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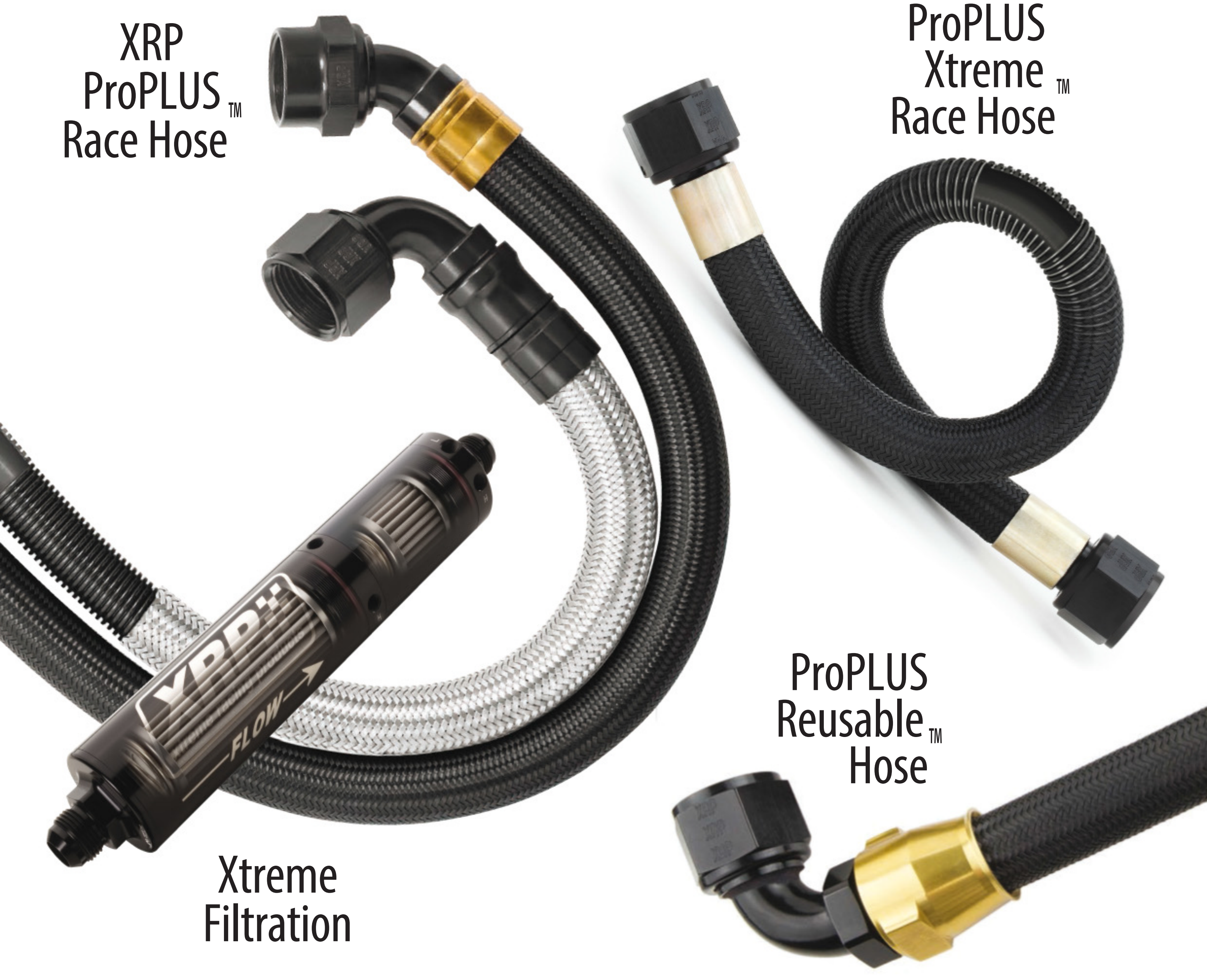

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Carlos Sainz and co-driver Lucas Cruz were in dominant form on this year's Dakar Rally in the Audi Sport RS Q e-tron E2, and took overall victory, the first for a hybrid car on the event

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Under pressure

Tales of tackling the force that every engineer will encounter

Martin Brundle is often quoted as saying that, as an F1 driver, you are either giving or taking pressure. Very true from a psychological point of view, but what about the car, and the effects pressure has on it?

I'm no engine expert, but I have enough practical experience of changes in altitude to know and understand its dramatic effects on whole car performance.

My first experience was running a turbocharged Jaguar Group C car at the Mexico City circuit in 1990. Our turbo expert, Gerhard Schuman of BMW F1 fame, insisted we change the size ratio of the hot side to the cold side of the turbo to take account of the low ambient pressure caused by the track's 7300ft altitude.

He had a wealth of knowledge on the subject and had shown us turbo 'newbies' that things were not always quite as they seem with turbocharged engines. I remember him saying when he first saw our engine, 'In order to control the boost, we must first know what it is!'

We had wrongly assumed that putting a pressure tap on the plenum would tell us that, but with all the pulses and waves in there it did anything but. He introduced us to 'sample rails' which, as the name implies, sample the pressure in each inlet tract and average the pressure within that rail.

It was his understanding that made our car competitive at a very low ambient pressure track.

This is the circuit at which we now see F1 teams running Monaco-spec wings to get Monza levels of downforce, and struggle with the cooling of both water and brakes.

Lazy man on a tandem

My next experience of low ambient pressure was at Bonneville in 2006 where the success of the whole project hinged on the understanding of its effects on our twin diesel engine JCB streamliner. The salt flats are at about 4230ft.

The vehicle's twin-stage turbocharging was dependent on load increasing the exhaust gas temperature and spooling up the huge turbos.

This worked very successfully on the dyno, and at the low-level RAF Wittering air base where the car was tested prior to shipping to the States.

However, the reduction of ambient pressure tipped us over into a phenomenon that became known as 'lazy man on a tandem'.

Our whole first week was blighted by the fact that only one of the engines (at random) would bother to spool up its turbos. The first engine to load and get 600degC exhaust gas temperature would spool up, whilst the other would get taken off load and just go along for the ride! It took a great deal of head scratching and experiment to come up with a solution to the problem caused by just a little loss of ambient pressure.

In the end, a one-inch hose connecting the two engine plenums, and a strategy of dragging the brakes to load both engines for the first half mile of the run, eventually saw a 350mph outcome, which makes the JCB Dieselmax the world's fastest diesel to this day.

Volkswagen

Electric vehicles have an advantage at altitude as, unlike an internal combustion engine, changes in air density have no effect on powertrain performance

In 2015, I got to cross off my bucket list the Pikes Peak hillclimb in Colorado, USA.

If you add a little over 2000ft to the Mexico City elevation, you get the starting altitude of the 12.42-mile course that ends at a heady 14,115ft.

With 2000ft drops beckoning and very few barriers, it certainly is a challenge. At the peak, the air is uncomfortably thin, to the extent that we plumbed in oxygen for the driver.

The event was also memorable for me as the Jaguar F type I ran there appears to have been the last ever works Jaguar (ICE) racecar.

As many racing projects tend to, it started as a 'skunk works' development by SVO at Jaguar / Land Rover. They did not have the facilities to run the car themselves, so called on the services of Jaguar specialist, Don Law (Racing), and his son, Justin, a multiple Goodwood hillclimb winner.

I was called in to ensure compliance to the regulations, and to run the car at the event. Given the unique nature of the track, I was glad to see some very strict and strong rollcage stipulations.

The car itself was a former engineering car with a stripped-out interior, aero body kit, some carbon fibre racing wheels, slick tyres and, of course, a very strong rollcage.

We got to practice the course in three sections prior to race day, but the one and only time you run the full course is during the event itself. We therefore had to calculate the heat build up on all components, and its effects, on the individual sections we had run. Not an easy task given the track rises by over 4000ft to the summit and we were all rookies at the event.

That year, 2015, turned out to be the year of the British Justins in the Time Attack category for modified road cars. Justin Bell (son of Derek), Justin Wilson (IndyCar) and Justin Law all battled for honours, with Law coming out on top and on the class podium as a rookie at the venue.

To further show what we were up against, it snowed while our car was waiting to come down from the peak!

Power drop

Our production supercharged V8 may well have been producing almost 600bhp at sea level, but that dropped to a calculated 400bhp at 14,000ft. It was comprehensively out gunned by the winning Porsche GT3 turbo with its turbos tuned to be most effective at around 12,000ft.

The overall winner that year was a 4WD prototype EV. Electric vehicles are all but immune to altitude change and, with the race time of under 10 minutes, do not carry the weight penalty required for range in roadgoing EVs. This makes Pikes Peak a perfect place to showcase advances in EV technology, as proven in 2023 when a Tesla road car finished in the top ten.

All this before we even consider the pressure differential topside to underside of our cars that produces the crucial downforce, the pressure in the tyres which are key to grip, the pressure in the lubrication systems which allows the engines to run, the pressure in the cooling systems that prevent cavitation and allow the engines to cool.

Pressure is a very key word in motorsport.

I'm no engine expert, but I have enough practical experience of changes in altitude to know and understand its dramatic effects on whole car performance

Package deal

Photos: Joe Skibinski unless stated

IndyCar is set to become the first race series to run hybrids on oval tracks when its new system is delivered later this year

By ANDREW COTTON

IndyCar will this year become the latest top-level race series to introduce hybrid technology and, in doing so, will be the first to race on an oval with such a system.

It has been an intense and thorough route to fruition, but the series is now confident that, following validation tests at the end of January with production-spec parts and software, it can deliver a safe and robust system that is unique to the series.

IndyCar first introduced the idea of a hybrid system in 2019. The series invited companies to tender for the contract and be ready for 2022. It also announced that its two partner manufacturers, Honda and General Motors, would introduce new engines, increasing capacity from 2.2-litres to 2.4. However, under pressure from various external factors, the manufacturers opted to drop the new engine formula in favour of keeping the proven 2.2-litre unit.

At least Honda's engine did not go to waste, as it now forms the basis of the ARX-06 endurance racing prototype.

As the hybrid system upgrade has remained in place, introducing it into an existing IndyCar chassis has proven somewhat complicated, requiring support from all parties, including the series, manufacturers, teams and multiple suppliers. The Covid pandemic has not helped here, nor have ongoing supply chain issues.

Introducing [the hybrid system] into an existing IndyCar chassis has proven somewhat complicated, requiring support from all parties, including the series, manufacturers, teams and multiple suppliers

The concept of a hybrid system was first mooted in 2019, with the intention of introducing it in 2022. It was decided to integrate it into the existing Dallara chassis despite the lack of space in the car, and testing is still ongoing

In order to accommodate the hybrid system, more than 45kg had to be removed from the existing chassis in preparation for the ERS, which will be mounted inside a new Dallara-built magnesium bellhousing.

It was of little surprise, then, that in December 2023, IndyCar confirmed that the introduction of the hybrid system would be delayed until after the Indianapolis 500 in May, giving suppliers more time to test production-spec parts at Homestead, Florida, and ensure the system is as reliable and safe as it can be ahead of its introduction.

Having invited companies to tender for the project, IndyCar retained technical oversight of the development of the system with its dedicated team, and worked with multiple partners to deliver it. Honda took on the leadership of the hybrid project and engineered the capacitor pack, the DC-to-DC converter, the cooling system for the hybrid and the wiring.

Meanwhile, Ilmor Engineering took over from Mahle to finalise the installation of the MGU into the bellhousing. The MGU itself has been designed and manufactured by Empel Systems, which was founded in 2019 by former Integral Powertrain leaders, John Martin and Jason King.

The system was paired with the 2.2-litre engine for the first time in August 2023 at Sebring International Raceway.

It then completed more than 15,000 miles of testing before the end of last year, mostly with development parts, ahead of sign off.

Starter system

The system comprises an MGU, fitted where the remote starter motor currently attaches to the gearbox. Using the MGU to start the car will, it is hoped, reduce the number of full course yellows because currently a stopped car needs external help to be re-started. While a traditional IndyCar remote starter is expected to be used on pit road, the system could be used there, as in sportscar racing.

The supercapacitor, which will store the energy, will also be housed inside the casing.

The decision to use a supercapacitor means the car will be lighter compared to a battery storage system, and the system will also be smaller, which would be vital if it was to be retro-fitted to the current chassis.

Safety first

'We're very cautious, or very conscious, of safety in our paddock, because it's got a lot of cars,' says Darren Sansum, managing director of engines at IndyCar, 'and we also like to give fans close access to the cars with our open garage policy.

'We're aware there's an awful lot of process and safety requirements with high voltage systems, so we wanted a low, 48V system.

'We also needed it to fit in the current package, which basically left us with the space that's in the bellhousing between the engine and the transmission. There really isn't much alternative in a single seater without making the car longer, or different.'

The technical team initially considered the use of lithium-ion batteries, but later discarded the idea because generating the required power would take more weight and space than was available.

'We wanted a package that would fit in the bellhousing. For traditional lithium-ion batteries, that would be quite restrictive in terms of getting the power output we wanted, because generally you need a lot of kilowatt hours in order to generate high kilowatts,' says Sansum.

'Plus, ultra-capacitors are normally less hazardous to handle than a lithium battery.

'What the capacitor offers is relatively low energy density in terms of kilojoules per kilogramme but, in terms of kilowatts per kilogramme, they're actually pretty efficient.'

Deployment strategy

IndyCar has decided on a new way of using the hybrid system. Where other series allow for four-wheel drive over a certain minimum speed, or use it as a push-to-pass function, IndyCar has taken a very different approach by making the hybrid system constantly available. It's up to teams when to deploy it.

So far, IndyCar has not confirmed how the regen' will take place, but the likelihood is that it will use a combination of kinetic energy from lifting off the brakes, coupled with an option for the driver to manually regen' or deploy when needed.

Having a supercapacitor means there is a quick charge and discharge cycle, which is ideal on superspeedways where braking is rare. IndyCar also races on street tracks, road courses and smaller ovals, where regen' will be easier to manage.

'On a short oval, you lift and some of the time you need to brake, but you definitely lift coming into the turns,' explains Sansum. 'There's the opportunity there for regen'.

'And then on the superspeedway in the race, even if you're the leader as the car handling is going away, you start to lift a little bit so there's opportunity to regen' in there.'

One thing that has been learned, particularly in sportscar hybrid racing, is the need to manage power delivery from the hybrid system. Manufacturers have embedded their engineers with teams to help them get the most out of the system, and IndyCar will follow this same route to help reduce the financial strain on the teams, and to increase the speed of learning for their engineers.

'The hybrid control is all inside the McLaren ECU, the current IndyCar supplier' says Sansum. 'Honda have basically written the hybrid software, with agreement from the joint venture [partners], GM, Ilmor and IndyCar, on what features we have implemented. The overall code then gets released by McLaren.'

This is a clear carry over from the sportscar scene, where Honda has been the only manufacturer to introduce a new engine and select the TAG ECU. Many of its sportscar rivals, including GM, used a proven engine architecture and selected the Bosch control unit for their programmes.

The decision to use a supercapacitor means the car will be lighter compared to a battery storage system, and the system will also be smaller, which was vital if it was to be retro-fitted to the current chassis

Unlike other race series that use similar technology, IndyCar intends for the hybrid power output to be available at all times. The only limitation will be the maximum energy deployed per lap

The deployment strategies implemented by the teams are likely to be complex and, as has been seen in sportscar racing, the hybrid system is complicated too because it has control over a wide range of functions in the car. However, IndyCar is relishing the idea that teams will learn at different rates.

Converging solution

'I think they will start off doing different things, probably on a manufacturer per manufacturer, or per team basis, but they're all going to converge on the same solution,' suggests Sansum. 'It'll be interesting to see which solutions win over.

'We've had drivers give us feedback. Some want to have everything manually and some want everything to be automatic.'

One area where the IndyCar hybrid system differs from sportscar application is that in endurance racing the overall power output is limited, be it from the combustion engine or from the combination of combustion and hybrid system. For IndyCar, the hybrid sits entirely independently of the engine, and provides only extra power.

Therefore, while some sportscar teams are running with reduced electrical power and relying on the ICE, IndyCar teams will not have that option, so getting the deployment strategy right will be critical. 'If you don't have the hybrid system working, you'll be slow,' confirms Sansum. '[In IMSA], you are able to not run the hybrid and run more internal combustion engine. We don't have that restriction. Our internal combustion engine is doing what it has always been doing.'

Teams and drivers will be limited on the amount of energy they can regen' on a lap, which IndyCar will set on a track-by-track basis.

'From the testing we've done so far, on road and street courses, the drivers, teams and engine manufacturers... it's up to them how they will work it out,' says Sansum.

'We'll have a tool bag of things they can borrow, limited by the software. Everyone runs the same software, so it is locked in. And then they have some freedoms within the calibration to make changes.

'It will be up to the driver, the engine tuner or team to all have tools that allow them to tune the regen' based on braking. And it's then up to the driver-team-manufacturer combination how they choose to use that.

Engine impact

One of the key decisions to be taken was how to reduce the weight of the car to balance the introduction of the supercapacitor and MGU. That involved a lot of work with the partners, but IndyCar says the decision not to go ahead with the engine swap did not have a big effect on the weight loss programme.

The decision not to pursue the engine change was driven by the manufacturers. They prioritised the hybrid.

Honda took the lead in the project and developed much of the hardware, as well as writing the hybrid software, in agreement with GM, Ilmor and IndyCar. Control is done within the McLaren ECU

Even with the decision taken to retain the 2.2-litre engines, both Honda and GM had to re-design their engine blocks.

'In terms of the engine impact, the main difference is that the hybrid system sits behind the engine and it drives the clutch shaft,' explains Sansum. 'The clutch shaft is common from the engine back, so there's a small difference in length at the front on the 2.2 because the clutch is not in exactly the same position. There is a slight change on the pilot bearing arrangement, too. Other than that, the clutch is almost identical.

'So as far as the installation goes, it's the same between the two manufacturers. With the 2.4, we actually got them on a common page. We had a common clutch shaft, the clutch was in the same place and the pilot bearing was the same size. Unfortunately, going back to the 2.2 meant that split back to where it used to be, which is some subtle differences in culture.

'Other than that, it's not very different. The pattern between the bellhousing and the engine is almost the same between the two.'

Removing the starter motor is quite a common weight saving technique, and IndyCar took that decision early on, but that was only the start of it. Dallara had to re-design the entire bellhousing in lightweight magnesium and re-engineer the rear crash structure, notably on the right-hand side, to accommodate the cooling package for the hybrid system.

AP then had to re-design the clutch because the slave cylinder used to mount it is situated in the bellhousing.

Third wheel

The plan to introduce the new system was partially aimed at attracting a third manufacturer to help Honda and GM, which currently are soaking up costs to supply teams. Notably at Indianapolis, supplying the full grid for the 500 with engines is a challenge that is proving hard to meet.

While everyone involved pushed for the introduction of the hybrid, the system has not achieved its goal of bringing in a new company, yet. That does not, however, mean the system itself is redundant.

The plan to introduce the new system was partially aimed at attracting a third manufacturer to help Honda and GM, which currently are soaking up costs to supply teams

'Any big OEM marketing department needs to see some relevance for the future, which is electrification,' says Sansum.

The other issue the IndyCar team faced was that for one of the manufacturers it was important to introduce hybrid to the current cars in order to stay in the series. Plus, IndyCar itself wanted to be seen to be relevant to what is happening on the road.

'We introduced Shell's 100 per cent renewable race fuel in 2023, so it's not just the hybrid,' says Sansum. 'We're trying to look at making the series more relevant to the future on different fronts. We're looking at sustainability, and electrification would be viewed as part of that overall strategy. IndyCar wants it, the current manufacturers in particular want it, and any future manufacturer would also require it.'

Implementation

The deadline for introducing the hybrid system may have been pushed back, but IndyCar is not concerned with the unusual prospect of rolling out the new technology mid-season. Having made the decision to award the contract to Ilmor late in the day, it was always going to be a push to have it ready for the first race of the season in March. Any delay at any stage was likely to push back the introduction, and so it proved.

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'For Honda and Chevy and Ilmor to deliver this project in 12 months was a very, very tall order, and with how things are with the supply chain on top, it was basically just a lot to ask,' concludes Sansum.

'It was a programme that all needed to fit into place for us to be able to deliver at the start of the year. I feel confident now though. We've got some testing coming up, and it looks like we're going to add production-spec parts at that test, so I feel we're in a good position now to deliver after the Indy 500.

'I think we would have been putting everybody at some risk if we'd have forced it through to have it at the start of the season. The last thing we want to do is put it in the car and then have cars stopping on the racetrack because we've introduced the hybrid technology before it's 100 per cent ready.'

The focus at these final tests will be to run the cars, only topping up with fuel and changing tyres, and prove reliability, as well as learn software strategies that can be used. Although the first ever Indy 500 with hybrid technology is another year away, IndyCar will deliver a novel hybrid system in 2024.

The software running the hybrid will be spec, but teams, drivers and tuners will have freedom in its calibration to make changes

'We're trying to look at making the series more relevant to the future on different fronts. We're looking at sustainability, and electrification would be viewed as part of that overall strategy'

Darren Sansum, managing director of engines at IndyCar

Despite numerous setbacks in the development process, and ongoing supply chain issues, IndyCar remains confident it will be in a position to introduce a hybrid system after this year's Indy 500

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Gen 3 is the most extensive technical regulations overhaul of the championship since it began in the mid-1990s, and came about after manufacturers General Motors (Camaro shown) and Ford wanted to enter new two-door coupe body styles, which did not work with the existing platform

Christian Hartung

Bucking the trend

Supercars went for brand parity and better racing when it conceived the Gen3 platform, which cut downforce by 63 per cent. We examine the state of play heading into year two

By JACK BELLOTTI

Last year saw the debut of the 'Gen3' regulations in Australia's Supercars Championship. Gen3 is a technical regulation overhaul focused on reducing costs, improving competition and maintaining relevance to the road market.

Supercars aimed to achieve this by controlling component design, reducing downforce and using engines derived from OEMs, among other changes. The 12-round season has now been run, and won by Erebus Motorsport's Brodie Kostecki, so let's take a look at the regulations and their impact on Australia's premier motor racing category.

Project Blueprint

The first major technical regulations overhaul in Supercars history came as Project Blueprint in 2003, which aimed to improve parity by regulating engines, aerodynamics and suspension between the Holden Commodore and Ford Falcon models.

Engine port angles and deck heights were standardised, and pistons, rods and crankshafts were all given minimum weights. Common chassis pick-up points were established between the two models of car and a minimum front axle weight of 740kg was introduced.

Double wishbone front suspension layouts were used on both models (the Commodore previously had MacPherson struts) and wheelbase and track widths were controlled, as well as front splitter and rear wing dimensions.

The decade after the introduction of Project Blueprint saw consistency in the battle between Ford and Holden but without any other OEMs . This, in turn, led to the Car of the Future (CoF) regulations overhaul in 2013.

Car of the Future

CoF aimed to improve safety, reduce costs, improve competition and open the category to new manufacturers.

It used control components such as the rollcage, chassis, rear suspension (independent instead of live axle, as used in previous generations), transaxle (instead of separate gearbox and differential housings), wiring loom and MoTeC electronics. The idea was to minimise costs through reduced R&D for teams and to improve competition by further standardising components.

Nissan and Mercedes-Benz joined the championship with the Altima and E63 models respectively and, in 2014, Volvo signed up with the S60.

Safety was improved by moving the driver closer to the car centreline and positioning the fuel cell in front of the rear axle, instead of behind it.

Supercars achieved its stated aims with the CoF regulations, but the control chassis and rollcage developed in the process were never intended to be used with a two-door coupe body shape, which proved a problem when the Ford Mustang was introduced for the 2019 season.

So, a chassis to suit the new generation of two-door coupes, as well as a continued desire for improved safety, competition, road relevance and reducing costs is what led to the Gen3 regulations overhaul for 2023.

The pedal box is now mounted on a sliding rail system, allowing for more adjustability to suit different driver sizes

Gen3 Supercars are built almost entirely from control components. Most have to be bought from nominated suppliers

Control components

Gen3 is the most extensive technical regulations overhaul since the inception of the category in the mid-'90s. The car is now almost entirely made up of control components, with only the gear lever knob and dash display pages able to be modified.

The spec components on the car can be divided up into control supplier and control drawing. The latter are allowed to be manufactured by the teams, but must strictly follow the drawing and match Supercars samples. The former must be sourced through the nominated Supercars vendors.

Examples of control drawing are suspension arms, bodywork brackets and 3D-printed ducting. Control supplier components include brakes, dampers, air jacks and bodywork.

The initial design concept for Gen3 was initiated by Supercars but, early on in the project, the bulk of the design work was taken over by Triple Eight Race Engineering which won the 2022 drivers' and teams' titles, and is one of the two homologation teams within Supercars (the other being Dick Johnson Racing). The homologation teams are responsible for developing each specific model for racing in the series.

Traditionally, Supercars would have designed the model-generic chassis and suspension components, while each homologation team would design its own brand-specific bodywork on behalf of the teams running that brand of car.

Triple Eight not only planned out the Chevrolet components, but also did most of the design work, due to the size of the task and complications early on during Covid.

DJR, on the other hand, designed the Ford-specific components, while some teams helped design minor parts and sub-systems.

Unchanged DNA

The DNA of the car remains unchanged, with a front-mounted V8, rear-mounted transaxle with sequential gear lever operation, locked spool differential and 18in Dunlop tyres. However, at 1340kg, the new car is 60kg lighter than the CoF, with a minimum front axle weight of 725kg (CoF 755kg) and minimum driver weight of 95kg. Track widths are 70mm and 95mm wider front and rear respectively and wheelbase is 60mm shorter.

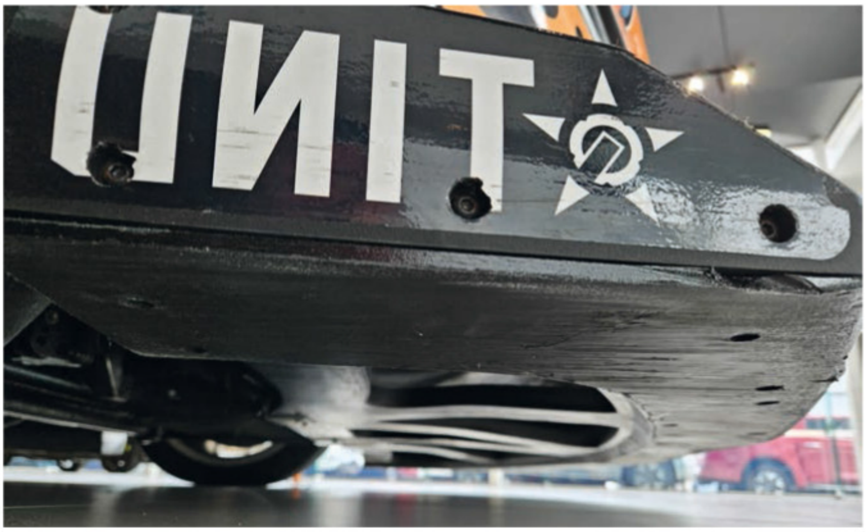
The chassis is still a chromoly tube spaceframe, but the Gen3 car uses replaceable front and rear sections known as clips. The front clip attaches to the main chassis just ahead of the firewall and mounts the front suspension, engine and front bodywork. The rear clip attaches behind the main roll hoop and mounts the rear suspension, transaxle and rear bodywork.

