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FORMULA 1 How technical directors' areas of expertise affect design philosophy

Inside the world of modern motorsport technology

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Racecar engineering™

Ferrari 296 GT3

Prototype thinking for stunning new racer

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Sarah Bovy became the first woman to score a pole position in the FIA World Endurance Championship at Monza in July, driving the Iron Dames Ferrari 488 GTE Evo

XPB

A question of philosophy

How F1 car designs are influenced by the career path of their technical directors

Like any other sport in the world, developing the equipment in motorsport is an effective route to getting ahead of the competition. As with other sports, typically, technical convergence occurs as understanding increases. However, the first half of the 2022 Formula 1 season hadn't seen the convergence some expected before this era started.

So, how does such a physics-driven problem create so many different design options? The answer is philosophy. More specifically, the philosophy of those that lead the various technical groups, and their relationship with the physics at play.

AlphaTauri technical director, Jody Egginton, for example, spent much of his early career as a mechanical design engineer and race engineer before he made the move into management, and explains his personal philosophy: 'We drew dramatically different cars in the concept phase regarding bodywork and the floor's details,' he says. 'The floor is one of the biggest aerodynamic performance differentiators but the devil is in the detail.

'The bodywork has its authority, but it's also a function of what you do with the floor, and where you are with the power unit. Following the design phase, the sensitivity of specific parts differed from what we expected. My philosophy was to design for flexibility and development scope and package protection to give ourselves a lot of opportunities for manipulating the car, particularly in the sidepod packaging.

'We haven't used much of that package protection yet, but we felt it was the right way to develop the car. The worst thing you can do is to develop a fantastic aerodynamic platform and then have to re-design a lot of the mechanical bits underneath it and shift them around to realise your dream.'

Engineering disciplines

James Key, McLaren's technical director, on the other hand, studied a bachelor of engineering degree, mainly mechanical, but which comprised a whole range of engineering disciplines. He started working in Formula 1 in 1998 at the age of 26 and became Jordan's technical director in 2005, aged 33. That made him one of the youngest to hold that position in the sport at the time.

'Your engineering background and expertise definitely influence how you view a car, and your technical philosophy,' he says. 'What influenced me most was that I started working trackside. When you see the sharp end as your first understanding of what Formula 1 is, that's an illuminating place to learn. You can put together the way the tyres are behaving, your control systems, your aero balance, where the driver is on track, your mechanical set-up and the track condition. You can put all that together in your head and see the wider picture.

XPB

Matt Harman, Alpine F1 Team technical director, spent much of his early career designing F1 power units, which influences his engineering philosophy as technical director

'But suppose you went to Formula 1 technical direction after working in specific subjects like aerodynamics and vehicle dynamics, or as a design or control systems engineer. If you're an aerodynamicist, you see a set of surfaces and, regardless of what's inside it, you want to optimise that to the nth degree. Anything that gets in the way of that, like a wishbone or something else, becomes a pain.

'However, those wishbones are fundamentally important if you're a mechanical person. With that [aerodynamic] background, for example, you sometimes carry that focus on, and it doesn't always render well in the context of the whole car.

'My technical directing philosophy focusses on optimising everything for the car on the track and configuring the team to operate at track level.'

Different angles

This year marks Alpine F1 technical director, Matt Harman's, first year in that position in F1. Harman spent half his F1 career designing power units, so comes at the position from another different angle.

'I think my background allows me to be quite critical and understand a lot of the compromises and trade offs we need to make on the car in many detailed engineering areas,' he says. 'Over the years, I've taken responsibility for lots of different areas of the car, and I've gained quite a lot of understanding of those sensitivities.

'My philosophy is to consider the harmony of systems, particularly in some of the areas like powertrain integration, for example, where things can often *feel* faster because they improve in a unit of kilowatts but actually, at the end of the day, once you've added up all the parasitic losses, we could end up with something that's not quicker.'

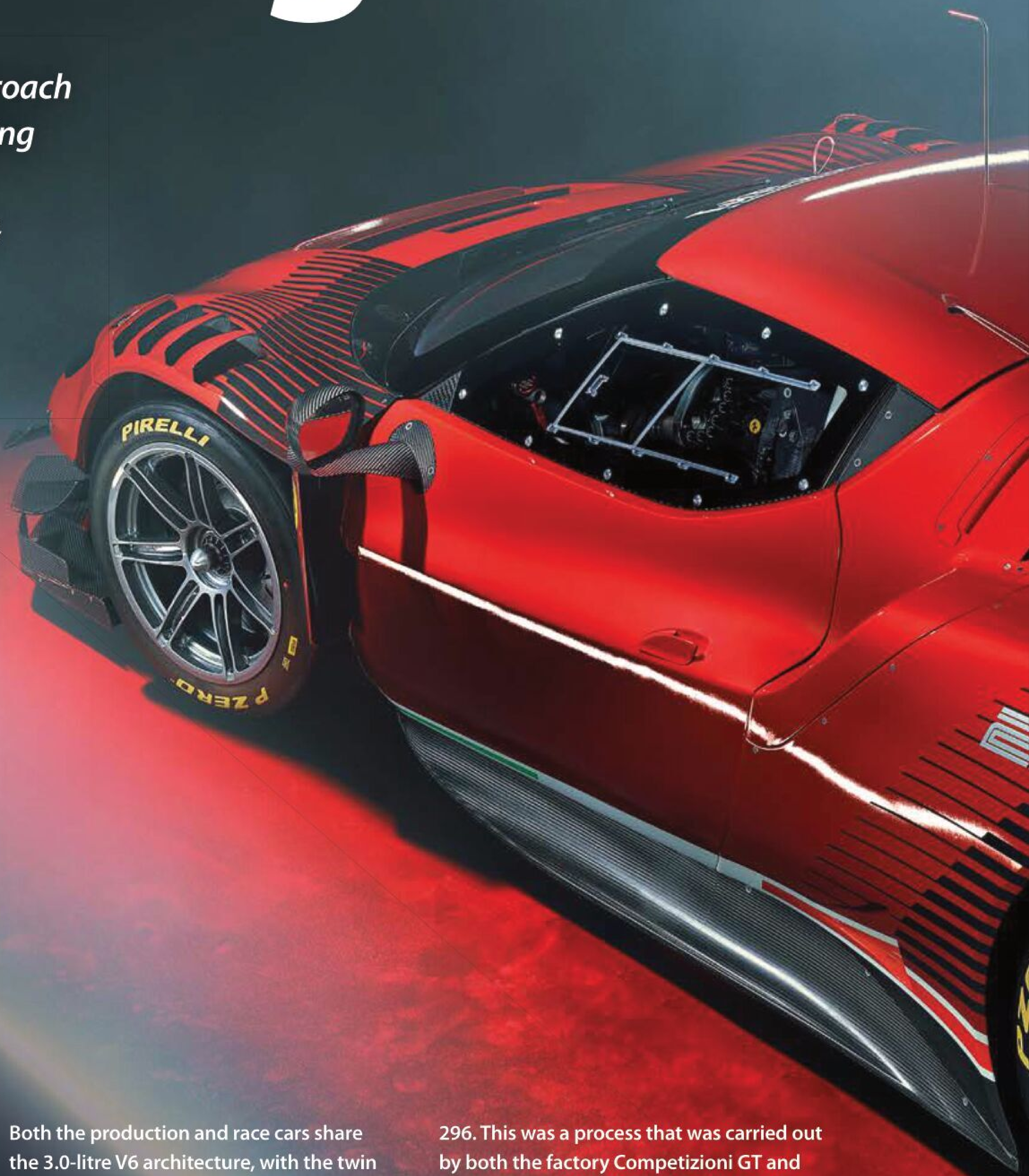
These differences in philosophy, and those of the other technical directors not singled out here, can be observed in the cars throughout the Formula 1 grid. As such, despite the multitude of tools available to the talents in Formula 1, the nature of the technical personnel's knowledge, their individual relationships with physics and their previous experience, when considered in the context of the car's environment, remain a considerable influence on the overall design and philosophy of the resulting machines.

The nature of the technical personnel's knowledge, their individual relationships with physics and their previous experience… remain a considerable influence

Thoroughbred

Ferrari has taken a novel approach to its new GT3 contender, taking advantage of new technical regulations to create a lighter, stiffer, more accessible car than its predecessor

By ANDREW COTTON



Ferrari has taken a radical new approach to the development of its 296 GT3 by taking full advantage of new regulations that allowed it to optimise the design from concept phase through to final build. Rather than having to present new ideas to an FIA committee for approval, which slows up the process and introduces uncertainty, the new technical regulations that govern the class are written in stone, and that allowed Ferrari's designers to focus on what they knew to be allowed from the start. That simplified the design process and meant the team was able to aggressively pursue avenues that have helped to produce a better, less expensive car for its customers.

The car is based on the hybrid 296 GTB, though the hybrid system has been removed from the racing version in order to comply with the technical regulations for the class. Both the production and race cars share the 3.0-litre V6 architecture, with the twin turbos mounted within the 120-degree vee angle, although the internals are completely different between the two engines.

Three degrees

The racing version has bespoke internals, a more robust design of pistons and conrods to improve reliability, and the whole engine is moved forward and down in the chassis to lower the overall c of g for the car to optimise longitudinal weight distribution. Exploiting the degree of freedom allowed by the technical regulations, the engine is also rotated three degrees tail up to allow for a more efficient rear diffuser.

The design team says it has carried over the strengths of the 488 GT3 and identified its weak points in order to improve on them where possible in the 296. This was a process that was carried out by both the factory Competizioni GT and customer teams and drivers. That led to a simplified rationalisation of the bodywork, more torsional rigidity, greater safety and improvements in areas outside the remit of Balance of Performance, such as braking efficiency, driveability of the engine and adaptability to different makes of tyre.

However, the biggest change is the application of prototype thinking to a GT car in terms of accessibility to key elements, with removable front and rear bodywork that allows engineers and mechanics better access to the engine and the gearbox.

'On the bodywork, we took into consideration the racing inputs, and now the car is fully oriented to a racing application and operation,' says Ferdinando Cannizzo, head of GT track car development at Ferrari. 'The way that we did that was to

The biggest change is the application of Prototype thinking to a GT car in terms of accessibility to key elements

split the bodywork, giving us the possibility to make a very fast swap of parts during a race, improving operations in the pit and in the garage. The simplification in the design in all areas made this possible, allowing us to have a sub assembly that is easy to manage.

'Systems integration with body and chassis are completely different to the 488, more like a Prototype than a GT car. That makes the car a real novelty.'

Regulation change

This generation of GT3 cars are built to a set of technical regulations written by the FIA with a view to firming up what is possible in the design of a car. Previously, manufacturers would design a car and then seek approval for it from a committee. Waivers would then be requested for various changes that were needed, but they were not guaranteed to be granted.

What this approach did was to allow the overall spirit of GT3 cars to be retained as extreme cars such as the Ford GT were rejected. The technical regulations now allow manufacturers to design with more certainty from the outset, which is obviously preferable for them.

Ferrari has used this change to improve its final product, taking an integrated approach to the overall design from the outset, although there is still the age-old problem of engineers reading, designing and implementing what is not expressly written. If they choose to exploit that, there is a real risk the technology and concept will rise out of control, as has happened with the GTE cars.

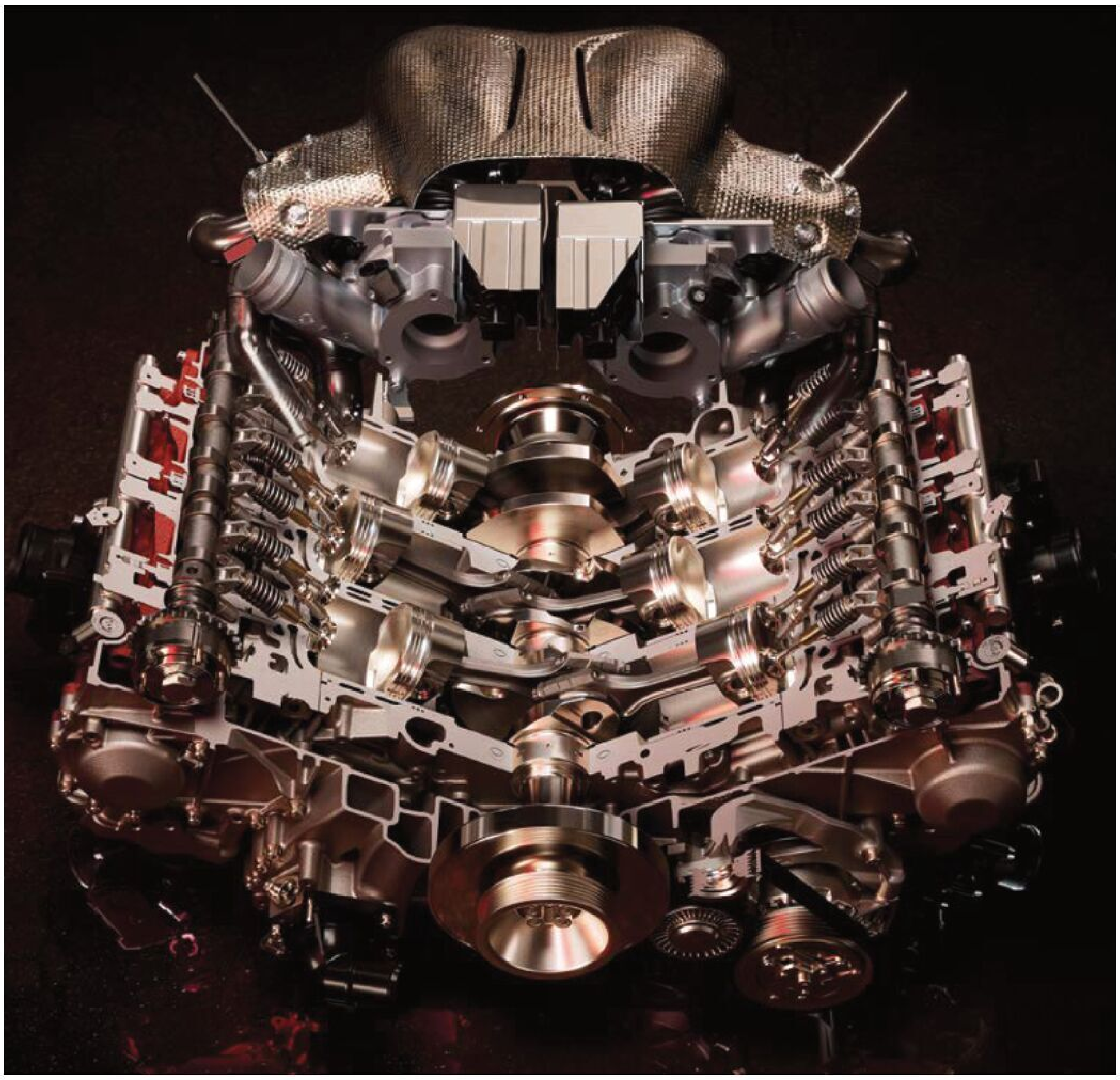
'Actually, the new GT3 rules are written as a proper technical regulation, but it does not bring a lot of changes,' says Cannizzo. 'Now we have a clear technical regulation, and the advantage with that is you know exactly what you can do, and what we can afford, in terms of technical design, without any risk of interpretation.

'We can say that this was possible because it was granted in the past for our cars, but this gave us the possibility to start the concept phase knowing exactly what is and is not possible in GT3.

'In the principle of freedom, we have the same freedom that we had in the past with the previous guidelines. There is no significant change.'

Priority targets

Faced with this new level of certainty, Ferrari attacked the design of the 296 with a view to reducing weight, lowering the c of g and increasing torsional stiffness. They achieved the latter by an estimated five to 10 per cent, but that was only part of the goal. The 488 was already strong in this area, so this was not the priority target for the design team.



Power comes from a 3.0-litre V6 based on road car architecture but with racing internals. Twin turbos are mounted hot side in the vee

'Systems integration with body and chassis are completely different to the 488, more like a Prototype than a GT car. That makes the car a real novelty'

Ferdinando Cannizzo, head of GT track car development at Ferrari

Multi-function programmable steering wheel also has a 12-layer shift control in the centre giving maximum functionality

Here's where that Prototype thinking is most obvious. As well as improving packaging and making the car easier to work on in the pits, torsional stiffness has been improved and the c of g lowered through a lightweight design approach

Lowering the c of g through lightweight design was, and of this the team is particularly proud. The reduction in the number of cylinders, from eight in the 488 to six in the 296, helped in terms of the size and location of the engine, but the team worked hard to make significant improvements in all areas around the engine bay.

It might seem perverse for the team to target lowering the c of g while retaining the 'hot side inside' concept with its turbos relatively high up but, taken in context, it was still the right decision, maintains Ferrari.

'You may argue that the turbocharger in the higher position than a cold vee configuration with the turbos on the side can lead to a higher c of g, but actually we were not focusing just on the engine, we were focusing on the whole car and the whole engine assembly, including all the ancillaries, and the benefits on the car installation pays for this technical solution,' says Cannizzo.

'You have to remember that the V6 is 120 degrees, so that's a wide vee, and that gives us the possibility to have a lower installation of the turbochargers.

'The hot vee configuration allows us to minimise the volume, and the losses of the air intakes and exhaust lines, increasing the efficiency of the turbo and limiting turbo lag as much as possible. As a consequence, that also allowed us to optimise the size of the intercooler.'

Improved cooling

'We were able to improve the efficiency of the engine cooling system so we have a smaller radiator, and you can see the comparison between this and the 488,' continues Cannizzo. 'The radiator at the front is much smaller and gives the same heat rejection potential required because the target power is basically the same.' Smaller radiators mean better aerodynamic efficiency, and less weight high up than its predecessor, which again helps overall car performance.

'We made an interesting choice with the alternator to move it from the front of the engine, as it is generally mounted on the road cars, to the back, attached to the gearbox to improve the compactness of the assembly between the chassis and the engine, and optimise the stiffness of the assembly. It is now easy to access, easy to change and improves the packaging.'

However, it is the gearbox where things become more interesting. Ferrari's designers worked hard on a bespoke external casing for the 'box to emphasise its integration with the engine, and make it compact and efficient.

The 296 boasts electronic gear change and clutch actuation, again improving efficiency. Having such systems makes it easier to calibrate and control according to conditions and driver, further improving driveability.

Naturally, a racing engine operates differently compared to a production engine, and in Ferrari's case there was plenty of scope for changes to the internal mechanisms to allow it to run in more extreme conditions.

'Clearly, many internal parts, such as the camshafts, cylinder liners, rods and pistons are specific for the racecar, mainly because we put the engine in a different operating condition than the road car and for reliability,' explains Cannizzo.

Though the design team has not yet completed its on-track endurance validation for the 296 GT3 engine, they have also had to consider that the car will be using a different fuel in the near future, as all championships are planning to introduce a bio fuel, starting in 2023. The World Endurance Championship is already at that point, but further steps in that direction are expected.

Suspension and braking

While the road car features a double wishbone suspension at the front, a design that is shared but optimised for the racing version, the rear suspension is completely new. The race car also uses a racing-spec double wishbone design, and the team has gone for a five-way adjustable damper for the car.

'We are working with one damper supplier, and we tried to optimise the damper itself, thanks to our supplier, as well as its installation on the car in order to cope with all potential different track requirements,' confirms Cannizzo.

The team has retained the same brake supplier as on the 488, but has developed the system for the new car, increasing braking power with a larger diameter disc and an improved front caliper design.

'At the rear things are different to make a better stiffness, specifically on the caliper,' says Cannizzo. 'The design has taken into consideration the possibility to have a quick change on the car in case of need, although the design target has been to not need to change brakes during long endurance races.

'The c of g was already good there, but we optimised it in consideration of packaging of the suspension, the tyres and the accessibility of components in the car.'

Cockpit constraints

One of the major concerns for the design team was the volume of the cockpit from the donor car, and how that would marry up to the new technical regulations concerning driver seating position, and the seat itself. The team had to find a way of meeting these new regulations while also maintaining good accessibility in and out of the car during the pit stops.

Seating position is more closely matched to the rear-most part of the rollcage. Ferrari worked with two seating positions, for small and large drivers, while also retaining access to a driver's head through the mandatory hatch in the roof of the car.

'We have a new regulation for the seat, and our donor car is pretty small in terms of volume,' says Cannizzo. 'A lot of work was done to optimise the applicability of the car for bigger drivers, which was not easy for us considering the constraint of the cockpit from the technical regulations.

'The rollcage has been optimised compared to that used on the 488 and it is now much more integrated with the roof of the car, so it is not just an add on, it is fully integrated with the road car structure at the top. That gave us bigger volume and allowed the required distance between the helmet and the 'cage, specifically for tall drivers.

'The pedals and steering wheel are adjustable to better match with the XL seat for bigger drivers and the medium seat for smaller, professional drivers. This was introduced in the 488, but we were forced to review the design to cope with the change in the technical regulations, which no longer allows going beyond the rear rollcage line and reduces the space in longitudinal position for the drivers.'

The steering wheel is multi-functional but the digital read out is mounted on the dashboard in order that amateur drivers are still able to read the data, even mid-corner. The wheel itself is programmable and from there the driver can select traction control, abs, pedal and engine maps and launch control settings, alongside the more commonly used dials for pit speed limits and radio. A rotary dial with the Prancing Horse in the middle of the steering wheel allows up to 12 layers shift for each button, extending the functionality to the utmost level.

In terms of safety, the racecar will use the front and rear crash structure of the road car, which are sufficient for it to meet the crash testing requirements of the GT3 regulations.

Aerodynamics

The donor 296 is completely different to the 488, but the team has made the most of its new design approach under the skin to make the top surface of its new car more efficient. As mentioned, the radiators are smaller than previously used, which means smaller air inlets and greater efficiency.

Carried over from the 488 Evo kit is the high lip concept on the front splitter, which helps to feed air to the rear diffuser. While the front downforce numbers are therefore compromised, the approach helps the car's overall balance, as Cannizzo explains: 'It is easy to grab front downforce, but that will kill the rear downforce. The compromise is to have the right aero balance between front and rear, but more than that, the minimum pitch sensitivity of the car. The car can change attitude without changing the aero balance and that is minimised in this design.'

> 'A lot of work was done to optimise the applicability of the car for bigger drivers, which was not easy for us considering the constraint of the cockpit from the technical regulations'
>
> *Ferdinando Cannizzo*

One of the most identifiable changes is the rear wing mounting that is now a swan neck design, with the fixing points arching towards the rear of the car and mounting on the top surface of the wing. The rear wing end plates are similar in size to those on the 488 GT3 but with a different trim to avoid adjusting position for each angle of attack.

While others have mounted the rear wing from the rear, retaining clean airflow to the leading edge of the wing, Ferrari decided that approach was of minimal advantage.

'We have changed the pick-up points, so to hold the wing from the top and not the bottom. That is the biggest change on the car,' says Cannizzo. 'You can say that having a clean leading edge on the

Aerodynamic package includes a high lip front splitter feeding a large rear diffuser and a new, swan neck-mounted rear wing. The design concept is to optimise balance and minimise pitch sensitivity, making it a more driveable car for amateur drivers wing makes it work better, but overall, we have explored that possibility and, in terms of packaging, we found this to be much better in terms of minimising the weight of the overall wing assembly.

'This is also quite stiff, and it complies with the technical regulation that the wing needs to be rigid, and not have any compliance. From a pure aerodynamic perspective, I don't think you would gain much by cleaning this area of the wing.'

The different trim on the rear wing end plates means the wing can be adjusted without needing to move them up or down to comply with the homologated box.

The team has also increased visibility at night through improved lighting from the car. The standard lights produce the same number of lumens as the 488 fitted with the complete 24-hour race package, and so on the car's debut at Daytona in January with an all-new light package, the Ferrari drivers will benefit from a greater depth of view.

'It is easy to grab front downforce, but that will kill the rear downforce. The compromise is to have the right aero balance between front and rear, but more than that, the minimum pitch sensitivity of the car'

Ferdinando Cannizzo

Assembled by ORECA

The other major change for this generation of Ferrari GT3 is that French team, ORECA, won the contract to build it and support customer teams, replacing Michelotto. ORECA has since ramped up its facility in Signes to meet what is expected to be high demand for the 296 GT3.

Ferrari designed the new GT3 car in house at Maranello, and used the expertise of ORECA to finalise the concept.

'The major role for them was to finalise the design, which is what they have done, and assemble the car,' confirms Cannizzo. 'Ferrari is taking care of the concept choices, and the first design of the car. We changed the equilibrium by outsourcing the [rest of the] job.

'What ORECA gave us is a different perspective and new ideas, things we have integrated into the car. They are very experienced, and this combination of fresh eyes gave us a lot and the integration was very good.

'We worked together to overcome the weak points of the 488 GT3, mainly by simplifying the general layout and the bodywork assembly, as well as cleaning up the electrical wiring to facilitate pit operations, improve mechanics' assembly and reduce time and repair costs.'

The final design of car can be split into three parts: the front splitter, bonnet and bumper that can be easily detached to allow access to the front suspension and braking system; the main chassis that is designed as a monocoque; and the rear engine deck, bumper and diffuser. Removal of this allows access to the engine, gearbox and rear suspension, Ferrari hoping that the days of mechanics upended in the engine bay to work on its cars are behind them.

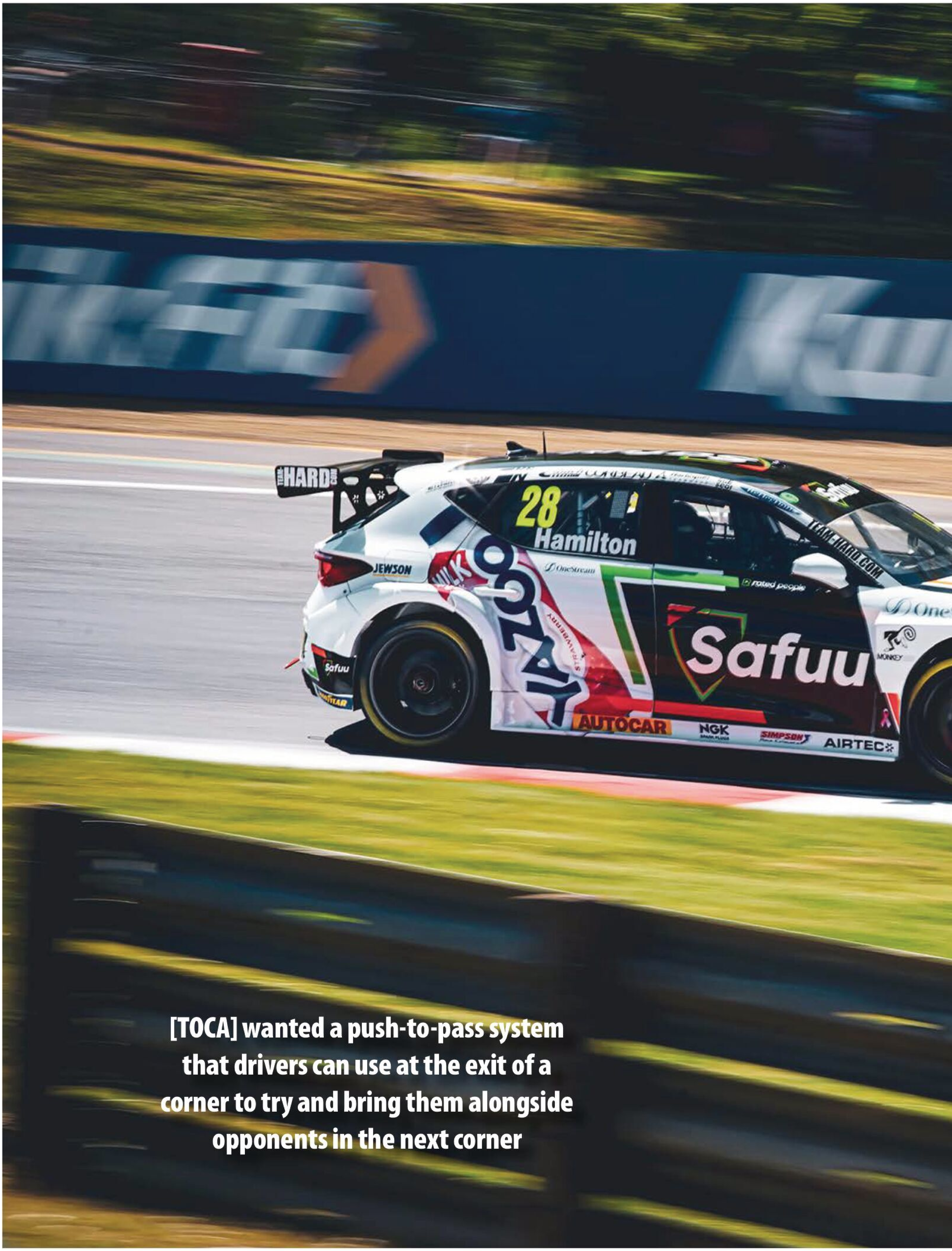
The overall result is a car that should be a step change improvement compared to the 488 it replaces.

'We worked in all areas that are not constrained by the regulations or monitored by the Balance of Performance, such as weight distribution, dynamic stability, aero sensitivity and suspension design that allows us to exploit the most from the tyre usage and improve consistency. These are the areas we focused on at the design and concept stage,' concludes Cannizzo.

'The other point we are trying to improve with the Prototype approach is to design the torsional and bending stiffness of the car. Starting from the front crash structure, chassis, engine and gearbox were all considered at the same time in order to have a clear target for the entire car. We were able to simplify the design to reduce the running costs of the car, too. That was something important for our customers.'

The car will continue track testing through the remainder of 2022, and will hit the track for the first time in competition at Daytona in January 2023.

Photos: Francis Bradfield, Cosworth unless stated



[TOCA] wanted a push-to-pass system that drivers can use at the exit of a corner to try and bring them alongside opponents in the next corner

On the button

Designed to replace the success ballast previously used in the BTCC, the new Cosworth hybrid package offers a unique solution to hybridisation

By STEWART MITCHELL

At the end of 2019, a tender was awarded to Cosworth by the TOCA-organised British Touring Car Championship (BTCC) to develop a hybrid system for the series. By the middle of 2020, some testing of the system had begun, but Cosworth first had to understand how to build its system alongside the prescribed turbocharged, inline, four-cylinder ICE.

Rob Morrow, now at Delta Cosworth, was initially project leader but handed over the reins in mid-2021 to Richard Woodgate, lead applications engineer at Cosworth, who was put in charge of the hybrid system and integration of it with the Cosworth 12V electronics. Based in Cambridge, UK, his role is purely working on the BTCC project.

Design philosophy

TOCA's primary target for the hybrid drive was 15 seconds of deployment per lap when the system was available to a given driver. This should translate to that car gaining 15m within those 15 seconds, assuming a corner exit speed of 100km/h. The organising body didn't want it to act like a DRS, only being deployed in some regions of the circuit and only rewarding chasing drivers, as it believes this overtaking is too fabricated. Instead, it wanted a push-to-pass system that drivers can use at the exit of a corner to try and bring them alongside opponents in the next corner. However, the driver in front would also be able to push to defend that position, keeping the racing close.

Cost was a significant consideration for the system. TOCA placed a lease cost limit on what the tender winner could charge. It was therefore evident a custom design would not be appropriate because the cost would have run out of control.

'The motor, inverter and ancillaries needed to be mostly off-the-shelf components for cost reasons,' confirms Woodgate. 'The only component that sits outside is the battery, which has been designed uniquely for BTCC by Delta-Cosworth.

'Because this is a hybrid system, and it isn't the primary drive for the vehicle, peak efficiency isn't the main driver for the specification. We needed a system that can deliver the required lap deployment duty, and only push enough energy back to the battery so we can recover a portion of that.

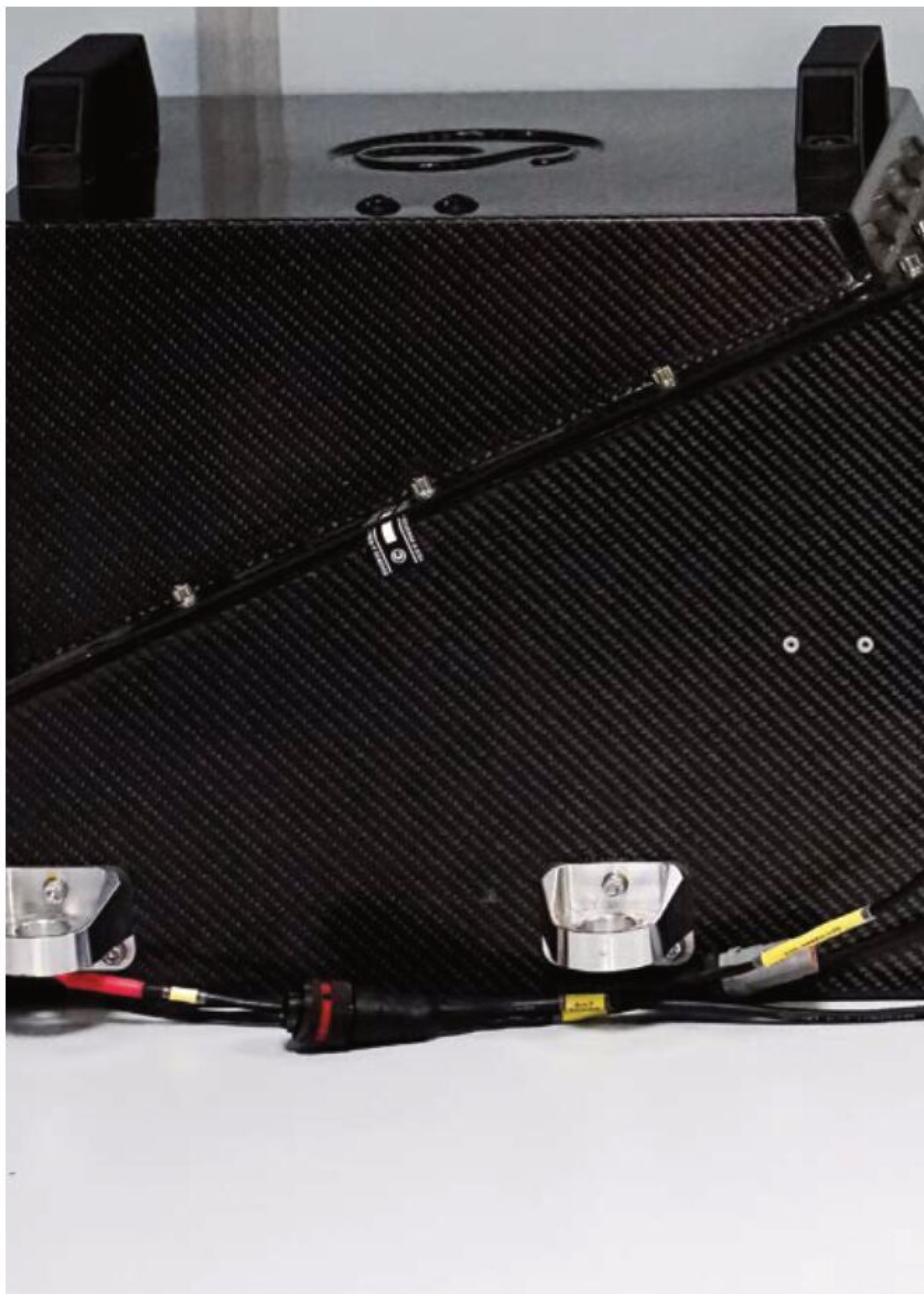
'So, the considerations are slightly different compared to what other hybrid and electric race series demand.

'We have managed to use a couple of suppliers and produce a safe, cost-effective system that meets all the targets.'

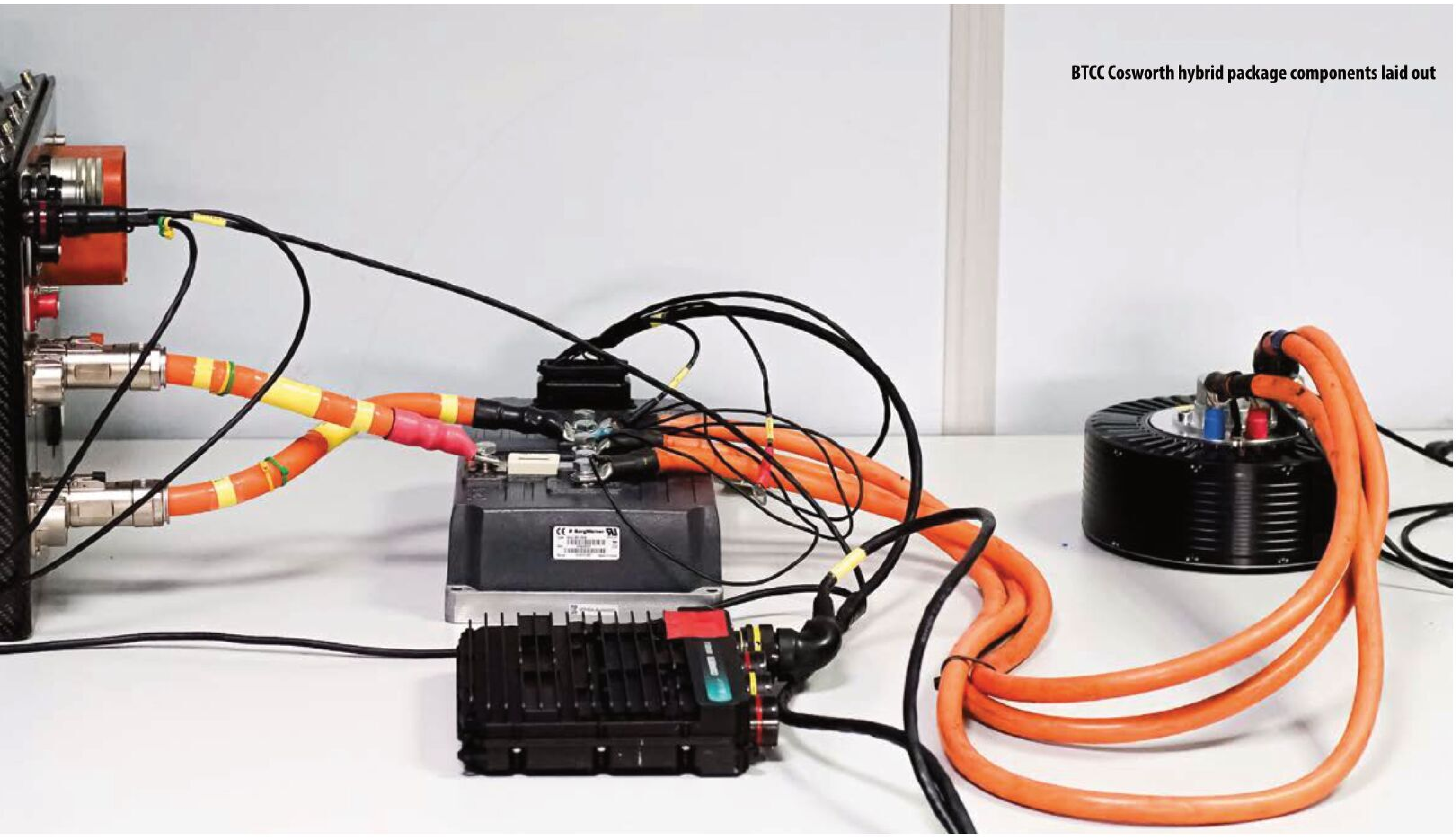
System specification

'Cosworth hybrid package' is the official name given to the system developed by Cosworth. It is based on TOCA's requirement for low voltage (sub 60V) and, uniquely for a motorsport hybrid system, is designed to replace the BTCC's success ballast concept, allowing it to be a racing tool rather than just a marketing gimmick.

