DRIVERLESS TECHNOLOGY: How the DTM proved concept on track – p32

Inside the world of modern motorsport technology

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Renewable fuels

We reveal how TotalEnergies will power the WEC from 2022

TYRE MODELLING
Testing methods and data capture in the lab and on track

WILLIAMS EXTREME E
Environmental research through motorsport

Lewis Hamilton and Max Verstappen's crash at Monza proved the effectiveness of the Halo beyond doubt but, with F1 looking to increase car weight, does the TV audience have the stomach for the even bigger crashes that are yet to come?

XPB

Current trends

Battery technology is moving at pace, and motorsport is leading the charge

It won't be news to you that there is a lot of development work going on in the world of cell technology for traction batteries. The current trend with cell chemistries is for the high capacity cells to become higher capacity at the sacrifice of peak power, while the high power cells are becoming more powerful at the sacrifice of capacity.

Lithium-ion based nickel manganese cobalt (NMC) cell technology is currently the most widely used for batteries in vehicle traction drive applications. However, this cell chemistry is approaching the practical limitations of the energy density of lithium-ion. Widely available high energy density lithium-ion cells have around 270W h/kg, and the practical limit is considered to be approximately 300W h/kg. Because of this, many high performance traction drive cell firms believe getting more and more capacity in lithium-ion cells implies diminishing returns.

A vast number of battery companies and labs across various energy sectors are investigating cell technologies exceeding lithium-ion NMC limits, searching for a step change in energy density of up to 400, 500, or even 600W h/kg.

One European cell lab has surmised the maximum energy density for sulfide solid-state batteries is as much as 410W h/kg. Silicon dominant anode technology, which has more than 80 per cent of the anode made from silicon, also offers significant benefits regarding high load stability.

More power?

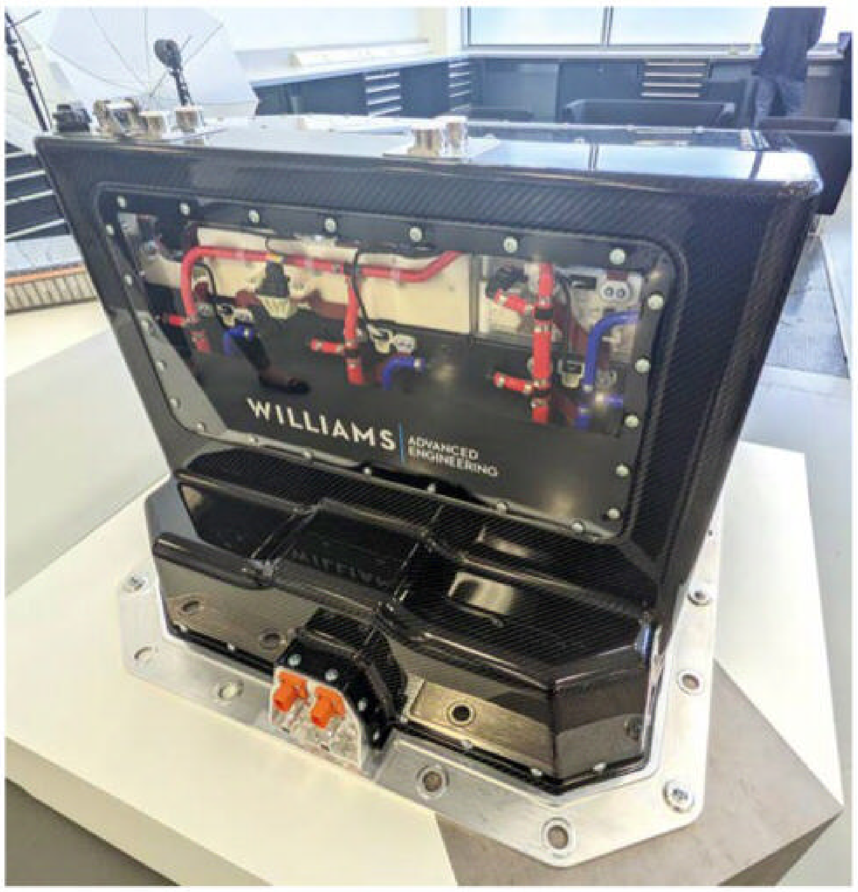
High power cells, which are prevalent in the upper echelons of motorsport, are a very different concept. For high power density, lithium-ion NMC cells are still the favourite. However, developments in recent years have seen lithium-ion cells designed to operate at very high temperatures and to sacrifice performance at low temperatures, allowing for more instantaneous power to be deployed.

For most motorsport, this is ideal as the majority of racing takes place above freezing point. The nature of motorsport sees heavy deployment and high cyclic loading, which means the challenge is to keep the cells stable at very high temperatures to take best advantage of this phenomenon.

Internal microstructure developments, electrode thickness changes and separator specialist treatments of lithium-ion NMC cell types can yield extremely high power capability from the cells and the electrolytes. Several specialist cell labs that work with Formula 1 teams have recently tested electrode interfaces formulated to tolerate very high temperatures, which helps with ion mobility and allows higher power extraction.

There are two factors at play here: the fundamental design of the cell and temperature. As cell temperature increases, it becomes closer to its safe operating limit, which is harmful. However, that increased temperature helps the ions transferring from one electrode to another move much more efficiently, which is beneficial.

Of late, Formula 1 battery engineers have put their energies into developing biased cell construction models to operate most efficiently toward the risky end of the cells' working temperature window.



Stewart Mitchell

Hybrid cell arrays, such as this Multi-Chem pack by Williams Advanced Engineering, may be a proficient solution for EV racing

The cells used in current Formula 1 batteries are very high power density cells, though they have chemistries that can potentially yield as much as 500W h/kg. The problem is their cost is prohibitive to almost all other applications, and the extreme operating conditions required to extract maximum performance from them is not acceptable in all applications.

Some of the more extreme interpretations of high energy Formula 1 cells are half the weight of a traditional lithium-ion NMC cylindrical traction cell for the same energy capacity. Still, if it can't meet the capacity requirements, it's useless.

The hybrid solution

Several firms, including some that operate in Formula 1, are now producing battery packs with a number of cell types and chemistries integrated into one unit. The hybrid battery pack concept solves some of the cell trade-off conundra from an engineering point of view, allowing both high power and high energy capacity cell chemistries to work together to meet the vehicle power and range targets.

The hybrid pack works by introducing a bi-directional DC-DC converter between different modules in a pack to allow some fraction of each cell type's disadvantage to be countered. This concept effectively enables the vehicle to take advantage of these advanced chemistries in both high capacity and high power technologies, while at the same time making up for the limitations each has in its characteristics because both cell types are present.

Successful implementation of this technique has yielded increased energy densities of as much as 50 per cent. This solution enables the power and capacity development trends to continue to optimise cell chemistry further, while bespoke hybrid battery packs take advantage of both.

The hybrid pack may therefore enable electric racing to make giant leaps in performance in the not too distant future.

The hybrid battery pack concept solves some of the cell trade-off conundra from an engineering point of view

The bottom line

We cannot control the weather, so Formula 1 has to find a way to work with it

Lest the Spa GP debacle fade too quickly from memories, especially those who have the authority to make changes, it is worth examining what could be done to avoid a repeat.

Firstly, however, the criticisms from public and media regarding the decisions on continually delaying, and then subsequently declaring the race run after just two laps behind the safety car, are understandable, but generally naïve. Yes, business and political concerns were as much part of this as the safety of drivers, track marshals and spectators given the awful conditions, but why is this regarded as wrong, or cynical? *Of course* much of the decision was about money!

Where does Lewis Hamilton imagine his colossal retainer derives from, if not from this same financial structure?

The realities of organising, promoting, running and participating in a Formula 1 race these days are complex and of considerable magnitude. It was in everyone's interests – even, long term, of the soaked and miserable spectators, even the poor marshals – that the circuit, race promoters and F1 itself did not take the huge financial hit of race cancellation.

I am not privy to the details of the penalties vs insurance issues involved. Or the niceties of sponsor contracts, among very many other considerations, but, given that the survival of the GP and of this fabulous circuit itself have frequently been under severe threat, it is possible that the future of both would have been severely harmed had this taken place. Especially with the tragic murder just a fortnight before of Nathalie Maillet, CEO and the driving force behind Circuit Spa-Francorchamps.

No idea

Postponement of the race to the following day would have been completely unrealistic. Anyone who believes this to have been an alternative clearly has no idea of what is involved in running a modern F1 race, nor any consideration for those who have jobs to go to on Mondays.

Nonetheless, what seems to be the bottom line of needing absolutely to declare a race result, however farcical, has to be re-assessed, as does a compensation fund for spectators.

Regards the former, better that the race result should be declared *force majeure* according to qualifying positions, which effectively it was, rather than via a pretend contest.

That doesn't mean alternative possibilities couldn't have been explored, and must be done so for the future. The wet weather situation at Spa is not going to go away, and not necessarily just at this track as extremes of weather become more frequent. Let's face it, not so long ago the race would have gone ahead, but greater emphasis on safety and general risk aversion, plus the now ever-present fear of litigation, have changed matters. This we must accept.

The two primary concerns of racing in the rain, of course, are aquaplaning and – particularly for open-wheel cars – lack of visibility due to spray from cars ahead. Bridgestone used to have legendary deep-tread, ultra-wet rubber, as have subsequent tyre suppliers to championships such as Super Formula in Japan, needed there because monsoon-type downpours often occur. The conundrum is that tyres that displace the surface water more efficiently and quickly to reduce aquaplaning are likely to worsen the visibility problem, even if maybe for a shorter period.

The tyres are not the sole source of spray of course. Diffusers and wings contribute heavily to the volume and upthrust of the wake. The new spec 2022 car aero may be better in this respect, as the intent of these regulations is to reduce the following aero wake anyway. Far brighter minds than mine may be able to devise technology that allows images to penetrate this 'fog', or very high intensity rear lighting enough to make drivers better aware of cars in front but, until then, I can propose some part solutions that are simple, even if they are neither elegant nor purist.

XPB

Racing in the wet can be dangerous, but it also presents opportunities for some of the most exciting displays of driver skill, and that's what motorsport is all about

Extreme options

Referring once again to Spa, the run from the entry to Eau Rouge and along Kemmel straight appears to create the greatest concern regarding visibility, especially for the first two or three laps when cars are bunched together.

In extreme conditions, such as this year, is there a case for this section only to be subject to Virtual Safety Car regulations during this period of the race? This would allow the worst of the water to be dispersed by the tyres while the cars are travelling much more slowly here, and with no overtaking permitted?

The idea is similar to Slow Zones in WEC racing when an incident occurs. At least the race can be started without the need for the Safety Car, which is of questionable benefit anyway in these circumstances as it can't be driven fast enough for the following F1 cars' brake and tyre temperatures to be managed effectively.

A more radical solution would be to start the race two cars at a time off the grid with, say, five or six seconds between each pair, if start lights etc. preparation can be made in advance for such an eventuality. That said, it could be achieved using a good old fashioned flag and digital stopwatch!

Each driver following the leading two would have the corresponding (but corrected for error to three decimal points) number of seconds deducted from his or her overall race time to cancel their starting disadvantage. Far from perfect and not entirely equitable, but at least it's a way of getting a proper race underway. Methods such as these could be applied to other venues also, until better solutions are found.

Safety has to be a priority, and so has acknowledgement of the responsibilities of the race officials. However, racing hard in the rain presents unique opportunities for brave, confident and talented drivers to stand out. It also makes for a great spectacle – too important to be compromised or denied entirely to competitors and fans alike.

Let's face it, not so long ago, the race would have gone ahead

2021: A climate Odyssey

Extreme E, the story so far

By STEWART MITCHELL

Though there has been some intense wheel-to-wheel action, as shown here at the Ocean X-Prix, any major crashes have been individual and largely due to the demanding terrain

Extreme E's founding purpose is to counteract climate change by accelerating the adoption of electric vehicles (EV) using motorsport as a platform to deploy and showcase EV technology. However, the series' premise is not simply the show, but also documenting the state of the planet's ecosystem, conducting environment science research and showcasing equality. If it sounds like a lot within one programme, it is.

To make it all that much more challenging, none of the Extreme E racing locations have an established racing infrastructure. As such, all the equipment needed for the series is carried by the RMS *St Helena*, a decommissioned postal ship. It is also Extreme E's operating base and home to teams, garages, hospitality, broadcast facilities and scientific laboratories.

From here, all operations that you'd see in a pit lane, a climate research facility, broadcast media centre and nine race teams' workshops all must work.

At time of writing, Extreme E had completed three events – the Desert X-Prix, Ocean X-Prix and Arctic X-Prix, held in Saudi Arabia, Senegal and Greenland respectively.

Design criteria

Fred Riser, chief engineer of mechanical development at Williams Advanced Engineering, is responsible for the 18 Extreme E cars during the season. Riser recounts early discussions about the series, saying, 'I have worked in engineering and operations for endurance events such as the Le Mans 24 Hours and the Dakar Rally, which I believed would serve Extreme E well, but this is a different sport, for sure. Extreme E was very ambitious from the beginning.'

Before any cars were made, the Extreme E engineers needed to set targets for the series' first season spec electric race vehicle, which would later be known as the Odyssey 21. There was no data or digital model to simulate the Extreme E racecar and its environment, so it was a clean sheet of paper design. However, the chassis, designed by Spark Racing Technology, bore a close resemblance to the T1 buggies of the Dakar rally.

In its inaugural season, every car is the same 1650kg Odyssey 21 machine

Extreme E

The series' premise is not simply the show, but also documenting the state of the planet's ecosystem [and] conducting environmental science research

powered by dual electric motors driving both axles. Peak output is 400kW and 920Nm of torque, which accelerates the Odyssey 21 from 0-62mph in about 4.5 seconds at gradients of up to 130 per cent. The chassis has a weight balance of almost 50/50, which, for an off-road, four-wheel-drive racer, is important for driver feel and stability.

The vehicle dynamics, battery drive cycle and safety were modelled using a Rallycross simulation package, also built by Williams Advanced Engineering. 'We had some internal tests that represent a certain amount of intense driving on such terrain as we'd see in Extreme E, but we had to amplify it to give us a closer representation of the actual use case and a factor of safety,' notes Riser.

'The car design considered the nature of the racing, which would likely see the cars sustain severe and regular damage. Here, designing it with as few unique components as possible was critical for repair simplicity and reducing the number of spare parts needed on the boat. It needed to be a nice, simple, robust piece of engineering.'

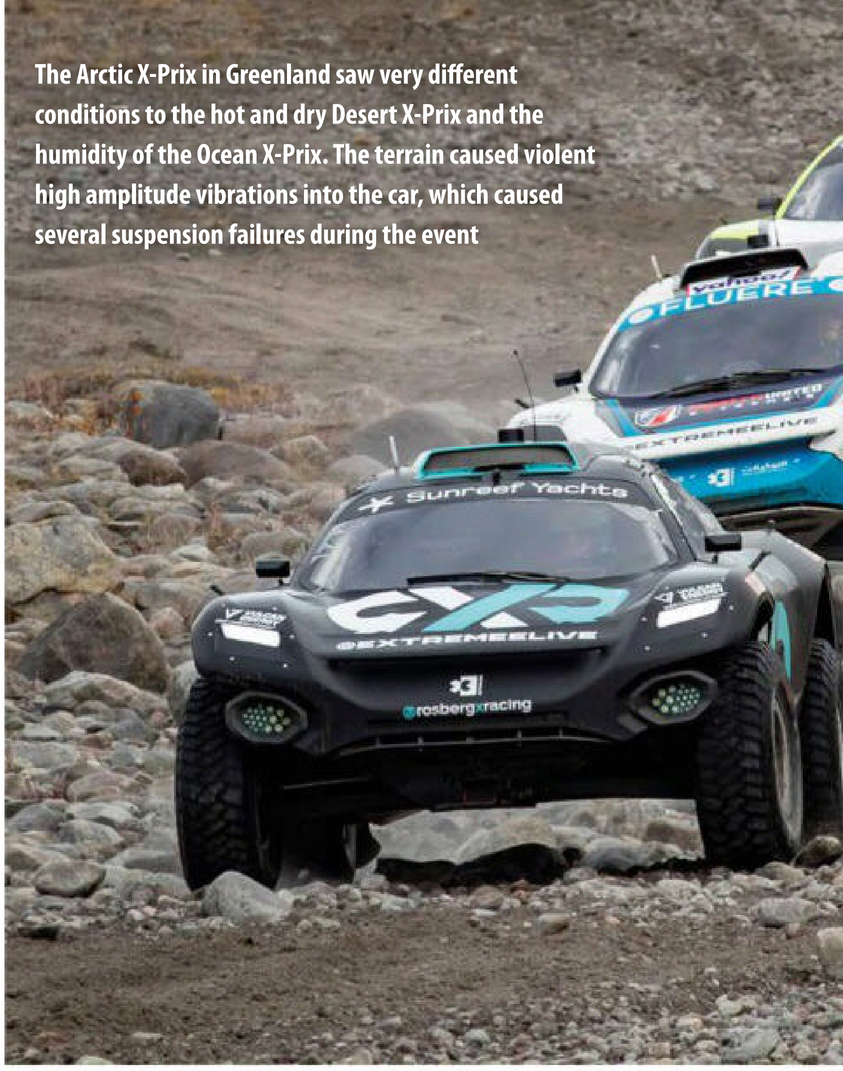
Battery engineering

Williams Advanced Engineering began defining what kind of drive cycle the car would be capable of while delivering continuous power output to provide exciting racing at every venue. Extreme E is an all-out, flat-out, maximum attack form of racing. Competitors start with a fully charged battery pack and complete the race duration without any concern of de-rating. The 400kW peak power output of the powertrain needed to deploy constantly over 10km of off-road terrain. In addition, the battery needed to operate within a 70degC ambient temperature window between -30 and 40degC.

'When it comes to the performance of a battery for an EV racecar, the number of elements within that influence performance are somewhat limited,' says Head of motorsport at Williams Advanced Engineering, Doug Campling. 'The mechanical installation influences that potential slightly, but it's a very narrow road to performance development.

'The primary influencer in motorsport battery performance is the software that governs how the energy deploys and regenerates. Deployment is primarily driven by how power is drawn from the cells within their operating temperature window.'

The Battery Management System (BMS) manages cell voltages and monitors temperatures, and feeds that information to the Vehicle Control Unit (VCU). Signals from the BMS are used as inputs to the VCU, which manages the cooling system and every powertrain element. Should the BMS signals identify high temperatures in any module of the battery, the software in the VCU is designed to address the power delivery to control the temperatures.



The Arctic X-Prix in Greenland saw very different conditions to the hot and dry Desert X-Prix and the humidity of the Ocean X-Prix. The terrain caused violent high amplitude vibrations into the car, which caused several suspension failures during the event

Extreme E

'The primary influencer in motorsport battery performance is the software that governs how the energy deploys and regenerates'

Doug Campling, head of motorsport at Williams Advanced Engineering

The Extreme E battery specifications

Williams Advanced Engineering

Williams Advanced Engineering

Rendering of the 54kWh Extreme E battery pack

Due to the deliberately remote nature of the sport, all paddock and pit lane facilities and equipment must be carried to the race site. Here is the typical paddock set up, this one in the desert in Saudi Arabia

Extreme E

A decommissioned postal ship, the RMS *St Helena*, is Extreme E's floating cargo and infrastructure base. It also houses the environmental research station that is an integral part of the series

Extreme E

For the Extreme E battery pack, Williams Advanced Engineering employs some novel techniques for temperature management. 'The battery pack uses dry ice and chilled fluids surrounding the heat-generating areas of the pack for a highly efficient cooling system,' explains Campling. 'Williams Advanced Engineering characterised many different cell chemistries and designed a unique pack construction to enable improved cell behaviour when operating as a pack.'

Designing [the Odyssey 21] with as few unique components as possible was critical for repair simplicity and reducing the number of spare parts needed on the boat

Fred Riser, chief engineer of mechanical development at Williams Advanced Engineering

Environment challenges

Races are head-to-head on challenging terrain in five distinct locations. The high-altitude environment is by far the most significant regarding concerns for the battery as the challenges here are related to electrical safety. Ambient air pressure is critical to electrical insolation between components as it affects what's known as the isolation breakdown voltage. Essentially, the air gap between electrical components provides some insulation from interference and current induction.

'As altitude increases and ambient pressure drops, the effectiveness of the isolation reduces as a function of air density,' notes Campling. 'The distance over which electricity can flow, or an arc can form, increases proportionally to the change in air density. To maintain the same isolation, the distance between components must increase compared to the battery systems used in racecars at lower altitudes. These are pieces of hardware within the battery pack and cannot be repositioned to compensate for the pressure change, so this needed to be considered in the design phase.

'Every component in a battery is designed with specific clearances between electrical components to ensure they are electrically isolated in all environments.'

As per the technical targets for the batteries, all of them are the same. The maximum delta allowed between each pack is 400g, which would be negligible for the vehicle's performance. In terms of delivering that energy to the drive wheels, the teams have a chance to set up the deployment and regeneration characteristics to suit each driver.

'Teams can choose everything from sensitivity to capacity of deployment and regeneration strategies if they want to,' emphasises Riser. 'There is a vehicle control module with characteristics programming within it, and this talks with the battery management system to deploy the desired power strategy.'

In terms of safety, the car has *g*-force modules on board to identify if it has rolled over, and sensors that can identify insulation breakdown, opening the battery contactors and cutting the circuit to the driveline.

All chassis-related mechanical adjustments are free. Teams have access to the suspension springs and damping and braking system to set up as they like, though cannot change specifications. Because all the cars are so similar, a small change can make a big difference. The individual car's set-up must therefore be a compromise between driver preference and terrain characteristics.

Season so far

The Covid pandemic significantly affected the testing programme for Extreme E ahead of its inaugural season. When Spark Racing Technology and Williams Advanced Engineering *were* able to get together and build the first prototypes, the challenges of completing the testing programme were more extensive than the engineering teams had imagined.

'We had very little chance for testing before the first round of the season in Saudi Arabia,' declares Riser. 'We only did a few tests, and the first one in France was very difficult because of the restrictions. There was only one driver, two Spark personnel, and me. I had to rent a caravan because there were no hotels open during that time.

'We were able to collect some data from that test, but it was limited.'

Extreme E completed the first full test with all 18 cars in Spain at the end of December 2020. It was just four days of testing, though, before the cars were loaded onto the RMS *St Helena* and sailed off to Saudi Arabia for the first round.

The first race in the desert was tough. The hot ambient conditions, high altitude, thin air and deep sand proved challenging for the debuting Odyssey 21 race machines.

'There should have been four Williams Advanced Engineering personnel on the ground at the track, but this didn't work out,' says Riser. 'Two of us flew in advance, and there was a software engineer and a data engineer that were supposed to come and help on the race weekend. One of them tested positive for Covid on arrival, meaning both were forced to spend the entire event isolating in the hotel! That left just two of us to support all 18 cars at the event.'

To make things more complicated for the two engineers on the ground, there were cooling upgrades to be put onto all the cars that Williams Advanced Engineering had developed since the tests in Spain. This meant all battery packs needed to come out of the cars and the batteries opened on workbenches among the dust and wind of the desert.

Crash test

Claudia Hurtgen tested the robustness of the car and the systems onboard very early on when she had a big crash in the ABT Cupra car at the Desert X-Prix. Hurtgen was able to walk away unscathed but the organisers reduced power in the cars for the remainder of the event to reduce the risk of it happening again.

'Although the Odyssey 21 is a great vehicle, the c of g is relatively high, the car's width is considerable, it's heavy and the way it delivers torque to the wheels is very sharp compared to internal combustion-powered cars'

Fred Riser, chief engineer of mechanical development at Williams Advanced Engineering

On this, Riser was moved to comment: 'Although the Odyssey 21 is a great vehicle, the c of g is relatively high, the car's width is considerable, it's heavy and the way it delivers torque to the wheels is very sharp compared to internal combustion-powered cars.

'The drivers are great, but the car is very different to whatever anyone else has driven, even for those that have had experience with Dakar or other Rally Raid machinery.

'We started on the most challenging surface of all with the deep sand of Saudi Arabia, which can be extremely power demanding, and very inconsistent as it moves around a lot. Once compressed under the tyre, it grips very hard and it's easy to get caught out.'

Extreme E kicked off its inaugural season in one of the harshest and most climate change-affected regions of the world at the Desert X-Prix in Saudi Arabia

Extreme E

Enduring legacy

Extreme E showcases and tests on and off-car technologies in some of the harshest environments on earth

myenergi

Extreme E, its drivers and partners actively seek to leave a positive legacy in all the areas they visit, from implementing renewable infrastructure to mass beach cleans. Known as the Legacy Programme, it consists of a panel of leading academics from the UK's Oxford and Cambridge universities, which make up the Scientific Committee. This committee is driving the racing series' overall climate advice and practice initiatives.

Onboard the RMS *St Helena* are a team of environmental research scientists who document the state of the planet's ecosystem at each event and conduct environmental scientific research. The data gathered by these scientists informs the development of climate change-countering technologies. Extreme E partners with firms that produce both on and off-car technologies, showcasing and testing them in the environments seen both inside and outside the series.

myenergi, UK designers and manufacturers of eco-smart devices that increase renewable energy self-consumption, have worked with the XITE ENERGY RACING Extreme E team since its inception. myenergi joined Extreme E for the Greenland round, and the conditions of the ice caps witnessed first hand brought to attention the severity of the climate change problem.

'One thing scientists are certain on is that we can slow this process right down, buying more time whilst we figure out how to deal with the wider issues to tackle the fallout of global warming,' says Jordan Brompton, co-founder and CMO at myenergi. 'The most significant challenge is encouraging people to have a vested interest in the subject of global warming and climate change around their own lives.'

myenergi is leading a project to leave a legacy through the Extreme E championship. It is installing a ground-mounted solar array, battery storage system and micro-generation diversion device in a remote school in Greenland local to the race circuit. Wirelessly connected, the system collectively provides the school with free renewable energy and hot water – a complete carbon-neutral utility solution. In addition, myenergi is fitting a charging wall box, known as a zappi, allowing staff with electric vehicles to top up their batteries during the day. The project, which aims to showcase renewable connectivity, is part of the championship's commitment to making a positive environmental difference at each race location.

The project… is part of the championship's commitment to making a positive environmental difference at each race location

Brompton: 'We're committed to taking sustainability to the masses and helping to inspire widespread behavioural change. While being involved in the championship has provided an unparalleled platform to share our vision, we knew there was more we could offer.

'Renowned for our eco-smart home energy technologies, having the opportunity to transform a local school into a hub for renewable energy demonstrates what the future could – and should – look like. The school can now operate completely off grid thanks to state-of-the-art renewable technologies – zero carbon, zero reliance on mains supply, zero utility costs. It demonstrates precisely why embracing green energy is such an important part of the global energy transition.'

In total, Ganassi Racing had two crashes, ABT Cupra XE one and Veloce Racing another during the first event, and none were caused from wheel-to-wheel racing.

Senegal was a very different story. Instead of the desert's dry, hot, ambient conditions, the humidity was high, and so too was air pressure. That yields a very high condensation risk for systems onboard the car, though there were no technical issues during that round.

Water test

The Arctic X-Prix in Greenland saw very different challenges again. Here, standing water on the circuit led to concerns about water ingress into the car and the complex onboard systems.

'It is easy to imagine how an Odyssey 21 could get soaked, or even stuck in the water,' says Campling. 'For these conditions, Williams Advanced Engineering sought to protect the battery by using a special sealant to prevent ingress into the unit as it is a significant safety consideration. It was critical to ensure the battery had an ingress protection rating of at least IP67.

'It is designed with the battery's operating core electrically separated from the housing to be extra safe because electricity can arc through water and debris should the housing be damaged, or ingress occur.'

According to Riser, even just this sealing requirement makes for a huge logistical challenge. 'Whatever you miss when you are at the Extreme E race locations, you won't get. There is nothing in terms of infrastructure at any of them, and certainly not for racing. It was therefore critical to support the races very accurately with car parts, spares and consumables required for the upcoming event.

'The consumables include 'dangerous goods', which mean we cannot fly them so they must be delivered on land, or by water craft. These include the non-porous, inert sealant that essentially glues the upper shell of the battery to the base. Every time we open the battery, we must use more of this.

'Between Senegal and Greenland, the RMS *St Helena* stopped in Lisbon for a couple of weeks, where all freight was replenished, and any 'dangerous goods' were loaded. The logistics of Extreme E are critical for maintaining the cars in the remote locations and the carbon-neutral framework around which the sport exists.'

Beyond the technical and logistical challenges of Extreme E, there has also been much to learn about the safety aspects of the cars. Extreme E looked to Formula E here for protocols on battery emergency disconnects, as well as post-incident procedures for the drivers, as well as marshals on approach to an accident. All were carried over as, by the time Extreme E started, Formula E already had seven seasons under its belt.

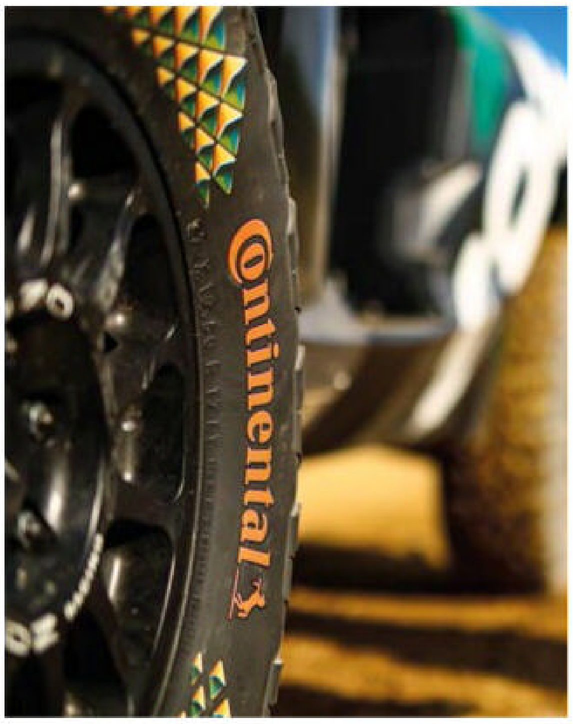
'We didn't have to start where Formula E did regarding electric racing vehicles,' notes Riser. 'This gave the design and engineering teams the confidence to go to a much higher performance level straight away, giving the first generation of Extreme E car 400kW output in the very first season.'

Extreme E has certainly had its successes in its first season, but it's more than just another EV race series. Its organisers recognise that current research on global warming isn't sufficient to draw genuine interest and elicit public action. To bridge that gap between research bodies and the public, the series hopes to be the outlet to convey the evidence and the facts about global warming through technological innovation and a high-intensity racing series.

Cross country running

Racecar investigates the rubber that's putting Extreme E to the pavement

By STEWART MITCHELL



Continental

Continental is the sole tyre supplier for Extreme E. Its CrossContact tyres were purpose made for the challenge

Extreme E's nature means it needs a robust grip solution for the tyres to provide traction in the wild off-road environments in which it competes. The tyres must deal with sand, rocks, water, ice and mud, as well as extremes of hot and cold temperatures. The series turned to the Continental group for the answer, and the tyre company designed the CrossContact tyres specifically for this arduous challenge.

Additionally, each Extreme E tyre is fitted with a wireless sensor array called ContiConnect, which provides the engineers with valuable insight into tyre inflation pressure and temperature in real time. This technology advantage allows the drivers to focus on driving while the engineers collect data to develop the car.

As the drivers come from a wide range of racing disciplines, there's every chance they will need to change their driving style to stay within the window for ideal tyre performance. The engineers can provide them with supporting data as they get to grips with the purpose-built Odyssey 21 racecar.

Development

The Extreme E and Continental journey started in 2019, two years ahead of the first round of the all-new electric racing series. Catarina Silva, Continental's product management team leader for summer, 4x4 and van products, and her team, analysed the tyres for the Extreme E series and was central to the development operations.

Speaking about the CrossContact Extreme E tyre for season one, Silva says, 'We had plenty more testing to do before the pandemic hit, and then we were in the situation where we couldn't do the testing. It meant we had to carry out and rely on internal testing by ourselves, leaning on the experience of our other projects and the many years the Continental group has had in the off-road segment. It was challenging, but we reverted to different ways of examining the CrossContact Extreme E.

'Just before the season, we were in contact with a good portion of the teams who had received tyres from us, and some of them were able to carry out private tests. The driver feedback was quite positive. We also received many pictures of the tyres before and after usage, and they looked excellent.'

Construction

The construction of the CrossContact Extreme E tyre is unique and very robust. Anuj Jain, one of the Continental engineers developing the Extreme E tyre, explains: 'The most important factor is the robustness of the sidewall. We made sure it is very strong and tough to prevent punctures or other damage.'

The tread needs to comply with many different surface types as the tyre will operate on a wide range of surfaces during a season. 'The tread is an all-terrain pattern with big blocks on the contact surface, an off-shoulder design, and ribs on the shoulder, which makes it perfectly optimised for the different surfaces,' continues Jain. 'There is also some technical geometry in the blocks that acts as a stone bumper, designed to reduce the likelihood of stones becoming stuck between the blocks.'

'All the racing teams in this championship are very experienced so, for us, it's a fantastic opportunity to learn together with them and to exchange our expertise on tyres with their expertise on motorsport and racing,' declares Silva of her experience to date in Extreme E. 'There's good cooperation between the teams and us supporting the tyre supply.

'All data that we collect we make transparent. That's our role here. We want all the teams to understand the challenges, our observations, and the following steps to support the development of the cars. We are here to answer all their questions, and all this

Extreme E

The tyres have to work in multiple environments, from the scorching desert sand of Saudi Arabia to the frozen mud and ice of Greenland

insight that we gather will go into developing the tyre for the second season.

Season two

'We are already preparing the new specifications and a new recipe of the CrossContact Extreme E tyres for season two, which we will test at the Island X-Prix in Sardinia in round four of season one.

