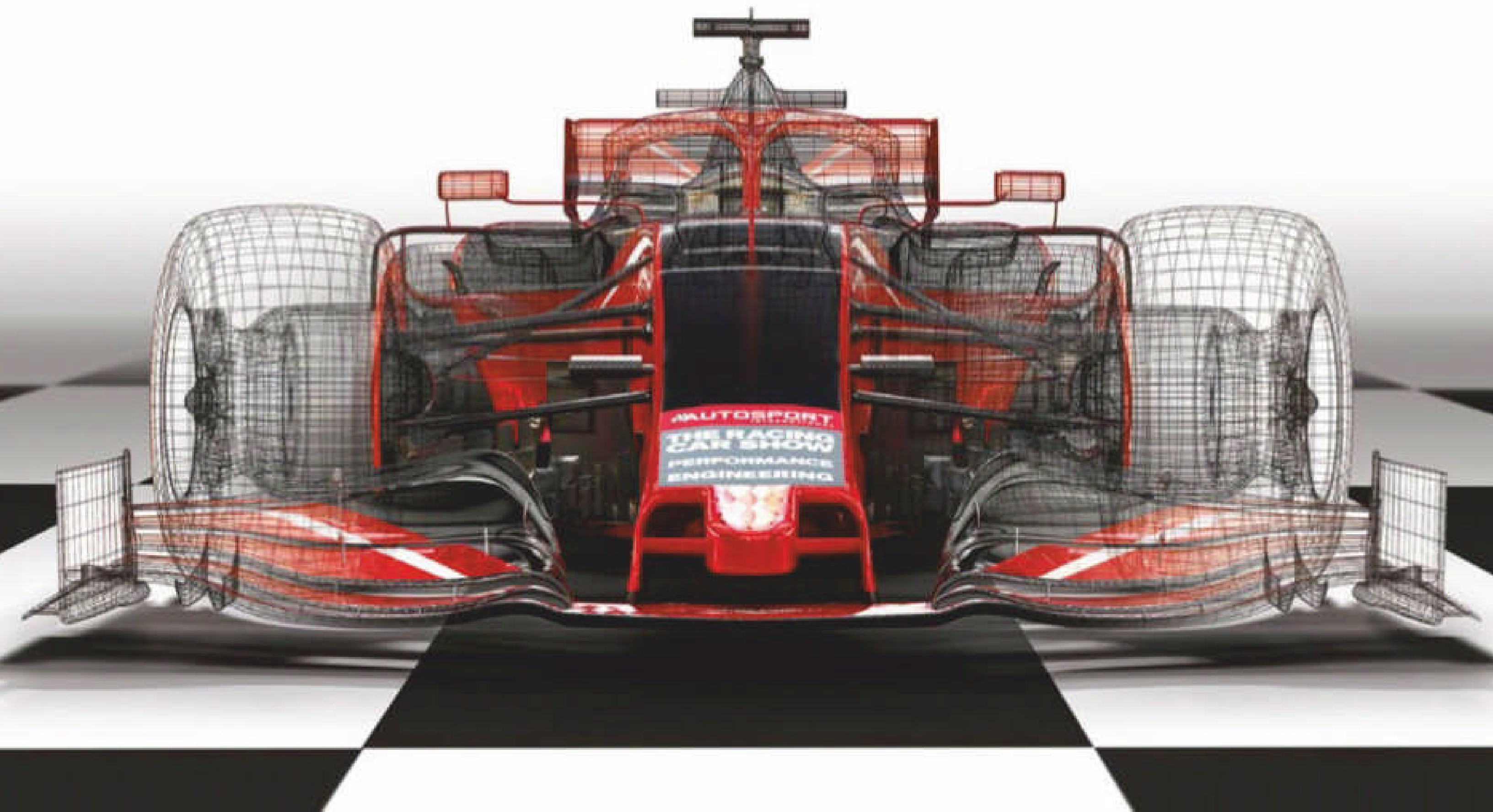
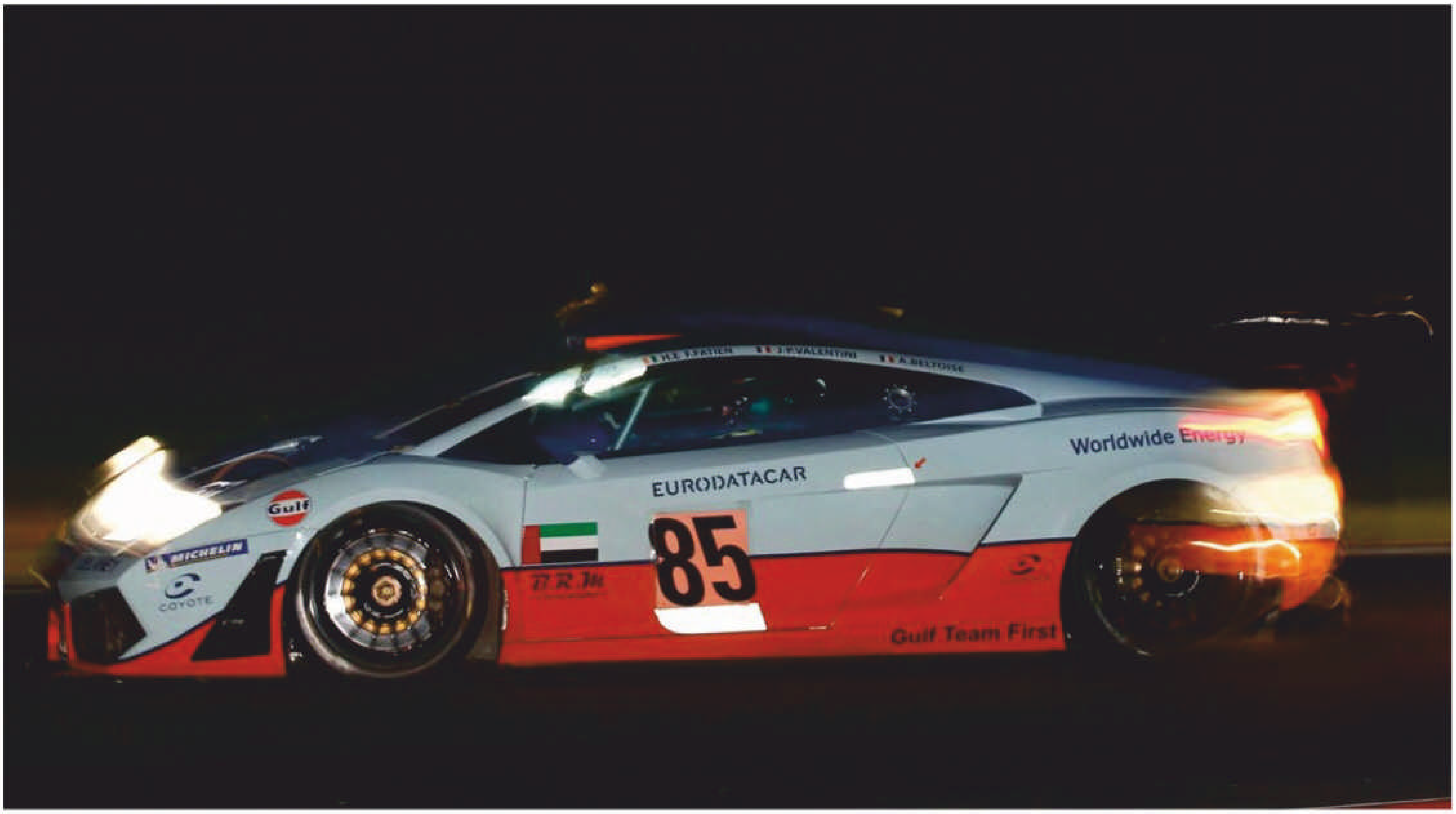