The fuel cell mounts to the main chassis behind the main roll hoop.

The front and rear chassis clips are designed to be replaceable during a race weekend, should major crash damage be sustained. In previous years, any damage would need to be managed for the rest of the event until a thorough repair could be carried out back in the workshop on a chassis jig.

So far, this has proven a successful solution in most cases, though some teams have suffered distortion to the main chassis at the union between it and the front clip. In these examples, a misalignment between

Downforce has been reduced by a massive 63 per cent from the CoF vehicle, with only a six per cent reduction in drag



In place of the diffuser on the CoF, Gen3 uses a replaceable skid block, which contributes to the reduction in downforce

Rear wing has been reduced in size, has smaller end plates and lacks a Gurney. It also sits lower and further forward

The front and rear chassis clips are designed to be replaceable during a race weekend, should major crash damage be sustained

the replacement clip and the existing chassis has been noted, making a simple swap impossible. This issue caused the no.5 Ford of James Courtney to miss the second race in Newcastle at the start of the season.

Supercars has since released updates to the main chassis to help reduce the chances of this sort of damage recurring.

The pedal box sits on sliding rails for the first time and can be adjusted from the seat to allow drivers of different heights to pair together for endurance races.

Above the chassis, a hatch has been added to the roof panel to allow medics quick access to a driver's head and neck in case of injury after an accident.

Aero changes

The bodywork and aerodynamics of Gen3 have seen a significant change from the previous generation. Total downforce has been reduced by 63 per cent, with only a six per cent reduction in drag. Cars now only make 170kg of total downforce at 200km/h. This has been achieved primarily with the smaller rear wing and lack of a front bumper undertray or diffuser.

The front bumper features a replaceable skid block leading edge with a flat frame leading back to the chassis in place of a diffuser. The frame that supports the leading edge of the splitter is a truss design with large triangular openings.

The rear wing is a simple profile with no Gurney and smaller dimensions than that used on the CoF car. Wing mounting is also lower and further forward than on CoF and the end plates are smaller.

Rear wing angle can be adjusted, but minimum and maximum angles are specified and controlled by Supercars.

The rear diffuser is similar to CoF, being made of moulded plastic and connected between the rear crash attenuator and bumper.

The result of the reduction in downforce is closer racing with more overtaking. Braking zones have become longer and aero wash in high-speed corners is reduced, which allows cars to follow closer and attack under braking.

In terms of bodywork, doors are now full carbon frame, as opposed to the carbon skin bonded to production steel frames used in CoF. The only production parts used in the bodywork now are the front grille, tail lights and the OEM badges and emblems.

Beneath the bodywork, the rear of the car is very similar to the CoF, with the same independent rear suspension, transaxle with spool, dampers and tyre as the previous generation car, but the front suspension and anti-roll bars are now controlled.

The front anti-roll bar is driven by a pushrod, rocker and drop link (as was popular with CoF teams) with eight mounting hole options in the rocker for adjustment. Lengths of the pushrod and drop link are adjustable to give linear, progressive or digressive roll bar rates in pitch and heave.

The rear anti-roll bar is directly connected to the lower control arm with two tube diameters to choose from (there's only one tube choice for the front). Anti-roll bars were cockpit adjustable in the CoF, but this feature has been dropped for Gen3.

The anti-roll bars are still driven by adjustable blades, but the change in blade angle must be done by a mechanic when the car is stationary. Ride heights are adjustable on the spring perch, or at the upper shock mount in the chassis.

Dampers are a control, sealed Supashock unit with 80 clicks of bump and rebound damping and are directly connected to the lower control arm. Bump rubbers, packers and the use of more than one spring per corner are no longer permitted.

Spring rates are adjustable but controlled between 65 and 155N/mm in roughly 5N increments. Roll centres and camber are adjustable at the top upright outer point.

Suspension pick-ups are attached to the chassis using a shimmed clevis, which is common across all 16 pick-ups. The common part has five vertical mounting holes to allow roll centre, anti-dive and anti-squat geometric changes, while shims behind the clevis allow track width, wheelbase and castor to be adjusted, as well as taking care of any anomalies arising from construction, or damage sustained during an event.

Kinematic change

The biggest change for teams in suspension kinematics has come with the move to a front-mounted steering rack. Traditionally, the steering rack was mounted behind the front axle with pro-Ackermann geometry and high castor angles. Gen3 has small anti-Ackermann percentages with a mandated maximum castor value of 17 degrees.

Skilled mechanics in a Supercars team can typically make any of the above adjustments during a 30-minute practice session except for large geometric changes that require the wheel alignment and / or bump steer to be reset. Spring / dampers, ride heights, cambers, anti-roll bar blade stiffness and rocker positions, roll centres and wing angles can all be adjusted in only a few minutes, even when working on a smoking hot car.

Rear suspension layout remains largely unchanged from CoF, though anti-roll bars are no longer cockpit adjustable

Supercars say the DNA has not changed. Gen3 cars are still rear-wheel drive with transaxles and sequential gear shift

Chassis are still substantial chromoly spaceframes, but incorporate further safety advances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TECH SPEC: Gen3 Supercars

Weight	1340kg
Power	600bhp
Tyre size	280/680 R18
Track width	2000mm maximum
Wheelbase	2745.5 – 2767.5mm
Fuel capacity	133 litres
Transaxle	Xtrac six-speed sequential with spool
Electronics	MoTeC

The adjustability available in the Gen3 car allows engineers to explore different set-up philosophies without having to go to the expense of designing and developing new components for the car. For this reason, the Gen3 car has been likened to 'Carrera Cup, but with more adjustability' by some engineers.

Historically, teams have had strengths and weaknesses in their cars depending on their set-up philosophies, and this trend has continued into the Gen3 era due to the freedoms allowed with control components.

Under the hood

Engines are another major change for Gen3, with completely new power units introduced and a new style of managing engines implemented. Previously, engines were owned by teams and typically managed by an external engine builder, although some teams ran their own engine programmes.

The engines themselves were 5.0-litre race motors that were being constantly developed and required expensive and frequent rebuilds to maintain peak performance. The new Gen3 motors are production-based units with more relevance to the current road car market and are far cheaper to own and operate. Initial build cost has dropped from AU$150,000 to $80,000 (approx. £78,700-£42,000 / US$100,000-$53,400). Rebuild cost has reduced slightly from AU$40,000 to $35,000 (approx. £18,350 / US$23,350) but intervals have been extended from 4000km to 8000km, with all motors sealed by Supercars between builds.

Capacity has increased to 5.4-litres for the quad-cam, four-valve Ford motor and 5.7-litres for the pushrod, two-valve Chevrolet motor. Thanks to the increase in capacity, the motors are still producing 600bhp, despite utilising OEM components.

Teams are no longer allowed to manage their own engines, with only two engine builders approved for the whole field. All Chevrolet engines are built and serviced by KRE Race Engines, which previously supplied all GM / Holden teams, other than Walkinshaw Andretti United and Erebus Motorsport. All Ford engines are built and serviced by Herrod Performance (previous supplier of Dick Johnson Racing).

Engines are now based on production units. The 5.4-litre V8 Ford and 5.7-litre V8 Chevrolet (shown) produce 600bhp

Engines built by the two approved builders are randomly allocated to teams, ensuring no team, or driver, gets special treatment.

Using OEM components has necessitated a change to a single fly-by-wire throttle, instead of the eight individual cable-driven throttles that were developed for optimum throttle response and peak power. Gen3 throttle response has been partially managed with careful throttle pedal vs butterfly mapping, but drivers who were previously left-foot braking in the CoF have struggled due to the reduction in throttle response.

Traditionally, most Supercars drivers use their left foot to activate the clutch pedal on downshifts and their right foot to brake and blip the throttle to match rpm in the lower gear. This heel and toe downshift technique is becoming ever rarer in the racing world, but Supercars (in consultation with the teams) decided to keep the technique alive by not allowing automatic throttle blips on downshifts and retaining the centrally-mounted sequential gear lever.

As well as wanting to retain the skill level and showmanship that has been a staple of Supercars, the heel and toe technique is favoured by both drivers and engineers because it helps look after the rear tyres and can save fuel, relative to a driver not using the clutch on downshifts.

The Gen3 lap time is only slightly slower than the CoF (0-2 per cent slower, depending on circuit) despite the huge reduction in downforce

Left foot braking demands perfect throttle blip timing to not upset the rear tyres and introduce chatter in the braking zone. Alternate throttle maps can be selected via a steering wheel-mounted rotary pot and some maps include aggressive throttle butterfly openings while the brake pedal is activated to improve throttle blipping on downshifts.

Improved racing

The result of the new Gen3 car on track has been improved racing and spectacle. 2023 saw 10 different pole positions and 10 different race winners (up from seven and six respectively in 2022). Two teams had first time wins and one driver achieved their first win.

The Gen3 lap time is only slightly slower than the CoF (0-2 per cent slower, depending on circuit) despite the huge reduction in downforce. Gen3 generates lap time relative to CoF on the straights, but loses out in higher speed, aero-dependant corners. In slower speed corners, the cars are comparable due to less overall weight, lower c of g, wider track and the softer Dunlop tyres being used.

In response to the reduction in tyre vertical load, the 2023 tyre allocation was revised to use tyres one step softer than previous years. This proved contentious at some rounds, with drivers clearly driving to a lap time and managing tyre wear to avoid dropping off towards the end of a stint.

While racing has undoubtedly been improved due to the characteristics of Gen3, with less aero wash and bigger braking zones, the tyre still drops off significantly in hot air traffic and overtaking opportunities are diminished as the following car overheats its tyres. This thermal tyre problem is arguably worse with the softer compounds used in Gen3 and may be evaluated in future seasons.

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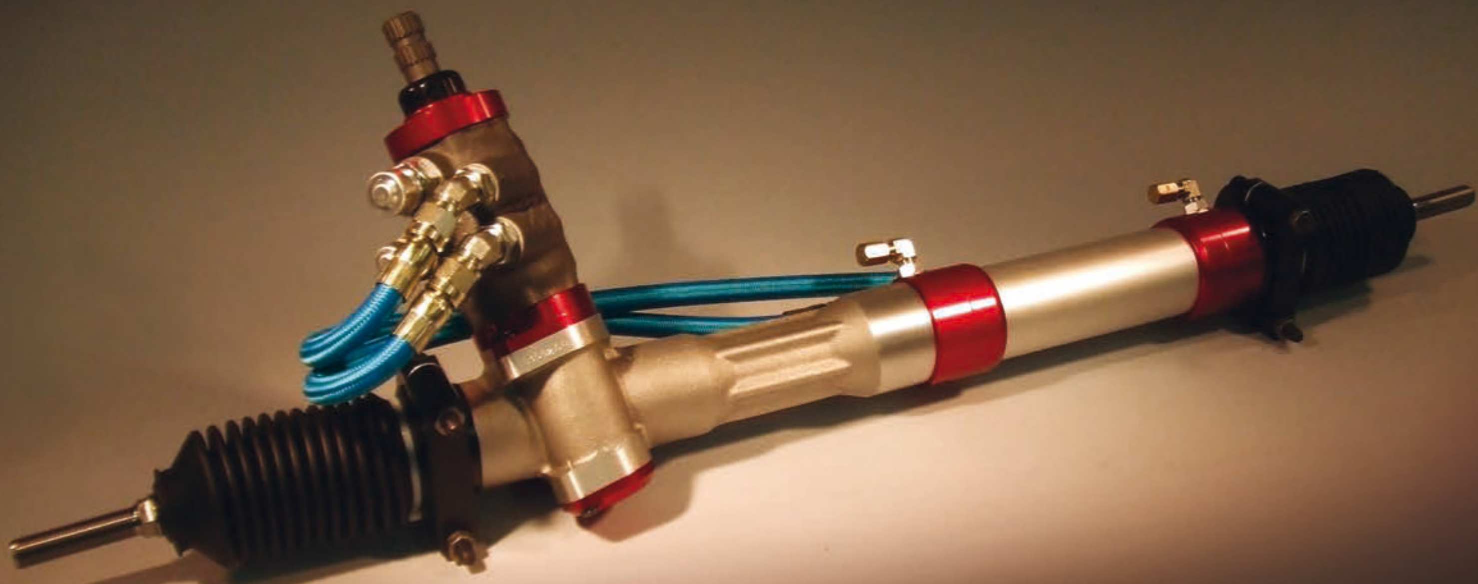

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For now, though, the drivers must make overtakes while the tyre quality is good, or risk getting stuck in hot air until the next pit stop. They must also not hurt the tyres early on, or they may be vulnerable to cars behind towards the end of a stint.

Running costs of the new car are reduced, with bodywork lasting significantly longer than previous years. Two full carbon doors instead of four carbon / steel ones means far fewer door repairs and replacements. Front bumpers were routinely removed each night during a race weekend to have the undertray filled and smoothed with resin, but this laborious task is now achieved on Gen3 by unbolting a skid block.

Engines last longer between rebuilds, and cost less when they need to be rebuilt.

Finally, as development of so many of the car components is no longer possible, teams are not spending additional money on designing and manufacturing parts.

Brand parity

Supercars aimed to achieve parity in Gen3 with engine power, aerodynamics and c of g adjustments between the Mustang and Camaro, so any driver and team has equal chance of success with either model of car. The aim of the adjustments is not to penalise any driver or team for their individual success.

Engines were run on a dyno during the development phase and air intake restrictors were fitted to limit overall power. Engine mapping is controlled by Supercars and ignition angle and cam timing (Ford only) were used to help paritise the power and torque characteristics of both engines across the rpm range.

In-season adjustments were then made to the gear change ignition cut delay period when it was discovered by Supercars that the Ford motor was not accelerating through the gears as quickly as the Chevrolet. Consequently, since the early rounds of the season, the Camaro has been running a gear change cut delay three times longer than the Mustang.

Aerodynamics were finely tuned and adjusted over a series of straight-line tests at a local airport with adjustments made to bodywork profiles between runs. This testing is known as VCAT (Vehicle Control Aerodynamic Testing) and has been used by the category since 2003 to paritise aerodynamic downforce and drag. However, it is important to note that this test is straight line only, with no yaw condition.

The initial Gen3 VCAT results were scrutinised by a homologation team and the process was repeated in early 2023, resulting in a small adjustment to the Camaro front bumper to increase downforce and drag. Similarly, engine bay ballast was mounted to the Camaro cylinder heads to increase total weight and raise the c of g of the Chevrolet single cam motor to match that of Ford's four overhead cam design.

Before the 2024 season starts, Supercars will have run both models in the Windshear wind tunnel in North Carolina, USA and engines will be re-mapped using a transient engine dyno

Ballast of 4.9kg was also added to the Camaro rear upper damper mounts after round two in Melbourne when a selection of cars underwent a c of g inspection and it was discovered that, overall, the Camaro was marginally lower than the Mustang.

Further parity adjustments were made through the season – after round five, Darwin, and round 10, Bathurst, when the Supercars parity trigger was hit. This trigger compares race lap times between several Ford and Chevrolet cars and requires Supercars to recommend technical changes if the lap time differential is above a specified threshold for a certain number of races.

The threshold was exceeded after round five and so the Mustang models were given rear aerodynamic adjustments intended by DJR (the Ford homologation team) to fix the braking instability and rear tyre wear issues the Ford drivers had been experiencing.

Although it was generally agreed that parity had been achieved during the VCAT process, it was believed that the braking instability issue occurred at ride heights outside of VCAT's scope and during yaw conditions that the test process does not account for.

The Mustang rear wing was subsequently moved forward and down, with a reduction in maximum angle, and a boot lid spoiler added.

After round 10, the Mustang was given further aerodynamic adjustments and went on to win all four of the remaining races in the 2023 season including the Bathurst 1000. This time the wing was moved rearwards and upwards, wing span was increased 100mm, wing angle increased, side skirts were modified and front fascia packers were added.

Secure future

It is clear from the results in 2023 that parity between the two models has not entirely been achieved, with Chevrolet dominant at the start of the season and Ford dominant towards the end, after mid-season changes.

The lopsided results show how difficult it can be to achieve true parity, but Supercars continues to invest in solutions to further improve the situation. Before the 2024 season starts, Supercars will have run both models in the Windshear wind tunnel in North Carolina, USA (see news, p76) and engines will be re-mapped using a transient dyno to remove the disparity in gear change ignition cut delay and improve engine performance parity.

The future of Supercars as Australia's premier motor racing category is well secured, with Gen3 delivering on its goals and the championship continuing to push and improve every aspect of the sport.

Gen3 has perhaps made the greatest difference to the smaller teams at the back of pit lane. Suddenly, everyone has the same equipment and engines that make the same power and are capable of achieving the same lap time. As an example, the same driver, engineer and team competed with car no.34 in 2022 and finished 21st in the standings. Last year, that position was greatly improved to 12th. The difference was Gen3.

Despite appearances, the only production parts used in the bodywork are the front grille, tail lights and OEM badges

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Made in Germany

The brand with the four rings will be racing in Formula 1 for the first time in 2026, but there are many hurdles to overcome before then, both with the engine and the team

By CHRISTIAN MENATH

In 2026, Audi will become the second major OEM from Germany to enter Formula 1, after Mercedes, and when Audi announced its commitment during the 2022 Belgian Grand Prix, it couldn't resist a little side swipe at its country folk in the press release: 'This is the first time in more than a decade that a Formula 1 power unit has been built in Germany,' it stated.

Although Mercedes has been an engine manufacturer in Formula 1 since 1994, the engines are developed and manufactured in Brixworth in the UK. The Stuttgart-based car maker had gradually taken over engine manufacturer Ilmor, which itself had emerged from Cosworth spin-offs, Mario Illien and Paul Morgan. The last Formula 1 engines to actually be made in Germany came from BMW in Munich and, ironically, Toyota in Cologne.

Now, the Motorsport Competence Centre in Neuburg an der Donau, around 20 minutes from Audi's headquarters in Ingolstadt, is once again producing Formula 1 engines made in Germany.

That means that for the first time since 2015, F1 has not one but two new engine manufacturers, with Red Bull Powertrains joining in partnership with Ford. Back then, Honda was a latecomer to the turbo hybrid era, and the Japanese manufacturer struggled to gain a foothold in the class.

The 2026 Formula 1 power unit regulations were framed in such a way as to try and attract new manufacturers into the series. It worked with Audi, but the German auto maker had a few demands of its own before it agreed to sign on the dotted line

Audi has learnt from Honda's mistakes, and it is no coincidence that it is joining just when the new rule set is coming in. Audi was already at the table when the negotiations on the 2026 PU regulations were taking place.

Basic requirements

'We achieved a lot of what we wanted,' Stefan Dreyer, CTO at Audi Formula Racing, told *Racecar Engineering* confidently during a visit to Neuburg, shortly after the decision to join was finalised. 'That was a basic requirement, otherwise we wouldn't have joined.'

Dreyer is responsible for the technical development of the power unit and reports directly to CEO, Adam Baker.

It was not possible to negotiate an all-wheel-drive system during the discussions, but the most important goal was achieved with the elimination of the MGU-H.

When Formula 1 returned to turbocharged engines in 2014, the turbocharger was electrified. The motor-generator unit gives the turbocharger an e-boost at low engine speeds and recuperates electrical energy at higher engine speeds. It is what makes the current power units so efficient, but also extremely complex.

'It is a very, very complex component where the others have a huge head start,' says Dreyer, 'but, as things stand today, the MGU-H has no relevance to series production.

'That's why it wasn't of any interest to us to push this technology.'

Engines for the Audi Formula 1 programme will be developed and built at the Motorsport Competence Centre in Neuberg an der Donau. There is also an existing wind tunnel at the facility

Audi pushed for four-wheel drive technology in Formula 1, but that request was rejected. However, the FIA's decision to drop the overly complex MGU-H system and significantly increase the electric component of the powertrain output brought the German manufacturer onboard

In order to focus its attention on Formula 1, Audi has withdrawn from all other motorsport series except Dakar

That was reason enough for Audi to want to see the back of the MGU-H.

Without the MGU-H, the Formula 1 power unit is significantly less complex. It remains a 1.6-litre, V6, turbocharged engine with electric boost, which the MGU-K pushes onto the crankshaft. Essentially, it will remain the same in 2026; only the proportions will change.

Ebb and flow

The combustion engine will have less fuel flow, and therefore make less power. Where a maximum of 100kg of petrol may flow per hour today, in 2026 an energy flow limit of 3000MJ of synthetic fuel may be transported into the engines' six combustion chambers per hour. This will reduce the power output of the combustion engine from 600kW currently to around 400kW.

However, to ensure overall system power remains roughly the same, the output of the MGU-K is to increase from 120 to 350kW.

The significantly higher proportion of electric power was also high on Audi's wish list and, to achieve this, the FIA had to find a compromise in the regulations. It wanted to make it as easy as possible for new manufacturers to be involved but, at the same time, not alienate those already competing.

Hence why the basic engine architecture remains unchanged, and key dimensions such as cylinder bore diameter (80mm) and maximum valve stem diameter (4.95mm) have been retained.

If anything, the new regulations are even more restrictive in terms of architecture than the current rule set, but are strongly orientated towards the existing engines.

Despite the elimination of the MGU-H, newcomers will still start at a disadvantage, as Dreyer explains: 'The bottom line is that it remains the 1.6-litre V6 with the same bore, the same cylinder bank angle and much more. It will look more or less the same from the outside, and we can twist and turn it however we like.

'The others just have years of experience in this area, but we agreed to the V6.

'The talks then moved in the direction of what we need to change so we can quickly gain a foothold as a newcomer in the series with our experience of the last 20 or 25 years of engine development.'

Mario Illien, who is still heavily involved in Formula 1 as an external service provider, takes a similar view. 'It's still not easy for newcomers,' he says. 'The manufacturers involved don't necessarily have a head start, but they have been working with the technology for a long time. It takes time and the right people to get there in a short space of time, and time is already short.'

Compounding this problem is the fact Audi only has partial expertise in racing engines. No combustion engines have previously been developed at the Neuburg Competence Centre where the Formula 1 power unit is being developed. Audi's previous racing engines were developed in Neckarsulm, around 200km away.

In recent years, there has been no racing engine development at all, certainly nothing to do with Formula 1. For the Dakar race programme, the company's existing DTM turbo engine was coupled with the electric motor from Formula E.

'We achieved a lot of what we wanted. That was a basic requirement, otherwise we wouldn't have joined'

Stefan Dreyer, CTO at Audi Formula Racing

'We have a lot of respect for that,' says Dreyer. 'We haven't had any high-revving concepts in our motorsport projects in the past. The DTM engine ended up revving to 9500rpm, the diesels were lower anyway.'

Putting this into perspective, current Formula 1 regulations allow engines to spin up to 15,000rpm, and in practice it will probably still be around 12,500rpm in 2026. There is also a Formula 1 speciality – pneumatic valve control. Audi has no experience with this either.

Material struggle

In the struggle to agree a suitable piston material, Audi initially prevailed. While the manufacturers already involved favoured steel, the Audi engineers insisted that aluminium alloys should also be permitted.

Although steel pistons are heavier, it is easier to make them stable at the high ignition pressures required for an efficient combustion process, so Audi also negotiated a lower compression ratio maximum of 16:1 (currently 18:1) and a boost pressure limit of 4.8bar at the engine inlet.

However, this was apparently not enough to make aluminium pistons a viable alternative, and since version two of the new PU regulations, only steel alloys are permitted for the pistons. In return, minimum piston weight was increased from 300 to 350g.

In general, the rather conservative weight specifications are favourable to newcomers. The combustion engine itself must weigh at least 130kg and the entire power unit at least 185kg. There are also specifications for the individual sub-assemblies.

'After initial concept analyses and estimates, we were of the opinion that this was achievable,' says Dreyer. So there will be no weight arms race.

Mammoth task

Despite the numerous restrictions on the concept and dimensions, Audi is quick to admit it is still facing a mammoth task with developing its combustion engine.

'The regulations are not an installation manual,' notes Dreyer.

Above all, the architecture of the block is prescribed. With the cylinder head, where the engineers can gain the most performance, there is still a great deal of freedom.

As far as the turbocharger is concerned, the backlog of experience Mercedes, Ferrari, Renault and Honda have is likely to be of limited value. Complex technologies such as variable geometry turbines, for example, are prohibited. In addition, the turbocharger will probably shrink in size compared to the existing regulations.

Manufacturers can currently install a fairly large turbocharger because the MGU-H plugs the turbo gap. Without the MGU-H, turbo lag will become a bigger issue again and the dimensions will probably be adjusted accordingly. Because individual components can never be considered in isolation, the operating parameters for the entire ICE will also change due to the different exhaust back pressure.

It is not only the technology that poses challenges for the German brand. The Motorsport Competence Centre is an impressive facility where extremely successful sports prototypes have already been developed, but the infrastructure was not ideal for engine development. Not least because previous racing engines came to Neuberg completely assembled.

Bench pressure

Assembling a Formula 1 engine is like open-heart surgery, so first of all the relevant factory hall had to be upgraded in terms of cleanliness. In addition to production, the development department also had to step up its game. There were no single cylinder test benches there, for example.

Even then, work on any such test benches is only the very beginning of the engine development process. After the concept phase, the combustion chamber and the fuel need to be optimised before the full engine is developed. This requires a fuel partner, as the 2026 engines will run on customised synthetic fuel.

The Driver-in-the-Loop simulator also had to be upgraded. The specially hired test driver, Neel Jani, now has a single seater monocoque, and the corresponding software required has been installed.

Major upgrades had to be made to the Neuberg facility to build F1 engines, and Audi is well aware of the enormity of the task ahead

In principle, kinetic energy works in exactly the same way in Formula 1 as it does in Formula E, so Audi is ideally positioned in this regard when it comes to test benches

On the upside, a wind tunnel was part of the original plan for the Neuberg site, and that opened in 2014. Because Audi developed its LMP1 cars in the Sauber wind tunnel at Hinwil, the space at Neuberg remained free.

Next to the engineering building, known internally as F6, the excavators rolled in as soon as the Formula 1 decision was taken, and the upgrade of the existing infrastructure was completed last year.

For the remaining test benches, Neuberg was well prepared right from the start. Audi Sport has a total of six test bench cells, five of which are equipped with wickedly expensive and complex test facilities from Austrian specialist, AVL. Some of these had to be dismantled because Formula 1 only has one drive axle, whereas the LMP1 hybrids had two, but at least they were already there.

