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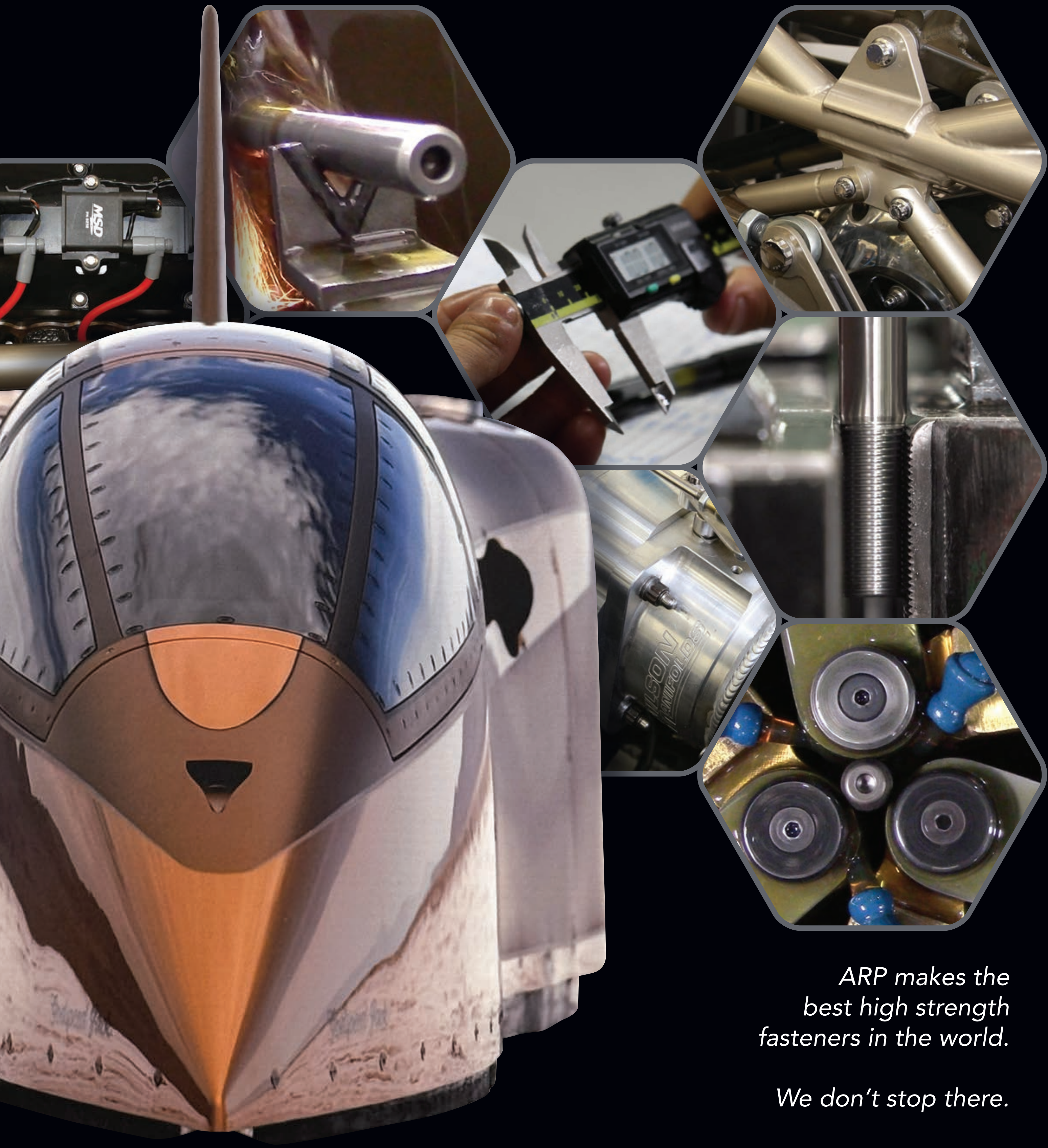
The Prodrive-built Dacia Sandrider claimed a 1-2 on its debut in Rallye du Maroc, putting it in good stead for January's Dakar Rally



Audi aftershock

The company's F1 focus has a huge impact on wind tunnel usage

The final race of this year's DTM championship saw the end of an era as Audi and its partner team for 25 years, ABT Sportsline, parted ways. The partnership yielded multiple titles in the series, including two apiece for Mattias Ekström and Timo Scheider, and lasted through the Class 1 period into the GT3 era.

The success it enjoyed in the DTM was impressive. Half of Audi's 10 drivers' title wins between 2002 and 2020 came with the ABT squad. That form continued into the series' GT3 era, where the team - which is switching to Lamborghini next year - has claimed 11 of Audi's 12 race victories.

The German manufacturer's Formula 1 ambitions are having a big effect on the wider world of racing. The company torched its endurance racing heritage by killing its sportscar programme starting in 2016, taking back cars from various museums and allowing contracts with drivers and teams to lapse. The decision to axe the relationship with ABT is a further nail in that particular coffin.

Sauber grapes

These impacts pale into insignificance, though, compared to the decision to use the Sauber facility in Switzerland to develop the F1 car ready for entry in 2026. The closure of the wind tunnel to outside teams means organisations such as the FIA must now find other tunnels from non-competing outfits to undertake their aerodynamic tests.

The Sauber tunnel is, apparently, still commercially available until the end of 2024, after which it will be turned over exclusively to Audi's works F1 project.

So, what other options are on the table? Some have suggested the Pininfarina tunnel in Italy. It's not perfect as it is quite small, but it can at least fit a full-size car. Other tunnels are either owned by rival teams, not available at all, or only capable of taking scale models, which leads to a whole new round of dramas, including developing items like scale wind tunnel tyres that have to very closely match the real thing.

The FIA currently uses Sauber and Windshear in North Carolina to performance balance top-level sportscars, placing them in a narrow window of lift and drag. The proposal on the table at the moment is to increase tunnel time at the Windshear facility and ask the European teams to go there for testing in 2025. However, Windshear is already operating at near capacity, and this would mean teams in Europe facing a hefty travel bill, not to mention a logistical headache. Ferrari has already stated it would add around €1m to its testing programme if it had to ship both its LMH and GT3 cars to the US for tunnel testing next year. Other European teams will face a similar budget increase.

Wind tunnel-developed, downforce racecars are extraordinarily capable beasts, but could the answer to current problems actually be to dramatically reduce the reliance on wind tunnel testing?