Follow the leaders

The viability of all-electric and KERS in GT racing

By DANNY NOWLAN



SRO/DPPI

Our baseline car for this discussion is the Lamborghini LP 560 GT3, shown here at Spa, but calculations are for the Bathurst 12 Hour at Mount Panorama using data from 2012

A hot topic of debate in motor racing right now is in which direction do we take the sport? In particular, the focus on green racing has led to the introduction of KERS in LMP1 and F1 and the emergence of Formula E. While these are necessary and important steps, a key question has been lost. Is this of *real* engineering benefit and, more importantly, will it make the cars quicker? We'll explore these questions in depth in this article in relation to a GT3 category racecar.

To focus this study, we'll be narrowing our discussion down to a contender for the Bathurst 12 hours. Note the use of the word contender in that sentence. One of the problems with motorsport these days is, due to the challenges we are facing as society, the regulatory bodies are grasping at anything to keep it relevant. However, this takes away from motorsport's key goal, and that is to go as fast as possible. Everything flows from this, and we are losing it at our peril. So, with this as our perspective, let's examine where electrics and KERS come into the picture.

I'm using the Lamborghini LP 560 GT3 as our baseline car here as this is a car I have been closely involved with. In 2012, I was the data / performance engineer for the Consolidated Chemical LP 560 entry in the Bathurst 12 hour. **Table 1** shows some specifics for that car, which will appropriately frame our discussion as we consider what the options look like.