The 2026 engine regulations set limits to the F1 test bench craze. An engine manufacturer may operate a maximum of three single cylinder and three power unit test benches. In addition, one test bench for the entire powertrain and one test bench for the entire vehicle without aerodynamics are permitted. In Audi's case, the latter is to be built at the works team in Hinwil, Switzerland.

The regulations allow two further test benches for the energy recovery system, plus one bench on which only the battery may be tested. As well as limits on the number of benches, their use is strictly governed, in a similar way to restrictions on wind tunnel use.

Audi has invested heavily in test benches in recent years and the significantly larger electric component in the regulations comes at just the right time. Even though the battery is a standardised component in Formula E, the team developed its own battery for the LMP1 programme, so expertise and test benches are available to continue this work.

In principle, kinetic energy recovery works in exactly the same way in F1 as it does in Formula E, so Audi is ideally positioned in this regard when it comes to the test benches. Of course, the competition knows this too, which is probably why Audi did not make any concessions in terms of test bench times when the new regulations were being agreed.

Big spenders

The newcomers requested more dyno time from the regulations, but were unable to get their way on this front. Instead, Audi and Red Bull Powertrains are allowed to spend more money than existing teams.

Since 2023, there has been a budget cap for engine manufacturers, which initially stood at US$95 million. Newcomers will be allowed to spend $10m more in 2023 and 2024, and five million more in 2025. Costs for the current engines are not included in the budget cap, which is why Audi and Red Bull have $25m net more available for the development of the 2026 engine.

Engines require the greatest lead time in vehicle development. The final decision by Audi to enter Formula 1 was not made


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until the second half of 2022, and the implementation phase was only started with the handbrake on a few months before public communication. Prior to that, the first employees with non-disclosure agreements were recruited in the spring of 2022.

When Audi was finally able to put the pedal to the metal, Red Bull already had its first V6 engine on the test bench.

'You can only congratulate them that an engine is already running on the test bench. You have to tell it like it is,' said Dreyer at the time. At that point, Audi was not even running its first single-cylinder engines.

Audi's plan was to have the first complete power unit, consisting of ICE, MGU-K and energy store, on the test bench by the end of 2023. It has around 350 employees now working on the F1 drive system at the Neuburg site, and only a small number of positions still left to fill.

Works team

Developing its own engine is a mammoth project in itself, but Audi will enter Formula 1 in 2026 with a complete works team. No customer teams are currently planned. Sauber was chosen as a partner, and Audi is gradually taking over shares in the experienced Swiss racing outfit until it joins.

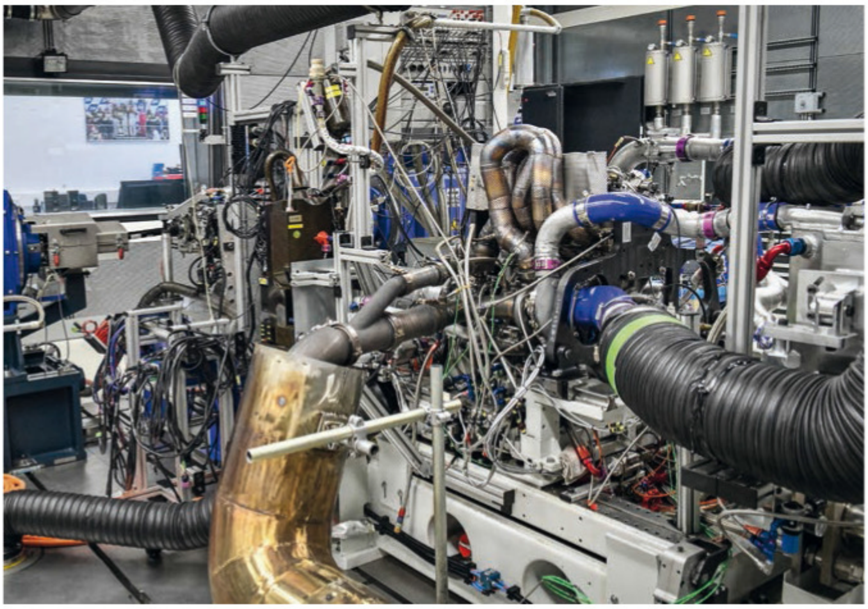
With Andreas Seidl, a key person was already installed in the position of CEO at the beginning of 2023, but the past season has shown there are no low-hanging fruits to easily be plucked in Sauber's Hinwil base.

Sauber finished in penultimate place in the 2023 Constructors' Championship; only Haas was worse. When BMW made Sauber its own works team in 2006, the Hinwil site was brought up to the level required to be a top team in Formula 1 but, following BMW's withdrawal at the end of 2009, Hinwil's infrastructure haemorrhaged.

Major investments? Not a chance. Sauber only recently put a Driver-in-the-Loop simulator into operation for the first time, so is still lagging behind compared to the top teams in that regard. The team's in-house production capacities are also far behind the industry standard, so it is clear there is a great deal of work to do there.

It is well known that a Formula 1 team cannot be re-organised within just one season. The power of an OEM is also limited, especially in times of the budget cap. Manufacturers cannot just throw millions around the way they used to because the regulations simply don't allow it.

At least there are exceptions for infrastructure. Sauber's poor performance last season gives it a few extra million dollars from the capital expenditure limit. Even so, it takes years for infrastructure to come fully online, and even longer for it to materialise in results on the track.



Audi has invested heavily in test benches in recent years, so is well set up to start its engine development programme

A request for extra dyno time was denied, but new teams are able to spend additional money in the first few years

Audi's plan was to have the first complete power unit, consisting of ICE, MGU-K and energy store, on the test bench by the end of 2023

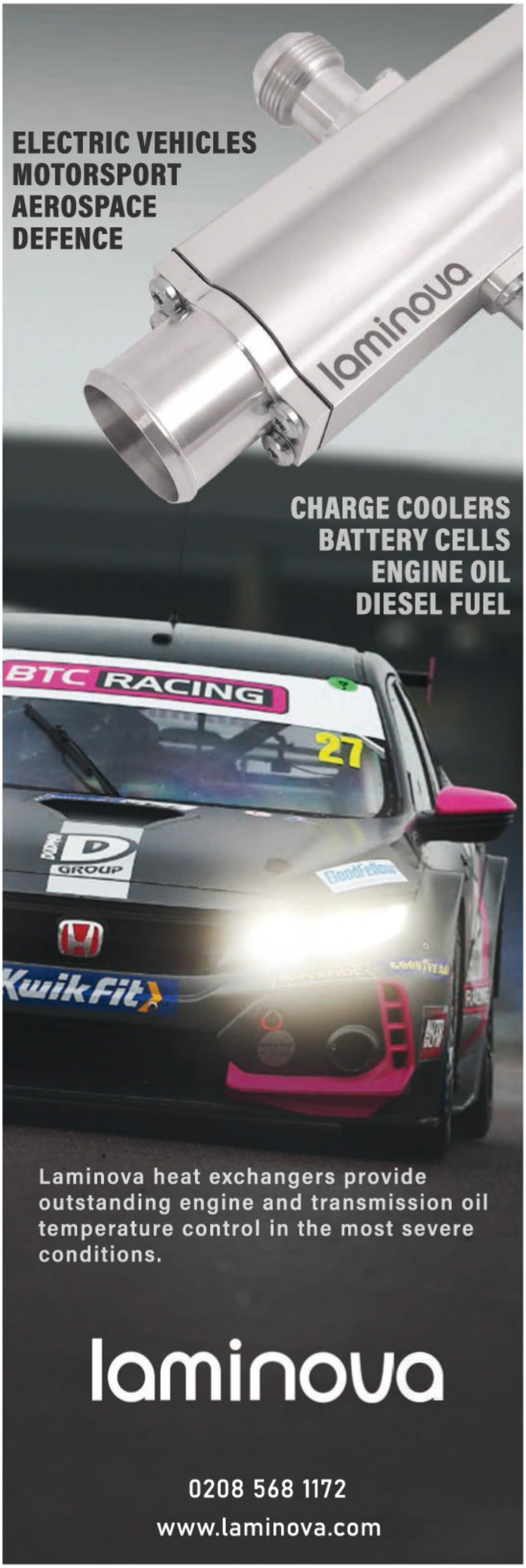
This raises the question of whether Audi is doing everything possible within the framework of the regulations.

Initially, it was difficult because another OEM, Alfa-Romeo, was at least *pro forma* on board. After its recent withdrawal, things will be a little easier, but the ownership structure will determine who has to contribute how much money to the programme. Some have therefore tried to speed up the takeover of Sauber, though performance clauses delayed the process.

Nevertheless, Audi recognised early on that Formula 1 is not a normal motorsport project. That is why all other racing activities, with the exception of the Dakar programme, were cancelled. Showing its commitment to F1, a practically fully developed LMDh car will now never race, although the resources behind it have been pooled for the F1 effort.

That said, there are sceptics, even in Audi's own camp. Those voices became louder when Audi appointed a new CEO in Gernot Döllner in September 2023. Markus Duesmann, under whose leadership the decision was made to join Formula 1, was removed as CEO of Audi AG ahead of schedule, independently of the new single seater project.

In the meantime, Döllner put his foot down, on the gas, and backed the project, which now continues with the originally approved budget, allowing it to operate at the limit of the budget cap.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Podium position

Podium regularly features in the Financial Times annual list of Europe's fastest-growing companies. It now employs over 80 people

How an Italian engineering start up grew to become capable of winning a prestigious FIA world championship tender

By DANIEL LLOYD

Eyebrows were raised in early December when Podium Advanced Technologies was announced as the chosen battery supplier for the fourth generation Formula E car in 2026-27. The Italian engineering firm was a relative unknown compared to the likes of McLaren Applied and WAE Technologies, which had previously held the post, so its selection came as a surprise to some. For the people working at Podium's expanding headquarters in north west Italy, it was a just reward for their hard work behind the scenes.

Podium is an very busy company, with its hands in many pies, from motorsport to marine. It was founded as Podium Engineering in 2011 and has grown since then to become capable of winning a major FIA tender just over a decade into its journey.

With that rate of progress, the company is on a trajectory that could see it mature into an engineering powerhouse with the size, resources and reputation to challenge those of much longer established concerns, such as esteemed Italian racecar constructor, Dallara.

Right place, right time

Podium is based in Pont-Saint-Martin, a small town close to the mouth of the steep sided Aosta Valley that winds up to Mont Blanc. It's on the outermost fringes of Italy's colloquial Motor Valley region, the bulk of which is located further east towards Lombardy and Emilia-Romagna. However, this geographical positioning on the outskirts played a part in getting Podium started in the early 2010s.

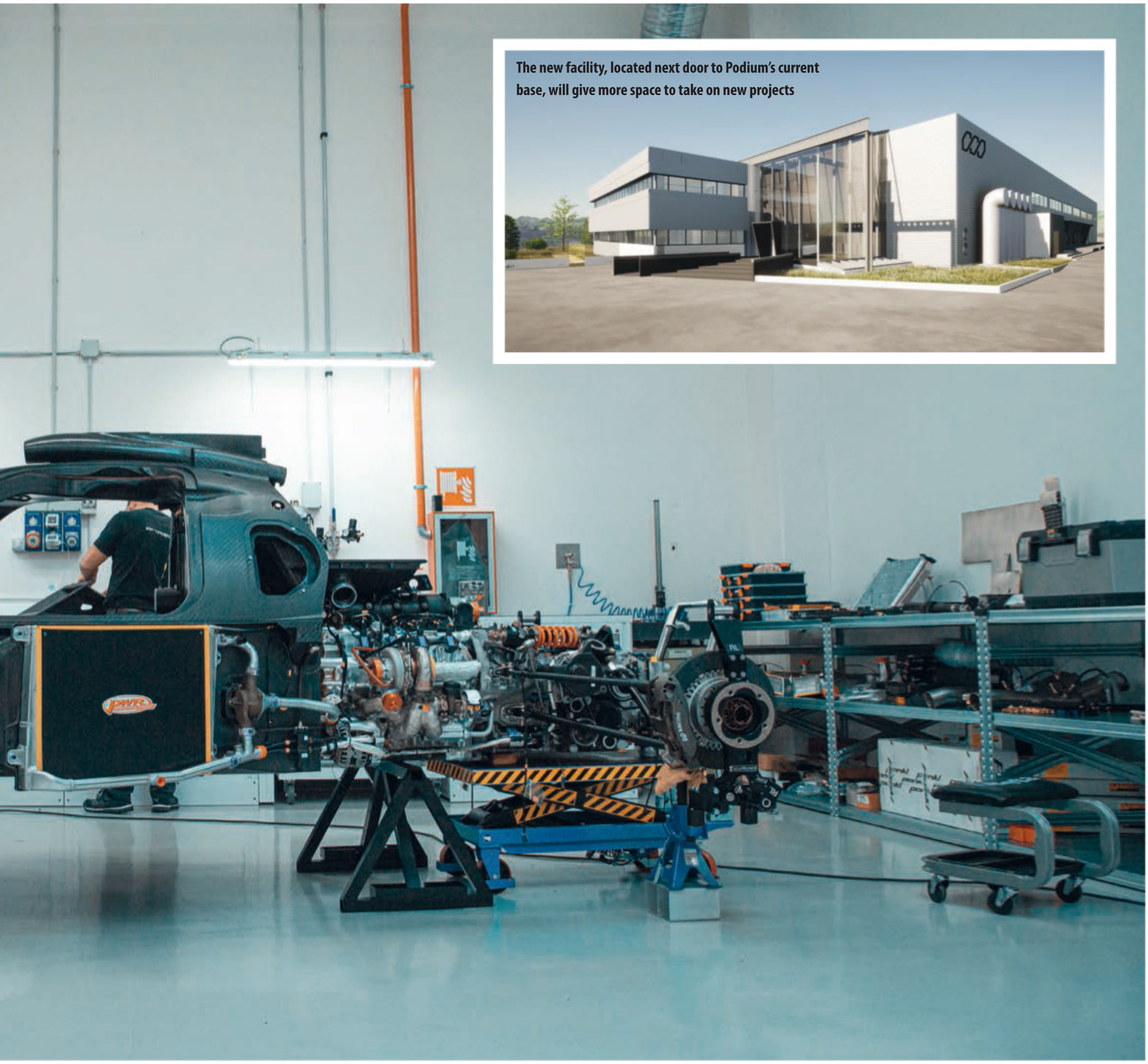
'We are located in north west Italy, which is historically well known for coachbuilders and designers like Pininfarina, Giugiaro and Bertone,' says Luca Ciancetti, head of automotive and motorsport at Podium, and one of its three co-founders. 'These companies are great names in the area of design, but the [geographic] area was not so attractive for mechanical engineering, powertrain and electrification. So we decided that there was some space for a company like ours.

'If we were positioned in a different area of northern Italy, like Emilia-Romagna further east, it would have been a different story.'

Ciancetti co-founded Podium Engineering alongside fellow Turin-based engineering graduates, Igor Zanetti (now the principal control engineer and IT manager) and

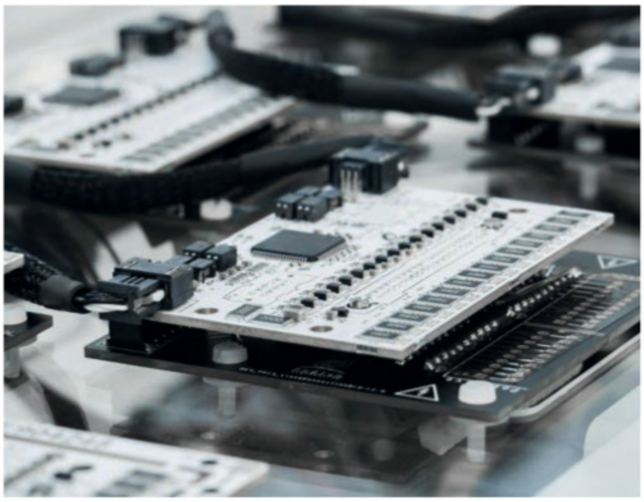
Turin is the nearest major city and has a technical university that produces plenty of engineering graduates hungry to get a foot in the door with Podium

Podium has simulated electric and thermal behavioural models for lithium battery cells, and has applied this knowledge to create bespoke battery packs up to 900V



The new facility, located next door to Podium's current base, will give more space to take on new projects

The prototype workshop contains equipment for racecar construction, parts testing, validation and 3D printing



Podium's battery management system has scalable slave-master architecture that works on systems up to 1000V. It is designed to be versatile for all sorts of applications

Mario Chiera di Vasco. It was a trio of 30 somethings full of ideas and ambition.

As those ideas turned into the reality of building and testing batteries, the company was re-named Podium Advanced Technologies in 2018 to better reflect its commitment to e-mobility projects.

One of the company's first major assignments was a commission from American film producer, financier and petrolhead, Jim Glickenhaus, to engineer his P4/5 Competizione racecar with a kinetic energy recovery system with a 400V battery.

The hybrid-powered Glickenhaus finished an encouraging 12th at the Nürburgring 24 Hours in 2012 and the two parties continued to work together. Their partnership blossomed as Podium helped to develop two subsequent non-hybrid Glickenhaus racers, the 003C and the 004C, and ran the American automaker's factory team at the Nordschleife.

In 2017, a Glickenhaus SCG 003C, driven by Jeff Westphal, claimed a shock overall pole position for the gruelling 24-hour race, beating FIA-homologated GT3 machinery.

'We started work with Glickenhaus in 2011 on the P4/5 Competizione, then the 003C,' confirms Ciancetti. 'This started the growth as we then began to work with suppliers.'

When 24 Hours of Le Mans organiser, the ACO, announced in 2018 that it would replace LMP1 with a new Hypercar class, Glickenhaus set about working with Podium to build a car for the LMH regulations. The development and operation of the non-hybrid Glickenhaus 007 soon thrust Podium into a world championship where it could compete against the factory might of Toyota.

Podium finish

The overall podium finish at Le Mans in 2022 stands out as the programme's finest achievement, although it probably would have taken a race win at Monza that season had a freak turbocharger failure not occurred.

Glickenhaus is not returning to the FIA World Endurance Championship this year (see p40), but its Hypercar effort helped raise Podium's profile and was a definite fan favourite, gaining a reputation as a plucky but mostly reliable machine that didn't quite have the resources behind it to provide a lasting threat to the oncoming manufacturers.

In parallel, Podium continued to work on electrification. A key project has been its development of the spec battery for the fleet of Ducati motorbikes racing in the FIM MotoE World Championship. Its contribution is an

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Luca Ciancetti, co-founder and head of automotive and motorsport at Podium Advanced Technologies

Francesco Monti, chief executive officer and head of battery systems at Podium Advanced Technologies

Podium's work on the Glickenhaus P4/5 Competizione's KERS system set the ball rolling in terms of hybrid drives and electrification

The Glickenhaus SCG 003C ran at the Nürburgring from 2015 to 2019. Podium assisted with the design of the car, which was powered by a 3.5-litre, twin-turbo, Honda V6 modified by Autotechnica Motori

XPB

800V battery pack, consisting of 1152 cells, with a capacity of 18kWh, a maximum power output of 200kW and a weight of 110kg.

Last year marked the first season of the Ducati era in MotoE with a field of 18 bikes. 'Based on knowledge [gained from the Glickenhaus P4/5], between 2013 and 2015 we have been able to supply batteries and energy storage for other racing series,' says Podium CEO and head of battery systems, Francesco Monti. 'Our customer at that time was Marelli and it was one of the first projects we delivered in that area. This is the foundation of our current capability in batteries. We are expanding, not only on motorsport projects like Formula E and MotoE, but in sectors like aviation and marine.'

Investing in research

Podium operates in a 'self-financing capacity', according to its website. This means that a chunk of its profits is reinvested to support research and development, amounting to around 10-15 per cent during its first decade.

'The main key is that we have invested in people and knowledge… We have also been lucky enough to find programmes and customers that challenge us in doing that'

Francesco Monti, CEO at Podium Advanced Technologies

The company's structure is very straightforward. It has five shareholders, including the three co-founders. There is no mysterious overseas fund in the background pumping money in, with the hope of then taking money out again. Its growth has taken place over a carefully executed cycle of project obtention, delivery and reinvestment.

In the summer of 2022, Podium launched a three-year investment plan worth over €20 million called 'Tech-Bat', focusing on electrification and battery systems. It is partially financed by a regional government grant and is aimed at bringing Podium up to the point of assembling more than 1000 battery packs per year.

'The main key is that we have invested in people and knowledge,' continues Monti. 'We always accept technical challenges. We have also been lucky enough to find programmes and customers that challenge us in doing that. For example, Mr Glickenhaus is a guy who trusted us, and allowed us to develop and deliver an LMH programme running three years consecutively at Le Mans.

'We have also been partnering on MotoE with Ducati, designing and producing all its batteries that last year raced in the championship. These kinds of things have been crucial. The other part is not being afraid to fail.' Ciancetti adds that forging and maintaining close relationships with clients has also been crucial to Podium's growth.

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Podium's long association with Glickenhaus was rewarded with this kind of scene, when the American independent automaker went up against the likes of Ferrari and Porsche at Le Mans

'Our approach is to be involved with the customer. Their failure is our failure,' he says. 'We want our projects to be successful. When you have commercial discussions, there are many factors involved. But what we were able to establish in our relationship is that we are committed to their success. We have always tried to transform that feeling into reality.

'We were able to create a track record of projects to start and deliver and most of them have been successful within all the constraints that a technical project can have.'

Room to expand

A clear physical sign of Podium's expansion is the commissioning of a new headquarters adjacent to its current base. The 17,250m^2 facility, established on a long-empty building, will house Podium's two main divisions – battery and vehicle – with testing facilities and assembly lines included. It is a keystone of the company's Tech-Bat investment plan.

'It's a brownfield site, so we are converting a former building,' says Monti. 'We are investing more than €10m (US$10.9m) in the new facility. Last September, we moved our first activities related to batteries there, and we plan to move all the people and operations this year. We are currently finalising the last few things, but it is already partially operative.'

Moving into a larger home will give Podium space to expand when it takes on more projects. It also accommodates the increasing number of full-time staff, which doubled to more than 80 between 2020 and the end of last year and includes auxiliary departments like human resources that grow in line with the engineering workforce.

'The new facility will allow us to have new capabilities, new test and build facilities for batteries, to make proper R&D development and to build cars,' adds Monti. 'Some parts will not be so much different [to the old facility], but some parts will be completely new, especially the part that is devoted to production.

'We will have semi-automatic benches to assemble batteries, which will be completely different, and a new operation in terms of warehousing, traceability and quality.

'We are also setting up new functions within our organisation to have the quality required to supply batteries for prototypes and automotive applications.'

The building Podium has now outgrown was established in 2016 and has received a series of upgrades since as the company took on new projects. For example, in 2018, Podium added a prototype workshop with nine assembly bays, while the following year it introduced an Industry 4.0 CNC machining workshop for the fabrication of custom parts.

Commissions have been diverse and not fixed on racing, with examples from other sectors including the development of battery systems for the Riva El-Iseo motorboat and the Hitachi-built trams used in Florence

Project commissions have been diverse and not fixed on racing, with examples from other sectors including the development of battery systems for the Riva El-Iseo motorboat and the Hitachi-built trams used in Florence.

It's not all been plain sailing, though. An accident during a battery assembly caused a fire to break out in the prototype workshop in 2021, although no injuries were reported and work resumed after repairs and inspection.

A pleasant surprise

Despite winning the MotoE battery tender, the news that Podium would be entrusted as Formula E's exclusive Gen 4 supplier came as a 'big surprise' to Monti, who was a hybrid powertrain engineer at McLaren Automotive before joining Podium in 2012.

Podium will create and assemble the Gen 4 battery pack, using cells from an external supplier that is yet to be confirmed.

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Alastair Staley/Formula E

Formula E's Gen 4 battery is set to be heavier than the current WAE pack, but with more power and capacity. Podium will arrive with experience of a big tender having supplied MotoE batteries

'When we decided to apply last summer, honestly, we felt our chance was not so high,' Monti candidly admits, 'but we ultimately did a really great job in the technical and other aspects of the tender.

'In the autumn, we started discussing with the FIA. We realised that our proposal was solid and, at the end of the year in December, when the final announcement was done, all the team was really happy.

'We are very proud of this big achievement. It's going to be another game changer for us, and another challenge in terms of project scope, but it matches our background. When batteries and motorsport join together at the highest level possible, it is something great. We are looking forward to making this project as successful as expected.'

For obvious reasons, Monti is limited in what he can say about the Gen 4 battery's technical details, other than predicting that it will be 'an improvement with respect to the current generation.'

The FIA tender proposed a maximum power output of 600kW, a capacity of 55kWh and a target battery pack weight of 340kg.

'Technical-wise,' Monti says, 'the targets are always the same: weight reduction, energy, the capability to deliver high power, supplying energy to the powertrain, harvesting and recharging with a quick process. We are working closely with cell suppliers to have something capable of doing that. And also, battery manufacturing-wise, optimising aspects like cell joining, thermal management, safety and reliability with proper electronic and software development.'

This year is an important one for Podium's Formula E project as it gears up for integration into the Gen 4 prototype car in early 2025. The company's foremost goal in the coming months is to produce the first prototype battery back that will be taken through the FIA's homologation process.

Testing and maintenance of the batteries will then be carried out at Pont-Saint-Martin in Podium's new headquarters.

'We already have a testing facility for cells and modular battery packs in our current building,' notes Monti, 'and we have announced one in the new building as well. All the performance programmes will be run in-house, battery-wise.'

Hydrogen hunger

Podium's growth as a battery supplier forms only part of its focus on sustainable technologies. The company has always been involved in electrification, with battery management systems and pack design being central activities, but it recently delved into the realm of hydrogen power when it developed and built the Blizz Primatist, a land speed record prototype that set eight FIA world records at the Nardò Ring last year.

Podium is now hoping to be involved in more hydrogen projects as the technology becomes more prevalent in racing.

> **'[winning the Formula E battery tender] is going to be another game changer for us, and another challenge in terms of project scope'**
>
> *Francesco Monti*

'We are investing in growing in other technologies and in software,' says Monti. 'Many of the new developments will also be software related, so this is what we are currently targeting in terms of establishing ourselves as a real international player.'

Podium has grown into a company with high potential in a short space of time. Its performance as the Formula E battery supplier will now be crucial in cementing trust across the wider racing industry.

OEMs are also taking note of its growing reputation and one has assigned Podium to help develop a new FIA GT3 car for 2026. But what does the long-term future hold for the company? Does it want to emulate its compatriot Dallara, and become synonymous with prowess in motorsport engineering?

There are smiles when the name Dallara is brought up as it's clearly a company that Podium's lead figures have looked up to during their engineering careers.

'Yeah, that is a dream,' says Monti. 'We are targeting being Dallara-like in these new technological fields.'