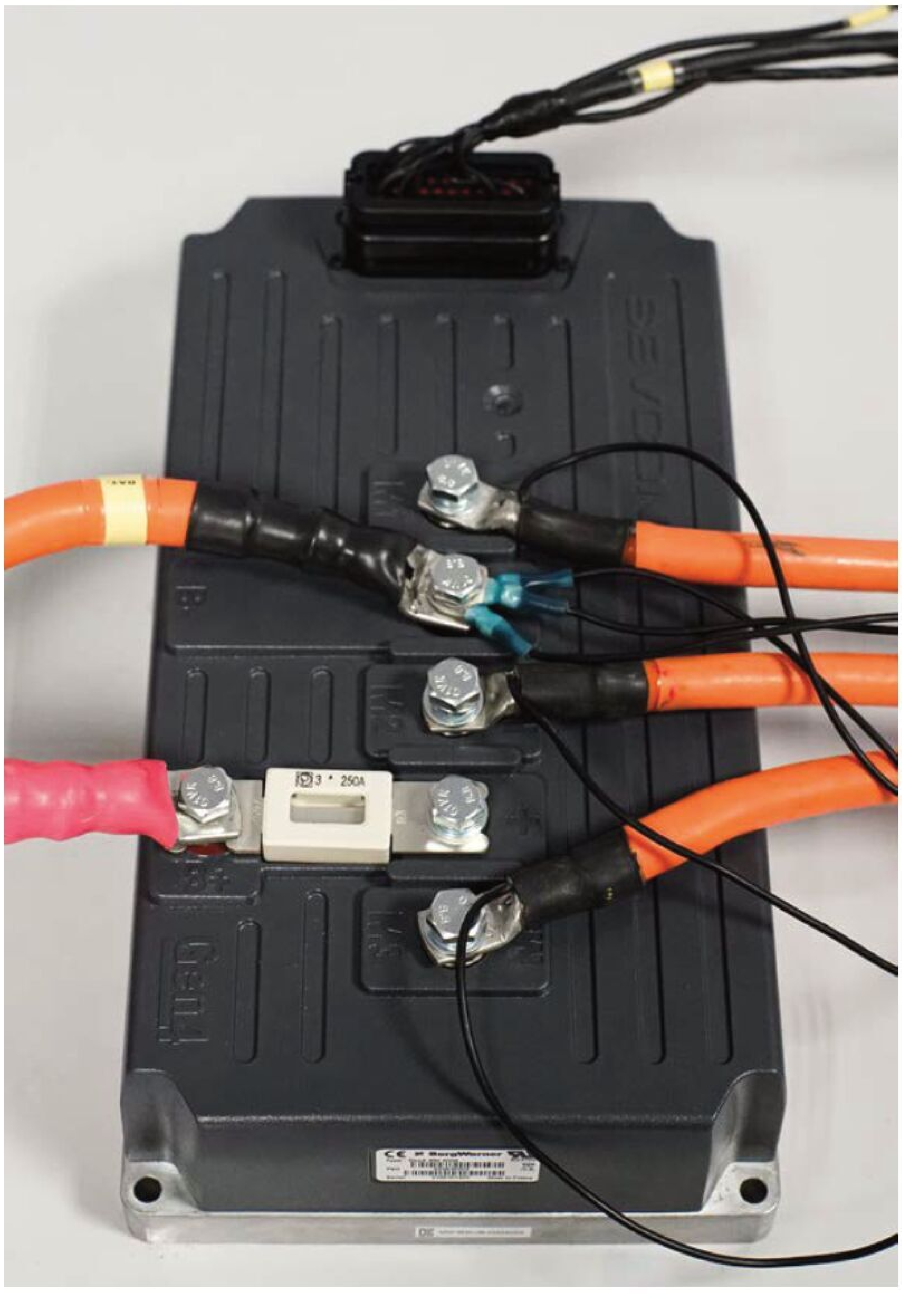
'BTCC is famous for its overtaking, and TOCA didn't want to lose that,' highlights Woodgate. 'Also, TOCA chose a low voltage operation for ease of use. It means they (teams, marshals and event organisers) don't have to go through high voltage training, acquire specialist equipment and so on.'



The 1.7kWh total capacity Delta Cosworth battery



BTCC Cosworth hybrid package components laid out



Above: the heart of the system is an EMRAX 188 external rotor, permanent magnet, three-phase electric motor

Left: the Sevcon Gen4 MOSFET-based inverter

Anything below 60V is classed as low voltage, and the Cosworth BTCC hybrid system's peak voltage is around 56.5-57V from the battery. Running range is between 43 and 57V, with a nominal average about 51V.

The motor is an Emrax 188 – an axial flux, external permanent magnet rotor unit. In terms of control, three phases were deemed sufficient for the application on cost grounds.

'Obviously, six phases would be great as then you can share your current across more phases, but we were limited by what we could buy off the shelf,' explains Woodgate.

The motor weighs just 7.3kg and produces 30kW of continuous power and a maximum 50Nm of continuous torque, with a peak of 90Nm. It's relatively small too, being 188mm in diameter and 77mm deep. In other words, 'an ideal package as an off-the-shelf solution,' as Woodgate describes it.

The axial flux architecture was chosen for speed matching alongside the ICE as the motor is mounted in parallel to the gearbox, driven off its input shaft. As such, it had to be rpm matched to the engine, and uses what is known as P2 parallel off-axis hybrid architecture, a highly flexible way of facilitating parallel hybridisation.

More specifically, TOCA and Cosworth decided to build the BTCC hybrid unit in a P2 off-axis drive module configuration at a 1:1 ratio, which sees the electric motor drive parallel to the crankshaft axis for a more compact axial package. This minimises the changes necessary to implement it with the existing internal combustion engine and transmission. The design offers compatibility with the series' racing transmission, and addresses the tight packaging requirements of the BTCC drivetrain.

'When the tender process went out, we looked at all the available packaging on the gearbox,' says Woodgate. 'We chose this solution in terms of power for the voltage range, and its power output is suitable for the speed range. So that was the key winning combination of factors.

'This axial machine bolts through the centre, and the rotor spinning around the outside gives us a higher torque delivery for the size. That was our main reason for choosing it.'

The continuous power figure of 30kW is achieved most efficiently at 4500rpm, but it can run up to a maximum of 8000rpm for a few seconds with the magnetic field weakening. Being direct drive with the ICE, the electric drive will spin at engine rpm, which, for 95 per cent of a BTCC car's on-track life, is between 4000 and 7000rpm.

'Under deployment, we adhere to our current limit of 650 amps, so we're creating a power limit based on that,' says Woodgate. 'We're normally around 25kW output, which equates to about 43 to 35Nm of torque through that speed range.'

The motor controller is a Sevcon unit supplied by Voltsport, which also performs the calibration.

'It's not Formula E performance levels, but it's quite efficient,' notes Woodgate. 'We see 96 per cent efficiency out of it. We couldn't find anything in the price bracket that will do a better job, so we are happy with it.

'The Sevcon unit controls the motor directly and is a slave to the Cosworth Antares 8 vehicle control unit [VCU], which runs all systems onboard the car. The Antares 8 VCU controls all the torque demand to and from the hybrid system, and the Sevcon unit delivers what we need to or from the motor, and manages the switching accordingly.'

The axial flux architecture was chosen for speed matching alongside the ICE as the motor is mounted in parallel to the gearbox, driven off its input shaft

The switchgear inside the Sevcon unit is simple but effective MOSFET technology, with a switching frequency of 12kHz, specified based on the BTCC duty cycle.

Battery technology

The battery design is based on automotive systems, and the BMS software carries a standard automotive safety layer. The battery has been developed around high voltage principles and contains all the necessary interlocked connectors and a manual service disconnect so engineers or marshals can isolate it quickly and easily.

The British Touring Car Championship adopted hybridisation in 2022, becoming the first Touring Car championship worldwide to do so

Daniel Osei, control systems engineer at Delta Cosworth, working on the BTCC hybrid system

The BMS also carries out isolation monitoring and automotive standard safety protocol while in use.

'We've kept the high voltage systems for this battery because our thought is, in the future, if BTCC wanted to go to a higher voltage, then people will already be familiar with a certain level of safety involved,' highlights Woodgate. 'So, it's trying to future proof it a little bit there.'

Cosworth chose the capacity based on the drive cycle TOCA proposed. That battery contains 14 cells in one string and produces 1.5kWh useable capacity and 1.7kWh total capacity. Safety standards drive the dimensions and location of the battery (alongside the driver). There's an unoccupied volume inside it so, if there's a significant impact, the unit has a built-in amount of deformation before anything inside is affected.

Although the battery architecture is quite conservative, it uses a lot of the knowledge Delta-Cosworth has amassed from developing electric powertrain for both the automotive world and bespoke high-performance racing machines. The cell sourced, and their packaging, are all designed to make the liquid cooling system as compact and light as possible, as well as meeting the low cost target of the BTCC.

'The battery is a massive credit to the Delta-Cosworth team because racing batteries are a difficult thing to design, manufacture *and* make reliable,' says Woodgate.

Like much of the rest of the system, the BMS is an off-the-shelf product too, and communicates directly with the Antares 8 onboard. It reads individual cell temperatures and voltages, and implements derating, should it be necessary.

'We have a private network in the car, which is for the battery inverter and the Antares 8, and has several CAN outputs,' explains Woodgate. 'So, we use one solely for the hybrid system.'

On track, deployment is around the 450A mark. 'It's a lot because we are a low voltage system,' notes Woodgate. 'This system could produce the same amount of power at a higher voltage and be much smaller, and probably quite a bit lighter, too. But when cost is key, keeping design limits in place is important.'

In terms of battery longevity, Cosworth calculates there will be three seasons before they see a drop off in cell performance. Batteries are returned at the end of a season to be tested and validated against original profiles, to ensure any drop off is within acceptable limits

'We'd like to stick to that if we can, because we don't want to be replacing cells often,' continues Woodgate. 'Across 30 cars, that's a big task. The system's longevity and reliability are essential when it comes to one-make series. It needs to be set up so teams can look after these cars and get the same performance each time they press the button.'

'We see 96 per cent efficiency out of it. We couldn't find anything in the price bracket that will do a better job, so we are happy with it'

Richard Woodgate

To stop the various electronic control systems meddling with each other's signals, electromagnetic interference (EMI) shielding also needed to be considered.

'Shielding is something we've had to design into our wiring looms to try and protect against EMI as best we can,' says Woodgate. 'EMI is a very complicated subject that normally an automotive manufacturer would spend a huge amount of money on, placing components in specialist chambers and having it measured. We don't have the access, or budget, to do that. So we've just had to, from the outset, add insulation on our chassis harnesses and screening on all our analogue inputs and CAN networks.

'We've taken a bit of a belt and braces approach to try and minimise our noise interference into the 12V system because that's where data is extracted from. We don't want that to be covered in EMI. And so, careful consideration of grounding, trying to make sure we don't have any ground loop issues has been a big part of the programme.'

Regarding the configuration of sensors and telemetry, the BTCC limits what the teams are allowed to take off the car. The onboard sensor arrays are the standard set of racecar inputs you'd expect – dampers, steering, speed sensors and so on. There's also an inertial motion unit on the car measuring *g* force in three axes. The ICE also has its sensor suite, with all required measurements of temperature, pressure and flow rates, while inside the battery is an independently designed onboard temperature monitoring unit run by the BMS – although no telemetry access to the BMS is allowed.

Slave operation

The hybrid system runs in what is known as a slave operation. 'It's not using its onboard VCU,' explains Woodgate. 'We do all the vehicle control within our Antares 8 ECU. This means we can manage what the system will do more accurately and then pass torque demand across to the inverter. We knew that we didn't need to have all that processing power onboard the hybrid unit, we just needed a product that was going to be reliable, easy to fit and cost-effective.'

Ease of use was critical for the BTCC project too, and the last eight months of testing have been dedicated to that.

'There were a lot of procedural elements that needed to be captured and covered so teams didn't have to worry about that,' confirms Woodgate. 'It needed to be that the car looks after itself and all the teams have to do is just switch it on.

'BTCC has been on an electronic suite for the last 10 years, and the cars have been brilliantly reliable. Teams have become used to that, and they expected that in 2022. We knew it would be difficult with a completely

'It needed to be that the car looks after itself and all the teams have to do is just switch it on'

Richard Woodgate

The 23kg Delta Cosworth battery pack is positioned alongside the driver, with all the regular safety protocols adhered to

The three-phase electric motor is mounted in the P2 off-axis configuration inside all entries in the British Touring Car Championship

new generation of cars, and a completely new generation of electronics. We knew teams would have a steep learning curve getting to grips with new 12V systems, let alone having a hybrid system off the side of it. For this reason, we made the system standalone, so it looks after itself as far as possible.'

Safety by design

Some of the design for ease of use includes procedural elements, such as being unable to switch the car on and start the engine before the hybrid battery has closed its contactors. Because the motor unit is directly driven from the gearbox input shaft and uses a permanent magnet, as soon as the engine is started, it starts generating energy. If that happens before the battery contacts are closed, the inverter knows this is a problem and will go into fault mode immediately.

In terms of calibration of the hybrid machine and inverter, an independent supplier takes care of that so, again, it is a 'fit and forget' situation. The calibration of the inverter, which Voltsport carries out, is quite conservative regarding how the deployment and recovery demand is tuned. This is so it doesn't run into system limiting factors, whether thermal, speed or load.

The Cosworth Antares 8 control unit is ultimately in charge of the torque demand, as Woodgate explains: 'We've created our torque generation maps based on pedal demand, speed of the motor and the current limit of the battery. We also know there are some other physical limitations, such as we can't surpass 650A DC. And then, if the battery temperature increases and current becomes a limitation, we start to adhere to that. We can back calculate our power into torque, and that's how we're sticking to a limitation.

'Ultimately, we're always asking the maximum we can achieve from the system when we deploy, but there's a bit of safety margin in there.'

In terms of that margin, the BTCC hybrids have been achieving the proposed 15m advantage over 15 seconds of deployment at 25kW. That's ideal for Cosworth as it means the system has a little headroom, and the losses caused by standard switching, and the mechanical losses from the electric machine into the system, are a little bit less. This has the knock-on effect of not pumping quite as much heat into the cooling system, and consequently the system operates more consistently throughout the race, even as things heat up.

'Being conservative for a spec system is always safer because we need to be able to achieve the reliability expected here,' highlights Woodgate. 'We're still making the right amount of power to achieve the target advantage. This also means we could calibrate this system for higher output, should the rulebook want to, for example, go for a longer hybrid on-time per lap, or increase the torque output.

'At the minute, deployment makes for roughly 20 per cent hybrid system duty per lap it deploys. If we started to push that any further, we'd have to reconsider our regeneration balance, which is currently set at 12 per cent duty over a lap.'

Strategy element

The system's regeneration is designed this way so an element of strategy is required for all the teams with hybrid deployment capability. Towards the end of the race, drivers will run down the battery's state of charge (SOC) so, even for teams who have the full 15 seconds per lap deployment for the race, by the time they reach the chequered flag, they will be starting to run low on SOC. Those with fewer deployment laps must decide whether they choose to deploy early or later in the race, making sure they maximise their available deployment.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'Strategy has been lacking in BTCC in previous years because, generally, all the cars have been so competitive. It has just been all-out racing,' says Woodgate. 'That's good because it's what makes the spectacle, and the new cars haven't changed. It's just they've got this edition now with the hybrid. How drivers and teams decide to use it on top of the already exciting racing adds another dimension.

'Most drivers and teams are now starting to realise when is the best time to use the torque available. On some circuits, it seems obvious, but on others it is still a challenge. Some teams have employed people to help them make the most of it, and others have to learn it race to race.

'Additionally, TOCA does a good job of keeping the parity between the internal combustion engines so close that it is obvious when drivers use the hybrid.'

During a race, the status of the hybrid system is indicated to the driver on the Cosworth display in the cockpit. LED light panels in the side windows are used to display hybrid activation to fans, but currently have no diagnostic feature for the system

'The choices the BTCC made in terms of data access goes back to having to make the car a very solid, user-friendly machine,' explains Woodgate. 'Because nobody in the pit lane can see the car's status, it needs to flag any issues and then shout the message at the driver.'

Driver input

'With the hybrid system on board now as well, drivers have a lot of new responsibilities, including handling the SOC of the battery, deployment and managing its usage across a lap, and the number of laps they can use it. The Cosworth display shows everything on the screen in front of them, but they have a job on their hands now.'

When it comes to using the hybrid deployment, there is a specific window within which it can be deployed, and Cosworth has tried to make it as simple as possible. The driver must meet certain criteria, including throttle position, speed and gear before using the electric drive. Once they've achieved that, all they do is push a button.

A blue lightning bolt illuminated in the window indicator shows fans and spectators when the hybrid system is being used

'Teams are allowed to build their alarms, messaging, lights or whatever they want to indicate to the driver that they can deploy,' notes Woodgate. 'A lot of them have gone with a status LED that, when lit, means the driver can deploy. However, also managed in the software is a penalty system. If the driver presses the deployment button below one of those criteria, it adds a delay before deployment engages. That is to prevent drivers sitting on the button and letting the system come on automatically when all those criteria are met, taking out the driver element.'

What the system does take care of automatically is the 12 per cent regeneration per lap. TOCA didn't want teams to be able to calibrate or adjust that. Regeneration occurs off throttle above a specific rpm and below a certain amount of throttle. Part of the calibration of regeneration was to ensure the car's deceleration felt natural.

'Our biggest concern was rear-wheel drive regeneration because, obviously, the characteristic for the front-wheel-drive is that we could probably put more torque across the front axle and not affect braking at all,' says Woodgate. 'But with rear-wheel drive, where weight transfer takes place, the driven axle gets lighter.

'The fact is, we can generate a maximum of about 20Nm of torque under braking with both in its current configuration if we need it. We could increase it to 35 or 40Nm of brake torque and start to pull back nearly double in terms of power with this system, but this first season is set out already, and again we are being conservative.

'Most drivers have said, with the system off or on, they can't feel the regenerative braking input at the wheel.'

A small amount of contact is always expected within the very close racing environment of the BTCC, and this formed part of the development process.

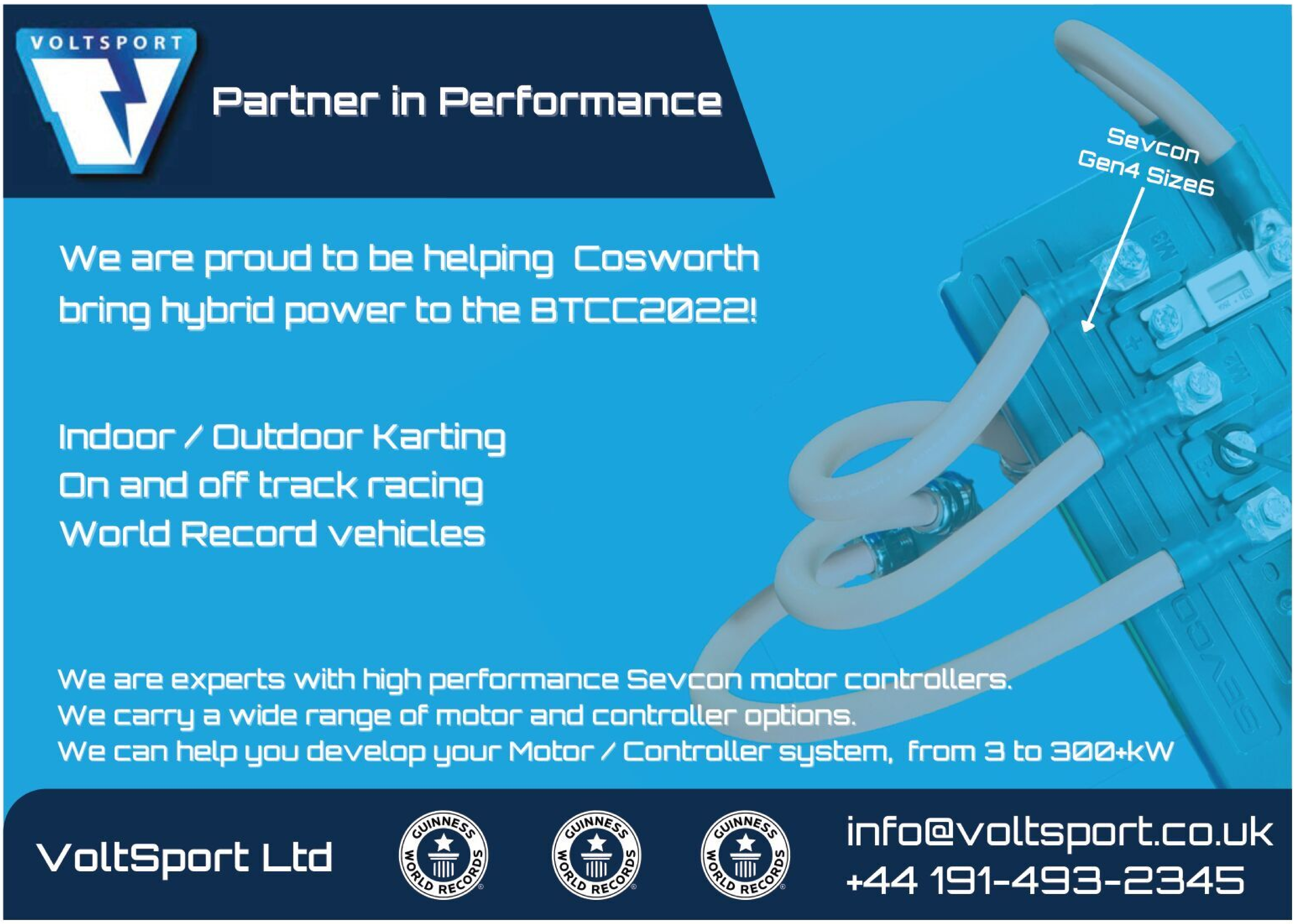
'Crashing was one of our biggest reliability concerns, having two radiators in the front bumper,' says Woodgate. 'Front bumper real estate is hard to come by with a turbocharged ICE with an intercooler and radiator already. So all the available frontal area is used for that. Our coolers are a lot smaller and are fitted under the subframe on the corner extremities.

'Sadly, there's not a lot you can do if, or when, an on-track incident takes place. You'll probably be okay if it's one lap from the end of the race. If it isn't, then you will probably have to come in. That's just a factor of racing in the BTCC.'

'With the hybrid system on board now as well, drivers have a lot of new responsibilities, including handling the SOC of the battery, deployment and managing its usage across a lap'

Richard Woodgate

BTCC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Virtual Lion

How Peugeot Sport and its partner, Capgemini, is using artificial intelligence to gain a competitive advantage on track, but also for the greater good

By ANDREW COTTON

In a Balance of Performance category such as the WEC, any gains that can be found are hard won and of vital inportance. Together with Capgemini, Peugeot Sport is creating a digital twin of its 9X8 racer to help look for them

Making data the absolute truth is the target of the Peugeot Sport team, and motorsport boss Jean-Marc Finot (pictured) believes that it will be a big advantage if perfected

Peugeot has embraced the digital world in the development of its Le Mans challenger, the 9X8, and is now in the process of developing its relationship with supplier, Capgemini, in order to improve the digital accuracy of its World Endurance Championship contender.

Embracing artificial intelligence to analyse large amounts of data coming from the car is not new, but Peugeot Sport is trying to optimise its strategy on track, problem solve during races, and make efficiency gains off track to find performance advantages in this Balance of Performance category.

The relationship with Capgemini and its AI functionality started after the initial design process of the car had been completed. Peugeot Sport created the 9X8 in digital form, comprising 51GB of data and more than 15,000 files. This is not huge, but the ability to analyse each packet of data and process how designed parts would react in the real world was the job of artificial intelligence, backed up by the company's engineers.

Since the digital model was first created, the team has worked with Capgemini to increase its digital knowledge of the car, and have that learning reach into all aspects of the project. Using artificial intelligence, the company aims to eventually reduce the carbon impact of racing in line with the FIA's stated targets for teams, as well as find performance opportunities hidden from the BoP.

Further, Capgemini and the Stellantis Group are aiming to use the learnings of the Hypercar Le Mans programme to improve the efficiency of production car technology.

Digital twin

It's a mammoth job, and the companies are only at the start of their journey together. Although Capgemini has a long-standing relationship with parent company Stellantis, the company was only confirmed as a partner to the race team early in April and admits it is still a long way from creating the complete digital twin of the 9X8.

The use of AI technology in racing is becoming increasingly common, and teams in the WEC have different ways of making it work for them. From the monitoring of parts moving around the world to set-up sheets at the lower end of the scale, AI companies are now helping teams find that hidden advantage over the rest of the field and some have used AI in the development of their cars.

This symbiotic relationship is not exclusive to endurance racing; for example NASCAR is also increasingly using AI technology, and leaned on it heavily to develop its Gen7 car.

Peugeot's 9X8 was already a complicated racecar, with a forward weight bias that allowed the team to design the car without a traditional rear wing. Engineers were confident the digital calculations would match up to reality but, until the car actually ran at race pace on track, there was a niggling doubt that it would actually work. Fortunately, the figures *did* match up, which meant Peugeot Sport could continue with its idea of developing the original concept.

Capgemini and the Stellantis Group are aiming to use the learnings of the Hypercar Le Mans programme to improve the efficiency of production car technology

Before it became a real car, the 9X8 was created in entirely digital form, allowing engineers to use artificial intelligence to analyse and process its various systems prior to building any hard parts

Digital technology and the calibre of our simulation tools… [meant] we were already familiar with the theoretical performance and behaviour of the car

In fact, so accurate was the digital data, the company said there were no surprises in the initial testing phase.

'Thanks to all of our software, we have the ability to envisage a wide range of dimensions, shapes and materials, and work on the weight of the car in line with the technical regulations,' commented Francois Coudrain, vice president WEC power unit and chief engineer at Group PSA Motorsport. 'As with the choice of base concept, being able to take a purely digital approach to trialling systems and components allows us to assess a large number of potential solutions, which would quite simply be impossible to achieve in the real world.

'Before taking to the circuit, our Hypercar was for a long time stored on a hard drive. There is one other thing that should be noted: digital technology and the calibre of our simulation tools enabled us to gauge the interaction between different components and systems, meaning we were already familiar with the theoretical performance and behaviour of the car before testing it for real.'

That thought process is backed up by Stellantis' director of motorsport, Jean-Marc Finot: 'Artificial intelligence is an invaluable tool for dissecting the tremendous amount of data to be found on a racecar.

'Our 'big data' processing applications enable us to simulate a large number of different hypotheses, helping us to see if we need to modify the design of any parts to meet our target values. It is only once we have defined the characteristics and simulated performance in a variety of environments with a wholly digital car that we begin the manufacture of its physical parts.'

The first stage of the process is to map the racecar. Although the car has been designed and developed in the digital world, real-world applications are slightly different. The FIA World Endurance Championship reduced the number of data channels coming from car to pit this year, which means the teams have less data to work with while the car is out on track in race conditions although testing is a completely different proposition.

Building information

As this is Peugeot's first year in the championship, the team does not have the same testing restrictions as Toyota, for example, which has been competing in the WEC under the Hypercar rules for more than a year. As such, Peugeot can run more sensors on the car when privately testing. Following its competition debut at Monza, and with races at Bahrain and Fuji scheduled, Peugeot has the advantage of taking real race data to the test track and validating it.

Monza was, for example the first time the 9X8 ran with any others on track at the same time, so dealing with debris and traffic was all part of the learning experience.

'When we test the car, we can put on all the sensors we want, but they are limited in racing,' confirms Finot. 'We are building the information with virtual information, a statistical algorithm database to have information as close as possible to reality.

Data channels are reduced compared to the LMP1 era, but Peugeot Sport is not bound by the same testing regulations as it is in its first year, so validation of the Monza race can take place

Capgemini is able to accurately create a virtual car, which can then be used for the development in the simulator

Toyota's Kamui Kobayashi was an interested observer of the Peugeot 9X8 Hypercar at the Monza WEC race in July

'We didn't start yet, but we are also thinking that if we have any issue on the car, we can rebuild the virtual sensor on the car to carry on racing.'

What all that means is that Capgemini is able to accurately create the virtual car, which can then be used to problem solve on the real world car should a problem arise.

'We are talking about a virtual twin,' explains Portier. 'It is a totally virtual twin of the car inside the data. In order to make all the simulation that you want to do, test something very quickly, test and learn, that is one of the targets we have, and we have already had some good results.

'The first thing to do is to collect the data. You see there are so many points of calculation so you need huge data capabilities, storage and management. From one race you have one set of data, and you need to multiply it and track and trace it. You have to find the data quickly, and compare it.'

Prying eyes

The enormous amount of computing power then also has to be protected from prying eyes and from hackers, and so security is also a top priority for the team.

'We had some assets that are IP from Capgemini and we delivered it to motorsport for this, which was mainly how to use more efficiently the Cloud capability,' says Portier.

'The second issue is to make this data into something understandable by the team, so computing the data, cleaning the data, classifying the data. This is pure data engineering. The second part [of the process] is to analyse the data through classic analysis, and on top of that put in algorithms, to work not from a statistical point of view but an algorithm, so machine learning.'

With the data 'cleaned' to eliminate anomalies, it is then analysed in detail, and the results narrowed down to manageable clumps, which are then delivered back to the team for implementation on the car. 'The point is how we are tracking the data, from

Embracing technology

Capgemini is a global company with more than 340,000 employees around the world, and is proud to boast that the average age of its employees is less than 34. It is a global leader in partnering with companies to transform and manage their business by harnessing the power of technology at an early stage and has since applied it to various areas of industry, including production cars.

Part of its brief is to help manufacturers head towards carbon zero in terms of design in the digital world, as used by Peugeot Sport, as well as planning, design and build processes. It also is able to calculate the amount of carbon offset that will need to be purchased in order to meet carbon neutrality targets, but it has plans to go even further. The company is currently looking at autonomous driving technology, as well as helping manufacturers navigate a rapidly changing world.

Having already developed a relationship with the Stellantis Group, it was not a huge leap for the company to delve into the racing programme. 'There are multiple phases, so the race itself is the first, the second will be the car for all of us,' says Capgemini's vice president and global account executive for Stellantis, Clement Portier. 'For technology transfer to a real car, there are a lot of topics. One is all about the hybrid, and how to manage a better way between the thermic engine, battery and brakes. What can we take from the race from this technology to improve the efficiency of the car?

'The price of oil will continue to grow, as will the price of lithium. There are topics of autonomous driving. Here we are managing a car on track with 30-40 cars, and so we are learning about traffic. What can we learn from this to put into the scenery of testing and validating autonomous driving?'

Once it is complete, Capgemini's digital twin will give the team an invaluable resource that can be developed in the digital domain

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the simulation, to the test, to the race, and make it seamless,' says Portier. 'During the race it is totally data driven. The data is the truth, that is the objective. And to do this you compile, check, compile, check…'

Making data the truth is not the work of a moment. By leaning on machine learning, it is hoped any mistakes will be factored out.

'Using Capgemini's skills in deep learning we made a quicker calculation, [and created] more room in our ECU to put in new algorithms so that it is now very powerful,' says Finot. 'Sometimes the calculator is not fast enough to get all the information. You can miss something. We can avoid having such issues and we are sure that the information will be taken into account in this management. This increases the power of the calculation without having bigger ECUs.'

'It is a key point working for a big company,' says Portier. 'You have a big Cloud, but that is cold data. During a race you have the calculations from the car, and [although] it is a very small amount of data, you have to optimise the algorithm to be able to run efficiently. It is a very efficient, frugal algorithm.'

Training plan

Having trained the ECU to transmit the required data, and then trained the computer to analyse it at great speed, delivering to the track an assessed and approved set of figures, the next stage is to use the virtual twin to protect the car in the event of a sensor, or mechanical, failure. While sensors are notorious for shutting themselves down, or mis-aligning themselves leading to a car shut down or retirement, the AI technology at play here can help to keep the car running, even in higher risk circumstances.

The plan is to train the system to work within a set of parameters so that even in the event of failure there is a chance for the system to accurately guess what is going on. For example, if the air inlet temperature sensor fails, the engine is not sure what the temperature of air being fed into it is, so might shut down to protect itself. The AI technology would prevent that happening.

'The algorithm can look at the parameters,' explains Finot. 'You can have some historical data, it is not physical, but it is data management in statistics. You can say, for example, on July 8 the average temperature is 32degC. Today, we have between 27 and 35degC without looking at the temperature measurement. By associating real physics with artificial intelligence, it is like our brain.'

Navigating BoP

Alongside these applications, the system is also helping the team to delve into the vehicle dynamics of the car in order to help it extract performance within the Balance of Performance system. Here, again, AI technology can be a help.

'The first row parameters are taken into account, so weight, downforce, drag and power,' explains Finot. 'Then we have the second order parameters, and then we need AI technology [to analyse] how to make the best stint, and go through the system of BoP. AI is very relevant.'

The final aspect of AI technology is reducing the carbon footprint of Stellantis, Peugeot Sport and of Capgemini itself. It's commonly known, although not often spoken about, that taking photos of your lunch or dinner and storing it on the Cloud actually contributes to global warming as that image has to be stored on a server that consumes energy, and then needs cooling to keep it functioning. Cloud computing is not normally associated with global warming, but the vast servers are held in remote locations far away from prying eyes. However, Capgemini is well aware of its own impact and is taking steps to reduce it.

The system is also helping the team to delve into the vehicle dynamics of the car in order to help extract performance within the Balance of Performance system

'We have a carbon net zero road map for ourselves,' explains Portier. 'We have also taken a road map to reduce the carbon footprint of our clients by 10m tonnes of CO_2. That is a commitment we envisge for every client, every project, including what we do for Peugeot Sport and Stellantis. We have to find a way to reduce the impact of motorsport.

'We must reduce requests to the Cloud, because the Cloud has an impact. Having a code for eco design is something we do, it is not new at Capgemini. We have been working on it for two or three years now. We have a learning path for everyone to follow, which is to reduce the impact of what you are typing on the keyboard.'

It's a bit of a leap from development of a racecar in the digital world to reducing the carbon impact of Cloud computing, but the influence of Capgemini can be felt throughout the Peugeot 9X8 project.

Looking further ahead than just racing in the WEC, Capgemini is using the data to collect information on cars running in traffic, which is crucial information for autonomous driving programmes


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Oxford Brookes took a bold step into electrification with its 2022 FS challenger. **Racecar** *speaks to team leader, Ole Ramming, about some of the hurdles the team had to overcome in the car's development*

By STEWART MITCHELL

During stable regulations in most open competitions, design, operation and strategy converge as understanding increases. However, IMechE's Formula Student (FS) is a contest that defies this logic. The technical rules accept various technologies, but the competition itself has been very similar for a long time. Over the years, teams have won the numerous parts of the competition, running diverse technological approaches to realise the FS car. The 2022 Formula Student competition at Silverstone, UK, which took place on 9-10 July, was no different.

Following the Covid pandemic, Formula Student UK was back to full strength this year. The 2022 competition sported some new elements, notably the mandatory inclusion of the expanded Lap Time Simulation event, which will encourage teams to develop vehicle dynamics in a virtual environment.

Powertrain overview

Oxford Brookes Racing (OBR) picked up no fewer than seven awards for the team's FS and FS-AI squads, including the prestigious Formula Student Engineering Design and the Lap Time Simulation (Formula Student Class) awards for their electric FS race car.

OBR has an impressive history at Formula Student at Silverstone, finishing as a top team on seven occasions and holding the record for the most top three finishes of any UK team.

OBR team leader, Ole Ramming, a masters student in Motorsport Engineering, comments: 'Bringing back some silverware is a great reward for all the work our team members have invested in the past nine months. In particular, winning the Engineering Design Award gives us a brilliant foundation to work on for the coming seasons.

'Building an electric car is a very complex challenge compared to a combustion-powered vehicle. The combination of advanced control strategies with our four-wheel-drive system gave OBR's design an edge, standing out from its competitors.'

The OBR squad built its 2022 car evolving on a long-standing foundation. The university has 23 years' experience in FS, predominantly with internal combustion cars, but decided to go all electric in 2019. The first dyno testing occurred at team partner firm, GKN's, facilities in late 2020, with the bulk of the testing taking place throughout the first half of 2021, ahead of the 2021 FS competition.

The team was set to run its first electric car in the 2021 competition, though the number of system operation challenges it faced meant it didn't turn a wheel that year.

'There are always hiccups in developing new racecars, and in 2021 there were enough hiccups to derail it far enough that the car didn't run,' explains Ramming. 'The accumulator wasn't in a finished state. Everything else was fine as far as the electronic system was concerned, and we passed all the electrical checks up to the point where we needed proper accumulator operation. Unfortunately, the accumulator wasn't in a state where we could present it. But we learned from that and got the car to work developing the old platform and transitioning to a new one.'