Lap data

To kick this discussion off, let's consider what an all-electric option looks like. To do this, we need to review what a typical lap looks like, and that is presented in **Figure 1**.

As discussed in one of my earlier articles on electric propulsion, what we need to determine is the time spent on brakes and the time under full throttle. The data for this from the typical lap is shown in **Table 2**.

We now need to put in some specific electric numbers. The electric motor we'll use is the Remy HHV-250, and we'll base our cells around Thunder Power Rampage 7700mAh 65C cells. The relevant parameters for this are presented in **Table 3**.

Table 1: Lamborghini LP 560 GT3

Parameter	Value
Mass	1300kg
Peak power	380kW
Time for a stint	45 min

Table 2: Specifics from Bathurst lap for electric analysis

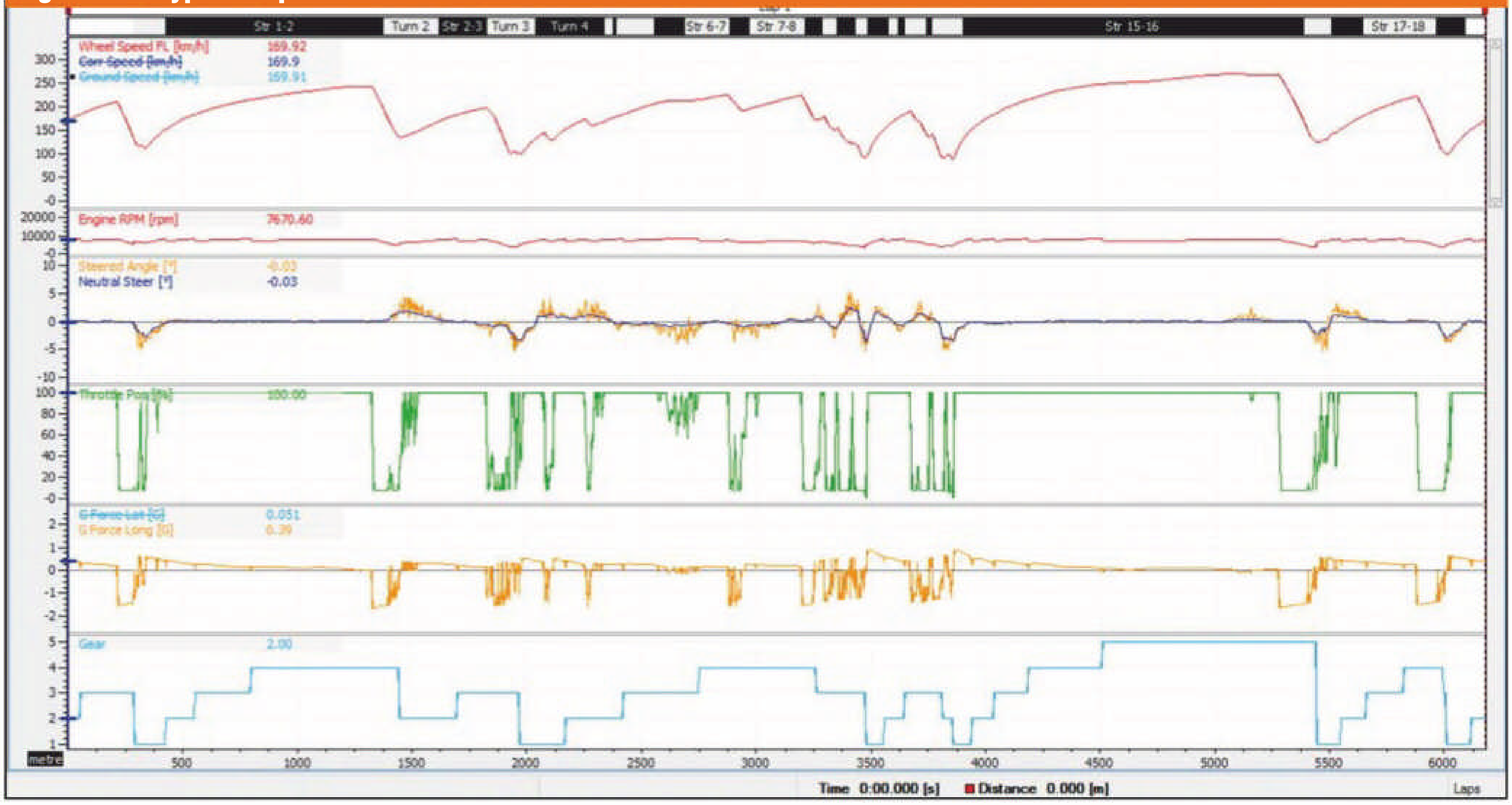
Parameter	Time
Time under full throttle	82.6s
Time under part throttle (50%)	13.46s
Time under full braking	28.5s

Table 3: Electric powertrain parameters

Parameter	Time
Remy HHV-250 peak power	305kW
Motor operating voltage	650V
Cell weight	0.2kg
Regen power	150kW
Cell operating voltage	3.5V

Given the peak power of the motor is 305kW, we'll need to run an AWD configuration. This will bring us to our peak power configuration of 380kW.