Unless another tunnel is found, and calibrated to the FIA and ACO's satisfaction, another option is that there will be fewer aerodynamic tests. GT3 cars, which are performance balanced, do still need to be measured, but less often. The BoP system varies wildly from series to series and, although aero efficiency numbers are very useful, perhaps they are not needed quite so regularly.

For the Hypercars - LMH and LMDh - a reduction in tunnel time could be risky as the aero numbers are critical to the whole system. So, it is time now to try to find another way? Wind tunnel testing is, after all, not foolproof. In the past, we have seen cars such as the Audi R15 pretty much solely developed in the wind tunnel. If the conditions on track matched those in the tunnel, the car was incredible, but outside that particular operating window it was a handful and the team spent months trying to figure out how to effectively widen that window.

Tunnel time is vital at certain parts of the development path but, with budgets being squeezed every year, it may be that a huge aero test programme is beyond an increasing number of teams. Cheaper and equally reliable solutions will then be sought and that could mean a greater reliance on simulation data.

Increasing cost

F1 teams are still investing heavily in their own wind tunnels, such as Aston Martin and McLaren, and it's clear that tunnel testing is still preferred where possible. But in the US, IndyCar seeks a new chassis in 2027 while NASCAR will also investigate its next-generation car. Tunnel time from facilities such as Windshear will come at a premium. So, what's the consequence of not running a full test programme? In 2007, Audi won the DTM and, for some reason, invited me to drive the title-winning car. Given it was a downforce car, it was like nothing I had ever driven before. Cornering to the maximum of the car's ability? Forget it. The golden rule was, and always is, to just bring it back to the pits in one piece.

Nevertheless, I can report its straight-line acceleration was epic and its braking wonderful, even if my cornering was woeful. It wasn't until Martin Tomczyk took me on a run that I understood how such a car truly worked. While wings have been part of racing for decades, I have also driven a BMW M3 GTR around Vallelunga and had way more fun than in the Audi.

Would racing be worse if aero was developed by sim', or good old fashioned runway testing? Could the solution to improving the racing really be to reduce tunnel time and, in doing so, make the cars more difficult to drive? I think so.

The German manufacturer's Formula 1 ambitions are having a big effect on the wider world of racing

Vantage point

Aston Martin has been isolated in the middle of the F1 standings, but could its aggressive expansion plan help transform it into a title winner?

By DANIEL LLOYD

Aston Martin has yet to recapture its early 2023 form, but there is a bigger picture at play

It has been a disparate season for the Aston Martin Formula 1 team. On the one hand, its Mercedes-powered AMR24 has underperformed. The car became marooned in fifth place in the World Constructors' Championship, unable to break into the top four that its predecessor accessed so spectacularly for part of last year. On the other hand, it has been an exciting period off-track, as team owner Lawrence Stroll's ambitious vision to create a title-winning organisation continues to take shape. The sparkling new factory at Silverstone is growing by the week, and the building blocks of an all-star technical leadership structure have fallen into place, headlined by the signing of former Red Bull Racing chief technical officer, Adrian Newey.

The disparity between a challenging year on the track and a thrilling one off it helps visualise just how tough it is to reach the upper echelon of F1. It also demonstrates the bigger picture at play. The gap to the leading teams can now be expected to close, based on the wider changes being carried out as part of Stroll's uncompromising pursuit of excellence.

The AMR24 was the first car to be designed and built in Building One of the new Aston Martin Racing Technology Campus, which opened last year for an initial cohort of 700 staff. It was developed during a period of infrastructural transition, as Aston Martin was still using the Mercedes wind tunnel located 10 minutes down the road in Brackley. Nonetheless, it benefited from newer design facilities and systems than those housed in the old base, situated in the same fields opposite Silverstone's entrance, which was first built for Jordan in 1992.

Current context

When the AMR24 was launched in mid-February, Aston Martin F1 technical director, Dan Fallows, said the team wanted to 'broaden the car's operating window' and make it 'more of an all-rounder.' The previous year's contender, the AMR23, made a stunning start, especially in the hands of Fernando Alonso, who achieved six podiums in the first eight races. However, its performances tailed off as the season progressed and some upgrades yielded undesired traits, although Alonso still held it together and finished fourth in the Drivers' Championship.

Aston Martin's primary goal for this year, then, was to make the AMR24 perform with greater consistency at a wider variety of tracks, although that does not necessarily lead to an outright faster car. The AMR24 initially proved a reliable scorer, taking 44 points in the first seven races (many of which had lots of high-speed corners) but it wasn't giving the likes of Red Bull, Ferrari, McLaren and Mercedes anywhere near the amount of trouble the AMR23 did. At time of writing, Alonso's fifth place at round two in Saudi Arabia was the car's best result of the season.

In 2024, instead of battling for podium positions, Aston Martin has found itself scrapping for the small points against the likes of Haas, Williams and Alpine

‘We’ve come to realise we’re in a fairly substantial growth phase of the team, and some of our tools that we’re using and relying on aren’t necessarily giving us the right steer, in that regard’

Dan Fallows, technical director at Aston Martin F1

The AMR24 front wing at the start of the season (above), which saw the nose attached to the bottom flap instead of the main plane. The revised wing introduced at Imola (below) added an indent at the outboard end of the upper flap

‘There are some twin aims for AMR24,’ says Fallows, when asked if he feels the car’s operating window has become wider. ‘One, that we stated at the start of the season, was to make a step up over the previous year’s car, and to make it more adaptable to different circuits. I think, to some extent, that was achieved, though we’ve had some handling issues, or characteristics of the car, that have lurked in the background. We have partially managed to get on top of them but, as we’ve gone through the year, we’ve found an increasing number of things that meant we weren’t getting *fully* on top of them. That’s a problem we’ve seen a lot of teams having.’

The current generation of F1 cars, which rely on ground effect to generate huge amounts of downforce from underneath the floor, are very difficult to upgrade effectively. ‘Upgrade attempts’ would perhaps be a more accurate description because they have rarely produced wholesale gains, except for isolated cases like the McLaren MCL38 at Miami. This is because the cars are highly sensitive to adjustment. Subtle changes to mechanical characteristics such as ride height have significant impacts on the loading of aerodynamic components like the underfloor and front wing. Likewise, updates to aero components can have negative side effects like instability at different cornering phases.

There is also the age-old racecar conundrum of adding downforce without increasing drag so much that it inhibits the vehicle’s straight-line performance. Although the pursuit of downforce is not the only factor driving performance today.