'The key to season two for Continental will be sustainability. One hundred per cent of the tyres from this championship will be recycled and converted into material that can be used for playgrounds, sporting bases or other applications.

'At Continental, we are very proud to be the tyre supplier for Extreme E because as a series it addresses the critical topics of today. And so this is a journey that we feel very fortunate to be a part of.'

Extreme E

Drivers come from all different motorsport disciplines. Here, Molly Taylor sits on a set of Continental CrossContact tyres in Saudi Arabia

A 100 per cent renewable fuel that will reduce CO_2 emissions by at least 65 per cent

Waste management

TotalEnergies announced at Le Mans a new fuel for the World Endurance Championship and European Le Mans Series next year. Racecar *investigates*

By ANDREW COTTON and STEWART MITCHELL

To remove the risk of any potential discrepancies, TotalEnergies has produced 1000m^3, around a million litres, of Excellium Racing 100, enough to service the WEC, ELMS and support races for the period of its agreed three-year association with the series

A hydrocarbon-based fuel from ethanol produced in the process of fermenting wine

With such a variety of racecars in the WEC, there is some concern the new fuel will suit some better than others, but TotalEnergies refutes this, and teams in all classes are currently bench testing it to ascertain if any PU modifications are required

The traditional Friday press conference at Le Mans heralded the announcement that fuel partner, TotalEnergies, will supply 100 per cent renewable fuel that will reduce CO_2 emissions by at least 65 per cent for the 2022 FIA World Endurance Championship.

This was quite some claim, one that potentially would have a huge impact on the engine development teams in each of the classes as previous renewable fuels have different properties compared to traditional oil-based petrol.

Not so, says TotalEnergies. It has worked to produce a fuel that mimics the petroleum competition fuel used this season.

With more than 60 cars on the grid at Le Mans featuring a combination of turbocharged and normally aspirated engines, there is a risk the new fuel will suit some layouts and sizes better than others, which is why the manufacturers currently have the fuel on their test benches ahead of track testing, with the possibility of modified power units later this year.

TotalEnergies has made a hydrocarbon-based fuel from ethanol produced in the process of fermenting wine, a popular activity in France. Although the French are well known for their wine making, the fuel could be made from other traditional alcohols such as whiskey and vodka, and from all kinds of crops, including wheat and corn. In fact, any process that creates ethanol would be suitable for making the base needed to produce fuel, says the company.

Crop-to-wheel

As such, the emission from the exhaust pipe is not where the quoted CO_2 savings come from. TotalEnergies has neatly side stepped the ethanol production process by taking what would otherwise be wasted material, fit either to be burned or disposed of, and creating the fuel from that waste product.

The reduction in CO_2 emissions is therefore from crop-to-wheel, compared to well-to-wheel in production of gasoline, but nevertheless is a product the manufacturers involved in endurance racing have been looking for in order to extend the life of the internal combustion engine in a racing application.

There is nothing new in the production of ethanol and its use in fuels. A percentage of all fuel put into your everyday car includes an amount of ethanol, E5, E10 or E20 denoting the percentage of it in the finished product. However, the ethanol content does not have the same high calorific value as traditional fuel, and so fuel consumption is higher, although the higher octane level increases power and performance.

What TotalEnergies has succeeded in doing is to create an ethanol-based fuel that performs similarly to a regular competition petrol.

Volume control

The timing of the announcement took many by surprise, and there was good reason to keep the announcement quiet because TotalEnergies was not certain it could produce the volume of fuel required to service the championship and its supporting races.

Although the FIA and ACO have been looking at alternatives to oil-based fuels, they had previously denied making any final decision and were pinning their hopes on hydrogen, which will have its own class in 2025.

However, a decision had been taken to produce a new fuel that would reduce the CO_2 footprint and continue the sustainability drive the ACO and FIA is looking to achieve.

'Even though we started the technical discussion with the manufacturers on the fuel formulation and the impact on the engines, we wanted to be sure we had the volume for the 2022 season,' said Romain Aubry, TotalEnergies' multi-energy technical manager, who was project leader on the development of the renewable racing fuel. 'The decision came early in summer. If Le Mans was mid-June [as originally scheduled] we may have been short of time.'

Prior to Le Mans, the company had already conducted single-cylinder testing on its own test benches and created a fuel that had minimal impact on engine performance, not only in terms of power but also burn temperatures and consumption. This was critical to the championship that consists of engines from Gibson that have been supplied to LMP2 since 2017, as well as newer engines in the top Prototype class from Gibson, Pipo Moteurs and Toyota. Not to mention the GT contenders.

'On a mono cylinder [engine] we tried different formulations with a renewable fuel and we wanted the impact to be very small compared to [our existing] fuel, because the formulation uses hydrocarbons,' says Aubry. 'That means our raw material is ethanol, and then we use a process called ETG, so ethanol to gasoline. We transform the compound into a real hydrocarbon. The fuel is pretty much the same as that made from oil, except all the fuel is renewable. The fuel generally is composed of paraffin, olefin aromatic and oxygenate compound and you will find all these compounds in this new fuel.'

Process of evolution

The process takes the ethanol that is created from the fermentation process of the wine lees or grape pomace, after which it is dehydrated, and then the ethanol compound

'I think this kind of fuel was what the manufacturers want in terms of corporate communication to move from oil origin fuel to a renewable one'

Romain Aubry, multi-energy technical manager at TotalEnergies

At 40MJ/kg, the calorific content of the new fuel is the same as that of traditional oil-based fuels, and early tests suggest it has minimal impact on engine performance. Any that it does have will be addressed by BoP in the GT and Hypercar classes

Technology step

This is not the first time endurance racing has experimented with plant-based fuels. As long ago as 2003, the British Nasamax team took to the track at Le Mans with a bio ethanol-fuelled Reynard. Since then, the fuel has gone through several iterations, notably in the ALMS, where first and second-generation waste was used in its production.

However, these were oxygenated fuels, which meant they did not have the calorific value of fossil-based fuels. What also became apparent was that produce that could have been used for human or animal consumption was instead being grown to provide fuel.

'We are putting into competition biofuel rather than food,' says Aubry. 'All our raw material is waste, and cannot be used by animal or human feeding. It should have been burned or not used. That was one of the first decisions, to ensure we were not using first generation [material] and that was something that was needed.

'The first generation of bio fuel was made with oxygenated content. Using oxygenated methanol, ethanol will always reduce calorific value, and that will increase fuel consumption to make the same energy from the engine. The technology step [we have made] is to produce real hydrocarbons from waste, meaning we maintain the calorific value, the octane and so maintain the fuel consumption of a standard fuel today. This was to show that we still can work with standard hydrocarbons, but made from renewable materials.'

'All our raw material is waste, and cannot be used by animal or human feeding'

Romain Aubry, multi-energy technical manager at TotalEnergies

is evolved into hydrocarbons through a blend with Ethyl Tertio Butyl Ether (ETBE), itself a by-product made from ethanol. It is then combined with several performance additives issued from the Excellium technology developed by TotalEnergies.

Although it would be possible to transport the dehydrated core material to make the fuel elsewhere, there is little point in doing so as it is the gas created throughout the process that is the key element, so it makes sense to complete the process in one go.

TotalEnergies needed to be sure the batch was all the same quality and so produced 1000m^3 of fuel, around a million litres, at the same time in order to service the WEC, ELMS and support races. That figure comes after a three-year association with the series in which precise amounts for testing and race conditions were already confirmed. Producing the full amount of fuel required in one batch means the product is predictable in its properties and there is a reduced possibility of discrepancies.

The fuel will be introduced on track by the end of the year, and both TotalEnergies and the race organisers are waiting on the results of this testing to see what changes, if any, need to be made to the Balance of Performance for each class.

'It is probably too soon to say what the effect will be on the different engines for the whole championship,' admits Aubry. 'We are waiting on test results from the different manufacturers, and will discuss with them over the winter.

'The fuel was ready just before Le Mans, and we started delivery of the fuel since then for them to test. They are testing on the bench for the moment, and it will be on track this year, but they will have to do some engine tuning at the factory.'

Calorific value

By retaining the hydrocarbon element, the team has been able to maintain the same calorific value as traditional fuels. This means stint lengths and fuel consumption will be unchanged from the 2021 race or, if there are differences, they will only be minor.

Whatever changes there are can be controlled by the Balance of Performance system in place for the Hypercar and GT classes.

'We are at 40MJ per kilogramme, so that is the same as a standard fuel. The octane level is above 100, though, so we are really comparable to a racing fuel,' says Aubry. 'If you do all the different chemical and physical tests on the fuel, you won't see any difference. The only difference is the adaptation from carbon 14.

'If we look on the combustion process, it will remain the same. The 65 per cent reduction [in CO_2] is made on the complete life cycle of the fuel, so not just combustion from well-to-wheel. This is from crops-to-wheel. We based all the calculations on European legislation RED, which is Renewable Energy Directive taken from the European commission, so we ensured that we used something known in the field. It is not our calculation, it is well known by the profession.'

Even though there was an opportunity during the development process to tune the fuel differently, either to provide better efficiency or more power, that was not the point of its introduction. Improvements in the chemical properties of the fuel for power or consumption figures will come further down the line.

'This introduction of Excellium Racing 100 was the first step for the championship to reduce its CO_2 emission,' confirms Aubry. 'We wanted to bring consistency through the season. We don't want to change the fuel in two or three seasons, we want to see how the technology from our process will evolve, and the engines, to see if we can have a second step in four or five seasons.

'I think this kind of fuel was what the manufacturers want in terms of corporate communication to move from oil origin fuel to a renewable one. We are still all learning [about it] and then one of the steps after will be to reduce fuel consumption again.'

Learning process

The process started when the company was involved in Formula 1, and it continued when it took over from Shell as the sole supplier to the WEC in 2018. 'We are still learning about fuel but, if we can improve the efficiency of thermic engines, we need to do it,' says Aubry, keen to emphasise this is only the first stage of the process to improve the carbon efficiency of the ACO's endurance racing series. The next is to close the loop by providing the factory that produces the fuel with renewable fuels, followed by the extension of uses for the fuel into other areas in the paddock, such as powering the trucks that transport the cars between tracks.

This is only the first stage of the process to improve the carbon efficiency of the ACO's endurance racing series

Further steps are critical to ensuring the fuel is relevant for mass transport needs. Other racing series are moving to non-fossil-based fuels, even though in Europe the main drive is towards electric for passenger vehicles. This is why TotalEnergies is also heavily investing in 150,000 charging points across Europe.

'Electric mobility for passenger cars in Europe is more of a political decision than a technological one,' says Aubry. Other regions will likely become a focus for renewable fuel in passenger vehicle use, including central US, Africa and Asia.

In Europe, other solutions will likely be found for heavy goods transport, perhaps hydrogen fuel cell, while maritime shipping could be the ideal home for biofuels.

'The European commission made a decision to move to electric for passenger cars but, if you look at heavy duty or mass transport, they will move to hydrogen, either combustion or fuel cell for trucks and trains,' predicts Aubry. 'For passenger vehicles, electricity will [be dominant] for some years, even if gasoline and bio fuel will have a part in the global market.

'At TotalEnergies we want to be in a position to supply what is needed, so renewable electricity, natural gas for maritime transport, renewable fuel and biomass fuel, and hydrogen fuel. Aeroplanes and air transport will be the last to move [away] from liquid energy.'

Pump it up

There was some consternation in the GT paddock when it was revealed the category would run at Le Mans in 2021 with E10 fuel, rather than E20 used in 2020. Balance of Performance changes were quickly made, particularly to the Ferrari 488 GTE car, reducing its fuel capacity before the race, but TotalEnergies say this was not only due to the introduction of the fuel, which was intended to bring it closer into line with pump-based petrol.

'When we did the introduction of Excellium Endurance, the fuel used on track, the idea was to come back to something closer to pump fuel,' explains technical manager, Romain Aubry. 'Previously it was E20 and, when we decided to introduce the renewable hydrocarbon, we decided to come back to closer to a standard petrol, so E10. Next season it will be something similar in terms of oxygenated content.'

TotalEnergies sees the introduction of the new fuel as the start of an evolutionary process to improve carbon efficiency in endurance racing, from the track into the paddock and then beyond

Mission statement

The Munich Motorshow saw the unveiling of the Mission R, a concept image of Porsche's future in racing

By ANDREW COTTON

Using 900V technology, Porsche says the car can be charged from five to 80 per cent in just 15 minutes and that battery recuperation is possible in almost every driving condition. Maximum charging capacity is 350kW

Porsche's Mission R concept car may look close to production ready and, from the press material produced, you would be forgiven for thinking it has its final details worked out, but nothing could be further from the truth.

Despite proclamations of 800kW of power in qualifying trim and raceable power close to GT3 Cup standard, the car is still five years away from being ready to race and has still yet to be driven around even the closed circuit in Weissach.

The fact it has no series in which to race yet is one hurdle that can easily be overcome with the introduction of a new one-make category, but slightly more important is the fact that Porsche's racecars are normally based on a roadgoing model, and there is no roadgoing version of the Mission R. Yet.

That is not to say the Mission R project is pure fantasy. The fact there is such a long lead time to create a race-ready car means the team can investigate new ideas, such as a seat built into the monocoque, which normally cannot be addressed due to short development times.

Copper cooled

The car uses the electric motors taken from the Taycan production car, cools them using a technique that involves running copper wire inside the sealed motors, and the design team has also thought through the idea of using active aero to achieve race times of around 35-40 minutes, depending on circuit layout.

In order not to create conflict with the Carrera Cup or Super Cup, Porsche is also looking at a completely new race format, a decathlon that involves different track surfaces and applications for this electric car that it hopes will appeal to a new audience.

Perhaps the most impressive part of the announcement, however, was Porsche's confirmation that the electric motors would be oil cooled using a new method that is far more efficient and improves the de-rating of the batteries.

The design process for this cooling system started in 2018 when engineers started work on powerful, highly efficient electric motors using direct oil cooling of the stator. That enables very high peak and continuous power output levels to be achieved. While conventional electrical machines cool using fluid that flows through a jacket outside the stator, in the case of direct cooling, the oil flows through it along copper windings.

The electric motors would be oil cooled using a new method that is far more efficient and improves the de-rating of the batteries

This allows more heat to be dissipated at source. Additionally, the slots in the stator can be made smaller, which means greater efficiency in real driving cycles.

'It is quite simple,' explains Matthias Scholtz, director of GT racing at Porsche. 'We have taken the Taycan e-motors and put the oil cooling directly in the motor. It was possible for us to make the copper linings and bring them closer together so the motor has more efficiency, and we could achieve higher rpm for the motor.

'The cooling system itself is simple, too. We directly cool the inner part of the motor, and the complexity is more to seal the motor from the outside to the inside where the fluid is. We developed a liner, a thin seal that is the most complicated part of the motor, to make it robust without affecting the production of the motor.'

An optimisation algorithm was used to determine the ideal shape and position of the magnets in the rotor. The resulting geometry eliminates an old conflict of objectives, which is to combine electromagnetic properties with high mechanical strength at high speeds.

During production, the magnets are inserted into the rotor laminations and extrusion-coated with plastic. As a result, they do not move, despite high centrifugal forces, and the balancing quality of the rotor remains stable. At the same time, the plastic helps dissipate the heat generated in the magnets.

The battery, developed with partner Custom Cell, has a total capacity of 82kWh. High-end cells are used to take advantage of the high power density and the oil cooling system is a further benefit. It makes use of the entire surface of the cells, meaning a large amount of heat can be transported from the battery into the cooling system.

Rapid charge

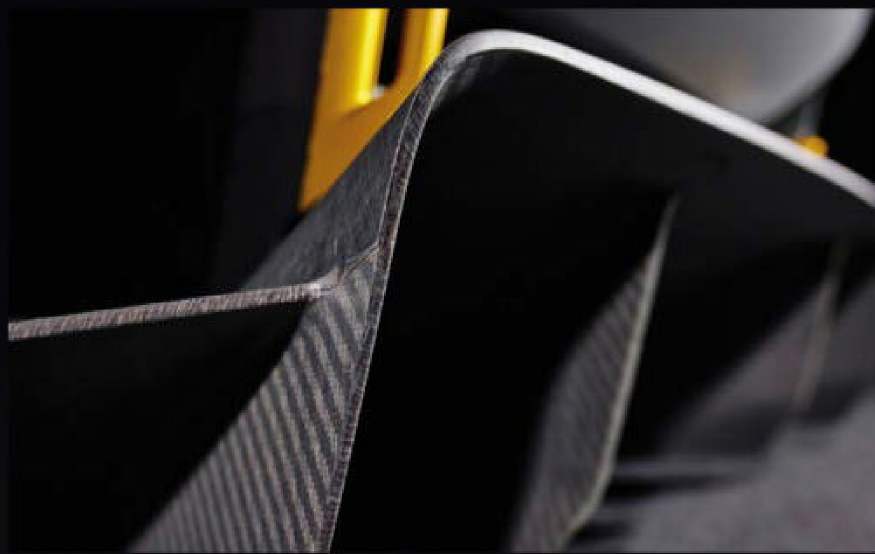
While the Porsche 919 Hybrid introduced 800V technology, which then fed into Taycan production, the Mission R targets 900V, leading to further improvements in continuous power, weight and charging time. The latter is expected to be around 15 minutes from five to 80 per cent charge, at which point the car will be race ready.

'In case of qualifying, we go to 100 per cent because it is not necessary to recoup energy over one lap,' says Scholtz. 'Then it is possible to use 800kW. In race mode we use 500kW and therefore for a bit of strategy during the race it is better to have an SoC at 85 per cent.

Electric power steering calculates the optimum assistance required on the go

The seat, steering wheel, controls and 'screen all lie on the same axis for driver comfort

Car features adaptable Porsche Active Aerodynamics (PAA) and drag reduction system



With 800kW peak power, performance is said to be on a par with a Porsche 911 GT3 Cup

The Mission R is said to offer a preview of the next generation of electric motors

The high voltage safety concept is the same as that found on series production cars

'The active aero has a lot of influence on how long you can race the car, and the duration of driving the car'

Matthias Scholtz, director of GT racing at Porsche

Rolling renewables

The Mission R rolls on 18in, centre lock Cup wheels. With smooth-surfaced carbon aeroblades, the magnesium wheels are flow optimised, their twin spokes milled to save weight.

Michelin, long-standing tyre partner of Porsche, has developed new slicks exclusively for the Mission R with a 30/68 (front) and 31/71 (rear) tyre format. They consist of bio-based and renewable materials, which is a key component in the overall sustainable concept of the Mission R. The tyres also have a high resistance to wear and are protected against damage caused by deposits on the racetrack.

The collaboration with Michelin also included networking with the vehicle. The tyres can be fitted with sensors that communicate in real time with the on-board electronics during a race and provide the driver with information on tyre wear. Based on this data, an optimum time for the next pit stop will be suggested to the driver.

Michelin produces its tyres entirely from renewable raw materials. In line with the French company's holistic sustainability strategy, all Michelin tyres are manufactured in CO_2-neutral plants and transported using a CO_2-optimised logistics chain.

At the end of their life cycle, the used tyres are broken down and then recycled into new tyres.

Porsche remains committed to BComp's flax fibre concept, a renewable alternative to carbon fibre

'One of the main tasks over the next couple of years, in development with our partner Custom Cell, is to improve the cell so it has a lower resistance, so we can lower the recharging time and recharge with more power, and faster. Or to have the best cooling, or so the battery has more SoC, so it is not 80-85kW, but up to 95-100kW with the same weight. That is very important for us.'

The drivetrain has yet to be fitted to the car, but the plan is to have it testing by the second half of 2022, with a view to steering the future regulations for series such as the DTM and the FIA's proposed Electric GT series.

'At the moment there are ideas of such a series, but there is not a rule or regulation, and with this vision we wanted to discuss with the FIA to create this Electric GT series as well,' explains Scholtz.

State of flax

Porsche remains committed to BComp's flax fibre concept, a renewable alternative to carbon fibre that has been tested and raced extensively in the company's GT4 Cayman programme. Much of the bodywork for the Mission R has been designed using this sustainable technology and it is expected to be used in other race series mandated by the ACO and the FIA.

The materials are based on flax fibres obtained from farming, which do not come into conflict with cultivation of food crops. The natural fibres are roughly as light as carbon, and deliver the stiffness required for semi-structural components with a low additional weight of less than 10 per cent. Compared with conventional plastics, natural fibres have an ecological benefit too, with 85 per cent less CO_2 generated by the production of the fibres compared to those used for carbon fibre, Porsche tells us.

With a base weight of 1500kg, the company uses a combination of double wishbone suspension on the front and MacPherson strut at the rear and says that, although it did consider active suspension, feels this is a car that should be affordable for a customer and therefore not too complex.

That didn't stop them introducing active aero though.

'Normally, active aero shouldn't be there because it is too complicated, but in an all-electric racecar it is such an important detail to race the car. Not only in a high-downforce configuration, but also to lower it on the straights,' explains Scholtz. 'The active aero has a lot of influence on how long you can race the car, and the duration of driving the car.'

Drive by wires

A brake-by-wire system will be used in the car to manage the hydraulic and electronic brakes. What's notable is that, due to the high amount of regen', the conventional brakes are much smaller than a traditional high-performance car, with the fronts carrying 380mm discs, the rears 355mm.

Although the car features an electric power steering system, it will retain the link between the wheel and the rack, unlike the 'steer-by-wire' system that has been developed and raced at the Nürburgring. That technology has not yet developed to the point that it is lighter than a conventional system, so Porsche elected to leave it off this concept.

The car's main exterior body panels are made from a sustainable biofibre composite material developed from flax fibres obtained from farming

The bodywork hangs off a custom-made chassis, which forms part of the roof structure and is therefore at least partly visible from the outside. The carbon fibre rollcage provides a framework around which six transparent polycarbonate segments comprise the rest of the roof. The exoskeleton solution is a modern interpretation of the Porsche Targa,' says Porsche's press release.

Safety seats

For driver safety, a new seat concept has been created that is part of the monocoque. 'Normally, when we start the development of a project, there is 1½ to two years to the race debut of a car, so it is not possible to develop the seat itself. But with this concept, hopefully we can produce this as a realistic race seat in four or five years,' says Scholtz.

'The idea is to make a monocoque seat for the driver that is very nice, and very safe, so you have a triple stage of safety in the car: the bodywork, with the crash structure, the rollcage and the monocoque structure of the seat.

'It is a very simple natural fibre composite, so everything will be done to fit the driver in the seat, and the legs are safe as well. That is the idea of the seat. The cooling system is also then possible.'

The seat features a 3D-printed bodyform full bucket, with the centre section of the seat, including the cushion and backrest, produced through additive manufacturing. This is now available for 911 and 718 models.

In the Mission R, the driver's seat is actively ventilated and upholstered in breathable fabric made using a resource-saving 3D knitting process. The lattice structure helps dissipate body heat, leading to a more comfortable environment.

Five-year plan

So, there are clearly ideas to develop technologies in the Mission R that can be used in production and other racecars, but what's the plan for this Electric GT car over the next five years before its competition debut?

'We are already working on a first prototype, in which we want to install the drivetrain and test it to show it works, and that it is possible to race the car for 25-30 minutes,' says Scholtz.

'We are also working on a new race format that is additional to a one-make series, a decathlon with different surfaces such as gravel and ice so that it is not in conflict with the Carrera Cup. We don't want to copy a series, but to invent a new format that is maybe more interesting for other kinds of fans and customers.

'These two things we are already working on, and we hope to show in the second half of next year the results of this.

'Then [we will see] if we can develop the car. There are so many discussions internally with the board, we will see, but I am sure we will bring a GT racecar around 2026 that it is possible to race.'

For now then, Mission R remains a fascinating mix of fact and fantasy.

Battery technology

Porsche is investing a double-digit million-euro amount in the new Cellforce Group GmbH. Cellforce's production facility is scheduled to go into operation in 2024 with an initial annual capacity of at least 100MWh, and will produce batteries for around 1000 motorsport and high-performance vehicles.

The chemistry of the new high-performance cells is based on silicon as the anode material, which makes it possible to significantly increase energy density compared with current standard batteries. This means the batteries can be made more compact but with the same energy content.

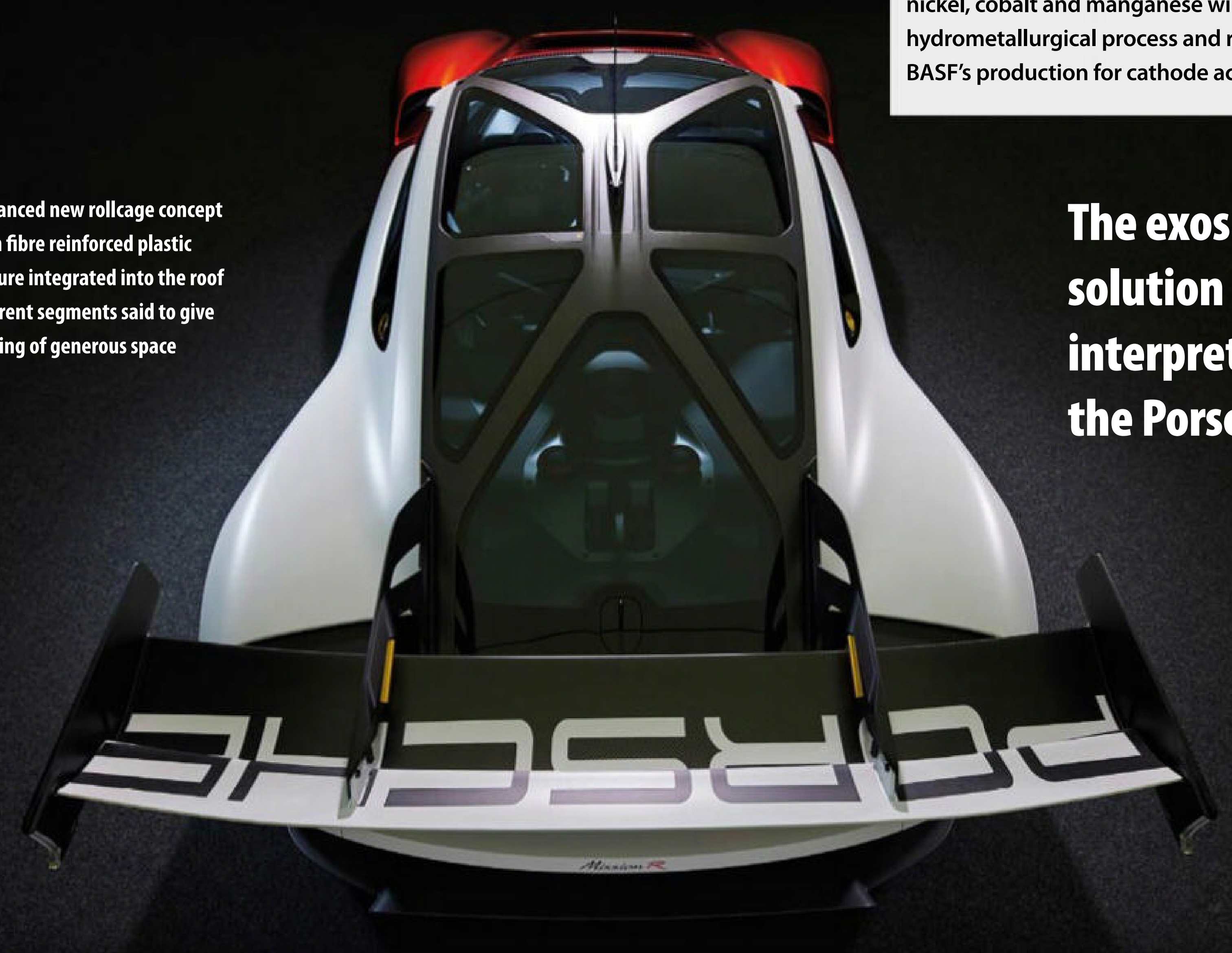
The new chemistry also reduces internal resistance, which allows the battery to absorb more energy during recuperation. Fast charging can also be carried out more efficiently.

Another special feature of the Cellforce battery cell is it will be better able to tolerate high temperatures.

BASF, the world's leading chemical company, has been acquired as a cell development partner for the next generation of lithium-ion batteries. As part of the collaboration, BASF is to be the exclusive supplier of high-energy HEDTM NCM cathode materials for high-performance cells that provide fast charging and high energy density.

BASF's production facilities for precursor cathode active materials in Harjavalta, Finland, and for cathode active materials in Schwarzheide, Germany, will enable BASF to provide battery materials with a low carbon footprint from 2022 onwards that will set standards for the industry to follow.

The production waste from the Cellforce Group's future battery production facility will be recycled at BASF's prototype battery recycling plant in Schwarzheide, neatly closing the loop. There, lithium, nickel, cobalt and manganese will be recycled in a hydrometallurgical process and re-introduced into BASF's production for cathode active materials.



The car's advanced new rollcage concept sees a carbon fibre reinforced plastic (CFRP) structure integrated into the roof with transparent segments said to give drivers a feeling of generous space

The exoskeleton solution is a modern interpretation of the Porsche Targa

Remote racing

It may only have been a bit of fun, but the driverless DTM car that lapped the Red Bull Ring in Austria showcased how far autonomous driving technology has come

By ANDREW COTTON

DTM

Ellen Lohr, director of motorsport at AVL, whose vehicle dynamics simulation software, VSM RACE, helped make the extraordinary demonstration possible

'Software behind the simulator is absolutely state-of-the-art and differentiates us from our competitors'

Ellen Lohr, director of motorsport at AVL

History was made at the DTM race in Austria at the start of September as the all-new electric car that will form the basis of the future DTM rule set lapped the Red Bull Ring at full racing speed. Not only did it complete a lap of the Spielburg circuit in the hands of former champion driver Rene Rast, but another driver, Tim Heinemann, also took the car around the Austrian track from behind the wheel of the AVL simulator, more than 80km away.

The latter was an extraordinary achievement, marrying some established technologies to create a unique occasion. Using the communications from Riedel, the 5G network from Cisco for network communication and AVL's hardware-in-the-loop simulator, the combination allowed Heinemann to complete the lap with speeds of up to 150km/h.

There is nothing new in terms of bringing together hardware-in-the-loop technologies, but sending a 1200bhp, full-size racecar around a circuit without a driver on board in order to demonstrate it to a live audience took some courage. However, it was the next step in the development of the DTM Electric concept that was announced in 2019, which has now matured into a full demonstration racecar a year later.

Remote run

'The DTM Electric Remote Run is the next step on the way towards a fully electrified high performance race series,' says Benedikt Bohme, managing director of the DTM organisation ITR. 'The project is showing elements that in the future could be used in a fully new, global, electrifying race series like we want to establish with DTM Electric, alongside the proven DTM.

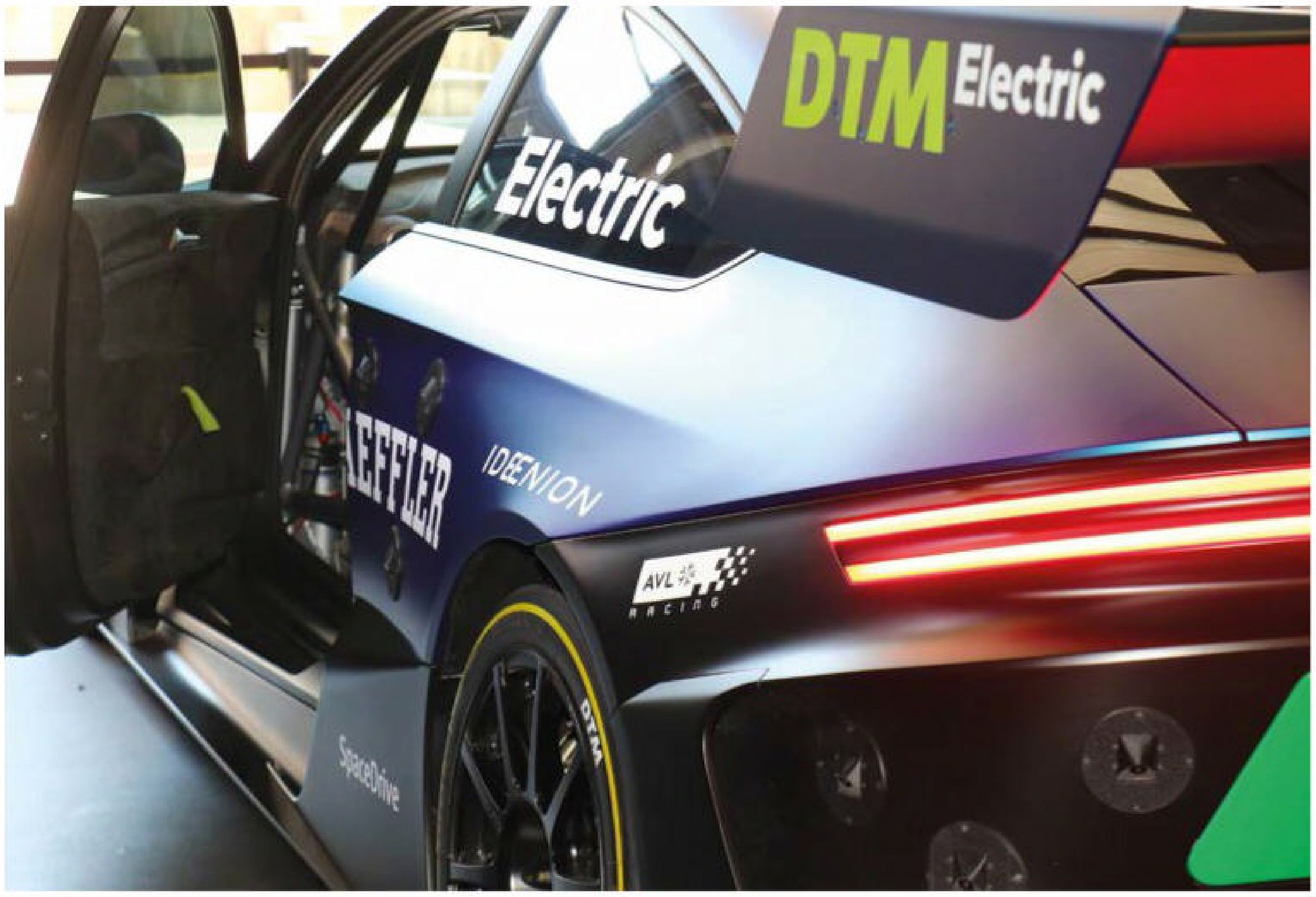
'Moreover, it shows the innovation power our platform has for developments aimed at mobility in the future.'