Figure 1: A typical lap from Bathurst



You don't need to be a rocket scientist to figure out a pack mass of 1264.8kg is simply not practical

Now let's crunch the numbers. Firstly, we'll establish the currents under power and regen'. For acceleration we have **Equation 1**, and for regen' we have **Equation 2**.

Now that we have established the acceleration and regen' parameters, we need to calculate the Ah used over the lap, as shown in **Equation 3**.

Critical point

We now need to calculate what we need from the battery pack. This is the critical point of this discussion. Given that we'll be running 20 laps over a 45-minute stint, we'll need at least 253Ah of capacity. The number of cells we'll need is shown in **Equation 4**. You don't need to be a rocket scientist to figure out a pack mass of 1264.8kg is simply not practical.

As an interesting aside, the Tesla Model S 85kWh battery pack weighs in at 540kg and has 7104 cells, so is this an option? To find out, we need to perform some basic maths.

The Model S has engine options that range from 285kW right through to the 568kW option. Given the HH-250V has

EQUATIONS

EQUATION 1

$$P = V \cdot I$$

$$I = \frac{P}{V} = \frac{380000}{650} = 584A$$

EQUATION 2

$$P = V \cdot I$$

$$I = \frac{P}{V} = \frac{150000}{650} = 230A$$

EQUATION 3

$$Ah_{DISCHARGE} = \frac{t_{FT}}{3600} \cdot I_{DISCHARGE} + \frac{t_{PT}}{3600} \cdot 0.5 \cdot I_{DISCHARGE}$$

$$= \frac{82.6}{3600} \cdot 584 + \frac{13.46}{3600} \cdot 0.5 \cdot 584$$

$$= 14.5Ah$$

$$Ah_{CHARGE} = \frac{t_{Charge}}{3600} \cdot I_{CHARGE}$$

$$= \frac{28.54}{3600} \cdot 230$$

$$= 1.82Ah$$

$$Ah_{LAP} = Ah_{DISCHARGE} - Ah_{CHARGE}$$

$$= 14.5Ah - 1.82Ah$$

$$= 12.68Ah$$

EQUATION 4

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

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

a base power of 305kW, it's a pretty fair estimate that this motor and the Tesla motor would be running similar voltages. So, calculating the Ah we have,

$$Ah = \frac{Wh}{V} = \frac{85000}{650} = 130.77Ah$$

That is about half the capacity we need, which means the battery pack would need to be changed mid-race. Factor in the practicalities of getting a 540kg battery in and out of a car every 30 minutes and an all-electric contender for the Bathurst 12 hour is simply not practical. That said, I'd love someone at Tesla to prove me wrong.

The KERS option

However, while the all-electric option for a GT3 contender doesn't appear to be practical, we now have the mathematical basis to nail down what a KERS electric option would look like.

From our earlier analysis, we can charge about 1.82Ah per lap, so re-visiting **Equation 4** and using a 3300mAh Thunder Power pack (the cells weigh in at 80g), we have **Equation 5**.

The other thing to keep in mind in this analysis is we haven't optimised anything yet

EQUATIONS contd.

EQUATION 5

$$No\_of\_cells = \frac{V_T}{V_{CELL}} \cdot \frac{Ah_{TOT}}{Ah_{CELL}} = \frac{650}{3.5} \cdot 1 = 186$$

$$Pack\_mass = No\_of\_cells \cdot m_{CELL} = 186 \cdot 0.08 = 14.88kg$$

Table 4: KERS parameters

Parameter	Time
Discharge limit	300kW
Charge limit	150kW
Charge limit	2MJ
KERS weight	60kg

That shows us that to store the energy charge for a lap, we would need a battery pack that weighs about 15kg. By the time you install cooling and battery protection, this might jump to 20kg. Remembering the Remy HHV motor weighs in at 43kg, and you see that tacking a KERS system onto a rear-wheel drive car would incur a weight penalty of 63kg.

Serious numbers

It is now time to put some serious numbers into this, so let's investigate using the ChassisSim KERS feature. For the purpose of this investigation, we are using the parameters shown in **Table 4** for the KERS feature.