‘Once you’ve got a car you’re relatively happy with, you’re then faced with the problem of how do you add additional performance to it without handing over some of the aspects you were happy with,’ says Fallows. ‘That is something we have struggled with a little bit. During the season, we’ve come to realise we’re in a fairly substantial growth phase of the team, and some of our tools that we’re using and relying on aren’t necessarily giving us the right steer, in that regard.

‘At the same time, we’ve been trying to make the car as useable as possible at different circuits, and add downforce and performance. We’re also trying to tick off these correlation exercises to make sure that, as we go into the later season and next year, we don’t suffer the same problems of not knowing what it is you’re going to get at a certain circuit.’

Upgrade progression

Aston Martin certainly hasn’t been shy in rolling out upgrades over the past season. Substantial packages appeared in Japan (four performance-related changes), Imola (nine) and Hungary (six), and these were interspersed with regular updates to items at other events. Round four in Japan, for example, saw the introduction of an updated floor, with a reduced chord of the floor edge, and a modified diffuser. For round seven at Imola, the AMR24 came with a new front wing, sporting a new indent (more on that later), a much straighter main plane and increased volume at the nose. The floor was also updated further, while the central trim of the engine cover was shortened as a cooling option, reducing the airflow exiting down the middle of the car.

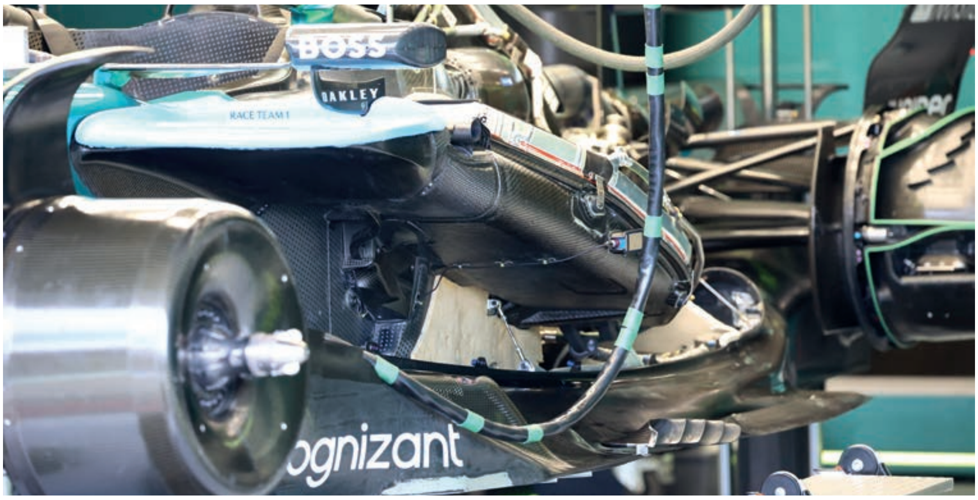
However, the substantial changes didn’t yield any obvious improvement. If anything, the Imola package brought undesirable characteristics to the surface. Alonso met the tyre barrier after losing the rear on entry to Rivazza 2, bringing out a red flag. The two-time world champion then exited qualifying at the first stage after an off-track moment at Tamburello, and subsequently started from the pit lane as his mechanics took the opportunity to make some suspension set-up changes.

Stroll, meanwhile, finished ninth in the race to deliver two points, whereas Alonso – whose pit strategy helped his teammate’s cause – used the Emilia Romagna Grand Prix as a test session for the updates.

After Imola, Aston Martin continued to bring new parts, introducing a front wing at the British Grand Prix with a modified twist distribution of the wing elements, designed to alter the load across the span and improve interactions with the floor and other aero components downstream. The AMR24s finished seventh and eighth, better than last year’s visit to Silverstone, but only the team’s fourth double points finish of the season.

In Hungary, a raft of performance updates appeared on the car, including a more aggressive version of the front wing flap introduced at Silverstone, and new vanes attached to the Halo and cockpit, which were aimed at controlling the lower energy airflow

A raft of aerodynamic upgrades were introduced at Imola, but Alonso found the car difficult to drive and hit the tyre barrier in FP3



Sidepod detail of the AMR24 at the British GP. The lower lip of the radiator inlet was extended even further than on last year's car

'It is very hard to do something that is unequivocally good in every dimension you look at. You have to make some kind of trade-off, and hope those trade-offs will work. That's the fundamental reality of designing an update package'

Dan Fallows

Flow-vis paint helped the team to visualise the airflow around the AMR24 sidepod during pre-season testing in Bahrain

in that area. The floor was also subject to further evolution with the target of improving load on the lower surface. But, as the team continued to play about with set-up options, the results showed little signs of improvement, and Alonso and Stroll continued to battle for the small points.

Trade agreement

'It is very hard to do something that is unequivocally good in every dimension you look at,' reflects Fallows. 'You have to make some kind of trade-off, and hope those trade-offs will work. That's the fundamental reality of designing an update package. Obviously, you then have some correlation aspects of that as well, if it does anything on track you don't necessarily expect it to do.

'As we've put things on the car, it's not just been Suzuka, Imola and so on… we've tried to have this continual update progress as we've gone along. We have found that, by and large, they do as expected, though sometimes there are slightly unintended consequences… or ones we did know about but that then had a more profound effect on the car performance.'

Aston Martin has kept all the parts it has updated, according to Fallows, although some components have been restored to the car, depending on circuit characteristics. One of the changes for Imola that Aston Martin continued to use was a unique indent in the upper flap of the front wing. This was situated on the outboard side, in line with the inside of the front wheel, and was designed to help manage airflow around the tyre.

'With the regulations we have, which are relatively restrictive, we don't have the luxury of elaborate front wing end plate / foot plate geometries where we could generate multiple vortices and direct them exactly where we wanted to around the tyre,' explains Fallows. 'We have to try and use the structures that are there, or the geometry that we can make, and try to use that the best we can to get the same benefits. In some of the more extreme conditions, that can be challenging, so you're having to decide which ones you want to trade off against each other. That feature on the front wing is another way of containing some of those structures and making them behave in the way you want. As always with these things, [there are] varying degrees of success.'

Corner to corner

Whereas Aston Martin had a car that would, broadly speaking, perform differently from circuit to circuit last year, with the AMR24 it found it had a car that would produce inconsistencies for the drivers from corner to corner. At the final European race of the season, the Italian Grand Prix, the team's performance director, Tom McCullogh, noted the car was strong in the mid-speed Roggia chicane but was off the pace through the faster corners around Monza. 'That's partly the overall grip level, but also overall balance,' he said at the time. 'Parabolica is nearly a 180-degree corner; we have struggled to give the drivers the confidence on entry and the rotation mid-corner. It has been, at that car speed, a bit of a limitation for us.'