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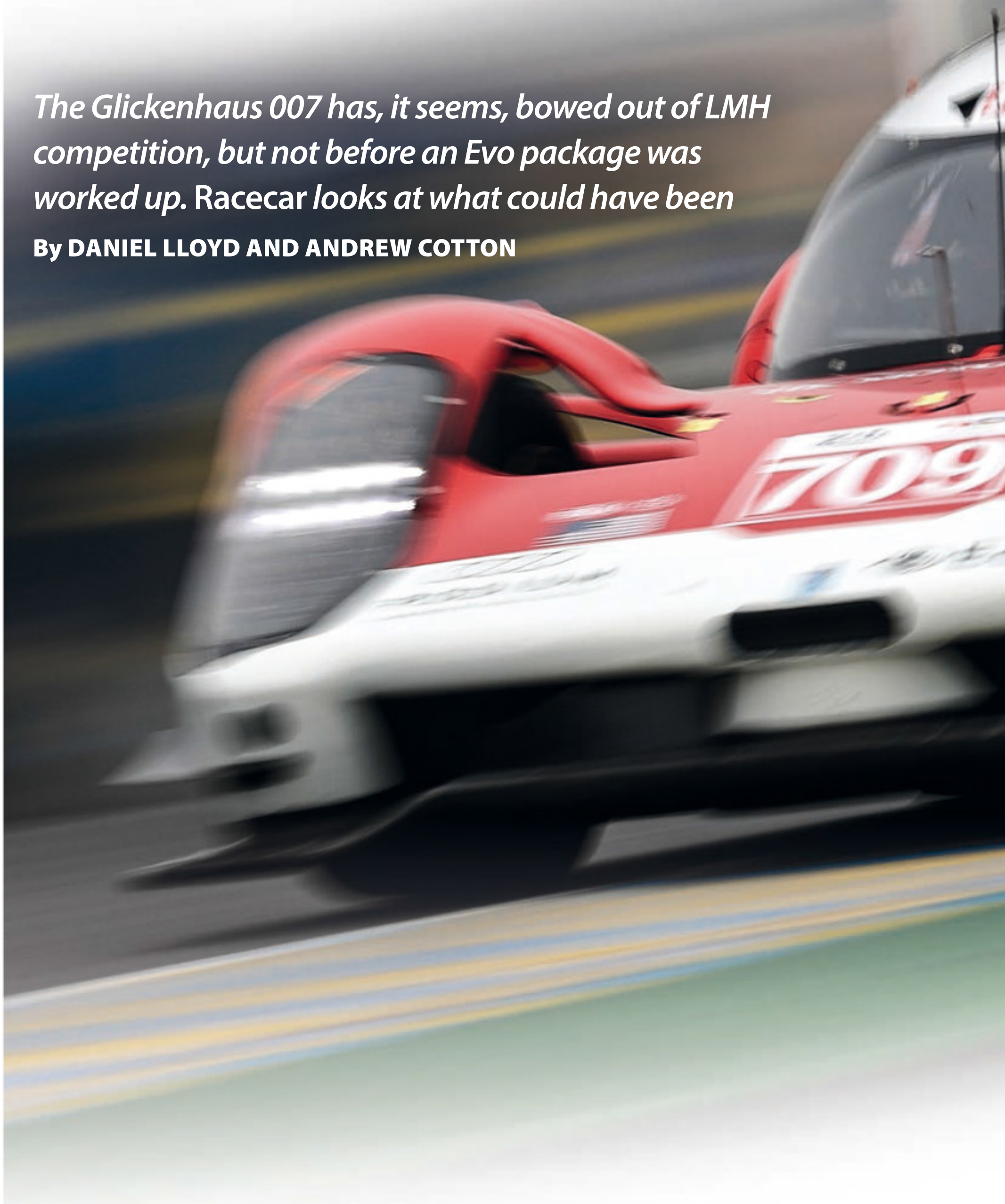
Ghost rider

The Glickenhaus 007 has, it seems, bowed out of LMH competition, but not before an Evo package was worked up. Racecar *looks at what could have been*

By DANIEL LLOYD AND ANDREW COTTON



The Glickenhaus 007 was a car built to LMH regulations and, like Toyota, it had to make compromises throughout as the demands changed to accommodate teams that never arrived. Originally, the LMH rules attracted the likes of Aston Martin, and the engine power requirements were raised to cater for the V12 unit that was fitted to the Valkyrie. That forced Glickenhaus to ditch its original Alfa Romeo twin-turbo V6 and go for a more powerful V8 engine from Pipo Moteurs.

But once Aston Martin confirmed it was not coming, leading to the creation of LMDh, the power demands were reduced again. In the middle this, Jim Glickenhaus and his partner team, Podium Advanced Technologies, were trying to accommodate these changes and build a competitive car.

Arguably, Podium did a better job of adapting its car than Peugeot, which only recently has managed to make the necessary alterations with its Evo kit just tested.

The Glickenhaus raced for three years, scoring two pole positions and two overall podiums including one at Le Mans, but the team did not have the finance to complete a full season, despite its car showing promise.

Strong running

'If you look back to our programme, it's clear that in the last two years, the car was strong in terms of reliability and performance on high-speed, low-downforce tracks like Monza and Le Mans,' says the car's designer and WEC team principal, and Podium's head of automotive and motorsport, Luca Ciancetti.

'In general, we were probably lacking aero performance in terms of downforce and, mainly, in terms of downforce stability. To be able to use the aero platform in a wider window with different set-ups, that was really the key lack of performance of the car as we were already at the minimum weight and maximum power.'

LMH cars, like LMDh, are balanced in terms of weight and power, but the second order differences caused the field to split.

'We had no structural issues on the car that didn't allow us to exploit the BoP performance window but, in terms of downforce distribution and set-up freedom, the car was really constrained,' says Ciancetti. 'The idea for the improvement was to have a new aero package to sort out the issues mentioned, with the target of being able to improve tyre warming up in the new regulations of cold tyres.'

The old adage is that no matter where you are on the grid, your job list is as long as everyone else's and it's only budget that dictates how much of it you get done. That was particularly true of the Glickenhaus.

The team knew what was needed, and indeed had an Evo design completed, but it was never built. Team owner, Jim Glickenhaus, maintained, with good reason, that the BoP should have sorted out performance discrepancies, and that it was in place specifically to avoid needing to spend money on car improvement.

'This Evo was actually designed and CFD tested last year, before the 2023 season,' says Ciancetti, 'but mainly for budget and timing constraints – at least when we had the budget for races – it was too late to integrate it, so it was never finalised in terms of development. However, the results from the simulation were really promising.'

Aero advances

One of the features of the revised car that set it apart was its adjustable front aero device. By regulation, LMH cars are limited to either a front *or* rear device, and the majority of the field went for a rear wing as it's the most powerful tool there is, and easiest to access.

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‘When we developed the car, the cooling system was designed for a higher power output that was then reduced in the regulations, so the car is still equipped with a cooling system that is more powerful than what we need’

Luca Ciancetti, Glickenhaus Racing team principal and head of automotive and motorsport at Podium Advanced Technologies

The 007 went the other way, and the Evo design aimed to clean up airflow around the front of the car. ‘It was only related to the management of airflow in the front section of the car,’ confirms Ciancetti. ‘There were some modifications [made] in the floor, the area of the front axle and the forward front section of the sidepods as we had a different way of managing the airflow coming from the side of the car. The car was actually very good from a cooling perspective, so we had the chance to reduce the cooling power a bit.

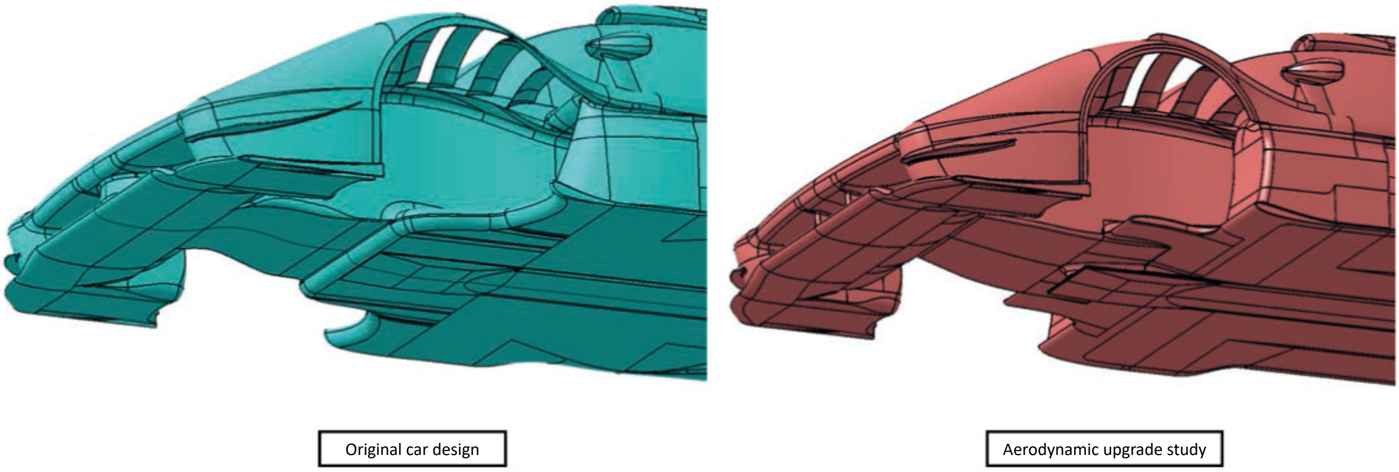
‘You have to consider that when we made the car, we had no data about LMH. And when we developed the car, the cooling system was designed for a higher power output that was then reduced in the regulations, so the car is still equipped with a cooling system that is more powerful than what we need.

‘When we designed the potential Evo, we knew we had this kind of freedom in the management of the airflow to the cooler. Removing some airflow from the coolers gave us some freedom to manage the downforce better.’

The air intakes were therefore reduced in size, which would have allowed for more room under the intake to better manage airflow to the rear. The car would still have had to fit within the aero limitations set for the class, with all cars featuring similar lift / drag numbers, but flow to the rear would have made a big difference to the performance of the rear tyres.

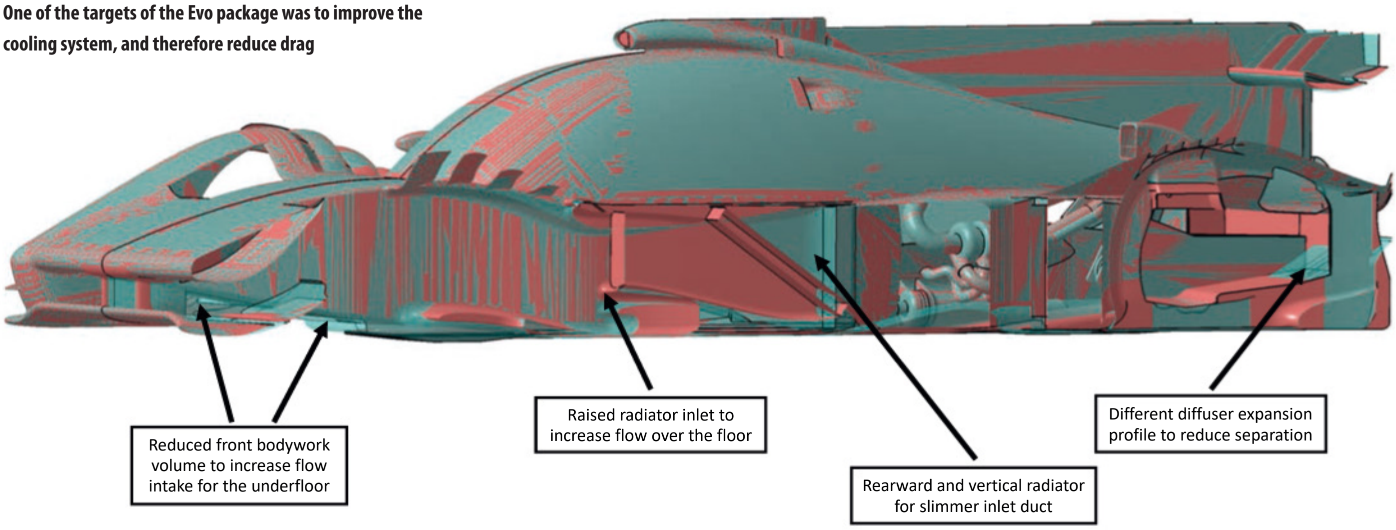
Indeed, one of the major drawbacks of the car was that it was a hungry beast when it came to rear tyre wear.

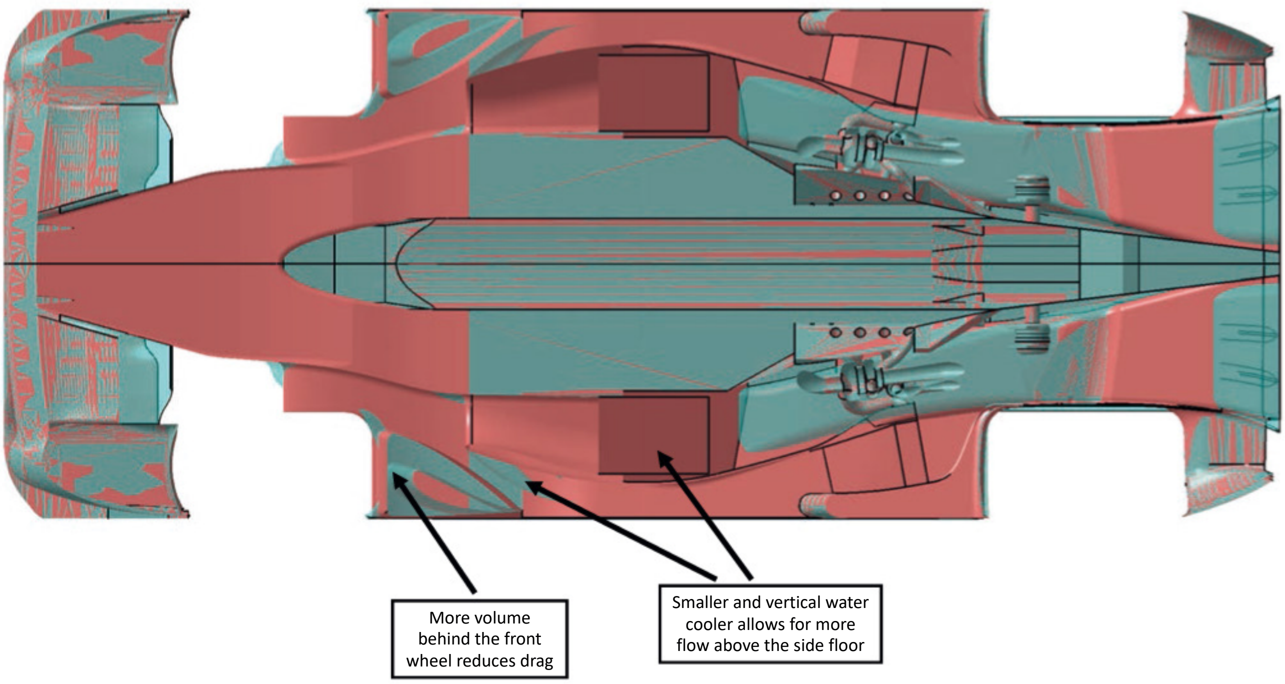
‘You always have to compare the actual result against your simulation,’ says Ciancetti. ‘If we took as reference the potential performance improvement given by the simulation output, we could have been way more competitive during the races. We ran the races based on reliability and pace over distance, but with the Evo I think we could have had a pace that was way closer to our competitors.



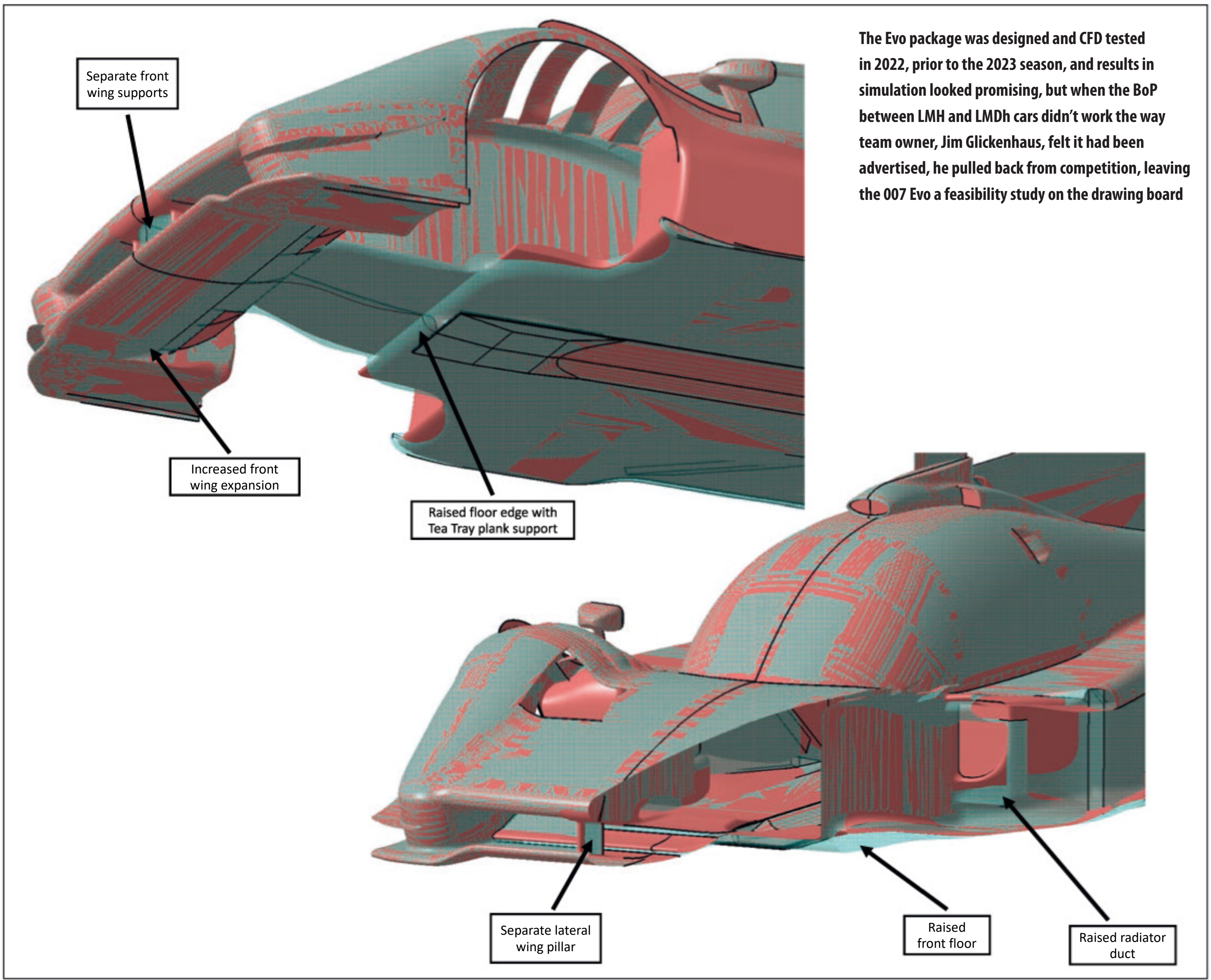
A major change to the design was to clean up airflow around the front of the car, which featured a front-adjustable aero device unlike many of its competitors

One of the targets of the Evo package was to improve the cooling system, and therefore reduce drag





The 007's designers agreed the car was lacking downforce stability in certain set-up parameters, so improving that was another focus



The Evo package was designed and CFD tested in 2022, prior to the 2023 season, and results in simulation looked promising, but when the BoP between LMH and LMDh cars didn't work the way team owner, Jim Glickenhaus, felt it had been advertised, he pulled back from competition, leaving the 007 Evo a feasibility study on the drawing board

'If the result would have been different… it's really too much unknown. All I can say is that we were expecting a consistent performance gain from our Evo.'

Although constructors are limited in what they are able to do, there are five so-called Evo jokers that can be played, allowing the car to be updated during its life cycle. As the cars are performance balanced, the FIA and ACO have to agree it's a reliability issue that is being solved, or approve a performance-based joker, which then has to be measured. It is no guarantee that, once the evolution kit has been designed, you can fit it to the car.

'You have some jokers and you have a full new homologation available,' says Ciancetti. 'Depending on the amount of modification, after the finalisation of the design, we could discuss the impact of the jokers, or request a new homologation. It's a complex process, so it's difficult to say.

'Once you have an Evo package, you can discuss in detail with the FIA to see if they will homologate it, and what kind of process you will follow. The regulation is quite clear, but it cannot cover 100 per cent all the details of the car modification. It is always up to the manufacturer to present to the FIA your ideas, and it's up to them to approve it and indicate what kind of upgrades they want to use.'

Ultimately, the car never made it to the FIA for joker deliberation, as Glickenhaus chose to focus on his company's other projects rather than keep pushing to finance the WEC effort.

Significant differences

The performance of the updated Toyota GR010 was certainly significantly different compared to 2022 as it dominated the opening two rounds at Sebring and Portimão.

'When we entered, we were told we would have a fair and equal chance to win,' said Glickenhaus at Spa in May last year. 'Last year [2022], we were within that window, or not too far off. This year, though, it is substantially different. We have to see if we believe there is a way forward to be successful. I am not going to race with no chance to win.'

At the Belgian race, he had already threatened to close down the LMH team, and said he would take the decision when it was obvious he could no longer compete.

'I don't think that if Toyota wins by a big margin, it will be good for anyone,' he said. 'If without investment it is impossible to compete, then we are being forced out of the championship. I think that's not in the spirit of the championship, and not something I am interested in.'

Against that backdrop, although the upgrade *could* have made a difference, and potentially brought the car closer to the front, it still would have been hard to keep up with the factory might of Toyota or Ferrari.

'It could have been a joker, or a new homologation,' concludes Ciancetti. 'We never got to present it to the FIA because we just made some studies and simulations. If you don't have the budget to finalise it, you are not going to disturb the FIA.

'If we had the budget to make it real, then we would involve the FIA and define how to make it legal from a homologation integration point of view.'

The team did not file an entry request for the 2024 WEC season, bringing to an end a popular privateer Hypercar effort that had more in the tank in terms of technology.

Hot shots

With fascinating aerodynamics and asymmetric set-ups, UK National Hot Rods are as interesting as the racing is spectacular

By MIKE BRESLIN

In the United States they say sidewalk, in Britain we say pavement. They say cookie, we say biscuit. They say stock car, and we say hot rod, which is especially confusing for 'car guys', but that's another matter.

That's simplifying it, but in essence National Hot Rods (NHR), one of the most popular and quickest of the United Kingdom's many short oval formulae, can be compared to NASCAR, or its lower divisions at least. The main reason they're not actually called stock cars over here is that another, older, British category uses this name.

To muddy the waters even further, in the US, the National Hot Rod Association (NHRA) governs drag racing, not short oval racing.

Nomenclature aside, there's no doubt NHR provides great racing, and the hot rods themselves are very interesting machines.

The class grew out of the hugely popular hot rod scene of the 1970s, which featured production-based cars, usually Ford's Anglia and then Escort, that developed into more specialised machinery through the subsequent decades. The cars are now rear-wheel drive, full spaceframe, silhouette racers, weighing 700kg with around 260bhp on tap, which translates to top speeds of over 90mph and cornering speeds of about 60mph around the tight asphalt ovals they race on (usually a quarter mile or 440 yards / 402m, but some are as short as 380 yards / 347m).

Interesting mix

There are plenty of hot rods competing in different series throughout the UK and Ireland, with grids of 34 not unusual. There's also an interesting mix of base cars, including Vauxhall Tigras – these small sports coupes have been winning races for many years – Peugeot 206s, Ford Fiestas, and even Ginettas and Lotus Evoras.

Paul Wright, who at the time of writing was leading the points standings for the run off-style World Championship Final qualification, is one of the many who competes in a Tigra, made for Spedeworth Fabrications by renowned racecar constructor, Sonny Howard's SHP Engineering concern, which builds the chassis for the majority of the NHR cars.

'The Tigra is still just a sleek, modern design,' Wright says of the car, which has not been available as a road car since 2009. 'It's small, aerodynamic and the centre of gravity is quite low.'

The Ginetta, meanwhile, has been designed and developed by Carl Boardley, an NHR world champion, former British Touring Car Championship driver and the reigning TCR UK champion.

While Ginetta's G40 might not seem an obvious choice for NHR, Boardley had some compelling reasons for choosing to develop it.

'In my opinion, it's just got everything going for it,' he says. 'The roofline is low, so there's not a lot of weight up high. Also, I had an association with Ginetta [having raced in the G55 Supercup circuit series]. But it's a bespoke car, and underneath it's nothing like a G40 made at the factory.'

The cars are now rear-wheel drive, full spaceframe, silhouette racers, weighing 700kg with around 260bhp on tap

With sturdy spaceframe chassis and extravagant aerodynamics, hot rods are the most technically advanced cars on the UK short oval scene

Cars based on Vauxhall's Tigra have been developed over many years and are still winning, partly thanks to the model's sleek silhouette

Martin Kingston / MK pics

Martin Kingston / MK pics

Martin Kingston / MK pics

Ginetta's aerodynamic G40 is a very familiar sight on UK race circuits, but is now making a name for itself as a short oval racer, too

While Ginettas and Tigras are rarely seen on UK roads these days, Simon Smith of Autoxross, an independent racecar constructor, has developed a Ford Fiesta more in line with the original hot rod philosophy.

'When I first started, the cars used to be based on small size family saloon cars,' he says. 'And then a few years back they let the Tigra in, which was more a two-door sportscar than a saloon. My dream was always to build a family-sized saloon car-based hot rod, and that's why we went down the Fiesta route.'

Sturdy frame

The regulations allow for the Fiesta shape to be 'chopped', to bring its profile more in line with the smaller cars, which means it's reminiscent of a 1970s Special Saloon.

While the Fiesta might be loosely based on a regular road car, it's pure racecar under the skin, with a very sturdy spaceframe at its core.

NHR spaceframes are mainly made of CDS, with T45 allowed on some critical parts of the structure. Perhaps surprisingly, there is more steel in the spaceframe than you would find in a regular circuit car, all of which is strictly controlled by the regulations.

As are things like the seating and engine position, which are both noticeably further back than you might expect.

'There's a regulation as to where the seat can be [which is] a minimum distance to the centreline of the rear axle,' says Boardley. 'There's also a minimum distance for the engine position, from the engine to the rear axle centreline.'

Over the spaceframes sit dramatically-styled body kits, made from a mix of Kevlar and GRP. 'Kevlar won't stand up on its own, so you need glass fibre to strengthen it,' notes Smith. 'The panels must be built to a certain thickness, and it's the same for bumpers and side skirts. It's basically layers.

'For instance, the front bumper has to be 5mm thick, so you put four layers of 600g glass fibre on, each of which is approximately a millimetre thick, and then you put a layer of woven Kevlar through it.'

In that respect, the material is a true composite, while it also has some practical benefits. Even though NHR is supposedly a non-contact category, close racing on tight tracks inevitably leads to, well, contact.