For brevity, we selected discharging down the start / finish straight. The results were a dead heat with a lap time of 2:04.95s.

However, the overlays of the data show a very different story, as illustrated in **Figure 2**.

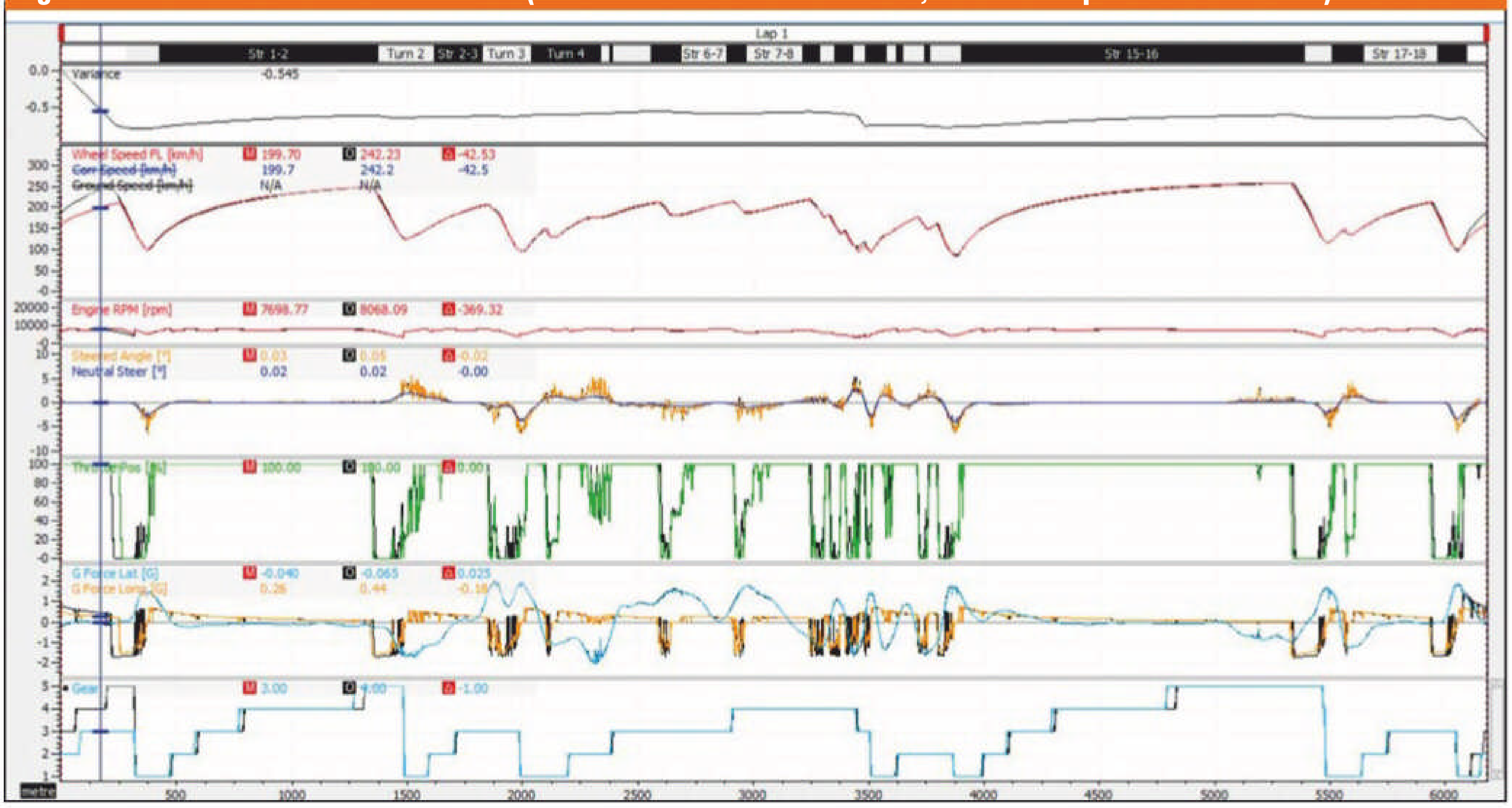
Due to the fact the start / finish straight is short for Bathurst, this has skewed the C-Time plot, but the impact is completely obvious. Unsurprisingly, we do pay a corner speed and end straight speed penalty for the KERS system. This averaged about 0.2-0.3km/h per corner and we were down 1-2km/h going down Conrod straight.