Of course, having an electric car is not critical to making a vehicle autonomous. There is every opportunity to make an internal combustion engine car autonomous as well but, in order to lap the track with a driver in another postcode, the high level of electrical systems onboard were key to making the project work.

These electrical systems included Schaeffler's Space Drive system, which has been tested in race conditions for a number of years. The steer-by-wire system removes the steering column from the process, so the signal is simply transmitted to the simulator, rather than the steering wheel.

However the complexities of driving the car around a track include avoiding latency in the signal, which could cause the driver to miss a braking point, for example, and travelling at full speed that could lead to a sizeable accident. For that, there was a kill switch for the physical car that would have applied the brakes immediately and fully, while there was also a kill switch in the simulator in case of blue screen for the driver.

To bring all these technologies together, and have them function to the point where a car could be driven at speed, took great coordination. Other companies such as Tripleye provided the connected camera system, including the all-important computer unit, and Vosys supplied the software, its integration for tele-operated driving. Memotec, a proven sensor partner of the current DTM platform, was also involved, ensuring communication between car and simulator was clear.



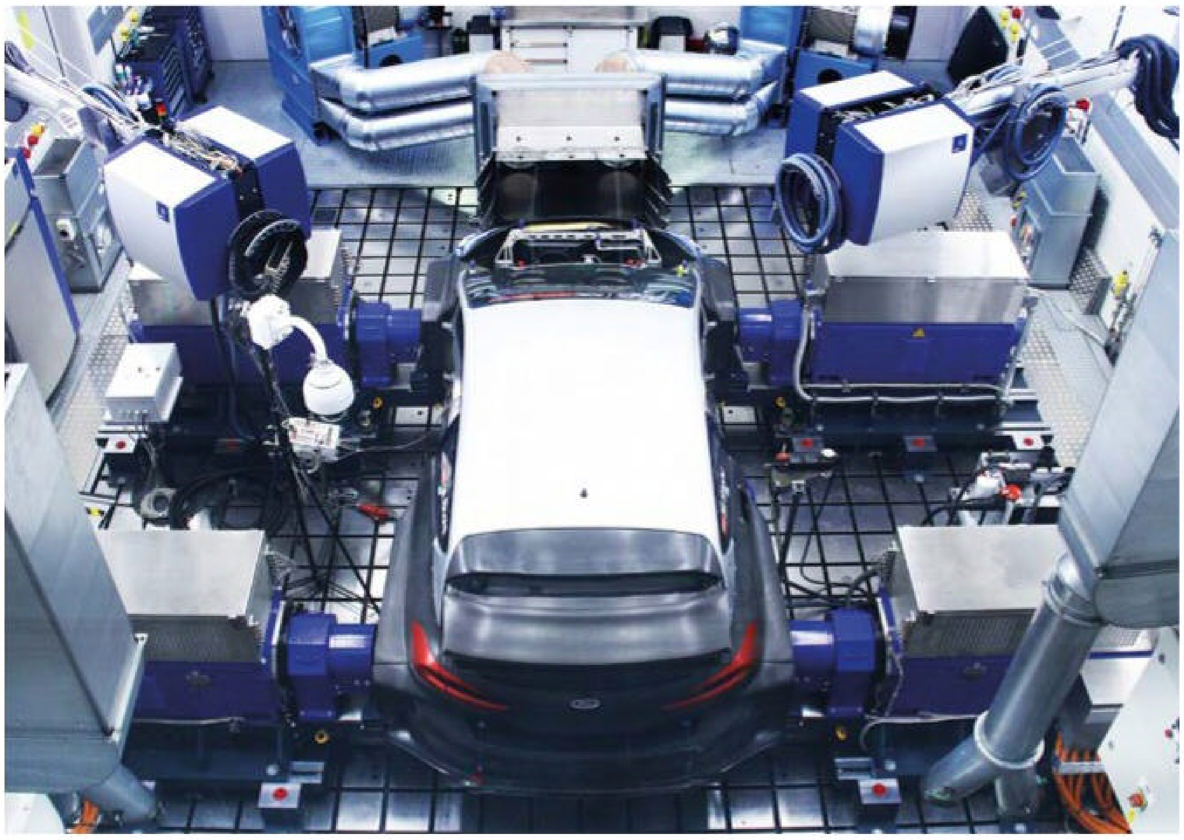
Farid Wagner

DTM organiser, ITR, sees the recent Remote Run as the next step on the road toward a fully electrified, high performance race series

It shows the innovation power our platform has for developments aimed at mobility in the future

Predictive behaviour

Key to making the virtually-controlled lap happen was AVL's vehicle dynamics simulation software, called AVL VSM RACE, which can be used in offline simulations, in the cloud or in real-time applications such as driving simulators, and vehicle and battery test benches. The software accurately



The car on AVL's Full Vehicle Dyno, capable of generating the 800kW needed for Formula 1 and modern EV race cars

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simulates vehicle behaviour and enables improvement of all vehicle systems from the concept to the testing phase.

'We do not actually have the most expensive driving simulator,' admits AVL's director of motorsport, Ellen Lohr. 'Top motorsport teams may have more expensive ones, but our software behind the simulator is absolutely state-of-the-art and differentiates us from our competitors.

'We can do everything from modelling tyres, different concepts of cars, and we can run hundreds of thousands of laps in simulation with a click of the mouse. We have several features that make our software stand out from the rest. One that we are particularly proud of is the real time connection between the driving simulator and the actual car, which is at the same time being run on our Full Vehicle Dyno. In this case, you have the driving simulator and the actual car in completely separate buildings.'

There is a different challenge to driving a genuine car that goes around the track at close to full racing speed compared to driving a simulator. The first thing that had to be addressed was safety, and in this case the primary concern was latency in the system. If the latency in the system was too high and there was significant delay between the physical car and the input from the system to the driver in the simulator, the driver would have less control of the car if it went sideways, for example, and there would be a higher risk of accident. Even having a missed braking point could have had at best embarrassing consequences, at worst a crashed car.

Practice runs

'Undoubtedly, having a low latency was crucial to be able to drive the car at high speed,' confirms Ull Thaler, senior software engineer, racing at AVL. 'Before we attempted remote runs with the real car, we used the simulator with a modified VSM model where we added artificial latency in order to test the effects on driveability in a controlled setting. We found that a round-trip latency of 150ms is the maximum where the driver still felt they had a good positional control over the car, that they could hit the apex reliably.'

This may sound like a lot, particularly when Vosys, which provided the network over which the DTM car was able to communicate with the simulator, has a quoted latency of 60ms over a 4G network that it uses in its association with companies such as Volvo trucks, but actually it isn't. Even with the smart video packaging that makes sure only video crucial to the operator or driver at any given moment is available, which minimises the area sent over the video link, latency was still a concern for AVL.

'This latency number [of 150ms] refers to the sum of all elements of the system including cameras, network links, actuators in the car, data transfer back and forth, sensors, processing time, projector response time and so on,' says Thaler. 'When you put all of these elements together, it does not leave a lot of margin for the individual subsystems.'

> **'A round-trip latency of 150ms is the maximum where the driver still felt they had a good positional control over the car'**
>
> *Ull Thaler, senior software engineer, racing at AVL*

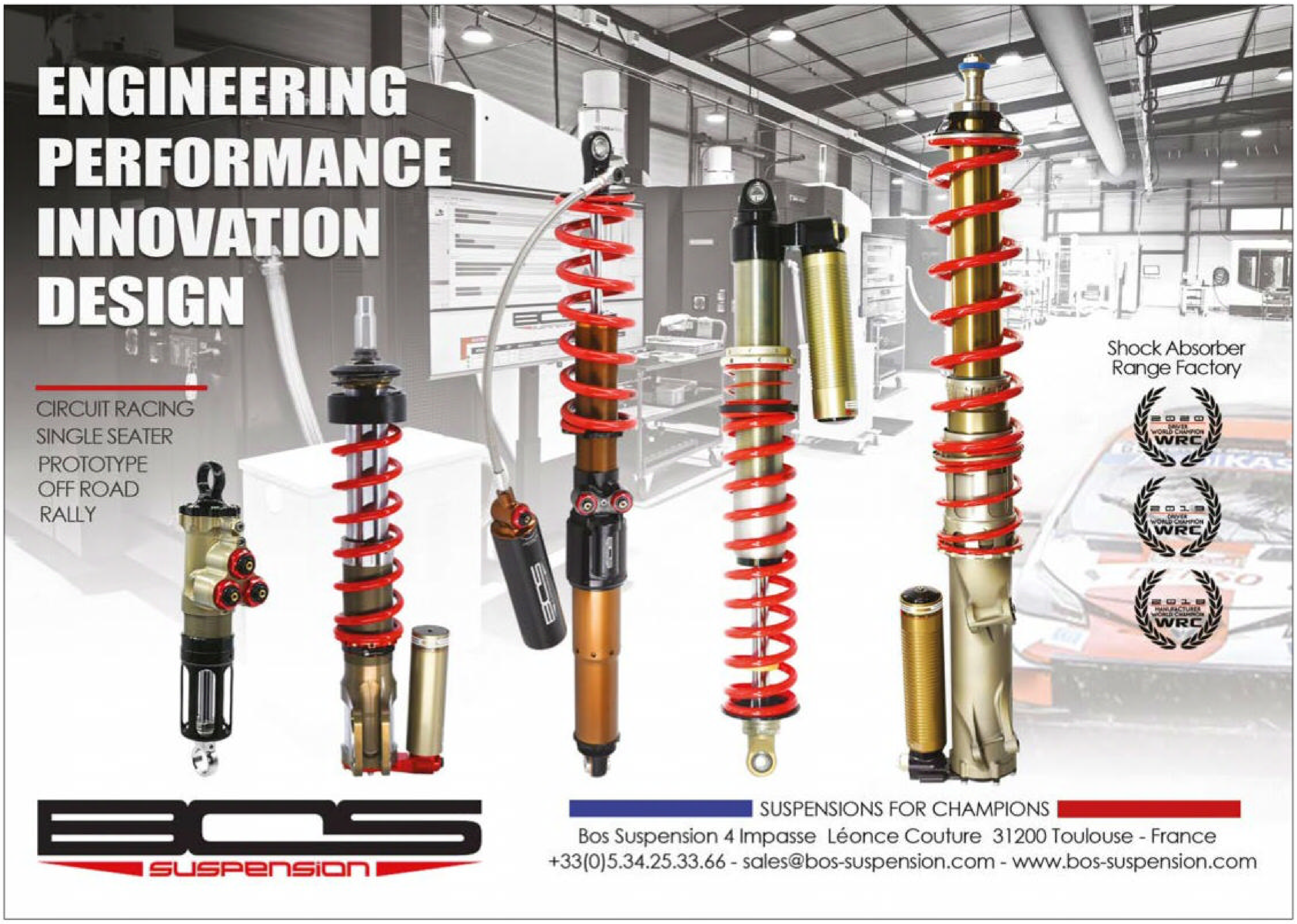
Cumulative latency

Having fixed the latency number and put in safeguards around any peak that was above what AVL considered acceptable, the next question of cumulative latency arose. Would the latency continue to accrue as the car completed a greater distance?

'The latency does not increase with running time, only when the car switched between the network nodes that were placed around the track,' explains Thaler. 'The latency would increase for an instant, but overall we stayed well below our established limits.'

Redundant links and super fast congestion control algorithms further reduce the risk

Before the Remote Run took place, simulations were conducted with a modified version of AVL's VSM model with artificial latency added to test the effects on driveability in a controlled setting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of unwanted latency. When the bandwidth starts to drop, the system reacts within milliseconds to avoid latency peaks. However, with the parameters set for safe operation of the car the project could continue.

The next issue that needed to be sorted out was the communication between the circuit and AVL's facility in Graz, 80km away. Radio communications at a racetrack are pretty lively during a race weekend at the best of times, particularly with the security surrounding your own data stream from car to pit, and protecting that from hackers and nosey rival teams. But when you are running a 1200bhp electric car around a circuit, you need to be sure the communication network is secure and that it will not fail.

Corners of concern

One of the concerning aspects of the Red Bull Ring in Austria is that it is an undulating track.

'What we needed was a very stable connection, and that was quite a bit of work for our partners,' says Lohr. 'Actually these quick networks are what you need for autonomous driving in the future and all the partners were testing them successfully in the tough racing environment.'

To give Heinemann the best chance of controlling the car, the feedback from the car to the simulator had to be accurate, and in this case AVL's team worked hard on ensuring the physical cues were as good as they could be. Visual and aural cues were as important to the driver as the physical feeling through the wheel and pedals.

'We did our best to give him a real feeling on the steering and the brakes,' says Lohr. 'Together with our partners we also worked on other senses, so that the sound was right, for example. It was not like we normally work with our software, we really had a partnership between many other companies.'

Technology showcase

Heinemann's lap time was not comparable to that of Rast, at least over this run, as the team was only there to showcase the technology rather than to set lap records. While the DTM is talking about remote racing, for AVL this was not the main point of this exercise.

'It was about making the technology visual,' confirms Lohr. 'We wanted to show what was possible and give it a bit of fun for the spectators.'

Having secured the parameters around latency and network reliability, attention turned towards the car itself, and the components needed to make it physically possible to complete the lap with a virtual driver. Many of the advanced technologies introduced into modern racecars, such as

Autonomous driving?

Schaeffler believes that by 2035, around 30 per cent of all new cars and light commercial vehicles will be operated at least partially by automated system, while half of them will offer the capability for highly automated driving.

'The increasing automation of driving functions on the road to fully autonomous vehicles also imposes more rigorous requirements on chassis applications in respect to reliability and safety,' says Viktor Molnar, president chassis systems business division at Schaeffler.

'We are continuing to ramp up our activities at component and system level, and are well on track to becoming a preferred technology partner for intelligent drive and chassis solutions.'

'Once we had a point where the DTM was more advanced than Formula 1 and we need to get back there'

Gerhard Berger, manager at DTM

AVL VSM RACE SIMULATION

After the collapse of the Class One concept following the withdrawal of its competing manufacturers, the DTM needed a quick solution, and turned towards the most successful production-based racing formula of all time, GT3.

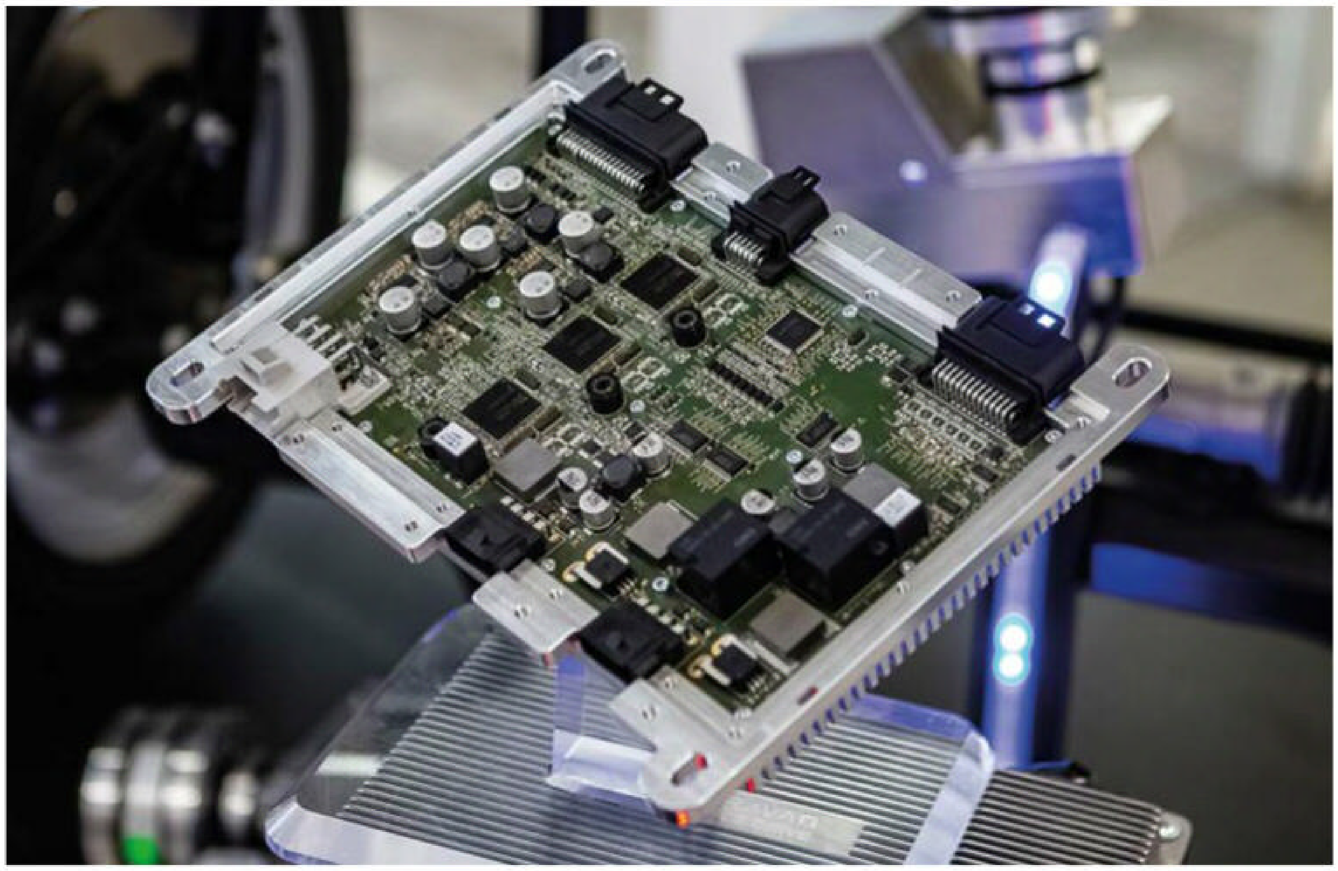
Balancing performance has become a key element in modern racing, taking over many categories in a bid to increase the number of potential competitors at a price that they can afford as it negates the development cycle that would otherwise be needed. Not only is it prevalent in GT racing, but it has also been adopted by the FIA and the ACO in its Hypercar class competing for overall victory at Le Mans. But it has to be accurate.

Although switching from a Touring Car platform to GT attracted criticism, each of the major manufacturers involved in the DTM, including Mercedes, Audi and BMW, along with Aston Martin, already had GT3 cars with which to compete, as did many others that were important to the German market, including Porsche. Not only that, but they also had customers willing to race in the DTM.

The issue was how to balance them, and in order to do so in the short timeframe that they had available they turned to AVL, which was able to use its vehicle simulation software to work out the most effective and accurate balance of performance. The VSM RACE simulation software allows AVL's engineers to simulate up to 100,000 laps by means of cloud computing in such a short time that it can be completed between practice sessions. This allows for track collected data to be processed on event, which is useful when settling any arguments from manufacturer representatives between sessions.

AVL's system relies on state-of-the-art virtual laboratory conditions, taking into account a huge database gathered from races, as well as specific data sources from test sessions, practice sessions and races throughout the DTM season. The more information gathered, the more accurate the Balance of Performance can be, and AVL's system was able to quickly and accurately map each of the cars.

In the process of creating a BoP model in a virtual environment, AVL's system is also able to exclude external factors such as temperature differences and different track conditions in determining overall Balance of Performance, but it is also able to factor these elements into the calculations in a controlled manner.



Schaeffler's Space Drive is a key part of the DTM Electric concept, allowing the car's steering to be entirely controlled by electronics

brake, throttle and steer-by-wire have all been developed to the point they are reliable.

Space Drive

Schaeffler's Space Drive, which has been tested in the NLS, racing around the Nordschleife at the Nürburgring, and which will be used this year by Audi, BMW and Mercedes, was one of the key elements to providing the electrical feedback to the virtual driver. The system removes the steering column from the car and operates the steering wheels by electronics.

It is not necessarily lighter than a conventional system with a steering rack, and so was discounted in the Porsche Mission R, for example, but for this application it was crucial. The electronic signal was transmitted from the car back to the simulator for the key elements of control, including steering, braking and accelerating.

'The Space Drive system that has been implemented in the DTM Electric concept car is a key technology for autonomous driving,' says Matthias Zink, board member automotive technologies at Schaeffler AG. '[It has been] excellently proven, with over a billion kilometres completed on public roads.'

For the DTM series itself, it is aiming to introduce electric as one of its five pillars of racing alongside the DTM Trophy, DTM Classic, the DTM itself and DTM Esports.

'We have to think about the platform and work on sustainable technologies,' says the DTM's manager, Gerhard Berger. 'Once we had a point where the DTM was more advanced than Formula 1 and we need to get back there. As a racing driver, where the power is coming from is irrelevant. What you need is power, plenty of it, and the skill as drivers is to handle the performance in the right way.'

What AVL and its partners have achieved is to prove that even the location of the driver is not all important. With a stable connection, vehicles could be driven all over the world from base, which has applications in many areas of our lives, not least defence.

(Left) AVL's simulator is supported by market-leading software that allows for highly complex calculations to take place. The simulator itself can be wirelessly connected to a physical car in another building or another town. It is versatile enough to develop tyres and different concepts of cars, crucial in terms of accurately balancing GT3 cars for the DTM

AVL

(Above) Tim Heinemann completed a physical lap of the Red Bull Ring from his seat in the AVL simulator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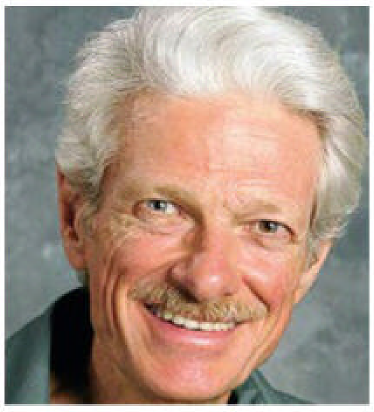


Flipping the ring

The right and wrongs of going against transmission manufacturers' orientation in mid-engine applications

By MARK ORTIZ

Q This isn't a suspension question, but it relates to handling, specifically, what to use for an engine and where to mount it.

I'm interested in building a small car with a rear mid-engine. I'd like to use an older VW transaxle for reasons of cost, and I'm told you can flip the ring gear in these, mount them backwards and still have four forward gears. However, some people say that's a bad idea because everything except the ring gear turns backwards and the gears drive on the coast side of the teeth. Can you shed any light on this?

GM

GM's infamous Corvair. Had it been mid-, rather than rear-engined, Ralph Nader may not have had cause to vent

THE CONSULTANT

A This depends on the reason you want to flip the ring gear. If you are doing it to reverse the mounting of the transaxle and using a conventional rotation engine (crankshaft turns clockwise as seen from the timing end) like the VW, it works fine.

The problem comes when you try to flip the ring gear to accommodate an engine that turns the other way, such as a Corvair, which turns counter clockwise as seen from the timing end.

The cheapest way to get four forward gears with this combination is to invert the ring gear and differential, but the gears and bearings won't last long. In fact, you really cannot reverse engine rotation with any transmission that has helical gears, as roadgoing transmissions always do for quiet operation.

Spreading force

Some readers may benefit from an explanation of this. When any pair of gears transmit torque, they try to push away from each other. With straight-cut spur gears, the spreading force is purely radial, meaning it just tries to spread the shafts apart. But when the gears are helical, they also try to spread apart axially, along the shafts.

In the VW transaxle, this force tries to push the input shaft, also called the mainshaft, toward the end cover (to the front of the car in the original configuration, rearward in a mid-engine application). Conversely, it tries to push the output shaft, also called the pinion shaft, toward the differential (rearward in a VW, or forward in a mid-engine application). The bearings are designed to resist thrust loads in these directions. They must also resist loads in the other direction under overrun, but these loads are much smaller. When we reverse the rotation of the gears in the transaxle, we reverse these forces.

In most front-engine cars, the transmission is a three-shaft design. The input shaft is in line with the output shaft or mainshaft, and underneath these is the countershaft, also called a layshaft or cluster shaft. There is one direct gear, where the input shaft is coupled to the output.

In all the indirect gears, the power goes through two sets of gears, one at the front of the 'box that transmits torque from the input shaft to the countershaft, and one of a series of gear pairs that transmit the torque to the mainshaft. The helix angles on the gears are arranged so the input shaft and mainshaft are pushed toward the ends of the case, and the gears on the countershaft are pushed toward each other, making their thrust forces partly cancel. As with a two-shaft design, reversing the direction of these loads is highly inadvisable. The transmission will still operate that way, but its life will be shortened.

The teeth on most transmission gears are symmetrical in profile: the drive side has the same pressure angle as the coast side. However, most ring and pinion gear teeth have an asymmetric profile: the whole tooth is tilted toward the drive side. The pressure angle is therefore smaller on the drive side and the flank of the tooth is more upright. This reduces pressure at the tooth interface, reduces spreading forces and reduces friction and wear. Therefore, it is inadvisable to have the ring and pinion operating on the coast side of the teeth. As with reversing transmission rotation, the system will operate, but its strength and longevity will be reduced.

The proper solution when adapting a Corvair engine to a VW transaxle is to reverse the rotation of the engine. This is simple to achieve. You just have to fit a reverse rotation camshaft and distributor gear, and use a starter that rotates opposite to stock. You then do not flip the ring gear, unless you are building a mid-engine car.

Certainly, vehicle layout is just as important for handling as suspension, but it all must work in harmony with the tyres. Different layouts, and tyre choices, will affect performance potential in their own right.

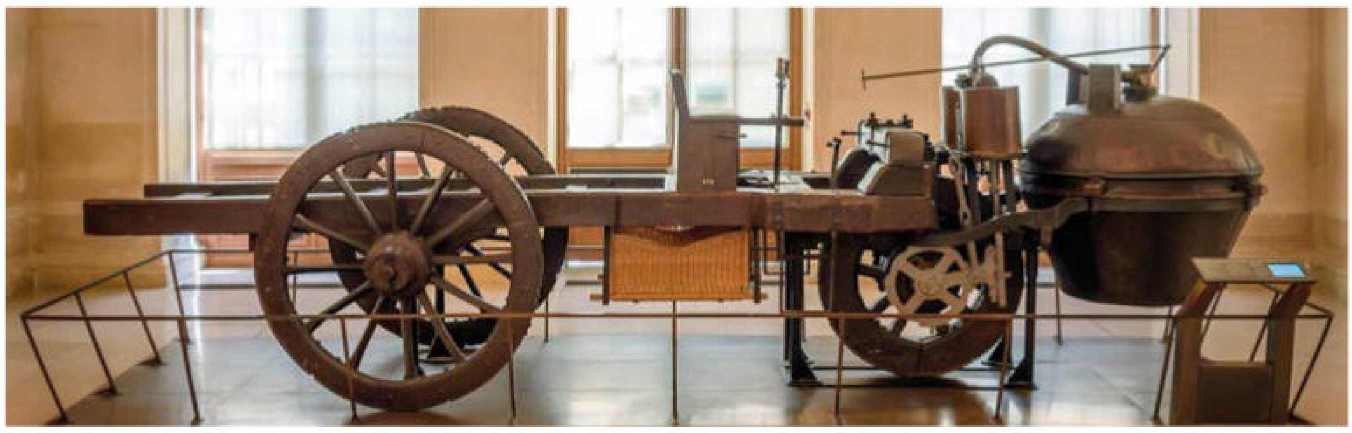
You really cannot reverse engine rotation with any transmission that has helical gears

In-wheel motors

Q The latest *Automotive Engineering* has an article touting the merits of electric motors built into the wheels of a vehicle, called in-wheel motors (IWM). The author, who appears to have impressive credentials, makes some claims that raised my eyebrows, and on which I would like your opinion:

1. **Unsprung weight is not as big a problem as people suppose, because of modern advances in suspension design.**
2. **Having the motors built into the wheels reduces delay in power application to the wheels, and this reduces pitch and roll.**
3. **Having separate power units for each wheel has advantages from the standpoint of serviceability and packaging.**
4. **Having separate power units for each wheel increases cost of the power units themselves, but may reduce overall vehicle cost, or at least be cost-competitive overall, due to cost reductions in the rest of the vehicle. Evaluating the overall effect will require a more integrated approach to vehicle design, which currently tends to be highly compartmentalised in large vehicle manufacturers.**

What are your thoughts on these, and on the general idea of building motors into the wheels? Also, what sort of anti-squat properties do you get that way?



Joe deSousa

The earliest in-wheel motor, Nicolas Cugnot's 1769 *Fardier à vapeur*, used a ratchet to convert reciprocating motion into rotary motion

Having the motors in the wheels emphatically does *not* reduce pitch or roll, or improve vehicle dynamics

THE CONSULTANT

A The idea of driving the wheels directly has been with us since Nicolas Cugnot's steam wagon, which had a powerplant directly driving a single wheel.

There have even been attempts to build internal combustion powerplants into wheels and axles. There was an early American racecar that had a huge, unsprung, inline four driving the front wheels. There was a Jawa motorcycle with a rotary engine built into the front wheel and the Tucker was originally planned to have an unsprung six in unit with the rear axle.

The idea is more appealing with electric motors. The motor mass is less than for prime mover engines and the inability to provide a transmission matters less since electric motors make great torque at low (or even zero) rpm. They can also be run backwards for reversing.

There are still practical problems, though. The motor must be very well sealed from contaminants such as water and mud. At the same time, it must be kept reasonably cool.

Even disregarding the effects on ride and handling, the effects on the motor itself from having it unsprung are pretty daunting. Think about the under-car videos you've seen of suspension systems at work, and the fact electronics don't like vibration and shock any more than they like heat or water.

Finally, there's the problem of transmitting electrical energy to an assembly that's moving like that. It's easy to make stranded copper electrical cables flex, but copper has extraordinarily poor fatigue life, and all known insulation materials become brittle and crack.

On the plus side, having a self-contained corner module has advantages from a service standpoint. Spares can be kept on hand and reconditioned on the bench while the vehicle is promptly returned to service.

There have been some improvements in suspension that somewhat mitigate the effects of heavy unsprung masses, but there is no magic. Better dampers help, but they help with light unsprung masses, too.

Air suspension reduces the effects of load variation on ride heights and natural frequencies. These effects are greater when the sprung structure is a smaller percentage of the unladen vehicle mass but again, there is no magic involved here.

About the best that can be said is that increased unsprung mass *may* be worth putting up with in certain applications, *if* there are benefits that outweigh the penalties.

Dynamic thinking

Having the motors in the wheels emphatically does *not* reduce pitch or roll, or improve vehicle dynamics in any way. If we compared cases where wheel rates are constant, having more of the total mass unsprung would result in higher sprung mass natural frequencies and reduce roll and pitch that way, but not if we hold sprung mass natural frequencies constant, which is more reasonable.

When the motor is in the wheel, torque reacts through whatever the stator, or non-rotating part of the motor, mounts to. This means torque reacts through the suspension linkage, even with independent suspension, as it does with an outboard brake. If there is a beam axle, it is 'live' and torque transmits through the linkage, but the driveshaft torque we usually have with a live axle is absent.

There are potential advantages in terms of low-speed manoeuvring. With no need for jointed driveshafts, the wheels could be made to steer through large angles. If each module has its own electric steering motor, and those and the wheel motors can be individually controlled, a vehicle can be made to travel at any yaw angle desired, with any yaw velocity. The possibilities for rock crawling, for example, are interesting to contemplate.

It is possible to realise a lot of these conditions without necessarily having the motor unsprung, or built into the wheel. It would be possible to have the motor steer with the wheel but not go up and down with it. For example, the motor could be sited above the wheel with its shaft vertical, and drive the wheel through a slip-jointed shaft and a ring and pinion.

Finally, I would agree that, in general, compartmentalisation in large companies creates obstacles to innovation.