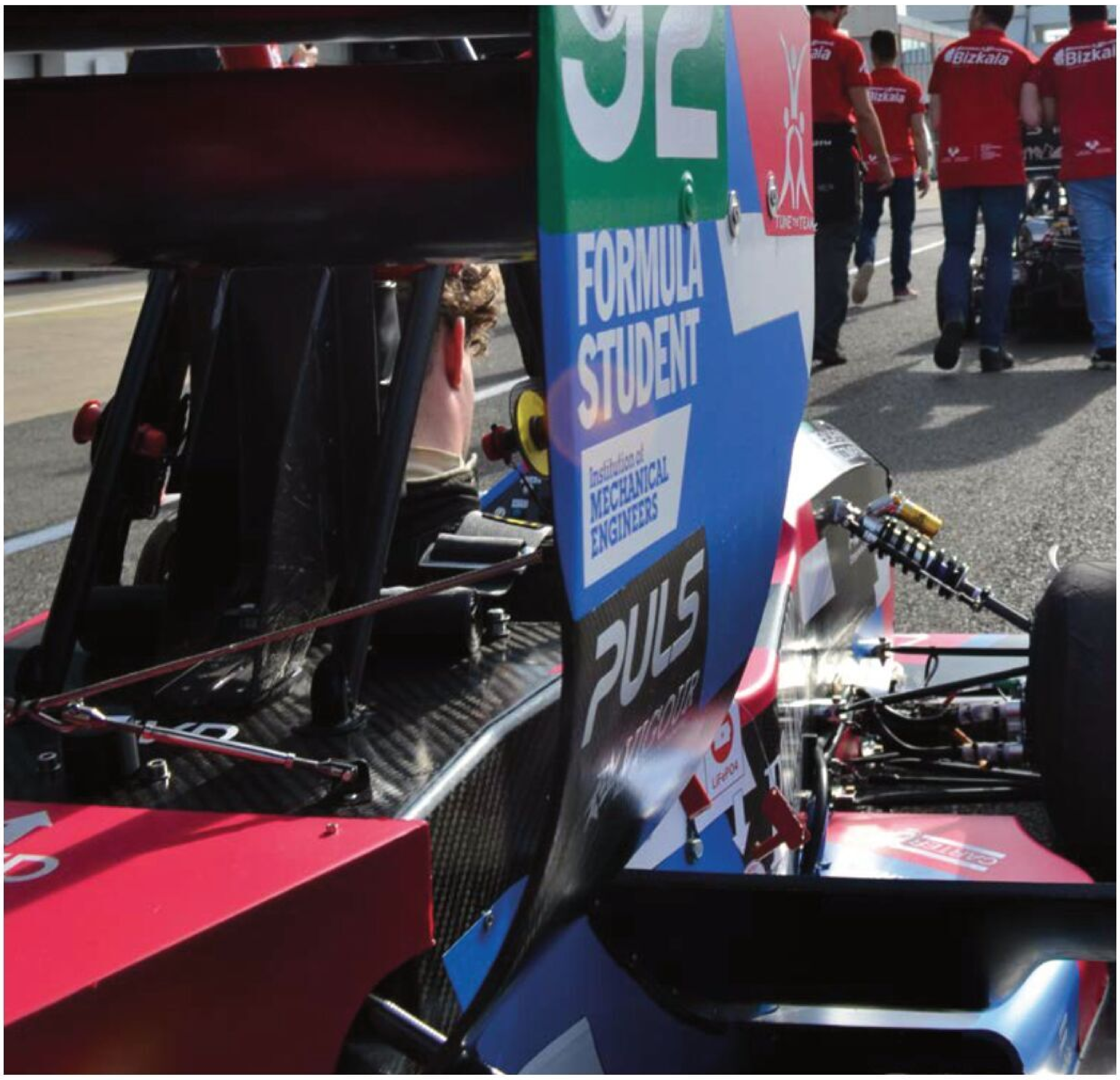
OBR knew the 2021 car's accumulator concept fundamentally worked, validating it and testing it on a pack level. On a system level, the powertrain itself was good. However, there were a lot of issues in terms of communications – mostly CAN bus communication systems. So the team re-worked the wiring scheme, making it much more modular to service it better.

'The previous year's design was a bit of a nightmare, especially with troubleshooting something like communications, as we had two main harness wires going through the entire car and a bunch of strands going from those to every component,' notes Ramming. 'Troubleshooting that if you can't access those connections is quite tricky. Especially if they then interface with the high voltage system. So we re-designed that part of the car from the ground up, and it's now much more stable and reliable.'

The OBR team also made significant structural changes to the chassis to better integrate the accumulator.

'We wanted to change the rear impact structure to integrate directly with the accumulator. It is now permanently attached to the accumulator and holds it in place rather than being separate structures,' explains Ramming. 'Most of the chassis was adapted to support this, including revising the laminates for the monocoque. Fundamentally, it's the same concept but with a higher-grade material.

'Silverstone Composites is our composites partner and advised heavily on re-designing, as well as helping us access other partners.



Oxford Brookes Racing

The car's accumulator is directly integrated into the rear impact structure, sitting in a high-grade carbon fibre case behind the driver

They've got an autoclave that fits our chassis, which was ideal for consolidating the entire structure, leaving room for optimisation thanks to that.'

OBR tested the 2022 car for the first time at the end of Q1 2022. The most critical items the team recognised needed to be checked and calibrated ahead of the competition this year were the electronic loom, communications, safety and stability systems.

[The accumulator] consists of 288 pressurised pouch cells configured in a 144S 2P arrangement with six modules of 100V each

Powertrain overview

The new chassis provides slightly different dynamics than its predecessor because it extends behind the rear axle, and the accumulator sits further back in the car. The centre of mass of the accumulator is slightly in front of the rear axle, providing the desired driving weight balance front to rear.

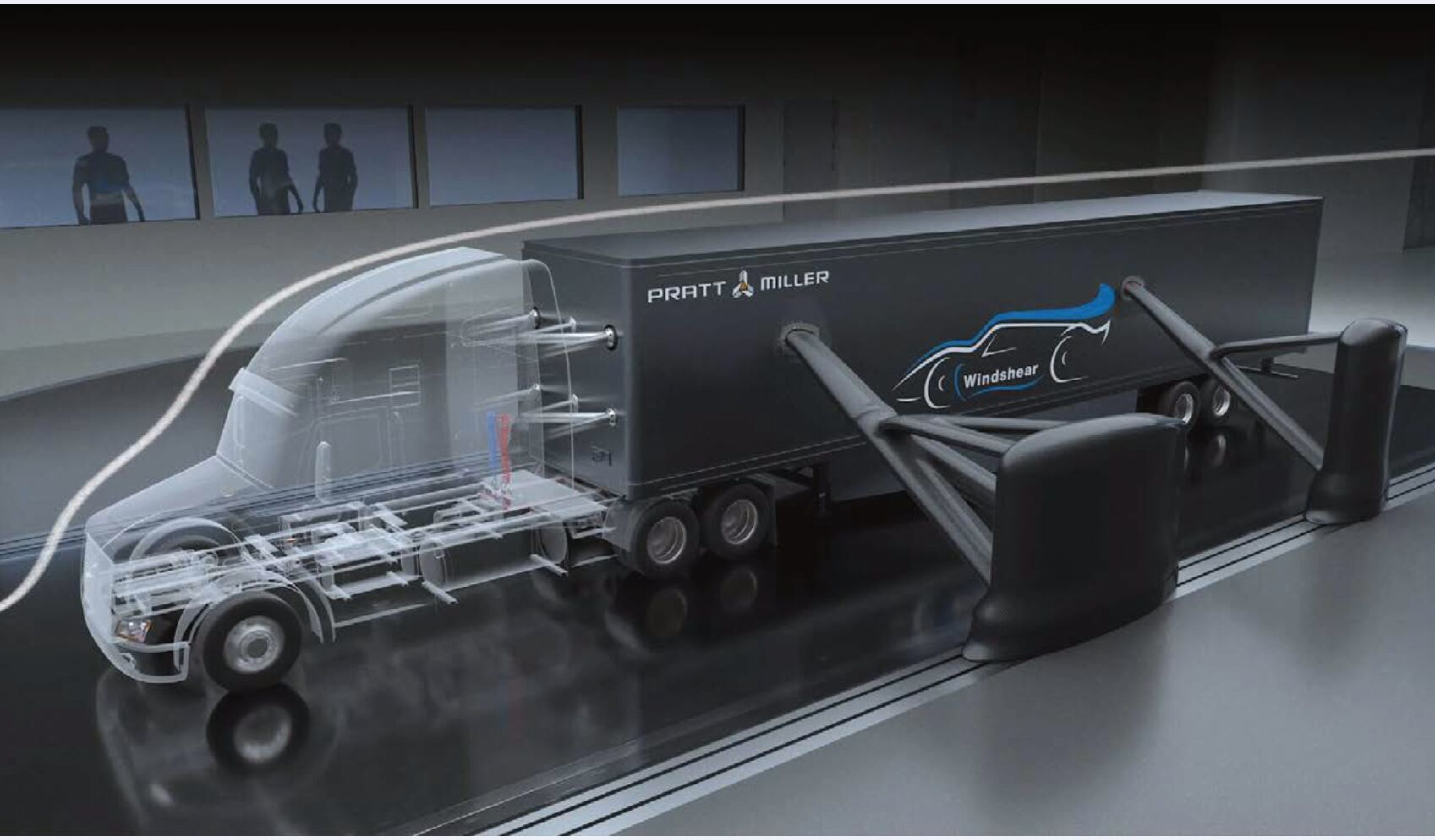
It consists of 288 pressurised pouch cells configured in a 144S 2P arrangement with six modules of 100V each. OBR defined this arrangement from a functionality standpoint. The pouch cell design is convenient for packaging, but can be slightly more challenging to cool. For simplicity, the cells are actively air cooled via a fan, which drives air through the pack at a constant load while the car is in operation.

600V DC bus voltage is the highest allowable in FS for electric vehicles. Additionally, the motor and inverter package are regulation limited to an 80kW peak output. As these systems work more efficiently at a higher bus voltage, the team opted to reach for the top voltage figure.

'To operate the motors most efficiently at the 80kW maximum deployment, we want the highest pack voltage to bring the current down,' notes Ramming. 'Fundamentally, high voltage means low current; that's our chosen trade-off. High current means bigger cable sizing, power electronics, higher operating temperatures and all the other electronic knock-on effects of having high currents, which were unacceptable for our design.'

Pressurising the cells provides consistent and constant performance across the pack in operation (power output in terms of efficiency) and temperature management.

'It runs hardwire logic, so there are many relays, an external disconnect shutdown



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circuit, overcurrent and grounding measurement and protection – similar systems used in electric / hybrid series across motorsport,' explains Ramming.

'We also designed in many failsafes to prevent single points of failure and prevent the car from going live and high voltage if a specific sequence is not triggered. That involves several steps and more than one person. Fundamentally, it is the system checking itself, then the electrical safety officer, or someone outside the car, turning the car on, then giving control to the driver, who also has to confirm that in several steps. At any point, the control system, the driver, or an external person can shut the car off, which then renders the car safe.'

Four-motor drive

The car is four-wheel drive with an AMK-supplied in-wheel motor on each corner. AMK supplies a complete package with both motors and inverters. In terms of performance, they deliver 35kW each and are easily integrated into the in-wheel location.

'Their size means we can package all-wheel drive nicely, giving you access to regenerative braking on all wheels, torque vectoring and other dynamics you want on an EV car,' notes Ramming. 'We considered having the single electric motor with a conventional differential and others that run two motors with a digital differential. But we decided early in the concept in 2019 to go with the four in-wheel motors and build a control system for it ourselves.

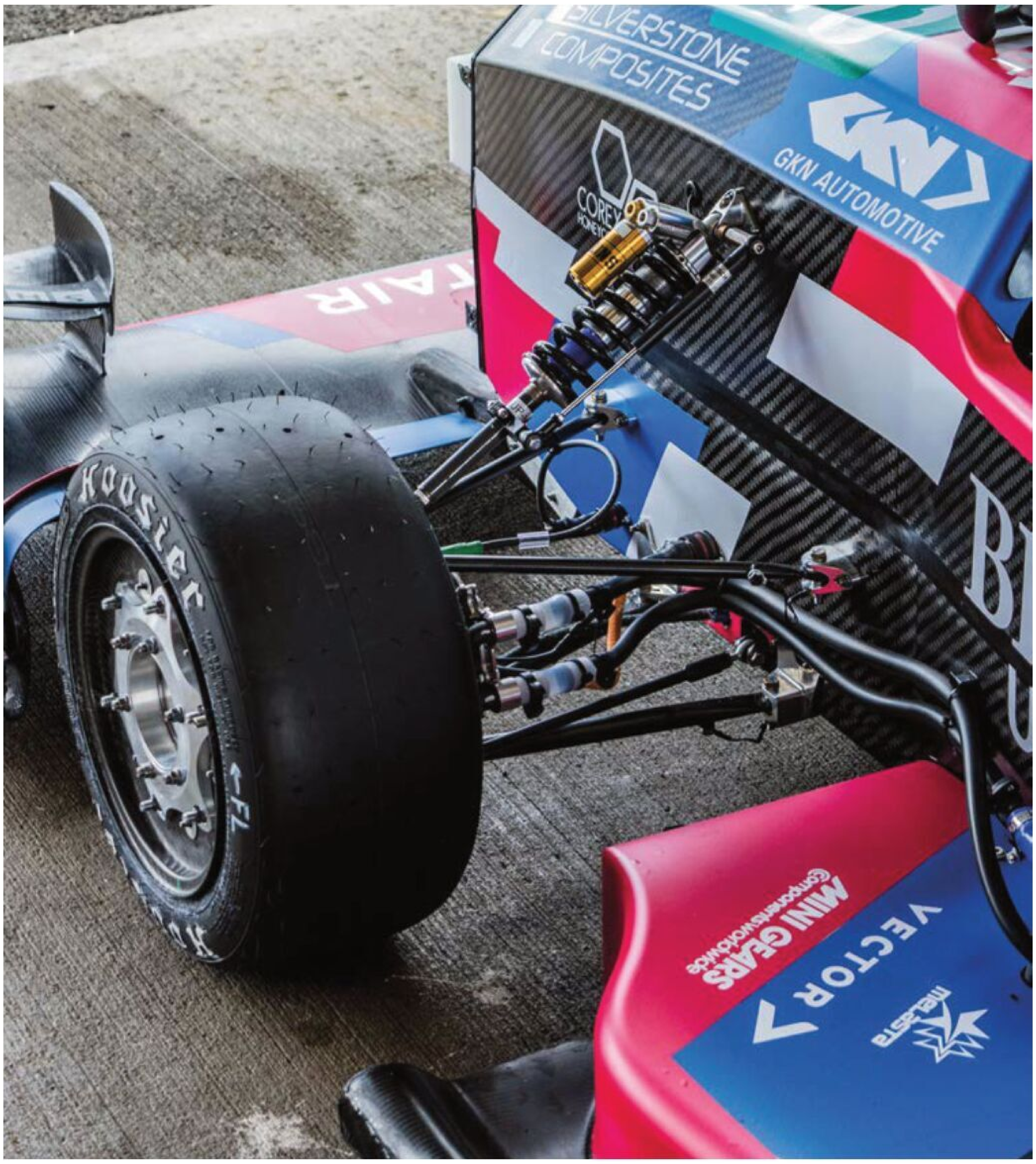
'It's one thing we must consider early because it influences the accumulator pack sizing, the power electronics, the wheel packaging and the chassis packaging. It is a bold step into electrification. It is not just adding the complexity of the EV system in the first instance, but the complexity of in-hub systems and all-wheel drive.

'Several years into the development, we understand the system well enough to exploit its potential.'

An in house-designed torque distribution system independently controls each and makes up part of the vehicle control system.

Regarding cooling the inverters and motors, as a package from AMK, the team receives heat rejection figures and has to design a cooling system to suit. OBR went for water cooling, necessary for the motor type and performance density.

'Being in the airstream around the wheel group components wouldn't be sufficient for the cooling requirements,' notes Ramming, 'but there is too much in the way to get a nice air stream to feed the motors. The inverters are especially hard to cool as they are inside the car. We've got a dedicated inverter circuit and two cooling loops for the motors on each side of the vehicle. It required an additional pump, but it also means the temperatures themselves are a lot more consistent. Much thought, simulation and validation went into developing the cooling system to ensure we stay in the temperature ranges we want.'



IMechE Formula Student

The four-wheel drive car features liquid cooled in-wheel motors. Note the coolant lines from the onboard heat exchanging system

EMI mitigation

Electromagnetic interference (EMI) is a constant battle in any high voltage system with switching frequencies of this magnitude. Much of the mitigation is in the form of a physical shielding between the components that emit or are susceptible to EMI and grounding. OBR carried out a lot of testing on stands and offline to deal with this.

'The placement of electrical powertrain elements makes a huge difference,' highlights Ramming. 'Things like the high voltage cables had to be well thought out in such a small car because there's not much room to position them. Putting them close together, we found, is not a lot of fun. So that's something we learned over the process of actually building it. We initially didn't predict that in the design phase because we had never developed an EV FS car before. This year, we can finally benefit from having done it.'

It is a bold step into electrification. It is not just adding the complexity of the EV system… but the complexity of in-hub systems and all-wheel drive

The front two motors connect via high voltage lines from the car's rear, where the accumulator and inverter are located. The original design saw two high voltage cables run parallel down the car's centre, but without any shielding in between. That caused communications to drop, which then can shut down the signal to the motor, meaning the motor delivered no torque and could deploy no power.

This year, OBR fixed that by adding aluminium shielding between the cables. Copper mesh is used for the inverter boxes and graphene spray on the junction boxes.

We're looking to regenerate quite a high amount of energy – upwards of 20 per cent

The 5.86kWh accumulator pack was sized appropriately for the most challenging part of the competition, the 22km endurance event.

'We understand the power demand from the motors running them at 80kW maximum and within the operating window,' explains Ramming. 'Then the question becomes, how much of that do we actually need to bring with us? Regenerative braking is essential for us. The pack was sized with a certain amount of regenerative braking, based on lap time simulation around the Silverstone track, which we know pretty well because it's quite consistent between years.

The regenerative braking amount depends on the set up and power demand.

'We're looking to regenerate quite a high amount of energy – upwards of 20 per cent,' highlights Ramming. 'That makes the pack relatively small and leaves us with a lower margin for error, or degrades performance if we get the use case wrong.

'The track lends itself to regeneration because we have a lot of braking and transitional throttle moments where we can make the most of it. We can regenerate many tiny moments between the intense braking moments, especially in an all-wheel drive torque vectoring system. We benefit from that.'

Vehicle dynamics

Managing the vehicle dynamics alongside that regenerative braking, in terms of brake feel and what happens to vehicle handling when it goes into that pinch moment as negative torque from the wheels, was a big challenge. OBR developed the vehicle dynamics and the kinematics of the car with the effects of regenerative braking in mind. The team then tune the behaviour using regular mechanical car set-up elements such as spring stiffness and damper settings, as in other forms of motorsport.

The driver can also adjust the amount of regeneration from the cockpit with electronic tools. A certain amount of deceleration must be hydraulic braking at the end of pedal travel, but the rest is through regeneration. OBR can also change this via pedal spring settings so, if the driver wants a shorter pedal travel for different spring stiffness for the initial bit of regeneration before they hit the hydraulics, that can be tuned in.

The regenerative braking is very sophisticated, though it isn't the most challenging part of driving in this car,' notes Ramming. 'The most significant change from the driver's perspective was getting to grips with electric all-wheel drive. That's probably the most prominent sensation as it's potential has a much higher performance ceiling and delivers torque in a very different way.

'Once we run the car even more, we can get the visibility of nailing that down. But that's probably years of development rather than just days of testing.'

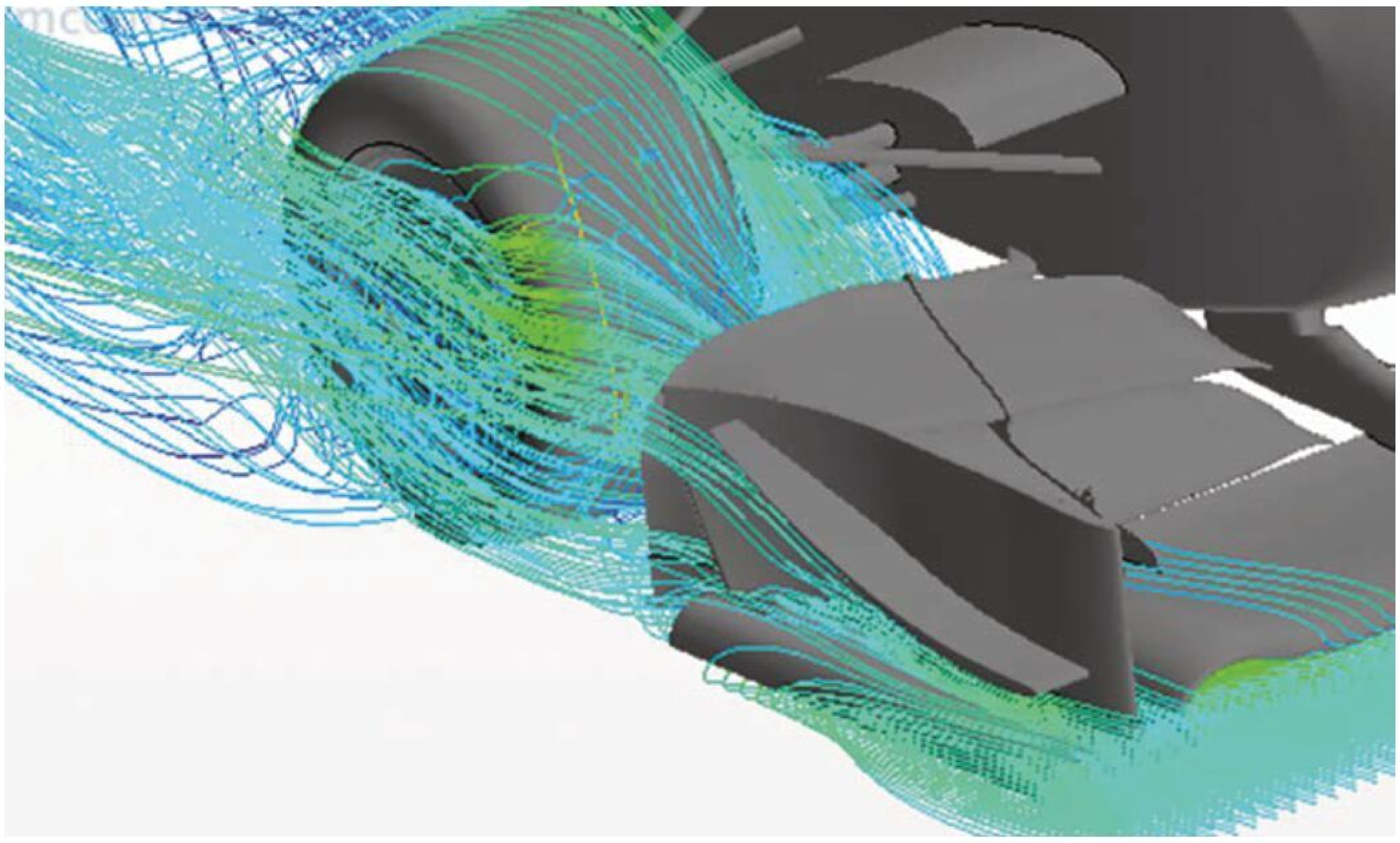
FS cars have such extreme aero nowadays that they can produce load at as low as 20mph. Like most FS teams, in terms of design, OBR's 2022 car's aerodynamics is something the team started from the ground up when designing the vehicle, and it's been iterated over several CFD runs before they generated the final solution.

'We reviewed every iteration we made in CFD internally and with industry expert partners. We're lucky enough to have that,' says Ramming.

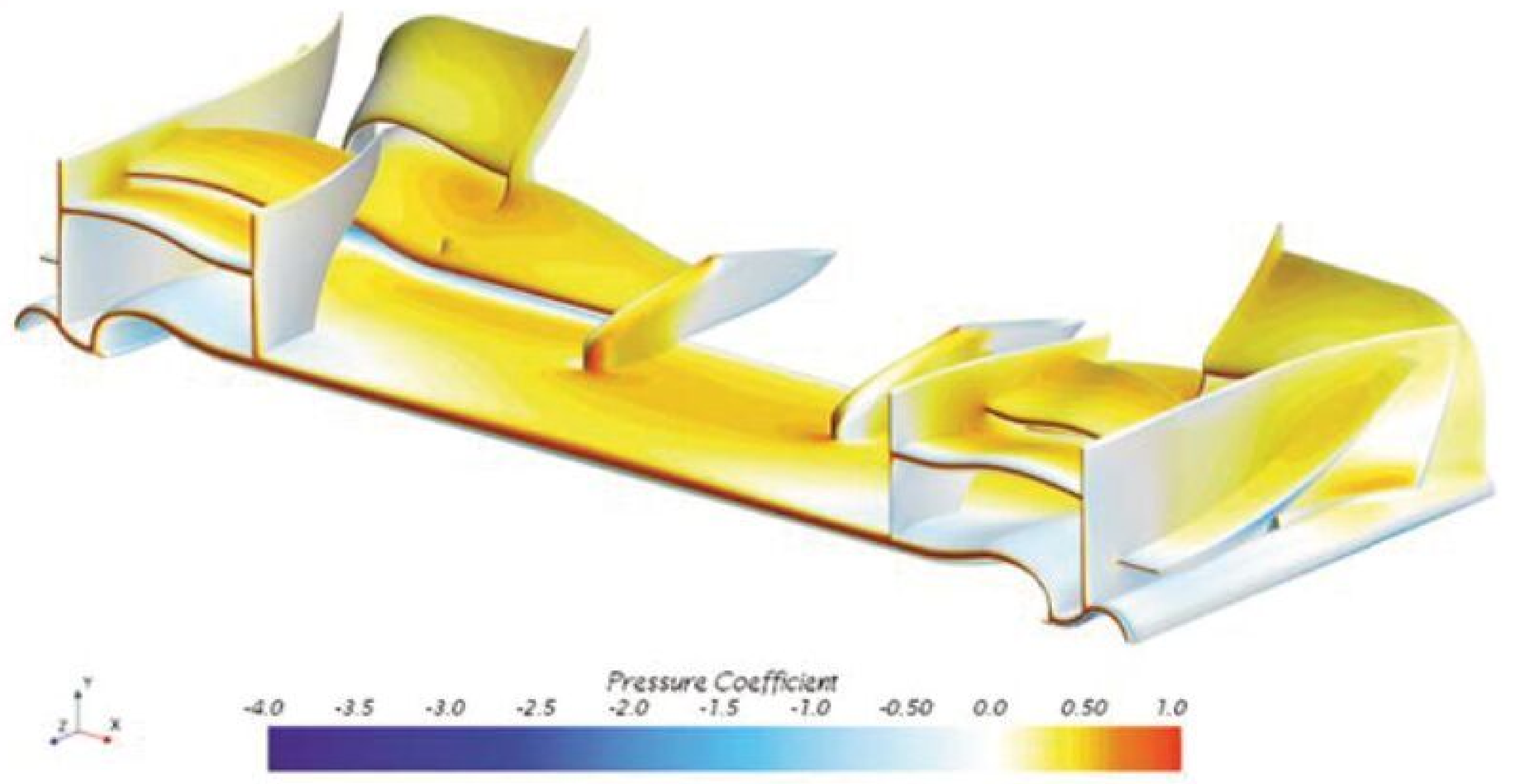
'With the shift from IC to the electric powertrain, our cooling demand has changed. We considered that as a large part of CFD in terms of what we developed. We don't have an exhaust now, so we're not messing much with the car's rear-end airflow. That is probably offset, or at least traded, with getting cooling in from the front of the car as we now need throughput to the accumulator.'

IMechE Formula Student

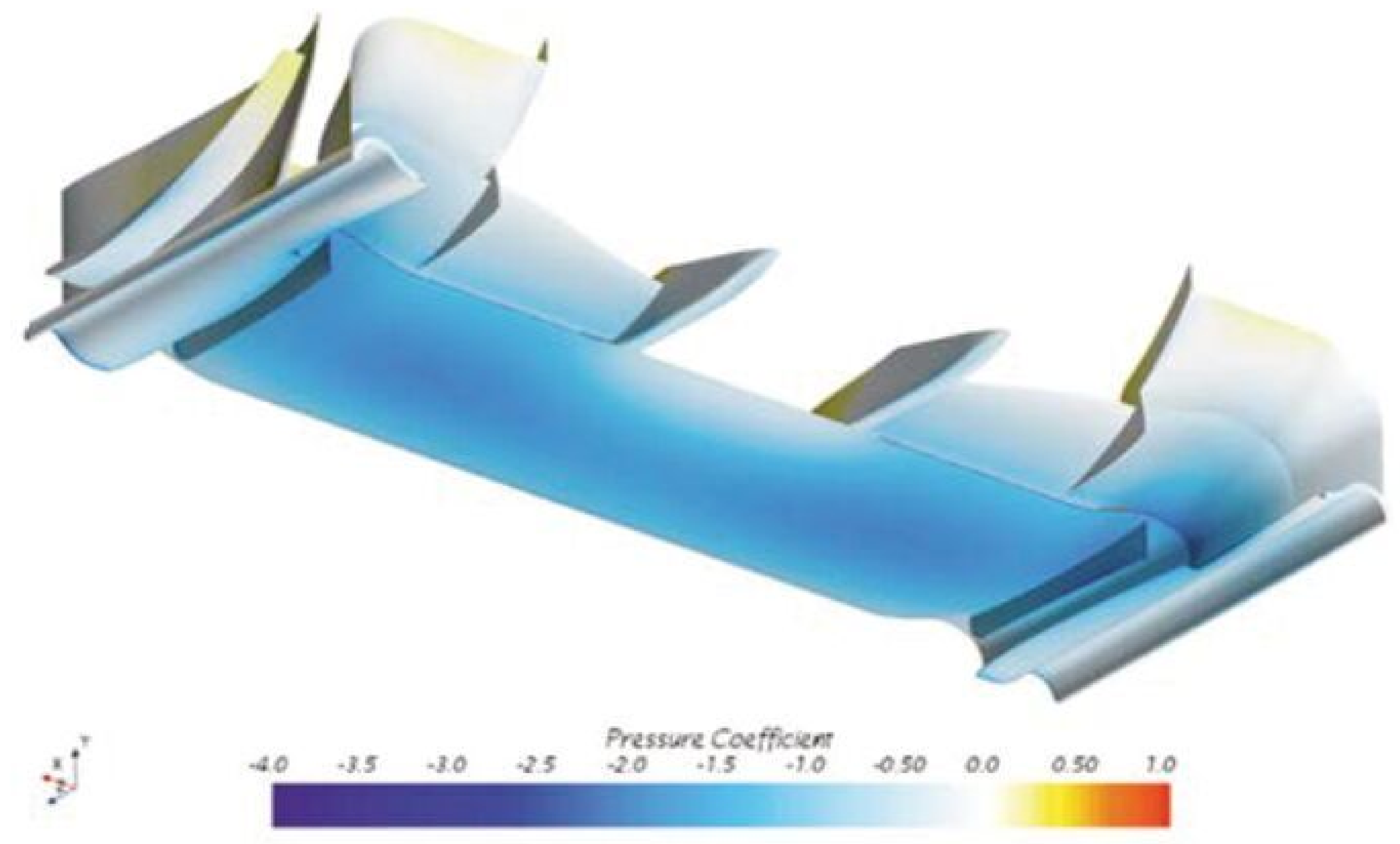
The advanced front wing design provides high front end loads as well as flow field conditioning for structures behind the front axle


xford Brookes Racing

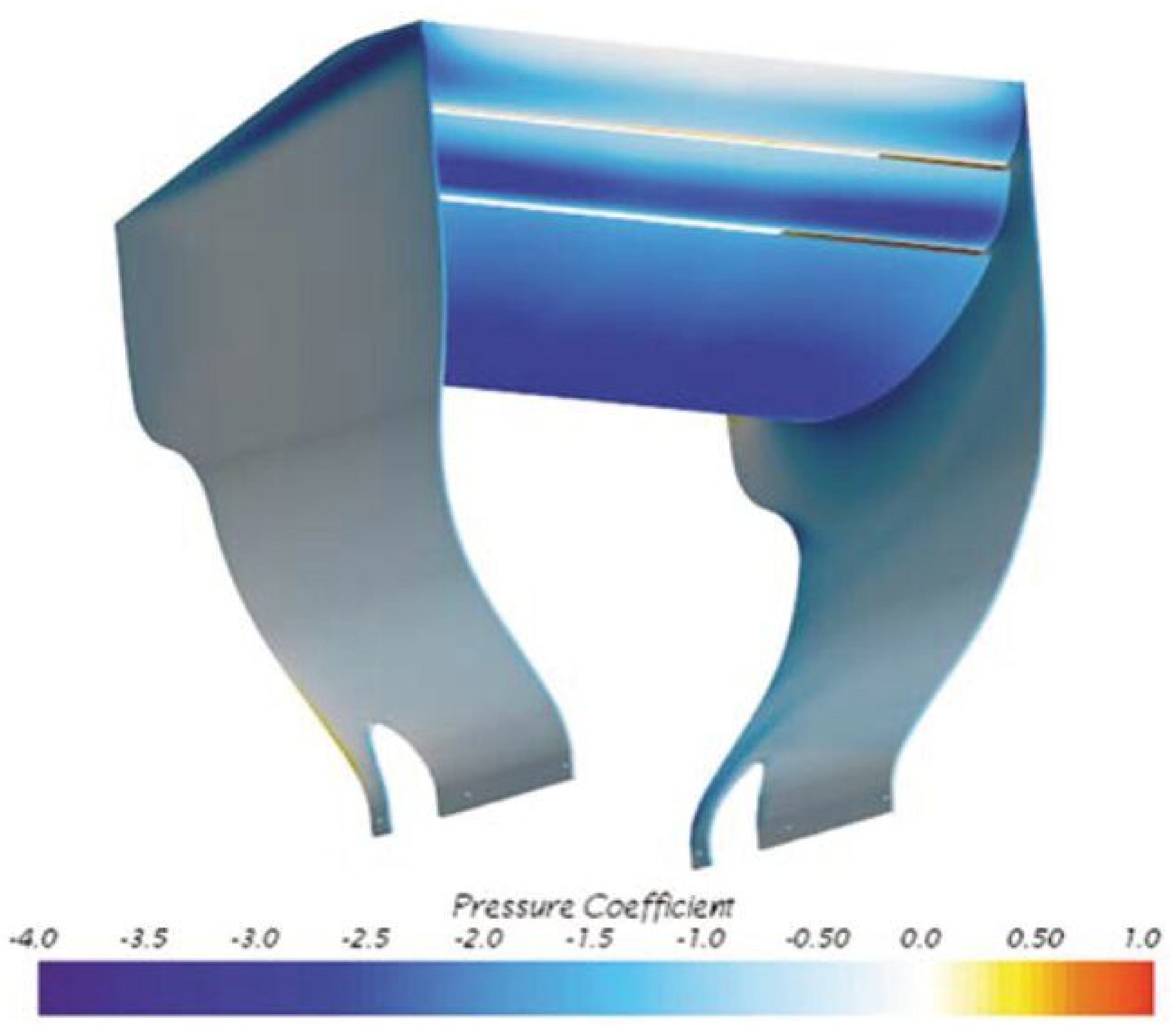
The car's aerodynamics are a refined version of the team's 2021 design. This is one of its CFD renderings of front wing flow structure



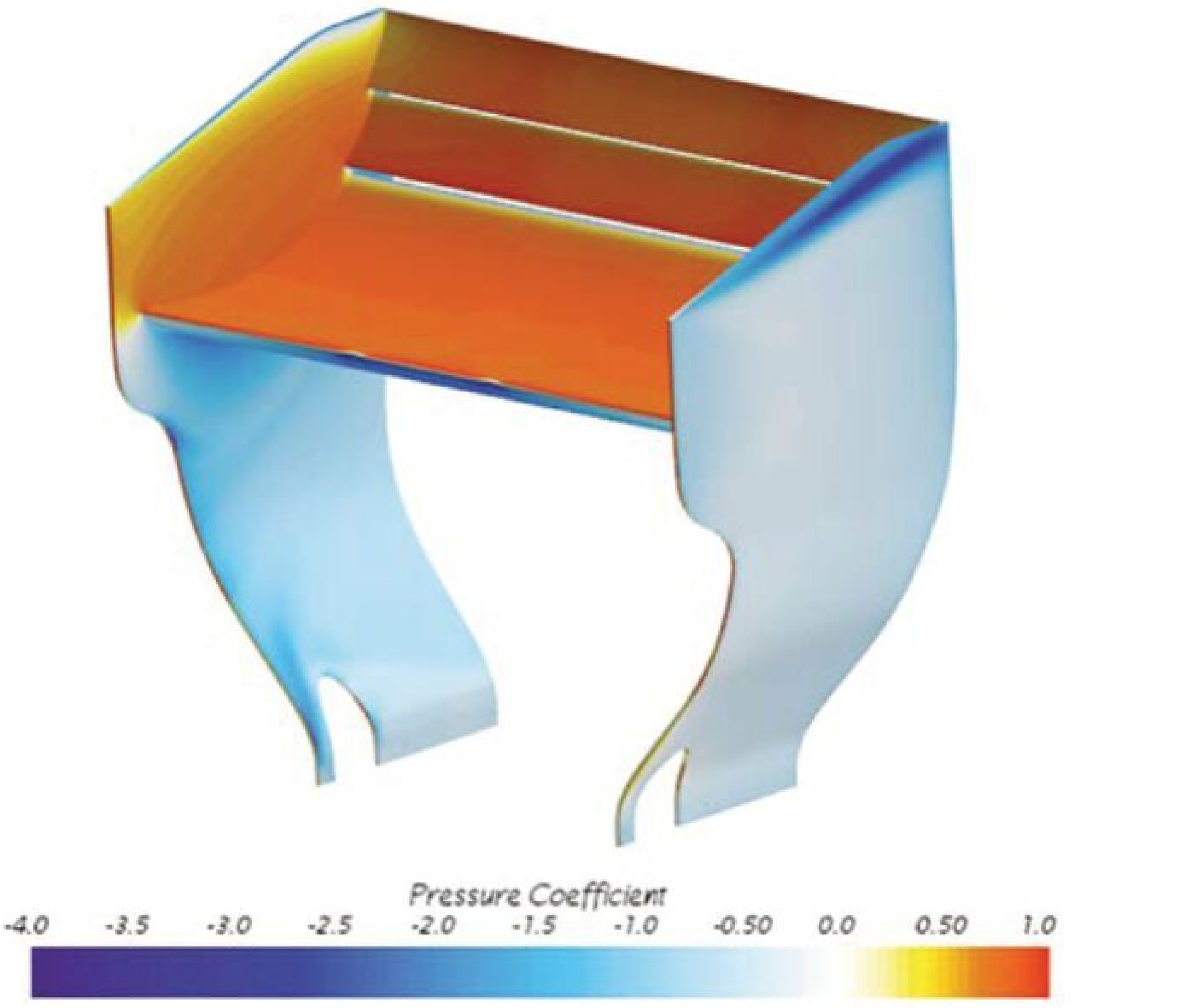
Front wing upper surface aerodynamic load profile



Front wing lower surface aerodynamic load profile



Rear wing lower surface aerodynamic load profile



Rear wing upper surface aerodynamic load profile

Oxford Brookes Racing

As for the entire aerodynamic concept, OBR ran a similar system last year, but it's been refined in many details.