With the KERS engaged, and with a 300kW discharge, the results down the start / finish straight are stark. Going into turn one without KERS, the end speed is 211km/h. With the KERS on, this jumps to 251.4km/h. This is a push-to-pass advantage you cannot defend against. Also, unlike DRS, this is a legitimate push-to-pass that can then be optimised.

The other thing to keep in mind in this analysis is we haven't optimised anything yet, but literally tacked it onto an existing car. I haven't even played with the brake bias, let alone optimising where on the circuit we could best used this advantage. Just imagine this unleashed climbing up the mountain, or going down the mountain on Conrod straight.

Also, if the KERS system were to be designed into the car from day one, I would wager the weight penalty could be appropriately minimised.

Figure 2: KERS vs non-KERS at Bathurst (non-KERS baseline is coloured, the KERS lap is shown in black)



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And with a battery pack that can store 4.28MJ of energy, you have plenty of options, and can easily imagine the effect this could have when you have complete liberty of where to use it.

Nevertheless, there is one spin off from this, and that comes from looking at the front tyre forces, as shown in **Figure 3**.

In this graph the key traces to observe are the bottom two where we see max longitudinal tyre force plotted against lateral force. I'd like to bring your attention to where the cursor lies. There is a differential force of 100kgf on the inside front and 200kgf on the outside front. Strictly speaking, to calculate the available force I should do a traction circle calculation, but I'm actually going to go off the minimum forces because I am deliberately doing this to be conservative. So, to estimate the engine power we could apply, we use **Equation 6**.

To put this into perspective, this represents 15.6 per cent of the base 380kW. Most engine builders would sell their souls to the devil for this kind of improvement. And don't forget we are applying this at the wrong end. Can you just imagine the implications of this being incorporated in an all-wheel-drive platform such as the Nissan R35 GTR?

SRO/DPPI

This analysis proves the KERS electric option is viable and, according to Danny, you'd be mad not to consider it

EQUATIONS contd.