CONTACT

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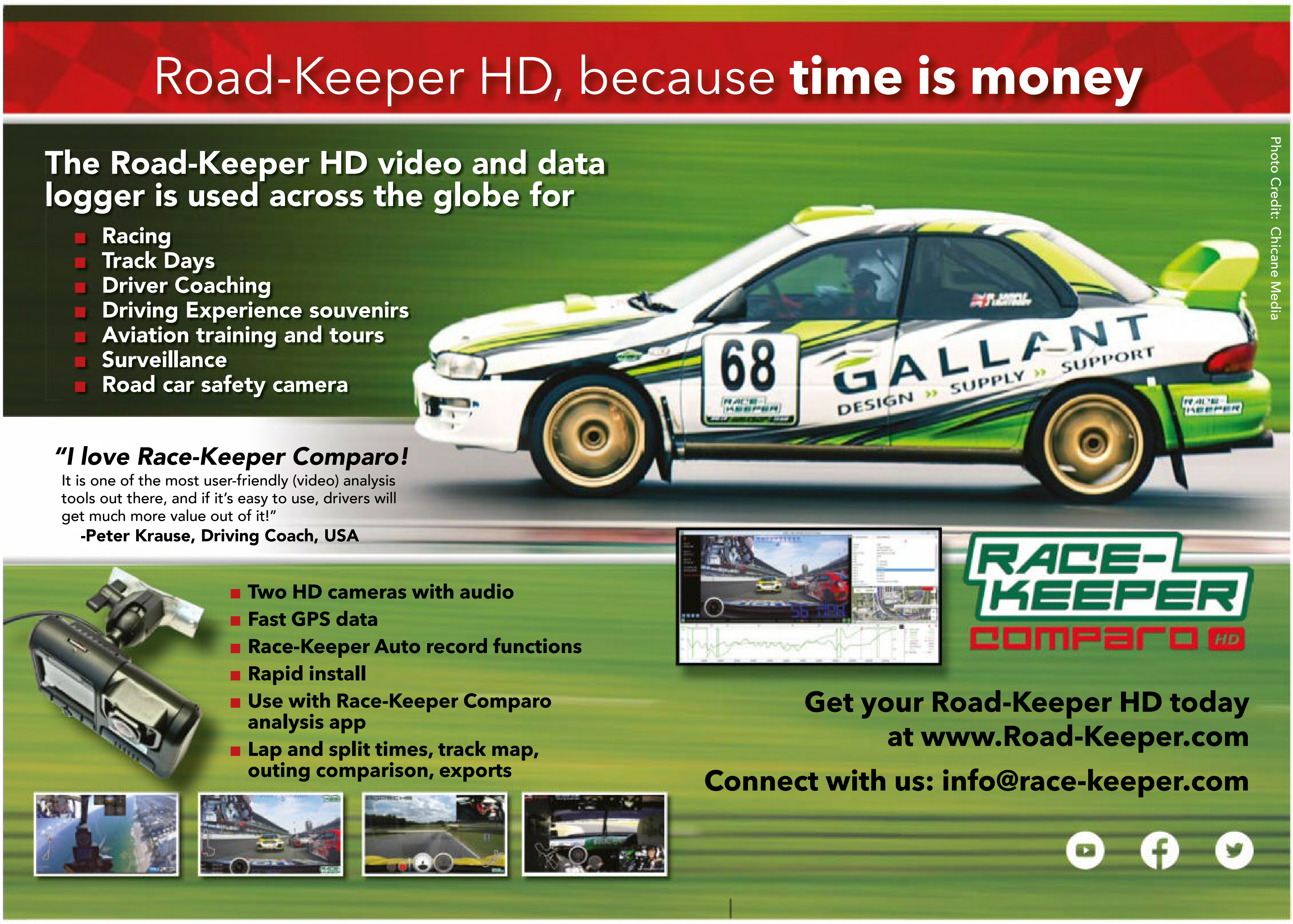
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Fig 1: The Camaro in pre-aero project guise

Daniel Buchi

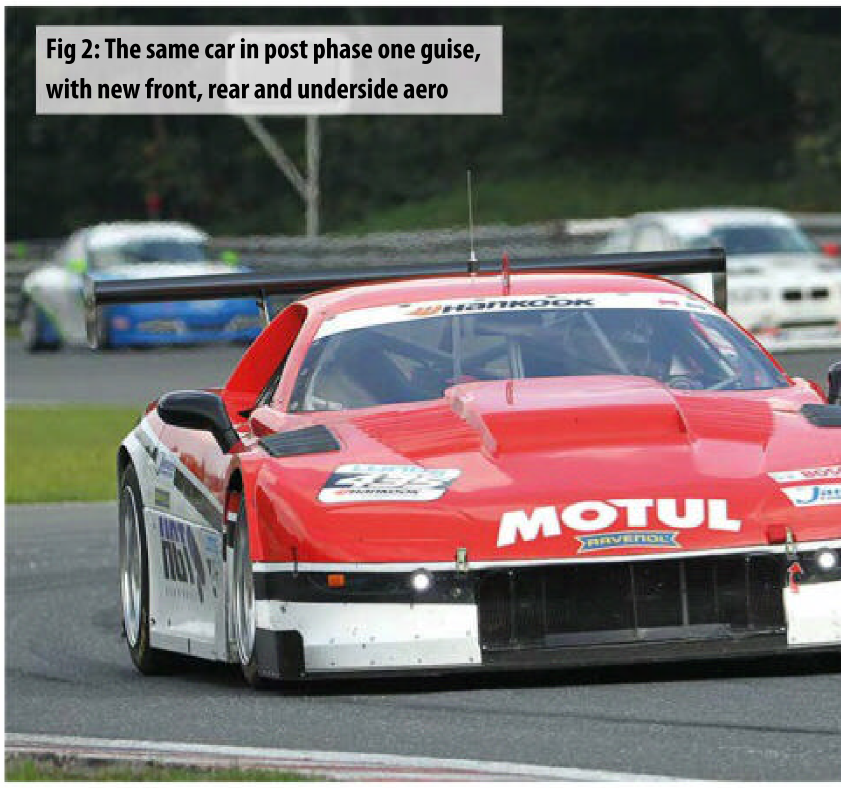


Fig 2: The same car in post phase one guise, with new front, rear and underside aero

Peter Tomschi

Duct taped

With a virtual wind tunnel sitting under the desk, the pandemic provided opportunities for home office projects

By SIMON MCBEATH

Fig 3: Post phase one and leading the field at the Salzburgring

Peter Tomschi

Having ANSYS CFD software and a decent workstation available enabled your fortunate writer to avoid thumb twiddling during lockdown. In this feature, we're going to examine the optimisation of a cooling duct in one recent project.

The 1995 TransAm series Camaro GT1 of Swiss owner / racer, Daniel Buchi, seen in **Figure 1**, is raced in the Histo Cup in Austria, Hungary, Slovakia and Croatia, alongside the very similar car of his friend and colleague, Robert Brandli (although the two race in different classes). My relationship with this team goes back to late 2017 with the supply of new rear wings for both cars and, by early 2018, with ace CAD pilot, James Kmieciak of Black Art Customs, onboard, we were analysing the whole aerodynamics package of both cars using ANSYS CFD.

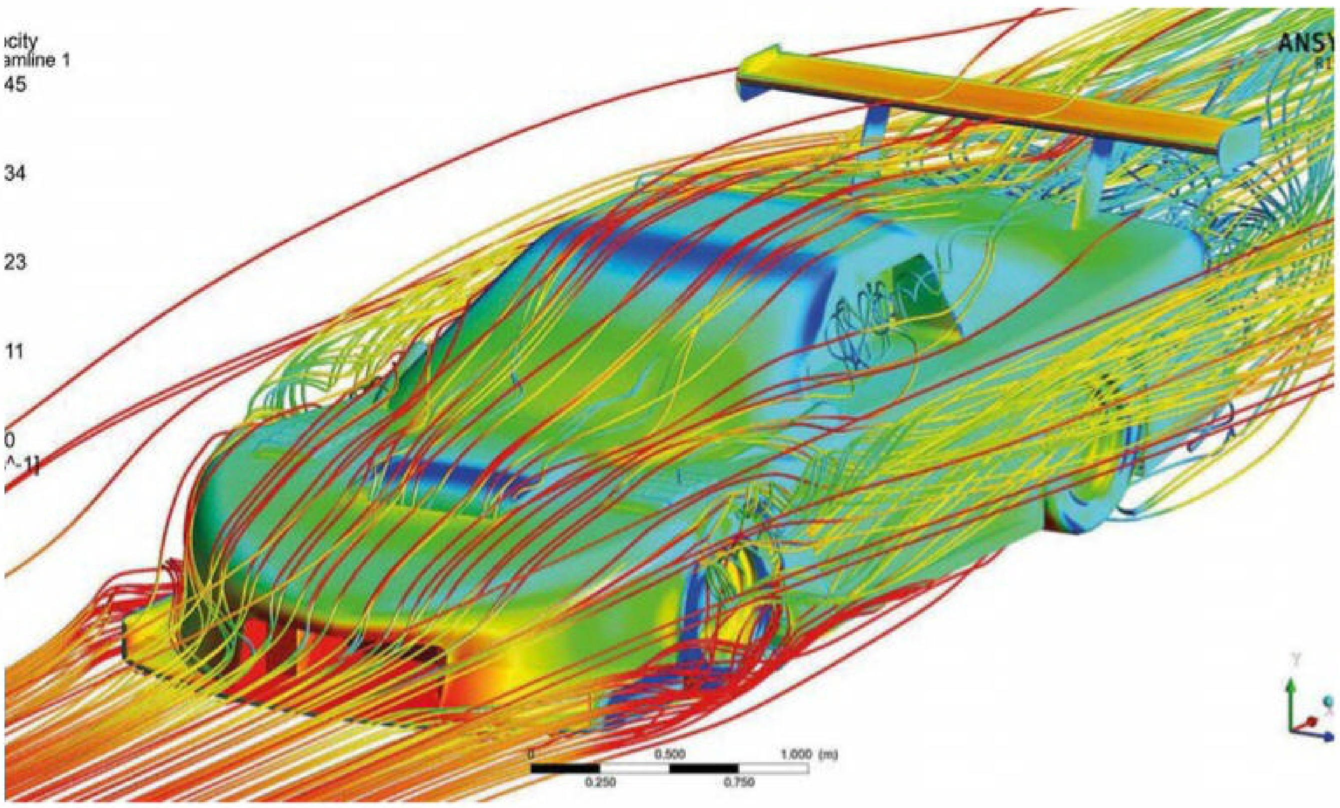
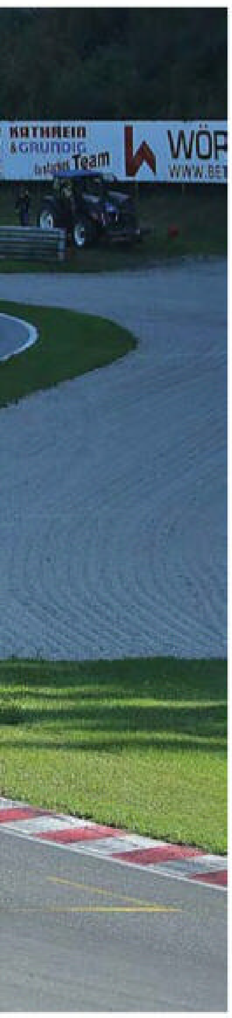


Fig 4: The first phase of CFD analysis on the Camaro led to significant aero gains, and highlighted areas for future work



A simplified but effective 'slotted block' to simulate radiators and other coolers has proven to be efficient in terms of meshing and keeping to sensible solution times in CFD

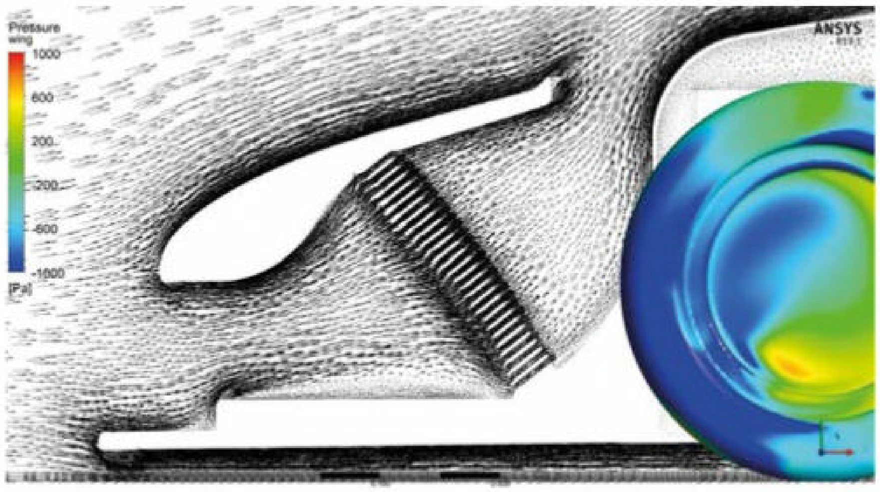


Fig 5: Vector plot on the centreline of the front radiator duct suggested fairly good use of the available radiator area

Images: S. McBeath

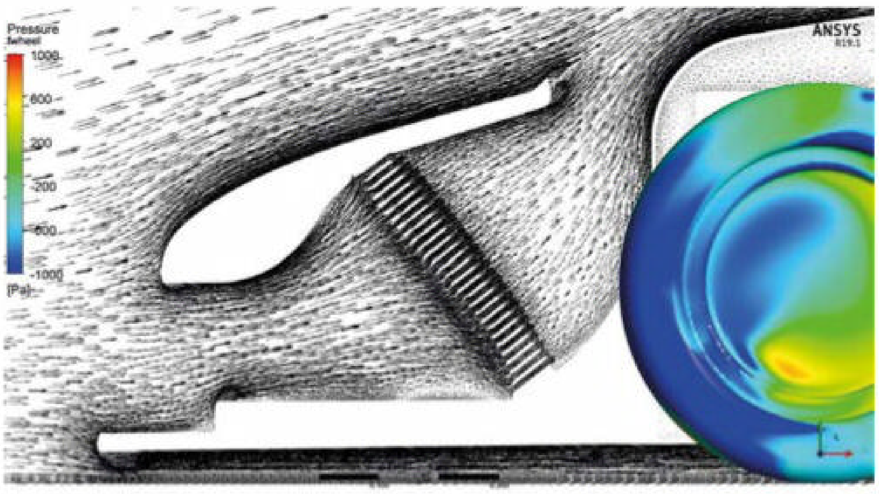


Fig 6: 50mm from the centreline the flows were still good

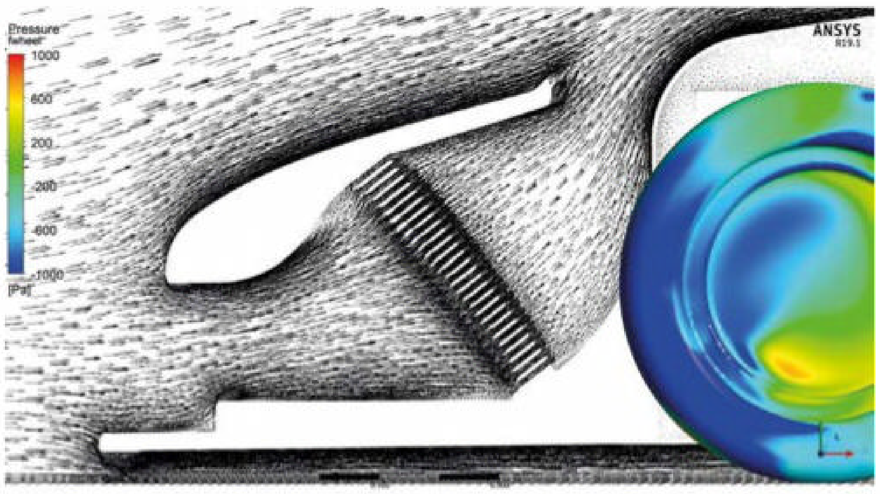


Fig 7: But at 100mm from the centreline, there was the hint of separation in the upper corner in front of the radiator

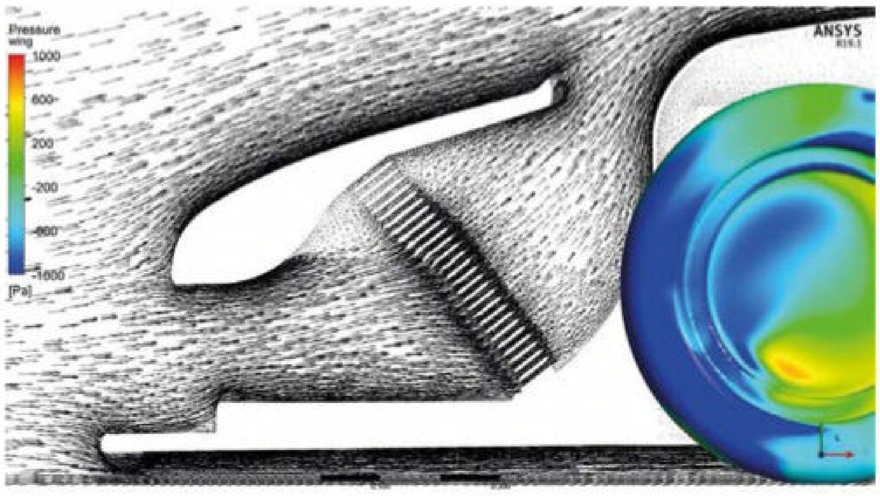


Fig 8: And at 150mm, the separation in the upper corner had fully developed

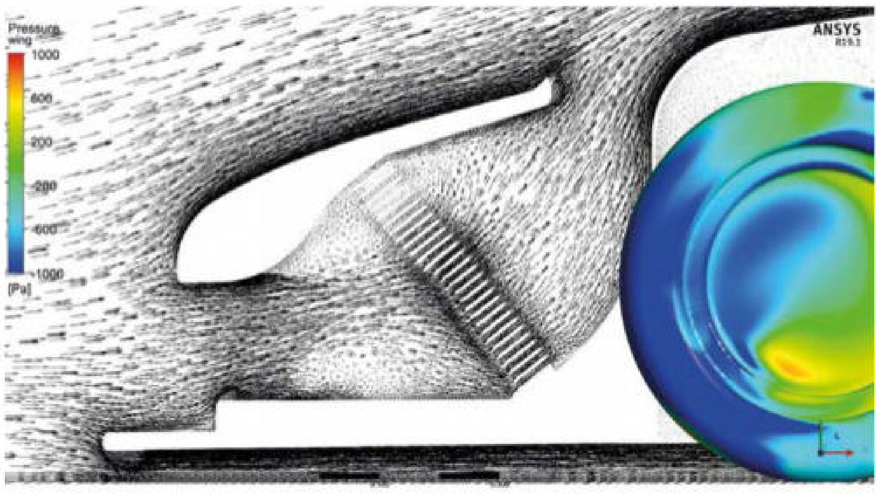


Fig 9: At 200mm, separation in the upper corner was joined by more in the bottom corner, constricting flow to just the centre of the radiator

Briefly summarising that part of the story, the baseline downforce figure with the car's original wing and aerodynamics package was increased by just over 50 per cent with a drag increase of less than 14 per cent, while retaining a good front-to-rear downforce balance. When applied to the actual cars, these aerodynamic changes, along with other over-winter chassis improvements, helped the duo move to the sharp end of the grids in their respective categories with a win and podiums in only their second double header meeting of the season at the Salzburgring (see **Figures 2** and **3**).

Following on from these successes came another phase of analysis and development with improved detailing in key areas around the front of the car, including better simulation of flows through the front-mounted radiator, as shown in **Figure 4**, which led to further aero gains, including optimisation of the cooling duct design.

Cool flow

Intrinsic to the 'reduced detail' CAD model approach employed for our projects, a simplified but effective 'slotted block' to simulate radiators and other coolers has proven to be efficient in terms of meshing and keeping to sensible solution times in CFD. Crucially, it has correlated well with real-time performance on track, as well as in the wind tunnel, too.

In this instance, it made it possible to see in the CFD post-processed output that, although in principle the radiator duct followed the idealised schematic shape in side view section, the radiator area was not being fully utilised because of internal flow separations in the inlet portion of the duct.

To address this, there followed an iterative sequence in which internal radii at the intersections between the roof, side and floor walls of the duct, as well as the external lips around the duct opening, were refined to reduce flow separation within the duct. In turn, this helped improve utilisation of the radiator matrix area.

Turning vanes and vortex generators within the duct were also evaluated.

Looking at the first run in this sequence, **Figures 5** to **9** show velocity vectors in the radiator duct on vertical fore-aft planes at incremental spacing of 50mm, from the centreline to close to the duct sidewall.

In **Figure 5** we can see the flows were attached to the roof of the duct, but that the bluff entry to the bottom of the duct caused flow separation over the floor along the centreline symmetry plane. However, the flow had turned down in time to enter the bottom of the radiator matrix and it appeared that the full height of the radiator matrix was being reasonably effectively utilised. Had not the other plane cuts at 50mm increments been further examined, it might have been assumed from this that the whole duct was working rather effectively.

However, as **Figures 6** to **9** illustrate, this was not the case. The flow was still effective 50mm from the centreline, but at 100mm there were the first signs of flow separation near the duct roof, just ahead of the radiator face. This became more pronounced further from the duct centreline until at 200mm from the centreline in this 450mm wide duct, quite close to the duct sidewall, perhaps less than two thirds of the radiator's height was receiving a decent air feed. The flow was actually *reversed* ahead of the uppermost portion of the radiator.

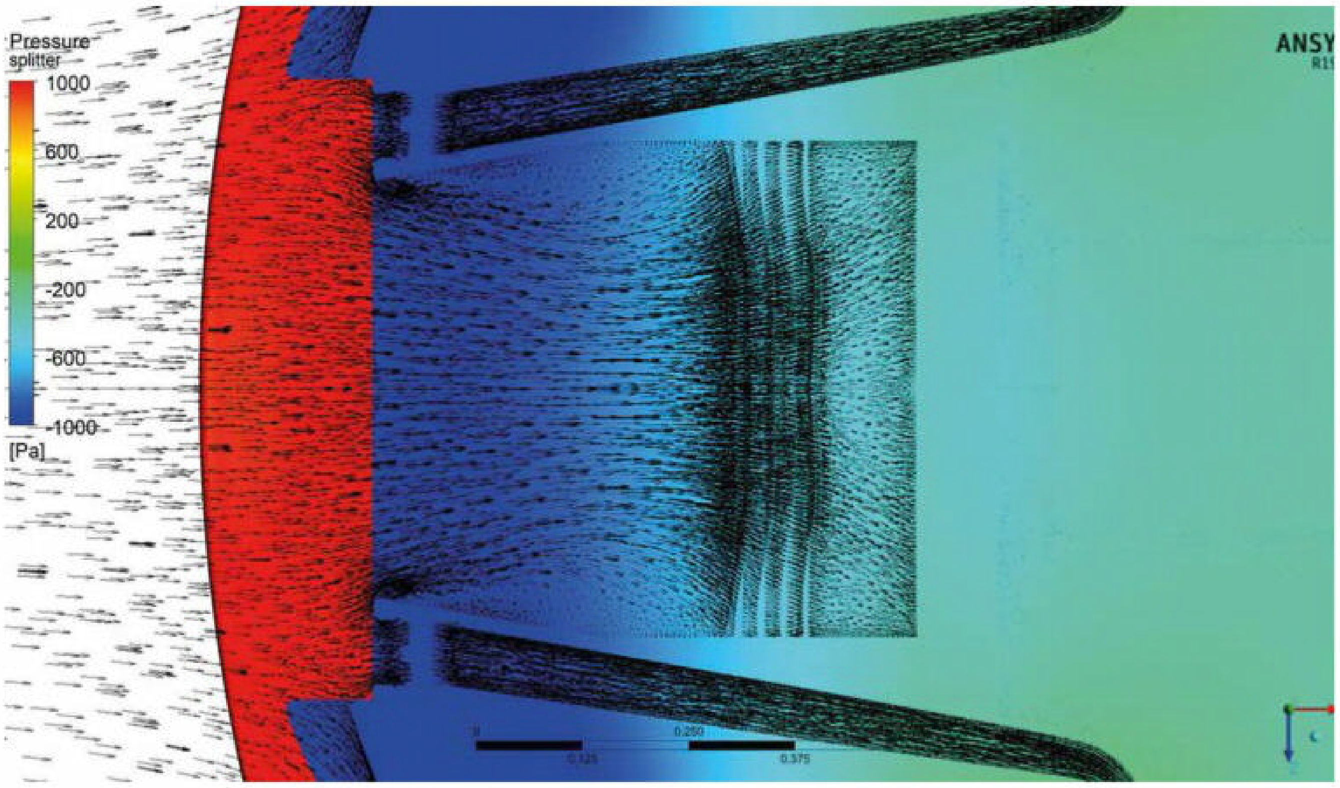


Fig 10: Viewed from above, vectors on a horizontal plane level with the upper brake duct showed the flow separating at the radiator duct inlet and converging from there

Separation anxiety

Looked at the duct from above provides another perspective. **Figure 10** shows a horizontal plane slice through the radiator duct and upper brake cooling ducts, with velocity vectors superimposed. It is very evident here that, instead of the flow gently expanding, slowing and flowing toward the radiator's front face, there was pronounced flow separation at the inlet of the duct, which was causing the flow to constrict.

With velocity mapped onto this same plane in **Figure 11**, it is clear that, rather than the flow slowing down in the inlet duct, it was in fact accelerating because of this convergent flow and entering the central bottom part of the radiator at not much below the car's velocity (160km/h or 44.4m/s).

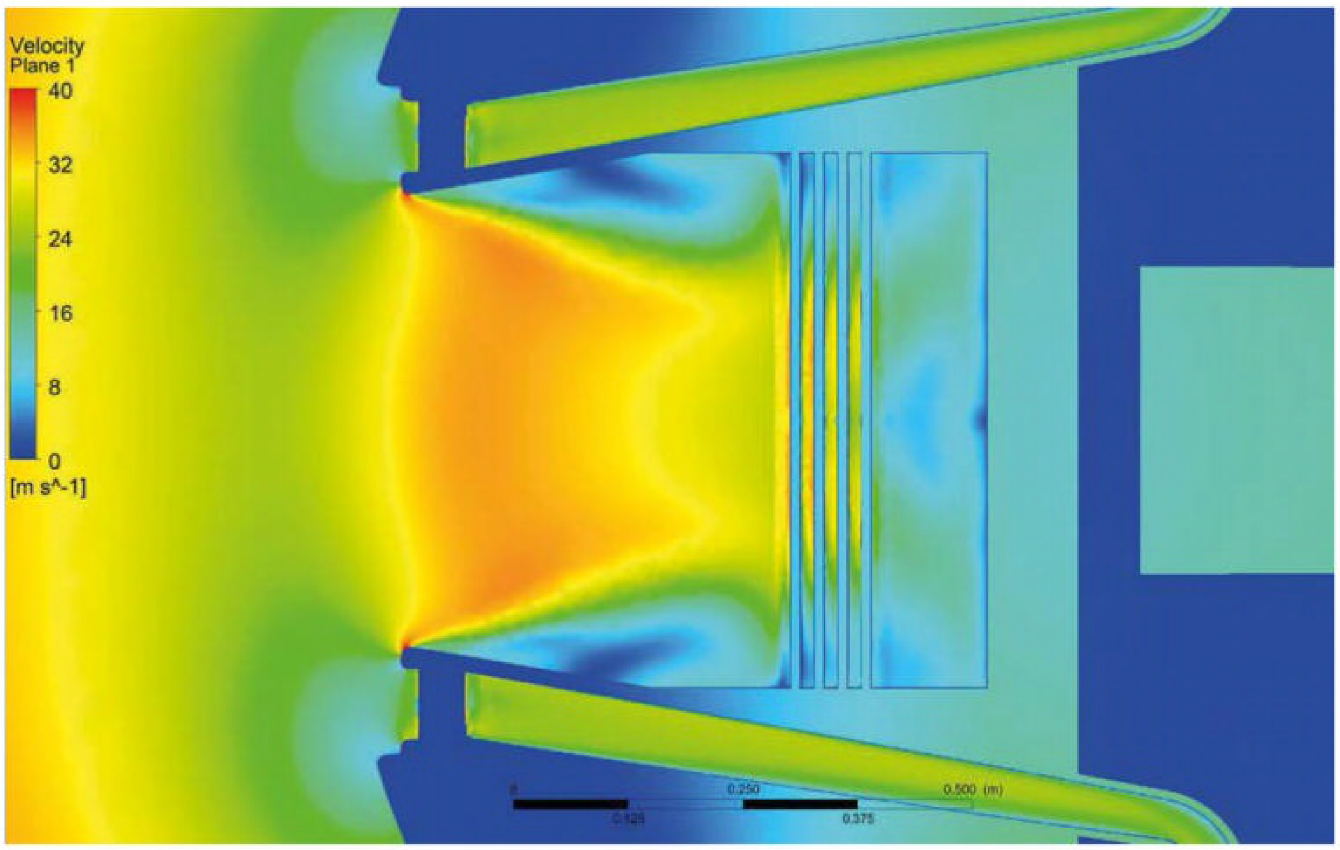


Fig 11: Plotting velocity onto this horizontal plane shows airflow was accelerating in the duct when it should have been decelerating

The objective from here then was to reduce these flow separations and try to ensure maximum utilisation of the radiator's area. With this in mind, the brake ducts, which were originally located within the same wide, recessed duct either side of the radiator inlet, were moved outboard to enable the central duct to feed *just* the radiator, and to allow some optimisation of the duct entry and its internal shape.

After a sequence in which further detail modifications were made to external and internal duct radii, as well as smoothing of the duct floor, most of the flow separations were finally eradicated.

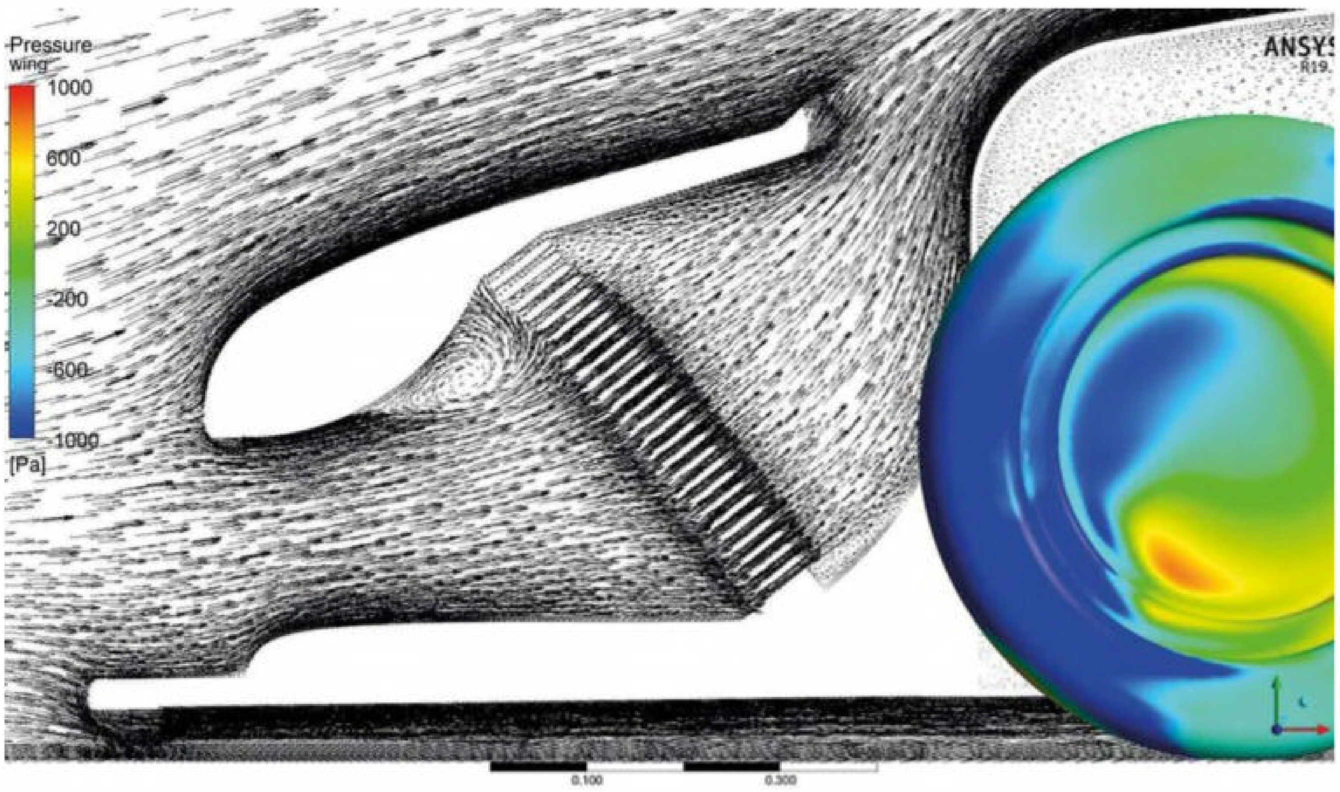


Fig 12: Even after improvements to shape and external and internal radii, there remained a stubborn separation zone in the upper corner of the inlet duct

Stubborn zone

Even then, there remained a stubborn zone from 150mm to 250mm from the centreline in the upper, outer corner of the duct ahead of the radiator face, which was still exhibiting separation and reverse flow, as shown in **Figure 12**. It's clear it was asking a lot for the flow to remain attached in this region where roof curvature was at a maximum and the

boundary layers of the roof and the side were interacting in the adjoining corner.

Vortex generators attached to the roof of the duct shifted these separation zones inboard but did not mitigate or eradicate them. However, a few trials with turning vanes produced an improved solution which, though some flow separation was still evident around the vanes, did enable clean flow through almost the whole radiator matrix, as **Figures 13** to **16** show.

Figure 13 shows the dual-element turning vane that was adopted. A single-element vane was tried first, which eradicated the separation in the duct roof region, but exchanged it for a separation area under the turning vane's own lower surface.

Figure 14 shows an isometric close-up view of the surface pressures around the duct area of the car, with velocity vectors on a horizontal plane across the area showing that the air was going where it was supposed to.

The vectors in **Figure 15** at 250mm from the centreline show that the troublesome separation zone ahead of the top of the radiator had all but been eliminated.

Finally, the velocity plot at this 250mm plane in **Figure 16** indicates velocity across the radiator face is now quite even, considering the upper third of the radiator in this outer region had previously seen almost zero face velocity.