'The Kevlar itself is a really strong material and it's got a very good memory, so it will always go back to its original shape, while glass fibre tends to shatter,' says Smith. 'So, when someone gets damage, if you unbolt the crash frames off the front, the body kit normally springs back into shape. And then you can put a new crash frame on it and go back out and race it again.'

Wing things

Where these cars visually differ from their roadgoing cousins is with the aero, particularly the big rear wings.

'They have to stay within the confines of the original car,' notes John Durrant, NHR's dedicated scrutineer and tech chief, 'except for the height.

'We changed the rules two years ago, because they used to have to be below the roofline. Also, the bit at the front [the splitter] as well, because that was very restricted. We opened that up, so you can have that as long as you like now, but we don't allow aero under the car.'

That last point is a relatively recent change, and Smith estimates the cars lost around 25-30 per cent of their downforce when the full undertrays were removed. Much of that has been clawed back with the large rear wings, which most agree are very effective devices, despite the relatively low speeds the cars operate at.

Martin Kingston / MK pics

Autoxross has swum against the tide of current practice and chosen to build and develop a Ford Fiesta-based car that, while very much a contemporary racecar, is also a nod to the old days of National Hot Rods when the cars were based on regular family saloons

'If you take the wing off the back, it will rotate fairly sharpish, especially under braking on corner entry,' says Terry Hunn, one of the frontrunners in NHR. 'When I first started to run a wing, it instantly made the back more planted, and you could attack the entry of the corner a lot better.'

Boardley, partly because of his circuit racing experience, has devoted a lot of time to the aero on the Ginetta.

'We're running air scoops and stuff through radiators and moving air in different directions,' he explains, 'and then we will run a windscreen on it to send the air over the top of the car. We're also playing about with aerofoils and things like that, too.'

Smith also sees the benefit of a 'screen.

'We have found an advantage in running a window screen,' he confirms, 'though obviously when it's a dirty track, because you can't run window wipers on them, people tend to take them out. On a dry, sunny day, though, some put 'screens in.'

Hunn, who races a Fiesta, points out that there's more to the frontal aero than just a removable 'screen: 'The front's designed to make the air go around the sides to meet the turbulent air off the wheels. The manufacturer [Smith at Autoxross] did the wings [fenders] the way he did, squared off, because he felt that would give an aero advantage.'

Because of this, the Fiesta has an interesting aero quirk while running in traffic.

'When you overtake around the outside, you leave a gap,' notes Smith. 'You leave a couple of foot, and that's to get the airflow around the car. If you leave this gap, you will drive around them easily,' though the same can't be said for the car being passed.

Indeed, Hunn says he has had a couple of drivers come up to him and say, "When you're next to me, my handling feels terrible. Once you go past, it comes back again."

NHR spaceframes bear a resemblance to those used in NASCAR. They are CDS with T45 in some critical areas, and are certainly on the sturdy side. Note how far back the seat is mounted within the car

The Autoxross Fiesta is very well developed aerodynamically. So much so, its drivers leave a relatively large gap to other cars around the outside of bends to allow the aero to work at its best

Windscreens are optional, and are used as a simple aero tweak if conditions allow. Current NHR regulations say rear wings can be higher than the roofline, while splitter-style bibs at the front have been a recent area of aerodynamic development

'They clobber the fence, and they clobber each other, so if you built it like a circuit car, you wouldn't even do a couple of laps. You'd be in the fence'

Simon Smith, director of racecar constructor, Autoxross

Martin Kingston / MK pics

With the tight packs of cars that are a feature of National Hot Rods, there's plenty of action, which means the suspension also needs to be on the robust side to ensure the car makes it to the flag.

Clobber job

'It's fairly chunky,' concurs Smith. 'They clobber the fence, and they clobber each other, so if you built it like a circuit car, you wouldn't even do a couple of laps. You'd be in the fence because your suspension is broken. So you have to build it fairly robust, though it is still finely tuned.'

A mandatory beam axle at the rear means there's not so much work there, but at the front there's plenty of scope for development.

'The front end is free, though we try and keep it quite simple,' says Boardley. 'It's a wishbone set up and everything's adjustable but, once you've got it set and it works, it's fairly easy to keep on top of and to maintain.' Overall suspension philosophy, however, is very much down to the driver.

'Some drivers like a stiff car, some like a really soft car,' says Smith. 'But the new Hoosiers are quite a soft tyre and, if you have the suspension too hard, it wears the tyre out too quickly, so for that reason most tend to run softer springs.'

With the above in mind, it's no surprise to learn that effective damping is very important. However, what is surprising is the cost cap of £600 that's been placed on dampers. At first glance, this restriction seems inspired, but it doesn't mean people aren't still spending good money in that area.

'The dampers play a very big part in it. They have to be right, and they have to be valved right,' explains Smith. 'The damper costs [a maximum of] £600 [approx. US $765] a corner, but if you then want to change your valving, you can spend more on each damper. So each set keeps within the rulebook, but you've then just spent all this extra money having them finely tuned.'

One of the defining features of oval racing is the cars only turn one way, and in the UK that's to the right, which means there are some "staggering" tricks to make the cars as right-handed as possible.

'They've got a shorter wheelbase on the inside than the outside,' says Smith. 'And the car is raised up higher on the outside than it is on the inside to allow it to sit flat through the corners. We normally run about 20mm difference [in wheelbase] between one side and the other with the Fiesta, but some people run 25mm difference, depending on what car it is.

'So, when you let go of the steering wheel, the car turns right. That means you have to fight with it in a straight line, but turn-in is really easy.'

Tyre banking

'Also, with the tyres, you measure their diameter, because every tyre comes out slightly different. You then put your bigger tyres down the outside and your smaller tyres on the inside to create even more stagger.'

Tyre allocation is strictly controlled using a barcode system, with only a single new Hoosier slick allowed per meeting, though this does not necessarily mean there will be a disparity of grip across the car.

'You're allowed to bank the tyre,' explains Boardley. 'So, although you're only allowed one new tyre per meeting, you don't have to use it. What we tend to do is have three or four meetings without putting any new tyres on, and then we put a set of four new tyres on.'

This means the tyres need to be carefully looked after, both on and off the track.

'It's just keeping the tyre surface clean and scraping any excess rubber off, and stones and stuff like that. Basically, keeping the tyre in as good a condition possible,' confirms Boardley. 'And from a driving perspective, trying to be a little bit conservative with them, too. Because if you're going to be using it for three or four meetings in a row, that's potentially six or eight weeks that you're going to have the same set of tyres on the car.'

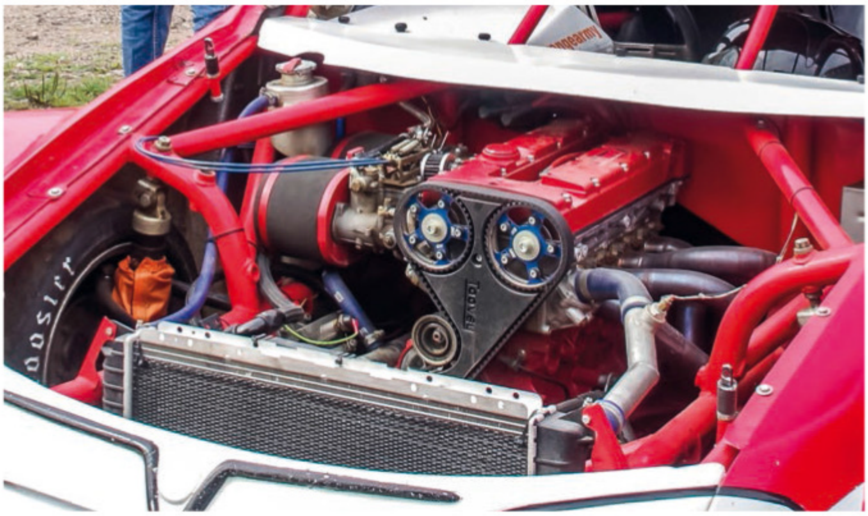
Engine philosophy

It's not surprising, then, to learn that tyre life drives the engine philosophy, to a certain extent at least.

'You can have more power, more torque, but then you can't make the tyres last because you haven't got the grip,' says Shane Bland, a former hot rod racer and the 2018 European champion, who now helps with the promotion of NHR.

‘You can waste a lot of time with a powerful engine that can make a car really quick for three laps, but the tyres can’t tolerate it’

Shane Bland, 2018 European Hot Rod Champion



Martin Kingston / MK pic

Power comes courtesy of race-tuned, 2.0-litre, 16-valve engines from either Ford or Vauxhall. The former (shown) being the venerable Duratec, the latter the ‘Redtop’ XE. Whichever you chose, they must run on carburettors

Carl Boardley’s engine building concern assembles Vauxhall (shown) and Ford engines. Both develop around 260bhp, but the all-aluminium Duratec is 8.5kg lighter than the XE. However, that’s not necessarily seen as an advantage

‘You can waste a lot of time with a powerful engine that can make a car really quick for three laps, but the tyres can’t tolerate it. There’s always a trade-off, where you say, okay, I need to bring the power down and then I can drive it faster for longer. There’s a lot of that involved.’

Hence the powerplants are often tuned to make them more driveable, whether that’s through cam timing or the carb’ settings (the regulations state that engines must run on carburettors, not fuel injection).

Those engines are either the Ford Duratec or the Vauxhall XE ‘Redtop’, both 2.0-litre and 16-valve, which can cost anywhere between £8,000 and £12,000 from a specialised engine builder.

Boardley is one of the most successful power unit builders in NHR, piecing together both Ford and Vauxhall units for many competitors. However, he notes that while there are plenty of Duratec base engines still around, the Vauxhall motor is becoming increasingly hard to find as a donor.

Further complicating matters, the XE comes in a variety of specs, so you need more than one base engine to build a race one.

‘With a Vauxhall engine, they have to buy three engines at the moment to get the right combination of parts,’ explains Durrant. ‘It’s just that certain bits on certain engines work. The crank’s a light crank in one sort of engine, but that’s got the wrong block. The right cylinder head – I think it’s Cosworth – is only on certain engines, but not the ones with the right block, and they’re not with the right crank.’

Stock base

Despite the stock base, NHR engines are far from standard when finished.

‘They’re quite complex,’ says Boardley. ‘It’s fresh pistons, fresh rods, a dry sump system with an external pump. That takes care of the bottom end.

‘Head-wise, we’re allowed to port to a certain point, sort of in the valve throat area and around the valve head. Then it’s replacement guides and valves, new springs, retainers, buckets, new cams, new vernier wheels… Literally everything’s changed. We use a head casting, a block and a crank. That’s it. Everything else is replaced.’

While there doesn’t seem to be much difference in terms of performance between the two engines, the more modern Duratec does have an aluminium block in its favour.

‘I think the difference, if you were doing the complete installation, is that [the Ford] is probably around about 8½kg lighter,’ notes Boardley. ‘It’s not a massive advantage, but it’s a little bit of weight that could help.

‘However, for the short ovals, I personally think that what you gain with a Duratec in weight distribution, you lose, potentially, in a little bit of reliability, because it’s an aluminium block and head.

‘I’m not a lover of the aluminium block for the racing we do. We’ve had an instance where someone went into the wall and the aluminium block actually twisted. In that case, rather than repair the car and go out again, it was like, oh, we’ve crashed and we’ve knackered an engine.’

Another major area of development is the exhaust. While the silencer on the tailpipe is a controlled part, the manifolds are free, and it’s here that much of the development takes place, with special coatings to combat heat, but also elaborate contortions to make sure each tube is exactly the same length.

Durrant mentions that, in the long term, NHR might look at allowing newer engines, to counter further sourcing issues, while fuel injection could also be permitted.

As far as the electronics are concerned, MBE ECUs are mandated.

‘They have two seals,’ notes Durrant. ‘They have a seal from MBE and then I seal them, and I carry two with me. So, if I think something’s a bit quick, I can say, “Can you just plug this in for today, please?”’

Gearbox graft

The power is transferred via full race sequential gearboxes, usually from Quaife or Elite. ‘Most people use the Elite gearbox, which is a three speed,’ says Smith. ‘You have a first gear and two seconds [second and third gear are very close in terms of ratio] so, if you’ve got a clear track, you can

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'You can't be racing at the end of your car. You've got to be racing three, four or five cars in front… Racecraft is a massive thing in this game'

Carl Boardley, four-time NHR world champion

Sequential racing gearboxes from Elite and Quaife are popular options, though racers typically only use two gears in a race, occasionally three. Differentials are free and can be changed to suit the different tracks the series races on

get it into third and it gives you a couple more miles an hour. If you're in traffic, you drop it back to second, which gives you a little more snap out of the corners.'

Although the small oval tracks the series races on appear to be very similar, there are massive differences between them, so ratio changes for each venue are common, as are changes to differential settings, and even the diff' on occasion. These are free and Titan and Elite plated units are popular options.

Driving perspective

It is actually quite amazing how different these ovals are, to the extent that you will get drivers who are super fast at one venue, yet not so hot at another.

'They're very different from a driving perspective,' confirms Hunn. 'Ipswich, for example, because of the way the corners are, you can carry a lot more speed into them. Hednesford is more flat out, so you're more aggressive and, because it's banked, it's real fast all the time. And then you go to the lower speed tracks, somewhere like Yarmouth or Aldershot. They're more technical in how you enter and exit the turns.'

The driving challenge is, of course, magnified when fighting in traffic, something Boardley says is the real secret to success in NHR.

'You've got to be seeing what's going on way in front of you. You can't be racing at the end of your car. You've got to be racing three, four or five cars in front. Because if someone's getting boxed in, or there's a slower car on the inside, you've got to be making that move to position the car before the person in front of you does.

'Racecraft is a massive thing in this game.'

To be a competitive part of the game, you would be looking at spending around £50,000 (approx. $63,800) to have a new car built from scratch, though after that initial outlay Boardley says it's quite feasible to race on a budget of around £1000 (approx. $1275) a meeting.

'If you did a whole series, with rebuilds and a bit of damage, I think a realistic budget would be around about 30 grand [approx. $38,300],' he concludes.

Which is pretty good, considering you get a few outings at each meeting, and you're all but guaranteed door-to-door action in every race. There's also plenty of events throughout the year, which is another thing that makes it a bit like NASCAR.

So, if you fancy an affordable, NASCAR-style engineering challenge in the UK, NHR could be just the thing. Just don't call them stock cars…

Martin Kingston / MK pics

The secret to NHR success is to be aware of what's happening in the pack way ahead of you, and to position yourself early to best advantage. From this angle, the height of the rear wings is clear


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Jean-Pierre Jabouille enters the Renault pits in a new RS10 during practice for the 1979 Dutch Grand Prix at Zandvoort

Blown in the wind

How Renault pioneered the use of turbochargers in Formula 1

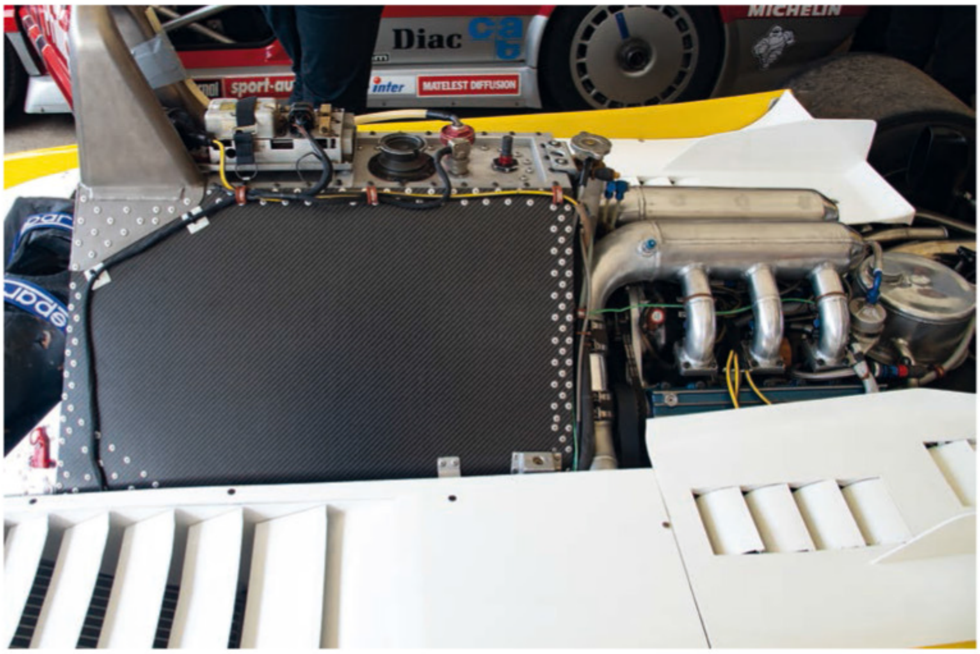
By WOUTER MELISSEN

Grand Prix Photo

The Renault Gordini EF1 V6 was also used in the manufacturer's endurance programme and powered it to victory at Le Mans before it withdrew from sportscar racing to concentrate on Formula 1

History was made during the 1979 French Grand Prix. The epic fight between Gilles Villeneuve in a Ferrari 312 T4 and René Arnoux in a Renault RS10 is the stuff of legend. But however tantalising the wheel-to-wheel fight was, it was 'only' for second position for, while all eyes were on the brawling duo, Jean-Pierre Jabouille was making history as he drove his Renault to the very first grand prix win for a turbo-engined Formula 1 car.

Three seasons in the making, Jabouille's victory did not come easily. The first Renault grand prix racer was dubbed RS01 but, especially in the British media, was often referred to as the 'yellow teapot' as the French V6 engine that powered it had a habit of expiring quite spectacularly. Very much an experimental racecar, not only was the RS01 the first F1 car powered by a turbocharged engine, it was also the first to use radial tyres.



The thirsty twin-turbo engine required an additional fuel load, which was carried in a tank mounted between the engine and driver

Sportscar victory

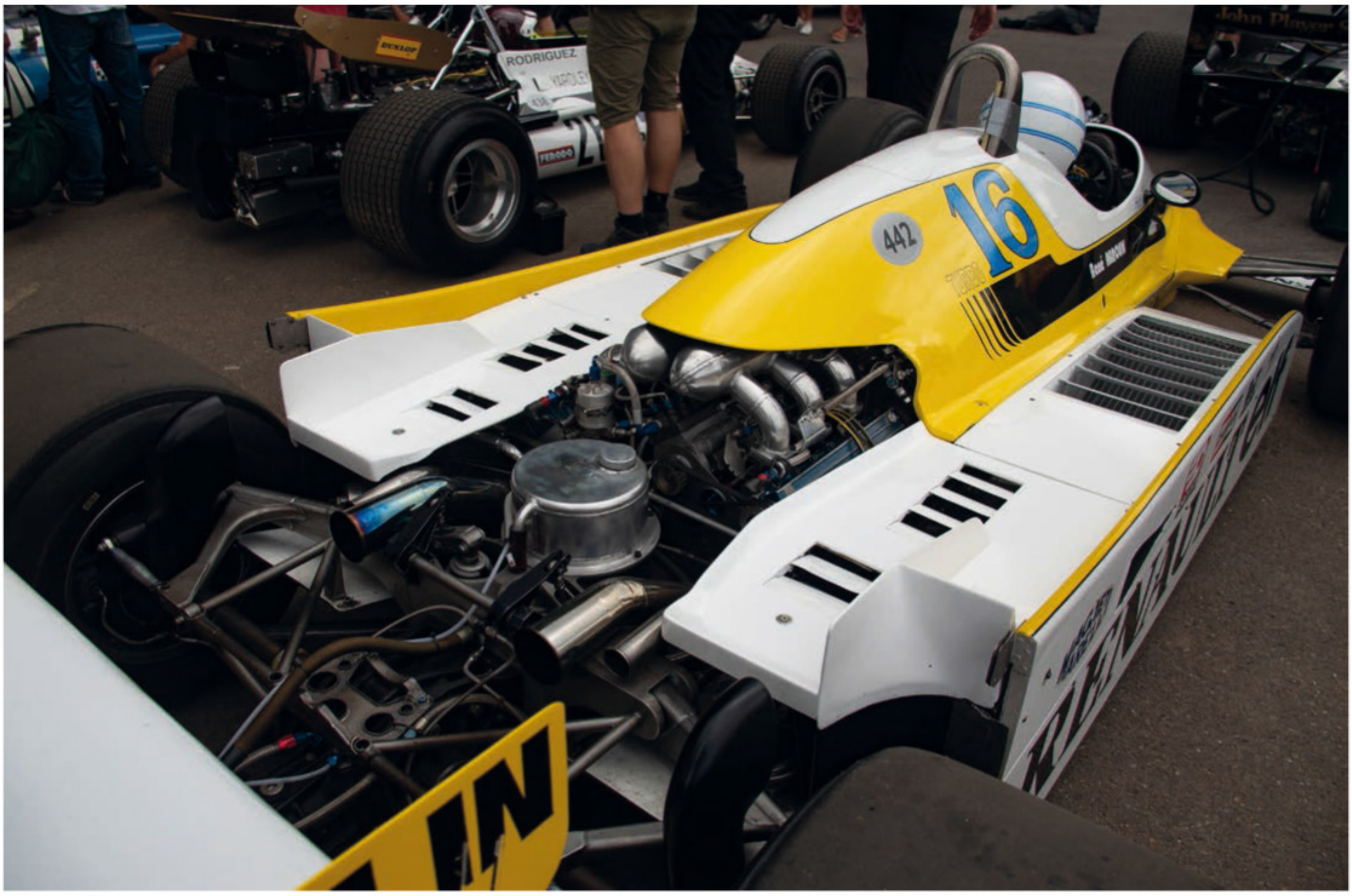
During the 1977 and 1978 seasons, Renault Sport ran its F1 programme alongside a sportscar effort. Although very different machines, both racecars used versions of the same, single turbo, V6 engine

The sportscar programme came to a natural close in 1978 when Didier Pironi and Jean-Pierre Jaussaud beat the Porsches to victory in the 24 Hours of Le Mans.

Elated at reaching the top, Renault Sport withdrew from sportscar racing with immediate effect to focus on F1.

Apart from the engine and tyres, the RS01 was a wholly conventional 1970s grand prix racer. Compared to its contemporaries, like the ground effect Lotus Type 78 and Type 79, the first Renault Formula 1 car was lacking, certainly in terms of aerodynamics. The RS01 made up for that thanks to the power of its turbocharged V6 engine, which exceeded that of the naturally aspirated, 3.0-litre engines of rival teams.

In its third season, the RS01 scored a maiden pole position at the 1979 South African Grand Prix, with Jabouille driving. However, engine and gearbox reliability issues thwarted the Renault during the races.



F1 regulations at the time limited forced induction engines to 1.5-litres (vs 3.0-litres for NA engines), so Renault tried increasing the size of the turbo, but eventually opted for two smaller units

Running two smaller turbochargers aided driveability by significantly reducing turbo lag, but it was also hoped they would improve reliability, too

With all resources now available for the Formula 1 programme, a brand new car was developed. Dubbed the RS10, it would ultimately make its debut in the 1979 Spanish Grand Prix, the fifth of the 15-round Formula 1 world championship that year. In charge of the design were technical director François Castaing, chief designer Michel Tétu and engine man Bernard Dudot.

Driver Jean-Pierre Jabouille, had a double duty as he also served as engineering director, focusing on engine development.

While the Formula 1 engine was similar in design to the Le Mans-winning V6, it had to operate in a different performance window. For sportscar racing, the governing bodies had agreed on a 1.4 equivalency factor between forced induction and naturally aspirated engines. This meant that Renault could run a 2.1-litre turbo in the 3.0-litre prototype class at Le Mans.

The Formula 1 regulations had the same 3.0-litre displacement limit, but only allowed for 1.5-litre forced induction engines.

More boost

To make up for the significant reduction in displacement, a larger Garrett turbo was fitted to the Renault-Gordini EF1 that powered the RS01. Not designed to run for 24 hours, a higher level of boost could also be used. While the bigger turbo helped the 1.5-litre V6 match the power levels of the 3.0-litre V8 and flat 12 engines used by Renault's rivals, it suffered from excessive throttle lag. By the time the large, exhaust-driven turbine had spun up sufficiently, the power arrived with such brute force that the car was very difficult to drive.

The original EF1 was also prone to overheating, and the extra boost didn't help.

To address these issues, the EF1 was extensively re-worked for the RS10. The most fundamental change was the use of a pair of KKK (Kühnle, Kopp and Kausch) turbochargers. Running two smaller turbochargers aided driveability by significantly reducing turbo lag, and as a side effect it was also hoped they would improve reliability, too.

The turbochargers were mounted either side of the engine and fed fresh air through small NACA ducts in the bodywork.

The 'boosted' air was cooled by one intercooler per turbo / cylinder bank before being ducted into the intake plenums.

Driven by belts at the front of the engine, the French V6 sported twin overhead camshafts and four valves per cylinder. Fuel injection was provided by German specialist, Kugelfischer.

The 1.5-litre EF1 V6 was rated at around 510bhp, running at 1.6bar boost. That was a similar figure to the power outputs of the most powerful 3.0-litre atmospheric engines used by the other teams. Especially compared to the high-revving Alfa Romeo and Ferrari 12-cylinder units, the EF1 did produce more torque but, thanks to its additional ancillaries, was also the heaviest engine on the 1979 Formula 1 grid.

Stressed member

Mated to a Hewland-sourced, six-speed gearbox, the compact V6 served as a fully stressed member of the chassis.

The drivetrain was bolted to a relatively narrow, but long, aluminium monocoque, the dimensions of which were dictated by the ground-effect tunnels that ran on either side of the chassis and the considerable size of the fuel tank, which was placed between the driver and engine. The reason for this was the twin-turbo V6 was quite thirsty, requiring an additional fuel load be carried.

As a result, the RS10 had one of the longest wheelbases of the field, despite having the shortest engine.

As on the RS01, the front suspension consisted of double wishbones with rocker-actuated coil springs and Koni dampers. At the rear, the disc brakes were moved outboard, while the springs and dampers were moved inboard. Sandwiched by the engine and gearbox, these were also actuated by rockers on the top wishbones.

Ventilated and cross-drilled disc brakes with twin calipers were fitted on all corners and, as before, Michelin radial racing tyres.

The changes to the rear suspension and the design of the monocoque were the result of the ground effect aerodynamics adopted by Michel Têtu. These relied on a clean airflow through the tunnels mounted in the sidepods on either side of the engine and gearbox. These had a reversed wing shape to create a venturi effect, accelerating the air running through them and creating negative pressure, effectively sucking the car to the track. The front and rear wings served mainly to trim the downforce and balance the car.

Radial switch

Renault also continued its partnership with Michelin to run the radial slick tyres first used in F1 by the RS01 during the 1977 season. Michelin had patented radial tyres for use on cars in the late 1940s, but their use in motorsport came much later.

Compared to the bias ply tyres used previously, the radials featured more compliant sidewalls, which distorted under cornering load, allowing for the much stiffer tread area of the tyre to maintain contact with the surface. Although the new tyres were superior in theory, Michelin faced a huge learning curve in F1.