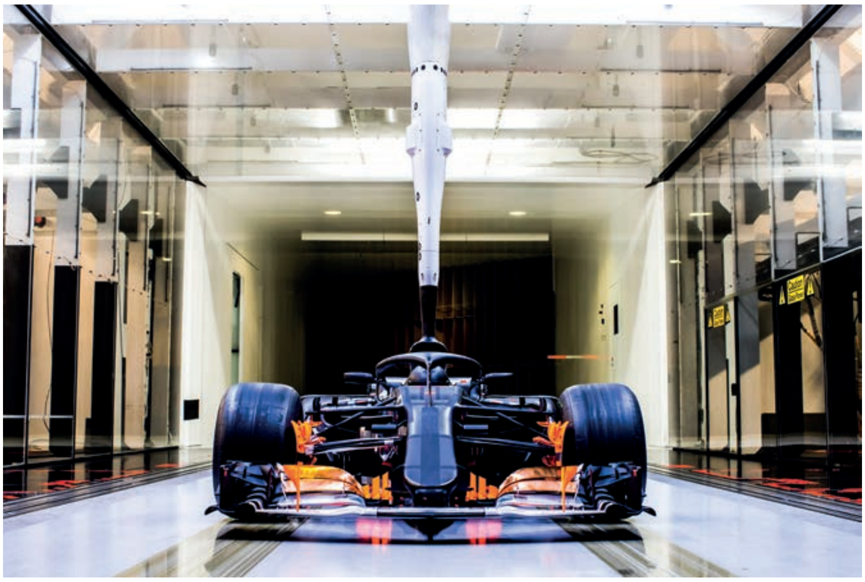
After finishing 11th in the Italian GP, Alonso suggested the team needed to 'raise the bar' for next year as it was coming under pressure from the likes of Williams and RB. He also said the AMR24 is 'quite hungry on tyres' and, without the required downforce through the high-speed corners, that forces the driver to rely on mechanical grip, which hurts the tyres even more.

The problem of having a car that is inconsistent from corner to corner is something Aston's engineers have tried to get on top of throughout the 2024 season, and Fallows admits the inconsistency 'made life harder' for the race day engineers as they struggled to prioritise the items to change, giving drivers myriad different options to run.

'I think that is typical when you've got a car that is overly sensitive to some conditions, and it forces you in a certain set-up direction,' suggests Fallows. 'You have to pick the thing you're most worried about at that time, and iron out that particular characteristic. Though it does mean you leave some other things on the table.

'You're trying to produce a car that has the broadest operating range but, if it doesn't have that, you find you're playing this balancing act. That makes your set-up decisions at circuits quite tricky, because you're always having to work out which is the thing you want to attack first in order to get the minimum lap time.'

This conundrum is something the team's ambitious growth plan may help to iron out as it looks ahead to the 2026 rules refresh. By upgrading the facilities at the engineering team's disposal, therefore increasing the chances of picking up and solving issues before they manifest in a race weekend, Aston Martin may give itself a better chance at keeping pace with the front runners.



Mercedes

Aston Martin has been limited to using Mercedes' wind tunnel three days per week, but it will be freed of the associated constraints once its state-of-the-art in-house wind tunnel switches on later this year

Building blocks

Infrastructure changes have been a hallmark of Aston Martin's ambition to become a title winner. The team's new 37,000m^2 factory at Silverstone, the AMR Technology Campus, is the first completely new F1 team headquarters in two decades. It is a three-building complex, with each of those connected by an elevated walkway.

This year, work on Buildings Two and Three has moved forward. Building Two was completed in the summer and is now operational, primarily housing staff wellbeing and logistics facilities. It is also home to a new driver-in-the-loop simulator, which along with the new wind tunnel in Building Three is set to be fully operational by the end of the year. The wind tunnel is arguably the headline development and the establishment of this latest fixture at the AMR Technology Campus will free Aston Martin from the constraint of borrowing time at Mercedes' headquarters. Additionally, the case of McLaren and its impressive run of form with upgrades on the MCL38, which was developed in a new wind tunnel at the Woking team's base, demonstrates the kind of elusive material gains that can be achieved.

'The Mercedes wind tunnel is a fantastic facility,' says Fallows. 'It's a modern wind tunnel with all the kit you'd like. The main thing is access time: having to shoehorn all our development into three days over a weekend is incredibly challenging from a logistical point of view. It also means having to ask people to work at the weekends, and not just the people working at the wind tunnel, but everybody who is supporting it back at the factory. It means we don't have the luxury of using that time in a cleverer way.'

Using an in-house simulator will enable Aston Martin's aerodynamicists to be 'much more progressive' in how they build up their understanding of the car, according to Fallows. They might take readings on an element that

The wind tunnel is arguably the headline development and the establishment of this latest fixture at the AMR Technology Campus will free Aston Martin from the constraint of borrowing time at Mercedes' headquarters

Aston Martin F1

The AMR Technology Campus continues to evolve and grow. The team's brand new aerodynamic and vehicle dynamics testing facilities will be up and running by the end of 2024

suggest it needs tweaking, so they can go away, quickly build a prototype model and return in a few days to re-test it. In the meantime, other items could be tested. That sort of flexibility hasn't previously been afforded to the team during its time using the Mercedes wind tunnel.

'There are things we would like to do operationally, or from a technology side, that we're not able to do in someone else's wind tunnel,' adds Fallows. 'They're quite small things, but the small things do tend to add up. That's something we'll be able to do with complete freedom in our own facility.'

Aerodynamic testing for the 2026 breed of F1 cars starts in January, so the new wind tunnel *must* be up and running by then, at a minimum. However, Aston Martin also plans to use the new facility for validating the 2025 car, so it's important to have everything in place as soon as possible.

It is also crucial to have the wind tunnel properly calibrated because such tests are regulated in number. An older generation F1 car will be used towards the end of what has been an extensive calibration process to ensure the tunnel readings and data delivery are accurate before being used in any official credits, as tunnel testing on a current or future car are restricted.

'We have a commissioning phase,' Fallows explains. 'There are a lot of systems we need to commission, a lot of flow visualisations we need to make sure are working properly. We can do that with a very stripped-down model [F1 car] that is just a bare bones of the electronics and motors. Then, when we get to the point when we're doing some load commissioning, we can use an old-spec model from some time ago.

'We have conversations with the FIA about what we're allowed to do. It's a fixed configuration – we're only allowed to run it for a certain period of time – so we try to make sure that period of time, when we're actually running a fully clothed wind tunnel with forces measured, is just the end of the process. Once we get those forces in place, there will be a brief couple of weeks before we're into AMR25 development. Then, once we're getting into next year, it will be AMR26.'