'If you compare the aerodynamics from the previous year to this year, you'll find a lot of re-profiling,' says Ramming. 'There's been a lot of optimisation of profiles within the boundary boxes. Rather than changing conventions, we're running the same tip-loaded concepts on the outboard front wing, and everything after that is also optimised.

'We're at the point where the downstream aerodynamics are now a relevant factor, and we have to think about how we manage the flow around suspension and tyres. In terms of complexity, we're at the upper end of what you'll find in a Formula Student paddock, which is something we're proud of.'

Generally, getting to this year's competition wasn't easy. With the fall out of Coronavirus and chip shortages still causing chaos throughout the technology industries, the strength of the field and the number of cars running this year was great to see.

25 years of innovation

Formula Student UK competition was back to full strength for 2022, which marked the 25th anniversary for the UK competition.

The Silverstone paddock was packed with teams from numerous national and international universities all vying for glory. Despite the formula remaining similar over the years, the open technical nature of Formula Student has seen teams develop vastly different racecars. Recently, many universities have shifted from internal combustion (IC) cars to fully electric. The 2022 event saw more than half the teams competing use electric power, though even these were vastly different in concept.

The powertrain configurations at this year's competition ranged from inline four-cylinder and twin-cylinder motorcycle IC engines to single or multiple radial flux electric motors in rear-wheel-drive layout to four-wheel-drive arrangements, driven by four radial flux in-wheel motors to dual motor formats operating digital differentials for the front and rear axles respectively. Some cars ran with advanced energy recovery technology, electronically-governed torque vectoring traction and stability control systems, and even hydraulically-controlled active suspension.

Interestingly, the chosen powertrain configuration seemed to have little bearing on cars' success in the competition. Glasgow Racing won the event overall with its IC-powered car, the first team from Scotland to win the event.

Runners up in the main competition were the IC-powered University of West of England, with the IC-powered University of Malta in third place.

Oxford Brookes University's electric machine (detailed here) prevailed in the Engineering Design category, and the University of the West of England won the Presentation event. The University of Strathclyde scored highest for the Cost event with its electric car, and University of Porto won the Concept class overall for its RWD direct single-motor electric machine.

Formula Student continues to demonstrate that, despite our deep technical understanding of motorsport engineering, innovation can still lead to success. This is precisely what the competition aims to instil in the participants.

Jon Elsey

Secret Formula

It's one of the oldest racing series in the UK, features a wide range of cars and is a hidden gem of motorsport engineering. Say hello to 750 Formula

By MIKE BRESLIN

Formula 1 carries the perpendicular digit because it's considered the highest level of motor racing, literally *numero uno*. But it is not the first formula ever to race. That honour goes to a UK championship that has been around continuously, with very few major regulation changes, since 1949: 750 Formula.

Run by the organisation that owes the category its name, the 750 Motor Club, 750 Formula (750F for short, never Formula 750) is thriving, with healthy grids and, perhaps more interestingly in these days of spec formulae, a huge variety of cars.

In fact, when *Racecar* attended the first 750 Formula meeting of the 2022 season at Silverstone, it proved impossible to find two identical cars. That's all thanks to a rulebook that allows for plenty of engineering creativity and encourages competitors to build their own cars. That, and relentless car development over the years.

'With 750 Formula you're able to race a sports formula car, on slicks, with aerodynamic wings, yet it's still affordable motorsport,' says championship representative and Darvi Mk5 owner / driver, Steve Boother. 'A major part of the attraction is that people are actively encouraged to build and develop their own cars, which is why we have such a diverse grid.'

Down on power

There are some things that do have to be the same across the field, though, such as the engine, which is not the most exciting element of the package. But then this formula has never been about outright power.

Through the years, 750F cars have used the 750cc engine that powered the Austin 7 (hence the name), then a Reliant motor and, since 2003, the 1108cc Fiat FIRE engine, as found in a variety of Fiat models, including the Panda, Uno, Cinquecento, Seicento and – more usefully – in many scrapyards.

'You can buy a bog-standard 1.1 engine out of a Fiat Panda, as long as it's got the right cylinder head on it [with a required part number], for £200. It's about £300 for a control camshaft, and then you can put that in and race it,' says Boother. 'You don't need to do anything else with it.

'There are a few people who swear by just putting engines straight out of a Panda in the car, with the control camshaft, and off you go. And you can be competitive with that.'

To keep things on an even keel, engine modifications are tightly restricted.

'We are not allowed to do porting work to the cylinder head or lighten the cranks and

A typically diverse 750 Formula field at Silverstone. Here Peter Bove (Darvi) leads Olly Collett (Racekits Falcon) and Chris Gough (CGR2)

'I think I spend less than £5000 a season, and that's with hotels and everything'

Peter Bove, reigning 750F champion

rods and stuff like that,' confirms Boother. 'The way they regulate that is, normally, the top three to six engines in the championship get sealed at some point in the year, and they are then inspected at the end of the season.'

Induction is restricted to a single factory carburettor, though exhaust system design and manufacture is free, while traction control and other driver aids are not allowed. The only other major aspect of the formula that is controlled is the tyres, which are Yokohama N2669 slicks (wet tyre choice is free) that cost around £500 a set and are said to be very durable indeed. In fact, we're told it's not unusual for one set to last a season, and many racers make do with second hand rubber.

There is a minimum weight limit of 480kg, including driver, and the chassis must be constructed from metal. Composites are not allowed in the suspension either, but otherwise this area is largely unrestricted, though there are some limitations at the rear, depending on the powertrain layout chosen. Most cars seem to run conventional double wishbone suspensions on the front, some outboard and others pushrod operated.

Dampers, although unrestricted, are not a major area of development, largely because of the cost involved in doing so, though we're told one competitor did recently experiment with Ducati motorcycle shocks.

Budget racing

By now, you've almost certainly picked up on one of the most attractive aspects of this category: it is *not* expensive. In fact, it seems unlikely there's another slicks and wings series that comes anywhere close to 750F when it comes to value for money.

How cheap? Well, Peter Bove is the reigning champion, so who better to ask for a benchmark on costs?

'I think I spend less than £5000 a season, and that's with hotels and everything,' he says. Others say much the same, while some spend a bit more, and some as little as £3000 to £4000. On top of this, if you opt to buy a racecar rather than build, you can pick up a decent one for £5000. Even a very good one, with lots of top-end parts on it, will cost you less than £10,000. That wouldn't even buy you an engine in most racing formulae.

Of course, budgets in motorsport are notoriously elastic, and if you wanted to do additional testing then the numbers quoted above would increase. That said, testing a 750F car can be frustrating, as Bove explains. 'With these cars, because they're so slow in a straight line and so fast through the corners, the way you make lap time is different from everybody else,' he says.

'So, at a test there will always be other cars that can be incredibly quick in a straight line, but then through the corners they're all over the place, which is frustrating. Not least because the chance of being wiped out because of that is just a bit on the high side.'

Aero diversity

Which brings us to aerodynamics. Aero packages in the formula are incredibly diverse, with wing, splitter and underfloor development commonplace, as the driver / owners strive for the perfect, yet elusive, balance between drag and downforce.

Yet with such a low-powered racecar (the engine gives around 100bhp at best) some might think wings and diffusers a little out of place. But remember, these cars have durable slicks that need to be switched on, and with such a lightweight chassis they do require some downforce.

Those that race 750F will readily attest that the aero does its job. The cars are around four seconds off BTCC pace at Brands Hatch, which is decent for such a low-powered car, and drivers certainly notice when it's suddenly not there.

'I had a wing come off once,' says Chris Gough, owner / driver and builder of the CGR2 Evo. 'Somebody went into the back of me at Copse [Silverstone] and, when we got around to Luffield, the rear body came off. When I pressed the brakes, I just ended up going backwards.'

Transmission vamp

The other main talking point in 750F is transmissions. This area is also largely free, but there are some limitations, dependent on car layout. To simplify, the most popular design philosophies are front engine with a propshaft, or rear engine with a transaxle. Any four-speed gearbox is allowed for the former, though the cars have to then run a live rear axle (suitable units now becoming more difficult to source).

The transaxle option involves a transversely-located rear engine using the Fiat unit's original five-speed gearbox. This layout has the added advantage of allowing free suspension options at the rear, but the downside of it being a heavy production unit, with fixed ratios and slow gearshifts.

All cars competing in 750F run the Fiat 1108cc FIRE engine with single carburettor induction and a control camshaft. Engine positioning is free. In this Darvi, for example, it sits up front, very close to the driver

Chassis construction must be of metal, but otherwise is open to interpretation. This car has the engine mounted transversely in the rear, which means it has to use a production Fiat gearbox

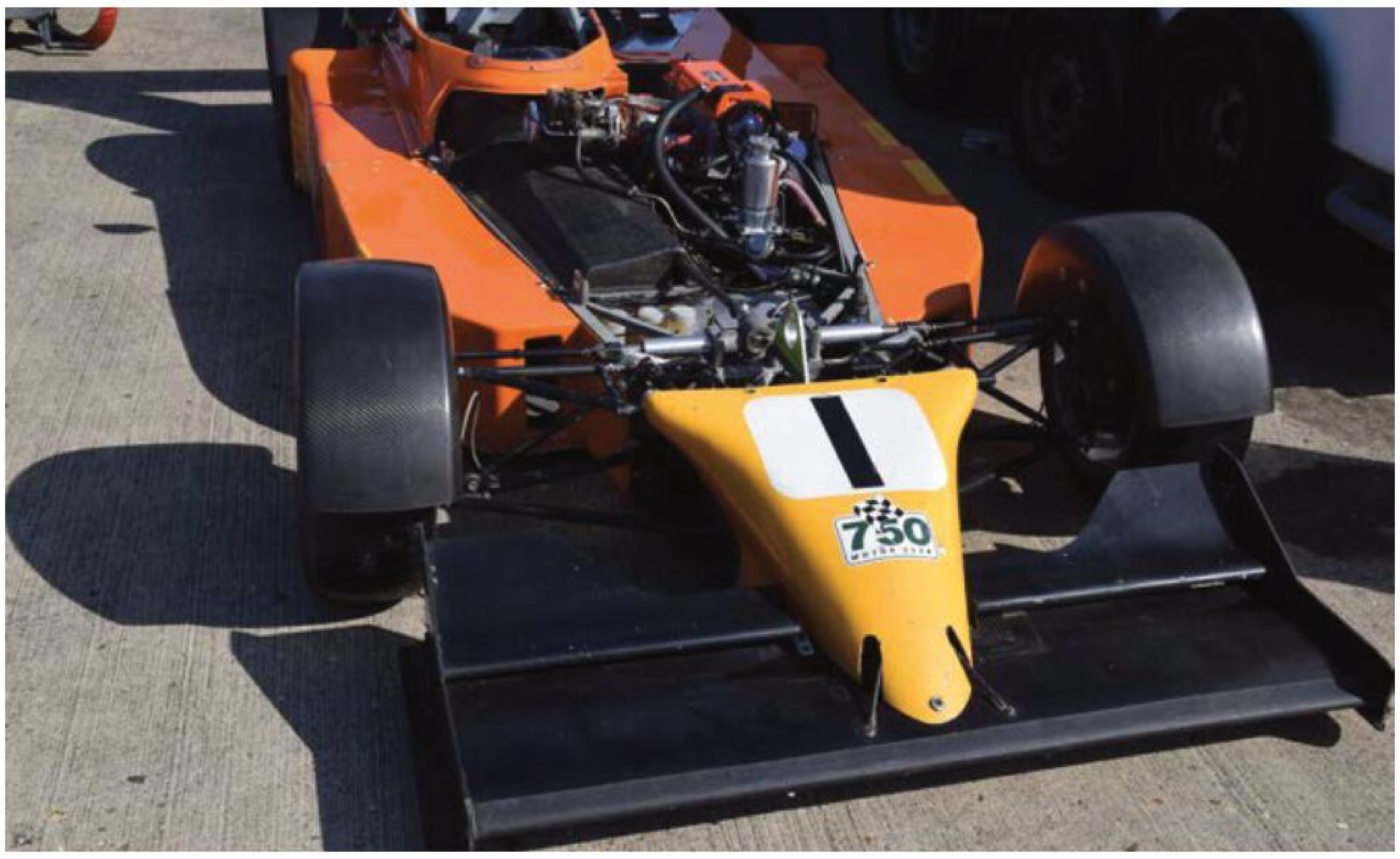
Despite the low-powered engine, aero development is rampant in the series, and most cars sport fairly large wings and diffusers – the latter is a recent addition to the SZT Mk1 pictured here

Sequential gear shifting is allowed on propshaft cars, and Quaife's QBM1M four-speed offering, originally designed for short oval racing, has been growing in popularity recently. It's relatively expensive, but we're told it can work out cheaper in the long run, as Gough explains: 'As my gearbox man said when I told him the price [of the Quaife], "Well, that's only £100 more than the rebuild." That's because we were having to have specialist parts made for the older gearbox.'

Aero packages in the formula are incredibly diverse, with wing, splitter and underfloor development commonplace

Where space age meets iron age: front-engined cars must run live axles and this example, in the highly developed CGR2 Evo, is from a British Morris Minor so is at least 50 years old, maybe considerably more

Racekits Falcon provides kits that help short cut the self-build process. This example, campaigned by Racekits' boss, Martin Kemp, features a number of custom aerodynamic solutions



Peter Bove is the series' reigning champion, and his Darvi features a large one-time Formula Palmer Audi front wing and a very neat front suspension layout

With so few restrictions, this is clearly a dream category for anyone with ambitions to build and develop a proper racecar. Yet there seem to be fewer new self-build cars on the grid these days. That said, many competitors have bought the Racekits Falcon chassis and bodywork kits, built and sold by 750F competitor Martin Kemp, and have then gone on to develop these, while Boother tells us there are quite a few self-build projects in progress in garages across the UK.

Different times

Reasons for the relative lack of self-building, at least compared to earlier years, is probably to do with the different times we now live in. As Bove points out, few new houses in the UK are built with garages these days, while modern road cars do not encourage tinkering or modifying, and skills are being lost.

What is more of a puzzle, though, is why there are so few motorsport engineering students, and colleges, involved. It seems unlikely that this is any more expensive than Formula Student, and it surely offers plenty of opportunities to learn about racecar engineering, while at the same time actually competing with a real car.

Olly Collett, a competitor in the championship and also a motorsport engineering professional, confirms our thinking: 'It's a great way of learning, and I took a lot from this into my career.'

Anyone who does take up the challenge of building their own 750 Formula car will certainly be following in some illustrious wheel tracks, with people like Colin Chapman and Gordon Murray (see box out on p46) both involved in the category at early points in their motorsport careers.

As for those involved right now, we've picked out five very different racecars to give a flavour of the world's oldest formula.

Car focus: Darvi 88 P

This is the classic 750 Formula design, with the engine up front and cycle wings over the steered wheels. Dick and Jon Harvey built the first Darvi in 1974, and the cars have been winning races and championships on a regular basis ever since. Indeed, the orange car of Peter Bove featured here is the 2021 championship winner.

While outwardly conventional, this racecar has seen plenty of development since it first hit the track in the 1980s.

'There have been many changes over the years,' says current owner / driver Peter Bove, who bought the car in 1992. 'The chassis is the same, but a couple of years ago I fitted the Quaife sequential gearbox. The back axle is identical, though.'

The front suspension is pushrod operated, and there's been some aero development, too.

Explaining that last comment further, Bove continues: 'I loaned it to [former F1 engineer] Robin Gearing for, I thought, a couple of years, which turned out to be nine.

'At the time he was working for Williams, and then Wirth, and he changed all the aerodynamics on the car.'

The car's double-element front wing began life on a Formula Palmer Audi, while the car also boasts a decent-sized diffuser at the back. It's a package that's effective – Bove won the first four races of this season – and, just as importantly, it's low maintenance.

'I think once you get the balance, you keep it. Although I have reduced the rear wing a notch recently as I was suffering some mid-corner understeer.'

Car focus: SZT Mk1

If anyone exemplifies the essence of 750 Formula it's Bill Smith. The former rally driver is a recent convert to the category, going into his second season this year with a self-built racecar that has been developed and raced on a shoestring.

'I tried to follow the spirit of the formula, and it was self-built from scratch,' he tells us. 'It took about two years, and we didn't have any plan to work from. I copied the front end from a Lotus [Caterham] 7 and the back end is just sort of made up. Whatever works really.

'The big struggle was getting the engine in. You need a big area for that.'

That big area has subsequently helped Smith and his small team of volunteers to get a handle on the car's aerodynamics, fitting a large rear diffuser, after running with just a wing and no underfloor aero last year.

This year the car has also been lightened, but it's still a little over minimum weight, admits Smith, which might partly be down to its full bodywork, which is based on a kit car, from which a mould was made.

Always keeping to that low cost 750F philosophy, Smith sourced his engine and gearbox from a scrapyard for just £150, and has mounted it transversely in the rear. Many parts are machined, including adapters to marry Ford driveshafts to the Fiat gearbox, while the car also features an interesting cable-operated gear linkage.

Bill Smith's SZT has a body derived from a kit car. The driver position is on the left, to help balance the weight bias resulting from the transverse-mounted engine

Car Focus: Racekits Falcon

While carbon chassis are not allowed in 750F, the wonder material can be used elsewhere, and Olly Collett has done just that, developing an enclosed composite body that's transformed his Racekits Falcon.

Collett designed the body on Solidworks CAD/CAM while studying for a masters degree in engineering, and then built it together with his father, Ben.

'Using carbon was a little bit to do with the weight [the car is now 20kg lighter], but the body shape is all about aero,' Collet says. 'The cycle wings aren't great for aerodynamic performance, so we wanted to get an increase there, and it's worked really well.'

This also goes for the underbody, thanks to the increased floor area.

'It's a big flat floor with rake, so we're doing quite well on that. But because of the car's transverse engine layout, we're not able to start the tunnel quite as far forward as some of the other cars.'

One of the reasons Collet opted for that layout with the Fiat gearbox was simplicity, he says. 'But also, I think we will benefit from the independent rear suspension. We haven't got that fitted yet, but we have got the ability to adjust cambers and things like that, and that's important to us.'

Olly Collett runs a lightweight carbon body on his Racekits Falcon, which has allowed him to improve the aerodynamics while not adding too much weight to the overall package

However, the transverse engine means weight across the car is now slightly biased.

'That is something we are going to be working on. It's a bit of a flaw. If you're doing it from scratch, I would have the driver on the other side of the car, but we've inherited this chassis and that's what we're working with.'

Car focus: CGR2 Evo

Chris Gough's vivid purple car is designed with straight-line speed in mind, hence its striking all-enveloping bodywork.

Looking more like a land speed racer, the design of Chris Gough's CGR2 Evo has taken the quest for straight-line speed to the extreme, but downforce generation has not been forgotten along the way

'It works at the faster circuits,' says Gough. 'You find that at low speed you're paying a penalty for the extra weight, but at high speed, say over 100mph, it really starts to come into its own.'

The car also features a front splitter, rear wing and diffuser, but getting the aero balance just right can be tricky.

'We did some testing with wing angles. We cranked the wing up and I came back and said yeah, it's much better. But they all looked at the stopwatch and said, "No it isn't!" It was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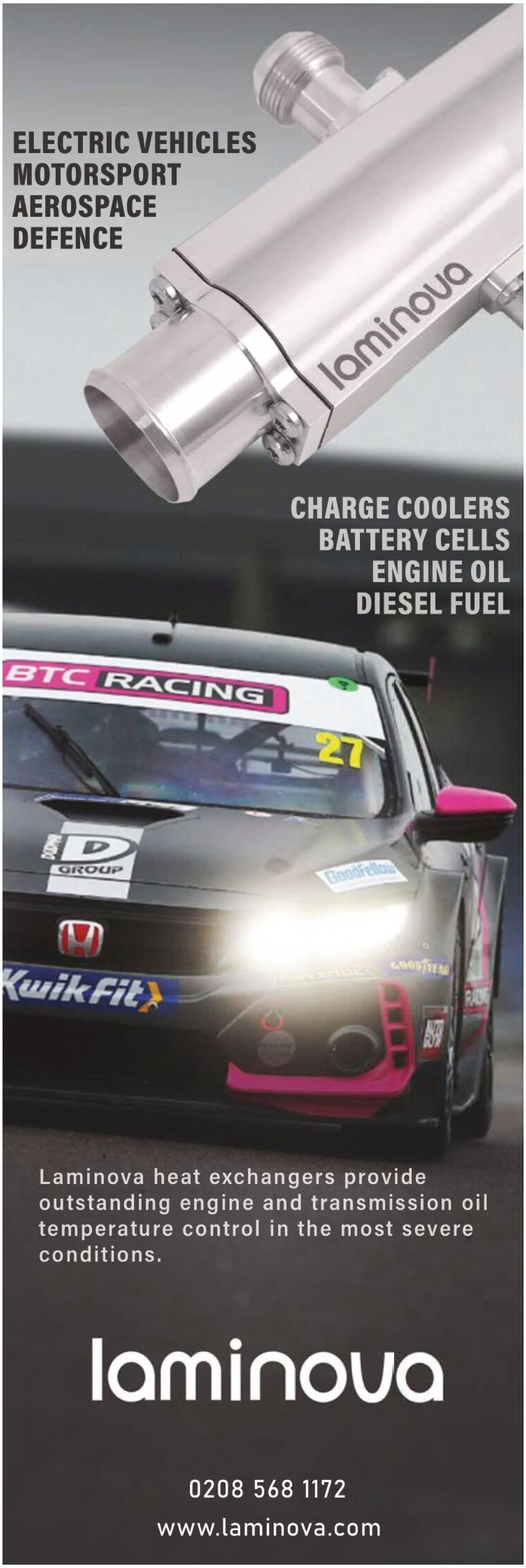
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just slowing the car down, but it *feels* like you've got more grip,' says Gough.

'We've got some potentiometers on the wishbone, so we can measure it, rather than just feel it. We did a couple of tests, and we get about 70kg of downforce.'

It's not just about the aero, though. 'It's a semi-monocoque as well,' says Gough. 'It's based on a Formula [Vauxhall] Lotus design, where you have two large pieces of honeycomb down the sides.'

The engine has a dry sump and is mounted in the front of the car, and it runs with the Quaife sequential four-speed gearbox, which means it uses a live axle. Keeping to the budget theme, the one in this car is from a Morris Minor.

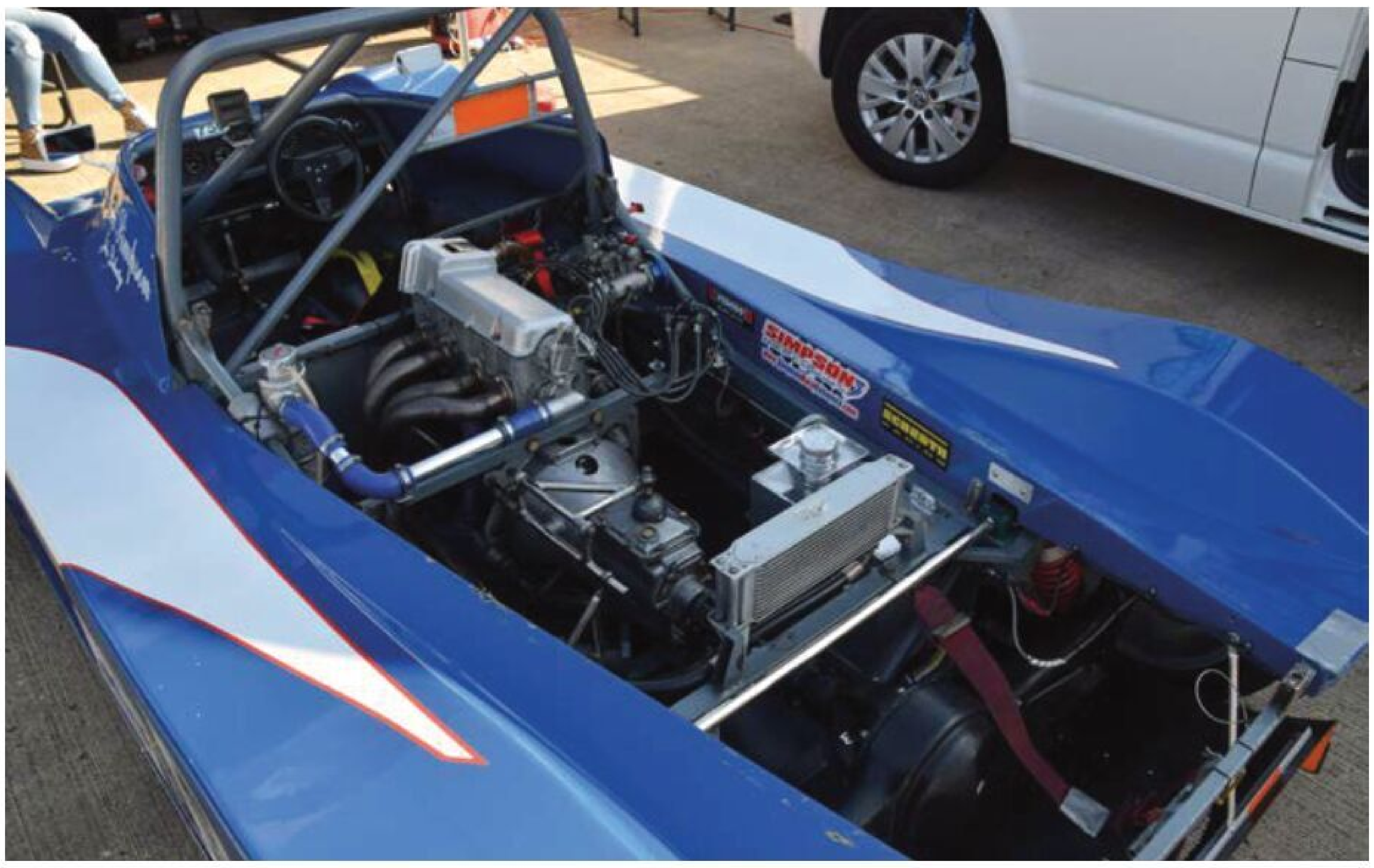
Gough built this remarkable looking machine himself. 'I spent a year doing the chassis, and then a year doing the pattern work for the body. It takes a lot of time in the workshop and a lot of energy,' he says.

Car focus: SS/F 750

If you're thinking you quite like the look of 750 Formula, but worry that you might get bored, then you need to have a chat with four-time champion Bob Simpson, who has been racing in the category since 1968, and still loves every minute of it.

A sprightly 77 now, Simpson campaigns his SS/F 750, a car he's owned since building it in 1991, and this year he's sharing it with his grandson, Jake Doherty.

The car is rear-engined, Simpson being one of the first to opt for this format, and it has been developed pretty much ever since it first hit the track 30 years ago.



Bob Simpson has been racing in 750 Formula since 1968, and has driven this SS/F 750 for the last 30 years. The car was one of the first in the series to run with a rear-mounted engine

'We just do little bits every time we go out, so you're always trying something,' says Simpson enthusiastically.

It uses a Reliant gearbox case with modified internals, which drives an antiquated BMC back axle. But if he were to start again from scratch, Simpson says he would look at doing something different with the transmission.

'I've got two options really, one is to turn the engine around [it now sits longitudinally] so we can use the Fiat gearbox, because Reliant gearboxes are very limited [in terms of availability] at the moment. Or do a front-engine car where we have endless gearboxes to choose from. Because you've got the length of the drivetrain, you can shorten the propshaft as much as you like. So you can put a longer gearbox in, and a stronger gearbox as well.'

As far as the aerodynamics are concerned it's also a bit of an ongoing job: 'It's got no vices as such as a car, but we seem to have lost a lot of straight-line speed, so we've got a smaller splitter on the front for this year,' Simpson explains. 'The front splitter is only plywood, so we can play around with it as much as we like. It's not an expensive thing to do, just a bit time consuming.'

As for his thoughts on the formula in general: 'The whole family is coming along to support today. We've been doing it 54 years this year, every year, and I still love it. I can't get enough, really.'

Big ideas in a little car

Arguably, the most influential 750 Formula car ever designed never actually raced. The IGM 750 T.4 001 was conceived by F1 legend, Gordon Murray, in 1972. At the time, Murray was still keen to drive racecars himself and saw the low-cost category as a perfect way to get out on track, while also giving him the opportunity to display his engineering genius.

Indeed, the car features a few things that went on to become Murray hallmarks. The pull rod rising rate suspension, often cited as being first used on the Brabham BT44, was actually designed for this car. Then there's the ultra-low frontal area, which meant a then radical rear radiator, 10in wheels and very lowline driving position, which Murray would go on to take to extremes in F1 with the Brabham BT55 of 1986.

Murray also showed an early knack for playing the rules to his own advantage with the IGM T.4. Back then, the regulations said the chassis should contain at least two steel tubes, in order that bodies would be built around spaceframes. Murray, however, really wanted to use a monocoque, so he drilled a bunch of holes to lighten the tubes and then built a body that, in reality, was the tub.

Oh, and if there was any doubt that this is a Murray creation, make a note of the weight: a mere 280kg (there was no minimum weight limit back then).

While the car was not completed in '72, because his promotion to chief designer at Brabham took precedence, in 2019 Murray managed to track down the chassis he had built 47 years earlier and the team at Gordon Murray Design then pieced it all together.

Gossip in the 750F paddock suggests Murray might even return to race the newly rebuilt car in the Historic 750 Formula series that still runs to the old regulations.

GMA

Gordon Murray designed this super lightweight car in 1972, but it was not built until recently. Note the trademark lowline chassis and pull-rod front suspension

Mickey Mouse

Oddball or ahead of its time? That was the mystery that surrounded Porsche's Type 645 Spyder.* Racecar *tells the story of the advanced prototype whose behaviour won it its unlikely nickname

By KARL LUDVIGSEN

One of the oddest episodes in Porsche history is the brief but meteoric career of the Type 645 Spyder, which was in public view in Germany for less than four months, from its first appearance to its last in the autumn of 1956. Its design, which dated to more than a year earlier, had been prepared as a successor to the Type 550 that would be lighter, more aerodynamic and superior in roadholding.

Porsche pitched its 550 Spyder into Europe's most competitive sports car racing class. France was in the 1500cc category with its Gordini, Britain with Cooper and Lotus, East Germany with its six-cylinder EMWs, Italy with both Maserati and OSCA and Germany itself with fuel-injected Borgwards. Although the 550 was off to a good start with the Fuhrmann engine's 1954 introduction, its chassis concept dated in some respects to Walter Glöckler's racers as far back as 1950.

Egon Forstner decided to address this shortcoming. An Austrian who had joined the Porsche cadre in Gmünd in the 1940s, Forstner was a versatile engineer with patents in brake design, cooling systems, valve gear and tractor design, among others. Moving to Stuttgart, he took over from long-serving Josef Mickl as head of the calculation department. It consisted of his assistant, Ernst Henkel, and, from 1956, newcomer Hans Mezger.

The D-Train

'The calculation department office was above the experimental department,' recalled Mezger, 'where everything was in one big area. We were on the third floor above the second floor office known as the D-Zug, or D-Train, because it had side windows like those on a train, looking out on the experimental area below.

'In the D-Zug office were about eight engineers in total, with the chassis people on the left and the engine designers on the right.'

In the latter part of 1954, Forstner started work on the design of a new body and chassis to carry the Type 547 four-cam engine. Counting on their enthusiasm for racecars, he appealed to other Porsche staff for help with the project, given the Type 645 designation. Two who signed up were engineer, Ernst Fuhrmann, and body designer, Heinrich Klie.

Fuhrmann's involvement could well have been because he saw the project as an opportunity to burnish his credentials in the design of racing vehicles, as well as the engine field in which his four-cam engine was already established as successful. Ambitious as he was to lead Porsche's engineering team, Fuhrmann needed to be seen as more than 'just' an engine expert.

So their Type 645 could slip more smoothly through the air, the engineers reduced its frontal area by narrowing its track. Instead of the 550's 49in (124.46cm), this became 46.9in (119.13cm) in front and 45.3in (115.06cm) at the rear. Producing a fifth-scale clay model, Klie fitted its body closely around the wheels, partly shrouding those at the rear, and rounded its nose in plan view.

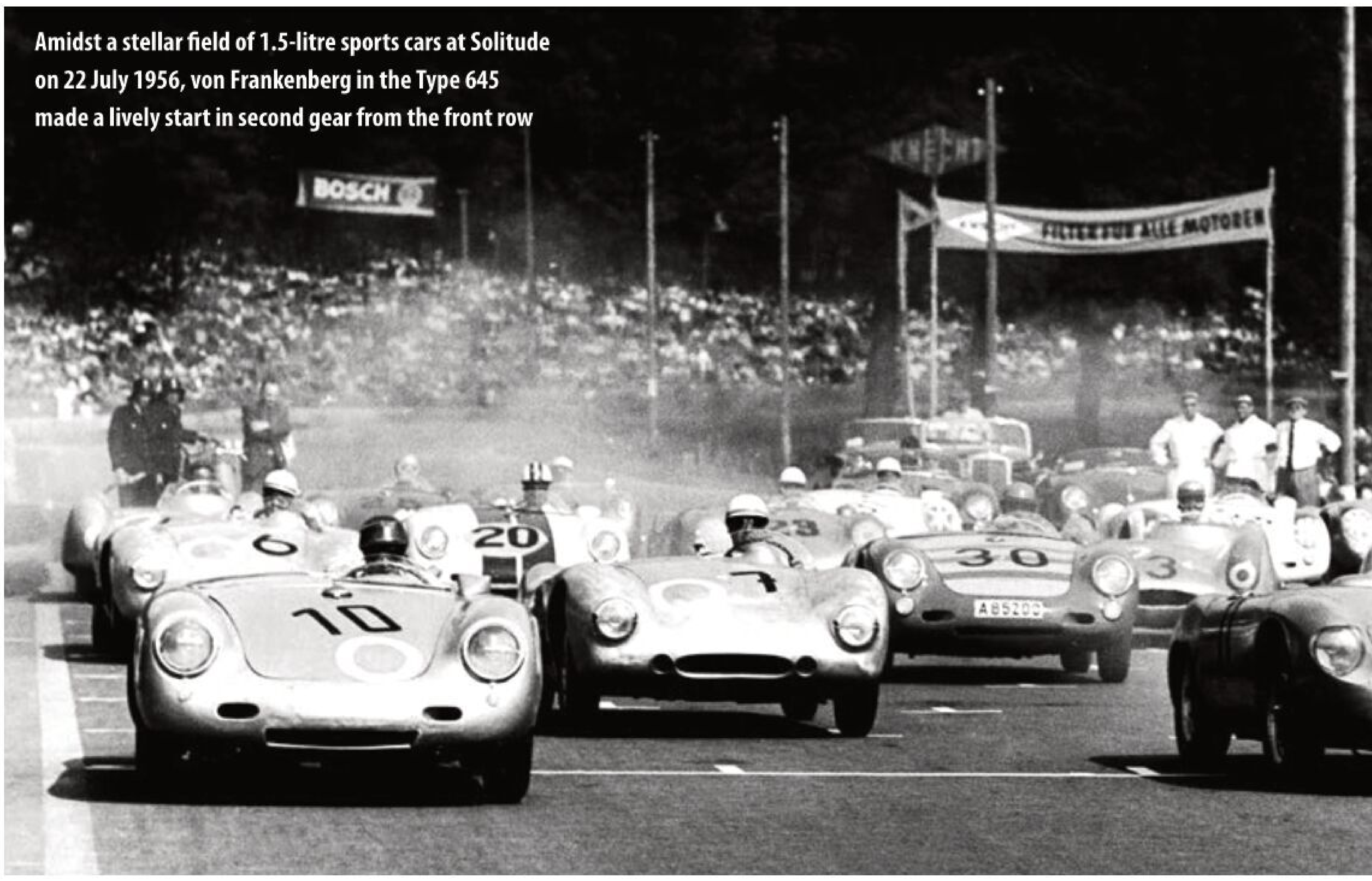
The usual drag-inducing opening for air for the oil cooler was eliminated by making the front lid itself a surface-type cooler, with a labyrinth of passages underneath its surface, left unpainted to improve heat radiation. Intriguing, highly-styled shapes were given to faired-in lamps at both ends of the car.