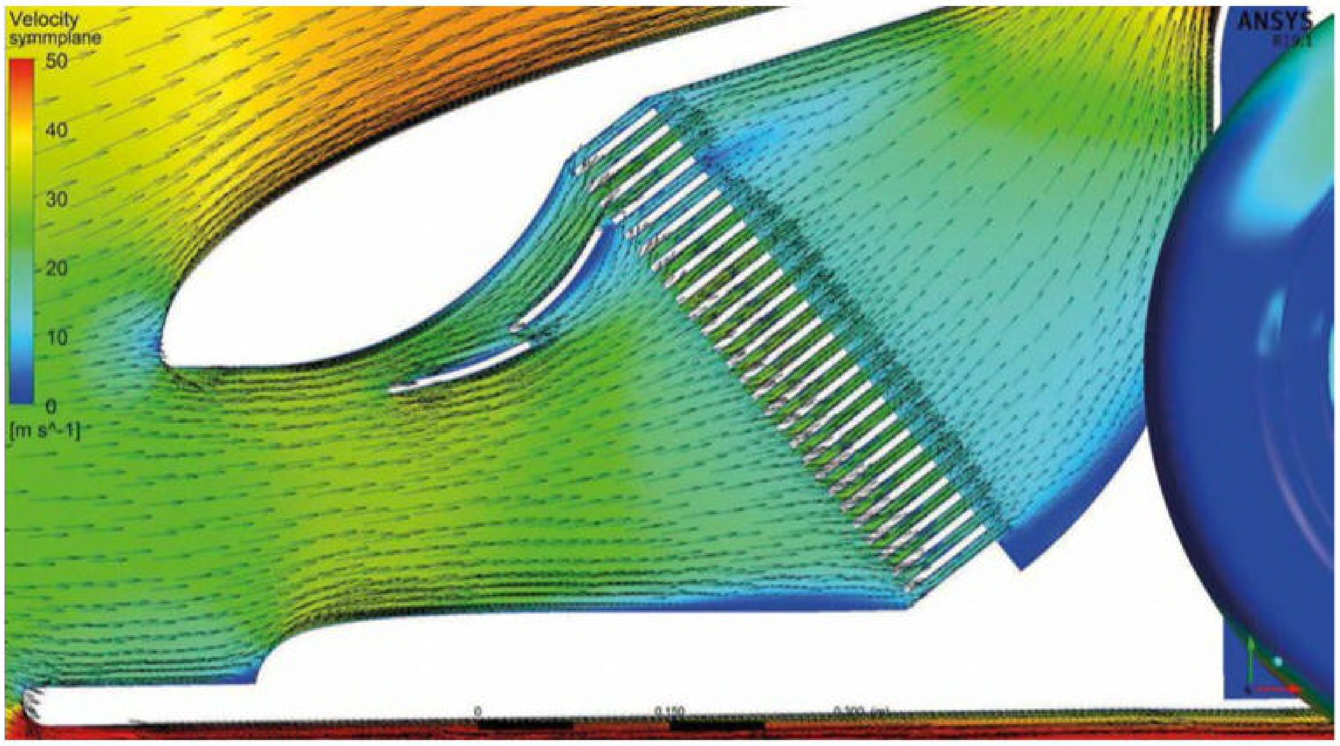


Fig 13: The addition of a dual-element turning vane in the roof of the duct brought significant improvement

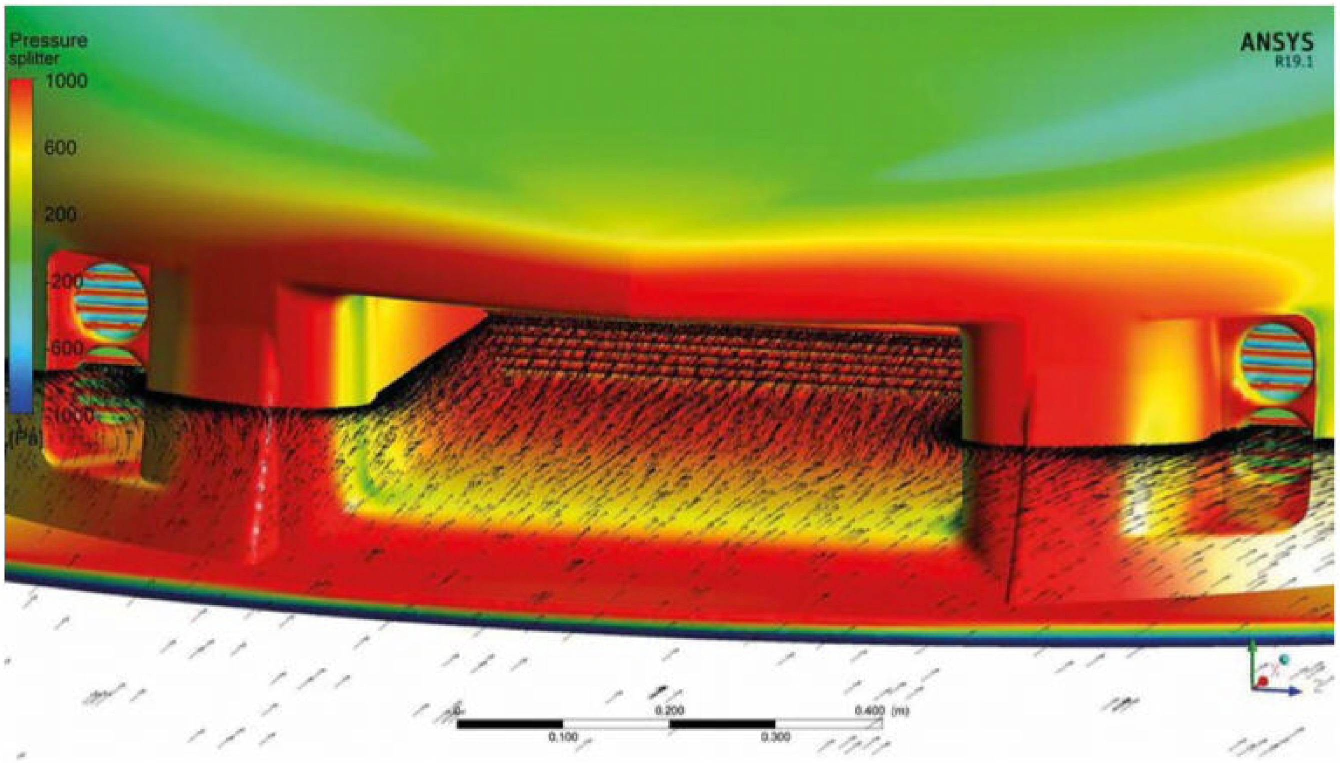


Fig 14: Vectors on a horizontal plane show general flows now going where they should

Diminishing returns

It is probable that, among the now diminishing returns, small improvements could still be made to the profile of the duct roof and the turning vanes, and maybe a smaller radiator could now be used. But at this point a line was drawn, with significant gains having been found using this basic CFD visualisation approach.

As a further bonus, optimising the radiator inlet duct yielded an extra 10 per cent total downforce for just a 1.3 per cent drag increase, and the downforce balance shifted from 43 per cent front to 47 per cent front, which was virtually on target for this car.

Although this exercise was just a small part of the overall project on this Camaro, it's a good example of how qualitative visualisation with CFD enables insights into where things are going right and, sometimes more importantly, wrong so remedial measures can be devised and assessed. A similar approach was also brought to bear on this car's engine inlet system, and we'll delve into that in a future article.

Thanks to ANSYS / CADFEM for support with the CFD software

As a further bonus, optimising the radiator inlet duct yielded an extra 10 per cent total downforce for just a 1.3 per cent drag increase

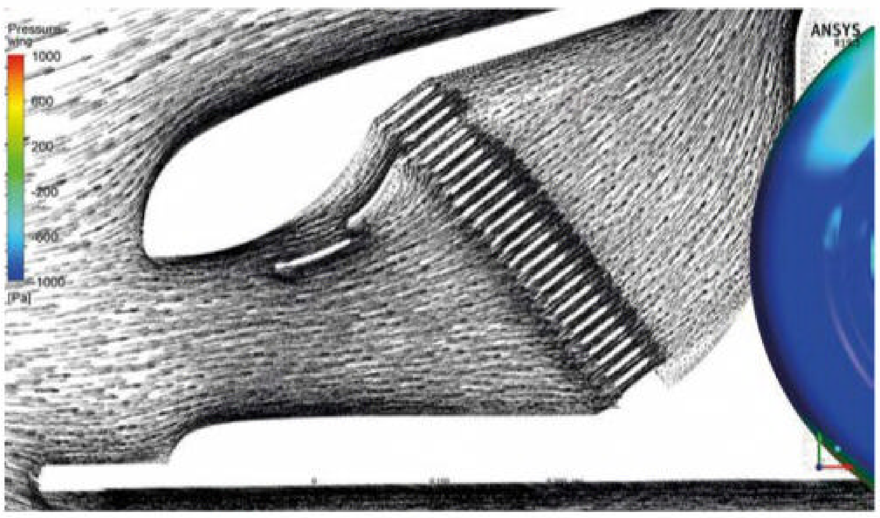


Fig 15: Now, at 250mm from the centreline, flow separation had been near eliminated

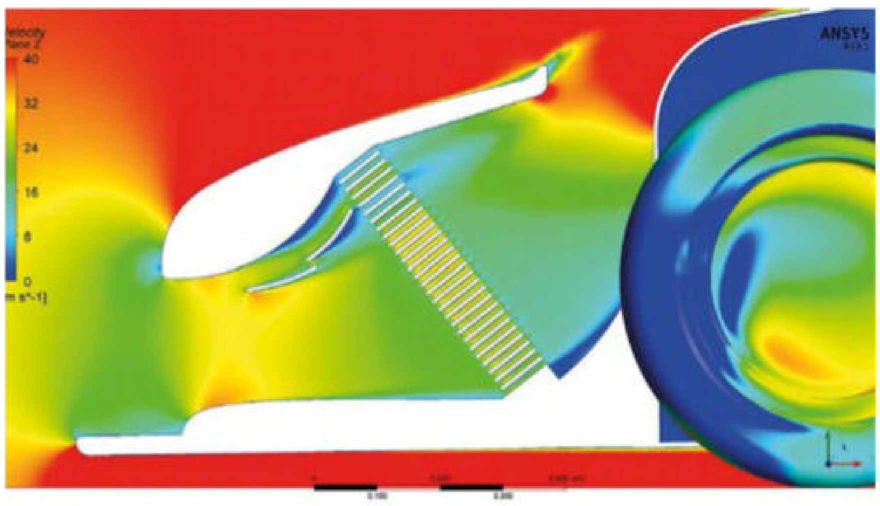


Fig 16: Velocities at the radiator face, at 250mm from centreline, are now fairly even

Rubber rings

In the first of three articles on tyre modelling, we focus on how tyres are tested and data collected and manipulated to generate models that can be used in different environments

By ANDREA QUINTARELLI

Explaining vehicle dynamics, the handling and performance of a racecar, is impossible without mentioning the role of tyres. The four rubber rings provide the point of contact between cars and road and, consequently, *every* motion a vehicle experiences is related to the forces the tyres exchange with the ground.

Unfortunately, tyres are probably the most complex subsystem of a racecar, and one of the few components that are not completely understood. It is a multi-disciplinary field of study, with the different materials employed in their construction leading to very different interactions with the track, and alternative behaviour within the tyre itself.

For a long time, knowledge about tyres was very poor, and mainly based on an empirical approach, at least for those that actually *use* the tyres, including race engineers. This is partially still the case in the lower stages of the motorsport ladder, where small teams have restricted resources. Even if they could, they would likely invest in more track days instead of modelling to better understand tyre behaviour.

This culture seems to have changed at higher levels in motorsport, though, where serious organisations understand how important a solid knowledge of tyres is, and how much a team can gain in terms of performance with good data and effective models that can help them to predict and improve their exploitation of the tyres. Moreover, tyre manufacturers now provide at least some kind of data to the teams, helping them kick off their analysis and simulations. In this first instalment of a series of three

High-downforce cars run very stiff suspensions and tyres can experience a bigger vertical deflection than the suspension itself

***Every* motion a vehicle experiences is related to the forces the tyres exchange with the ground**

Vertical stiffness is linked to a tyre's structural behaviour, and to the shape and dimensions of the contact patch, under different loading conditions

articles, the most common technologies and methods for tyre testing and analysis will be reviewed. In subsequent articles, a more innovative approach developed by a young start-up will be analysed, to understand what it does differently and how it can help better understand tyre behaviour. The end goal of which, of course, is to make racecars faster.

What to measure?

Pneumatic tyres have always performed an array of functions in a racecar. Ideally, a development and race engineer would love to have data about how a tyre fulfils each of them, and this is indeed the goal of tyre testing.

Before even considering how forces are exchanged with the road, tyres can be assimilated to a vertical spring that deflects under vertical load and whose stiffness changes depending on inflating pressure, inclination angle and rotational speed.

The vertical stiffness of a tyre is particularly important in high-downforce cars. Due to platform control and aero optimisation, high-downforce cars run very stiff suspensions and tyres can experience a bigger vertical deflection than the suspension itself.

A tyre's vertical compliance also influences the car's overall roll stiffness and lateral load transfer distribution, both very effective tuning aids with respect to vehicle balance. Its effects are also incorporated in other characteristics, and those measurements will be described later on, because vertical stiffness is linked to a tyre's structural behaviour, and to the shape and dimensions of the contact patch, under different loading conditions.

Fortunately, vertical stiffness can often be measured with the same machines used to identify forces and moments exchanged with the road, which are the variables more closely linked to tyre and car performance. This is done by measuring the distance between the wheel centre and the road plane, under a certain load, with a specific inclination angle, at a defined speed and inflation pressure.

The most interesting metrics are lateral and longitudinal forces, because these are the forces the tyres exchange with the road to accelerate, brake and turn. Tyre forces are linked to many parameters with regards to vertical stiffness, but the following also play a role:

- **Vertical load**
  Normally, the higher the vertical load, the bigger the planar forces a tyre can exchange with the road. The friction coefficient, expressed as the ratio between lateral or longitudinal force and the vertical load acting on the tyre, decreases with load. In other words, even if planar forces increase with load, they do so at a progressively slower rate as the load itself increases.
- **Slip**
  For a given vertical load, the magnitude of lateral and longitudinal forces depends respectively on slip angle (lateral slip) and slip ratio (longitudinal slip).
  The slip angle is the angle between the rim middle plane (in a car normally defined by the steering angle applied by the driver at the front, while it is about constant at the rear) and the effective

Tyre manufacturers supply some data to teams, which is useful to begin analysis and simulation but really it is just a starting point for tyre modelling direction the tyres follow. Due to the distortion of their structure under external actions, the effective heading direction is different compared to the desired one, because the contact patch is subject to a torsion and the difference between the two is the slip angle. This causes local slippage at the contact patch and the bigger the area interested by slippage, the closer the tyre is to its peak force. The slip ratio is linked to the ratio between wheel centre speed and contact patch velocity. Again, forces acting on the tyres leads to a deformation and local slippage of the contact patch, so that its effective speed is different compared to that of the wheel centre.

- **Inclination angle**
  The angle between the tyre and the road influences the size and form of the contact patch, and therefore the magnitude of the forces the tyre can produce. In the racecar world, this is often named camber and is intended as the front view angle between the tyre and the longitudinal middle plane of the car.
- **Inflating pressure**
  The pressure of the air used to fill the tyre volume. It affects different, performance-critical parameters like vertical stiffness, as discussed, but also what happens at the contact patch, so grip, cornering stiffness, the shape of the force, slip curve and more.

The magnitude of all tyre forces is also strongly influenced by temperature, as compounds used for tyre constructions are viscoelastic materials whose properties changes significantly depending on this parameter. Very complex phenomena are linked to surface and inner tyre temperatures. Interestingly, this is something that is normally measured, but not really controlled during testing.

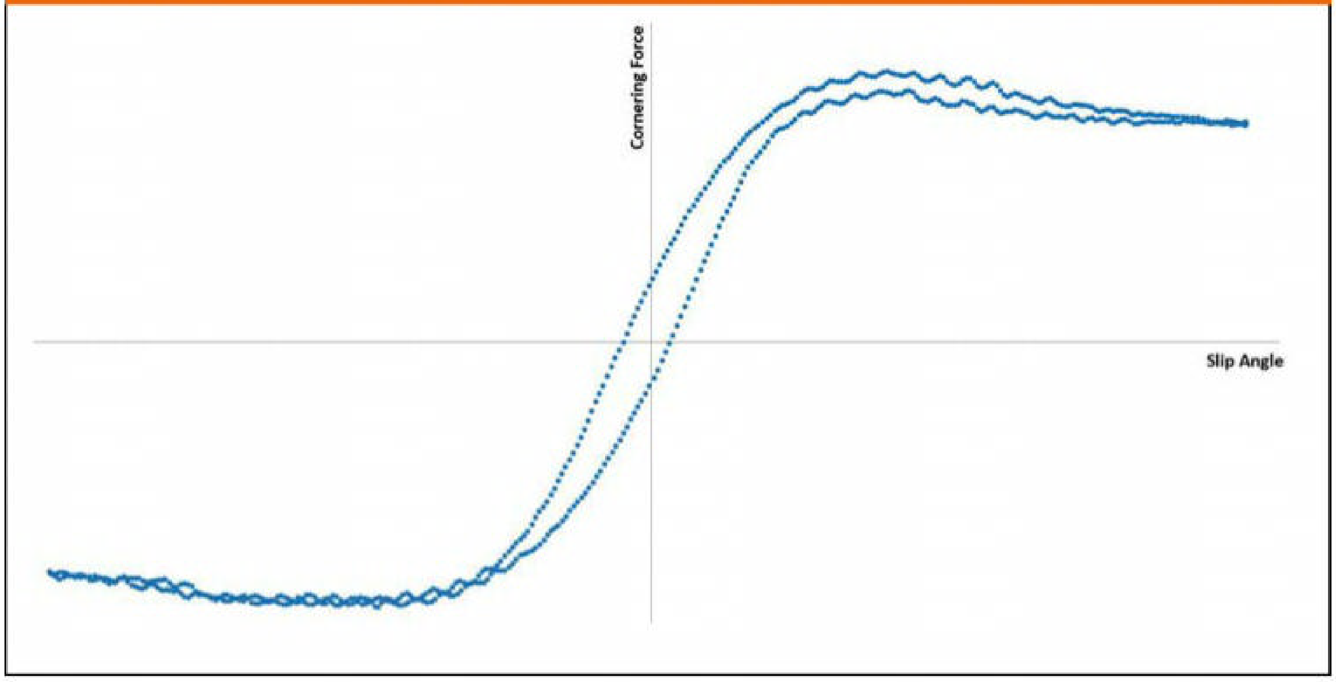
Test procedures

With respect to tyre testing, typical equipment usually includes sensors that measure tyre as well as ambient temperature and, sometimes, road / testing surface temperature, too. This data can then be used during the post-processing phase, but there are no publicly available standards for this.

One possible way of presenting tyre data is in the form of plots (slip curves) where the slip factor (slip angle or slip ratio) is on the horizontal axis and force is on the vertical one. Each tyre manufacturer has its own testing procedures. They are a very important part of the company's knowledge and consequently are not normally shared.

Depending on test equipment and procedures, one approach to testing tyres is to set the vertical load, inclination angle

Fig 1: Example of a measured cornering force vs slip angle curve. Data collected by applying a sweep of slip angles



and inflation pressure, and then keep them constant, applying sweeps of slip ratio or slip angle inside a given range and measuring the forces produced by the tyres. The results would look something like the plot in **Figure 1**, which shows the raw data collected during one such sweep.

An interesting point here is how the measured force follows different paths when going from the minimum to the maximum slip angle, compared to what happens on the way back. This sort of hysteretic effect can be linked to temperature variation during the test, or to transients or relaxation phenomena, should the sweep have been applied too quickly.

> **Among the biggest advantages of indoor testing are repeatability, the relative ease of installing sensors and controlling systems (if necessary), and well definable testing ranges**

Indoor testing

Conventional tyre testing can be divided into two big groups: indoor and outdoor testing.

Indoor testing is generally performed using laboratory-based machines that allow engineers to characterise tyres in a well-controlled manner. Because data is collected in a protected environment and testing devices are equipped with sensors and control systems, key variables can be kept within a specified range.

Among the biggest advantages of indoor testing are repeatability, the relative ease of installing sensors and controlling systems (if necessary), and well definable testing ranges.

On the other hand, indoor testing requires big, complex and expensive testing devices. This is why this kind of test is generally only performed by big companies or by dedicated testing centres that offer measurement services to customers.

Regardless of the test machine's architecture, these devices cannot employ tarmac as the surface with which the tyre interacts, so instead use something similar to sandpaper. In other words, despite offering high repeatability and control, the results can be very different to the forces a tyre exchanges with a real track. Data must therefore be manipulated to use it for performance prediction. However, since general trends are normally well represented, reliable information can still be extracted after data from this process has been manipulated.

The architecture of these machine dictates the material they need to employ as the test surface. Where normally a tyre would roll on a surface, in lab testing the tyres are attached to the test machine while the 'road' underneath moves. Tests are performed on a belt, sometimes called an F&M bench, where the F and M refer to force and moment. **Figure 2** is an example. The belt is tensioned and driven by two very big, steel wheels, or on a big drum.

Different surfaces with different grip can be employed as desired, the speed of the 'road' controlled, and the test area is usually temperature controlled, too.

The tyre / wheel assembly is mounted to a balance that contains the force and moment measuring electronics. It is also connected to a large motor that can drive the wheel, as well as a powerful disc brake system, for longitudinal slip testing. Lateral forces and moments are normally measured with tests where the wheel is free rolling instead.

Combined grip tests (combinations of slip angle and slip ratio applied) are also possible.

The other main form of data capture is outdoor testing. As the name suggests, these occur in a real-world environment, and any such tests performed outside cannot take advantage of such well-controlled conditions as those in a test laboratory. These tests are normally done using a trailer or a truck, similar to that shown in **Figure 3**, inside which the equipment used for measuring and controlling is mounted. This includes the structure holding the wheel, sensors, the electric motors to steer the tyre and the brake system to generate longitudinal slip. From a theoretical perspective, this kind of testing, and what is performed on a flat track machine are very similar, with the obvious exception being in this case the tyres roll on a real road.

Outdoor approach

This is the main advantages of this approach though. The tyres interact with real tarmac, offering more *realistic* results compared to laboratory testing.

On the other hand, repeatability is lower, both because ambient and road conditions are difficult to control, and because of limitations related to the measuring hardware. For example, it is hard to replicate very fast manoeuvres, apply high vertical loads or big inclination angles.

Another possible solution for outdoor testing is to instrument a real car with wheel force transducers and optical slip sensors.

Wheel force transducers are basically big strain gauges that measure forces and moments acting on the wheel. Slip sensors, on the other hand, are devices that can identify the real speed vector of a point of the car (for example, on one wheel) with respect to the ground. This means these sensors can detect both longitudinal and lateral speed components, allowing a measure of the slip angle.

Some systems employ one slip sensor per wheel, others only one for the whole car. In the latter case, single wheel slip angles are derived using rigid body assumptions and other measured metrics, like yaw rate.

The main advantages and disadvantages are the same as using trailers or trucks.

One addition in the disadvantages list is that this method introduces additional inertia into the wheel system, which probably has an effect on results. Another significant disadvantage is cost. The sensors are expensive, and the required investment could be compared to the cost of a racecar.

Experts in this field also mention how sensor calibration tends to drift in time, so this requires additional maintenance to keep that aspect under control.

On the plus side, this approach allows engineers to combine drivers' subjective

Fig 2: Example of an F&M (force and moment) indoor tyre testing machine, where the simulated 'road' moves beneath the tyre

IKA RWTH Aachen University. www.ika.rwth-aachen.de

Fig 3: Example of outdoor tyre testing equipment where the tyre rolls on an actual road surface, seen here on this articulated truck rig from the Institute for Automotive Engineering (ika) at RWTH Aachen University. Both methods have their advantages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feedback with objective data. In other words, to use the real car as a test bench, and measure forces using either real, track-like manoeuvres or standard tests.

Figure 4 shows an example of how such an instrumented car might look.

Tyre models

As briefly shown in **Figure 1**, the data then collected with one of the mentioned methods is basically a cloud of points that output values of forces or moments, with respect to load, inclination angle, slip angle and slip ratio.

Beside a general understanding of how the tested tyre behaves, data in this form is not really useable to complete engineering tasks, so a common practice is to fit it into a tyre model.

A tyre model is a mathematical formulation that allows one to associate a single value of lateral force, longitudinal force or self-aligning torque for each set of values of vertical load, inclination angle and slip (and, in more advanced models, further parameters such as inflating pressure). This was not the case for the plot shown in **Figure 1**, where the acquired results of a slip angle sweeps were illustrated. For a given slip angle value, at least two different cornering forces were measured, one while increasing the slip angle on the testing machine, one while decreasing it.

One of the most widespread approaches with respect to tyre modelling is named after Professor Hans Pacejka, and is often referred to as Magic Formula. What Pacejka developed was an equation whose structure has no particular physical behaviour, but fits very well to data collected for very different tyres. The basic structure of the equation is:

$$Y=B\cdot D\cdot \sin(C\cdot \arctan\{Bx-E[Bx-\arctan(Bx)]\})$$

where B, C, D and E are fitting constants and y is a force or moment resulting from a slip parameter x.

Figure 5 shows some slip curves plotted using Pacejka Magic Formula MF5.2, for different loads. The cornering force is on the vertical axis, while the slip angle is on the horizontal one.

For any given load, there is a unique cornering force for each slip angle value.

The latest versions of Pacejka's model also incorporates tyre pressure as one of the possible user inputs. As discussed, pressure is normally kept constant during a test and tyres can be tested at different pressures to isolate the effects of this parameter.

One of the biggest advantages of the Pacejka approach is the relatively low computational effort required by this formulation, which makes it particularly effective for simulation usage. Beside this, it has proved to fit reasonably well to measured data over the years, which is why it has become a kind of standard in the industry.

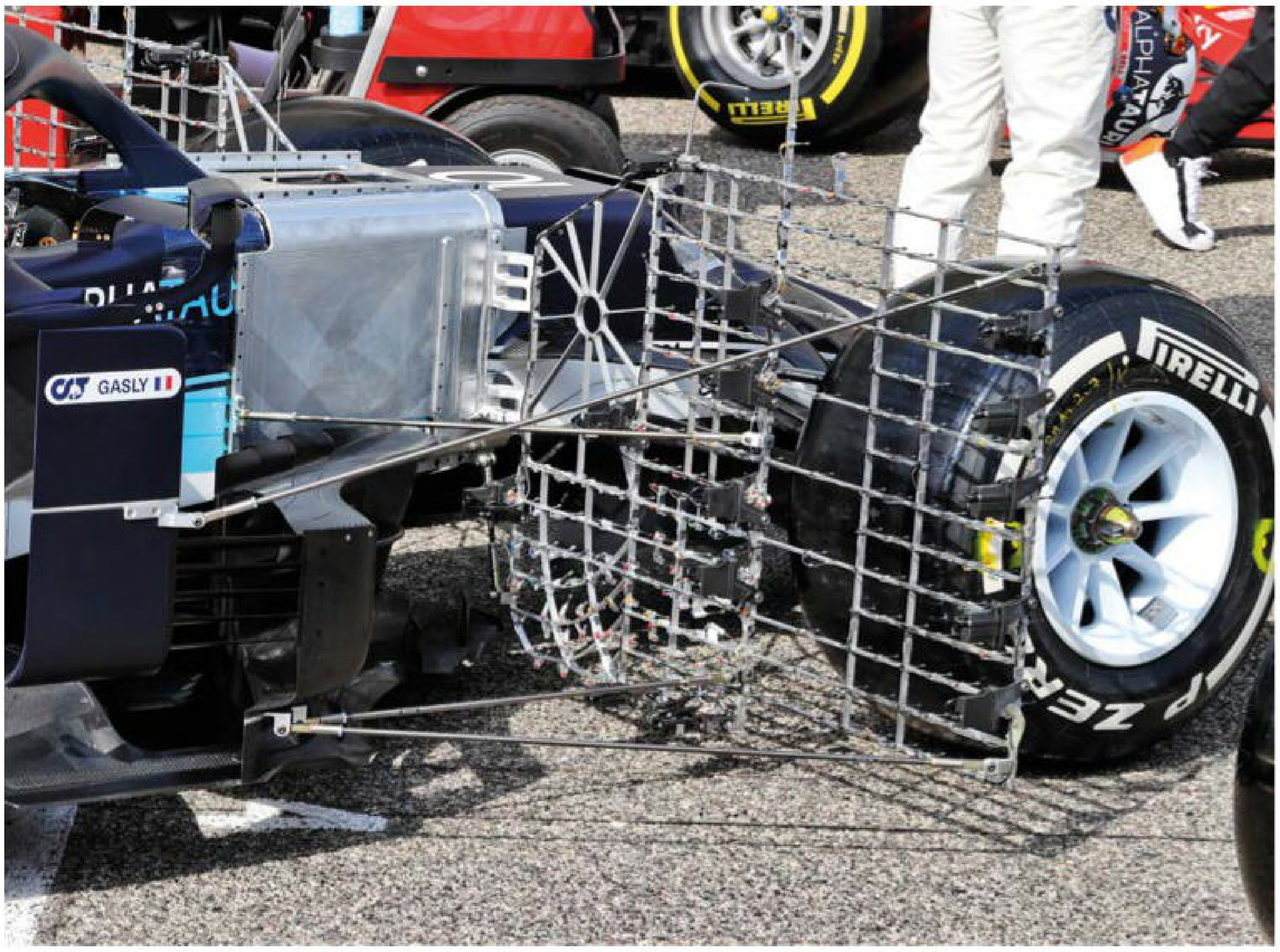
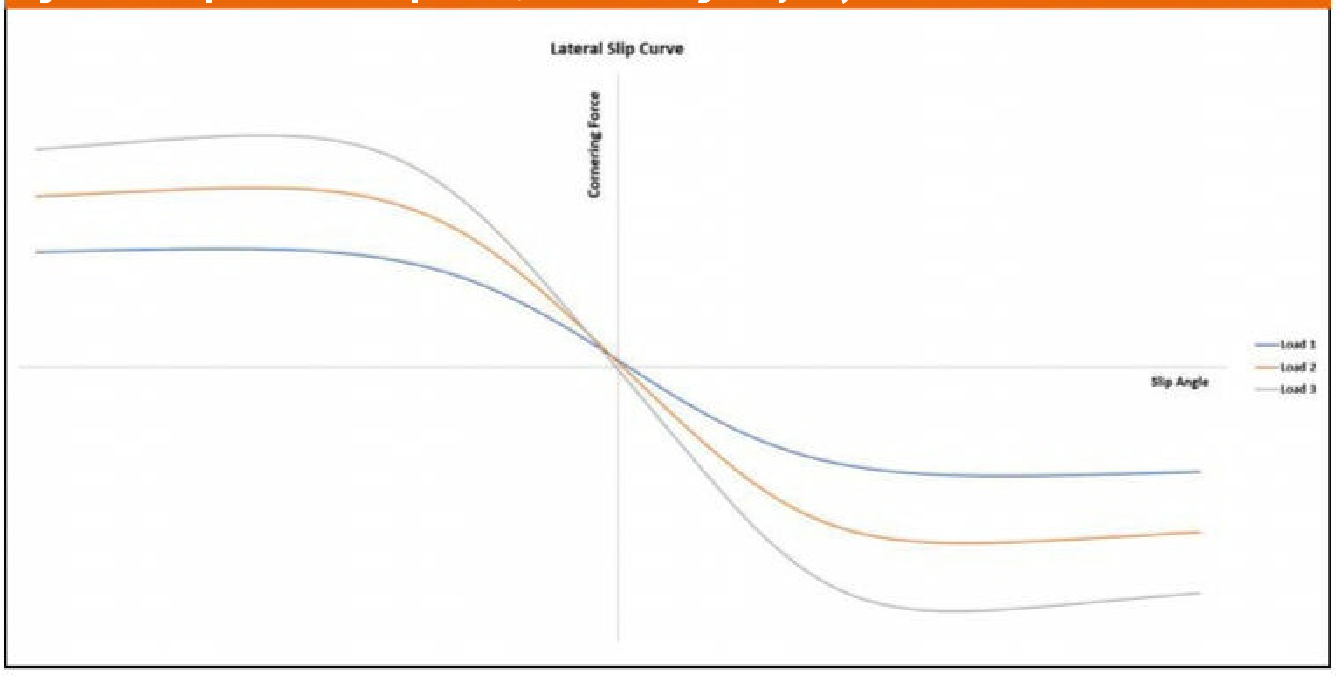


Fig 4: An example of a racecar instrumented with wheel force transducers and optical slip angle sensors

Fig 5: An example of lateral slip curves, derived using Pacejka tyre model MF5.2



However, as the astute reader probably noticed already, temperature is not a parameter for this model, neither as an input or output. This is an acceptable limitation for many applications in the automotive industry, but racecar tyres are *very* sensitive to temperature and, at high-level motorsport, a deeper comprehension of thermal and thermodynamical phenomena can make a big difference.

At high-level motorsport, a deeper comprehension of thermal and thermodynamical phenomena can make a big difference

Some more complex models do exist that allow us to analyse other areas of tyre behaviour, but they are generally more computationally expensive, and often not suitable for real time applications, like Driver-in-the-Loop simulations. With this in mind, an Italian start-up named MegaRide has developed a different approach to both tyre testing and modelling, with particular focus on the understanding of thermal and wear effects. It still uses Pacejka's work as a base for its advanced models and the methods used will be the topic of next month's article.

The message here is that no method of tyre testing or modelling is perfect, and the choice depends on the targeted application, on the project itself and on the available time and resources.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Buckell up

There are few in the British Touring Car Championship paddock as experienced as Steve Buckell, but what exactly is the West Surrey Racing chief mechanic's role?

By MIKE BRESLIN

It's the first of the three British Touring Car races of the day at Oulton Park at the beginning of August. The West Surrey Racing (WSR)-run BMW 330i M Sport of Tom Oliphant is tapped into a spin by a rival car at Lodge Corner, and then collected by another as it lies prone across the track. It receives two crunching hits, one to the back and one to the driver's side. In the words of the team's chief mechanic, Steve Buckell, the rear end is 'under the windscreen'.