Star power

Much has been said about Aston Martin's recruitment of star engineering talent for its push towards the pinnacle of F1. Many will have found it refreshing to see a decorated designer like Adrian Newey given celebrity treatment, the kind of which is normally only given to drivers, in the form of feverish speculation followed by a major press conference when his switch from Red Bull to Aston was announced in September. Newey will be the F1 team's managing technical partner and a shareholder in the company.

'[Adrian Newey's] ideas are only fixed until some new information comes along, and then he's happy to change direction and go somewhere else'

Dan Fallows

His role will enable him to feedback on different areas of the engineering structure.

Fallows and Newey know each other well. Both were at Red Bull for more than a decade, including during its first title-winning spell between 2010 and 2013. Heading into F1's hybrid era, Fallows became Red Bull's head of aerodynamics and liaised with Newey, who was then chief technical officer.

Newey starts with Aston Martin on 1 March, two weeks before the 2025 season opener, and the current technical group is striving to be in the best shape possible before he pulls up a chair at his drawing board and starts work.

'Having worked with him before, I know what he will bring to us,' says Fallows, who joined Aston Martin from Red Bull in 2022. 'He brings this single-mindedness and clarity to the engineering groups. Where we can maybe debate things as a group, as technical leaders in the business, Adrian brings a certain clarity that pulls people together. He's always been very clear that he's sort of the enabler, and he wants to bring that unified vision.

'What I've really enjoyed, working with him in the past, is that he's incredibly open to ideas. You might imagine somebody in that position would be the one generating all the ideas and providing all the answers, but it's very much not like that. He really wants to hear information from other people.

'I've always said he's the least technically arrogant person I've met in my life. His ideas are only fixed until some new information comes along, and then he's happy to change direction and go somewhere else.

Aston Martin F1

The recruitment of Adrian Newey, who had initially been tipped for Ferrari, was a major coup for Lawrence Stroll and his pursuit of a technical leadership 'supergroup'

'That open-mindedness and clarity of vision is an asset to any group, and I'm really looking forward to him bringing that.'

Stroll hailed Newey's agreement to join Aston Martin as the 'biggest part of the puzzle' in his project to transform the team into a title winner. However, it is never all about just one person. Equally notable was Aston Martin's hiring of Ferrari's technical director of chassis and aerodynamics, Enrico Cardile, to the role of chief technical officer. The recruitment of a new CEO in Andy Cowell, the former managing director of Mercedes-AMG High Performance Powertrains, was also a major move, as was the signing of Bob Bell as executive director from Alpine's Enstone-based team. It's turning into an F1 engineering supergroup, and how well that supergroup gels will be integral to its success. As will be how the new talents slot into the existing structure, which includes Fallows as technical director, McCullogh as performance director, Luca Furbatto as head of engineering and Mike Krack as team principal.

Honda support

Looking ahead to 2026, Aston Martin's Silverstone-based technical team will be supported on the power unit front by Honda. The Japanese manufacturer is developing a new works power unit for the incoming rule cycle, and Aston Martin will be the only team running Honda's 1.6-litre V6 engine next year. It will operate on sustainable Aramco fuel.

A gearbox dyno has also been installed at the AMR Technology Campus for the purposes of testing a bespoke transmission. Currently, Aston Martin uses the Mercedes gearbox and pushrod rear suspension, in addition to the power unit, as part of its customer deal, but that is set to change.

'There's an enormous amount of work that's gone on in Sakura,' says Fallows. 'Honda have been working on this project for quite a while now. They've done a reasonable amount of testing themselves and, as each month goes by, our interactions with them get more into the detail of what we need and what they need from us.'

The 2026 rules resemble a clean slate for teams that have struggled to match Red Bull and, as of this year, McLaren and Ferrari, in the current ground effect era. It remains to be seen to what extent next year's car will turn Aston Martin's recent lack of fortunes around. For the time being, its 2025 car is at least set to benefit from some correlation work in the new wind tunnel, even if that facility hasn't been online for all its development. That, combined with the new personnel hires, will be another important building block in Stroll's grand vision to transform Aston Martin from the ashes of the underdog Force India outfit into a world beater.

Braking news

Porsche and BMW have both recovered from poor debut seasons to become race winners, and one the IMSA series champion. Racecar *looks at how their LMDh cars have evolved*

By ANDREW COTTON

The 10-hour Petit Le Mans was the final round of this year's IMSA SportsCar Championship and, at the conclusion of the race, Porsche won both the Drivers' and Manufacturers' titles in the top class with its 963 prototype. The preceding six-hour race at Indianapolis saw BMW take a one-two finish, marking a distinct turnaround for both brands.

BMW's impressive result at The Brickyard was the only time an M Hybrid V8 finished on the podium in the US sportscar series this year, and only the second win of the vehicle's career, the other coming at Watkins Glen in 2023 after the winning Porsche was disqualified for excessive plank wear.

For Porsche, the 2023 season saw the factory squad outshone in the FIA World Endurance Championship by customers, and drivers had a hard time trusting the car's behaviour from corner to corner. This year, the 963 has won several races, and now titles, in the US and it's clear it is a very different animal to last year's offering.

The LMDh platform made its competition debut at the 24 Hours of Daytona in 2023. The regulations are the property of IMSA and the ACO, but have been adopted into the WEC Hypercar class by the FIA. Under the LMDh regulations, the spines of the cars come from Dallara, Multimatic, ORECA and Ligier. This includes the tub, suspension and brakes. The hybrid system comes from Fortescue (battery), Xtrac (gearbox) and Bosch (MGU).

Manufacturers, including Porsche, BMW, Acura, Cadillac, Alpine and Lamborghini, supply engines and aero kits, along with other associated requirements such as cooling, but the electronic control units (ECU) were left open to buy, and develop.

Software war

Acura opted for the McLaren Applied TAG-320 unit shared with Formula 1, while all the others chose to go with Bosch. A software war broke out almost immediately, and has been ongoing ever since. Electronic development is the key differentiator between the cars now,

Photos: Jake Galstad / IMSA

There's no doubt the BMW M Hybrid V8 has had a disappointing start to its racing career, but it all came together at Indianapolis when the German marque and its RLL team took a one-two

as they are balanced aerodynamically and from a power perspective, and teams have a better understanding of how to set their cars up in the different conditions.