Turbulent zone

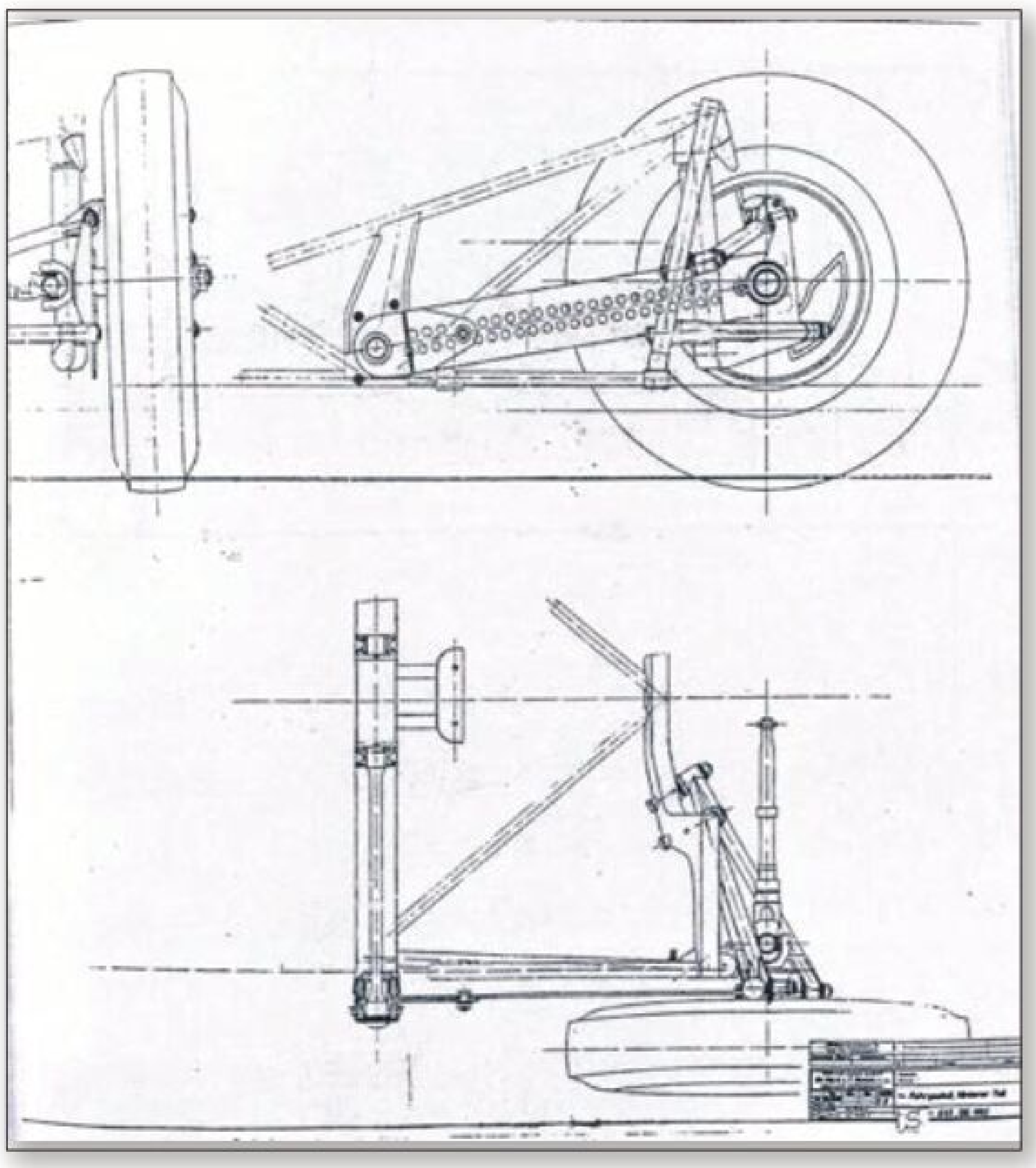
An aerodynamic feature that appeared on Klie's design model of the Type 645 was a headrest for the driver, behind which was an oval-shaped, grilled air passage into the engine room. As expressed in the patent granted to Fuhrmann and Klie on the design, the headrest was shaped to create a turbulent zone of high pressure behind it, above the grilled aperture, to reduce the power lost in supplying cooling air to the engine.

Also patented by Klie and Fuhrmann was an alternative means of delivering cooling air to the engine bay. This was a

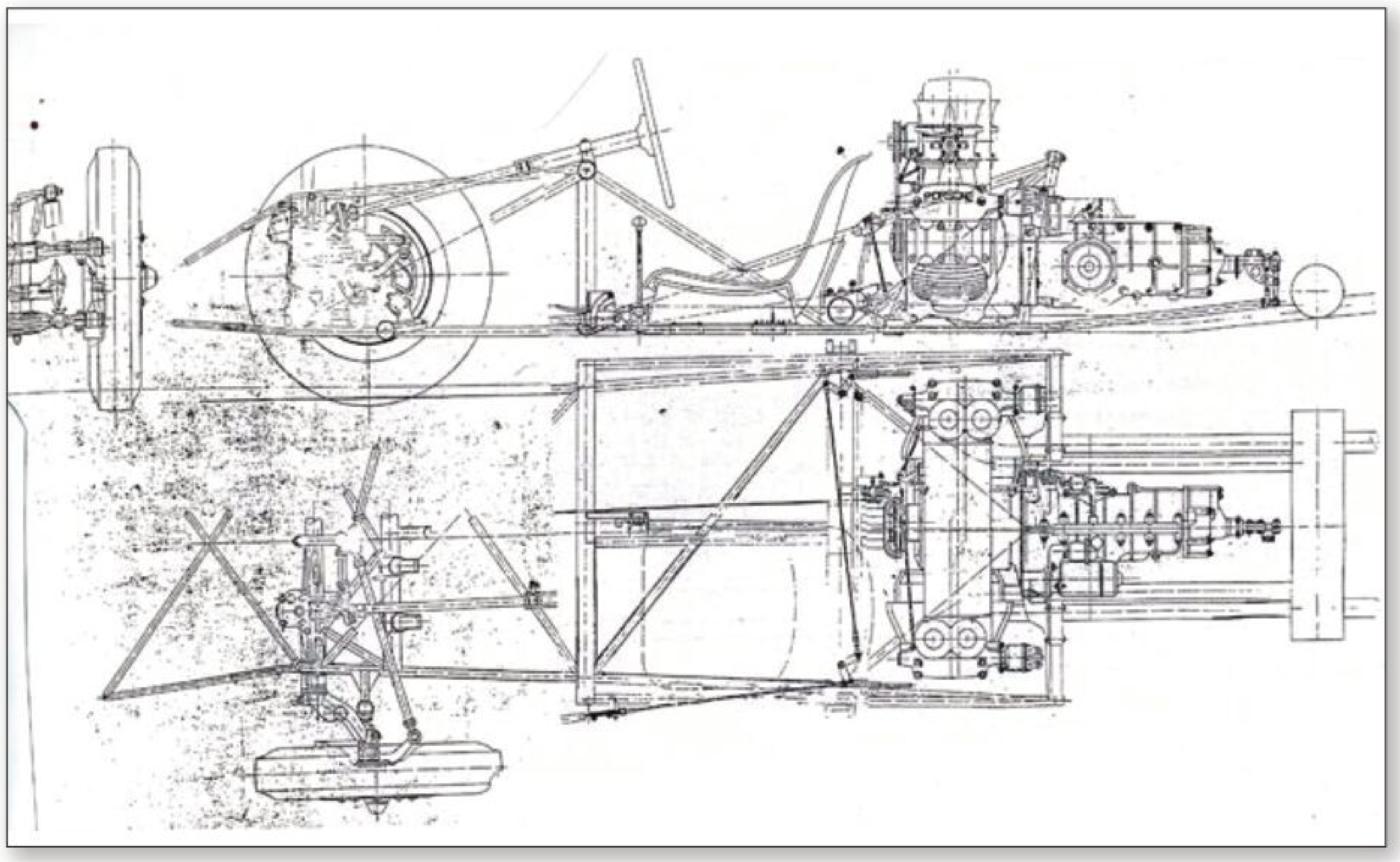
The Type 645's co-creator, Ernst Fuhrmann, in jacket and tie behind the car, shows fatherly concern for his creation at Avus in September 1956, the car's final race



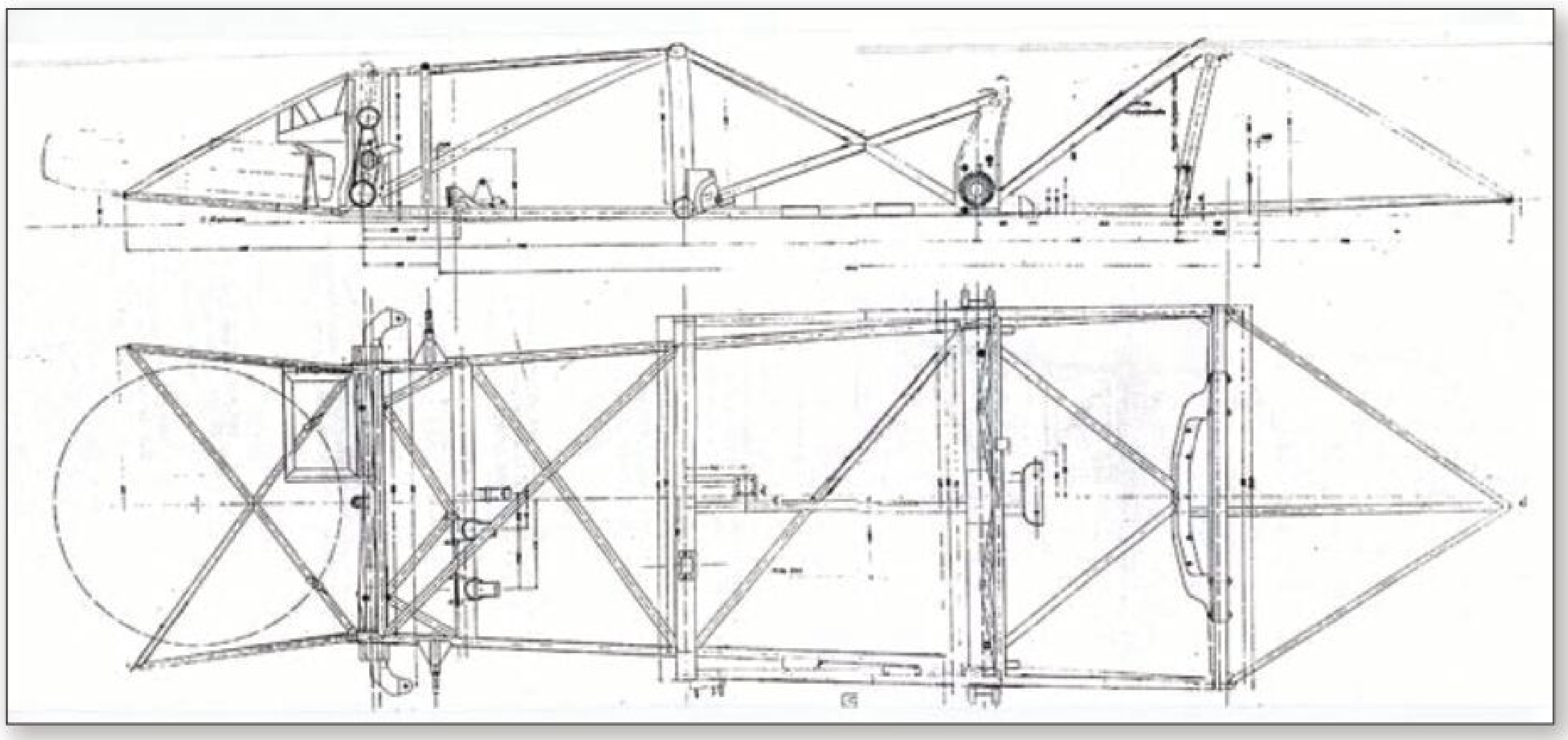
Amidst a stellar field of 1.5-litre sports cars at Solitude on 22 July 1956, von Frankenberg in the Type 645 made a lively start in second gear from the front row

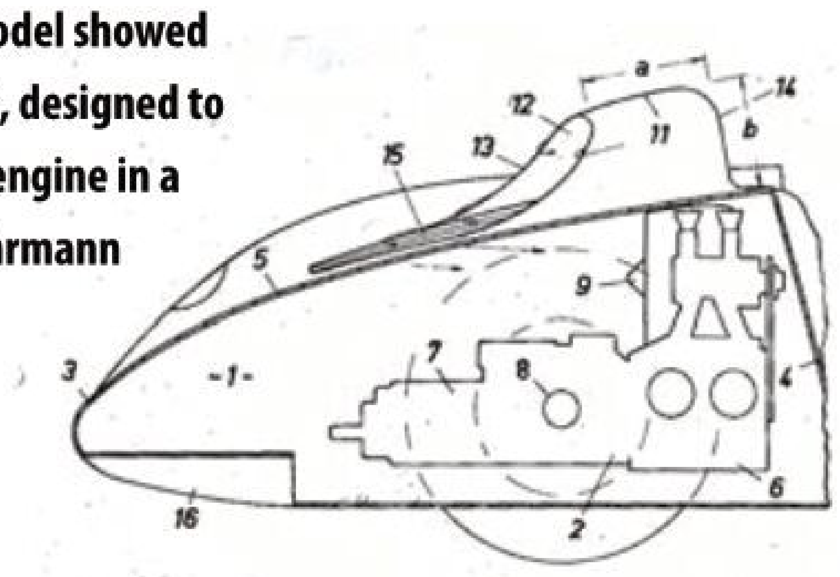


The Type 645's rear suspension used double lateral links to guide its rear wheels. This was a radical advance, though in practice proved too much for the car's trailing arm front suspension

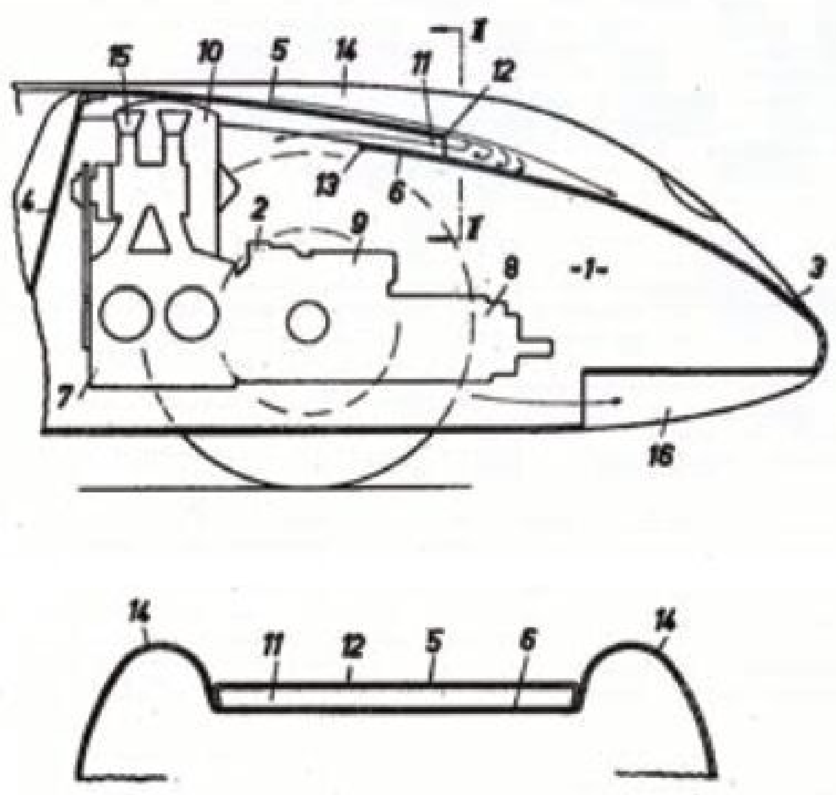


Engineered by Egon Forstner, with the support of Ernst Fuhrmann, the Type 645 took shape in 1955 as an advanced racing Spyder built on a lightweight, tubular steel, spaceframe chassis





The wind tunnel model showed a planned headrest, designed to capture air for the engine in a grille behind it. Fuhrmann and Klie were credited with the patent for this



Later, instead of the headrest inlet, Fuhrmann and Klie patented a slot across the rear deck which, tunnel tests showed, delivered a supply of air under pressure to the engine's cooling fan

Forstner and Fuhrmann worked with Porsche stylist, Heinrich Klie, to produce a wind tunnel model of their new Spyder, with much reduced frontal area for lower drag

The frame designed for the 645 was breathtakingly sparse

rearward-facing slot almost the full width of the engine lid, positioned and designed to preserve smooth airflow above the deck, while admitting air under pressure into the rear compartment. A small central bulge covered the engine fan housing. Rearward-facing air inlets were above the carburettors.

The narrowness of Forstner's Type 645 was to help make it lighter, as would a 6.2in (15.75cm) reduction from the 550's wheelbase to a mere 76.4in (194.06cm). It was to be bodied entirely in magnesium, lighter but less durable than the usual aluminum. There was no right-hand door, and indeed there could not be one, for the fuel tank was placed along the right side of the body, counterbalancing the weight of the driver.

Sparse frame

An important attribute of the new Spyder was a multi-tubular spaceframe chassis. The concept was well known to Forstner, and also to Fuhrmann, who had been with Porsche in Gmünd when it was working with Italy's Cisitalia, which specialised in such frames. Indeed, Erwin Komenda had designed a spaceframe for the mid-engined VW sports roadster of 1948, later hailed as the first 'Porsche' car.

The frame designed for the 645 was breathtakingly sparse. One key element was a rectangle of large tubes located at the cowl, carrying the steering column mounting. Three tubes at each side braced this to the assembly of cross tubes that carried the narrowed trailing arm front suspension and its anti-roll bar. Steering was by equally divided track rods, operated by a small drag link from the steering box, unlike the standard car's unequal length track rods.

Another important element was a braced structure of tubes above the lateral rear torsion bar tube. Rising rearward from it were small tubes that peaked at a high cross tube, whose ends were mounts for the rear dampers. Hanging from it was a fabricated cradle that carried the engine and gearbox assembly, attached under its bellhousing.

Completing the frame was an x-brace at each side of the cockpit, plus single, diagonal small tubes bracing each of the structure's open quadrilaterals.

Suspension advances

For the Grand Prix Cisitalia of 1947-48 the engineering team in Gmünd, Austria, working on Porsche's Type 360 project, designed a sophisticated rear suspension. Instead of the swing axles of the pre-war Auto Unions, it

Head of calculations for Porsche, Egon Forstner, planned the new Spyder to meet fresh challenges from fuel-injected Borgwards and East Germany's six-cylinder AWE

used upper and lower lateral links to guide each wheel hub, with brake and traction torque taken by a trailing arm. Giving precise wheel control with low unsprung weight and far less camber change than the usual swing axles, this was an immense step forward.

This suspension made its reappearance in the Type 645. Here, the trailing arms were the usual VW / Porsche blades, drilled for lightness and set at a static angle of 10 degrees above horizontal. Upper and lower tubular links went inward and slightly forward to pivots attached to the back of the engine cradle. While the lower links were horizontal, the upper ones sloped downward, toward the centre, at 13 degrees. This gave a rear roll centre higher than that of the Cisitalia, yet less elevated than that of a swing axle system. The design provided for two degrees of negative camber at rest to enhance the grip of the era's narrow 5.25 x 16 tyres.

Fabrications attached to the ends of the trailing arms carried each rear hub in a double-row ballbearing. Drive halfshafts had Hooke-type joints at their outer ends and pot-type inner joints that could slide to adapt their length to suspension movement. Although simply arrived at, with its telescopic dampers, this was a sophisticated linkage for 1955. Not until later in the 1950s would such suspensions begin to be adopted in grand prix racing.

Essential discussion

This ambitious project was well on its way to realisation when Porsche chief engineer, Karl Rabe, taking a break from his concentration on tractors, discovered what Forstner was up to. On 15 February 1955 he memo'd Porsche's senior executives that he felt it 'absolutely essential' that 'a fundamental discussion take place with Herr Porsche about this vehicle.' He made the following observations:

'I can't envision that one man carries this forward alone who, at the same time, remains the only remaining theoretician for the design office. I would not like to hide the fact that Herr Forstner has already asked several times for our help, which with the best will in the world I could not provide in view of the present workload in the design office.

'I consider it necessary to clarify the question of the cost of this vehicle. Hitherto Herr Forstner has only remarked that the vehicle will not be more costly because it will largely be built in-house. To this I would add that I have found no primary contract covering the creation of such a vehicle.'

Rabe had rumbled Forstner's end run around Zuffenhausen's procedures. Consequently, the Type 645 hit the buffers, apart from some discussion about the addition of lightness by using magnesium instead of aluminum for its gearbox housing.

Take two

It languished during 1955 when the existing 550 Spyders seemed able to hold the fort. But for 1956, when Borgward was known to be readying its 16-valve, fuel-injected four, competition looked to be intensifying. The Type 645 was therefore re-launched on 16 February 1956 by work order no. 9159, calling for the production of two cars 'as soon as possible.'

Assuming, sensibly enough, that Porsche's management wanted these cars to play some part in the 1956 season, on 28 February Forstner advised Messrs. Rabe, von Rücker, von Hanstein, Hild and Fuhrmann that he considered the timing 'exceptionally tight and requiring the greatest haste.'

Raw materials and drawings were available, he said, for the cars to be built in the experimental department, and the magnesium bodywork could be formed in parallel with other work to speed things up.

The latest development with the Type 547 engine was to drive its distributors from the nose of the crankshaft, instead of from the ends of the camshafts to eliminate variations in timing caused by the latter arrangement. Space for the new drive, said Forstner, was not readily available in the tightly packed 645.

'It was certainly faster, but totally undriveable. [Wolfgang] von Trips and I declined emphatically'

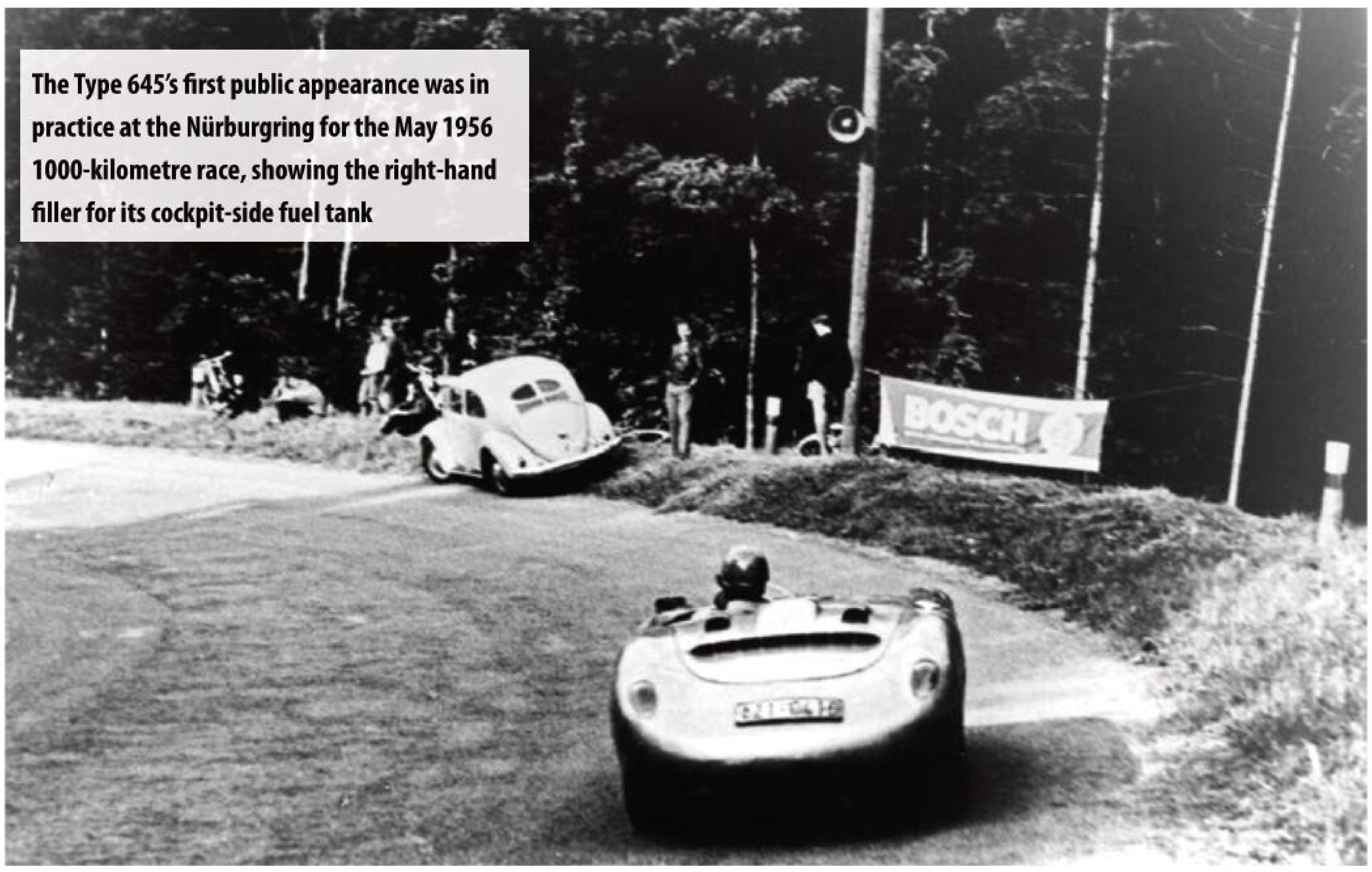
Hans Herrmann, racing driver

Although he requested a drawing that would show space for the newer engine, this never materialised, so his 645 would always be equipped with the older style of four-cam engine, whose output disadvantage Forstner considered as much as 20bhp.

Into the 'Ring

In mid-June of 1956, Forstner re-capped his brainchildren's state of affairs. One of the two cars had been completed at this point and tested on the Malmsheim skid pad. It was finished just in time to be taken to the 'Ring for trials on 15-16 May, alongside a 550 and a 550A.

A rear view of the Type 645 Spyder, as readied for racing, showed its rear deck slot for engine cooling, rear-facing inlets for its twin carburettors and low-drag, faired-in tail lamps



The Type 645's first public appearance was in practice at the Nürburgring for the May 1956 1000-kilometre race, showing the right-hand filler for its cockpit-side fuel tank

At the July 1956 Solitude race, the Type 645 with race number 11 parked next to two Type 550A Spyders. Its cleaner lines, shorter wheelbase and smaller cockpit are all clear to see

The Type 645's front view at Solitude displays its faired-in headlamps and the front lid that served as a surface cooler for the engine oil, the filler for the tank sited behind it

In action at Solitude, on the outskirts of Stuttgart. A sinuous and demanding circuit, Solitude tested both car and driver. Hampered by braking and oil cooling problems, von Frankenberg finished a creditable fourth

At the head of the field after the start, next to the 550A Spyder of Wolfgang von Trips, the smaller size of von Frankenberg's 'Mickey Mouse' is evident

Taking its wheel, Wolfgang von Trips just broke 11 minutes on his second lap but did not persevere further. In contrast, Hans Herrmann in the 550A kept slashing his times and, after various changes of tyre pressures and anti-roll bars, concluded with a brilliant 10:35.2.

Having also tried the 645, Herrmann was moved to note: 'It was certainly faster, but totally undriveable. Von Trips and I declined emphatically.'

Hermann's judgement that it was faster was a form of validation for what Forstner and his small team had wrought, but to be successful a racecar must be manageable as well as fast. Herrmann's verdict was anything but positive, because he was an undeniably skillful driver.

Nonetheless, the 645 was among the cars Porsche fielded for the 1000-kilometre race on 27 May at the Nürburgring, where it was driven in practice by Richard von Frankenberg. Still immature, it was rejected by Frankenberg in favour of the 550A Spyder, in which he turned faster laps.

The Type 645's expected high-speed advantage was, nevertheless, present. On straights, Forstner reported it had 'very steady roadholding'. With suitable gearing, and in spite of the horsepower deficit of its outdated engine (Forstner said its four was producing a meagre 98bhp), its maximum speed was 162mph, against 158mph for the 550A in its best 1956 factory trim.

Cannon shot

Handling, however, was judged treacherous. Herbert Linge tested it at Malmsheim and concluded, 'The car was so terrific in back that the front axle was overwhelmed'.

You must remember here that it was always hard to get enough testing time. Drivers wanted the latest, fastest car immediately, and there simply wasn't time to set up the 645's front suspension properly.

Continuing Linge's appraisal, he expanded to Jerry Sloniger: 'Rear adhesion was enormous. You started out with a great deal of understeer. But, when the tail did break loose, it came around like a cannon shot. Nobody could catch the spin.'

The new rear suspension offered better grip, but it was not counterbalanced by the cornering power of the car's front trailing arms, which leaned its wheels outward when the body rolled.

Forstner was not put off so easily: 'The existing difficulties that have shown up with cornering,' he assured, 'must be able to be eliminated by rational judgement without undue difficulty.'

Among the changes already implemented was a new linkage arm that sped up the steering by 28 per cent to help drivers catch the sudden breakaway. Interference between the new central steering arm and the abutment screw for the upper torsion bar was also eliminated.

At the same time, the Silentbloc bearings supporting the front of the engine were reorientated to prevent tearing, and the height of the fuel tank reduced to cut its capacity from 130 to 80 litres, lowering the car's c of g. Compensating for the lack of fuel onboard would be a tank of 40 or 50 litres outside the frame to the driver's left.

Desperate plea

Despite his car's evident promise, Forstner complained to Porsche, Rabe, von Rücker, von Hanstein and Hild on 19 June that, 'It's been standing in Experimental for weeks, completely abandoned.' He enumerated the improvements made in

When the Type 645 next raced at the Avus on 16 September 1956, additional vents were cut in its tail to further assist engine cooling. Numerous dents are testament to the fragility of its magnesium bodywork

Leading the race at the Avus for the first two laps, von Frankenberg visibly needed to steer to the left to hold his Type 645 on its desired course on the track's steep banking

For Ernst Fuhrmann, left, the Type 645 was intended to demonstrate his complete car design competence. The skilled driving role of Richard von Frankenberg, right, was vital to this

the interest of better roadholding, noting it would only take a mechanic two days to put its front suspension and steering back together. All that was needed in order to resume trials was an engine.

Moreover, Forstner added, the frame for 645 number two was half-finished. Some expenditure was needed to source rear uprights, halfshafts, torsion bars and dampers.

'The outlays already made oblige that the final step should be taken, namely to commence trials of the vehicle to win all the knowledge that is there to be won.'

Forstner concluded his report to Porsche's senior racing cadre with a heartfelt query about the future of the Type 645, its half-finished sister and its assortment of components.

Always insightful, the experienced Karl Rabe had raised reservations a year and a half earlier about the potential of what was essentially a one-man project in the demanding Porsche environment, where every man and every expense had to count. Now Forstner was asking – no, begging – the powers that be for their support of what would be his only attempt to create a complete automobile.

Their response was to leave the second car unfinished, but to authorise completion and testing of the first Type 645. However even after the aforementioned modifications, its handling remained demanding. Causing heavy initial understeer, in turns its rear tyres would grip much better than those in front. This would be followed by a very sudden transition to oversteer at the limit. Contributing to this were its short wheelbase and low moment of inertia about its vertical axis, a function in part of its centrally-mounted fuel tank.

Tricky Mouse

Having tasted the Type 645's speed in practice at the 'Ring in May '56, Richard von Frankenberg was willing to cast his lot with it. Then 34 years of age, and wearing glasses with heavy lenses, Frankenberg was both a skilled sports car driver and renowned for his bravery. Although he took this new kind of Porsche under his wing, he had no illusions about its attributes. It was he who dubbed it 'Mickey Mouse', not because of its smaller size, but in recognition of its tricky behaviour.

Mickey Mouse first raced, close to home on the Solitude circuit, on 22 July 1956.

It was [Richard von Frankenberg] who dubbed it 'Mickey Mouse', not because of its smaller size, but in recognition of its tricky behaviour

Von Frankenberg qualified the new model in the front row, second only to Herrmann in a 550A, but then lost first gear even before the 99-mile race began.

On his first lap, braking problems surfaced, a regular feature of the car that made approaching corners as exciting as driving through them. Power faded too as oil temperature soared – a limitation of the front-deck radiator perhaps – but von Frankenberg soldiered on to a fourth-place finish behind winner Herrmann, von Trips in a Porsche and Edgar Barth's East German AWE.

In August, Mickey Mouse ran in practice for the sports car race that accompanied the German Grand Prix at the Nürburgring, but did not compete. All Porsche's drivers concluded its handling idiosyncrasies were too daunting a challenge for a 312-mile race at that treacherous track.

Air at Avus

The Type 645's next appearance was at West Berlin's Avus for the 152-mile Grand Prix of Berlin on 16 September, round six of the German Sports-Car Championship. Because high speed was decisive at the Avus, with its long straights and steeply-banked turn, von Frankenberg chose the Type 645 for this race, in spite of the car's known quirks. Like Porsche's other Avus entries, it was given a tighter tonneau covering the cockpit, with a low wraparound windscreen sheltering the driver.

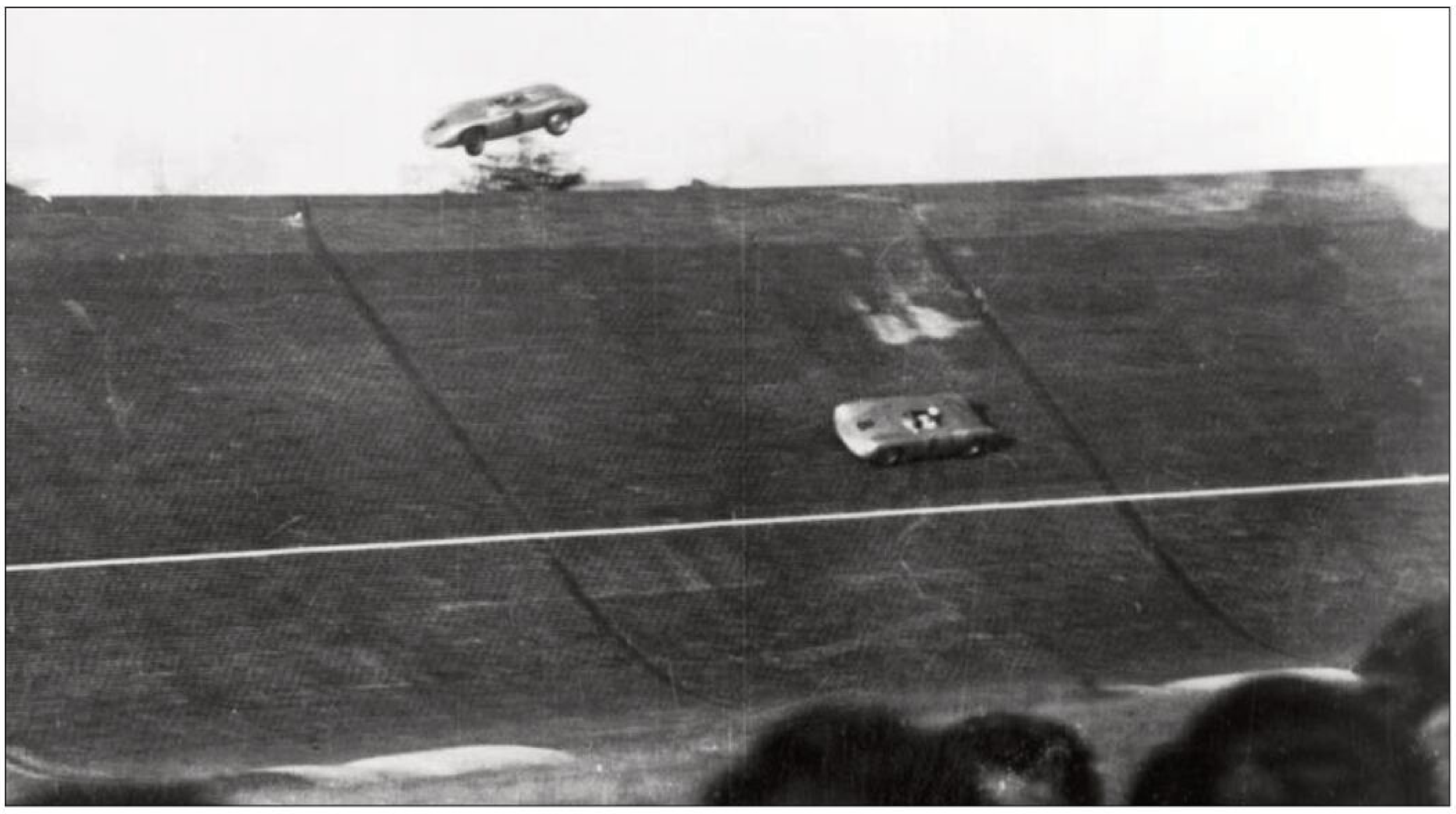
Practice at the Avus promised no dominance for the Mickey Mouse, which clocked the third fastest time behind Barth's AWE and Roy Salvadori's mid-engined sports Cooper-Climax. Soon after the start, however, von Frankenberg took the lead from Salvadori on braking for the flat South Turn and moved ahead of the field, trailed closely by the 550A of Wolfgang von Trips.

On their third of 30 laps, the two silver Porsches droned down the back straight and banked onto the North Curve. Built in 1937, it provided a running surface 24 yards wide, 13 yards of this banked at 43 degrees. It was a constant-slope banking intended to allow cars to run high and low. Rudy Uhlenhaut of Mercedes-Benz commented it was, 'very dangerous, and you had to treat it exactly as if you were driving on a normal road. If you went too fast, you just slid over the top.'

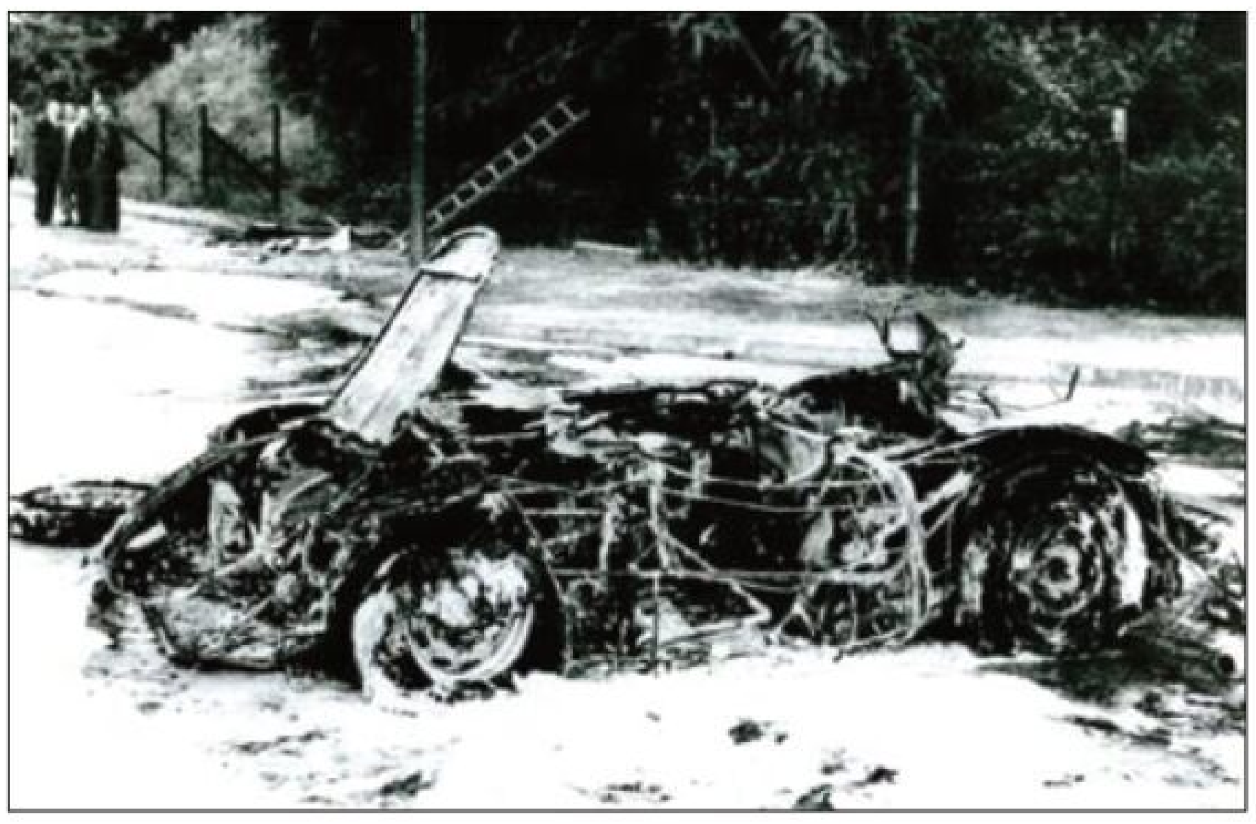
Among the 50,000 Berliners present, all eyes were on von Frankenberg when his car veered to the right and powered at an angle across and over the vertical lip at the top of the banking, which flipped it. Cartwheeling as it vaulted two yards above the rim, the car bounded off the outer earth wall, over a wire fence and landed, a crumpled flaming mass, in the street between a Mercedes 300SL and an open-topped Opel Rekord.