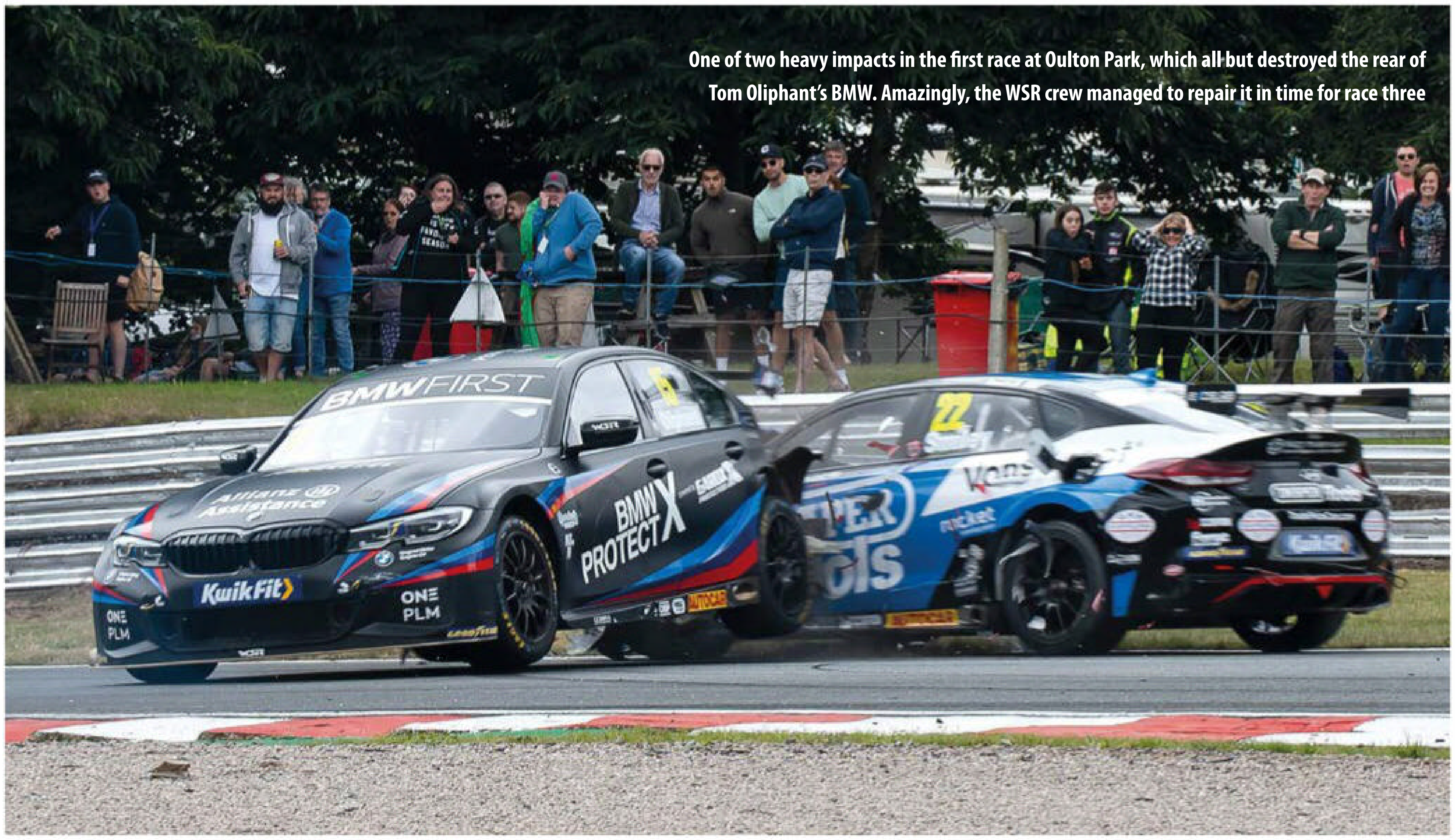
If this was a road car, it would be heading for the scrapyard, no question. But this is the BTCC, and this is WSR. There's about two hours until race two, and it's impossible to make the required repairs in time for that, but four hours before the final race of the day, and the car missing two races is simply not an option.

This is the time when a BTCC chief mechanic really needs to take control. Buckell did so and, remarkably, and thanks also to help from chassis specialist, Willie Poole Motorsport, the car was back out for the last race of the day, where

West Surrey Racing's chief mechanic, Steve Buckell, (left) has been with the team since 1989

If I'm running around panicking, then everyone else is running around panicking

Bresmedia



One of two heavy impacts in the first race at Oulton Park, which all but destroyed the rear of Tom Oliphant's BMW. Amazingly, the WSR crew managed to repair it in time for race three

BTCC

Oliphant fought back from the back of the grid to a creditable 14th position.

It was an extraordinary turnaround, given the severity of the shunt, but for WSR's chief mechanic it was largely all about keeping calm. 'If I'm running around panicking, then everyone else is running around panicking,' says Buckell. 'But I'm relaxed, mainly because I trust the people we have working for us. Every person out there has a role to play. In this kind of situation, everyone knows their place, and everyone helps out, I just oversee it all.'

It's a part of the job he doesn't wish for, but relishes when it happens. 'Of course, you never want these things to happen, but when they do there's a certain amount of adrenalin,' he says. 'You do enjoy it, even if the car has been crashed on the Saturday and you need to work into the early hours of Sunday to get it ready for the races.

'If you don't like working in this sort of environment, you're in the wrong job.'

Crisis management

Buckell also has his experience to fall back on, when it comes to dealing with a crisis. 'I've been in racing for so many years, and during that time there have been so many accidents and problems to fix and solve, I'm just used to it.'

Indeed, his motorsport career started in the 1980s, when he became involved with Ronnie Grant Racing – a privateer Formula 3 effort – while still working as a garage mechanic in Clapham, south London. From there, he moved on to West Surrey Racing in 1989 and, a brief sabbatical aside, has been there ever since. In that time, he's worked as number one mechanic for drivers such as Mika Hakkinen and Rubens Barrichello while the team was in F3, and then on the BTCC programmes since 1996 (see box out on p62).

He's held a variety of roles in the series, including transmission technician during the Super Touring era, before taking on the job of chief mechanic at the start of WSR's MG / Rover BTCC programme 20 years ago.

Multi-talented

Perhaps because he has been with the team for so many years, and has taken responsibility for so many things over time, Buckell's role is not as well defined as it might be, though in a nutshell he describes it as: 'I'm in charge of anything mechanical. I oversee the work on all three cars. Anyone on the shop floor, they're all experienced, but they will come to me if there's anything they're concerned about.

'I'm not on a car, so I don't spanner a car, but I still do a lot of hands-on work. I fabricate, machine, I build the dampers, dyno the dampers, and I do the electrics, making sensors and doing the wiring. Right now [during *Racecar*'s visit to WSR's Sunbury-on-Thames HQ] I'm fabricating doors and welding exhausts up, for example.'

He concedes that chief mechanics on other BTCC teams might not have such a broad job description, though. 'I think I have more hats than most, but I like to do a bit of everything. I love the variety of my job, and I suppose that's why I've never bothered to do anything else, really.'

Repeat business

When it comes to overseeing the day-to-day work at WSR, there's a certain pattern, which might be expressed as: race, strip down, assemble, race, repeat. 'After we've run the cars, each one of them gets stripped down and checked. I don't know if every team does that. If you go out to the shop floor now, the subframes are out, and it's all just starting to go back together to be ready for the next race.'

I love the variety of my job, and I suppose that's why I've never bothered to do anything else

The two subframes are controlled TOCA parts in the BTCC, incorporating controlled suspension, brakes and transmission, with the front subframe attached to specified rollcage locations. The 'cage itself is designed in house by WSR using the latest CAD programmes.

Another large part of the work undertaken at the workshop involves car builds in the off-season, when a new model comes along, which last happened before the start of the 2019 season when WSR switched from the 125i M Sport to the current car.

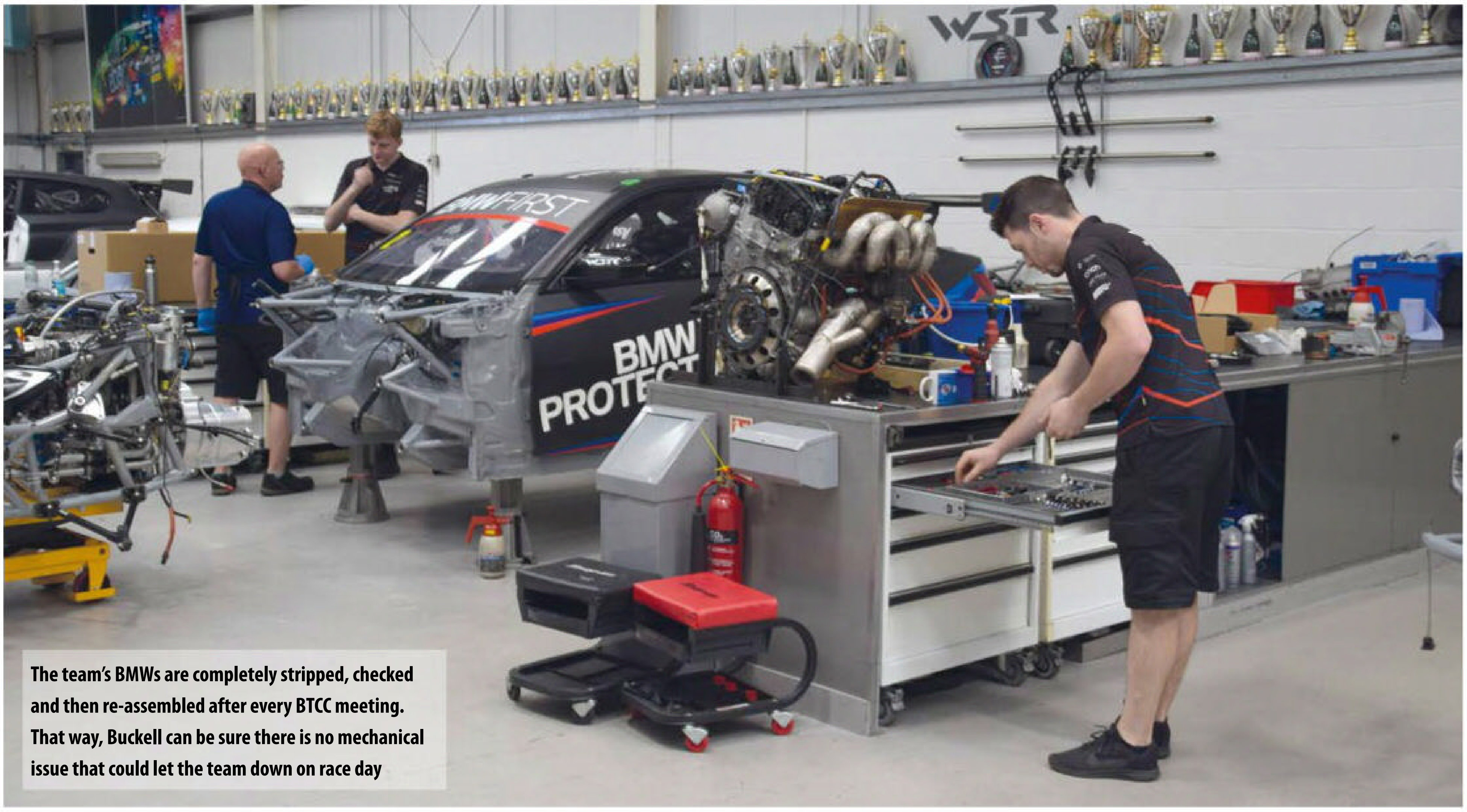
Over the 2020 - '21 winter, the team also built a couple of customer BMW 330i M Sports for Ciceley Motorsport.

While it's no surprise to hear Buckell oversees the build process, it's interesting to note that he's involved much earlier, always thinking of every possible eventuality, and this is where hard-won experience really counts.

Forward thinking

'A new build is always a challenge, turning up for the first race not knowing what you've got and all that. But I'm always confident that we've thought of everything before it leaves here. Every wire, pipe, tube… anything that might fret or rub through, is already taken care of in the design and build of the car.'

A good example is the headlights and tail lights and how they work with the Cosworth control-part harness. 'We use OEM lights, and



The team's BMWs are completely stripped, checked and then re-assembled after every BTCC meeting. That way, Buckell can be sure there is no mechanical issue that could let the team down on race day

Bresmedia

we have them connected up to the chassis harness, which is the championship harness we have to run. But if there's a crash and it goes through all the metal and cuts through the harness, we're in trouble, as the lights need to work for the car to run on track. So, during the build process I need to make sure there is a way we can change all that quickly.'

The same goes for many of the larger parts on a new WSR racecar: 'With the design team, engineering-wise, I look at how the car is going to come apart in an accident, and we try to build it to make it as user friendly as possible.

'I love that side of it. Because, for me, I helped design that car in some ways. Not on CAD, not sitting up there doing drawings and whatever, but physically. I can say to the designer, "I'll make one, here it is, now go and draw it."'

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The engine is fitted back into the front subframe of one of the team's three BMW 330i M Sports

Advisory role

At the track Buckell's role is more hands off, he says, until there's a crisis.

'I'm there in an advisory role for a race weekend, where if something comes up, or there's an issue, they'll come to me with it. I stand around with a cup of tea in my hand, and that makes me look calm and everyone thinks things are under control, and generally they are.

'But this [the workshop] is where it's won or lost. You leave here and, if you have ticked all the boxes, all should go well at the track.'

During a BTCC weekend, the cars are tended by technicians – they are rarely called mechanics these days.

'We have a number one and a number two dedicated to each car. At a race meeting we have a dedicated data engineer and a race engineer for each car. Data engineers are generally weekend only, but with our race engineers they are working in the background prior to each round, too.'

Some of the technicians are self-employed, but they do work at the Sunbury base in the week for much of the year. WSR employs around 12 people full time and a further 15 on a part-time basis. And if you're thinking of applying for a job there, it's worth noting that, above all, Buckell wants the technicians that come to WSR to have practical skills.

I helped design that car in some ways. Not on CAD, not sitting up there doing drawings and whatever, but physically

'I suppose everybody is doing all sorts of degrees in engineering and motorsport these days, and some of them are very good courses. But I prefer people who are hands on. I've had people come to us in the past who have got degrees and they can't even hold a screwdriver.

Next generation

'We have a very good thing here, a scheme with Brooklands College, where we bring youngsters, 16 and 17, in for work experience. They do a week and we see whether they are interested, or whether they wander around with their hands in their pockets. We pick those who are good and show initiative, then ask them to come back and do a couple of days here and there between their studying. Then we take them on race weekends, use them as a number three technician – cleaning, a bit of brake building – and then they slowly build up their knowledge and skills. Most of the people here now are ex-Brooklands. They have come through that scheme, and I'm quite proud of that.'

As for those wanting to build a career as a BTCC technician, and perhaps ultimately a chief mechanic, Buckell's advice is crystal clear. 'It's all about experience. Getting trackside. Anyone who has got some spare time at the weekend, just go and work on a team. Clean the car, get involved, see what's going on, ask questions and get stuck in.'

For his part, Buckell is still getting stuck in, and reaping the rewards, which for him is not simply success on track, although that's obviously a large part of it.

'I get my reward with my cars finishing the race because they are mechanically sound, and that for me is everything,' he says. 'If we don't have the performance there, it isn't because the car hasn't been assembled properly. That's down to the engineer, the driver and circumstances on track.

I get my reward with my cars finishing the race because they are mechanically sound, and that for me is everything

'For me, when I finish on a Sunday night of a race weekend, and the cars are good, it's job done.'

And then, of course, it's time to think about stripping them down, checking everything and re-assembling them for the next event, the cycle starting all over again. Not that Buckell minds this at all.

'My job is like a hobby I get paid for. That doesn't mean I'm looking at it in an unprofessional way, it just means I love doing what I do'

West world

This season is a big year for West Surrey Racing, as far as significant numbers are concerned, because 2021 marks its 40th year as a race team, and 25 years since it first entered the British Touring Car Championship. To further add to the celebration, it also scored its 100th win in the BTCC at Knockhill in August.

And in the foyer of the team's impressive Sunbury-on-Thames base – a facility where it's genuinely difficult to find wall space not filled with trophies – there's a reminder of its glorious past, a Ralt RT3 Formula 3 car resplendent in the livery of the team's first season, when it also scored its first championship win with Jonathan Palmer in 1981. It's a car the team's chief mechanic, Steve Buckell, has personally restored.

After that successful debut season, Dick Bennetts' team went on to win four more British F3 titles, running future F1 stars like Ayrton Senna (1983) and Mika Hakkinen (1990), before switching to Touring Cars in 1996. Since then, it's run factory-assisted Ford Mondeos, Honda Accords, MG ZSs and, from 2007, BMWs in the BTCC, along the way picking up four overall drivers' titles.

There was also a single season of F3000 in 1986 and three years of A1 GP in the 2000s.

When pressed on his favourite season, Buckell pauses for quite a while before saying: 'I think the 2009 Touring Car win [with the BMW 320si], when Colin [Turkington] won his first drivers' championship, because we won everything: independent driver, overall driver, independent teams and overall teams.'

As for unusual jobs he's had to do, Buckell pauses for a moment before recalling filing down the edges of the soles of Hakkinen's race boots so the Finn would fit in the team's Ralt RT34 F3!

But in as diverse an activity as motorsport, does he have any regrets, sticking with one team for 32 years?

'People ask me why I haven't gone and done this or that, and my only regret is that I didn't do Le Mans, because I think I'd like the challenge. I don't have any regrets about not doing Formula 1.'

You can't help thinking that WSR boss, Bennetts, also has no regrets about Buckell never having done F1.

Ralt RT3 Formula 3 car parked in the foyer of the team's west London HQ is a reminder of WSR's first season in 1981. It was personally restored by Steve Buckell

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Batteries not included

The complex logistics of transporting electric racing around the globe

By SAM SMITH

When Jean Eric Vergne hit the wall at turn three in qualifying for the Diriyah EPrix at Riyadh in November 2019, it took almost a year to move his damaged battery from Saudi Arabia to California to be repaired.

The reason was because no airline was prepared to put a damaged battery in one of its aeroplanes. As a result, engineers from McLaren Applied had to make a special trip to where the battery was stored in Saudi Arabia and work on it in the summer of 2020 for it then to be deemed safe enough to be allowed to fly to Atieva's base near San Francisco.

Flying and shipping hybrid and electric racecars, and the infrastructure that comes with them, adds headaches to the already complex world of motorsport logistics.

For Formula E, in its first rules set between 2014 and 2018, this included at least 40 cars with electric powertrains and lithium-ion batteries. It meant the series' logistics team had to very quickly learn a myriad certification and health and safety protocols.

While that continues to this day, it is much reduced in terms of absolute hardware. When the Gen 2 era of Formula E kicked in for the 2018 / '19 season, the field was immediately halved as two cars per driver became just a single Dallara-designed, Spark Racing Technologies-managed chassis, together with a single Atieva-designed and McLaren Applied-supplied RESS (Rechargeable Energy Storage System) per entrant.

Moving electric and hybrid racecars around the world is one thing, moving the batteries that power them has proved quite another

Paper trail

Yet plainly, with the cars travelling inclusive of their batteries, it means Formula E's logistics has to make sure all the regulations for the Civil Aviation Authorities (CAA) are complied with. This includes a colossal amount of documentation submitted to the airlines showing exactly what is being freighted.

The precise make up of a battery must comply with strict criteria issued via the International Air Transport Association (IATA) Dangerous Goods Regulations and details classification flowcharts for specific battery chemistries and products.

The spec Formula E batteries then travel under a specific UN number that allows the batteries to travel inside the cars. This is crucial because the Formula E Gen 2 battery design uses a different cell technology and construction and is located inside the monocoque of the Formula E chassis. It has a greater number of cylindrical battery cells and uses a higher voltage for faster charging and less degradation over a race distance and, as it can travel inside the car, is, relatively speaking, easier to transport.

The main difference between the cells used in the Gen 1 and Gen 2 batteries is the former were pouch designs from Zolt, while the latter is more like the classic AA battery design, sealed in a safety casing supplied by Dallara.

Something called bursts discs are part of the inherent safety system with the Formula E battery. These are sited underneath the battery and act as cushions to dissipate pressure and allow the battery to vent in the event of a sudden abnormal rise in pressure within the battery, negating any explosion.

Within the carbon fibre casing is a deliberate weak point that, should a battery experience a thermal runaway (battery fire) situation, will fail by design, rather than act like a bomb as it might were it to be fully enclosed.

The best way of discharging a Formula E battery is by throwing it into salt water, but clearly that's not a practical solution. So, in the event of a fire, the original plan was for a fire extinguisher to be plugged onto ports built into the engine cover. As the battery case is not tightly sealed, it would allow a slow flow of water through it. These fire ports are designed to feed a constant flow, which would ultimately fill the battery right up with water as the unit has a natural high point.

Dangerous goods

Spare batteries also have to travel but, unlike the ones housed in the cars, these fall into another category for transportation.

'We have to get another certification, called an A99, for these from the airlines for travelling dangerous goods, which is becoming quite difficult in these present times,' says Formula E's head of technical operations, Barry Mortimer.

'The airlines are very demanding. I guess it's not just us, though, but transportation in general in these pandemic times.

'There are only a handful of airlines that will actually allow us to travel with these batteries outside what they're supposed to be connected to.'

The precise make up of a battery must comply with strict criteria issued via the International Air Transport Association (IATA) Dangerous Goods Regulations

DHL, a division of German Deutsche Post, has been Formula E's official logistics partner since the championship started in 2014

***Racecar Engineering* believes a figure around the $19/20 per kg mark [for air freight] is reasonably accurate as it stands**

Mortimer and his team work closely with the Formula E teams and manufacturers on solutions to these problems. As an example: 'We're just working on a procedure where we can fit the spare batteries into the spare chassis,' details Mortimer. 'That will then be classed as the batteries travelling within the car and what it's connected to, so then we can move on from the A99.

'The civil aviation authorities are making it incredibly difficult for us with those regulations at the minute though.'

Mortimer is also working closely with DHL, the official championship logistics partner since its inception in 2014, and is almost on hour-to-hour levels of communication at present.

'I think there may be a lack of knowledge from the airlines side sometimes, a lack of technical knowledge that is, so they need to speak to the manufacturers and the manufacturers need to link up with the airlines and explain specifically the safety procedures we have inside the batteries,' continues Mortimer.

To make matters worse, the regulations for transporting batteries on airlines change by the year, and seem to be making it more and more difficult for Formula E in particular.

Consequently, the series has used alternative transportation methods and prides itself in its sustainable approach to operating. In 2020, it became the first sport series to have a net zero carbon footprint, using and developing internationally certified projects in its markets to offset emissions from its racing.

Express train

In its second season, it transported its cars and freight on the trans-Siberian express train to Beijing and sent its freight from this summer's double-header race in Puebla, Mexico to the following encounter in New York City via road haulage.

But sea freight, road and other alternatives are generally less flexible than flying, especially in an uncertain world where calendars have had to chop and change, as with Formula E since the start of 2020. Additionally, the over-arching disruption to the travel industry, and by proxy the logistical needs of major live sporting championships, means compromises have had to be found quickly.

Then there is the cost factor, which is not actually as different to regular motorsport freight plans as many believe it is.

'I don't think electric racing is any more expensive really than, say, Formula 1, because we still need to fly a certain amount of goods around in our freight,' says Mortimer.

'I've been gifted the huge project of reducing our air freight to an absolute minimum going into season nine [Gen 3], reducing it to flying just the absolute race-critical things.'

Two 747s are used for many of the Formula E events, usually across five continents. The costs are not in the public domain, and Mortimer wouldn't be pushed on specifics, but *Racecar Engineering* believes a figure around the $19/20 per kg mark is reasonably accurate as it stands.

Going back to the sea freight possibilities, costs have escalated dramatically there in pandemic times, making it a much less desirable option on a commercial basis, with an additional level of uncertainty to boot.

'If we go back maybe five years, you would say sea freight was around a third of the cost of air freight, but now the prices have risen astronomically,' confirms Mortimer.

'I wouldn't say it was as expensive as air freight, but they're not that far away from each other now. Though obviously, sending things with sea freight is more sustainable and a lot more economical than by air.

'This is what we're pushing even harder for 2022 / '23, to try and take an absolute minimum by air and then the rest via sea freighting. So that's potentially just the cars by air freight, and that's the big project we're currently working on.'

Radio rental

As you might expect, it isn't just the batteries in the cars that must be certificated and almost forensically detailed for transportation, there's the communications network to consider as well.

'We carry about 48 radios, something like that,' notes DS Techeetah's team manager, Nigel Beresford. 'Each one of those has a battery that is individually packaged and kept separate, and also certificated. There's an enormous amount of paperwork associated with the freight and additional detail now required.

'This is in terms of harmonised codes to characterise what each item in the freight is, what it's made of, what colour it is, what the serial number is etc. And that's for the thousands of items we carry around that are not actually in the car itself.

'That is how come you end up employing someone specifically to look after the logistics aspect,' adds Beresford.

DHL has shared a focus on innovation and sustainability with Formula E since 2014. In 2017, under its 'Mission 2050' strategy, Deutsche Post DHL Group set itself the goal of reducing logistics-related emissions to zero by 2050.

Electromobility is a vital part of that strategy and Deutsche Post DHL Group is a pioneer in the area of green logistics, particularly with its Street Scooter, a selfdeveloped electric delivery vehicle that has been deployed thousands of times in Germany and Europe and is also sold to third parties. The company also boasts a fleet of over 11,000 electric vehicles worldwide.

Pioneering spirit

'As an action-packed and, at the same time, green racing series, Formula E is synonymous with the combination of innovation, future viability and sustainability in motorsport, in the same way that Deutsche Post DHL is in the field of logistics,' says DHL's head of brand marketing, Arjan Sissing.

'The technical developments being advanced in Formula E in the area of electromobility are often significant because the racing series serves as a platform for testing new technologies.

'Other sectors, including the transport and logistics industry, are also benefiting from this pioneering spirit.'

For Formula E, the physical strength of its many containers is clearly crucial to appeasing the stringent protocols put in place by airlines. The freight boxes themselves have to go through vigorous safety testing and have to pass certain certifications. They must be effectively bombproof for, as with the cells inside the batteries, the potential for a thermal runaway scenario is always there.

This occurs when the heat generated within a device exceeds the amount of heat it is capable of dissipating to its surroundings.

In terms of a battery, if the internal temperature continues to rise, the battery current also rises, leading to a domino effect that is almost impossible to quell. The result would, obviously, be catastrophic on any transportation vessel.

'There is nothing you can do with it and you just have to let it run out by itself,' notes Mortimer. 'And all of that is encased within these freight boxes.'

Background noise

There's more to motorsport logistics than just moving batteries and cars around of course, and, having joined Formula E in his current role in 2019 after a variety of sporting and technical positions at Virgin Racing and NIO, Mortimer is in a good position to say that seeing how it works from the other side of the fence is 'a big eye opener'.

'Previously, I worked on the teams' side of things, and coming in on the championship's side you see it from a different perspective. You don't realise what goes on in the background to put on these events.

'It's just incredible. The way we've reacted to Covid, and how we've grouped together to put the events on is, I believe, unprecedented.'

Which brings us to another whole level of logistics that simply didn't exist before the Covid 19 pandemic.

Air freight was traditionally the most expensive mode of tranport, but the cost of sea freight has risen enormously in recent times

'The first thing we did was partner up with a health company. We do our own PCR testing on site, and just the logistics of that is immense.'

Mortimer has also overseen the moving of all the PCR equipment since the beginning of the pandemic, including the complex, temperature-controlled kit required to look after the medical pods, testing fluids etc.

The specially constructed boxes for this testing and tracking equipment to travel in has mimicked the attention to detail seen within a professional racing team.

'I'm used to managing teams to a minute-by-minute schedule from when we arrive at the circuit to when you leave,' he notes, 'but seeing it now from the Formula E side, the management behind all of the championship is just huge. You've got everybody gelling to bring these events together and make them happen.

'The background I've had has certainly helped because I've been involved with Formula E since the beginning.'

The team Mortimer manages is away for 15 days per event, which includes waiting for the freight to arrive, delivering all the myriad parts to their specific places and then prepping everything for the teams' arrival.

Straight lines

Placing equipment where needs to be requires accrate marking on the paddock floor before freight is unloaded from the sea freight containers. When it is then placed by forklifts in the paddock, the lines are perfectly straight with the same gaps between them. It takes a certain type of mind to be able to visualise that in 3D from an empty space.

'Everything has to go in its correct place, you know, including things like the Emotion Club [Formula E's mobile VIP centre] and building up the TV compounds.'

'Other sectors, including the transport and logistics industry, are also benefiting from [Formula E's] pioneering spirit'

Barry Mortimer, head of technical operations at Formula E

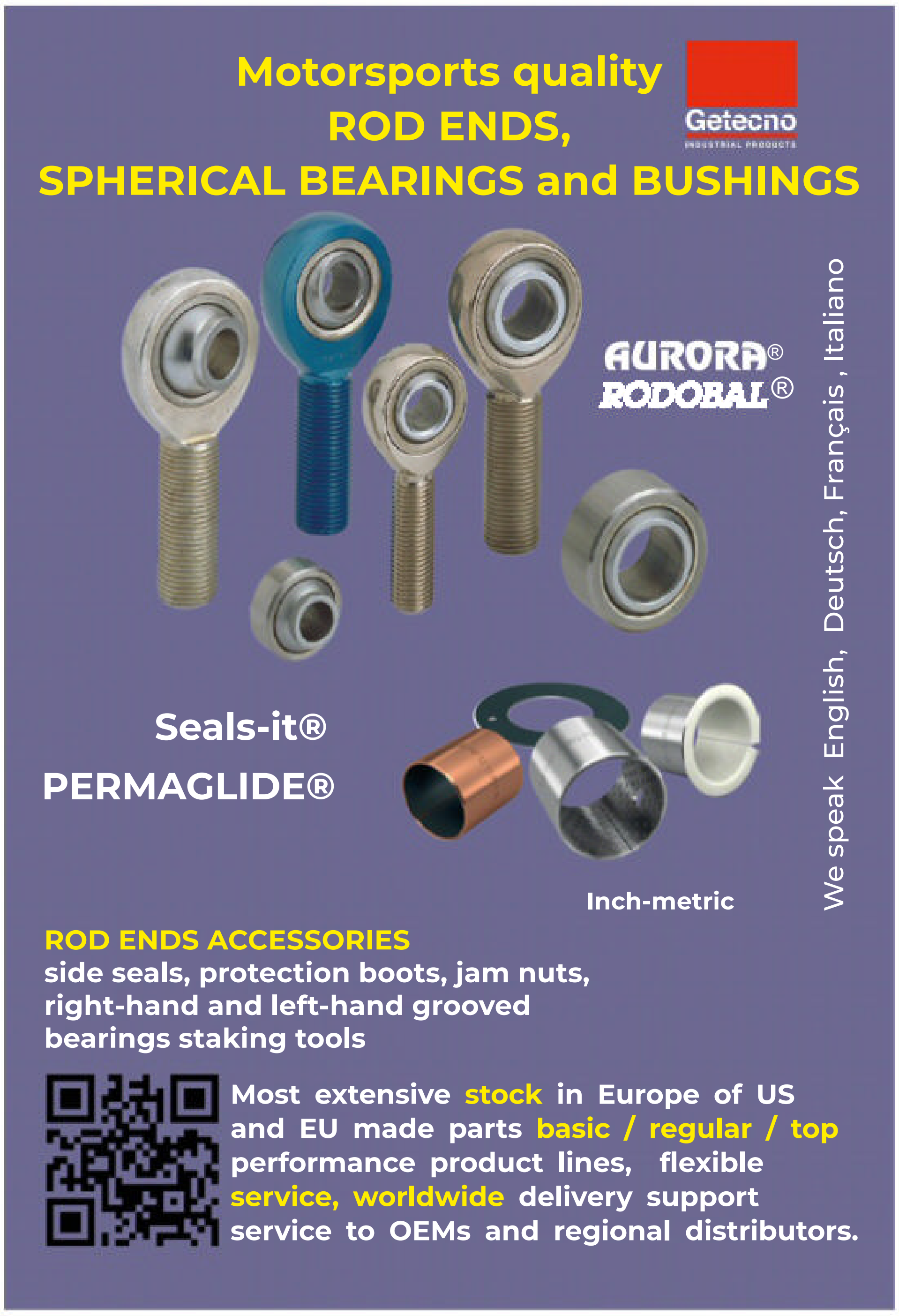
The latter is a key part of the logistical effort for the all-electric championship as the TV compound on its own is made up from 11 specially made pods.

'That's why we're working really hard now to bring all of that air freight down to the absolute bare minimum,' continues Mortimer. 'We've been flying around the world for the last six seasons using 747s. For season nine, we're going to the 777.

'That alone is a massive project. The 777 is a lot smaller, but it's more economical and can take the same payload. That's why we're working with the teams now to see how we are going to package everything for 2022 / '23 onwards.'

The sheer scale of safety protocols in moving electrically-engineered hardware around the world is one of the hidden challenges of modern motorsport, and one that is only going to grow in the future.

With the added challenge of a world still in the grips of the Covid pandemic, and the inevitable slow return to something approaching normality, those challenges now have to be met head on by the likes of Formula E and the host of new EV series, including Electric GT, Pure TCR and Electric Rallycross – pioneers all of a new way of thinking.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Loop the loop

How RML worked with ChassisSim to integrate their simulation packages to offer a better, more competitive solution

By ALEXANDRU BITCA, WITH FOREWORD BY DANNY NOWLAN

Race teams and constructors are now developing their own simulation software in house, but combining their expertise with market leaders in the field offers the best of both worlds

Over the years, I have spoken at length about what you can do with simulation, and how myself and others in the ChassisSim community have applied this to great effect. However, up to now I've been the one doing all the talking.

But over the last 18 months, ChassisSim has been working with RML Group to incorporate the ChassisSim Lap Time and Driver-in-the-Loop (DiL) tools with its internal tools. What has made this integration particularly exciting is incorporating the DIL engine with the RML Group's powertrain modules. For the purposes of this article, it serves as a useful insight into how the bigger motorsport engineering operations go about their business.

Don't take my word for it though. This month's article is straight from the horse's mouth, or at least that of Alexandru Bitca, principal engineer, simulation, at RML Group.