EQUATION 6

$$P = F \cdot v = 2 \times 9.8 \times 100 \times 109 / 3.6 = 59.3kW$$

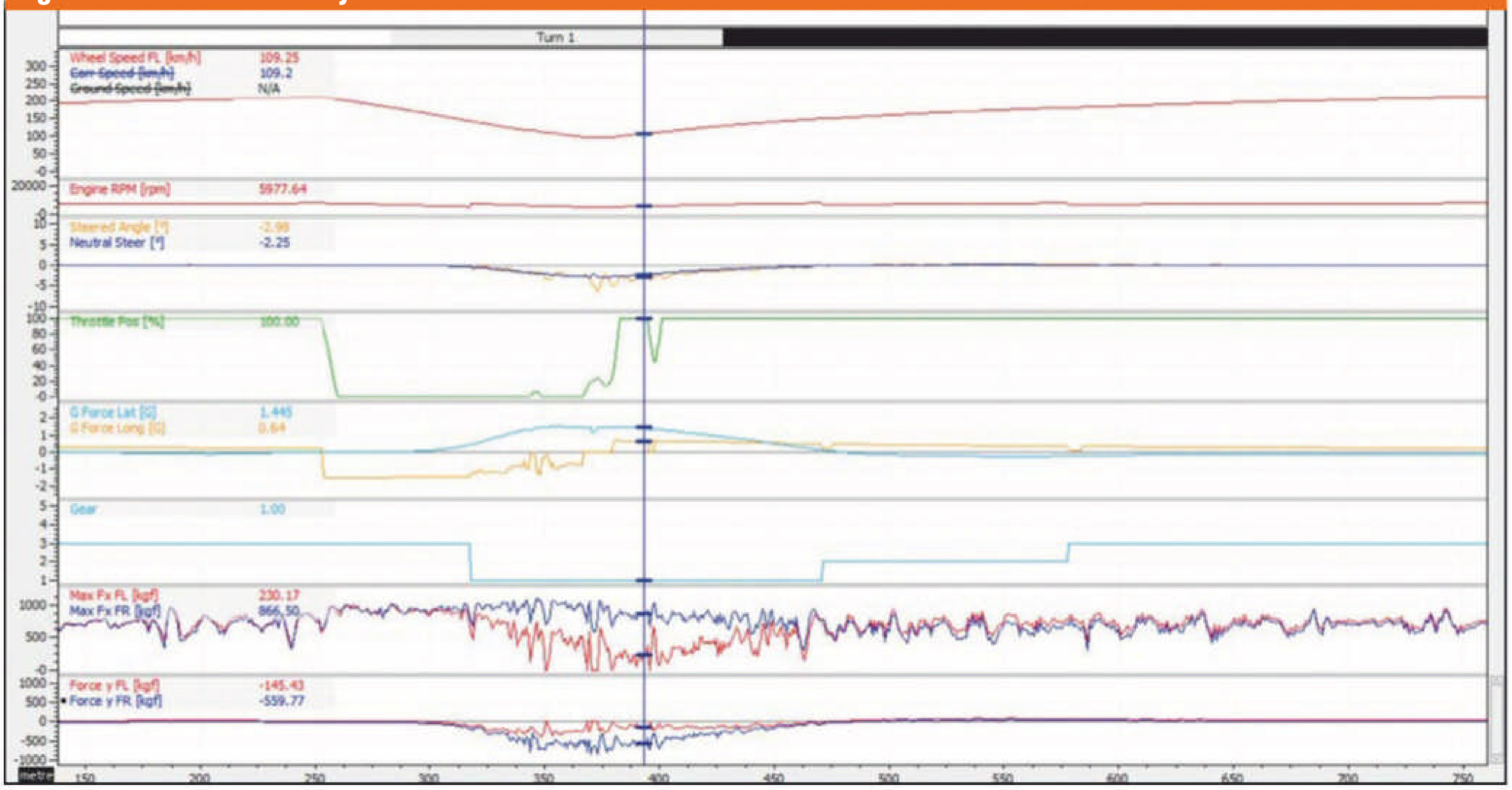
Conclusion

In closing then, applying KERS and electric technology to a GT3 car is far from a fool's errand. While the all-electric option was not feasible, the KERS electric option is not just viable in a technically open formula, you'd be mad not to consider it. The deltas on the start / finish straight speed of over 40km/h mean this is an option to consider very seriously, especially as the loss in corner speed was not onerous.

It also has the potential to add further excitement into racing because, in a wheel-to-wheel battle, you'll never fully anticipate where the KERS will be discharged.

What is perhaps the most striking in our study, though, is that we have just tacked this onto an existing car with no optimisation. Given that, it is no surprise both McLaren and Porsche have incorporated these systems into their latest Hypercar offerings. We in motorsport would be mad not to follow this lead.

Figure 3: Available front tyre forces in turn one

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It's a small world

After 45 years, the Tamiya Corporation continues to inspire, inform and impress through its scale model engineering

It says in the instructions for its radio control kits that Tamiya models are not toys, and so it has been proven. With R/C cars, and its famous line of scale plastic assembly models, Tamiya products have been a tremendous starting point for budding engineers for decades.

A young Adrian Newey built a Tamiya 1/12 scale Lotus 49B with his father, a moment which would change both his life and, in turn, possibly the shape of modern day Formula 1.

In recent interviews, Newey has openly declared it was that big scale kit of Graham Hill's Gold Leaf machine (a car he would later own) that fired his imagination and gave him an insight and knowledge into the inner workings of an F1 car aged just 10. He also remembered how the Tamiya instructions named each component precisely, allowing him to amass the correct terminology from a young age to form a base of knowledge to take his interest further.

Newey's tale is just one of many from those who have been touched by the hand of Tamiya. So why is the Japanese company so revered and respected after all these years? One word that crops up repeatedly is integrity. Tamiya enjoys a unique relationship with motorsport and the wider automotive world and is in the enviable position of having close ties with design departments and is even provided with direct access to CAD data.

Tamiya's own engineers then work hand in hand with the third-party designers and engineers to produce the most accurate scale representations possible of each subject, be it in static 1/12, 1/20, 1/24 or 1/10 scale. So much so, in the modelling sector, the term 'Tamiya standard' is used to describe the industry benchmark created by Mr. Shunsaku Tamiya and his products.

Domestic market

Naturally, car brands in the company's domestic market are amongst the closest of all. The likes of Honda, Mazda, Nissan and Toyota have enjoyed a long track record with the Shizuoka-based corporation, with the latter even launching its GR Supra on the same day in Japan as its radio-controlled version.

For aspiring race engineers, Tamiya's range of radio control kits provides an accurate insight into the workings and drivetrain of a racecar. It is a real world in small, perfectly formed scale, from understanding suspension components and steering geometry, through to motors and chassis construction. Through Tamiya's famously concise and helpful instructions, the modeller learns how a racecar is constructed.

For many, it is a magical moment, but for a young mind it offers the opportunity to understand how components like a differential or damper works, or how camber and anti-roll bar adjustment alter a vehicle's characteristics and dynamics.

As the automotive and racing world continues to embrace the electrification of the sport, one cannot help but think that Tamiya finds itself even more relevant today than in 1976 when it produced its first ever R/C car, a Porsche 934. Some 45 years later, Tamiya's latest kit is the Gen 2 Formula E, on an all-new and highly engineered TC-01 chassis. Art imitating life or life imitating art? Either way, it looks like the brand will continue to influence the next generation of designers and engineers for a few years yet.