Not until some five minutes after this spectacular crash did a Porsche technician, Harry Lörcher, discover the unconscious von Frankenberg lying in the greenery on the earth wall. Having plummeted from the Mickey Mouse as it brushed through an acacia tree he was not, thankfully, a victim of the white-hot magnesium flames that were consuming the inverted Type 645.

Richard von Frankenberg was never able to remember what happened during what was known as the 'miracle of the Avus' as the three minutes before his crash were erased by the impact of his fall.



This dramatic photo shows the Mickey Mouse sliding up and over the Avus banking with its front wheels fully to the left as von Frankenberg tried to keep it on course. Ejected from the car whilst airborne, he was injured, but the car was destroyed



When the Type 645 landed, outside of the circuit, its nearly full fuel tank and magnesium body combined in this terminal inferno

'That he survived with only slight injuries, or none at all, is mythical,' notes his son, Donald. 'He had to lie five weeks in a Berlin hospital, several weeks of those on his belly.' This was the result of severe injuries to the skin of his back caused by his ejection from the cockpit.

The organising auto club, the AvD, asked the fastidious engineer from the Glöckler racing days, Hermann Ramelow, to examine the wreckage on its behalf. He found no evidence of sudden failure or malfunction of the steering or suspension.

Some speculation centred on the right-side suspension, which had been virtually immobilised on all the Spyders to cope with the *g* forces on the Avus banking. Be that as it may, the Type 645 had worn out its welcome at Zuffenhausen.

'The Mickey Mouse type,' wrote von Frankenberg dryly, 'was not subsequently recalled to life.'

Lessons learnt

It did not expire without teaching the Porsche racers some useful lessons. The Type 645 had shown that frontal area *could* be reduced, and that performance benefits were derived as a result. Similarly, the oil cooler built into its front deck lid had proved its potential, and would be used

All Porsche's drivers concluded its handling idiosyncrasies were too daunting a challenge for a 312-mile race at [the Nürburgring]

in the RSK. Even further improvement of its suspension seemed possible, essential even, especially at the front end.

Best of all, though, its Spartan frame design pointed the new direction for the successful 550A, which Trips drove to victory at the Avus. It showed the clear advantage of the tubular spaceframe that later Porsche racers would use.

'The car led its race,' Herbert Linge reflected of the 645. 'It couldn't have been a complete failure, and it taught us a lot.'

As for Richard von Frankenberg, he was able to attend the Porsche company's Christmas festivities later that year with the aid of a cane (and raced again, winning, in 1957). He also managed to maintain his work as the editor of Porsche's *Christophorous* magazine but, wrote son Donald, 'number 23's appearance was delayed.'

Efficiency drive

Ergonomics is the study of best fitting people to their working environment. When it comes to racing, that's more important than you might think

By JAHEE CAMPELL-BRENNAN

Mercedes AMG

Cabin ergonomics are an integral part of the driver experience, and must be considered from the beginning of the design process

When we're looking at sports, and more importantly team sports, where running an efficient operation is a competitive edge, ergonomics becomes an especially interesting subject, and a particularly relevant one given the recent 24 Hours of Le Mans race.

Providing an ergonomically positive environment for a team of mechanics, engineers and drivers to perform their job of winning races is a complex and broad task. Mechanics need good tools and well designed, serviceable cars to perform work under time pressures without strain or fatigue, and engineers need good computing infrastructure and communication equipment to analyse, set-up and support the vehicle.

This approach feeds all the way up the chain to the driver, who needs to be in a cabin with suitable ergonomic design at their physical interfaces with the car through the seat, controls and to the sensory environments of sight and sound. Any failings in these areas affects their ability to race.

Ergonomic design for the driver requires controls to be positioned within comfortable reach, support in a comfortable yet not overly restrictive seat, and personal protection such as race suit and helmet which does not restrict their movement and keeps them cool.

They also need a clear, unobstructed, well lit view of the road ahead and suitable NVH qualities. Oh, and no porpoising!

Sensory experience

These considerations of the sensory experience must be incorporated directly into the engineering and development process from the beginning, not as an afterthought. This is especially relevant in endurance racing where drivers can spend upwards of three hours at a time in intense race conditions.

The first task for any racecar design, then, is to properly locate the driver seating position and controls. Whether the car be of a monocoque chassis construction or otherwise, the roofline and roll structure will largely determine how reclined the driver must be. This sets the basic seating format.

It's common practice to employ the use of digital mannequins representing the dimensions of the expected driving population to define initial cabin size limits. This ensures an overall cabin volume and positioning of major components so the majority of drivers can operate the racecar with appropriate comfort.

Different manufacturers have alternative methods of defining these mannequins, from the 95th percentile approach, which represents a form covering 95 per cent of the adult male population, to more specific approaches using data gathered on a specific range of drivers they know will be using a particular chassis.

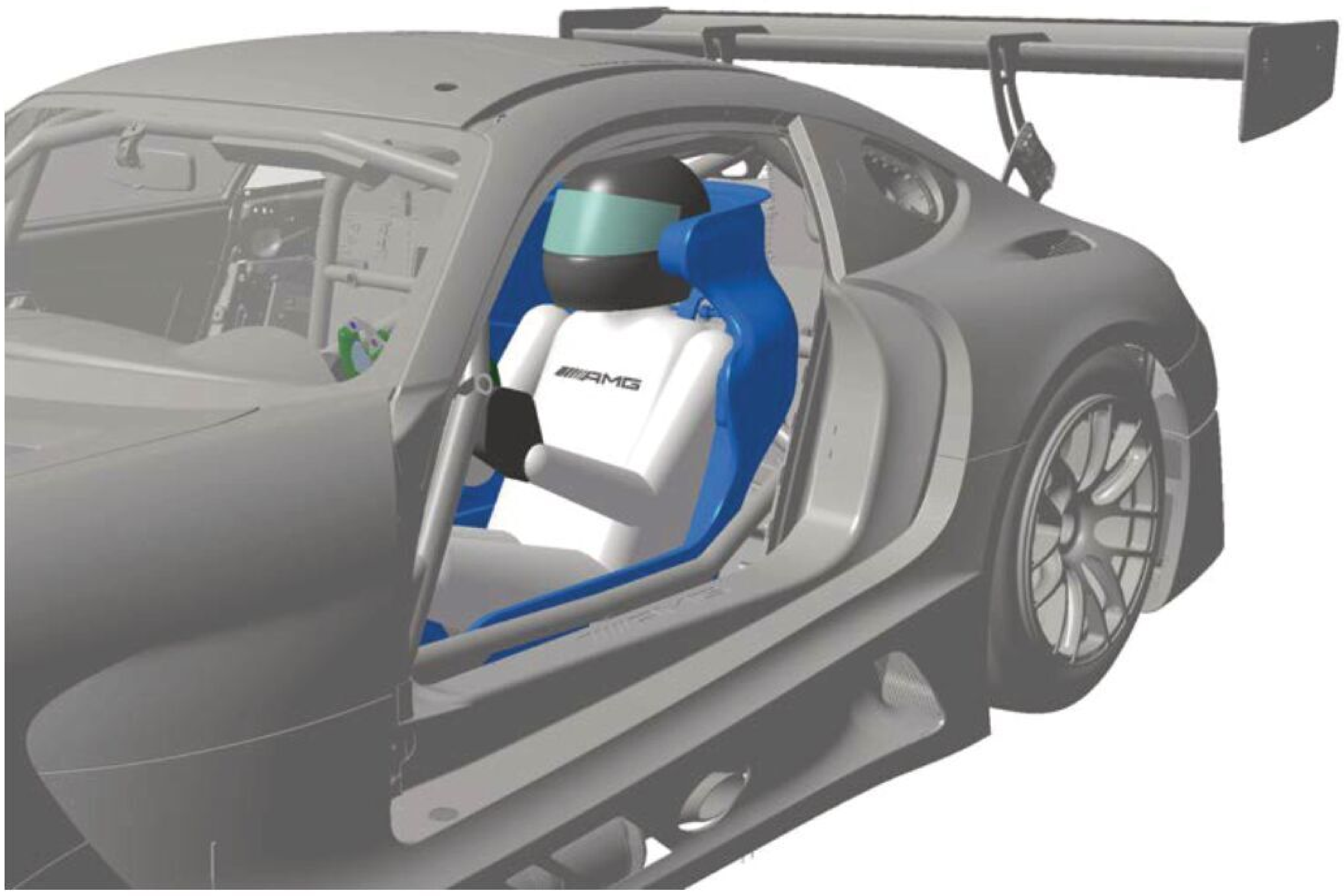
Manufacturers such as Audi Sport, who have the resource to develop car platforms from the ground up from a blank sheet of paper, spend significant amounts of time and money ensuring this is correct.

'We do the first driver placement using a virtual dummy and test this in a wooden cabin mock-up that represents the monocoque,' explains Axel Löffler, chief designer of Audi Sport's racecars.

'We put the driver in the mock-up and see how we can best make them comfortable using foam blocks in different thicknesses to bring them back and forth, and up and down within the available cabin space to define the optimum seating position.'

This seating position is also dictated by the driver's line of sight outside of the cabin, their so-called vision lines.

Providing an ergonomically positive environment for a team of mechanics, engineers and drivers to perform their job of winning races is a complex and broad task



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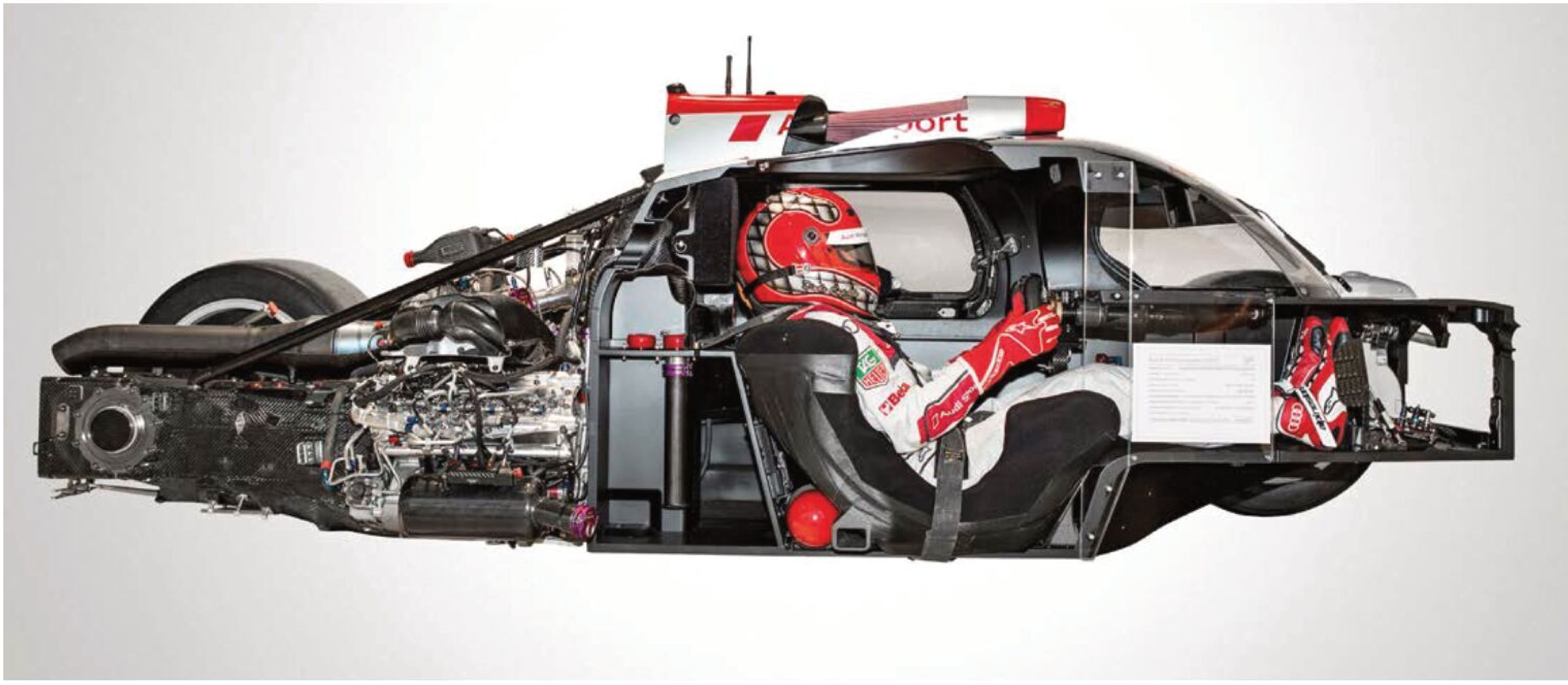

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Real and digital mannequins are used to determine the positioning of the seat and controls. The aim is to have the driver's head located in the same position, regardless of individual driver height

'The wooden mock-up we use for driver positioning also serves as a tool for us to ensure the driver's vision lines are correct,' continues Löffler. 'We have certain vision lines we try to respect and incorporate into the wheelarches and a-pillar design, which are critical. We then aim to develop geometry that will present these obstacles appropriately to the driver.'

Definition of these lines is something gained from experience, and invariably becomes something of a battle with vehicle dynamicists who push to position the driver as low as possible within the cabin to minimise centre of mass (CoM) height. In the past, this had led to some extreme driver positioning and, ultimately, accidents as the driver's sight was compromised.

'It was particularly interesting when LMP1 began to move from open to closed cockpits,' notes Löffler. 'In the open-cockpit cars the drivers were sitting quite high without penalty because there was a minimum dimension of the primary and secondary rollover structure. But the regulations for closed cars basically forced us to put the driver lower, in a more reclined position, and add the a-pillar.'

'People had to adapt. We had certain cases in our cars where drivers were looking through the louvres in the wheelarches to spot the track. It was really quite extreme.'

Pump up the volume

Ultimately, this lead the FIA to introduce regulation changes to raise the height of the drivers within the cars, and today there are certain volumes that must not be obstructed by bodywork to ensure a good driver view.

After defining the cabin, seating is perhaps the next most salient ergonomic concern, but is also a consideration for safety. The objective with seating is always to provide maximum containment, but to do so without discomfort. As the human body is not a one-size-fits-all, there is much to get wrong here, but also great opportunity for successful design.

Although the subjective nature of seating means it is a consideration that cannot possibly have just one correct solution, manufacturers have had decades of experience and innumerable driving hours of feedback from, so best practices are pretty well understood today.

'Our goal is to position any driver's head in the same position within the cabin, whether they are tall or short, not just to ensure they have a good view but also that they are a certain distance from the roll structure for safety reasons,' explains Gordian von Schöning, head of racecar development at HWA, which develops seating for racecars.

Whilst it may be a relatively easy task to physically fit a digital mannequin in the intended location, defining an ergonomically positive driving position is where the art lies.

The angle between the back and hips, for instance, can be the difference between comfortable racing and major annoyance. Consequently, the boundaries here are kept within known and well understood limits, as Matteo Repetto, R & D manager at motorsport seating and interior equipment manufacturer, OMP Racing, explains:

'We tend to take a relatively safe approach with respect to the main dimensions of the seat shell, and design at a slightly obtuse angle, perhaps around 95 degrees to the hips. We then adjust this with cushioning to reach a final form. This allows us to make the seats suitable for the widest range of people.

'You can undertake huge design studies to gather data and produce what you *think* is a great level of support, but with this you either produce a perfectly fitted seat, or one which is hated. This risk is what we try to avoid with 'safe' designs.'

The approach is to create a neutral design of the rigid shell and then to make smaller, comfort adjustments via foam inserts. This is learnt from decades of experience, and results in a product in which around 90 per cent of the final support is provided by adjustable cushioning, with only the remaining 10 per cent by the seat shell itself, which essentially acts as scaffolding to the main stage.

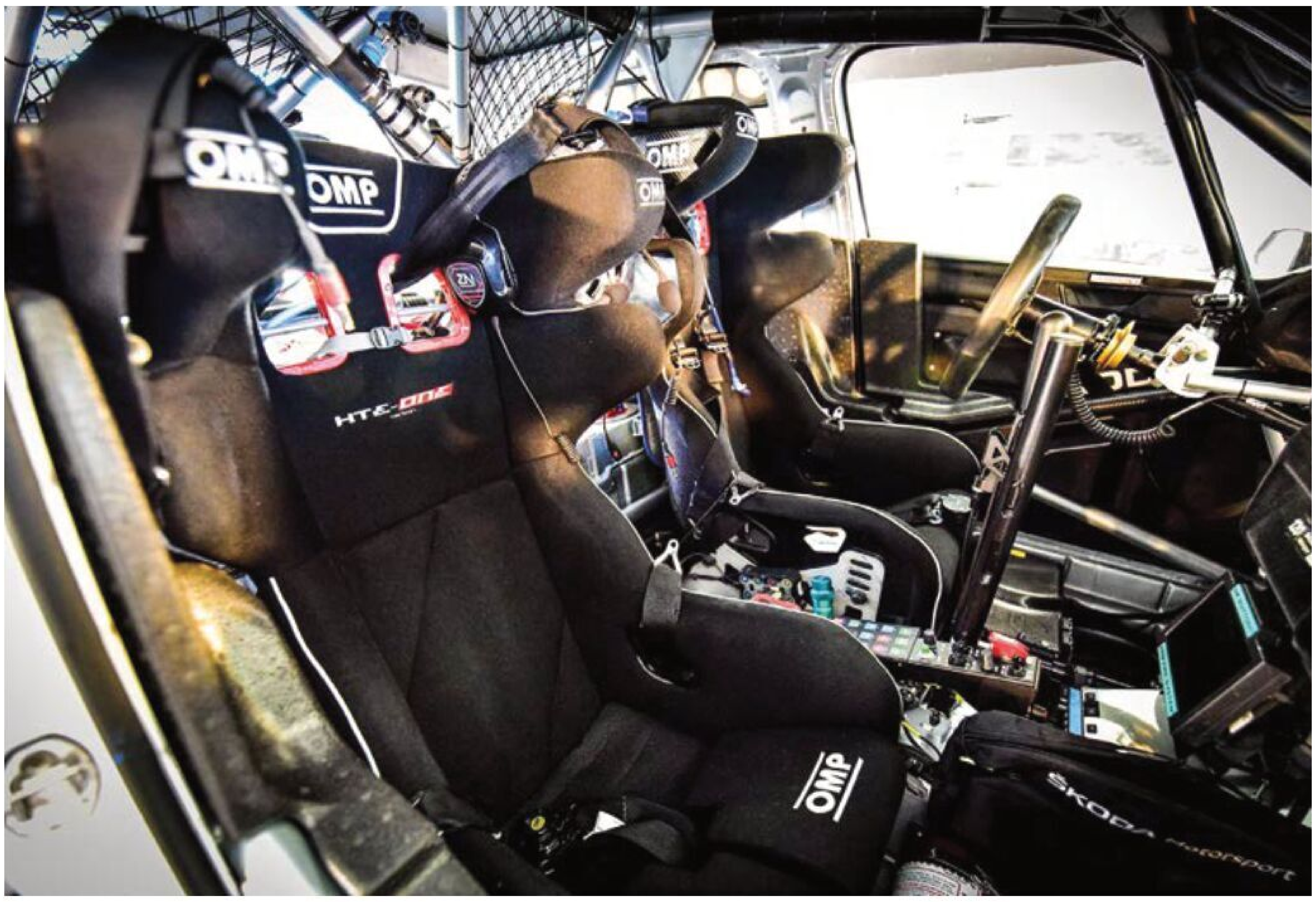
'Our process is generally to design the seat shell to accommodate the largest driver according to the 95th percentile, and then to enlarge the shoulder and side supports to contain the smallest possible driver,' continues Repetto. 'This is actually quite tricky though as, for example, the shoulder support for a smaller person would be positioned way too low for someone at the upper end of the scale and would be completely uncomfortable. So we need to play a little, but the smallest driver we accommodate with this technique is generally around 160cm (5ft3in).'

Design process

The initial static, off-track evaluation of a prototype seat design usually results in the selection of several cushion options from the samples available, giving more or less cushioning for larger or smaller drivers over the chosen baseline configuration.

'With foam cushioning, we generally don't go below 50mm of foam thickness. This is a critical factor in crash safety,' notes Repetto.

When a green light is given for the initial prototype, the seat manufacturer can then progress to a seat more closely resembling the final form appropriate for dynamic testing, hopefully resulting in another thumbs up from the reference driver and final sign off to put the design into production.


OMP

The shell of the seat is designed to accommodate the largest driver size. Adjustments for individuals are made using cushion inserts

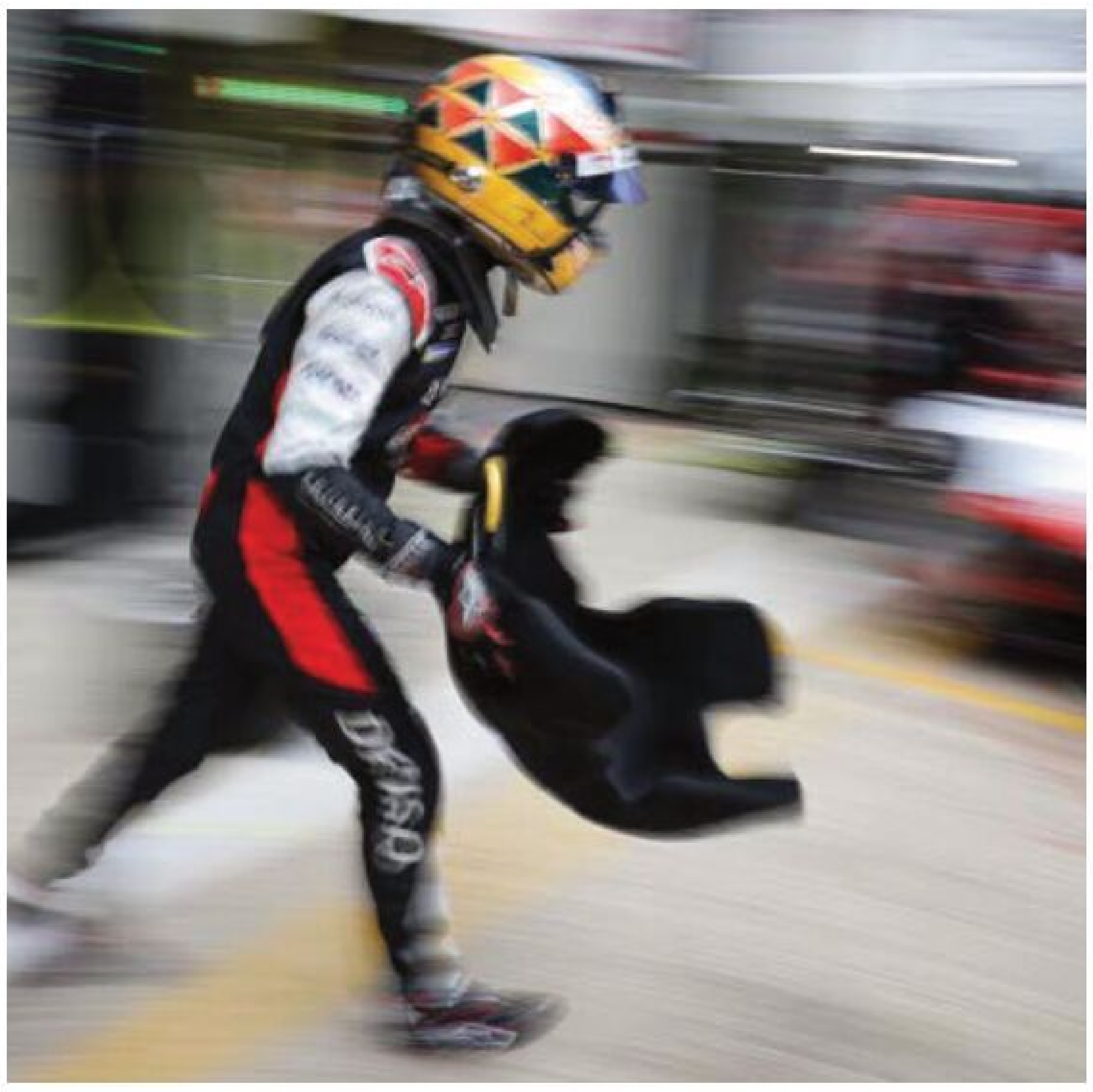
The approach is to create a neutral design of the rigid shell and then to make smaller comfort adjustments via foam inserts

'The reference driver's comments are generally taken without question so, if they need some adjustment, that's what we do. Some of the most important feedback we usually get is concerned with the side supports, so it's imperative we get that part right,' continues Repetto.

Though it all sounds reasonably straightforward, it is interesting to note how much seating solutions vary between manufacturers in different racing classes. This is especially true in amateur series such as Ferrari Challenge, Lamborghini Super Trofeo and the Porsche Cup, where the seating must more closely resemble that of the road cars the racecar are based upon.

In the higher level, professional categories of racing such as GT3, this relationship disappears as the cars are more extensively re-worked for the track. Seating designs then tend to converge on a more favourable, widely adopted format at this level.

In most forms of motor racing, regardless of level, a particular car is shared between multiple drivers. This is especially true in endurance racing, where three different drivers may pilot one car over a single race,


XPB

Removable seat inserts allow multiple drivers to sit comfortably within the same seat shell, and offers a quick solution at driver changeovers

so to provide a level of tailoring for each driver, removable seat inserts are created from expanding foam.

'Our drivers come to visit the AMG HQ in Affalterbach and sit in a mock-up jig we use to position them at the right height,' explains von Schöning. 'We then fit spacers between the driver and the seat shell, which we fill with foam to create individual, tailor-made inserts. These fit perfectly into the shell and form the finished seat for that particular driver.'

Seat of the pants

Consequently, at driver changes, you'll see the outgoing driver taking their insert with them and the ingoing driver fitting theirs.

Ergonomic focus then shifts to designing hand and foot controls at a comfortable distance, with enough 'wiggle room' to allow natural, unobstructed movement and a weighting for positive control feedback.

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As the seats in motorsport are fixed in place for safety reasons, steering wheels are generally adjustable in terms of height, reach and also the angle at which the wheel is presented to the driver. Similarly, the pedal box can move fore and aft to meet different drivers' feet in a comfortable position.

Rather than use the 95th percentile method to define the range of adjustment in this capacity, both AMG and HWA take a slightly different approach to defining expected driver sizes for their cabins.

'We actually took scans of several tall, short, large and small drivers to define what we feel are upper and lower limits,' explains von Schöning. 'We use these scans to create dummies in CAD, which we then use in our development process to design our steering wheel and pedal box adjustment to cover the expected range of drivers in terms of reach.'

Take the strain

Controls should be designed with appropriate load limits to prevent muscle and joint strain, which means particular attention must be focussed on things like joint angles, and the loads associated with repetitive movements.

This is something which is achieved largely through learnings gained from experience in defining systems that interact well together. Steering, for example, is an interaction of power steering pump power, hydraulic piston sizing and linkage kinematics. Implementing a system that works well, with adequate weighting and feedback, is somewhat of an art.

This also applies to switchgear, which must be intuitive for the driver in order not to distract from the job at hand.

Headlight stalks, radio operation, drinks buttons, brake biasing, powertrain and other vehicle controls must all be able to be activated by a driver under race conditions, wearing thick gloves and without looking.

In this sense, the objective is really to enable the driver to keep their eyes on the track by creating a layout which is both intuitive and provides positive haptic feedback to notify them that they achieved the desired changes by touch only.

'The location and feel of the switches and things like this is an interesting one to approach as, unlike other elements of racecar design, it's so subjective. It's something you can really only do from driver feedback rather than virtual design. We use development drivers to help us there,' adds von Schöning.

Shapes of things

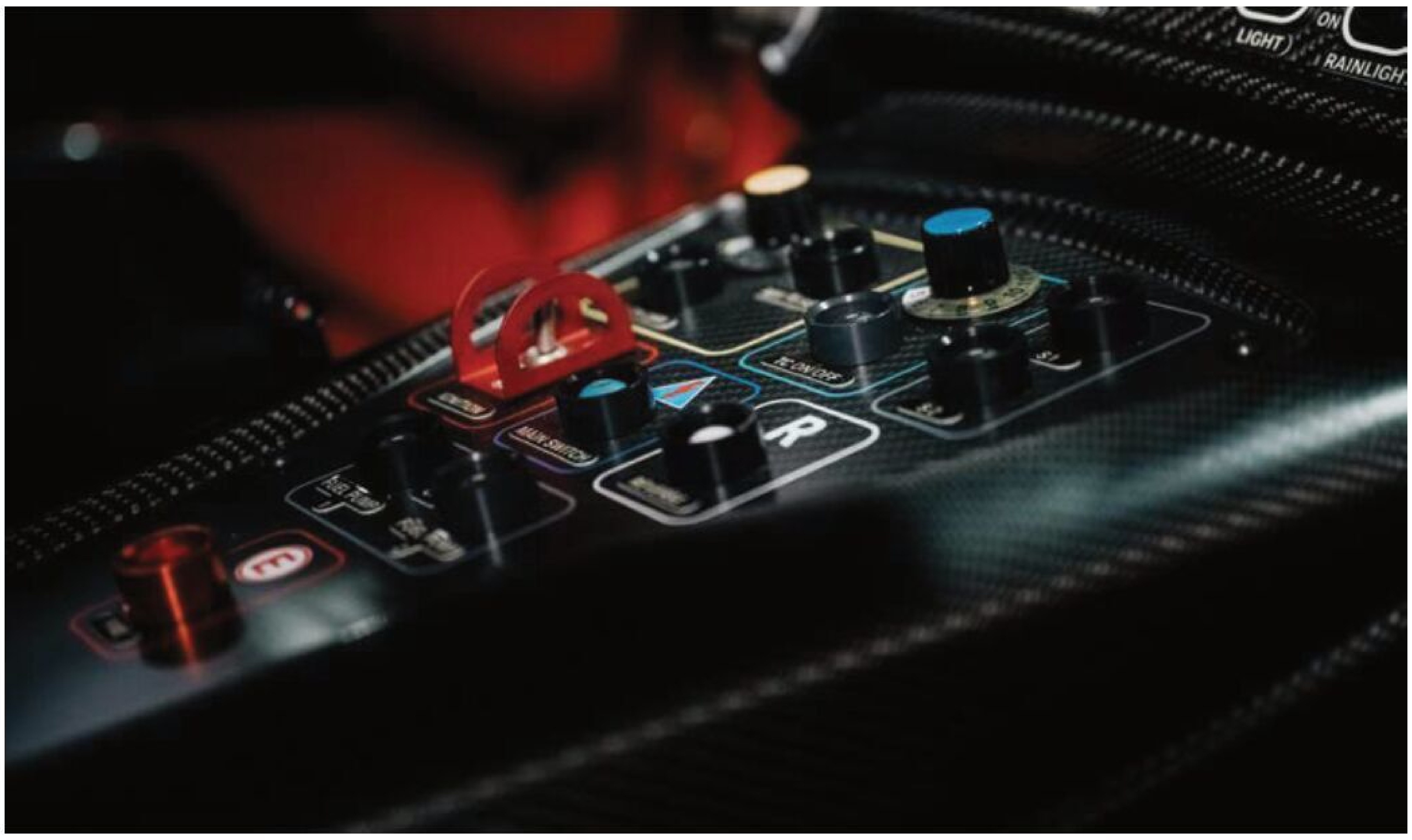
Of such controls, there are few more subjective, that differ from driver to driver, than the size and shape of the steering wheel. Drivers can get a completely different feeling from the same wheel, which leads to the hand grips themselves sometimes being tailor made to each driver, especially at the professional level.

'For a WRC driver we supply, we made several different hand grip configurations for him to try,' recalls Repetto. 'We ended up making five different wheels with variation of less than 1mm in certain locations between each iteration before arriving at the correct one. He won multiple world championships with that wheel, so it obviously worked!'

The introduction of more electronics into the steering wheel has evolved their appearance in recent times, and again we see different design approaches due to this. At some levels, such as Le Mans Prototypes and high-level GT racers, steering wheels more closely resemble flight yokes.

Despite their appearance, this works from a practical level, allowing the accommodation of electronics and switchgear without restricting the view of dash displays. Modern racecars are also designed with steering ratios sufficient that drivers can reach full lock without having to shuffle their hands around the wheel, so it works from ergonomic perspectives, too.

With FIA regulations requiring full race suits, gloves, shoes and helmets with fire retardancy and low thermal conductivity to


Mercedes AMG


Mercedes AMG

Switchgear design and placement must be intuitive and give the driver positive feedback without taking their eyes off the road

The objective is really to enable the driver to keep their eyes on the track by creating a layout which is both intuitive and provides positive haptic feedback

be worn at all times, a complex challenge is presented for manufacturers to meet all these requirements, whilst making their equipment light enough for good comfort and breathable enough not to cook the driver.

Racing is a very physical sport and drivers generate a lot of body heat, so this is a tough remit to meet, especially in closed-cockpit racecars where airflow over the driver's body is greatly reduced, and in-cabin temperatures can reach very high levels.

To manage temperatures, air conditioning can be used, but the added mechanical complexity, as well as the weight and power penalties it incurs, means if designers can avoid installing it, they will. However, attention must then be paid to airflow through the cabinto control temperatures in potentially very hot ambient conditions.

'Management of cabin temperature is something we spent a lot of development on with our GT3 platform to avoid using AC where possible,' concurs Stefan Wendl, head of customer racing at Mercedes AMG, 'and this is one of the strongest points of our package within the field.

'We wanted to ensure maximum airflow and air volume through the cabin, which, with the front engine and side exhausts, has traditionally been quite a challenge.'

Some championships mandate a maximum cabin temperature relative to ambient conditions, but this can be manipulated by cooling the sensors without truly catering for the drivers' experience.

From a driver perspective, a high volume of fresh airflow is crucial, but also the ability to direct it to key areas of the body – the feet, the torso and the head – depending on their specific preferences.

'Drivers generally give us great feedback on cabin conditions after double or even triple stints with this approach,' adds Wendl.

This approach is shared by those with the most experience and available resources at the top levels of motor racing.

'We used extensive internal aero work to manage cabin airflows, and even developed seat ventilation systems to aid in driver cooling,' says Löffler. 'We used this concept in our closed-cockpit LMP and DTM developments and avoided installing air conditioning as a result.'

Working with these systems, alongside objective monitoring from doctors, drivers were able to comfortably manage four-hour stints in the car without overheating, even in extreme conditions.

Suited and booted

The race suit and other equipment make a contribution to driver comfort in the sense not only of thermal regulation, but also free movement, which makes it an area of continual development and improvement.

'Comfort in race suits is certainly related to breathability and moisture control in terms of absorption, but also elasticity of the material,' says Repetto. 'When drivers first put on a suit, the first thing they do is simulate the driving motion to see if they feel any restriction. It's important for them not to be annoyed in any way by the suit. This is definitely a key point.

'We are also using strategically placed, breathable fabrics where we feel it's most useful, such as the back area and so on. This is an area of continual R & D for us.'

Shoes are another particularly interesting, yet very subjective, ergonomic consideration. Being a critical interface between the driver and the vehicle means they have an important role to play in enabling the driver to feel some of the finer details in pedal operation. Sensation here is very important.

Mercedes AMG

Steering wheels more closely resemble flight yokes in modern racecar applications, as shown by this one in a Mercedes AMG GT3

Mercedes AMG

Keeping switches at eye level is particularly important in customer-focused racing where non-professional drivers will compete

OMP

Race suits must offer a large amount of flexibility, whilst also being breathable, fire retardant and of low heat conductivity

XPB

Night racing requires powerful headlights to ensure visibility of not only the road ahead, but also either side of the car to aid spotting of braking markers and apexes

The parameter differentiating a good, or not so good, shoe for most drivers is the stiffness of the sole layer.

'I was speaking with a driver once who used to push on the accelerator with only his toes, so he wanted extremely soft shoes to maximise the sensation and control he was able to achieve. In contrast, certain drivers who are very hard on the brake pedal want very stiff shoes with plastic or carbon sole layers. It is *always* subjective,' says Repetto.

Visibility

So, we have a well-seated driver, kept cool and comfortable in all environmental conditions, but engineers would be remiss to neglect all aspects of external visibility on the driver's ability to race efficiently, and safely.

In the inevitable night conditions that are a feature of endurance racing, awareness of competitors, corner apexes, braking markers and even good sighting of crashes ahead can contribute massively to confidence and consistency. Illumination of the track to allow the driver to perform with confidence is refined down to quite a science these days.

The Nürburgring 24h, for example, has the 13-mile Nordschleife section of its near 16-mile lap in almost completely unlit conditions at night, which requires a lot of development go into the racecars' lighting systems.

Gone are the days of just bolting an additional set of spotlights on the front, lighting for cars used in night racing today is completely customised. Without legislation to protect oncoming road users, developers of these systems can be very creative in giving drivers the best possible experience.

'It's not just a case of projecting the brightest light everywhere, as this creates a situation where the drivers eyes are adapted to brightness and therefore become completely blind to areas outside of the throw of light,' comments Löffler. 'The transition to darkness at the extremes of the light projection also needs to be smooth.'

Audi AG

Endurance racing brings with it a whole different set of requirements when it comes to visibility, both of controls and track, at night

Some platforms feature lights that turn with the drivers' steering inputs to provide good apex illumination. Others incorporate corner lighting to achieve the same result.

The quality, or temperature, of the light is also key for vision. In previous years at the Nürburgring 24h, it was mandatory that the fastest cars use yellow light, with a colour temperature of around 4000 Kelvin (K).

'But there were so many complaints from the drivers that the yellow lights were a big disadvantage in showing contrast on the track, especially as the track was transitioning from wet to dry conditions,' adds Wendl.