Ferrari also recognised the benefits and switched to the French tyre supplier at the start of the 1978 season. Shortly thereafter, radial tyres were universally adopted by motorsport in particular, but also the automotive industry as a whole.

Another long-term French backer of Renault Sport retained for 1979 was Elf. In fact, the EF1 nomenclature of the engine was said to be in recognition of the oil company's long-standing support.

Ground effect season

While the Renault RS10 stood out because of its forced induction engine, the rival teams were all fighting to explore and harness the opportunities of the ground effect aerodynamics pioneered by Lotus in 1977 and 1978. The British team pushed the envelope too far with the wingless Type 80, whereas the likes of Ferrari, Williams and Ligier all produced their first ground effect designs in 1979. Such was the rate of progress that first Ligier, and then Ferrari, but ultimately Williams had the dominant car during the 1979 season.

Compared to the bias ply tyres used previously, the radials featured more compliant sidewalls, which distorted under cornering load, allowing for the much stiffer tread area of the tyre to maintain contact with the surface

Amidst all this, the first RS10, appropriately tagged with chassis number RS10, was ready to go racing at the 1979 Spanish Grand Prix at the end of April. It was allocated to Jabouille, while his team mate, Arnoux, was still in the RS01. The difference in time between the two cars was still minimal and Jabouille's retirement from the race showed that the RS10 was not the instant improvement Renault Sport hoped it would be.

At the Monaco Grand Prix, the team had chassis RS11 ready for Jabouille, so Arnoux could race RS10. It was another difficult race, but Jabouille did reach the finish, albeit seven laps behind the Ferrari of Jody Scheckter.

Next up was the all-important French Grand Prix. With Ligier winning three of the first five grands prix of the year, Renault was particularly keen to put on a good show. The RS10 was clearly on song that weekend, perhaps down to the altitude of the Dijon-Prenois track that favoured the

Grand Prix Photo

The RS10 evolved into the RS20 for the 1980 season. Here, Jean-Pierre Jabouille leads team mate, René Arnoux, and Alan Jones (Williams-Ford) in the 1980 South African Grand Prix at Kyalami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While all evolutions of the RS10 suffered from reliability issues, the car is still considered a defining moment in Formula 1 history as, by the mid-1980s, every car on the F1 grid was turbocharged

turbocharged engine, but perhaps due to other characteristics of the circuit that particularly suited the new Renault.

In qualifying, Jabouille was easily the fastest man on track with a 1m07.19s lap. Arnoux was second, and the only other two qualifiers within a second of pole were Villeneuve in a Ferrari and Nelson Piquet in the Alfa Romeo V12-engined Brabham.

For a change, Jabouille, and more crucially his Renault, managed to copy the Saturday form on Sunday and score a historic victory for a French car, powered by a French engine, using French oil and tyres. It was undoubtedly a great day for French motorsport.

In the process, Jabouille also became the first French winner of the French Grand Prix since Raymond Sommer in 1948.

It was a breakthrough moment for an exhaust-driven turbo engine and the first grand prix win for a forced induction engine since the Alfa Romeo 159 of 1951.

Epic battle

All the above was somewhat lost in the reports the following Monday morning, though, as all eyes had been on the epic battle for second place between Villeneuve and Arnoux. The Canadian Ferrari driver had grabbed the lead early in the race, but dropped to second behind the eventual winner on lap 46 of 80.

Towards the final laps, Arnoux closed the gap to Villeneuve and the two drivers swapped positions several times in the most spectacular fashion. Eventually, Villeneuve finished the race second and Arnoux a fraction behind in third, with Jabouille's victory almost a footnote to proceedings.

Years later, Arnoux described the battle as his finest memory of grand prix racing, although he also confessed that, at the time, he was mainly disappointed for losing the battle to Villeneuve.

With the Ferrari and second Renault also on the podium, it was an equally historic 1-2-3 finish for Michelin and the company's new radial racing tyres.

The RS10 continued to be very competitive for the remainder of the season, scoring several pole positions and setting the fastest lap during the Austrian Grand Prix.

It was proof of concept that the other teams and engine manufacturers needed to produce a forced induction engine and, by the mid-1980s, every car on the Formula 1 grid featured a turbo

However, reliability issues persisted and the only notable results in the remaining seven races were two second place finishes for Arnoux at Silverstone and Watkins Glen.

For the 1980 season, the RS10 evolved into the RE20, which was another hit and miss grand prix car. More successful, though, as it did score three wins, but Jabouille also failed to reach the finish in 11 of the 13 grands prix he started that year.

Forced development

Today, the RS10 is best remembered for the spectacular end to the 1979 French Grand Prix, but it should also be considered among the most influential Formula 1 cars of all time. It was proof of concept that the other teams and engine manufacturers needed to produce a forced induction engine and, by the mid-1980s, every car on the F1 grid featured a turbo.

The most powerful of these engines produced well over 1000bhp in qualifying trim, almost double that of the Renault that pioneered the technology in 1979.

Renault continued to be successful during this era, both as a manufacturer and as an engine supplier, but, ironically perhaps, did not reap the ultimate reward of a world championship success until F1 switched to naturally aspirated engines again from 1989 onwards.


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Message in a battery

How understanding and optimising energy use in EV racing is feeding back into the electric road car marketplace

By LAWRENCE BUTCHER

With a spec battery and all teams in Formula E converging on similar single, radial flux motor and single-speed transmission solutions, energy management strategies have become a vital tool in the race to the flag

All-electric racing may not be taking off at the same rate as EV road car sales but, over the past decade, motorsport has provided a valuable proving ground for the technology. Though the spotlight is often turned on hardware, the honing of energy management strategies is just as important.

In a previous issue of *Racecar Engineering*, we discussed the challenge of energy management in Formula 1 hybrid systems but, if one looks to pure electric racing, and Formula E in particular, it is energy management throughout a race that ultimately determines the winners and losers.

Of course, hardware has a crucial role to play. In the case of Formula E, the battery is a fixed quantity, but teams are allowed to develop the rest of the powertrain. This has seen everyone settle on a single motor (now by regulation) solution, coupled with a single-speed transmission.

It would appear the entire field also uses radial flux motor technology, which, within the constraints of the regulations, provides the best compromise between motor efficiency, power density and packaging.

Similarly, silicon carbide power electronics are the go-to solution, again thanks to their efficiency and ability to support very high switching frequencies. The result being that Formula E cars operate at efficiency levels of around 98 per cent.

This means hardware gains, though achievable, are hard to find. However, gaining advantage through the strategic use of available energy throughout a race remains an area of intense research.

Energy allowances

Taking the example of Formula E, simply because it is the most well-established series and has been through several generations of rules, it is important to differentiate between energy use limits in place due to hardware limitations and those imposed by regulation.

These technical and sporting limitations both have a similar impact on energy use strategy. Naturally, the ultimate goal is still to go as fast as possible through a race at the highest efficiency, but the *greater* the efficiency, the faster the car will be for a set amount of energy.

With the Gen 3 cars, the capacity of the WAE-supplied pack is 41kWh, but teams are not permitted to use all of this, the idea being to encourage efficiency rather than flat out racing. With the addition of powerful regen' through both front and rear axles (up to 600kW for Gen 3), the full pack capacity would permit teams to run full throttle when not traction limited for most races.

Instead, though, the regulators allocate an energy allowance on a race-by-race basis.

In the case of the final race of 2023, the London E-Prix, this was a piffling 27kWh with which to complete each race that lasted 36 and 34 laps respectively. Admittedly, that was the low point, as most races throughout the season were in the mid-30kWh range, with the highest allowance being 40kWh.

It should be noted that the energy picture can also change throughout a race. For the second year of Gen 3, fast charging is going to be introduced mid-season, allowing for a top up of up to 3.85kWh.

The length of the race can also be altered depending on safety car deployment (which provides energy saving opportunities). This latter feature being a considerable improvement on the previous system where energy allowance was reduced during a race if safety cars were required. This led to the farce at Valencia in 2021, when only nine cars were classified as finishers following a late race safety car and resulting energy cut.

Many teams could not adapt quickly enough, or had not left sufficient energy reserve, and several cars ended up crawling round the track at walking pace.

Contrary to uninformed comment at the time, this was not due to them running out of power as the cars were still at around 40 per cent SoC (State of Charge). They simply were not allowed to use that energy.

The job of the teams' engineers, then, is to understand all the aforementioned and, just as importantly, how their specific car package uses its energy allowance. Then to translate all that into a workable race strategy, which can be adapted at short notice to changing circumstances.

Simulation tools

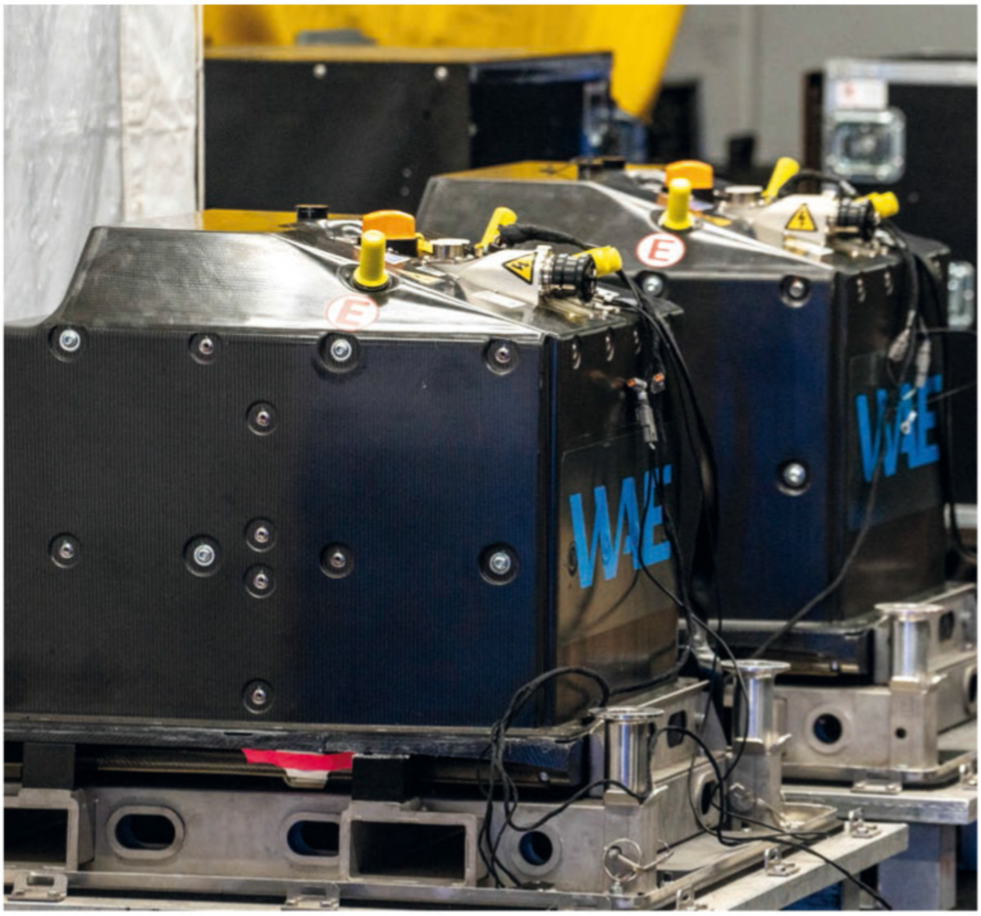
'We first need to establish what is the fastest way to drive a lap for a certain amount of energy,' explains Ash Willoughby, energy management and controls engineer at the ERT Formula E team. 'This is essentially finding the best combination of discharge energy to charge energy. There are many different ways to drive a fast lap!'

This being modern day motorsport, the answer, or at least part of it, lies is simulation.

'From an engineering perspective, we can use the simulation data to create lap frontiers that we can use to determine energy deployment strategies across the race distances'

Ash Willoughby, energy management and controls engineer at ERT Formula E team

Radial flux motor technology provides a solid compromise between motor efficiency, power density and packaging, making it a popular approach amongst teams in the Formula E paddock



The capacity of the WAE-supplied battery pack for Formula E Gen 3 is 41kWh, with up to a further 600kWh available through regen'

'We use a combination of external [to the team] and internal simulation tools to determine this optimal lap,' Willoughby continues. 'The simulation results can then help guide the driver with things such as driving line, throttle application, brake bias and even regen' point.

'From an engineering perspective, we can use the simulation data to create lap frontiers [tLap vs ELap] that we can use to determine energy deployment strategies across the race distances. Simple things like reserving energy to help facilitate overtaking need to be considered from an overall race pace perspective.'

Accurate modelling

To simulate a race with sufficient fidelity, it is important that the models a team uses are as accurate as possible. Teams will create some of these models themselves, using packages such as Simulink or MATLAB, depending on resource, though in the case of the battery, a model is supplied to the teams by the battery manufacturer.

With the Gen 2 cars, where McLaren Applied was the battery supplier, part of the service was provision of this battery model.

'We provided the teams were a guide, giving the limits for temperatures, power current etc. In effect a handbook for them

Regulators allocate an energy allowance per race, and are even at liberty to alter the length of the contest, so engineers need to have a robust yet flexible energy management strategy to run the battery,' says Ruaraidh McDonald-Walker, technical director at McLaren Applied. 'But we went a step further and provided a whole battery model, in a little black box, in Simulink. That had inputs going in, power, current, temperature and factors like coolant flow, and then an output model that they could drop into their vehicle models to predict how their race was going to go.'

Manufacturer teams can also build their own battery models, though these will always be something of a compromise as they do not have an in-depth view of the cell level behaviour, and run time of the batteries they have access to is limited for testing purposes.

'It is a double race,' explains McDonald-Walker, describing the treatment of the battery during an E-Prix. 'You are racing to the bottom of the pack [SoC] as efficiently as possible and as quickly as possible, while also racing to the top of the temperature limits.'

On this final point, it is important to note that the supplier-imposed thermal limits on the battery in Formula E are a hard stop, and car performance rapidly reduces when hit.

'Woe betide you if you hit either the thermal or the charge limit. It is a very steep cut off and you're not going to be able to cruise around gently'

Ruaraidh McDonald-Walker, technical director at McLaren Applied

'Woe betide you if you hit either the thermal or the charge limit. It is a very steep cut off and you're not going to be able to cruise around gently,' confirms McDonald-Walker.

Thermal load

Teams are permitted to run cooling blanking on their cars to reduce drag, so the aerodynamic gain vs the thermal load on the battery needs to be carefully considered. Here, the predictive models teams develop are of utmost importance, especially given the lack of live telemetry in Formula E.

'They can make or break a race if the operating conditions are tight,' states Willoughby. 'For some components, there is an aggressive drop off in performance beyond a certain temperature threshold, to the point where the car would be driving along at walking speed. These situations need to be avoided at all costs.

'In general, race strategies tend to be on the aggressive side, with very tight margins, so we rely a lot on models to help predict the state of components at race end.'

Accurately modelling the other components in the powertrain, and the vehicle's overall performance, is therefore equally important, but here teams have more freedom than with the battery. Motors and inverters can be extensively rig tested with cars run on full chassis dynos if needed, and in the wind tunnel to gather validated data.

'This is very important as there is a strong reliance on simulation tools to give direction to what is the most optimal way to use energy.

'In general, race strategies tend to be on the aggressive side, with very tight margins, so we rely a lot on models to help predict the state of components at race end'

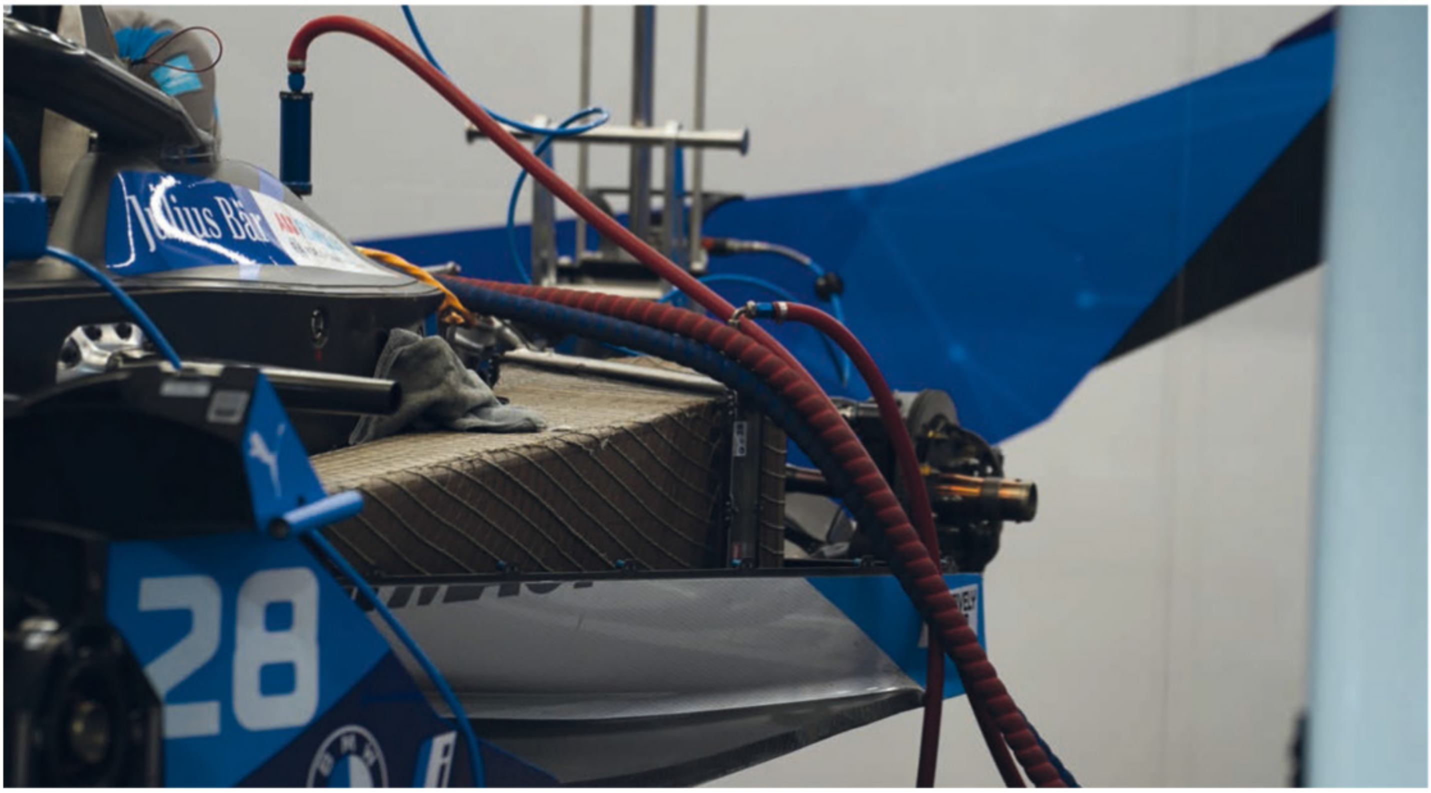
Ash Willoughby

Full car rigs / dynos are best for determining system efficiency, and individual rigs are used for sub-systems, which helps to understand where inefficiencies lie.

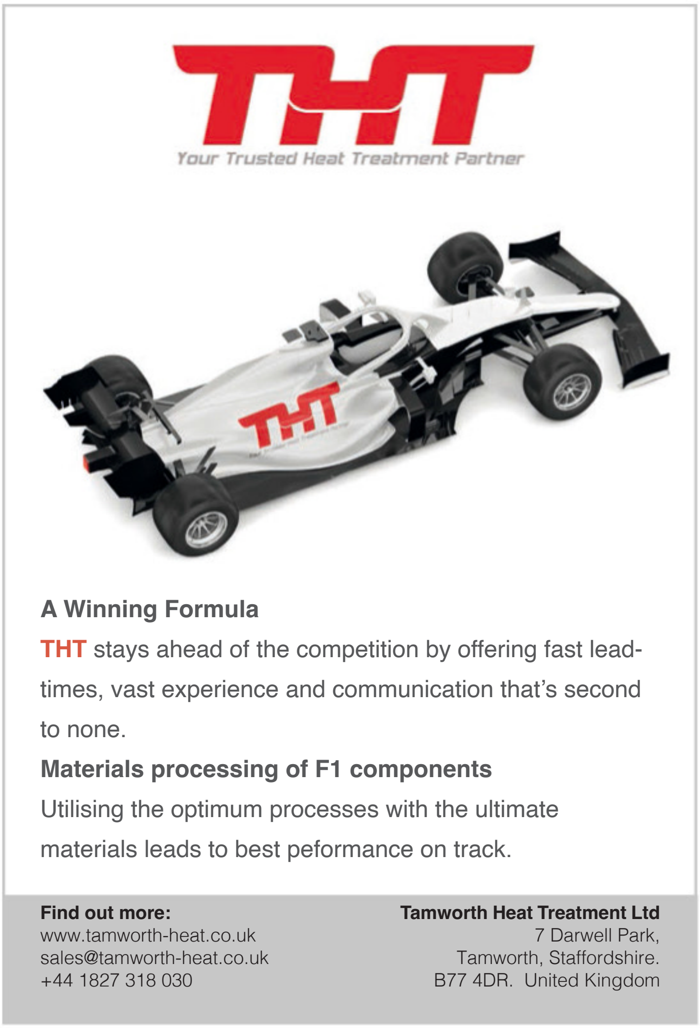
'You can sweep through variables in a controlled environment so you can get a full breakdown of the efficiency sensitivity for each input,' outlines Willoughby.

If incorrect assumptions are made on efficiency, poor performance is almost assured. For example, if powertrain efficiency is overestimated, it will likely mean a car consumes more energy, relative to what has been budgeted at the start of the race. With less energy left for the remainder of a race, lap times achieved with the lower energy availability result in a net slower race time.

'There is a huge benefit to being a manufacturer as there is full visibility of information regarding powertrain,' says Willoughby. 'It also means there is freedom to test and implement bespoke software changes to help the driver manage and use energy throughout a race.



Understanding the thermal load on the batteries is crucial. The battery supplier provides teams with thermal limits and predictive models are used to ensure the strategy doesn't exceed these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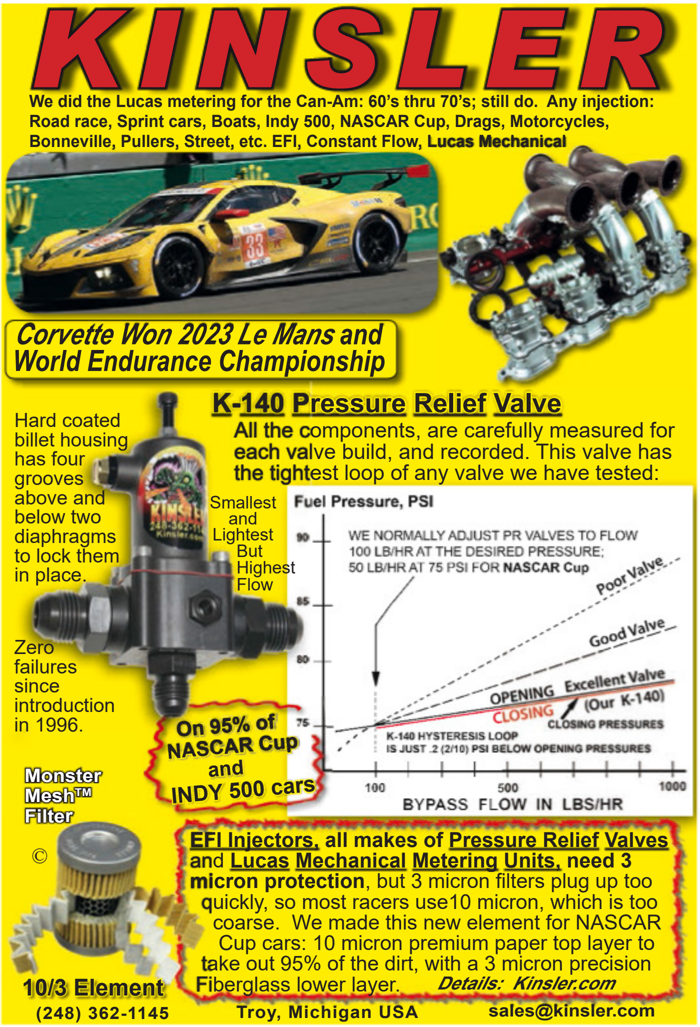
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'We are limited on how much track testing we can do in the formula from a regulatory perspective, but rig testing has much more freedom of use. The only limitation is the depth of your pockets.'

Coded messages

It is one thing to be able to plan out the ideal energy use strategy prior to a race but, as Prussian field marshal, Helmuth Karl Bernhard Graf von Moltke, famously observed, 'No battle plan survives contact with the enemy.' It is once the race starts, then, that Formula E engineers and their simulations really earn their money. With no live telemetry permitted, teams are heavily reliant on their models and communication from the drivers.

Notably, teams will not only run predictive models from the pits, but also on-car.

'We have bespoke software that predicts the energy consumption for the remainder of the race, and continuously adapts according to the consumption of the driver,' notes Willoughby.

Though it is hard to tie down some of the finer details of a race in this software, such as track evolution over time and changes in line, Willoughby suggests this can still be accounted for in the software coding, which constantly evolves along with understanding of a given car package.

To keep this flow of information, teams and drivers will exchange coded messages throughout the race, and GPS data is available to the pit wall.

'Two-way telemetry would definitely make the race a lot more involved from the pit wall as we'd be able to home in on problem areas [energy management-wise], which we can then feed back to the driver,' observes Willoughby.

'Thankfully, we get a lot of useful data from practice and qualifying sessions, which gets the energy management strategy 90 per cent of the way there. Despite no telemetry, we still have access to GPS data and you can infer a lot of information from that in terms of the deployment strategies of cars around you.'

The developments made in Formula E regarding optimising energy use are probably one of its greatest contributions to the automotive industry outside of motorsport. In road cars, strategies and software solutions can be implemented over-the-air, allowing manufacturers to improve the performance of EV fleets without having to update hardware.

The parameters may be different, but there is true road relevance to the work under way in Formula E.

The driver

As noted in the main feature, there is no telemetry from car to pit available to Formula E teams. Consequently, the driver plays a vital role in energy efficiency.

'This is by far the biggest learning aspect for any new driver to the category,' says Ash Willoughby, energy management and controls engineer at ERT Formula E team. 'The level of energy management is to a higher degree relative to tyre or fuel saving strategies adopted in other categories.'

Drivers must therefore develop an understanding of where it is efficient to use energy or, in some situations, where it is better to save energy for the sake of holding position. This intuition only comes with practice and experience with the car.

'Very simple things like driving line selection or driving inputs [throttle, brake and steering] can have a noticeable impact on lap time efficiency. For a driver to have this understanding means they can adapt to adverse situations, like rain or edge cases where the energy target decreases rapidly,' Willoughby adds.