Tamiya enjoys a unique relationship with motorsport and the wider automotive world

Tamiya entered the radio-controlled kit market in 1976 and, since then, has produced accurate models of many of motorsport's most iconic racecars

An accurate insight into the workings and drivetrain of a racecar

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Safety first

Sometimes innovation comes from the least likely places

The paddock at Daytona in the mid-1990s was a very different place to the beautifully laid out, fan-friendly structures that are around today. The paddock garages are now open plan and feature windows for fans to watch race teams prepare their cars. The roof forms a viewing platform, which is mightily popular with fans. The DPi cars are of the highest standard in terms of build quality and safety, while the GT paddock features cars sold from factories such as Porsche, Lamborghini, Corvette and Ferrari, so there is no lacking in quality there. The paddock is, today, world class.

That wasn't always the case. The old paddock featured rows of garages, billet-style, with no discernible logic behind their allocation. The only way of finding anyone was to walk them all and try to remember where you had seen the cars that were interesting. Teams filled every available covered space, with more than 80 entries and a variety of cars that would make a rental company blush. In fact, it was often wondered if there was an Avis rental on the grid with some stickers on it, such was the speed differential between the front and back of the grid.

Back then it was possible to have an English Lord in charge of the dead man's handle because he wanted to be part of a team. Rear-end accidents could be caused by drivers in slower categories picking their braking points out of thin air, leaving the pros nowhere to go.

James Weaver once described going into the first turn as like engaging warp drive, as the doctors and dentists that were a regular feature of the race hit the middle pedal by the start / finish line when he was still fully lit in his prototype for a further 200m. The closing speeds between the cars were suddenly massive and the first few laps in traffic were always more entertaining for those watching than those driving.

The Benny Khan media centre sat in the middle of the old paddock. It was notable for having very little working space, and a single telephone by the door. Basic was the very best that could be used to describe the building and, indeed, the entire paddock complex. The same word could also be used to describe the law enforcement officers of the time. The only two times I have been threatened with arrest were both at Daytona, once for making an illegal left turn (which was fair), another for trying to talk to Andy Pilgrim in the pits in 2001 when an armed guard protected the Earnhardts who were racing that year with Corvette.

The only two times I have been threatened with arrest were both at Daytona

It wasn't only the cars or the buildings that were exceptional compared to European facilities at the time, the drivers were pretty special, too. Looking out of the window of the press room as the Kudzu Mazda was being worked upon mid-race, its driver, Jim Downing, wore a contraption that looked like a death trap in the event of an accident. A double shoulder structure with wires attached to his helmet meant egress from the cockpit was rather more challenging than could be considered safe. We were told at the time that every driver would wear one in future, which was unbelievable at the time.

HANS up

Downing was, of course, wearing a HANS device, designed by his brother-in-law, Dr Robert Hubbard, and now complusory in pretty much every major motor racing series. After the deaths of notable drivers in various disciplines, Downing felt it important to come up with a solution, rather than simply wring his hands and lament wasted lives. What he and Hubbard created has undoubtedly saved many lives since.

Fast forward a few years from Downing's debut of the HANS system in IMSA racing, and we look at the 20th anniversary of the death of Dale Earnhardt senior, just weeks after finishing in fourth place at the Daytona 24 hours. The racing legend crashed on the last lap of the Daytona 500, on February 18, and suffered a basilar skull fracture, similar to that which killed Roland Ratzenberger at Imola in 1994 and Gonzalo Rodriguez in CART in 1999. The HANS device may not have saved these drivers, but the likelihood is they would have had a better outcome from their crashes.

From Downing's unconventional stance in the Daytona paddock, various racing series started to take the device more seriously. NASCAR mandated its use in 2001, Formula 1 followed two years later, while rallying and Australian V8 Supercars joined in 2005.

There is much about motor racing today that is different. Undoubtedly, the HANS device is a success, but the racing world also celebrates the best racing technology, while the attendant media enjoys fast internet connection in place of the dial-up modem. That said, a part of me is glad to have witnessed the chaos that was previously found at the 24 hours.

ANDREW COTTON Editor

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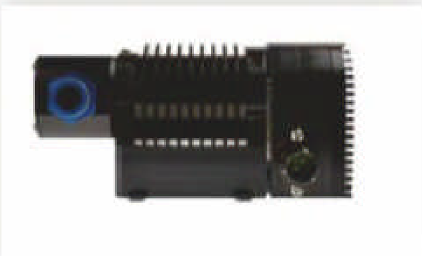


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