It's not just a case of projecting the brightest light everywhere, as… drivers' eyes [can] become completely blind to areas outside the throw of light

Rear visibility can also be a significant problem in many racecars, and situational awareness of other vehicles on track, which are sometimes approaching with very high closing speed, is extremely important from a safety perspective.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Despite advancements in camera and display technology, old school rear view mirrors are still preferable for rearward view in most forms of racing as they stay clean and provide better judgement of distance, especially at night. However, in mid-engined and Prototype cars, their use isn't possible.

Camera imaging systems have consequently been a great recent breakthrough in these situations. Not only providing the required rear view, but introducing the capability of overlaying markers onto the image, which can be colour coded depending on approach speed, and also let the driver know on which side they are being overtaken. This takes a lot of mental load off the driver, and lets them better focus on the task at hand.

'Especially at Le Mans, where switching from sunlight to dark and having bright headlights behind could be an issue for drivers, we found cameras to be preferable,' says Löffler. 'It needed some adjustment by the drivers to get used to the camera vision but you could manage contrasts much better and cover such a wide view angle that they were deemed a big help.'

Vibration isolation

The final piece in the ergonomic puzzle is the NVH (noise, vibration and harshness) the drivers are subjected to.

With engines hard mounted to carbon monocoque, and gearboxes hard mounted to the engine, there is a huge amount of vibration energy being transmitted into the cabin. But beyond an adjustment of seating foam to try and absorb some of this energy, engineers are limited in what can be done to isolate the driver from it.

The noise from combustion alone can be enough to give a driver hearing damage, which requires ear plugs to be worn to keep volumes within safe limits. Over short distances it may be bearable, but it is a cumulative effect and, in longer races, can become very distracting, even painful.

'In our Dakar platform, we're experimenting with noise cancelling systems to keep cabin noise down and make it a more pleasant environment for the driver,' says Löffler.

Certain other applications, such as GT racing, where the engines can be thought of as more characterful, seemingly the issue is quite the opposite.

'We have a naturally-aspirated V8 engine, so there are no noise complaints from the drivers. In fact, the drivers are even asking us to run without ear plugs!' jokes Wendl.

Von Schöning finished on the following comments. 'We really didn't spend much time on NVH actually. We worked on the exhaust in order to manage volume for required track noise limits, but otherwise, outside of ensuring brackets and such are not hitting resonance, NVH wasn't a concern in terms of the drivers' experience.'

With all the elements of ergonomic design we've covered in this article, the common theme is that giving an individual driver the control to tailor their environment to their personal preference not only results in a physical benefit, but also a psychological one.

This 'belief effect' is scientifically measurable. Even if there will be no physical difference to the performance of the car itself, enabling the driver to feel comfortable with their equipment is worthwhile in terms of getting the best out of that performance, and the more we understand about it, the better.

Even if there will be no physical difference to the performance of the car itself, enabling the driver to feel comfortable with their equipment is worthwhile in terms of getting the best out of that performance

If athletes have the knowledge that their equipment is formed to their specifications through their own input, that alone can produce tangible performance outcomes, though this often falls into the realm of subjective design rather than a scientific engineering exercise.

Integral part

Ergonomics, then, is one of the less talked about, but still very interesting and involved disciplines within racecar engineering, and it doesn't take too much understanding of it to see that it's an integral part of buiding and running an efficient, successful racecar.

Traditionally, racecars have a reputation for being loud, abrasive and uncomfortable environments that were suffered rather than enjoyed, but research and development has corrected this, and will continue to yield racecars that are comfortable and with minimal distractions to allow the driver to focus on their main objective – driving.

Mercedes AMG

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The joy of six

Adding extra wheels to a racecar might seem logical, but not always for the same reasons.* Racecar *charts the rise and fall of motorsport's six-wheelers

By LAWRENCE BUTCHER

Last year, the lunatics at Hennessey, a US creator of Lotus-based machines that top 250mph, previewed a concept called 'Deep Space'. The $3 million electric hypercar is designed to surpass 200mph and, in order to harness the presumably several thousand horsepower electric powertrain, it will feature six wheels.

Radical as this concept may seem to some of the younger generation, company CEO, John Hennessey, is not the first to decide four wheels just won't cut it, and in racing many have added extra wheels in search of performance over the years.

Rule makers – ever the spoilsports – clamped down on such antics in the 1980s, but fortunately a plethora of six-wheelers, some well-known, others less so, made it out into the wild before they did so.

The pioneers

The motivation behind bolting on an extra axle has evolved over the years, and in the early days it revolved solely around the general unsuitability of then current tyre technology for racing. The late 1920s and early '30s saw the idea of an extra pair of wheels, though not an extra axle, starting to come into vogue.

Possibly the earliest example is Raymond Mays' (who was later heavily involved in first ERA, and then BRM racing operations) Vauxhall Villiers TT. Hitting the track in 1929, it was based on a 1922 Vauxhall TT racer, sported a twin rear wheel set up and won that year's Shelsley Walsh hillclimb. Through the 1930s, several manufacturers, including ERA, would follow his lead.

However, the most well-known application of twin rear wheels is probably the Auto Union Type C of 1936. This not only ran in grands prix, but also competed successfully in European hillclimb events, for the latter fitted with twin rear tyres to help tame its Porsche-designed V16 engine.

Not to be outdone, Mercedes used a similar set up to great effect later in the 1930s. At the brutal Grossglockner hillclimb in 1939,

In the early days [motivation] revolved solely around the general unsuitability of then current tyre technology for racing

The six-wheeled, Porsche V16-engined Auto Union Type C of 1936, seen here at Goodwood, competed successfully in various grands prix and hillclimb events

Hans Stuck in the Auto Union Type C at the Hillclimb Grand Prix at the Schauinsland track near Freiburg in 1937

Audi

Audi

????

Mercedes followed Auto Union's lead with its similarly six-wheeled, but still only two-axled, W125, which triumphed at the Grossglockner hillclimb in 1939, with Herman Lang behind the wheel

Herman Lang triumphed in a Mercedes W125, a far more powerful machine that its W25 predecessor. At the start of the 1939 GP season, its supercharged inline eight was putting out 550bhp; by the time it ran at the Grossglockener, this was pushing on towards 600bhp, hence the quest for greater traction.

The year 1939 would also see the (partial) construction of what could lay claim to being the first true six-wheel racer, in so much as it had three axles, rather than four wheels sharing a single axle. The 8.24m long Mercedes T80 was intended to go after outright land speed records. There had been an ongoing duel between British drivers, George Eyston and John Cobb, on the salt flats in Utah, USA, which had driven the outright record up to just shy of 369mph.

The mighty T80, penned by Ferdinand Porsche (who Mercedes poached from Auto Union at the start of 1938), was to be powered by Daimler Benz's DB 603 RS aero engine, a water-cooled, inverted V12 unit that produced an impressive 2574kW (3500bhp) from its equally impressive displacement of 44.5-litres at a mere 3640rpm. As the project matured, its projected top speed – to be realised in Germany on an Autobahn of course – rose from 350mph to a staggering 466mph.

Mercedes

The Ferdinand Porsche-designed, Mercedes T80 land speed racer of 1939 was the first car to use three axles to mount its six wheels

Unfortunately, the outbreak of the Second World War meant the T80 never had the chance to run, though its original tubular body frame, and a chassis built by Mercedes Classic, replete with DB603 engine, is on view at the company's museum in Stuttgart.

Post war, the first three-axle, six-wheel circuit car made its appearance on the other side of the Atlantic, perhaps unsurprisingly at the hotbed of innovation that was the Indy 500. In an interesting take on the classic front-engine Indy Roadster concept, team owner, Pat Clancy, took inspiration from the heavy trucks that had made him a small fortune as a fleet operator around Memphis. He observed that on twisty mountain roads, his twin-axle trucks made faster progress than passenger cars of the time, so why not transpose the idea to Indy?

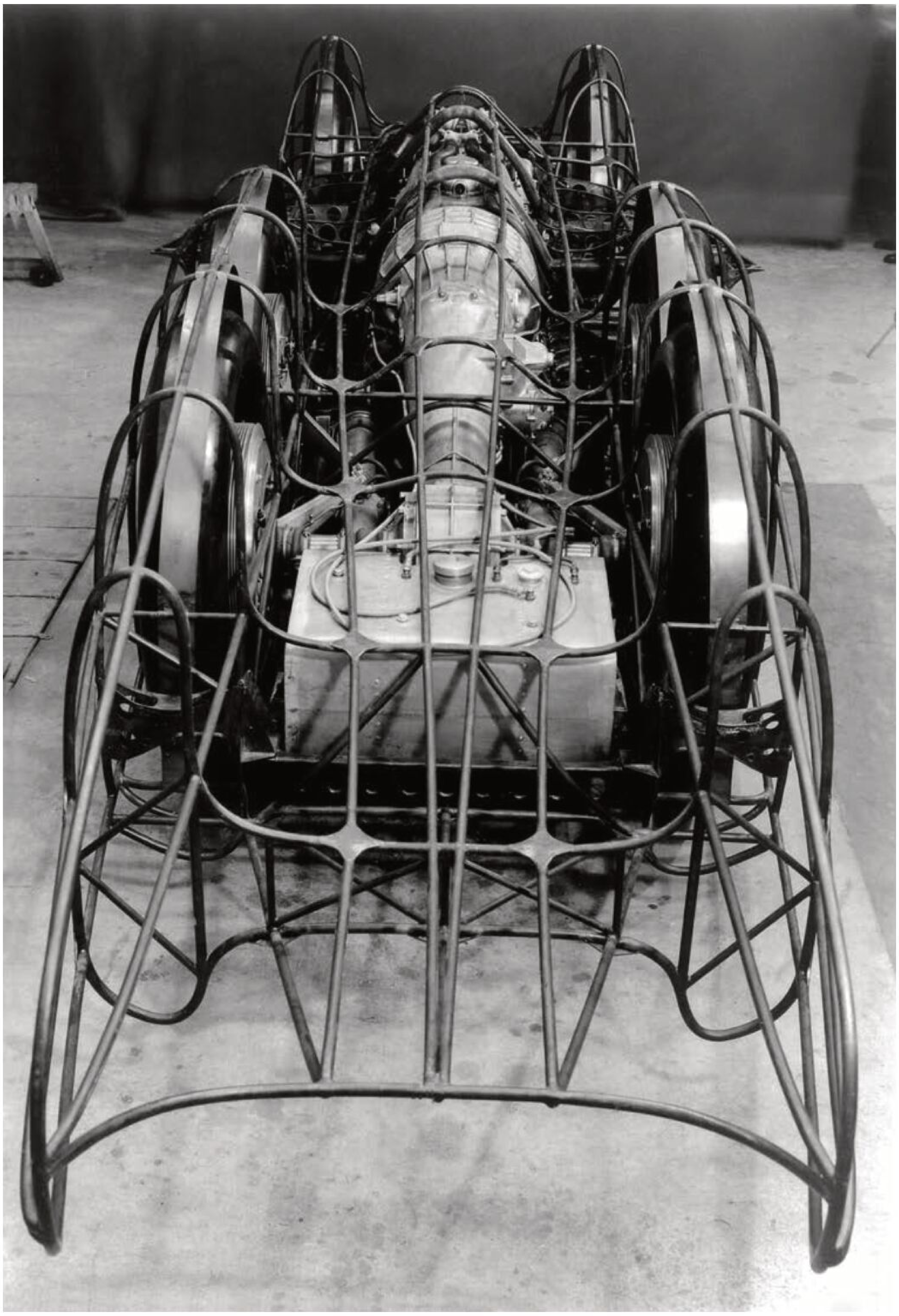
Using a body and frame from renowned racecar builder, Frank Kurtis, Clancy's mechanic, AJ Bowden, set about adding an extra axle and customising the body to fit. Drive was transmitted through a pair of quick-change Pat Warren axles, supported by quarter elliptic leaf springs with power provided by the ubiquitous 270ci Offenhauser four-cylinder engine.

While not a complete success, the Pat Clancy Special was far from a failure. Driver, Billy DeVore, qualified 21st at the 1948 500 and went on to finish 12th. The car ran again in 1949, but retired after 65 laps with driveshaft failure, and would later be converted back to a more traditional four-wheel layout. It seemed that any extra traction provided by the double axle was more than offset by the 200lb of extra weight and the mechanical losses inherent in the design. A six-wheeler would never again appear at the Brickyard.

1970's heyday

Fast forward 20 years to the 1970s and suddenly everyone wanted in on the six-wheel gig. The batting was opened by probably the best-known of the breed, the Tyrrell Project 34 (P34 for short). However, unlike those that had gone before, Tyrrell designer, Derek Gardner, was not primarily hunting traction with his use of additional wheels, but aerodynamic advantage.

His theory was that by tucking small wheels behind the shovel-like front wing (limited at the time to a maximum width of 1500mm), a useful drag reduction could be achieved. He quickly ascertained that using a single pair of small wheels would not provide the required levels of grip for racing so, with nothing in the rules to say he couldn't, and being no stranger to novel solutions (Gardner had previously worked at Ferguson on four-wheel-drive systems) he alighted on the novel idea of doubling up the front axle.



Mercedes

The outbreak of WW2 meant the Mercedes T80 never raced, but its chassis and engine are at the Mercedes museum in Stuttgart

To solve the issue of steering, the front set of wheels were connected directly to the steering rack with the rears piggybacking via a bell crank connection. Apparently, the result was light yet precise steering feel akin to a power-assisted system.

The design was not without its dynamic flaws, particularly if the wheels on one axle locked before the other. Brake cooling also proved problematic. A lack of development by Goodyear on the small front tyres also hampered the car's development. Despite this, the Tyrrell P34 was the most successful six-wheeler ever to run in Formula 1.

Unveiled at the tail end of 1975, during the 1976 season (sporting a slightly longer

Team owner, Pat Clancy… observed that on twisty mountain roads, his twin-axle trucks made faster progress than passenger cars of the time

Indianapolis Motor Speedway

The Pat Clancy Special competed in the 1948 Indy 500, finishing 12th, but was the only six-wheeler to ever race at The Brickyard

wheelbase than the first car), two P34s managed to snag 14 podium finishes, including a one-two placing at the Swedish Grand Prix, Jody Scheckter staking his claim there as the only driver to win a grand prix in a six-wheeler.

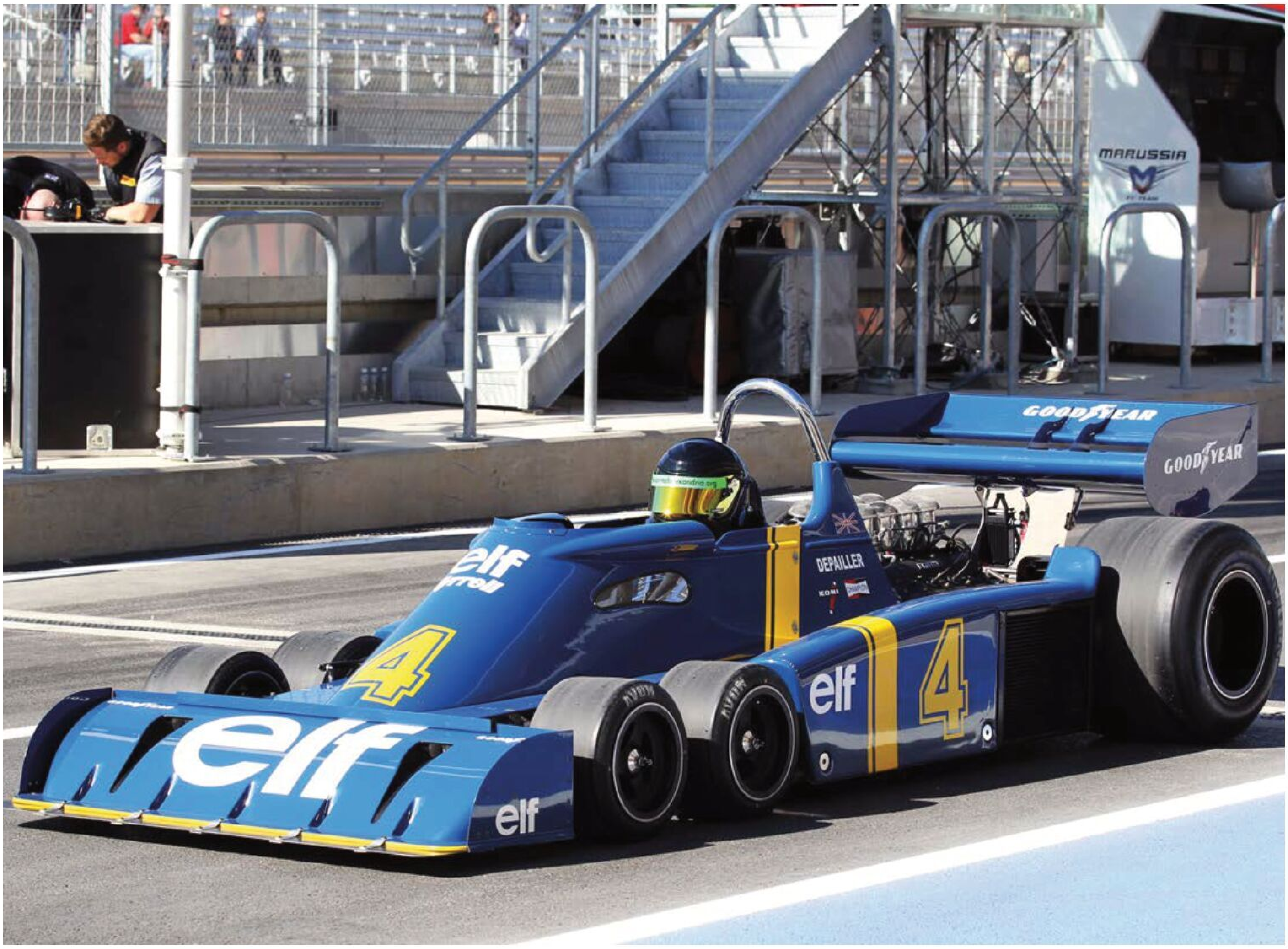
The 1976 season would be the car's peak, as a revised version in '77 was heavier and performed poorly, with Tyrrell switching back to four wheels for the following year.

Herd mentality

The P34 certainly grabbed peoples' attention and, ever the publicists, Max Mosley at March lobbied for his team to follow suit. Designer, Robin Herd, was unconvinced by the benefits of Tyrrell's layout and felt that if March was to go down the six-wheel route, greater advantage could be gained at the rear *à la* Clancy Special. Any aero benefits of small front wheels, felt Herd, were negated by the rear wheels sitting in the airflow. But, if four narrower wheels could be used at the rear, both an aerodynamic *and* traction advantage could be realised.

The problem was that at the time March was still a relatively small operation, and resources could not be spared for a full-scale development effort. Instead, as recounted by

XPB



The 1975/'6 Tyrrell P34 was the most successful of the six-wheeled racers, and also the only one to place the additional axle and wheel pair up front, in this case though for aerodynamic advantage

XPB

In 1981, Williams' Frank Dernie came up with the low-drag FW08B, in an attempt to keep its DFV engine competitive against the new turbo motors. The FIA banned it before it had a chance to race

Mike Lawrence in his book *March: The rise and fall of a motor racing legend*, towards the end of 1976, team mechanic, Wayne Eckersley, was locked away with a collection of existing March 761 parts and a bespoke transmission.

With the car far from complete, at the start of 1977 Mosley invited the press to see the team's latest creation, which, borrowing railway locomotive naming convention was dubbed the 2-4-0. The car might have only had a dummy engine and no gearbox internals, but it got the hacks buzzing.

Following a Herculean effort by March mechanics, the car hit the track two weeks later. Unfortunately, thanks to cost-cutting efforts that reduced the stiffness of the transmission casing, flex allowed the crown and pinions to separate, shredding them. The 2-4-0 ended up running as two-wheel drive but, thanks to wet conditions, no onlookers noticed.

Without the time or budget to properly develop the concept, the car was quietly shelved. It would later briefly re-appear in the British Hillclimb Championship in 1979 with driver, Roy Lane, at the wheel.

Despite the early mechanical failure, the 2-4-0 concept was sound and, if pursued to fruition, should have proved competitive. While it was undoubtedly heavier than its contemporaries, the added traction, improved braking and lower drag would have been a significant advantage.

It should be noted that around the same time Ferrari also tested a six-wheel concept that harked back to the pre-war hillclimbers. A 312T2 was fitted with twin rear wheels and tested by Both Niki Lauda and Carlos Reutemann at Fiorano in 1977. Clearly the idea did not net the desired results as Ferrari chose not to pursue the project beyond those initial tests.

Dernie flap

The soundness of March's concept was almost proved by Williams four years later, which followed the same layout with its 1981 effort. Unable to get his hands on one of the new turbocharged engines that were just taking off, designer, Frank Dernie, needed a way to cut drag and make its DFV engine competitive. Returning to the six-wheel idea, he calculated that drag could be lowered sufficiently to narrow the effective power difference to the turbo competition.

Working with Patrick Head and then young engineers, Neil Oatley and Ross Brawn, Dernie designed the car's bodywork and Head the transmission. It would be a ground effect design that could, Dernie reported, theoretically be run without a rear wing, relying on huge underfloor tunnels for downforce generation. A test car was built using the '81 FW07 as a basis and tested by Allan Jones, with a second car, the FW08B, put through its paces by Jones, Jonathan Palmer, Keke Rosberg and Jacques Laffite. Performance was promising and feedback from the drivers positive, so Williams committed to the design for the '82 season.

Sadly, the FIA got wind of the project and moved swiftly to ban cars with more than four wheels. The FW08B would never run in anger and was the last of the six-wheelers in F1.

Frank Dernie… calculated that drag could be lowered sufficiently to narrow the effective power difference to the turbo competition

Fortunately, it is not lost to the annals of time, and Williams has a restored example it occasionally rolls out for demonstration runs at events like Goodwood Festival of Speed.

Jules in the crown

Adding extra wheels to racecars was not the sole preserve of circuit racing, however, and one of the most bizarre six-wheelers ran as far from an asphalt track as one can get. The catchily-named Jules II Proto contested the arduous Paris-Dakar race in 1984, its creation stemming, as so many great endeavours do, from a bet.

The car's owner and constructor, Frenchman Thierry de Montcorge, wagered his friends that he could complete the 1981 Paris-Dakar race in a Rolls-Royce. It was a gamble he proceeded to win. His friends politely ignored the fact the Rolls was far from Kosher – it looked like a Corniche, but under the glass fibre body was a tube-frame chassis, a 5.7-litre Chevy V8 and the running gear from a Toyota Landcruiser. Smart chap.

That aside, the imposing beast caught the attention of perfume company, Christian Dior,

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Rallye Dakar

Thierry de Montcorge's Jules 2 Proto was built for the 1984 Dakar rally, and used a third axle primarily for the purpose of carrying spares, but it also helped reduce pressure on the sandy surface

who agreed to sponsor the venture to tout its latest fragrance, called Jules. At one point, the Rolls was running as high as 13th overall, but a driveshaft failure in a remote location saw it heavily delayed. Montcorge finished the race, but was not classified.

By then hooked on endurance rallying, he set out to create a new machine with the intent of racing in a proposed Peking to Paris event. The race never took place, but Montcorge's car was built and, retaining backing from Dior, was dubbed Jules II Proto. Looking more Thunderbird 2 than Lady Penelope, it featured six wheels, two at the front and four at the back, with only the front pair and the forward set of rear wheels driven.

The rear axle simply trailed along behind, yet was fitted with a full differential and running gear, the idea being it could be used as a spare for either of the other axles.

Under pressure

The spare axle also helped reduce the overall surface pressure the car exerted – a useful additional trait on the soft sand that abounded on the classic Dakar route – and meant the car could be driven on three wheels if a rear driveshaft failed.

Drive was taken from the same V8 used in the Rolls, though this time mid-mounted, to a Porsche 935 transmission that drove the rear wheels, with a transfer box and propshaft pushing power to the front differential (which, along with the rear, was fully lockable). With an output of 370bhp, and a dry weight of 1400kg, the Jules II Proto was said to be sprightly.

This low weight was in part due to the carbon / Kevlar bodywork, advanced for its day, with styling that resembled the love child of a Chevrolet El Camino and a Lancia Stratos. Doors were eschewed in favour of weight saving and the crew entered the cabin via hinged side windows.

Drawing on previous experience, self-sufficiency was a key element of the design brief. Jules II was festooned with kit storage lockers and even had an onboard power source to run a welder. The expansive rear deck provided ample additional stacking space for wheels and other spares.

The car was entered in the '84 Dakar event and was blisteringly fast, albeit only briefly. The chassis was not up to the task, and on the third stage of the event it split between the rear axles. Stuck some 400km from the nearest service point, even with the considerable onboard repair kit it was unsalvageable and had to be retired.

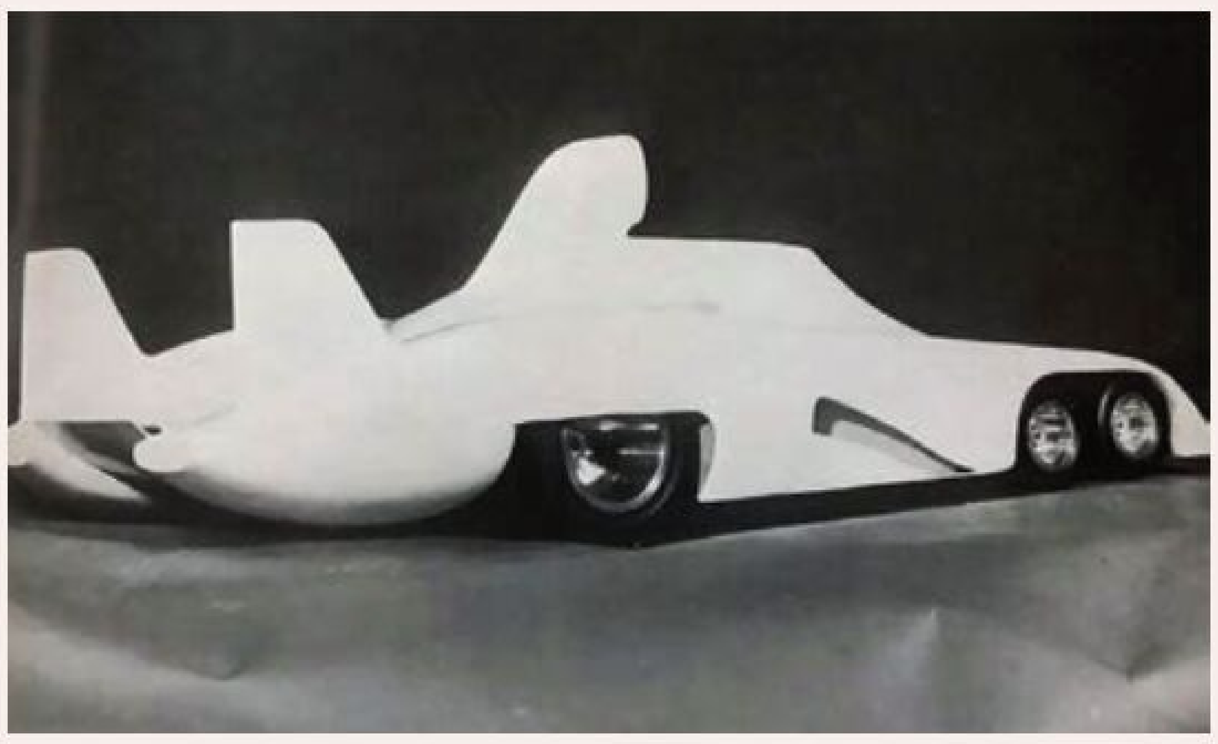
By the mid-'80s, six wheels were well and truly done for in racing, aside from the odd home-grown exception. If anyone cares to hunt for it, there are images on the web of a six-wheel drive, twin rotary engine Mazda 323 with four-wheel steering, which terrorised the rally stages of New Zealand sometime in the 1990s! And if six wheels aren't quite enough, there is always the utterly barmy, 12-wheel (10 of which were steered!) turbine-powered Lion Grand Prix concept to fall back on. But that story will have to wait for another day.

Six-wheel Sportscars

While F1 took something of a shine to six wheels for a period, the concept didn't gain quite as much traction in the world of Sportscars, though there were two notable developments.

The first was the brainchild of Belgian hillclimb racer, Daniel Lebacq, who converted a Lola F5000 car into the DL7, which debuted at the 1977 Gent Auto Show and then raced at the Trôs Marets hillclimb with little success.

Another 1977 car that never made it anywhere near production was conceived by the only man to have won Le Mans in a car bearing his own name, Jean Rondeau. The proposed M579 was to run a turbocharged Cosworth DFX and four small front wheels, with Rondeau persuading the government of Haiti to back the project! Alas, Haiti proved to be an unreliable business partner and work never progressed beyond a model.

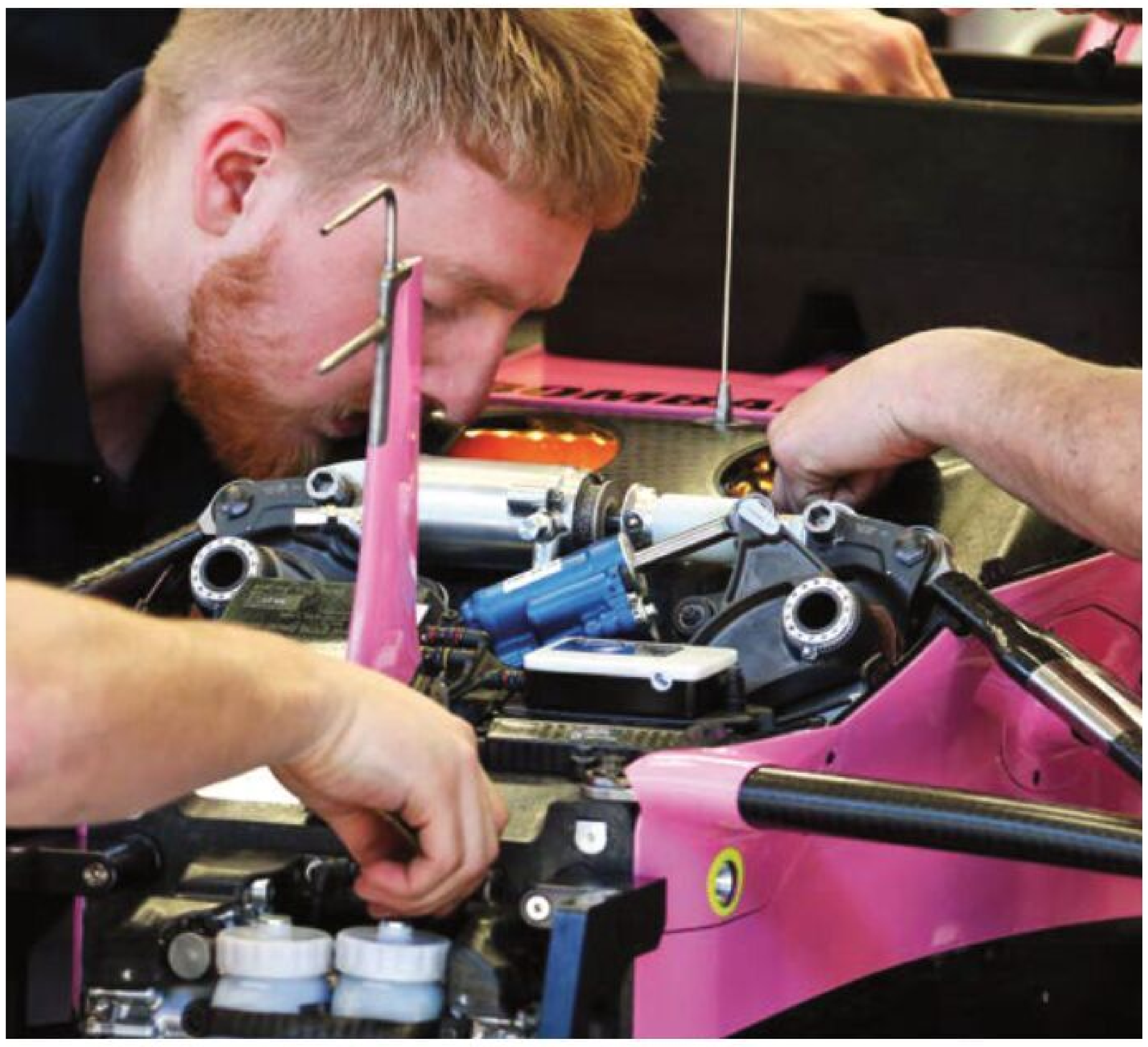


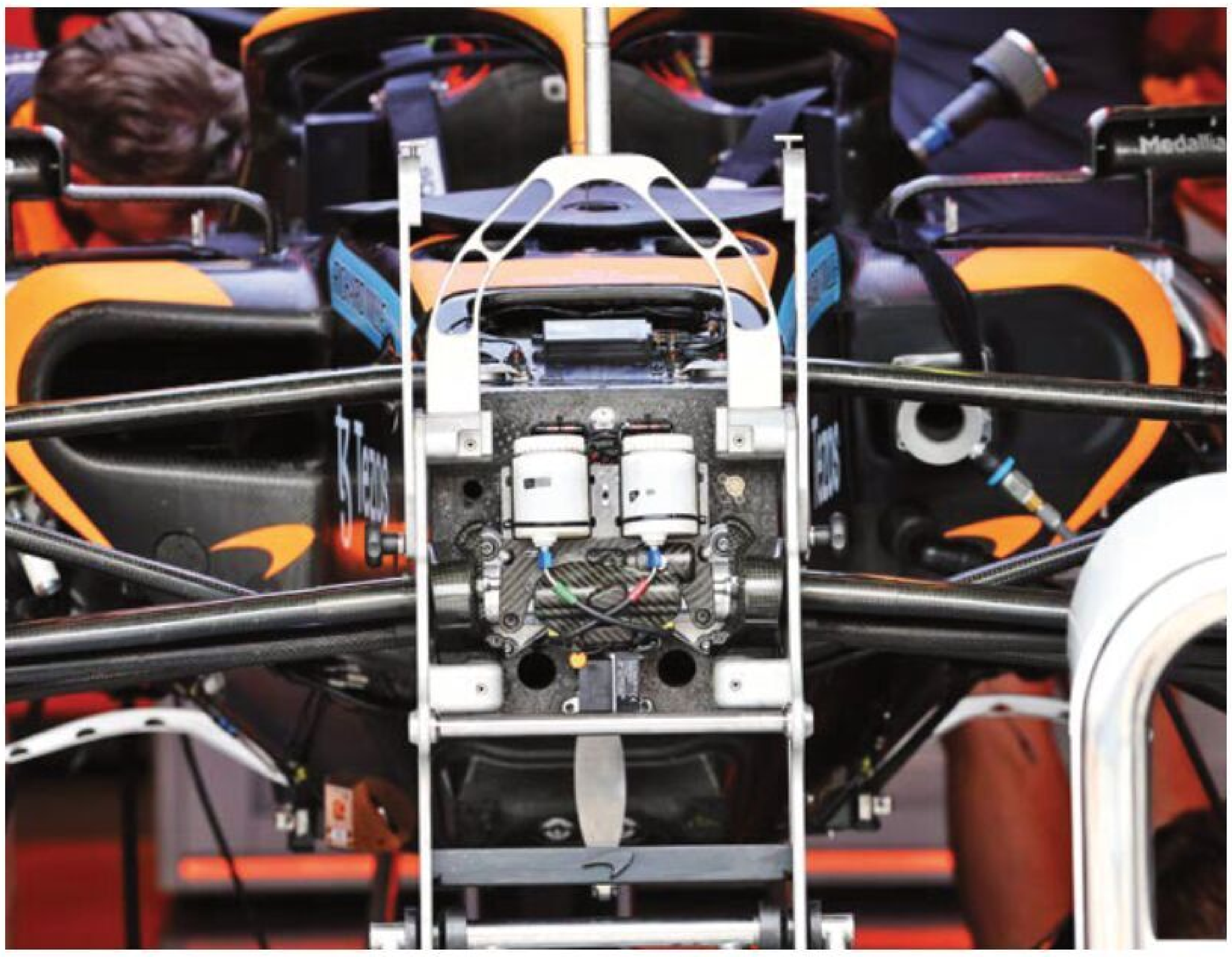
Sadly, Jean Rondeau's M579 only made it as far as the model stage

Missing links

Why mathematical reasoning is more important than ever now for racecar engineers

By DANNY NOWLAN





XPB

The latest simulation software packages are incredibly powerful resources, but they shouldn't be viewed as a replacement for hands-on learning, first principles and basic mathematical reasoning

Over the last couple of months, I have been working with a number of junior engineers at senior undergraduate level and junior post graduate level. While their enthusiasm has never been in question, I am shocked by the lack of basic skills I am seeing.

The two biggest areas of concerns are their inability to do hand calculations, and a complete lack of ability to reason mathematically. The first area of concern motivated an article I wrote a couple of months ago on the joy of hand calculations. The purpose of this article is to deal with the second concern.

If you are serious about being a capable engineer in any discipline, the ability to reason mathematically is a must-have skill. I am noting with increasing alarm how when junior engineers are given a problem, their fist instinct now is to plug the numbers into something like SolidWorks or ChassisSim and hit a button, hoping it solves their problem for them. Don't get me wrong, these are very powerful pieces of software but, used blindly and with no idea of the underlying principles, they can easily lead you to the wrong conclusion very quickly.

I can give countless examples of engineering disasters that could well have been averted if the time had been taken to have a proper think about the problem in the first place.

Conversion rates

To illustrate this, let's consider our first example, which is the conversion of anti-roll bar rates from moment per degree to a spring rate. At first, this might seem a little mundane, bordering on the trivial, but it serves as an excellent first example. The problem we need to solve here is how do we convert a bar rate quoted in Nm/deg to an equivalent spring rate in N/m? The answer is not as hard as you think.