Drivers also have to master absorbing the information the car is giving them via the dashboard and translate this into messages to the pits. Given the tight, street circuit nature of the majority of the Formula E calendar, this is no easy task.

'This component also takes time to adapt to, simply due to the changing circuits and the sheer amount of information the driver needs to be aware of, covering elements such as control system settings, lap count, energy codes, information on cars around them, car state of health and so on,' concludes Willoughby.

So, while the racing may not be as high speed as some other formulae, the workload of the drivers is substantial and requires far more than just an innate ability to drive by the seat of their pants.

With no live telemetry allowed in the series, drivers and engineers communicate using coded messages, but are reliant on simulation models and data gained from practice sessions

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Pen to paper

The importance of basic mathematical reasoning for race engineers

By DANNY NOWLAN

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

The two biggest areas of concern are the inability to do hand calculations, and a lack of ability to reason mathematically. The first area of concern motivated the article I wrote a couple of months ago; the purpose of this article is to deal with how to reason mathematically.

If you are serious about being a capable engineer in any discipline, the ability to reason mathematically is a must-have skill. However, I am noting with increasing alarm how the first instinct of junior engineers, when given a problem, is to simply plug the numbers into something like Solidworks or ChassisSim, hoping it does all the work and solves their problem for them.

Don't get me wrong, these are very powerful pieces of software but, if you use them blindly and with no idea of the underlying principles, they can lead you to the wrong conclusion very quickly.

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

Conversion rate

To illustrate this, let's consider our first example, which is the conversion of anti-roll bar rates from moment per degree to a spring rate. At first, this might seem a little mundane, bordering on the trivial, but it serves as an excellent first example.

The problem we need to solve here is how do we convert a bar rate quoted in Nm/deg to an equivalent spring rate in N/m? The answer is not as hard as you think.

Our first port of call is to calculate the moments generated by the bar for a given spring rate and roll angle.

The force given by the bar can be expressed as **equation 1**.

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

Where,
F_b = Force on the anti-roll bar
k_b = Bar rate in N/m
t = Track width in m
q = roll angle in radians
MR = Bar motion ratio (bar movement / wheel)

To keep things simple, let's assume the bar rate and motion ratios are linear.

The next step in the process is to calculate the moments being generated by the bar. We have two forces providing moments in equal and opposite directions so, assuming the c of g is in the middle of the car, we may write **equation 2**.

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

Where,
M = Rolling moment (Nm)

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

$$\frac{M}{\phi} = k_b \cdot MR^2 \cdot \frac{t^2}{2} \qquad (3)$$

Guess what? We're almost there. We now have our measure of roll moment per degree expressed as a function of bar rate. However, there is one last trick.

The supplied measure we have is in Nm/deg, while what we have in **equation 2** is in Nm/radian. No matter, this is easily fixed. The trick is recognising that one degree is π/180 radians. Doing the numbers, we see that shown in **equation 4**.

$$\frac{M}{\phi} = \frac{M}{\deg \cdot \pi/180} = \frac{180}{\pi} \cdot \frac{M}{\deg} \qquad (4)$$

So, subbing **equation 4** into **equation 3** and making k_b the subject, we have that shown by **equation 5**.

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

There you have it, a sure-fire way of calculating a bar rate given a bar rating in Nm/deg. Crunching an example calculation assuming a bar moment of 2000Nm/deg, a motion ratio of one and a track width of 1.6m, we have that shown by **equation 6**.

$$\begin{aligned} k_b &= \left(\frac{180}{\pi}\right) \cdot \frac{M}{\deg} \cdot \left(\frac{2}{t^2 \cdot MR^2}\right) \\ &= 57.295 \cdot 2000 \cdot \left(\frac{2}{1.6^2 \cdot 1^2}\right) \\ &= 89525 N/m \\ &= 89.53 N/mm \end{aligned} \qquad (6)$$

The great thing about this is how straightforward it is. We started off with a statement of the problem and then, using some very simple manipulation, have come up with an answer, without recourse to software.

Run to the hills

The next example that's really useful involves using data analysis and our knowledge of calculus to nail down car transient stability. One mention of the dreaded calculus word can send people

If you are serious about being a capable engineer in any discipline, the ability to reason mathematically is a must-have skill

running for the hills in terror, but at its core it is all about measuring slopes and calculating areas. That's all there is to it. The discussion here pertains to calculating slopes, so listen up.

Car transient stability can be articulated by a concept known as the stability index. Mathematically, this can be quantified as shown in **equation 7**.

$$stbi = \frac{\partial N}{\partial a_y} \cdot \frac{1}{m_t \cdot g \cdot wb} \quad (7)$$

Where,

$Stbi$ = The stability index
N = Sum of yaw moments acting on the car (Nm)
a_y = Lateral acceleration of the car (g)
m_t = Total car mass in kg
g = acceleration due to gravity (9.8m/s^2)
wb = Car wheelbase in m

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

The first is to have lateral accelerometers fitted on both ends of the car. In this case, the moment (N) being generated is given by **equation 8**.

$$N = m_t\left((1 - wdf)\cdot a_{yf} - wdf \cdot a_{yr}\right)\cdot wb \cdot g \quad (8)$$

The term wdf is the front weight distribution of the car as a percentage divided by 100. The great thing about **equation 8** is it is one of the most straightforward maths channels you will ever put together.

Next, you plot this against total lateral acceleration and take the slope. This is illustrated below in **figure 1**.

The good thing about this plot is that it gives you the stability index. Now, remember the sign of your lateral acceleration. If you have *ay* measured as positive for a left-hand turn, you'll have to multiply the slope by -1. This is the ultimate driver lie detector because you can instantly see what's going on.

At low lateral *g* the car is quite stable, but as we push, the plot becomes more wavy, indicating we still have some work to do at high speed.

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

Both these approaches give you a sure-fire driver lie detector. Ignore a tool like this at your peril when working in the modern motorsport environment.

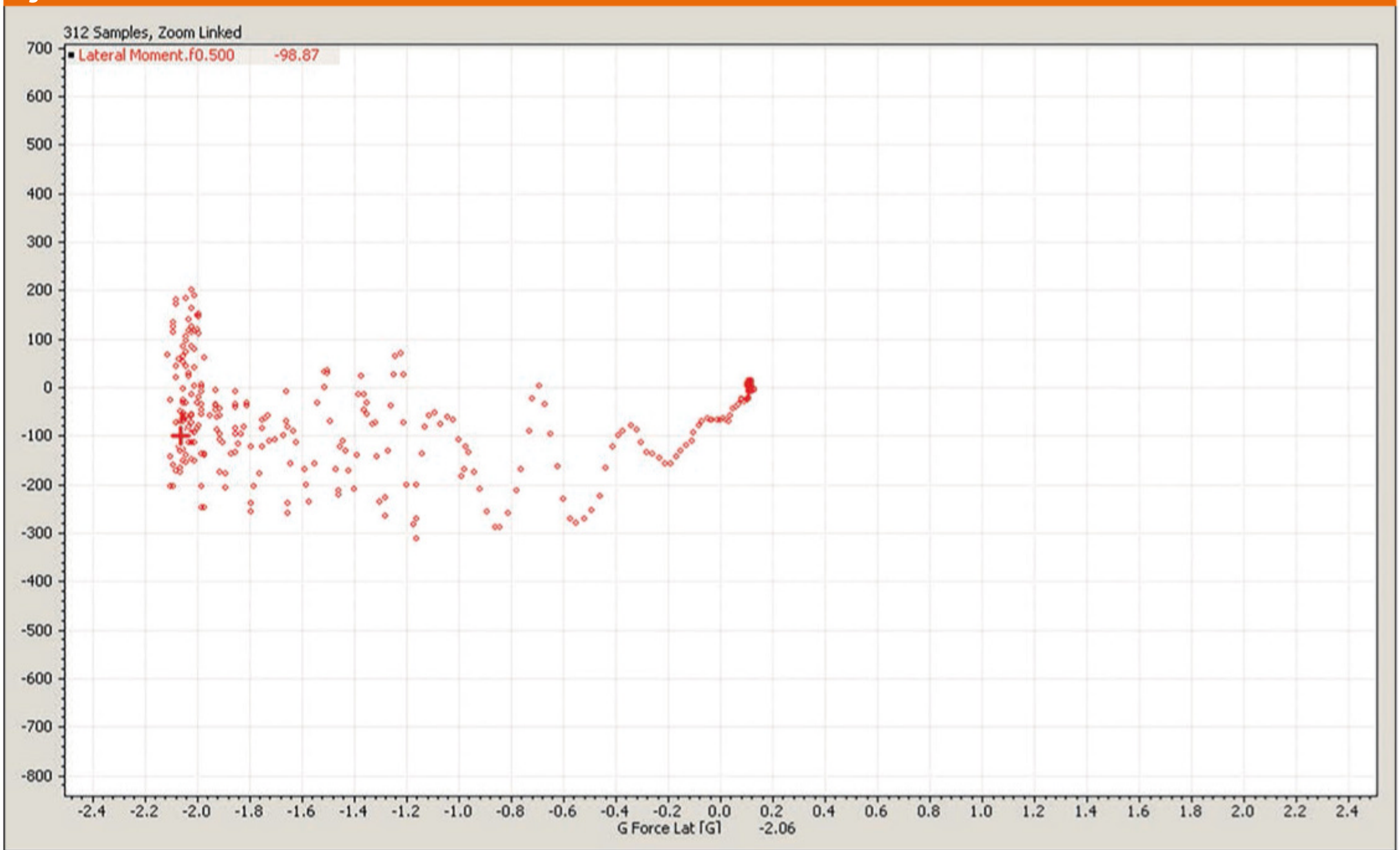
Off the mark

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

The discussion I witnessed tried to apply this thinking to an FSAE car, and you should have seen the encouragement to do detailed CFD studies of this scenario. I was so stunned by what I was hearing that I forwarded it on to colleagues of mine who

One mention of the dreaded calculus word can send people running for the hills in terror, but at its core it is all about measuring slopes and calculating areas. That's all there is to it

Fig 1: Plot of lateral moment vs lateral acceleration



XPB

With big cars travelling at speeds higher than an aircraft at take off, with a floor similar to a wing profile, it's no great surprise they can take off if subject to the right attitude

were senior aerodynamicists in various professional categories. Believe me, they were every bit as shocked as I was.

To explain why this discussion was so off the mark, let's explain what we mean and then do some rough approximations of the mechanisms involved.

An aerodynamic-induced roll over occurs when a car gets sideways at speed, the aerodynamic downforce reduces and it hits a bump, exposing the underbody to open airflow, leading to the car cartwheeling down, or off, the track.

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

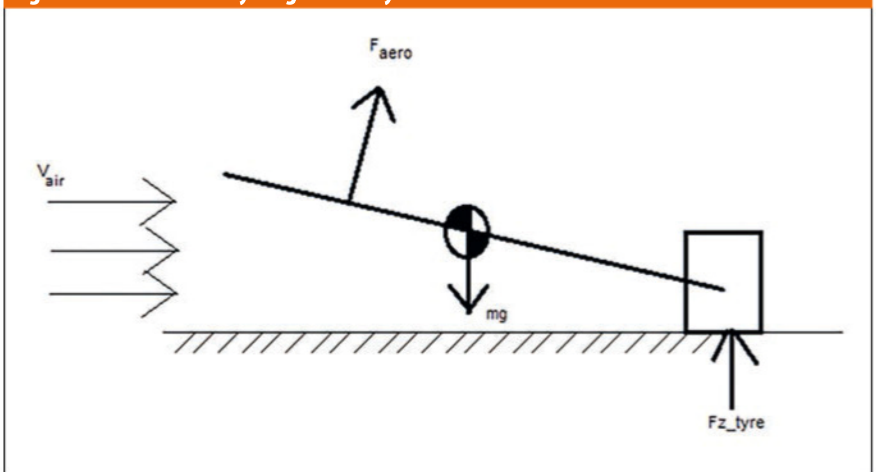
To keep this discussion simple, I'm going to assume the car has gone sideways, so it isn't producing any downforce.

As we can see, we have two major forces at play here. The first is the lift produced by the under body as a result of being exposed at an angle to the airflow. This will be applied at the quarter chord, or track point. This is what is going to roll the car over. The thing keeping us in check is the car's weight.

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

The trick here is to come up with an approximation for the aero forces, which is a lot easier than you might think.

Fig 2: Roll over free body diagram analysis



Our goal is not to try and predict the roll over moment, rather just to see whether we have a problem that needs to be dealt with.

Rough numbers

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

In terms of some rough $dC_L/d\alpha$ numbers (α being in radians) 2π is an okay place to start from. Since this is a imperfect aerofoil, let's approximate $dC_L/d\alpha$ at five. To further flesh this out, let's assume we've hit a bump and the angle of attack is five degrees. Given a typical underbody area of a modern sportscar of $10m^2$, the aero forces we are going to generate will be given by **equation 9**.

$$\begin{aligned} F_{aero} &= \left(\tfrac{1}{2}\right)\cdot\rho\cdot V^2\cdot C_L\cdot A \\ &= 0.5\cdot 1.225\cdot V^2\cdot 5\cdot\left(\frac{5\pi}{180}\right)\cdot 10 \\ &= 2.67\cdot V^2 \end{aligned} \tag{9}$$

Let's then assume the car width is 2m and the car weight is 1000kg. Taking moments about the tyre, we see that shown by **equation 10**.

$$M = F_{aero}\cdot\frac{3}{4}\cdot t - m\cdot g\cdot\frac{1}{2}\cdot t = t\cdot\left(F_{aero}\cdot\frac{3}{4} - m\cdot g\cdot\frac{1}{2}\right) \tag{10}$$

We know we are going to have problems when **equation 10** is equal to zero, so putting **equation 9** into equation 10 and solving for the zero condition we see that shown by **equation 11**.

$$\begin{aligned} F_{aero} \cdot \frac{3}{4} &= m \cdot g \cdot \frac{1}{2} \\ V^2 &= \frac{2}{3} \cdot \frac{mg}{2.67} \\ V &= \sqrt{\frac{2}{3} \cdot \frac{mg}{2.67}} \\ V &= \sqrt{\frac{2}{3} \cdot \frac{1000*9.8}{2.67}} \\ V &= 49.467 m/s = 180 km/h \end{aligned} \tag{11}$$

What all this tells us is that, at a ballpark figure of 180km/h, we are prone to aero-induced roll over (in reality, it's more like 220–240km/h in most circumstances).

Now see where the shock comes from.

Let's now see how these numbers look for an FSAE car, using the same aero figures as the sports prototype (which are already giving the aero roll over scenario considerable benefit of the doubt) but with a total mass of 250kg, a width of 1.5m and a floor area of $2m^2$.

Reviewing **equation 9** for the FSAE car gives us that shown in **equation 12**.

$$\begin{aligned} F_{aero} &= \left(\tfrac{1}{2}\right) \cdot \rho \cdot V^2 \cdot C_L \cdot A \\ &= 0.5 \cdot 1.225 \cdot V^2 \cdot 5 \cdot \left(\frac{5\pi}{180}\right) \cdot 2 \\ &= 0.534 \cdot V^2 \end{aligned} \tag{12}$$

Plugging this into our analysis for **equation 11**, we see **equation 13**.

$$\begin{aligned} V &= \sqrt{\frac{2}{3} \cdot \frac{mg}{2.67}} \\ V &= \sqrt{\frac{2}{3} \cdot \frac{250*9.8}{0.534}} \\ V &= 55.3 m/s = 199 km/h \end{aligned} \tag{13}$$

What this tells us is that there is indeed a case for concern about an aero-induced roll over situation for an FSAE car… at approximately 200km/h!

However, given that FSAE cars are limited to approximately 110km/h, it would be impossible for this to happen.

I should also add here , in sideways view, an FSAE car has all the aerodynamic attributes of a brick so, if we really wanted to get aggressive with this analysis, the predicted roll over speed would go up quite significantly more.

There's no need to do this, though. Simply by using first principles, and some very basic mathematical analysis, we've saved ourselves all that unnecessary work, and at the same time shown why furthering the initial discussion was so ridiculous.

Summary

At this point, it would be wise to give some pointers about how I go about problem solving. As with our hand calculations, start by stating your known and unknown variables. Then think about what class of problem it is and write down all the relevant equations. Next, work the equations to solve for the unknowns and write this down on a piece of paper. Yes, a piece of paper.

Computers are powerful tools but nothing replaces pen and paper when it comes to problem solving.

In closing, we have presented three separate but quite pointed examples of how to use mathematical reasoning to get on top of motorsport problems. The common thread has been to take some basic first principles, put equations to them and then plug in the numbers to quantify them. It may not give you an exact answer, but it will sharpen your instincts so you know what you are looking for. Or what you are *not* looking for.

Don't just rely on computers. Develop this basic skill and it will serve you well in your chosen engineering career.

Computers are powerful tools but nothing replaces pen and paper when it comes to problem solving

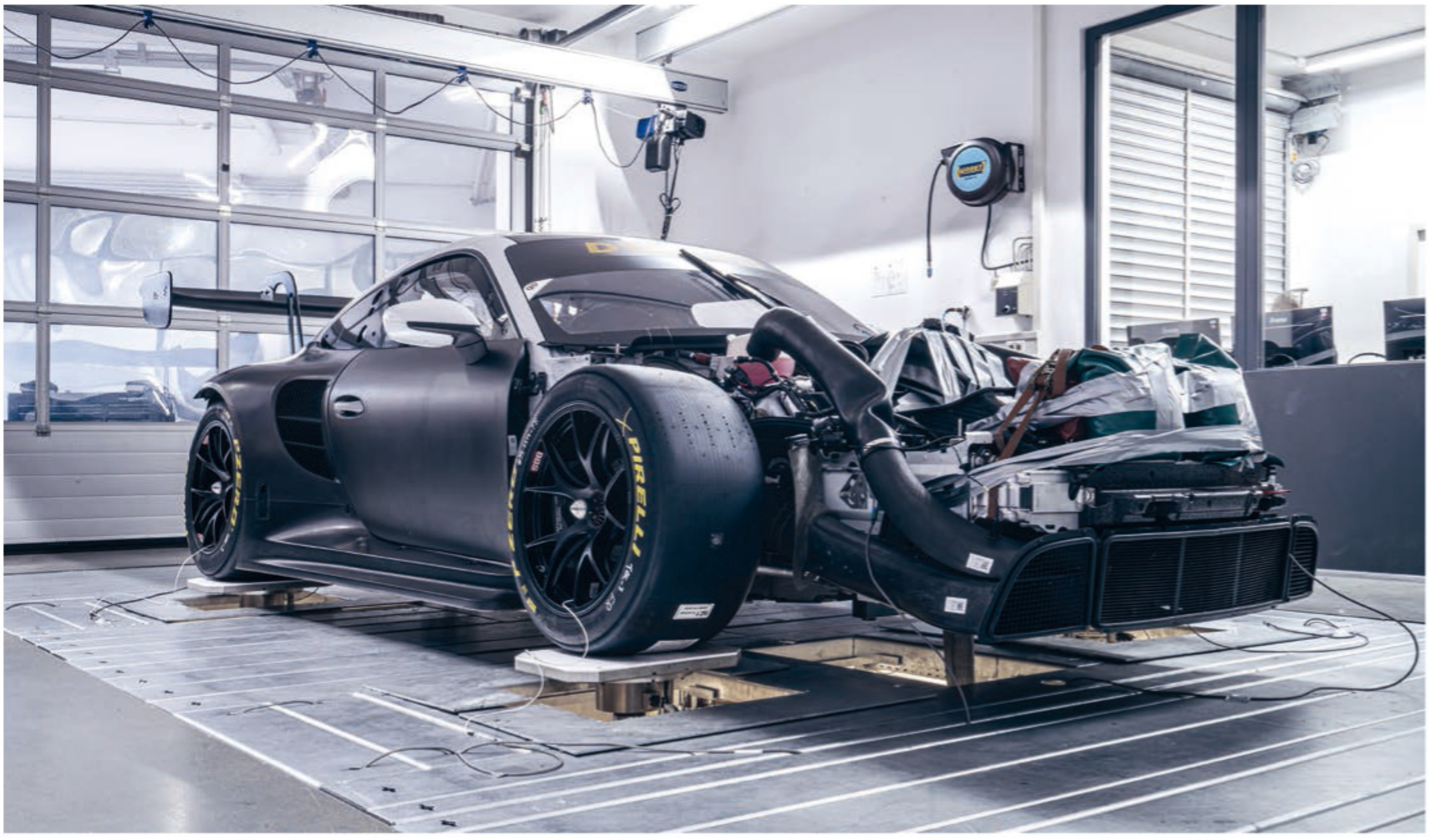
Thomas Lupson-Darnell

Mathematics tell us FSAE cars will have a take-off speed of around 200km/h, yet they are limited to 110km/h, so an aero-induced roll over is simply not possible. Any discussion on the matter ends here

Wave theory

Streamlining suspension development on a vertical dynamics test stand

By CHRISTIAN SCHMIDT OF KW AUTOMOTIVE



KW Automotive uses a seven-post vertical dynamics test rig to develop its damper and suspension systems. The company says the results obtained correlate very well with real-world track testing

Test drive, adjust, test drive, repeat. This was the common pattern for suspension development and tuning in the past. Recognising the inefficiency of this process, suspension specialist, KW Automotive, has successfully streamlined these iteration loops using modern technology. This has not only saved time, but also significantly reduced costs.

The suspension system is one of the most crucial components of any vehicle, encompassing all components that connect the vehicle to the road. These include the wheels, tyres, suspension, damping, stabilisers, axle design and steering as well.

It is often said that there are suspension designs that can do it all but, truthfully, this is not the case. All suspension systems are basically a compromise, developed to suit their market and relevant applications.

To minimise this compromise, OEMs, aftermarket companies, motorsport teams and automobile manufacturers invest a great deal of effort. Just as racecars and production vehicles differ, so do their dampers.

Although they fulfil the same tasks of damping shocks and the resulting vibrations, supporting the body structure and, ultimately, as a wheel-guiding element responsible for vehicle stability and wheel control, the way they achieve this, and how they are built, are fundamentally different.

To further refine these characteristics and deliver precisely tailored suspension solutions for the most diverse requirements, KW Automotive specialises exclusively in the development and production of dampers for motorsport, small-series equipment and aftermarket coilover kits.

Complex interplay

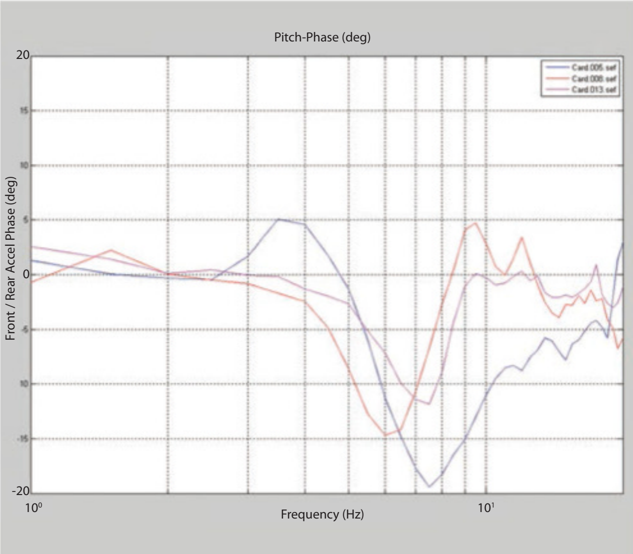
Located in Fichtenberg, southern Germany, the company uses a seven-post vertical dynamics test rig for suspension development. Simply put, this facility, also known as a vehicle dynamics test stand, analyses the complex interplay of elastokinematics, damper forces, spring rates, tyre carcasses and vehicle structure directly on the vehicle.

The goal of optimising a suspension system – in a performance-oriented context – is to minimise wheel load fluctuations

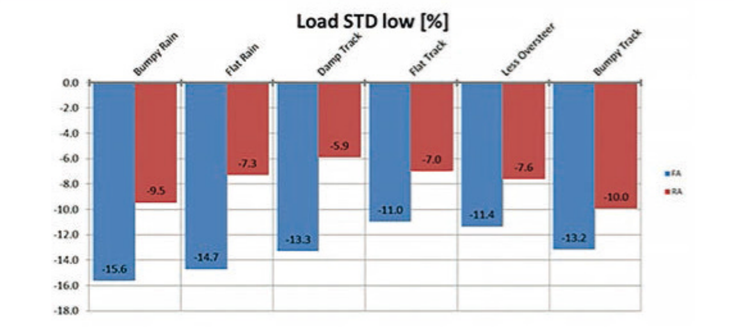
Why? To determine the ideal spring / damper configuration for the respective application of the vehicle, driver and tyres with the least amount of time and effort and under any weather conditions.

Of course, such a test stand cannot replace final road or track tests, but the results obtained indoors come very close to the real-world optimum, drastically shortening development time.

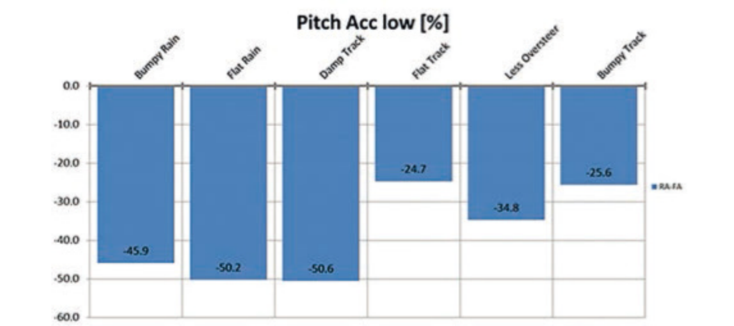
The goal of optimising a suspension system – in a performance-oriented context – is to minimise wheel load fluctuations, thereby improving traction between the road and tyre. This not only enhances acceleration and braking traction, but also allows for the generation of higher lateral forces in corners.