Simulation can be a very powerful engineering tool when used correctly. It can improve engineering decisions early in the life of a project, help optimise the choice and specification of vehicle components and reduce reliance on physical prototyping during vehicle development.

We at RML Group, a high-performance engineering company based in the United Kingdon but operating with a global customer base, believe simulation occupies a key position in the vehicle development cycle. The aim of this article is to gives some insights into how, in collaboration with ChassisSim, we've tried to advance the state-of-the-art in vehicle lap time simulation. This has been achieved by having closed-loop co-simulation between ChassisSim and RML-developed powertrain simulation software, all inside the Mathworks Matlab environment.

Taking a step back, the landscape of simulation software packages available to the automotive industry is rich and ever expanding. However, only in the last decade has closed-loop co-simulation between different but compatible software, each representing simulation expertise in its own domain, become a competitive advantage.

Spoilt for choice

Whether the requirements for simulation are to model the electrical and thermal behaviour of an 800V battery in a single seater around a lap of Laguna Seca in 40degC heat, or the longitudinal and lateral acceleration performance of the chassis in the same conditions, engineers are spoilt for choice with market options of simulation packages to choose from.

A different route for companies to take for reasons of better data management,

Only in the last decade has closed-loop co-simulation between different but compatible software, each representing simulation expertise in its own domain, become a competitive advantage

The landscape of simulation software packages available to the automotive industry is rich and ever expanding

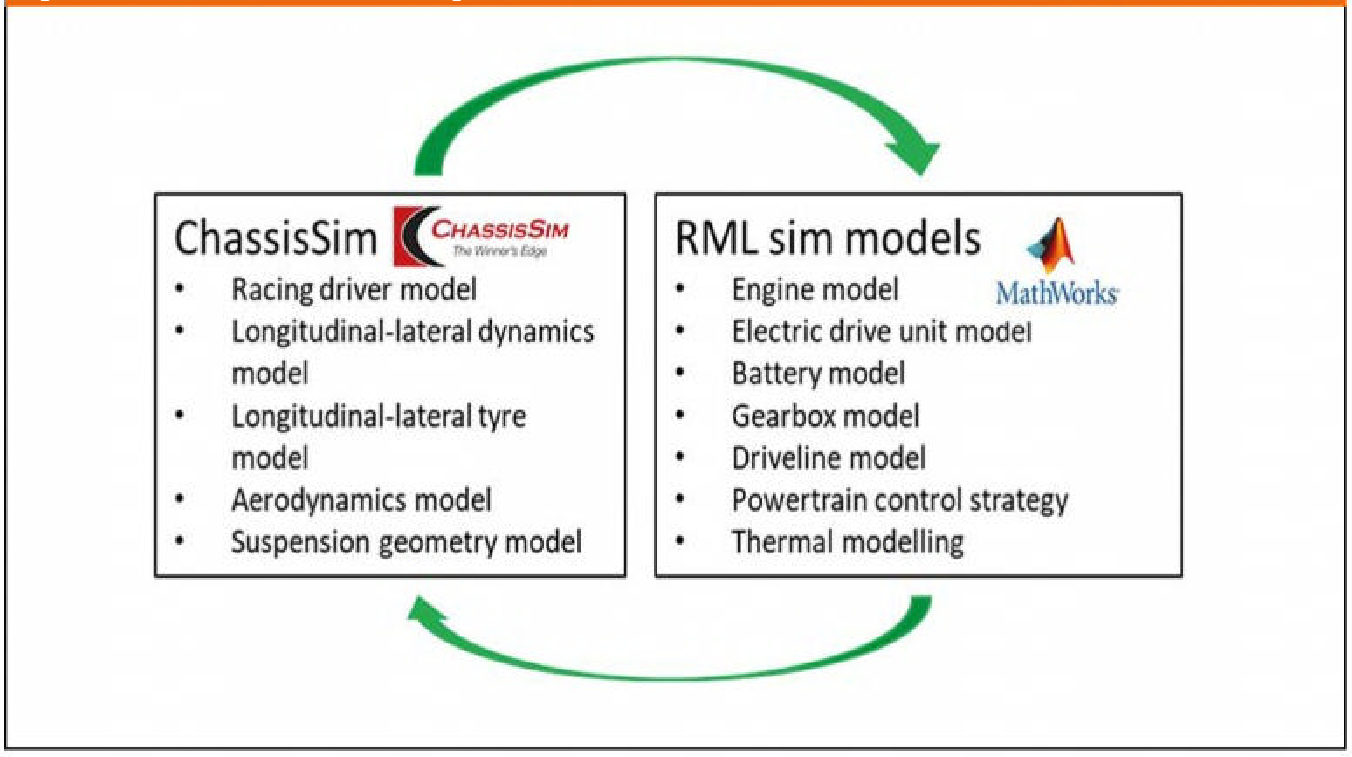
improved flexibility and control over the source code, quicker feature and updates implementation and better overall control over the software life cycle is to develop their own capabilities in house. We at RML Group are such a company and have developed a flexible, highly integrated, vehicle simulation software within the Mathworks Matlab environment that can model any conceivable powertrain architecture in a multitude of standard or custom conditions.

But there are areas where the development of simulation capabilities would be a time-consuming challenge and existing market solutions offer a better return on investment. Fully transient chassis dynamics plus racing circuit modelling represented such an area where a well-developed market solution was a better choice for us at RML. This is where the mature and ever developing capabilities of ChassisSim came into the picture.

This presented us with a new set of challenges. How do we integrate the sophisticated capabilities of ChassisSim into the Matlab environment, as shown in **Figure 1**, whilst ensuring closed-loop co-simulation between ChassisSim and RML-developed models?

Had ChassisSim been integrated into Matlab before? As it turned out, the ChassisSim Driver-in-the-Loop feature contained the key ingredient for achieving the desired integration.

Fig 1: The desired method of integration

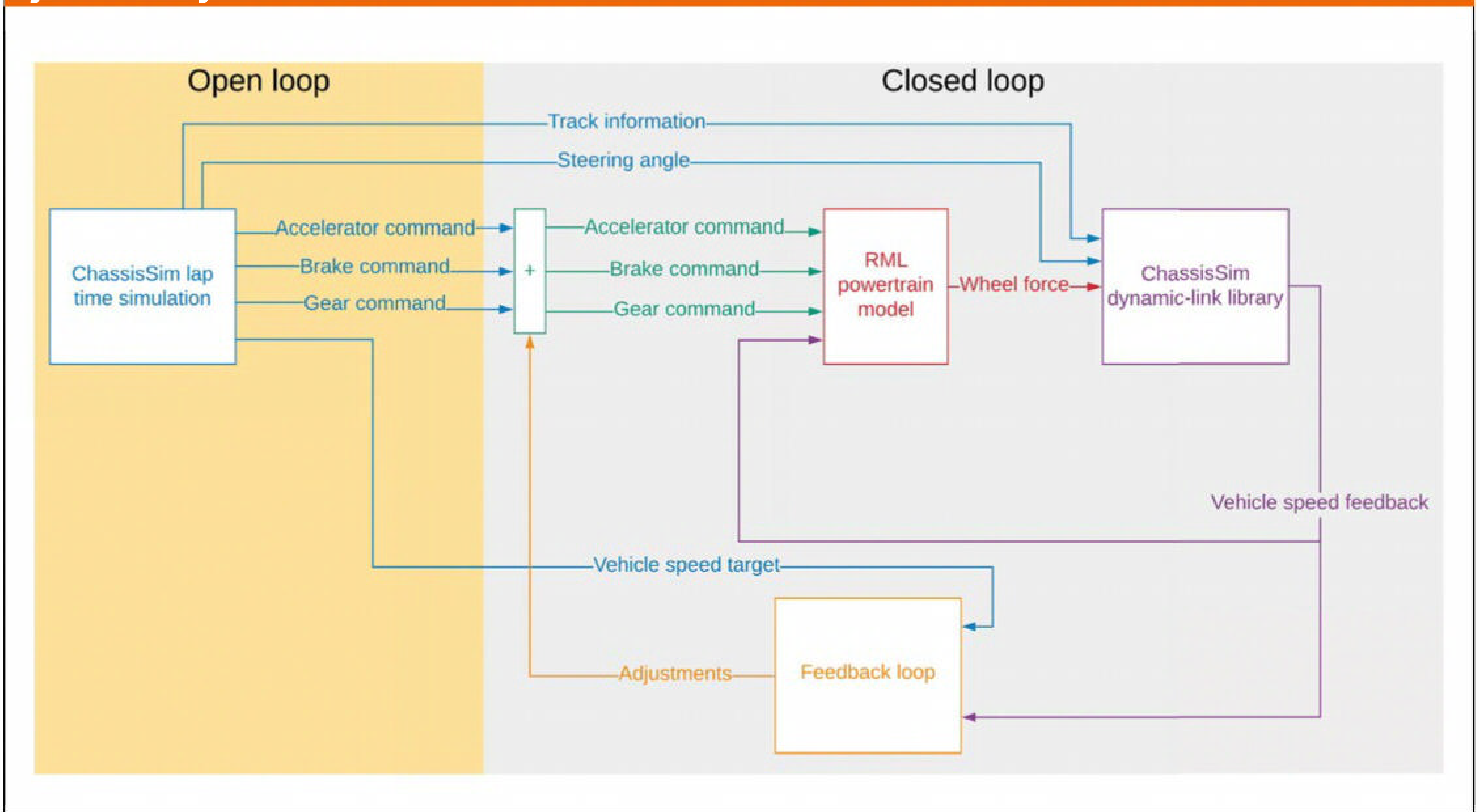


The challenge

At the heart of the ChassisSim DiL lies a library with access to the same physics and equations relied upon by the standalone version of ChassisSim (the one used to generate all the analysis that regularly fills this monthly feature in *Racecar*). The challenge for us then became this: how do we integrate said library into a simulation environment into which it had never been integrated before and ensure closed-loop co-simulation?

Following months of back and forth work and cooperation between ChassisSim and RML, plus a Eureka moment, just such an industry-first integration has been achieved (see **Figure 2**) and we have been reaping the benefits of this achievement ever since.

Fig 2: How the integration between ChassisSim and RML works



It enables understanding of the nuanced interaction between the performance of individual components of the vehicle

Fig 3: The less efficient open-loop process

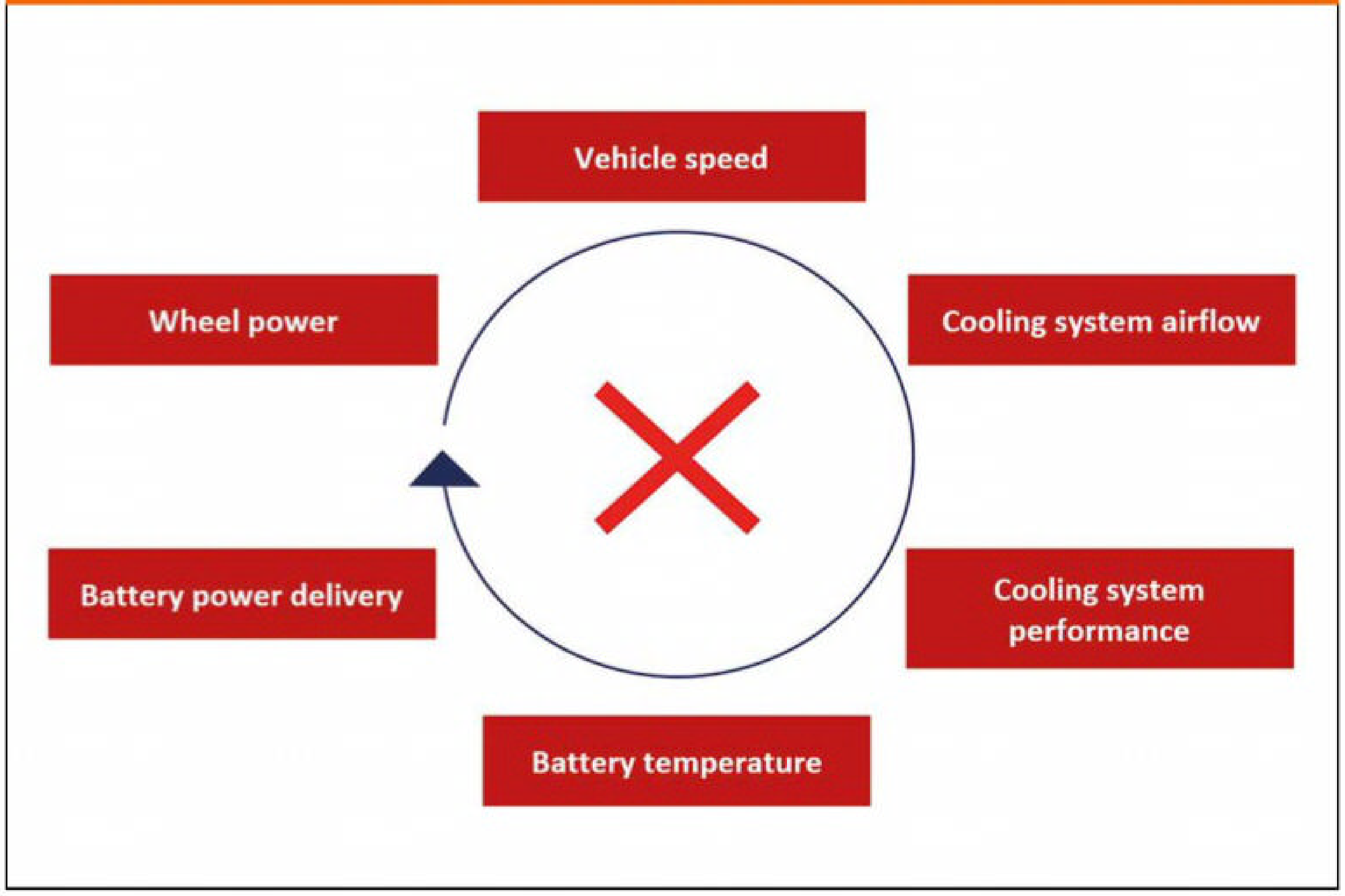
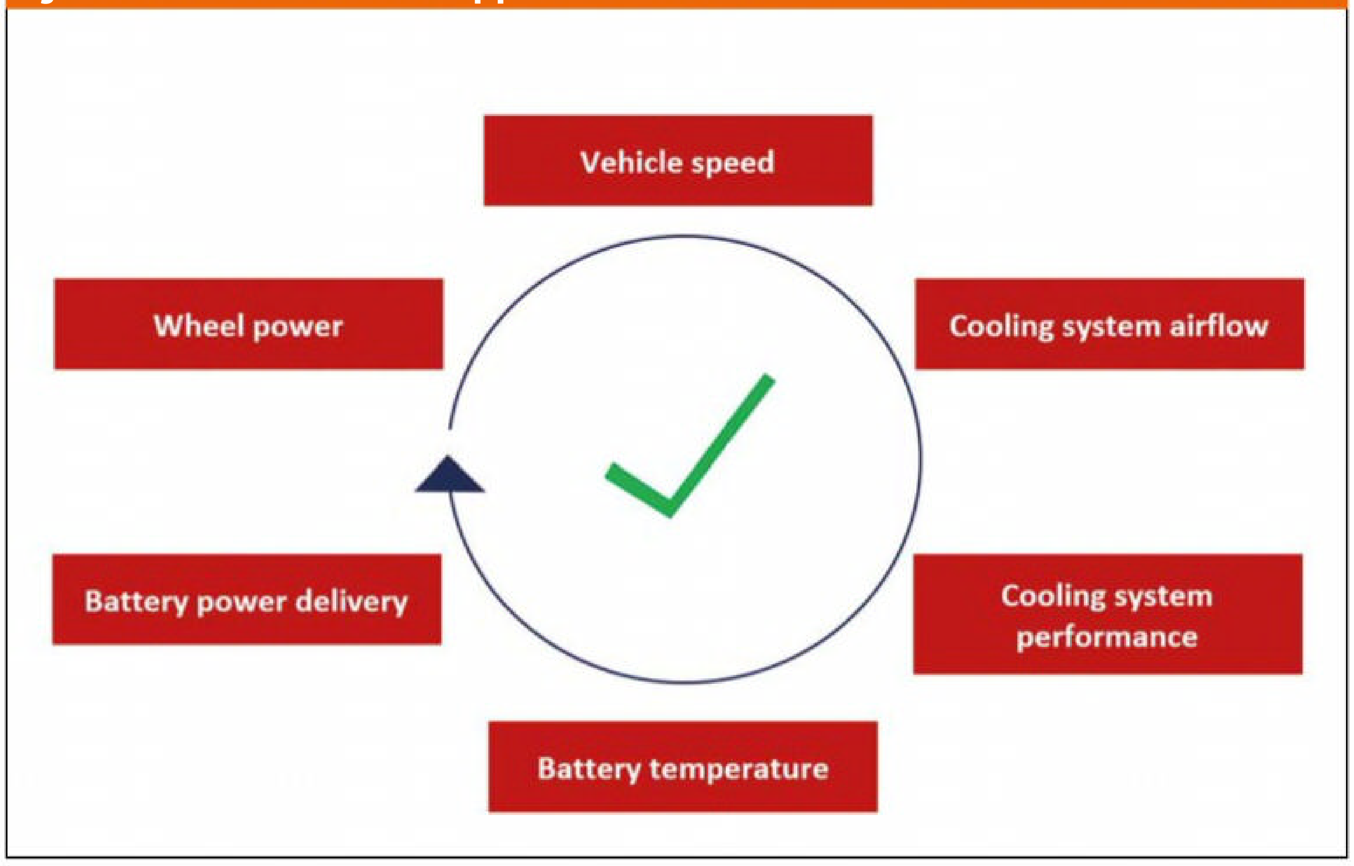


Fig 4: The more efficient closed-loop process



Having fully transient suspension, tyre and vehicle body dynamics modelled and co-simulating with in house-developed powertrain models with sophisticated control algorithms has opened up new possibilities. It enables understanding of the nuanced interaction between the performance of individual components of the vehicle, and how from those interactions emerges the performance of the overall vehicle around a lap.

As always with big claims of industry-first achievements, the proof of the pudding is in the eating. So how did we at RML put the co-simulation to use, and how has it helped us deliver a better product to market?

We have lots of examples to choose from, but let's look at one which truly challenged the simulation capabilities and highlighted quite how powerful closed-loop co-simulation has become for us at RML.

The mission

The mission was this: engineer the complete vehicle cooling system for a hybrid Hypercar with multiple electric motors powered by a liquid-cooled, high-voltage battery.

How we would have done it in the absence of closed-loop co-simulation:

1. Run ChassisSim to simulate the lap time performance of the car and generate a vehicle speed profile against time.
2. Feed the resulting profile into our powertrain hardware and software models to generate the duty cycles for each component, including heat rejection values.
3. Use the resulting heat rejection values in simple 0D (steady state) calculations to size the cooling system and estimate peak and average components temperatures.

It will be obvious to some already, but the open-loop process shown in **Figure 3** is very time consuming. It relies on the simulation engineer in the middle transferring data between different simulation environments. It also lacks the key ingredient: the entire process is an open loop whereby, for example, the temperature of the battery cannot affect the power delivery of the battery, which in turn does not affect the speed of the vehicle around the lap.

How we have done it using closed-loop co-simulation:

1. Run the co-simulation between ChassisSim, in house-developed powertrain models and the whole vehicle cooling system model.

That is it. No more middle engineers

The mission was this: engineer the complete vehicle cooling system for a hybrid Hypercar with multiple electric motors powered by a liquid-cooled, high-voltage battery

This is just the beginning of new possibilities in using vehicle simulation to deliver better engineered solutions

Table 1: Lap time increase with reduced state of charge and power delivery

Lap 1 time [%]	100.00
Lap 2 time [%]	100.22
Lap 3 time [%]	100.33
Lap 4 time [%]	100.33
Lap 5 time [%]	100.33
Lap 6 time [%]	100.35
Lap 7 time [%]	100.46
Lap 8 time [%]	100.49
Lap 9 time [%]	100.49
Lap 10 time [%]	100.49

Fig 5: Vehicle speed and battery electrical channels

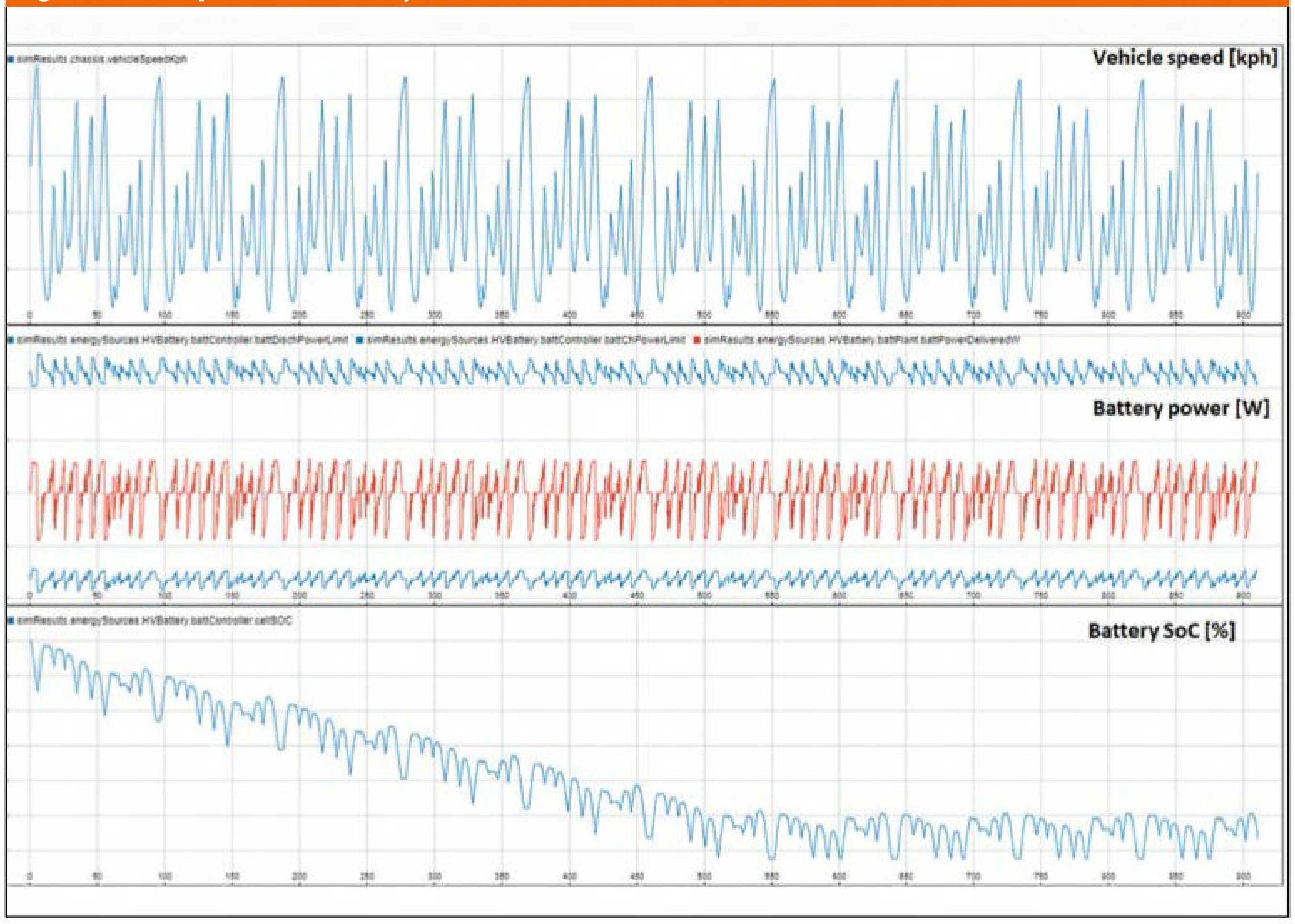
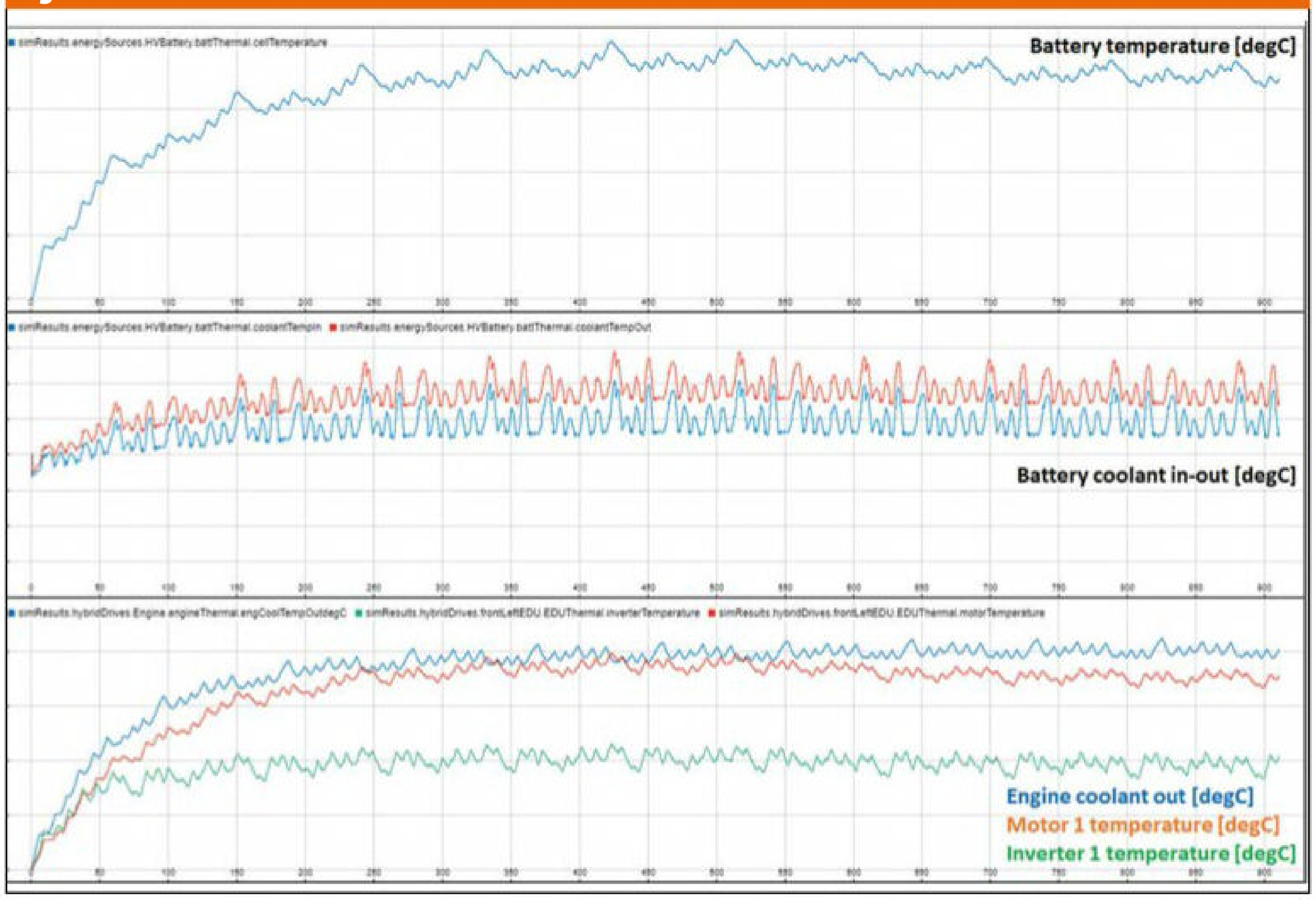


Fig 6: Thermal channels



transferring data between different software and, most important of all, the closed-loop nature of the co-simulation means the performance of the cooling system this time influences the temperature of the battery, which in turn influences the power delivery from the battery and consequently the speed of the vehicle around the lap.

Want to check whether increasing the size of a radiator, or the airflow through it, helps reduce battery temperatures, thereby helping with power delivery? No problem. Maybe the reduced temperature of the battery actually leads to *increased* resistive losses, which worsens power delivery, negatively affecting lap times? All of the nuanced cause and effect relationships are captured by the closed-loop nature of the simulation, with the final result being improved accuracy and realism.

Maximum performance

All this helped deliver a cooling system that maximised the performance of the vehicle in hot conditions, while also managing the temperatures of the powertrain components to within the defined limits. Being able to capture the warm-up of the battery and how the resistive losses of the battery change with temperature, and how that affects the heat rejection rate, was a very powerful capability and gave an accurate prediction of the number of laps that could be run before the battery reached a steady-state temperature. And what that temperature was.

Figures 5 and **6** show a co-simulation of 10 consecutive laps with the hybrid system on maximum deployment in 40degC ambient conditions. An interesting effect captured by the simulation was how, as the battery became depleted and the power delivery at low state of charge (SoC) (see **Figure 5**, bottom plot) was reduced, the heat rejection rate from the battery also went down, which drove the steady-state temperature of the battery down also (see **Figure 6**, top plot).

The reduced power delivery with reduced SoC also had a detrimental effect on lap times, as can be seen in **Table 1**.

The key take away from this is how well the co-simulation between ChassisSim and RML worked, delivering results closer to the performance of the car on track, including all the nuanced trade offs that affect it.

With plans to expand capabilities with new features including EV lift-and-coast optimisation, automated battery cell selection and sizing, suspension set-up optimisation and parameter Design-of-Experiments, this is just the beginning of new possibilities in using vehicle simulation to deliver better engineered solutions.

Lotus launches GT4 Emira

The Lotus motorsport division has revealed an all-new, competition-spec version of its Emira that will be eligible to compete in the GT4 series around the world.

Developed in collaboration with project partner, RML Group, the car was launched in July and will take over from the outgoing GT4 Evora.

Each car will be hand built with a new chassis design, lightweight motorsport components throughout and all the necessary equipment to meet the latest safety standards.

The car is powered by Toyota's race-proven, 3.5-litre V6 engine with optimised aero developed from the Evora.

'The all-new Emira GT4 is an exciting next step following the hugely successful launch of the Emira road car,' says Richard Selwin, race programme manager at Lotus. 'We have worked hard with the team at RML Group to ensure this next generation of Lotus GT car will deliver race-winning performance.'

Lotus aims to build a limited number of GT4 cars for the 2022 racing season, with plans to increase production for the 2023 season in line with global demand that it is expecting.

The car will be officially launched later in 2021 at the company's test track in Hethel, UK.

Lotus Cars

Move over Evora, enter Emira. New GT4 contender from Lotus is a collaboration with RML Group and will be available in limited numbers for entries in the upcoming 2022 racing season

Hybrid and renewable fuels for 2022 WRC

Further details of the World Rally Championship technical regulations were unveiled early in September, as the series moves towards hybrid and sustainable fuels for 2022.

FIA rally director, Yves Matton, FIA technical director, Xavier Mestelan Pinon, WRC promoter, Jona Siebel, and senior management of the three competing manufacturers, Hyundia, Ford and Toyota, all attended an event at the IAA Mobility show in Munich.

The hybrid system will have three principal modes – Full Electric, Stage Start and Stage. Drivers will be able to create up to three further personalised maps to decide how to deploy the extra 100kW of power ahead of the first round in Monte Carlo on 20-23 January.

P1 Racing Fuels will provide the sustainable fuel for the ICE, a blend of synthetic and bio-derived components. In its development, P1 will collaborate with global energy and chemical experts, Aramco, on the formulation of next generation biofuels and sustainable synthetic fuels derived from captured CO_2 and low-carbon hydrogen.

'Rallying is one of the harshest environments a production-based car can experience,' notes Siebel. 'The WRC is a tremendous platform to develop and validate hybrid technology and renewable fuel for mass-produced vehicles, on real roads and under all types of driving circumstance. We are raising the bar to play our part in developing sustainable mobility. Road car users all over the world will ultimately benefit from what we learn by using both on rally stages.'

Ford Puma Rally1 uses a turbocharged, 1.6-litre, EcoBoost petrol engine with a sophisticated 100kW electric motor

Hot on the heels of Cadillac announcing the Italian racecar constructor as chassis supplier to its LMDh programme, BMW follows suit

Dallara confirms BMW supply

Italian chassis manufacturer, Dallara, has been confirmed as supplier to BMW for the spine of its LMDh car, following on from Cadillac's announcement after Le Mans that it too will take the Dallara chassis.

So far, BMW has only committed to competing in the US IMSA series, while Cadillac says it will also compete in the FIA WEC, stepping up from its current US-only programme.

The two manufacturers will use the same chassis, suspension, gearbox and braking package, but will be allowed to use their own engine, cooling and bodywork that will allow them to reflect their brand identities.

Under endurance racing rules, Dallara, ORECA, Ligier and Multimatic will build cars to the LMDh regulations and will also build an LMP2 version of the car with a spec engine. ORECA will supply HPD with its chassis, while Multimatic will supply the Volkswagen Group's manufacturers, including Porsche, Audi and Lamborghini.

Dallara is also thought to be the chassis supplier to the Ferrari LMH car.

BMW confirmed it will run two cars in the IMSA series, and many believe the car will also run at Le Mans, should it receive an invite to do so.

'I'm honoured to have been selected by BMW M Motorsport, and with great enthusiasm I'm looking forward to begin this new adventure,' said Giampaolo Dallara, president of Dallara.

'Back in 1977, I had the opportunity to work alongside BMW on designing the M1 as Lamborghini consulting. It was a great experience and a lot was learned. I hope to repeat the same adventure in LMDh.

I firmly believe that we will do great things together.'

The Prototype is expected to hit the track early in 2022 at Verano, with a view to racing at Daytona in the 24 hour race in January 2023.

Racecar Engineering understands a team of Dallara engineers will be assembled specifically for the BMW LMDh project.

F1 weight limit under discussion for 2022

Formula 1 teams are pushing for a further increase to the minimum weight for the 2022 cars in a bid to save costs, according to Alfa Romeo's technical director, Jan Monchau.