The LMDh cars then faced competition from the LMH cars in WEC. The LMHs are manufacturer-built and developed from the ground up. The regulations that govern those are property of the FIA. Ferrari, Toyota and Peugeot have all built cars to this rule set, as have Glickenhaus, Isotta Fraschini and ByKolles / Vanwall. Aston Martin will join the LMH regulation set next season with a racing version of the Valkyrie.

Balancing two-wheel drive LMDh cars with four-wheel drive cars has been an issue for the WEC regulators. Jim Glickenhaus famously noted that no one would take the regulations seriously until an LMH car won an IMSA race at Daytona, and an LMDh car the FIA and ACO's showpiece event, Le Mans.

That came about because there seemed little hope that an LMDh car, which is by regulation rear-wheel drive, could perform at the same level as the hybrid LMH cars, which are mandated to have four-wheel drive. Should an LMH manufacturer bring a non-hybrid, as Aston Martin will, it will also only have a two-wheel-drive car.

The first competition, then, was between the LMDh manufacturers as the LMHs battled for wins. In the WEC, Cadillac and Porsche both regularly made statements that they had won their particular war, while in the US Acura was a formidable force from the start.

Electronic development is the key differentiator between the cars now, as they are balanced aerodynamically and from a power perspective and teams have a better understanding of how to set the cars up in the different conditions

Through the 2024 season, it was clear the gaps between LMDh cars had closed and, during the Petit Le Mans finale, there were favourite runners from Porsche, Acura and Cadillac, with BMW more of an outside bet.

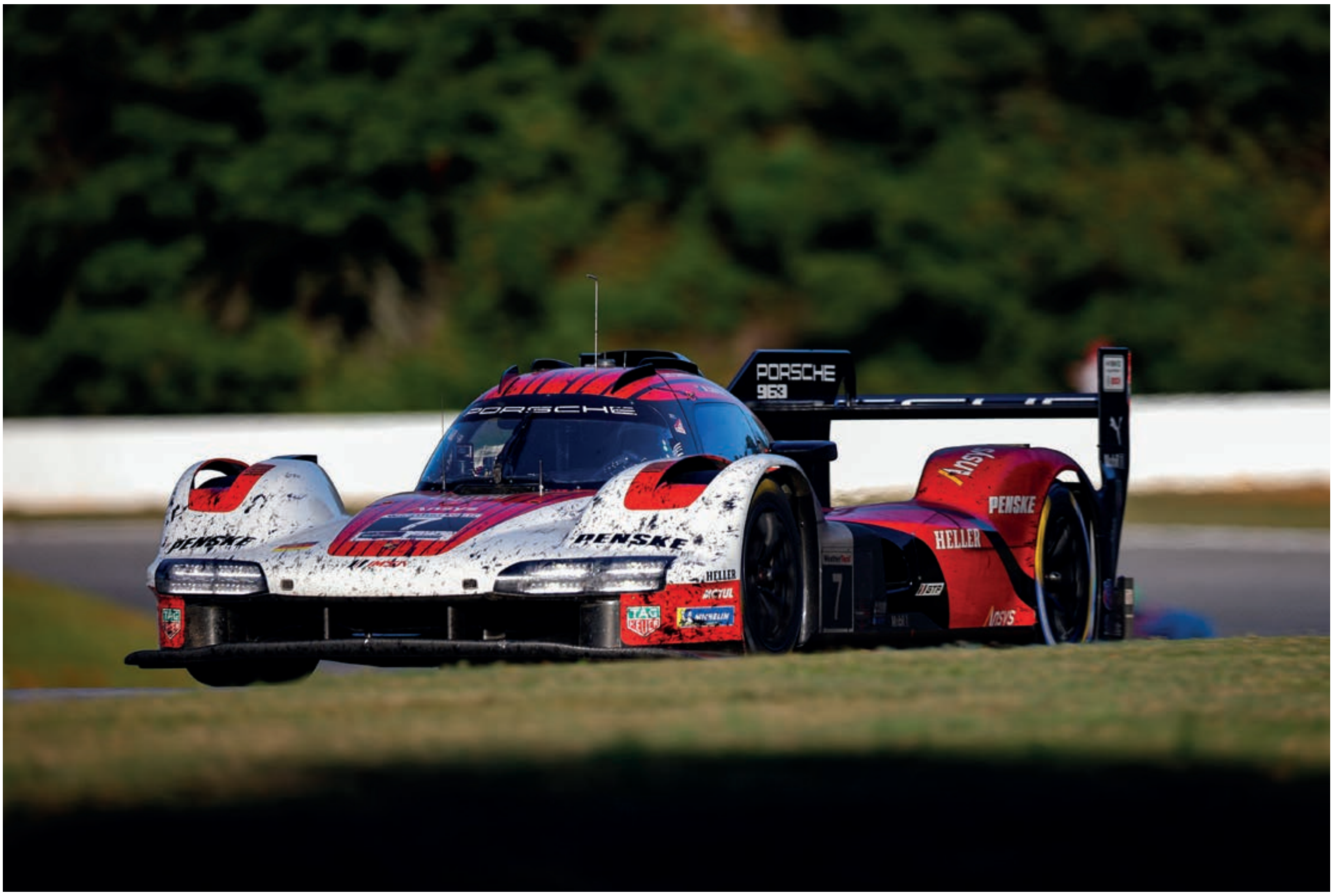
Porsche improves

In the WEC, LMDh cars started beating the best LMHs, with Porsche scoring wins in Qatar and at Spa. This put it in a strong position to win that championship, too. To reach that point, the German manufacturer made gains in two key areas of its car. The first was on tyre warm up. From the start of 2023, Porsche Penske Motorsport (PPM) factory drivers reported that rear tyre wear was hurting performance over long runs, but that changed for the 2024 season. The factory 963s are run extremely stiff, even compared to the customer cars, and with more camber. PPM has not only controlled temperature in the tyres, but also is now able to double stint, a necessary requirement due to the number of tyres allocated for each WEC race.

The second area of improvement compared to 2023 is reliability. The flat-plane crank engine caused vibrations that led to other areas of the car needing additional protection, especially the sensors. It was not uncommon to see the Porsche ground to a halt due to some electronic gremlin, but the team also made unforgivable mistakes, such as not putting enough fuel in the car at two separate races last year.

There was also an issue with handling. In 2023, the feeling was that the 963 had the best brakes on the grid, but only if it was going in a straight line. Turn in on the brakes turned it into one of the worst cars in the field, and the drivers had to adapt their driving styles to suit. Overtaking was particularly challenging, and the end result was the cars were not competitive.