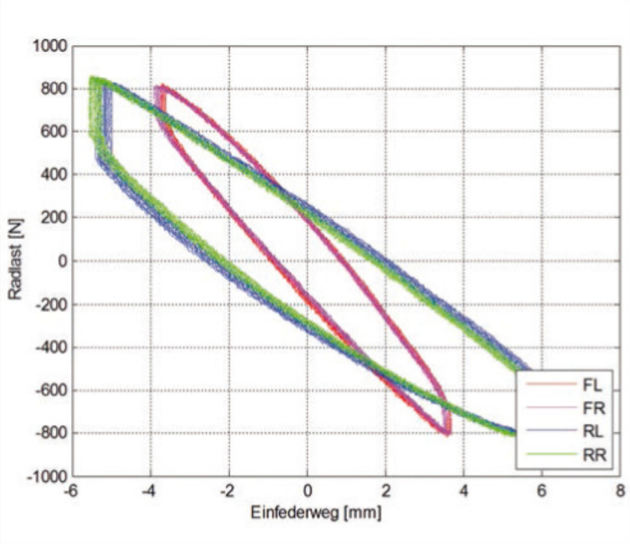
A frequency dependent analysis of the amplitudes and phase relationships between the front and rear axles of a vehicle, especially pitching behaviour, is a crucial step in understanding and optimising the vehicle's dynamic behaviour



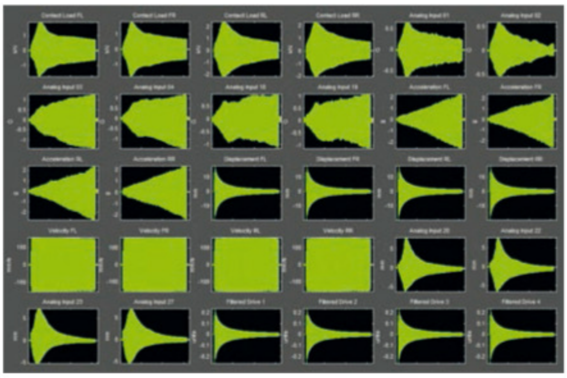
Comparison of dynamic wheel loads under different track and weather conditions with a dedicated focus on the front and rear axles



These diagrams provide an overview of the diverse range of data used to determine the suspension set-up and enhance the driving dynamics of both road and motorsport vehicles



A roll stiffness diagram shows the relationship between roll stiffness, jounce travel and wheel load. Engineers use it to evaluate the handling characteristics of a vehicle



The raw data provides valuable insights into the vehicle's dynamic behaviour under different conditions, enabling engineers to fine tune damper settings to achieve the desired handling characteristics for the intended racing environment

In pursuit of the ideal suspension set-up, vehicle dynamics engineers seek the optimal balance between tyre grip, body control and comfort, leading to the development of diverse damper designs. This four-way adjustable road coilover kit shows such innovation

The more lateral forces the suspension and tyres can generate, the faster cornering speeds can be achieved by a racecar. Lap times then invariably improve, and the car becomes faster in the race.

Perfect balance

Simply put, the task of dampers and springs is to maintain all parameters in perfect balance. In essence, vehicle dynamics engineers seek the best possible compromise to dampen vibrations without risking a loss of tyre grip or compromising body control due to excessive body roll or pitch.

For data acquisition, each racecar is equipped with various sensors, such as acceleration sensors and linear potentiometers for spring travel, all wired and additionally secured on the test rig.

The rig itself consists of a robust base, on which four powerful, dynamically controllable hydraulic cylinders are mounted, one under each wheel. In addition to integrated position sensors, these four pistons, on which the wheels sit, also function as wheel load scales.

Three additional cylinders, fixed directly to the chassis, can simulate additional forces acting on the vehicle.

In test operation, each individual piston is moved hydraulically, generating pressures of up to 230bar in the lines and hoses. The vertical movement of the pistons induces vibrations throughout the entire chassis. During this process, engineers analyse resonance frequencies, where the amplitude of the forced excited body is maximised. In this so-called hub sinusoidal oscillation, the vehicle passes through a frequency band from zero to 20Hz, at a constant speed in the phase null passage. If the inherent oscillation is not dampened, the entire system becomes uncontrollable.

Abstract thought

This might sound a bit abstract, and it is. Let's simplify it a bit. Engineers use the vibrations and data frequency bands to see how even small transverse joints, or wavy asphalt surfaces caused by weather conditions, affect the vehicle. For example, it helps understand what happens when a regular road car encounters a bump, or a pothole. Engineers can then see how quickly this force impulse can be balanced and dissipated through the springs and dampers. Only with optimal damping can the vehicle maintain its stability and stay on the ideal line, especially at high cornering speeds.

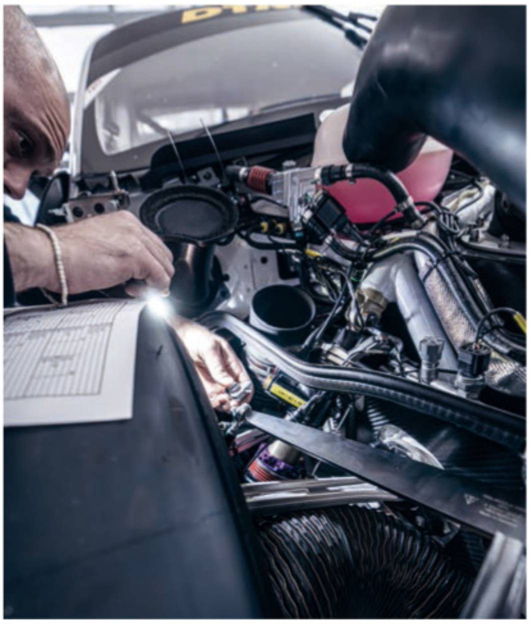
The individual measurement of frequency bands and resonances takes only 64 seconds. This is sufficient for the experienced KW vehicle dynamics engineers to uncover even the slightest suspension weaknesses.

In addition to measurements at constant speeds of 75, 150, 200 or 250mm/s (excitation speed of the pistons at the phase null passage), the test rig can also replicate various racetracks, or sectors, using a 'track replay' feature. This allows the simulation of stresses encountered during challenging drives, such as navigating the famous Fuchsröhre section of the Nürburgring.

The system must be operated in the 'seven-post mode' to achieve this. Here, the suspension is connected to the vertical dynamics test rig at two additional points – in the rear third of the vehicle and at the front. With these additional force application points, the entire aerodynamics, including lift or downforce, as well as moments of roll around the longitudinal axis and pitch around the transverse axis, can be simulated.

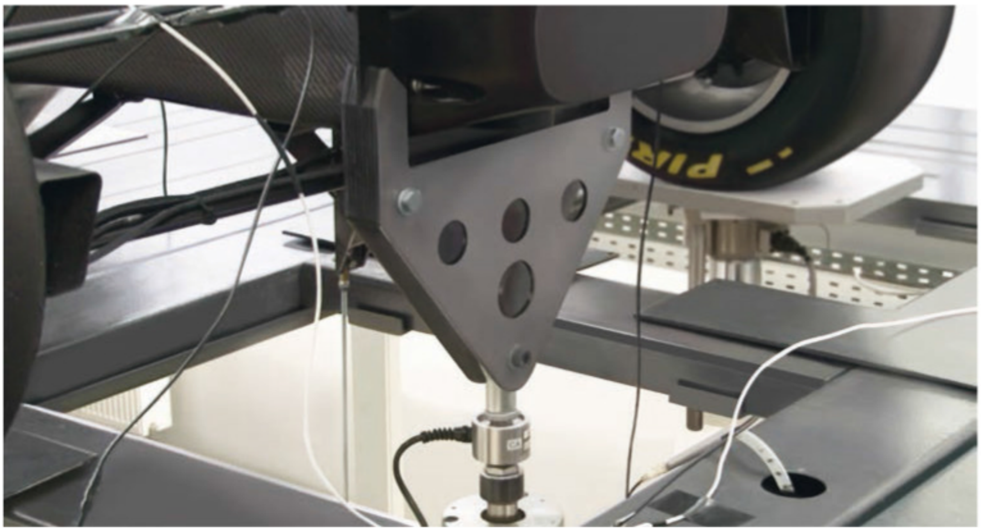
When a current GT4 racecar, or a high performance sports road car such as a BMW M4 CSL for example, which does not have as much aerodynamic downforce as a GT3 racecar, is put on the test rig for shock absorber and suspension development, the system is used in the vertical four-post mode without simulating an aeromap.

The vertical movement of the hydraulically-operated pistons induces hub sinusoidal oscillations throughout the chassis



Engineers then analyse the vibration frequencies to see how quickly force impulses can be balanced and dissipated through the dampers

The test rig can also replicate various racetracks, or sectors, using a 'track replay' feature. This allows the simulation of stresses encountered during challenging drives



On a seven-post rig there are three additional posts, fixed directly to the chassis, that simulate additional forces acting on the car

track performance
COILOVER SUSPENSIONS

RACING

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IN BRIEF

Brabham Group Ltd and Fusion Capital, the majority shareholder of the automotive company Brabham, have ended their collaboration, leaving **David Brabham**, director of the Brabham Group, the option to find new partners.

'It opens the doors for future business ventures in the motorsport, automotive and heritage sectors,' says Brabham.

The collaboration started in 2018 and delivered the BT62 and BT63 models that competed around the world. Plans to create a GTE car never reached fruition as the class collapsed before the company could prepare it.

Hyundai Motorsport has announced a new partnership with exhaust specialist, Akraprovic, to develop innovative exhaust and thermal management systems for the i20 Rally1 Hybrid.

'After decades of experience offering technical services and support to partners in various world championships, this is a new motorsport series for Akraprovic,' says **Davorin Dobocnik**, CEO of Akraprovic. 'We are pleased that Hyundai has chosen us as a partner to help develop efficient, lightweight solutions for the exhaust system.'

Formula E team DS Penske has signed a three-year partnership with **Syensqo**, which specialises in the chemicals industry. The Belgian company helps to make cars lighter and safer by replacing metals with high-performance polymers, as well as supplying materials to make more efficient batteries.

Toyota has changed its FIA World Endurance Championship management structure with **David Floury** taking on the role of technical director, replacing Pascal Vasselon, whose role in day-to-day operations has been temporarily paused. TGR-E, led by president, Masato Hirai, vice chairman, Kazuki Nakajima, and managing director, Rob Leupen, has taken this as a first step on the way to developing efficient management organisation and 'empower the next generation of leaders,' according to a team statement.

Malyon takes over at FIA

Tim Malyon has been named as the new sporting director within the single seater department of the FIA, reporting to Nikolas Tombazis, the FIA's single seater director.

The FIA also confirmed the departure of Tim Goss as technical director, who leaves to take up a role outside the organisation. The loss of Goss means the FIA will need to appoint a new technical director to oversee the 2026 F1 regulations.

Malyon previously worked for Red Bull Racing for 12 years before moving to Sauber as head of track engineering, and then going to the DTM with BMW.

FIA

Malyon will oversee the FIA's race direction and its Remote Operations Centre in Geneva

He joined the FIA as head of research in 2019 and was then appointed safety director in 2021.

Malyon takes over from Steve Nielsen, who left the FIA at the end of January 2024.

'Tim has been pivotal in creating a strong synergy between Race Control and the ROC with the introduction of new technology, including artificial intelligence and state-of-the-art data analysis and processing systems,' said Tombazis.

'He will continue to oversee advances in that area, as well as taking the lead on the evolution of FIA sporting regulations.'

Niels Wittich, meanwhile, will continue in his role of race director overseeing grands prix.

Balance of the muscle cars

Supercars.com

After extensive testing at Windshear in North Carolina, Australian Supercars says it has achieved parity between Ford Mustang and Chevy Camaro

Australian Supercars completed multiple days of running in the Windshear wind tunnel in North Carolina in December 2023 and early January 2024 as it sought to balance performance between its competing manufacturers, Ford and Holden.

The organisation now claims to have achieved the parity it has been seeking between the two designs after three days of intensive testing.

Previously, Supercars carried out its aero testing in the real world, but elected to go to Windshear with the Mustang and Camaro.

An additional day was set aside to enhance the aesthetics of the modifications made to the Mustang.

During initial testing, changes were made to the Ford's splitter profile to bring it into line with the Camaro, and both cars had changes made to their lower splitter surfaces and rear wings.

'A comprehensive report, along with detailed data from the December test, has been provided to all teams, emphasising transparency in the development process,' said Supercars CEO, Shane Howard.

'While both cars are still in the USA, a decision has been agreed by both homologation teams to conduct one further wind tunnel examination of the Ford model using the agreed modifications made after aero parity was reached during the December test.'

Both cars are now being held in *parc fermé* at the NASCAR R&D facility near Windshear, ready for further analysis and final adjustments to be made before the first race of the season at Bathurst on 24 February.

The Revolution will be updated

Offering LMP3 equivalent performance for under £200,000 (approx. $250,000), the British-built Revolution 500 EVO, with its 500bhp, supercharged Ford V6 engine, is finding a ready market in the US

United Kingdom-based Revolution Race Cars has launched an update package for its flagship sports prototype, the Revolution 500, which will debut in the Sports Prototype Cup series this year.

Revolution, a company created in 2018 by Radical co-founder, Phil Abbott, initially developed a car producing 427bhp but uprated that to 500bhp by supercharging the 3.7-litre Ford V6 engine.

The latest upgrade was instigated because Revolution wanted to further distinguish the performance gap between its 500 and 427 models without recourse to de-tuning the less powerful car.

The 500 EVO (starting at £198,000 / approx. $251,250) features larger wheel and tyre sizes for enhanced mechanical grip and load handling, along with increased brake diameters.

Goodyear, Hankook, Michelin and Pirelli tyre compounds are available.

The six-speed, paddle-shift, 3MO gearbox has been uprated to accommodate higher loads. The transmission now has an external pre-load adjustment for the differential, plus long and short ratios that increase the car's upper limit from 285km/h to 309km/h at 7500rpm. A consequence of the gearbox update is a new suspension layout that reduces friction and yields more favourable motion ratios.

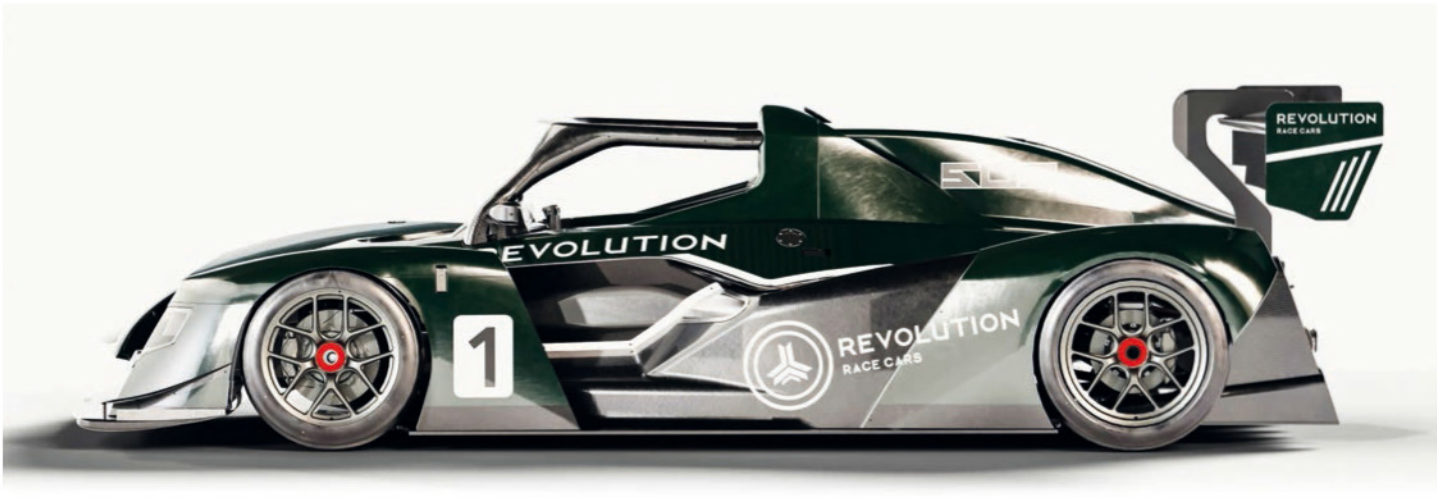
The upgrade package prompted Revolution to put the 500 EVO on a diet to avoid making it heavier than the 835kg car it is meant to replace. The carbon-reinforced polymer safety cell and steel roll structure, for example, are now 21kg lighter.

A new, top-mounted rear wing has been introduced to increase downforce and reduce drag, and one member of the team told *Racecar Engineering* that the 500 EVO is capable of matching LMP3 lap times.

Existing Revolution 500 customers can progress to the EVO with a bolt-on kit, comprising all the improvements minus the lighter tub. The thinking is that a customer who wants the EVO tub will be better off purchasing a brand new car.

Eight EVO 500s have already been sold in the United States, which is Revolution's fastest-growing market.

Testing took place in early 2024 and the development team is hoping to reach 4000km before spring.



Designed for 'high energy track work', the Revolution Race Cars EVO 500 offers an exhilerating drive, combined with FIA-standard safety, reliability, ease of servicing and long refresh intervals

Nürburgring endurance battle solved in court

In a battle of acronyms, the AvD has received the green light to host the same number of NES races as the NLS, which has the support of the ILN

After months of legal wrangling, a court in Germany has ruled that the VLN, which runs the NLS races on the the Nürburgring Nordschleife, can host an equal number of race dates as the Automobilclub von Deutschland (AvD) and its new series, the NES.

The AvD and NR Holdings, owners of the Nürburgring, had sought to launch a new series with its own identity. Initial plans to work with the VLN organisation to launch it faltered, leading to a split which had to be ruled upon in court.

A court in Koblenz ruled that the VLN should be allowed a number of races after the AvD and NLS sought to dominate the available race dates.

The VLN was initially awarded five dates on which it could host races, while the NES could take the remaining dates for its own new series. However, the NLS total has been increased to eight races this year.

An independent company, ILN, which features teams such as Manthey Racing, Black Falcon and Adrenalin Motorsport on its board of management, and which represents the interests of teams and drivers who compete in endurance racing on the Nordschleife, sided with the VLN and NLS.

The water was then further muddied when the marshals also came out in favour of the NLS.

'Finally we have the green light for NES,' said AvD managing director, Lutz Leif Linden, who is also president of the GT endurance commission at the FIA.

'Our aim is to gradually make the endurance series more attractive for the future. To this end, we have developed sporting, technical and organisational regulations with some new, innovative approaches for the NES.'

The Nürburgring 24-hour race, run by ADAC, and which is at the heart of German endurance racing, has this year for the first time integrated Stéphane Ratel's Intercontinental GT Challenge series for GT3 cars.

IN BRIEF

According to rumour, former Haas technical director, **Simone Resta**, who followed team boss, Guenther Steiner, out of the door of the UK-based American team, is set to return to Ferrari.

Porsche has confirmed that **Brandon Fry** has joined the IMSA WeatherTech team from BMW in a newly-created lead race engineer role. Fry will support the Penske factory team's two race engineers and help manage the performance engineers, too.

Angela Ashmore will become the third woman to work as a lead engineer in IndyCar when she takes up her role at Chip Ganassi Racing, working on Marcus Armstrong's car. Ashmore follows Diane Holl who was race engineer between 1996 and 2000, and Leena Gade in 2018.

James Allison has signed a long-term contract extension to remain as F1 technical director at Mercedes, the team has confirmed. Allison joined the team in 2017 and since then has worked for the INEOS Britannia America's Cup sailing project before returning to motorsport.

Toyota has received the all clear to distribute its new GR Yaris Rally2 to customers after the FIA approved the car's homologation. The first example went to Rookie Racing, the team led by Toyota chairman, Akio Toyoda.

Leon evolution set to continue winning ways

Cupra Racing has released its updated TCR car, the Leon VZ TCR, for competition around the world in 2024.

The Spanish brand was the first to commit to the new rule set in 2015 and this is the third generation of the car that has won titles in TCR Europe, Spain, Italy, South America, Japan, UK and Brazil.

The new model features revised bodywork, a new front axle and an updated Sadev gearbox, along with other evolutions for this season. The existing car may also be upgraded to the new kit.

The Cupra Leon VZ TCR follows in the successful footsteps of the Cupra TCR and the Cupra Leon Competicíon. Orders are already being taken

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Best foot forward

The A24 Show in Birmingham featured the latest in engineering excellence

A new feature of the 2024 show was race vehicles joining their drivers on the main stage during interviews. It also provided the perfect platform for the likes of M-Sport to reveal its 2024 car livery for the WRC

The Autosport International Show kicked off the 2024 season with a flourish over a four-day show, two of which were trade only.

There was no shortage of stories and interesting displays throughout the event, and not only in the Autosport Engineering section. Revolution demonstrated its car update (see p77), while oil giant ROWE attended, having set its sights on the UK motorsport and automotive sectors through its new importer, MediaCo Imports (MCOIL).

AER celebrated 25 years of business with its range of engine designs for all applications of the sport, including sportscar, prototype, rallying and single seater racing.

The British company has supplied engines for the IndyCar IndyNXT series since 2015 and has also been involved at the top level of endurance racing, finishing on the podium at Le Mans with SMP Racing in 2019 using its P60B engine in the BR Engineering BR1.

Elsewhere at the show, the Gobstopper 4 was on the Autoverdi stand. The car, borrowed from Roger Clark Motorsport, continues the company's project to test its products in extreme designs.

A technical forum, hosted by former Aston Martin F1 strategist, Bernie Collins, saw some of the current burning questions asked, including: is a world without fossil fuels possible? It also covered how AI is set to shake up the engineering industry, as well as identifying the next big trends in the sector.

With a host of well-qualified guests representing a cross section of the sport, the panel discussions provided a good opportunity to examine the future direction of motorsport.

In the main show, Autosport International had a fresh new look this year, with drivers and riders joined by their cars, karts and bikes on stage, led on Saturday by James Calado and the Ferrari 499P in which he won the centenary 24 Hours of Le Mans.

A technical forum saw some of the current burning questions asked, including: is a world without fossil fuels possible?

The show runs for four days with two of them dedicated solely to those working within the motorsport industry

'Winning at Le Mans was a surprise,' said Calado, 'as it was only our fourth ever race with the 499P.

'Taking the overall victory in the top class is different from our victories in the GTE Pro class. It's a very long event, with enormous pressure, and the effort we have to put in, including driving, is considerable because the Hypercars are very physical cars to drive.'

Alongside the Ferrari was the JOTA Porsche 963, the team and car having led Le Mans overall in the early stages before dropping back.

'Hypercar is growing. I think it's only going to get bigger as well, because everyone is looking to expand,' said driver, Calum Illot.

JOTA claimed LMP2 class wins in 2014, 2017 and 2022, and was one of the Hypercar stars at the recent November round in Bahrain.

There was also a focus on the environmental impact of racing and how the sport can bounce back. In that vein, MissionH24 showcased hydrogen-fuelled motor racing at Autosport International, updating fans on the construction of the new H24EVO.

Hydrogen offers tremendous potential in this regard, as Bassel Aslan, MissionH24's technical director, explained at the show.

Autosport International was rebranded as A24 for this year's edition and featured sections for motorsport, engineering, street car tuning and live action

M-Sport revealed its WRC line up on the stage, with Adrien Fourmaux and Alex Coria, and Grégoire Munster and Louis Louka competing with the latest Ford Puma Hybrid Rally1.

Both Fourmaux and Munster, who enjoyed strong 2023 campaigns in Rally1 and WRC2, will step up this year to take on the full WRC season.

The pair represent M-Sport's continued commitment to nurturing future talent in the sport and the team is looking forward to helping them achieve new career goals in 2024.

This year's Autosport International show had it all, from race suits to trailers, from high-precision engineering to the Live Action Arena, and from world championship cars to gymkhana and sprint cars.

The show celebrates new product launches, new technology and champions new ways of thinking

Industry experts took part in panel discussions on the future of motorsport

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Fuelling the debate

Why Toyota's chairman was right to come out in support of engines

One of the discussion panels at the Autosport International show in Birmingham in January centred around whether or not motor racing could continue to be interesting if alternative fuels were used. The implied subtext was whether racing could continue to be interesting if it is electric, with reduced aural stimulus. The overriding view of the panel was if the racing was good, that would be enough. I disagree.

As it seems does 'Morizo', aka Akiyo Toyoda, who declared to the Tokyo Auto Salon that he loves engines, and wants to continue building them. While something of a surprise in the current environment, his comment fits with my thoughts on another panel discussion regarding what motorsport might look like without carbon. Not vastly different to today, but probably better. With this I agree.

'Morizo' made a comment in his address that I think has merit. The enemy is carbon emissions, he said. With that at the heart of future mobility, things might look a little different. Using drop-in fuels that have lower carbon emissions, or preferably none, could see the 1.5 billion existing road cars move to a lower carbon output quickly and efficiently, without being scrapped.

Hydrogen and full electric will take longer than the switch to efuels, so surely the impetus should be on trying to bring forward a workable solution as early as possible.

> **If carbon is the enemy, we should be looking at all aspects of the car, including weight**

If carbon is the enemy, we should be looking at all aspects of the car, including weight. It's ironic that as the world mourns the effect of carbon emissions produced by transport, we happily buy bigger and heavier vehicles than ever before. SUV sales are, in some cases, keeping car companies alive, so there is a disconnect between the weight of the cars and what we are all trying to achieve.

Weight watchers

Small, lightweight, efficient cars are part of the solution, regardless of the powertrain, or fuel that goes into them. Which brings me onto the next point, which is more relevant to the panel discussion held in Birmingham.

As Adrian Newey pointed out in 2022, a fully-fuelled Formula 1 car weighs almost 900kg at the start of a grand prix. The cars are longer, wider, faster (and more expensive) than ever before, yet race on the same tracks, so there is less space. Overtaking is therefore harder, without the use of DRS. I still watch a DRS-enabled overtake and feel I have been robbed of a show, while I am sure the driver feels they have been robbed of the chance to compete as well.

Looking at the proliferation of hybrid, it seems current systems are little more than weight. Hypercars use between six and nine seconds of energy on a 205s lap at Le Mans and, while LMDh cars deploy for longer, it's at lower power.

The hybrid system is therefore pretty much inert, and certainly not road relevant. Competitors in national racing series are finding the same. The hybrid systems don't necessarily change anything other than their bank accounts, which are hurting. Motor manufacturers can sell the hybrid story to their board, but that's about it.

Hidden depths

Is there a point where we start to look at reality, rather than government policy? Many racing series are already using fuels that are better for the environment, either with lower CO_2 emissions or renewable, yet they are hardly spoken about, or even known inside the industry.

We cannot claim the cars are environmentally friendly, particularly when they run around with big wings and drag-inducing bodywork, but they are not monsters either.

The Garage 56 entry at Le Mans last year was a 5.9-litre, V8 NASCAR. It was powered by the TotalEnergies fuel developed for the series using waste from the wine industry. The claimed CO_2 reduction is 60 per cent.

IndyCar uses sustainable fuel, as does IMSA, Porsche Supercup, and this year GT racing, too.

The enemy is not the engine, and 'Morizo' confirmed this with his comments: 'To all those who have made engines up until now, let's continue to make engines. Everyone's help will continue to be needed. I will never let all the work you've all done so far go to waste! I hope this message will be firmly heard by our colleagues.'

The problem with new fuels is reaching the production volumes needed. Yes, the cost per litre will rise, but they are going up anyway, and higher fuel prices might encourage people to make more efficient choices with new cars.

Perhaps governing bodies will start to look at the devices that are not helpful to efficiency when writing rule sets. If the aerodynamics cost efficiency, maybe they should be looking at that as a better way of going forwards?

My final question at the discussion was whether the rest of the world cares as much as Europeans. The answer was yes, there is a push from manufacturers all over the world to reduce carbon emissions in racing. I hope that's true, and that future regulations for all major series reflect that.

ANDREW COTTON Editor

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