Talking to Dieter Rencken for Racefans.net, Monchau revealed that the increase of 38kg planned for 2022 could lead to expensive weight-saving materials and techniques being used, which would add complexity to the challenge of meeting the cost cap.

'The biggest discussion point lately where all the teams have a clear opinion is the minimum weight,' says Monchau. 'We think a couple of kilos more would certainly help, but also help save costs. It's one thing to achieve a target, but at some point its gets very, very expensive.'

The increased weight is partly due to the move to 18in wheels and tyres next season and the heavier associated parts, such as the brakes. However, any increase in weight will have additional impact on the rest of the car, including the tyres that have been designed by Pirelli and should by now have been distributed to teams, even if only in wind tunnel sizes and performance.

The minimum weight increased at the start of the hybrid era in 2014, with a jump from 642kg in 2013 to 690kg to accommodate the new power units. Since then, car weight has steadily crept up to 752kg in 2020, but the increase to 790kg for 2022 is a step change. However, Monchau and other technical directors consider the increase is still not enough and it seems certain F1 cars under the new rule set will soon breach 800kg for the first time.

IN BRIEF

Thomas Laudenbach has been named as Porsche's new motorsport boss, taking over from **Fritz Enzinger** from 1 October. The German, 53, was formerly head of Porsche's drivetrain department in racing before switching to Audi to head up the development of its hybrid system.

Enzinger led the motorsport department since 2011, and sought to hand the reigns to **Andreas Seidl** before the latter took up a job with McLaren.

Composites firm, **YCOM**, is working with **Manta Aircraft** to develop and manufacture prototypes of the first personal hybrid electric vertical and short take-off and landing aircraft.

YCOM is accelerating aircraft development by applying its advanced engineering and composite materials expertise to the creation of the prototypes.

The **FIA** has signed an agreement to provide the **ESE Entertainment** brand with marketing rights for the new-for-2021 global talent selection programme. FIA Rally Star has run this year with drivers aged 17-26 already selected from national finals, as well as 12 challenges that will lead to next season's Continental Finals.

Nicolas Perinn's Project 424 is developing an electric Hypercar that will take on the outright lap record set by **Timo Bernhard** in the modified Porsche 919 Hybrid.

Audi has announced it is now taking orders for its RS3 LMS entry-level Touring Car for delivery from the fourth quarter of 2021. The brand sold 180 units of its predecessor between 2016 and 2021 in North and South America, Europe, Asia and Australia, making it Audi's highest selling customer racecar in a single model generation.

Gearbox manufacturer, **Xtrac**, has again successfully met the standard of excellence required for a **Princess Royal Training Award**. The 2021 awards will be presented on 14 December and, after that, four undergraduates and eight apprentices selected from more than 120 applicants will commence their training with Xtrac.

Formula E to tackle global warming

Formula E has joined the Science Based Targets initiative (SBTi) and the Business Ambition Pledge for 1.5degC commitment.

The SBTi is a partnership between the United Nations Global Compact, World Resources Institute (WRI), CDP and the World Wide Fund for Nature (WWF) and is the lead partner of the Business Ambition for 1.5degC campaign, an urgent call to action from a global coalition of UN agencies, business and industry leaders in mobilising companies to set science-based, net zero targets in line with a 1.5degC future.

Announced during Climate Week NYC on the one-year anniversary of Formula E becoming the first and only racing category to be certified net zero carbon since inception, the new commitment corresponds to cutting the championship's emissions by 45 per cent by 2030. This is in line with the mission to reduce air pollution and fight climate change, and aligns with the FIA movement for a better contribution from motorsport to society.

Formula E has committed to new measures to meet its targets, including reducing its Scope 1 and 2 greenhouse gas (GHG) emissions (all energy used and purchased at its headquarters and events) by 60 per cent by 2030 and its Scope 3 GHG emissions (all other emissions including freight, business travel, food and beverages etc) by 27.5 per cent by 2030, compared with 2019.

In aligning with the SBTi, Formula E has also become a member of the Race To Zero global campaign to rally leadership and support from businesses, cities, regions and investors for a healthy, resilient, zero carbon recovery that prevents future threats, creates jobs and unlocks inclusive, sustainable growth.

'The ABB FIA Formula E World Championship exists to accelerate sustainable human progress through the power of electric racing,' says Jamie Reigle, Formula E CEO.

'One year ago, Formula E was the first sport to be certified net zero since inception. Today, we achieve another first in aligning with the SBTi, reinforcing our leading position in world sport.

'We are delighted to see other sporting events accelerate their own sustainability agendas to reach net zero faster. Formula E will continue to set the agenda for sport as a catalyst for change and showcase how we can all take tangible steps to reduce our combined carbon footprint.'

SHOW PREVIEW – ADVANCED ENGINEERING

UK engineering forum is back with a bang in 2021

What can you expect from this year's show?

The UK's largest annual gathering of engineering professionals, Advanced Engineering UK, will return to the NEC, Birmingham on 3-4 November 2021. Here, the UK's vast and talented engineering industry can meet again for the first time in almost two years to do business, make new connections and discover innovation.

This year, there will be seven show zones: aerospace; composites; automotive; performance metals; connected manufacturing; medical devices and, new for 2021, space and satellite. Also, for the first time, Advanced Engineering UK's sister show, Lab Innovations, will take place in the same hall.

Advanced Engineering UK hopes that having so many sectors under one roof will enable cross-industry collaboration and the formation of new business relationships after 18 months of limited interactions.

Leading voices

There will be four forums held during the two-day show, featuring some of the leading voices from engineering and manufacturing. A huge topic at the aerospace forum this year is de-carbonising aviation. During the show, there will be presentations on electrification, zero-carbon aviation and hydrogen propulsion from the Aerospace Technology Institute, Rolls-Royce, Ampaire, ZeroAvia and ID TechEx.

Supply chain management is a concern for many companies this year, so Advanced Engineering UK will welcome talks from Airbus UK and ADS on supplier expectations and supply chain excellence.

On day two, the forum will have a whole morning dedicated to space and satellite engineering, with talks from the UK Space Agency, Skyrora, D-Orbit UK and the Space Applications Catapult.

At the automotive forum, electrification and sustainability will be major themes, with talks from JCB, Ford, the Advanced Manufacturing Research Centre (AMRC), Jaguar Land Rover and many more.

On the composites stage, visitors can find out more about what digitalisation means for composite manufacturing, the 3D printing of composite parts and how composites are enabling the UK's move towards its net-zero carbon emissions targets. Composites UK CEO, David Bailey, will return, along with the National Composites Centre's head of digital engineering, Marc Funnell. BAE Systems and Transport for London will also take to the stage.

During the connected manufacturing forum, Ian Gardner, Industry 4.0 and Oracle specialist at IBM and Stephen Phipson, CEO of Make UK, will deliver keynote speeches. They will be supported by speakers from the Connected Places Catapult, Brunel University London and IoT North, to name a few.

The show already has several exciting features confirmed, including a prototype of the ExoMars rover, created by Airbus Defence and Space. The rover, commonly known as Bruno, is semi-autonomous and equipped with the same technology as the final rover, including the sensors, actuators and cameras that allow the rover to see in 3D while navigating Mars.

Space show

Advanced Engineering UK's new show zone dedicated entirely to space and satellite innovation will be Bruno's landing site for the show, and can be found in the existing aero engineering floor.

Also on display will be RS Electric Boat's Pulse 63. The boat's power source is a battery pack derived from the automotive industry, which harnesses a RIM drive unit rather than a propeller, increasing the boat's efficiency and offering a sustainable, zero-emissions power solution.

Advanced Engineering UK offers a great opportunity to meet suppliers, partners and generate business leads for the first time in over a year. Already, the show's exhibitor space is 90 per cent sold out – a sign that our industry is eager to come together again.

In 2019, over 10,000 professionals from the manufacturing sector attended Advanced Engineering UK. 70 per cent of visitors reported that they planned to place orders as a result of the relationships formed, and an impressive 93 per cent of exhibitors said they achieved their objectives at the show.

'Advanced Engineering UK marks the return to face-to-face business, which the UK has been craving since March 2020,' says Alison Willis, director at Easyfairs, the organiser of the event. 'The show offers the UK's engineering industry the chance to get together again, do business and discover the innovative technologies and products that have been created in the past year.'

So, are you ready to meet and hear some of the UK's top innovators in engineering? If so, register your attendance at Advanced Engineering UK on 3-4 November 2021 via the exhibition's dedicated website: www.advancedengineeringuk.com

Interview – Fred Barozier

24-hour power

When Glickenhaus wanted a power unit for its Le Mans Hypercar project, it turned to Pipo Moteurs in France. We chart the engine's journey with the company's managing director

BY STEWART MITCHELL

The 89th 24 Hours of Le Mans, held over the weekend of 21-22 August 2021 at the Circuit de la Sarthe, saw Jim Glickenhaus' dream of designing and building a Le Mans win competitive car come true. From a blank piece of paper to lights out at the circuit, the Glickenhaus 007C Hypercar came to fruition in 18 months.

With the rulebook for the Hypercar class very fluid throughout the process, the 007C's evolution, as with the other Hypercar competitors, was challenging – particularly in the powertrain department.

Glickenhaus appointed Guilherand-Granges, France-based race engine specialists, Pipo Moteurs, to design and build the power unit for the 007C project. The company's managing director, Fred Barozier, talks *Racecar Engineering* through the process from design to the finish line at the French classic.

'When Jim Glickenhaus contacted us at the start, we were very excited about a project to go to Le Mans in the top class,' says Barozier. 'Our conversations at the beginning were about the best platform to use, whether that was a road car-based engine or a custom engine.

'We were confident the bespoke engine was the best solution because we would be in complete control of the configuration of every element without restriction. We went this route, and we decided pretty quickly we would do a V8 that would take our learnings from our four-cylinder engine success in the world of WRC and Rallycross.'

Initially, the Glickenhaus 007C engine was going to be two WRC inline four-cylinder engines. Pipo Moteurs has a great deal of experience optimising these, and marrying two together into a V8 bottom end without modifying the blocks and heads seemed a good route to follow, but that soon changed, as Barozier explains: 'Our first sketch saw the cylinder head casting dimensions carried over directly from WRC. However, WRC engines are air limited and run restrictors on their 1600cc, inline, four-cylinder configuration. The air restriction formula therefore drives every other element of the engine.'

All photos: Pipo Moteurs

Fred Barozier is the managing director of Pipo Moteurs. Based in France, the firm specialises in the design, development, manufacture and maintenance of race engines

Pipo Moteurs carried out all its pre-manufacture engine tests on a four-cylinder unit, as it could carry the engine behaviour directly over to each bank of the V8

When it became clear the WRC cylinder heads were not ideally suited to a Le Mans Hypercar application, the process of designing a completely new engine began. The bore spacing and geometry of the block is the same as Pipo Moteurs' WRC engines, but that's where the similarity stops.

Head scratching

'We designed completely new cylinder heads, unique for each bank,' says Barozier. 'Because the Hypercar regulations consider efficiency and boost limit control, we created completely new combustion chambers, inlet and exhaust ports.'

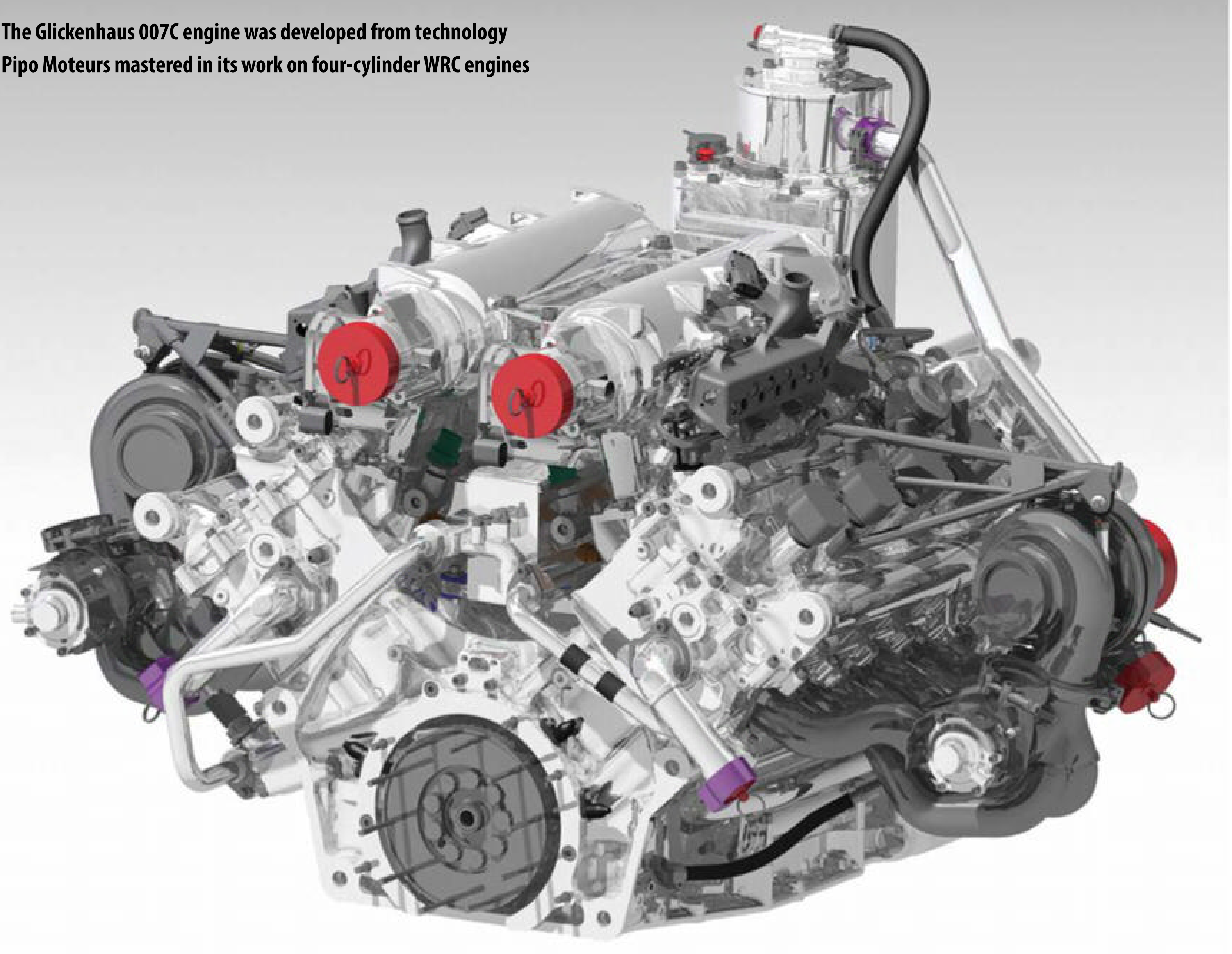
The reason the left and right banks being different is the offset between the cylinders, thanks to each vee pair's shared crank pins on the flat plane crankshaft. Each stretch over the camshaft drive and act as a stressed member to the back of the chassis. The track, vehicle and aerodynamic loads then pass through the rear tyres via the suspension, gearbox and power unit.

'We have reinforced certain places, especially between the cylinder heads and the camshaft covers, to make sure the engine can handle this stress.

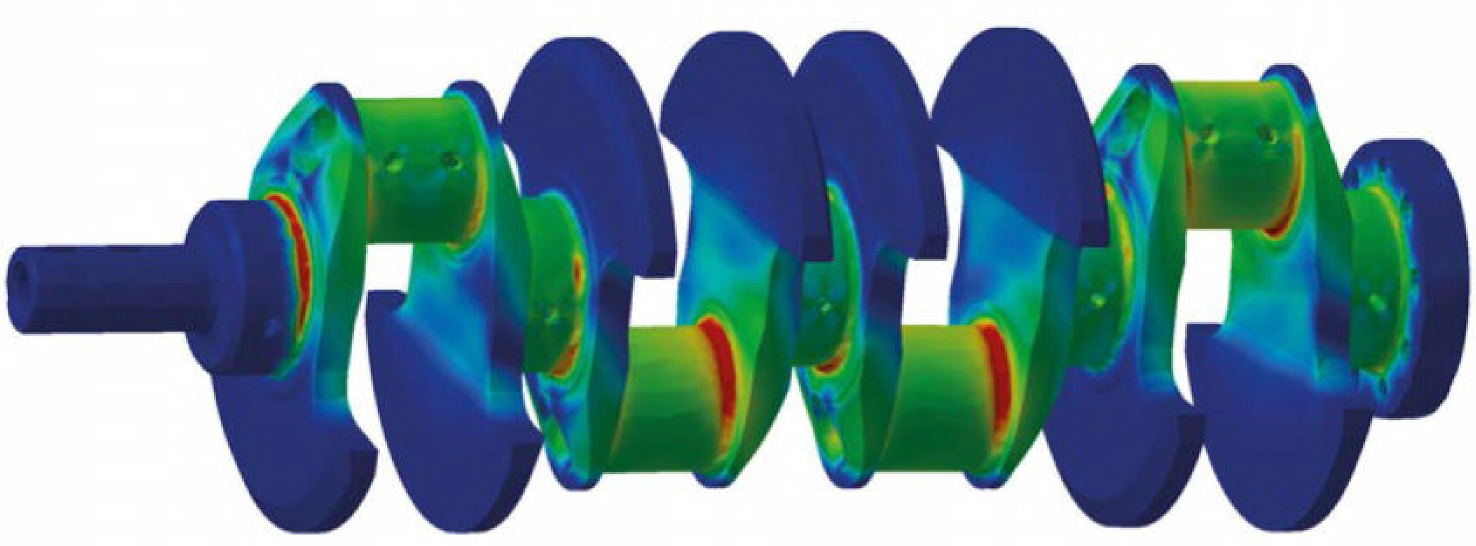
'We know from this bore spacing that we could run each bank anywhere between 1600 and 2000cc, and we established that the engine capacity needed to be between three and four litres for the performance we

Glickenhaus had a dream of competing at Le Mans. Pipo Moteurs built the PU

Glickenhaus' first attempt at the 24 Hours of Le Mans was a resounding success, the team finishing the race with both entries, in fourth and fifth positions overall



The Glickenhaus 007C engine was developed from technology Pipo Moteurs mastered in its work on four-cylinder WRC engines



Simulating and digitally testing the internal components was a big part of the development process. The flat-plane crankshaft had to be of a very thin design to enable two connecting rods to be attached at each journal. It was optimised for strength, reliability and efficiency

were targeting. This included the peak power output, rpm and in-cylinder pressures.

'There is more torsional vibration on a crankshaft with a long stroke on a large capacity engine, though reducing the stroke too much reduces the peak output potential. We found that the 3.5-litre configuration was a good compromise between the bore and stroke potential.'

The ACO initially selected a 585kW output limit for the Hypercar class, but reduced it to 520kW for Le Mans in 2021. Barozier notes that the higher output would have forced the use of a 3.8-litre V8 engine to optimise the car's potential. This configuration would have carried over the 85mm bore size but would have required a longer stroke of 81mm, with a peak in-cylinder pressure of between 180 and 200bar.

As soon as the regulations changed, however, Pipo Moteurs reduced the stroke on the crankshaft to yield a 3.5-litre engine. The peak in-cylinder pressure of 180-200bar remains.

Internal design

The crankshaft was the first of the engine internals to be designed. Barozier explains why: 'We started here because we wanted to carry over the bore spacing from the WRC engine as we knew how the harmonics of this geometry behaves. A significant challenge of this configuration was to fit two con rods on each pin within that spacing. We had to make the crankshaft thin for this geometry but strong enough to deal with the stress and vibrations.

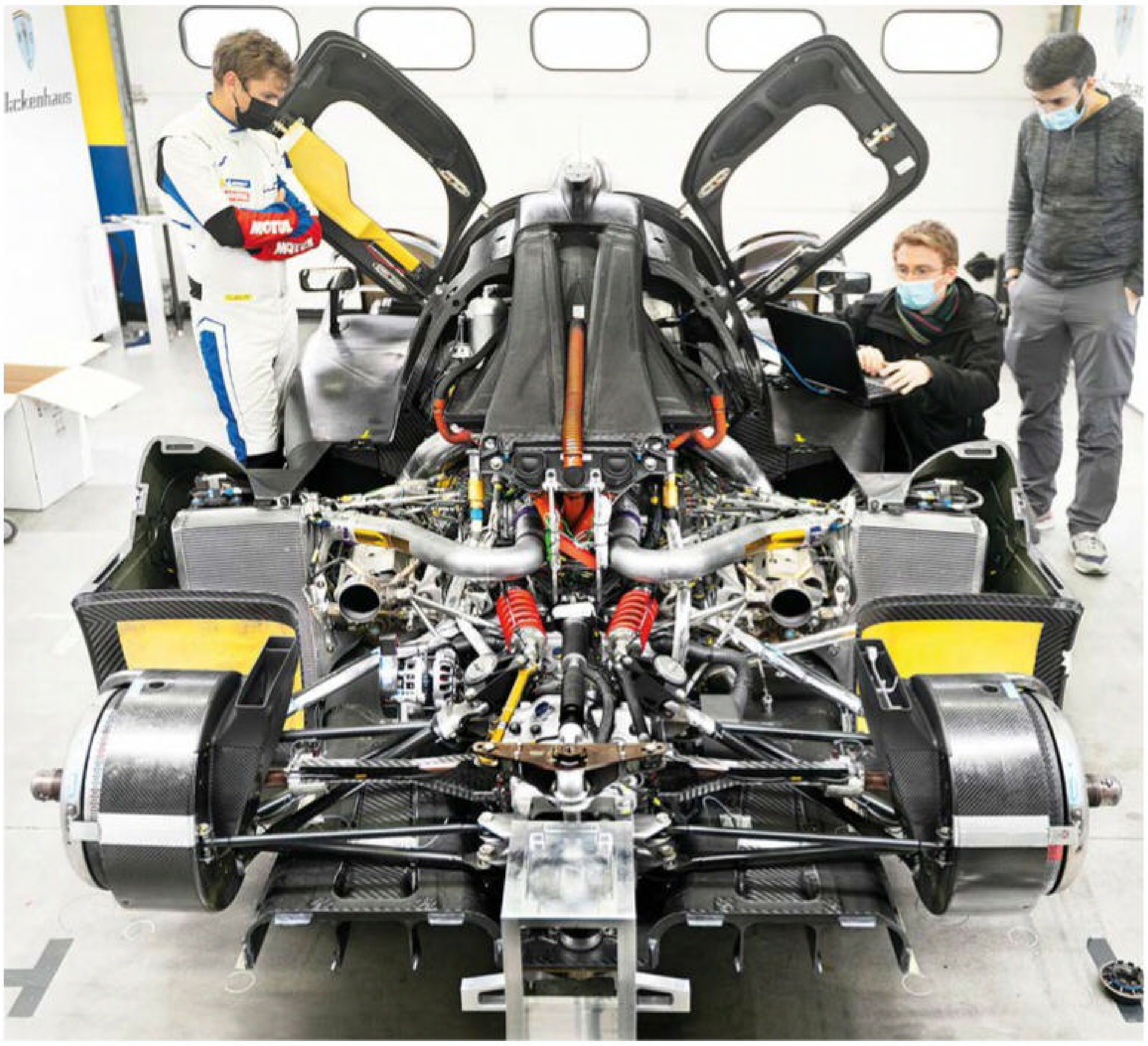
Despite the cross plane-type crankshaft configuration typically generating a smoother running engine vibration signature, Pipo Moteurs chose to use a flat-plane crank configuration.

'Part of our brief was to develop a particular sound for the car that resonated with the image Jim Glickenhaus wanted to deliver for the car. The cross-plane crankshaft that mimics the US V8 sound was not the right style. The race-inspired, flat-plane crankshaft sound was the target.

'We studied many configurations for the crankshaft and bore until we found the right capacity solution and ensured we didn't ever hit the crankshaft's natural frequency in the operating rpm range.'

Once the configuration was decided upon, the crankshaft weight, counterweight design, piston pin diameter and journal diameter were acutely tuned for the desired balance and stiffness.

'We have a lot of experience designing crankshafts with individual big end journals,' notes Barozier, 'though we had never done a V8 engine before from scratch. Previous V8s we have worked on have always been OEM based and carried over the OEM geometry from the road car engine to the race version.'



Once it was decided to use two mirror image turbos, instead of a single larger one, development partner Garrett Turbochargers engineered a bespoke reverse flow unit that allows the engine and its ancillaries to be symmetrical about the centreline on the 007C

Forced induction

According to Pipo Moteurs, the first iteration of the ACO's Hypercar regulations that set peak engine output at 585kW left more room for imagination with engine layout, particularly concerning the positioning of the turbocharger(s).

'It made sense to have just one turbocharger centrally mounted in the vee of the engine at the 585kW target,' confirms Barozier. 'It was still possible to use a single turbocharger when the performance came down to 520kW, but the layout was less optimal, given the big reduction in the engine's air demand.

'Also, the aerodynamics team could take advantage of having two turbos mounted lower down, which doesn't demand as much real estate as a large single one in the vee. We therefore decided to go with twin turbochargers mounted in the car's sidepods.'

In August 2020, at the beginning of the engine testing programme, Pipo Moteurs carried out tests on several different Garrett turbochargers to collect data to feed Garrett with information to build the custom ones that are used on the engine. The first unit was then delivered at the end of November 2020.

The turbochargers mirror each other to allow both to face the same way on opposite sides of the car. This technique means one turbocharger is designed with a regular flow rotation direction while the other is reverse flow. The benefit of this is all of the car's packaging is symmetrical down the centreline, reducing the parts count associated with the turbocharger system.

'We use the same base exhaust manifold on each side of the car, among other parts,' reveals Barozier. 'This means investment into manufacturing is lower, and the cost here was critical.'

Garrett Turbochargers was the chosen partner, and Barozier is very happy with the working relationship. 'It was fantastic to be able to deliver our geometry. The reverse flow turbocharger design was challenging, especially compared to the investment casting on the regular flow turbocharger, because it needed bespoke tooling to produce.'

The engine development programme took into consideration that the ACO would apply Balance of Performance (BoP) to the Glickenhaus 007C. As such, the engine needed to have an extensive performance range to accommodate all eventualities.

'We have a safe margin on the engine's performance, much more than the nominal 520kW output used for the Le Mans 24 Hours,' notes Barozier. 'The turbochargers run at very high efficiency at the 520kW output while at 165,000rpm, well below their maximum speed of 185,000rpm. The result is a compromise between maximum flow, pressure, efficiency and the minimum engine speed at which you have boost pressure. We have to manage the boost at about 3000rpm.'

Testing process

Pipo Moteurs carried out all its pre-manufacture engine tests on a four-cylinder engine, as it could carry the engine behaviour directly over to each bank of the V8. From an ECU point of view, each operates independently.

'The first four-cylinder engine tests were conducted in August 2020 to simulate half of the race engine. We then developed the inlet port design, compression ratio, camshaft profiles and the injector patterns using the four-cylinder test engine.'

The 007C engine features both port and direct injection. Barozier explains: 'We planned to use just direct injection on the

'There is more torsional vibration on a crankshaft with a long stroke on a large capacity engine, though reducing the stroke too much reduces the peak output potential'

The Glickenhaus 007C uses the engine as a load-bearing stressed member. This added complexity to the challenge for Pipo Moteurs

> 'The engine features a billet block with which we have a lot of experience, but this is the first engine we have created that operates as a stressed member of the car's structure'

007C engine, but we calculated that we would reach the limit of their flow rate when we were at the target output. We use a road car-based injector for this engine because their characteristics are well understood, and they are less expensive to implement.

'We reached the limit of the road car direct injectors on the air and fuel mixing in the injector's operation window, so we decided to add port injection to improve this mixing and lessen the burden on the direct injectors.'

The combination of all this planning and development work clearly works well as the feedback from the drivers is that the 007C is a very comfortable car to drive, with minimal engine vibration felt in the cockpit.

'Minimising the vibration signature and amplitude coming from the engine was mission critical for this project as it directly correlates with the car's reliability. This is paramount to finish at the 24 Hours of Le Mans.

'The engine features a billet block with which we have a lot of experience, but this is the first engine we have created that operates as a stressed member of the car's structure,' admits Barozier. 'With the stress element being new, the calculations needed to be accurate. Pipo Moteurs selected the block and crankcase material taking into account steering, aero, braking and vibration.'

Gear changes occur at 7500rpm, well under the engine's harmonic frequency, which transpires at above 7800rpm. Barozier notes that on a number of occasions during the Portimao race, drivers downshifted early and bounced engine rpm to above the gear shift speed, but the engines that ran over the rev limit remained intact and were used for the Le Mans test days.

Mission accomplished

'In the end, the engine ran with great efficiency at Le Mans,' says Barozier proudly. 'We ran to the stint length we wanted, and were able to fill the whole tank within the ACO-mandated pit stop time.

'We also managed to spend less time in the pits than Toyota and Alpine, though our nominal pace saw us finish behind.

'Completing the first attempt at the 24 Hours of Le Mans was a fantastic achievement for everyone in our team. The whole car was brilliant and we kept an open mind in development discussions from every department and the suppliers. The car is a best compromise of the options each element has within the framework of a rear-wheel drive, internal combustion-powered Hypercar.'

Pipo Moteurs has already started investigating the data collected at the 2021 Le Mans 24 Hours experience to feed further development of this engine.

'We don't know if the ACO, IMSA and FIA will change the performance targets further down the line,' says Barozier. 'If we start to race Sebring, for example, the conditions would be very different compared to where we race in the WEC. We would need a new cylinder head to accommodate this race in the car's performance window and we would need time to do the development, manufacturing, testing and everything else ahead of this eventuality.'

Regardless, on the development agenda is a new combustion chamber design, inlet port, pre-chamber injector system and other elements focussed on combustion and overall efficiency. At time of writing, Pipo Moteurs was unsure whether these plans are to be implemented ahead of next season or the one after.

'We have to draw the line with the development at a reasonable level because the Hypercar category is subject to BoP,' notes Barozier. 'The learnings we have from this programme we have to deploy as thoroughly as possible for the duration of each season and onto the next.

'Our commitment to this project is thorough, and we are doing as much as we can in house to manage time and resource pressure for every step.'

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Safety first

More weight and speed may lead to bigger accidents

The law of unintended consequences is a feature in motor racing, and this year has been no different. As Formula 1 teams look to save costs by raising the minimum weight of the 2022 cars close to 800kg for the first time ever, there is the small matter of the amount of energy such a weighty car will have to dissipate in the event of an accident. This may seem a trivial matter but, in today's world with a global television audience rarely exposed to the true dangers of racing, this is going to matter more and more over the coming years.

Evidence surrounding this argument is not hard to find. In the Spa 24 hours in July, Jack Aitken crashed his Lamborghini at the Raidillon complex and suffered two further impacts, each of them estimated to be at more than 150km/h. That left him and Ferrari driver, Davide Rigon, in back braces. The accident was horrific, and many in the press room at Spa were fearful the outcome for the drivers would be worse. Thankfully, once again, modern racecars stood up well to the impact, but the effect on social media was to call for a change to the corner.

Lando Norris was the next driver to become a global superstar cropper at the same corner, crashing in qualifying for the Belgian GP. Once again, his car took the impact well, and again the global internet community demanded a change to the corner, pointing out the W Series had a multiple car accident at the same spot. Thankfully, all drivers involved were able to walk away from the crash.

We cannot just assume the current technology in racecars will save everyone

Priority alert

It is clear something needs to be done at the Belgian circuit, as we cannot just assume the current technology in racecars will save everyone. Some way of alerting drivers sooner, and clearer than a flag, must be a priority, as must the insistence that more than a cursory lift is needed as accidents at that corner in particular are rarely small.

Of course, there will always be some crashes that cannot be avoided, Aitken's being one as the cars were so closely bunched together. The W Series was another as each of the drivers pretty much lost control in the same way, on the same piece of track, in quick succession.

Some crashes have the worst outcome of all, but changing circuits to suit the cars should not be a consideration. The faster the cars, and the more weight they carry, the more spectacular the accidents. So, barriers must be able to cope with the kinetic energy, and spectators need to be aware crashes are only going to get bigger.

What really matters, above all, is that the drivers walk away afterwards, and here we have much to celebrate.

In each of the globally-broadcast incidents mentioned, although drivers may have been injured, we can be thankful Aitken and Rigon were not killed. But we need to accept that in the real world this is not a completely safe sport.

Hail the halo

F1 finds itself facing the conundrum that increased crash protection is leading to much heavier cars *ergo* bigger crashes. This pursuit of endlessly faster cars through more power, more mass, leading to greater aero efficiency has actually spoiled the racing. And when we do have a good old-fashioned ding dong, the Twittersphere goes nuts.

Much has been made of the accident between Lewis Hamilton and Max Verstappen at Monza. There, clearly the Halo was instrumental in preventing a worse outcome. Credit needs to be given to those who designed it as the device took the weight of the rear wheel, suspension, engine and gearbox and did not buckle, so Hamilton emerged unharmed.

There was the usual argument over who was at fault, which is fun, but ultimately both drivers knew it was a low-speed corner, potential for damage was low, and I very much doubt either of them expected what happened.

What I was interested in was *why* the accident happened. Drivers are coached to micro level by the pit wall. No longer is the person behind the wheel in sole control over their own race, even their pace is managed. Can you imagine if Senna or Mansell had been told not to go for the fastest lap, as was Bottas at Zandvoort?

With such levels of communication, either Verstappen knew his car was faster and so had no need to make the move and could have waited, or it wasn't, in which case he had to give it a go and expect Hamilton to behave in the same way as the Dutchman did on lap one.

Thanks to safety improvements, drivers know the risk of fire is reduced compared to the 1970s, that the risk of structural failure is less than the 1980s, that the risk of head injury is reduced since the 1990s, and that impact protection is in a different league compared to the 2000s. That was the intended consequence of the various laws brought in over that time period. For all his faults, we can wave Jean Todt into retirement next month grateful that he at least continued Max Mosley's drive to safer racing.

ANDREW COTTON Editor