Porsche introduced upgrades to the 963 over the winter to help with this performance issue, including a different gearing for the MGU,



Porsche was outwardly more confident about its 963, but vibration and handling issues hampered the car last year. Updates made to the braking, hybrid and steering systems have paid off

which slowed the motor slightly and stopped it failing. It also brought a new power steering system, which allowed Porsche to alter the car's camber settings.

'That was a big element, because the drivers were more confident,' says Urs Kuratle, director of factory motorsport LMDh at Porsche. 'They had a more reliable car, and that was the game changer.'

Improvement in the braking zone came from the hybrid system, which assists the car's mechanical braking, its rotation through the corner and traction control on exit.

'As always, it is not just one thing, there were a number of things that changed,' continues Kuratle. 'The biggest chunk came on the braking, but that was a software thing. All the systems have to work together as a unit and give the driver confidence. We did not change the brake material, the calipers or anything like that. It really was software.'

Code breakers

There were big differences between the Bosch and McLaren Applied ECUs. Acura was proud that it chose the latter and wrote all its own code, but had to start from scratch and lean on its Formula 1 partner, Honda, where needed. Its engineers sat in the truck on site and re-wrote code for the next session.

For the Bosch teams, they received a system loaded with the basic parameters needed to make the car work, and have

'The biggest chunk [of improvement] came on the braking, but that was a software thing'

Urs Kuratle, director of factory motorsport LMDh at Porsche

added their own code as they complete more mileage. This is the area where Porsche has invested huge amounts of time and money, testing extensively to improve its system. It was the leader in delaying the reduction of test days to next season so it could improve the software this season, while PPM is the only team allowed to load up figures that have been requested by the private teams.

There is more work being done to the car around the front for 2025, including a new front suspension and nose, but that has not yet been homologated. Porsche is clearly pushing the development curve as much as it can before the reduction in test days for manufacturers (and increase in testing for private teams) comes into effect.

'Basically, Qatar was one of our best tracks compared to the competition,' says Kuratle. 'There is a big variant in tracks that we like or don't like. The update will also give us a more competitive car over the course of a race.

'It seems that the combination we have from systems working at one point, that's working. Also the drivers, the kinematics, and the whole thing is better, but I don't think that is unusual, it's just a characteristic of the thing.'

BMW development

BMW was another car that struggled on the brakes. The behaviour of the car has been famously unpredictable from corner to corner, lap to lap, and the drivers were starting to wonder what was going on. And, more specifically, when it would be fixed.

The initial development was completed by the Rahal Letterman Lanigan (RLL) team, which took part in last year's IMSA series. That was then added to this year with the appointment of the WRT team in Europe, which competed in the WEC. With double the amount of development time being put into the car, the BMW steadily started to improve.

WRT took many steps forward, quickly, but then realised it didn't know why the car was behaving as it did with the updates that were implemented. So, at Imola in May, it decided to retrace its steps in an attempt to better understand the car. The first glimmer of competitiveness came at Le Mans, where Dries Vanthoor headed the qualifying session, clearly having found some trust in the car behaviour. That session gave the factory teams on both sides of the Atlantic a clear direction in which to go regarding set-up.

Though some mechanical changes were made to the Porsche, the vast majority of the performance gains have come from software upgrades made to the hybrid control system and Bosch ECU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Similar to Porsche, the key to unlocking the potential of the BMW was a better understanding of the regen' phase of the hybrid system to improve braking. Tyre management is next on the list

BMW engineers embedded themselves with RLL at subsequent races, and performance improved, in the shape of a first IMSA win at Indianapolis in September. However, BMW M Motorsport boss, Andreas Roos, says the issues are not yet fixed.

'All our drivers said the car was unpredictable in some areas, and this is especially what we worked on, to understand where that comes from and how to make it work,' he says. 'It is not one single thing that we changed. It's mainly how we work with the brake system, generally.

'We also worked on the PPU margin [the gap between the maximum torque allowed by the regulations and what the car can actually produce], to be better in terms of how close we can go to the power band. This is a whole process, but it's mainly set-up and philosophy. I would say the main thing is we got a better overall understanding of the car, and were able to improve in every detail, though we have some bigger areas where we still want to work.'

Corner confidence

Like Porsche, BMW has to work on the regen' from the hybrid system to improve the braking phase of the car. 'The corner starts with the braking,' says Roos. 'When you don't get the braking right, the rest of the corner is normally [compromised]. So, when you get the braking right, you can rely on it, you know what to expect when you hit the pedal and then you get much more comfortable carrying the speed into the corner, brake later and so on. If you brake too early, you don't load the front tyre any more.'

'By starting late, you then don't have the same information and data or test days like others who already did both championships last year'

Andreas Roos - BMW M Motorsport director

Once the front of the car is compromised on turn in, there can be a higher steering angle, which then can lead to oversteer on exit. That then kicks in the traction control, which is not the best way to deliver power. Delivery of power over bumps is also a defining factor to PPU programming. 'Traction control has a big influence on your PPU margin,' confirms Roos. 'It is a complicated loop and you have to work on every detail to make it better.'