Our first port of call is to calculate the moments generated by the bar for a given spring rate and a roll angle. The force given by the bar can be expressed as **equation 1**.

$$F_b = k_b \cdot MR \cdot t \cdot \frac{\phi}{2} \qquad (1)$$

Where,

F_b = force on the anti-roll bar
k_b = bar rate in N/m
t = track width in m
q = roll angle in radians
MR = bar motion ratio (bar movement / wheel)

To keep this discussion simple, let's assume the bar rate and motion ratios are linear. The next step is to calculate the moments being generated by the bar. We have two forces providing moments in equal and opposite directions so, assuming the c of g is in the middle of the car, we may write **equation 2**.

$$\begin{aligned} M &= 2 \cdot MR \cdot F_b \cdot \frac{t}{2} \\ &= 2 \cdot MR \cdot k_b \cdot MR \cdot t \cdot \frac{\phi}{2} \cdot \frac{t}{2} \\ &= k_b \cdot MR^2 \cdot \frac{t^2 \cdot \phi}{2} \end{aligned} \qquad (2)$$

Where,

M = rolling moment (N/m)

Countless… engineering disasters could well have been averted if the time had been taken to have a proper think about the problem in the first place

What we now need to do is to manipulate **equation 2** to make it reveal what we need. Dividing **equation 2** by the roll angle, we see **equation 3**.

$$\frac{M}{\phi} = k_b \cdot MR^2 \cdot \frac{t^2}{2} \tag{3}$$

Guess what? We're almost there already. We now have our measure of roll moment per degree expressed as a function of bar rate. However, there is just one last trick. The supplied measure we have is in Nm/deg, while what we have in **equation 2** is in Nm/radian. This is easily fixed. The trick comes from recognising one degree is π/180 radians. Doing the maths, we see **equation 4**.

$$\frac{M}{\phi} = \frac{M}{\deg \cdot \pi/180} = \frac{180}{\pi} \cdot \frac{M}{\deg} \tag{4}$$

Subbing **equation 4** into **equation 3** and making k_b the subject, we have **equation 5**.

$$\begin{aligned} \frac{M}{\phi} &= k_b \cdot MR^2 \cdot \frac{t^2}{2} \\ \frac{180}{\pi} \cdot \frac{M}{\deg} &= k_b \cdot MR^2 \cdot \frac{t^2}{2} \\ k_b &= \left(\frac{180}{\pi}\right) \cdot \frac{M}{\deg} \cdot \left(\frac{2}{t^2 \cdot MR^2}\right) \end{aligned} \tag{5}$$

So there you have it, a sure fire way of calculating a bar rate given a bar rating in Nm/deg. Crunching the numbers in this example, assuming a bar moment of 2000Nm/deg, a motion ratio of one and a track width of 1.6m we have as follows:

$$\begin{aligned} k_b &= \left(\frac{180}{\pi}\right) \cdot \frac{M}{\deg} \cdot \left(\frac{2}{t^2 \cdot MR^2}\right) \\ &= 57.295 \cdot 2000 \cdot \left(\frac{2}{1.6^2 \cdot 1^2}\right) \\ &= 89525 N/m \\ &= 89.53 N/mm \end{aligned}$$

The best thing about this example is it isn't rocket science. We started off with a statement of the problem and, using some very simple manipulation, have come up with a very powerful tool.

Transient stability

The next example uses data analysis and our knowledge of calculus to nail down car transient stability. Often, when one mentions the dreaded c word, it sends people running for the hills, but really there's nothing to worry about. Calculus at its core is all about measuring slopes and calculating areas. That's all there is to it. The next discussion here then is about calculating slopes, so here goes.

Car transient stability can be articulated by a concept known as the stability index. Mathematically, this can be quantified as shown in **equation 6**.

$$stbi = \frac{\partial N}{\partial a_y} \cdot \frac{1}{m_t \cdot g \cdot wb} \tag{6}$$

Where,

$Stbi$ = the stability index
N = the sum of yaw moments acting on the car (Nm)
a_y = Lateral acceleration of the car (g)
m_t = total car mass in kg
g = acceleration due to gravity (9.8m/s2)
wb = car wheelbase in m

The stability index is a non-dimensional measure of the distance between the centre of the lateral forces and its moment arm from the c of g. It will return this as a percentage divided by 100. The idea is negative is stable and positive is unstable.

There are two ways you can measure this. The first is to have lateral accelerometers fitted on both ends of the car. In this case, the moment (*N*) being generated is given by **equation 7**.

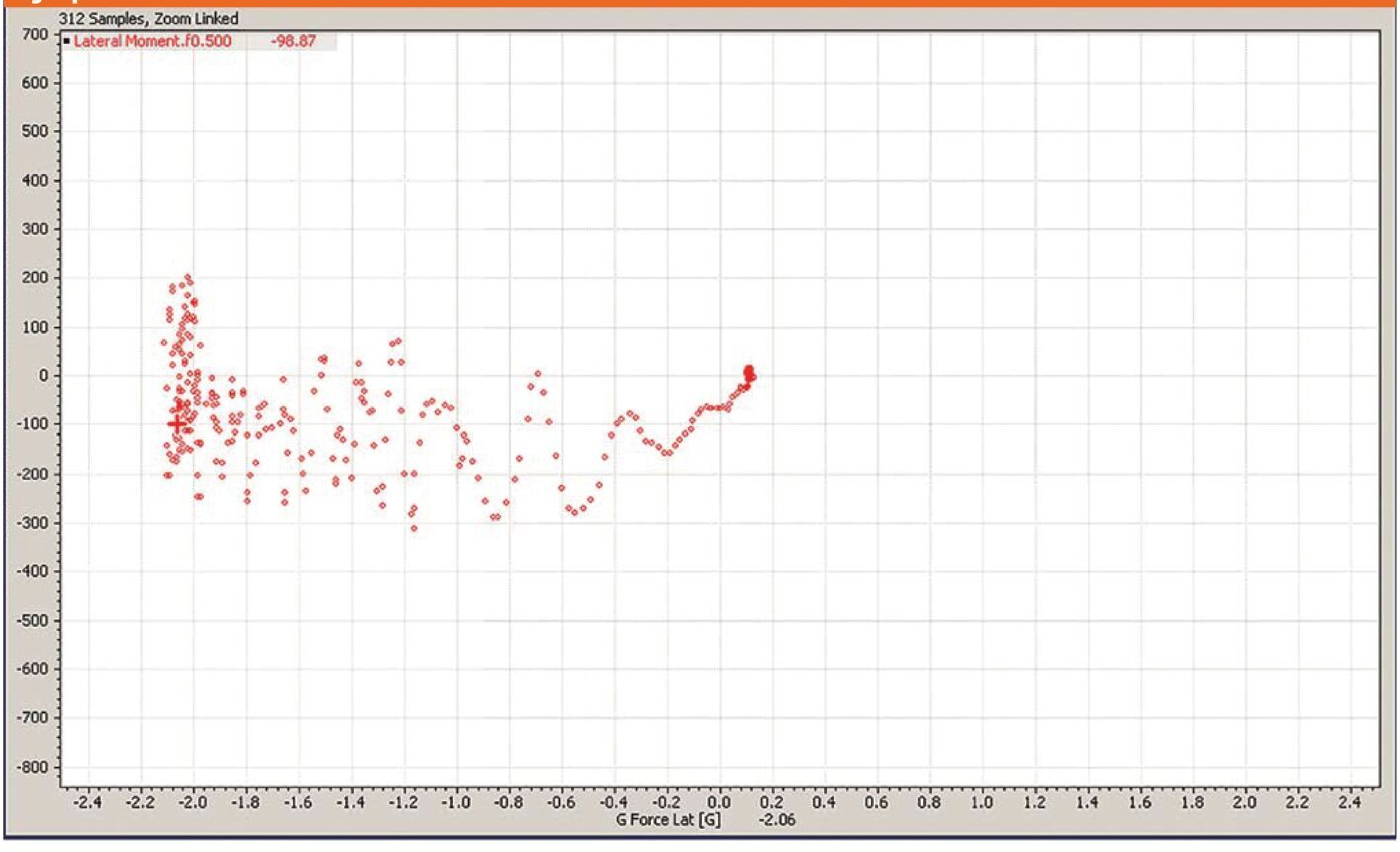
$$N = m_t\left(\left(1 - wdf\right) \cdot a_{yf} - wdf \cdot a_{yr}\right) \cdot wb \cdot g \tag{7}$$

The term *wdf* is the front weight distribution of the car as a percentage divided by 100. The great thing about **equation 7** is it is one of the most straightforward maths channels you'll ever put together.

The next trip is to plot this against total lateral acceleration and take the slope. This is illustrated in **Figure 1**.

The great thing about this plot is it gives you the stability index. But also remember the sign of your lateral acceleration. If you have *ay* measured as positive for a left turn,

Fig 1: plot of lateral moment vs lateral acceleration



you have to multiply the slope by -1. However, this is the ultimate driver lie detector because you can instantly see what is going on.

At low lateral *g*, the car is quite stable. But as we push, the plot becomes more wavy, indicating we have some work to do at high speed. This is not surprising given this is a simulated plot.

The other way of doing this is to plot yaw rate as a function of total lateral *g*. From the equations of motion, it is seen that the time derivative of yaw rate is the total lateral moment. Consequently, we can infer lateral moment by taking the derivative of yaw rate and multiplying it by the z axis of the second moment of inertia. The trick here is to filter the yaw moment derivative.

The great thing about both these approaches is they give you a sure fire driver lie detector. Ignore a tool like this at your peril in the modern motorsport environment.

Aero-induced roll over

The last example I'd like to talk about was one of the most extraordinary technical discussions I have ever seen over the last two years. And for all the wrong reasons. It centred on the discussion of aerodynamic-induced roll over of a racecar, a problem that plagues modern Sports Prototypes.

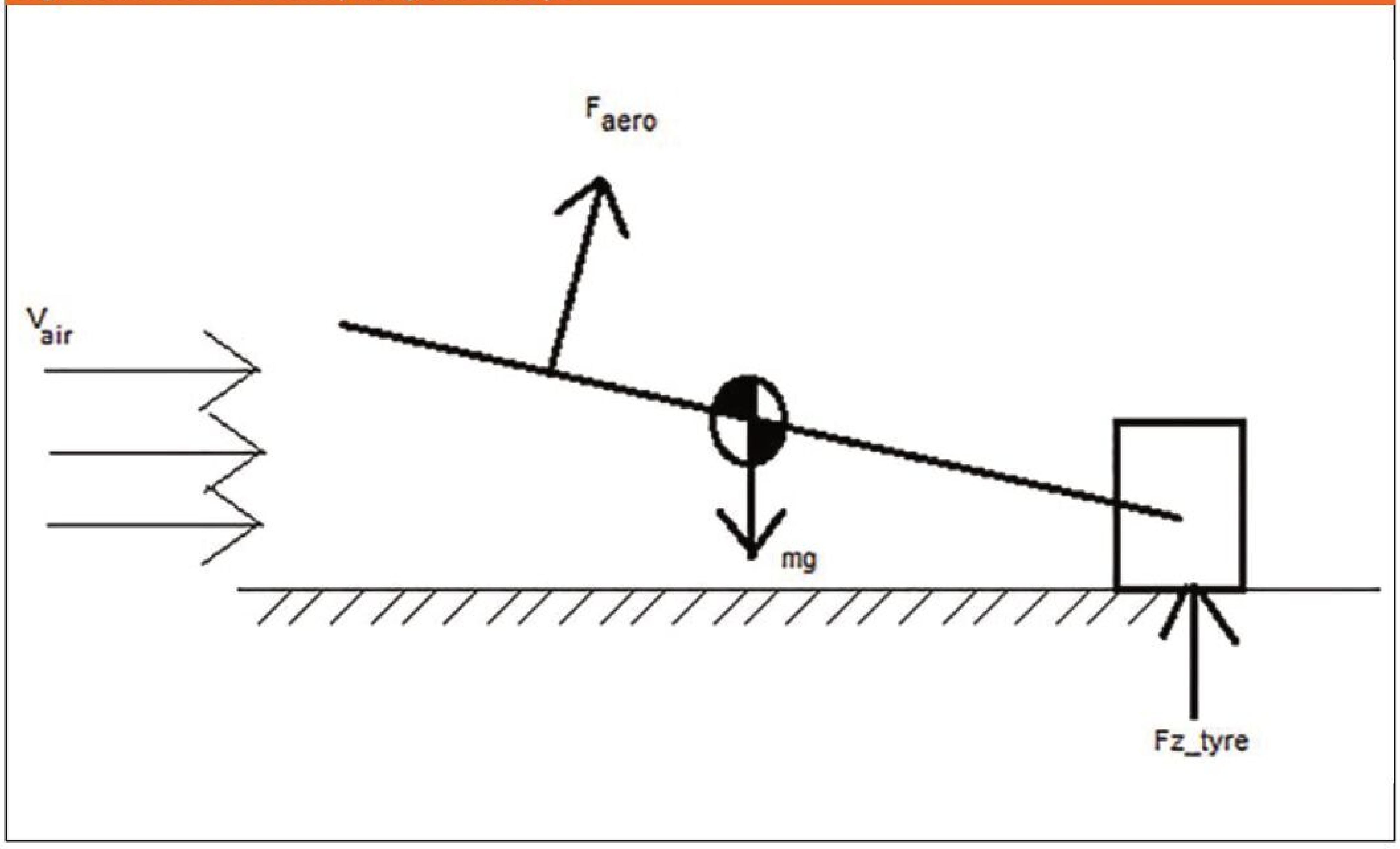
The conversation to which I refer tried to apply the same thinking to an FSAE car, and you should have seen the encouragement from all parties involved to do detailed CFD studies of this scenario. I was so stunned at what I was hearing that I forwarded it on to colleagues of mine who were senior aerodynamicists in various race categories at the time, and they too were in disbelief at what they were reading.

To explain why this discussion was so off the mark, let's make some rough approximations of the mechanisms involved in an aerodynamic-induced roll over. It occurs when a car goes sideways at speed, the aerodynamic downforce reduces and it hits a bump, exposing the car's underbody to open airflow. It then cartwheels over.

Believe it or not, we can actually put some basic numbers to this to see whether we actually have a problem or not. This situation is summarised in the free body diagram shown in **Figure 2**.

To keep this discussion simple, I will assume the car has gone sideways so isn't producing any downforce. As we can see, we have two major forces in play. The first is the lift being produced by the underbody as a result of being exposed at an angle to the airflow. This will be applied at the quarter chord, or track point. This is what is going to roll us over. What is keeping the car in check is its weight.

Fig 2: Roll over free body diagram analysis



Ignore a tool like this at your peril in the modern motorsport environment

What we need to do then is to take moments about the tyre still on the ground. If the aerodynamic moment exceeds the moment produced by the car's weight, then it will flip over. Simple.

The trick here is to come up with an approximation for the aerodynamic forces, and even that is a lot easier than you might think. Our goal at the moment is not to try and predict the roll over moment, we just want to see whether we have a problem that needs to be dealt with.

To that end, we can look at some typical C_L vs angle of attack plots of an aerofoil to get some ballpark numbers. As rough as this may seem, in this roll over situation this is pretty much what we are dealing with.

In terms of some simple $dC_L / d\alpha$ numbers (α being in radians) 2π is an okay place to start from. Since this is a non-ideal aerofoil, let's approximate $dC_L / d\alpha$ at five. To go one step further, let's then assume we've hit a bump and the angle of attack is, say, five degrees. Given a typical underbody area of a modern Sportscar of, let's say, $10m^2$, the aerodynamic forces we are going to generate can be given by **equation 8**.

$$F_{aero} = \left(\tfrac{1}{2}\right)\cdot\rho\cdot V^2\cdot C_L\cdot A$$
$$= 0.5\cdot 1.225\cdot V^2\cdot 5\cdot\left(\frac{5\pi}{180}\right)\cdot 10$$
$$= 2.67\cdot V^2 \qquad (8)$$

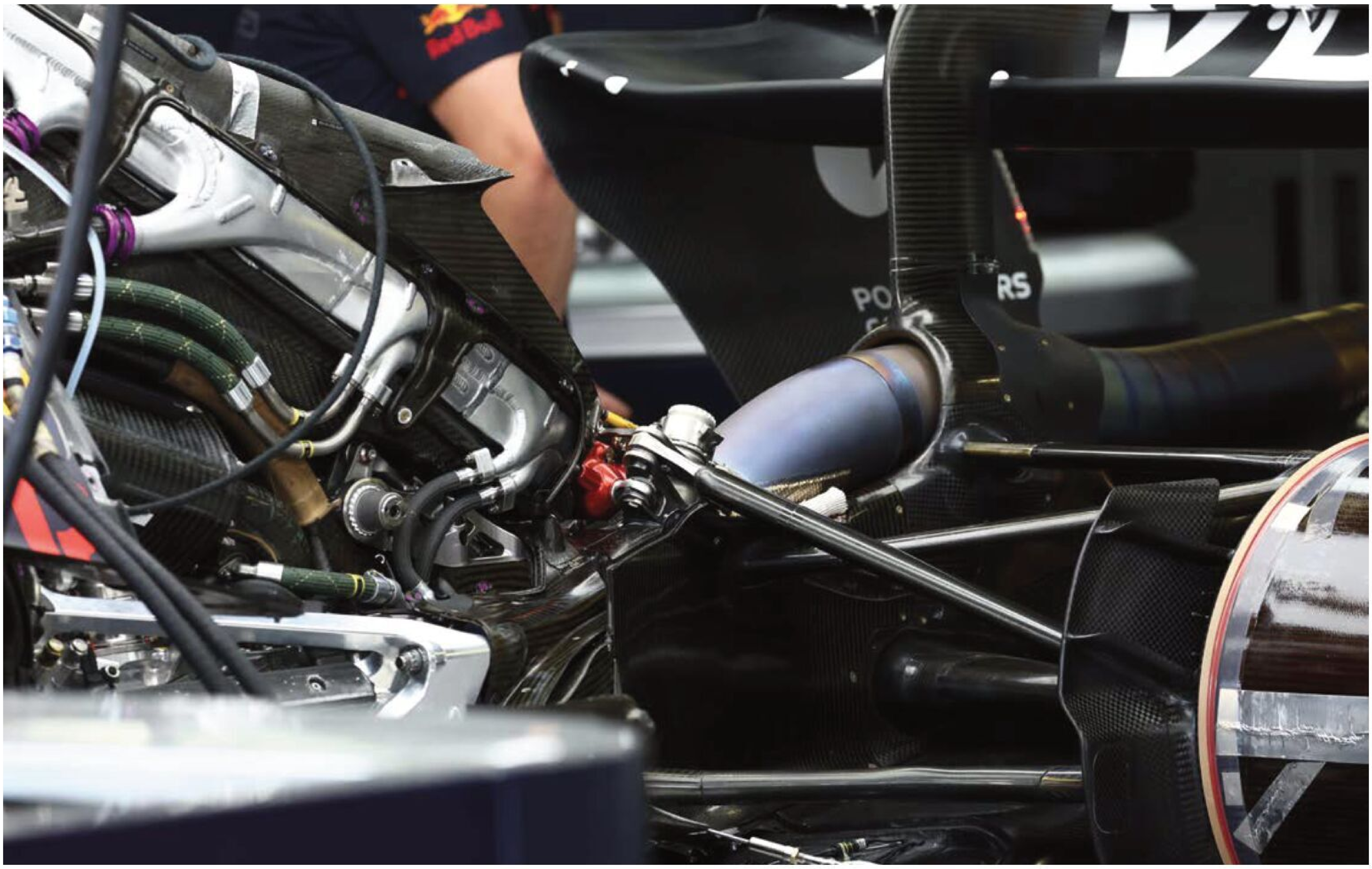
Let's then assume the car width is 2m and the car weight is 1000kg. Taking moments about the tyre, we see **equation 9**.

$$M = F_{aero}\cdot\frac{3}{4}\cdot t - m\cdot g\cdot\frac{1}{2}\cdot t = t\cdot\left(F_{aero}\cdot\frac{3}{4} - m\cdot g\cdot\frac{1}{2}\right) \qquad (9)$$

We know we are going to have problems when **equation 9** is equal to zero. So, putting **equation 8** into **equation 9** and solving for the zero condition, we see what is shown in **equation 10**.

$$F_{aero\cdot}\cdot\frac{3}{4} = m\cdot g\cdot\frac{1}{2}$$
$$V^2 = \frac{2}{3}\cdot\frac{mg}{2.67}$$
$$V = \sqrt{\frac{2}{3}\cdot\frac{mg}{2.67}} \qquad (10)$$
$$V = \sqrt{\frac{2}{3}\cdot\frac{1000*9.8}{2.67}}$$
$$V = 49.467m/s = 180km/h$$

What all this tells us is that at 180km/h we are prone to aero-induced roll over (in reality, it's usually a little bit more than that, say around 220-240km/h in most circumstances). However, as a ballpark figure, this indicates a situation we need to consider quite seriously.



XPB

A sound understanding of mathematics is critical at all stages of racecar engineering, from design to manufacture to running a car, as well as for conversion of such as anti-roll bar rate to spring rate

Let's now see how these numbers look like for an FSAE car. Using the same aero figures as the Sports Prototype (which, I might add, are already giving the aero roll over scenario considerable benefit of the doubt) we have the following numbers:

Table 1: FSAE car parameters

Parameter	Qty
Total mass	250kg
Width	1.5m
Floor area	$2m^2$

Using these figures to review **equation 8** for the FSAE car, we have,

$$F_{aero} = \left(\tfrac{1}{2}\right)\cdot\rho\cdot V^2\cdot C_L\cdot A$$
$$= 0.5\cdot 1.225\cdot V^2\cdot 5\cdot\left(\frac{5\pi}{180}\right)\cdot 2$$
$$= \quad \cdot V^2$$

Then plugging this into our analysis for **equation 10**, we see…

$$V = \sqrt{\frac{2}{3}\cdot\frac{mg}{2.67}}$$
$$V = \sqrt{\frac{2}{3}\cdot\frac{250*9.8}{0.534}}$$
$$V = 55.3m/s = 199km/h$$

…that we can indeed expect to see an aero-induced roll over situation with our FSAE car, but at approximately 200km/h! However, given that an FSAE car is limited to approximately 110km/h, it would *never* be going fast enough for this to happen.

I should also add that in sideways view an FSAE car has all the aerodynamic attributes of a brick so, if we really wanted to get aggressive with this analysis, the predicted roll over speed would go up quite significantly. However, for the sake of this discussion, by using first principles and some basic mathematical analysis, we've shown why the aforementioned conversation was so utterly ridiculous. And how much of a futile waste of resources a detailed CFD studies of this scenario would have been.

Computers are powerful tools, but nothing replaces pen, paper and a bit of common sense in problem solving

Problem solving

At this point it would be wise to give you some pointers about how I go about problem solving. As with hand calculations, start off by stating your known variables and unknown variables. Then think about what class of problem it is, and write down all the relevant equations. You then work the equations to solve for the unknowns. Write this down on a piece of paper, too. Computers are powerful tools, but nothing replaces pen, paper and a bit of common sense in problem solving.

In closing, here we have presented three separate, but quite pointed, examples of how to use mathematical reasoning to get on top of quite normal motorsport problems. The common thread in all three examples has been to take some basic first principles, put equations to them, and then plug in the numbers to quantify where we are at. That's all there is to it.

It may not give you an exact answer, but it will sharpen your instincts so you know what you are looking for. Develop this skill and it will serve you well in your engineering career. Ignore this skill at your peril.

IN BRIEF

Motul has developed a high-performance 100 per cent synthetic lubricant in conjunction with partner team **Mugen.** Working through its Motul Asia Pacific arm, MS-A by Motul is available in two viscosities, 5W-30 and 5W-40, both of which suit Honda road cars.

Suspension manufacturer, **KW Automotive**, has broken ground on another manufacturing hall for its products. The work is expected to be completed by the end of 2023, and the new facility will be used to manufacture more electromagnetic proportional valves for semi-active and active coilover suspensions and shock absorbers.

Formula E and **UNICEF** have launched a campaign to raise awareness of two billion children living in areas where air pollution levels exceed World Health Organisation standards. The two institutions are building on their ongoing partnership to drive action to address climate change.

Mercedes-AMG announced its commitment to invest in sustainable aviation fuel to help reduce its carbon footprint. With sustainable fuels expected to account for up to 37 per cent of energy demand in transport by 2050, Mercedes says this reflects its desire to make F1 more sustainable racing.

McLaren Applied has joined the MIA's CTS2022 Motorsport Engineering and Technology Show to be held at Silverstone circuit on 19-20 October. McLaren Applied supplies to Formula 1, Formula E, NASCAR, Extreme E and IndyCar.

Integral Powertrain has re-branded as **Helix.** 'We are more than an electric powertrain consultancy, we provide straightforward access to the most powerful, compact, efficient electric drivetrains available,' says Luke Barker, one of the founding directors. 'Re-launching as Helix is a natural evolution of our DNA, reflecting our progression from a high-tech engineering consultancy to a full-service supplier of world class electric powertrains.'

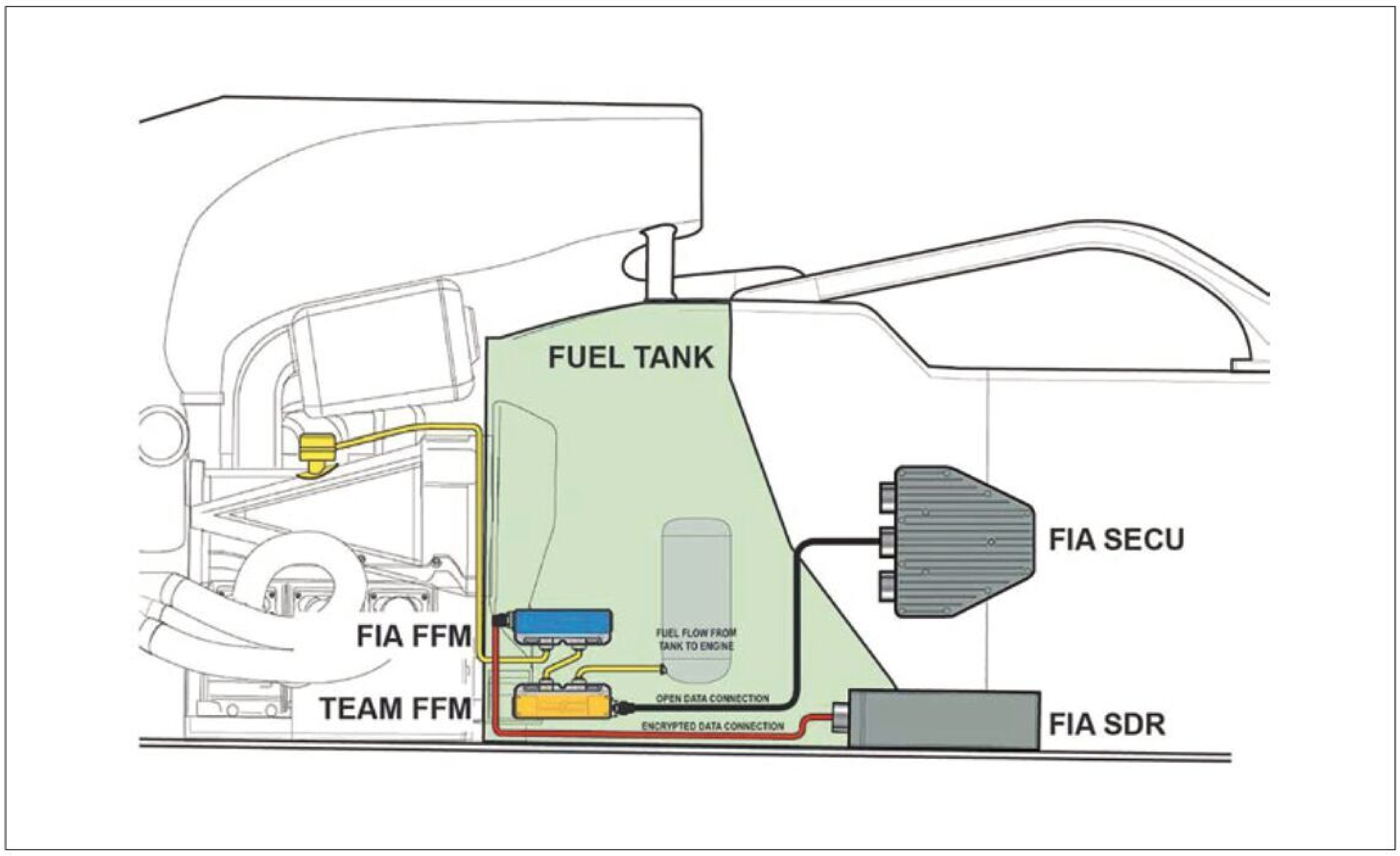
Sentronics continues in F1

British company, Sentronics, which has been the sole supplier of fuel flow measurement technology to the FIA Formula 1 World Championship since 2018, has been re-selected to continue the role through to the end of the 2025 season.

The company provides separate team and encrypted FIA fuel flow meters to make up the dual-sensor package that has been standard since 2020. Team sensor data is also available to F1 power unit manufacturers and fuel suppliers for research and development use.

'We have significantly evolved our products over the last few years to equip our F1 and other motorsport customers with outstandingly accurate and reliable sensors that perform in the most demanding environments,' says managing director, Neville Meech.

The company also provides its FlowSonic sensors to the FIA World Endurance Championship and the IMSA WeatherTech series in the US, where it has expanded to include an all-new ultrasonic pit refuelling tank level sensor.



Sentronics' dual-sensor fuel flow measurement package has been standard equipment in F1 since 2020, and is now set to continue until 2025

Riches retires, and succeeds

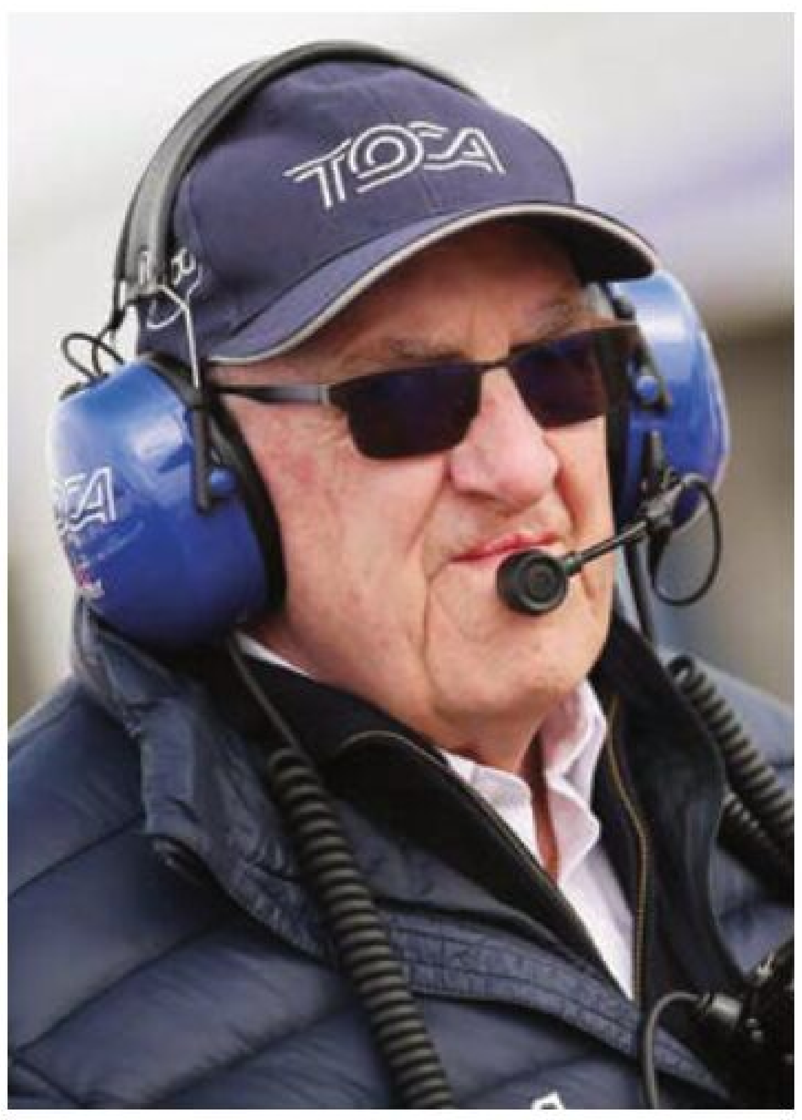
British Touring Car Championship technical director, Peter Riches, has announced he will be retiring from the position at the end of the 2022 season. Riches' BTCC career spans four decades, during which time he has worked at more than 320 race events, 820 races and 30 seasons.

The Riches name will continue in the role, however, as his son, Sam, will step into the role, having worked within the BTCC for more than 20 seasons. His father, meanwhile, will be retained as a consultant.

'This is something we've been preparing for, and I feel ready to retire,' said Riches in a statement. 'The world is so different now to where we started. I had a set of scales in the pit lane and a boost control system and that was basically it. Now we've got a 40ft trailer full of kit.

'[As a consultant] next year, I'll be in more of a guiding role, maintaining the things we've done well in the past and ensuring the wheel doesn't get re-invented and become square in the process, in order to have a smooth transition.'

DD Photography



After 30 seasons, Peter Riches retires as BTCC technical director, to be replaced by his son

JGR cars excluded

Joe Gibbs Racing had the ignominious accolade of becoming the first NASCAR Cup Series race winner to be excluded since 1960. Denny Hamlin crossed the line first at Pocono ahead of his team mate, Kyle Busch, but both cars failed post-race tech inspection and were disqualified.

'There were some issues discovered that affect aero of the vehicle,' said NASCAR managing director, Brad Moran. 'That part was the front fascia. There really was no reason why there was some material that was somewhere that it shouldn't have been, and that does basically come down to a DQ.'

JGR said it was 'shocked', and Joe Gibbs commented that the team 'plan to review every part of the process that led to this situation.'

Hypercars out in force

Ferrari gave its 2023 World Endurance Championship car its first miles on the Fiorano test track early in July as it prepares for competition starting in March next year.

In the same month, Cadillac and Porsche started their joint test session at Sebring with their LMDh contenders. Acura also had its LMDh car on track at Paul Ricard, but withdrew from the Sebring test.

The Ferrari is designed and built at Maranello, and observers at the test have commented on the build quality under the skin matching that of Formula 1 standards.

There is no word yet on the engine that the car will use, or even the name of the car, but it will compete as a Hybrid and therefore, by regulation, will have to be four-wheel drive.

Engineers performed multiple systems checks during the first days of testing, with performance testing set to begin later in the year.

Meanwhile, Cadillac and Porsche both completed five days of testing at Sebring in Florida, trying to put miles on their contenders after a summer of discontent with the spec hybrid system that will feature on all LMDh-specification cars. The motors have so far proven to be unreliable and Bosch brought its latest version to the Sebring test in a bid to cure the problem.


Cadillac

Cadillac (shown above) and Porsche both tested their new LMDh cars at Sebring in July, while Acura put some test miles in at Circuit Paul Ricard. The LMDh cars will make their full competition debuts at the 24 Hours of Daytona in January 2023


Ferrari

The new Ferrari Prototype, meanwhile, was spotted in urban camouflage at the company's Fiorano test track. Technical details of the car remain sparse at present, but it performed systems checks before performance testing begins later in the year

Inside the world of modern motorsport technology
Racecar engineering

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Sausage and mash

The perils of trying to keep drivers on the racing line

Safety came into sharp focus once again in July with a series of high profile accidents that highlighted the incredible advances that have been made in racecar and track safety, but also the hideous and potentially lethal sausage kerbs that have once again put drivers' and marshals' lives in danger.

As driver Harry Tincknell pointed out, the sausage kerbs are there for sporting reasons, but they need to be looked at on the grounds of safety. In that respect I don't think that they have a place on a race track.

The FIA doesn't seem to have learned its lesson. Since the stunning accident of Alex Peroni in the Formula 3 race at Monza, it took away one of the sausage kerbs on the high-speed Parabolica section of the track. So clearly, the organising body realised this was a danger that needed to be addressed. Abbi Eaten then ran over one in the W-Series and broke her back at COTA, suffering a compression fracture of a vertebra, which led to a long period of recouperation.

Then came the Formula 2 race at Silverstone. Following an on-track collision, Dennis Hauger found himself with Roy Nissany's DAMS Dallara on his head, the latter having been launched over the kerbs after losing control due to a front puncture. It was a shocking accident, and the Halo undoubtedly improved the outcome for Hauger, but the car should never have been launched by the kerb onto his head in the first place.

Halo effect

The following day, Zhou Guanyu had his accident at the first turn of the Silverstone GP, flipping the Alfa Romeo onto its rollbar, which collapsed, and the Halo, which didn't. Once again, the Halo was the single biggest factor in improving the outcome of the accident for the Chinese driver, who was well enough to race the following weekend in Austria.

Zhou's accident was an interesting one. Having made contact with George Russell's Mercedes, he flipped and continued at speed upside down through the gravel trap. In an F1 car that, full of fuel, weighed around 900kg, the energy carried, and the fact it was inverted, meant it travelled at speed across the stones. When it did, inevitably, dig in, there was still enough motion to carry it over the retaining wall and into the Geobrugg catch fencing.

While everyone was thankful the driver was uninjured, I was stunned that no one in the crowd was hurt. That was some testament to the safety improvements made at the circuits, as well as to the cars.

One week later, and Henrique Chaves lost control of his Aston Martin GTE car into the second chicane at Monza and, having hit a sausage kerb, was launched into a roll. The force of the initial impact with the kerb ripped a door off the car, and the car skidded on its roof before it too dug in and rolled, coming to a halt upside down against the guardrail. The driver was uninjured, but the question again is; why does the FIA persist in this ham-fisted, dangerous approach to force drivers to respect the track limits?

Damage case

There is nothing complicated about it. These kerbs are nothing short of ramps and have no place anywhere near a race track. Drivers that run wide by accident risk damaging themselves and their cars, while those that do so deliberately are able to avoid most of them anyway. It was only by the grace of God that Kamui Kobayashi didn't hit one at the end of the straight at Monza, having punctured his rear tyre. A Prototype weighing 1000+kg hitting a kerb at speed doesn't bear thinking about.

These kerbs are nothing short of ramps and have no place anywhere near a race track

The discussion in the press room at Monza led to the next question – what to do about it? The GT World Challenge stewards have appointed a track limits observer who has access to the GPS data from each car. She can therefore see who runs wide, and is able to dish out a penalty without waiting for the report from a marshal. The Austrian GP also saw penalties for drivers abusing track limits, but the system isn't perfected yet.

Emmanuele Pirro rather put paid to polystyrene after the monocoque of his Benetton was broken by the heavier than necessary blocks at Hockenheim in 1989, so that's out. Anderstorp experimented with giant plastic balls, but drivers struggled to get out of their cars if they stopped in them because they couldn't open their doors. And anyway, Anthony Kumpen went off at the end of the long straight and cleared a path through some fir trees with his Viper after his brake disc exploded.

My suggestion was either high-grip tarmac, as used at Ricard, but here track limits are treated as a notional target, or return to hay bales. I'd vote for the latter. If you hit one, you will pick up hay in your radiator, overheat your engine and be forced to pit. It will also make you unpopular with your fellow drivers as there will be hay all over the track, so they will likely come to have a short conversation with you. This all seems pretty reasonable to me.

ANDREW COTTON Editor

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