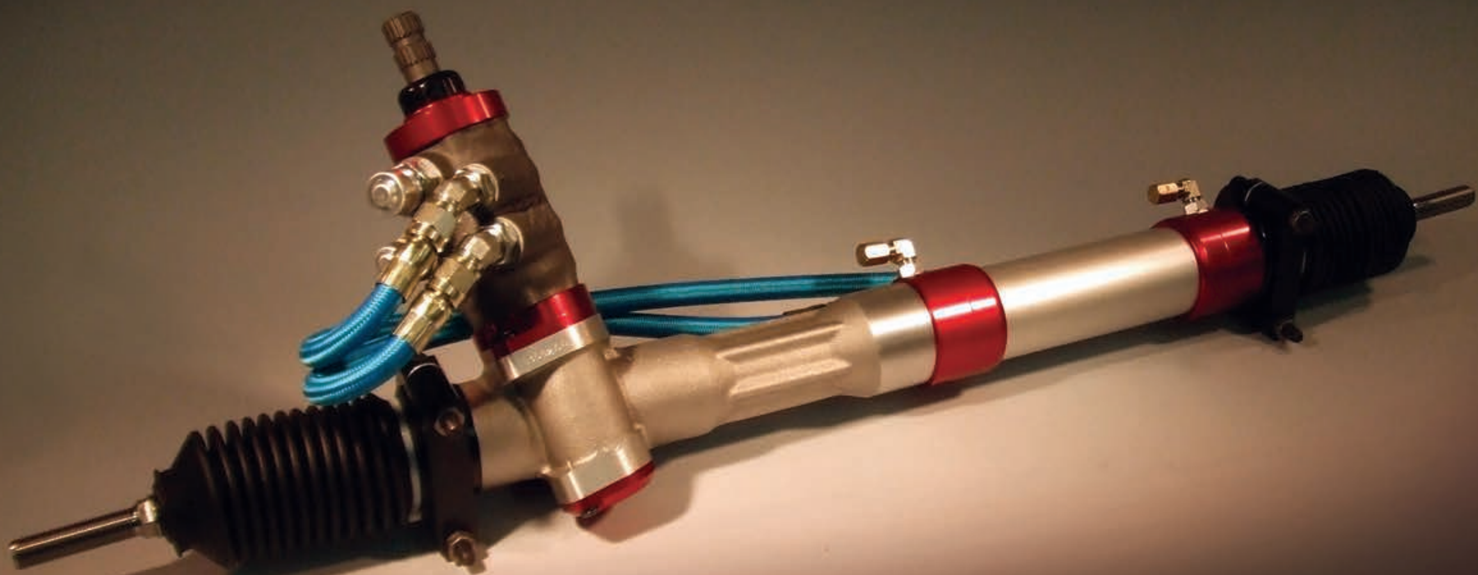
Generating heat into the tyres is also a major topic for both manufacturers. BMW admits it still has work to do in this area, and that too is linked to traction control. Different track conditions, such as cold temperatures or a wet surface, require different settings, and management strategies. If the car is not loading its tyres properly, that makes the whole thing harder to manage. 'The out laps, with the cold tyres, can easily cost seconds,' says Roos. 'This then affects your race result because you lose positions. On this low-grip surface, your drivers are not feeling comfortable to know when to brake into the next corner on the limit and then it all starts to get tricky.'

Test allowance

Having a factory team in only the IMSA series in 2023 meant BMW was allocated fewer test days than a manufacturer such as Porsche, which not only ran in IMSA and the WEC, but also had customer cars. Therefore, having another set of eyes on the development, by the WEC team WRT, should increase its test days and competitiveness.

Another compromise was that BMW committed to the prototype programme late, meaning it was limited in its options for the first season. 'It would have been too much for us but, on the other hand, starting late and having in the first year only one team running the car in one championship also generated less information, less input. By starting late, you then don't have the same information and data or test days like others who already did both championships last year,' says Roos.

There are further updates planned, and tested, for the BMW but, like those of Porsche, they have yet to be approved. However, one thing is clear – despite a stable rule set, there is still a lot of development work that can be done to these LMDh cars. So, the longer the rules remain stable, the closer and more performant the cars will become, and the more the competition will improve.



Courtesy of Hendrick Motorsports

Row upon row of engines wait in the state-of-the-art engine shop at the massive North Carolina facility. The annual output of power units makes Hendrick Motorsports one of the most prolific engine builders working in racing today

Motor city

Hendrick Motorsports produces over 600 NASCAR engines per year as it bids to reach 600 pro race wins

By ANDREW COTTON

Anyone who has been to Hendrick Motorsports' campus cannot fail to be impressed. Housed on 140 acres in Charlotte, North Carolina, the facility runs up Papa Joe Hendrick Boulevard to a series of factories that has steadily grown in size from 5000ft.sq in 1984 to an incredible 430,000ft.sq today.

On site is a full race shop for teams competing in various NASCAR-sanctioned championships, a museum that celebrates the 40-year history of the team, and a state-of-the-art engine facility that produces one of the highest number of bespoke power units per season in world motorsport.

Since April 1984, when Geoff Bodine won the NASCAR Cup Series race at Martinsville, products of the engine shop have powered winners every year, bar 1985. In the middle of this year, Hendrick driver, Kyle Larson, racked up the team's 310th victory when he took the chequered flag at Indianapolis, while further wins in the second-tier NASCAR Xfinity Series and the NASCAR Truck Series added to the impressive tally and have taken the company's record beyond 500 professional race wins. The next goal, then, is to hit 600.

Scott Maxim, director of powertrain at Hendrick Motorsports, is a man on a mission – one of consistency and quality

In the Cup Series alone, Hendrick fields eight engines, covering its own drivers Larson, Chase Elliott, William Byron and Alex Bowman of Hendrick Motorsports, as well as those of Spire Motorsports and JTG Daugherty Racing. Keeping up with this demand requires huge resources.

In 2024, engines built in the main shop have finished every race bar one, and that anomaly still grates with Scott Maxim, director of powertrain at Hendrick Motorsports: 'We had a broken valve spring on the no.48 car in New Hampshire,' he laments of the mechanical issue that stopped Bowman in that race. 'We had 29 events with eight cars, so we ran 232 Cup races, and that one out of the 232 still hurts!'

Reliability run

It's a long way from where engine reliability used to be. Even 20 years ago, it wasn't uncommon to see cars retiring from races due to engine failures, but power reductions from around 850bhp at their peak to a maximum of 670bhp today on street courses, short tracks and ovals, coupled with intensive development of the engine shops across the sport, mean such things are now a rarity.

Hendrick's race shop is one of the most prolific in racing, producing around 600 engines per year for competition in various series, each of them built from scratch by a team of around 100 highly skilled personnel, who also develop, test and maintain the engines over the course of the season.

The scale of the operation is staggering. Even sourcing the materials to create the engines, having the machinery and the workflow to produce them – to a schedule that is tightly controlled by NASCAR – and then to have them produce the same horsepower is a mammoth challenge.

Maxim says that to build eight engines for the Daytona 500, that are all within one bhp of each other, is not only extraordinary to achieve, but also to measure. The company uses its own dynos to test its engines' output before anything is strapped into a racecar to ensure parity across the units.

Resource management

The engine blocks are bought from GM as raw castings, then machined on site – main line, cylinder bores, lifter sleeves and main decks – using the latest CNC machines from Grob.

Even that is more difficult than it used to be. The Gen7 cars were introduced in 2022, mid-Covid, and many of the manufacturers involved in racing, and road cars, found themselves struggling to source materials. Meanwhile, the war in Ukraine continues to consume resource that might otherwise be used in racing, and Hendrick has had to find workarounds to maintain output.

'Dealing with supply chain issues is more of a challenge than it was five years ago,' admits Maxim. 'We always want to be a good partner to our vendors and, in that respect, they certainly have challenges when it comes to raw materials and production planning.

'[This year] we had 29 events with eight cars, so we ran 232 Cup races, and that one [engine failure] out of the 232 still hurts!'

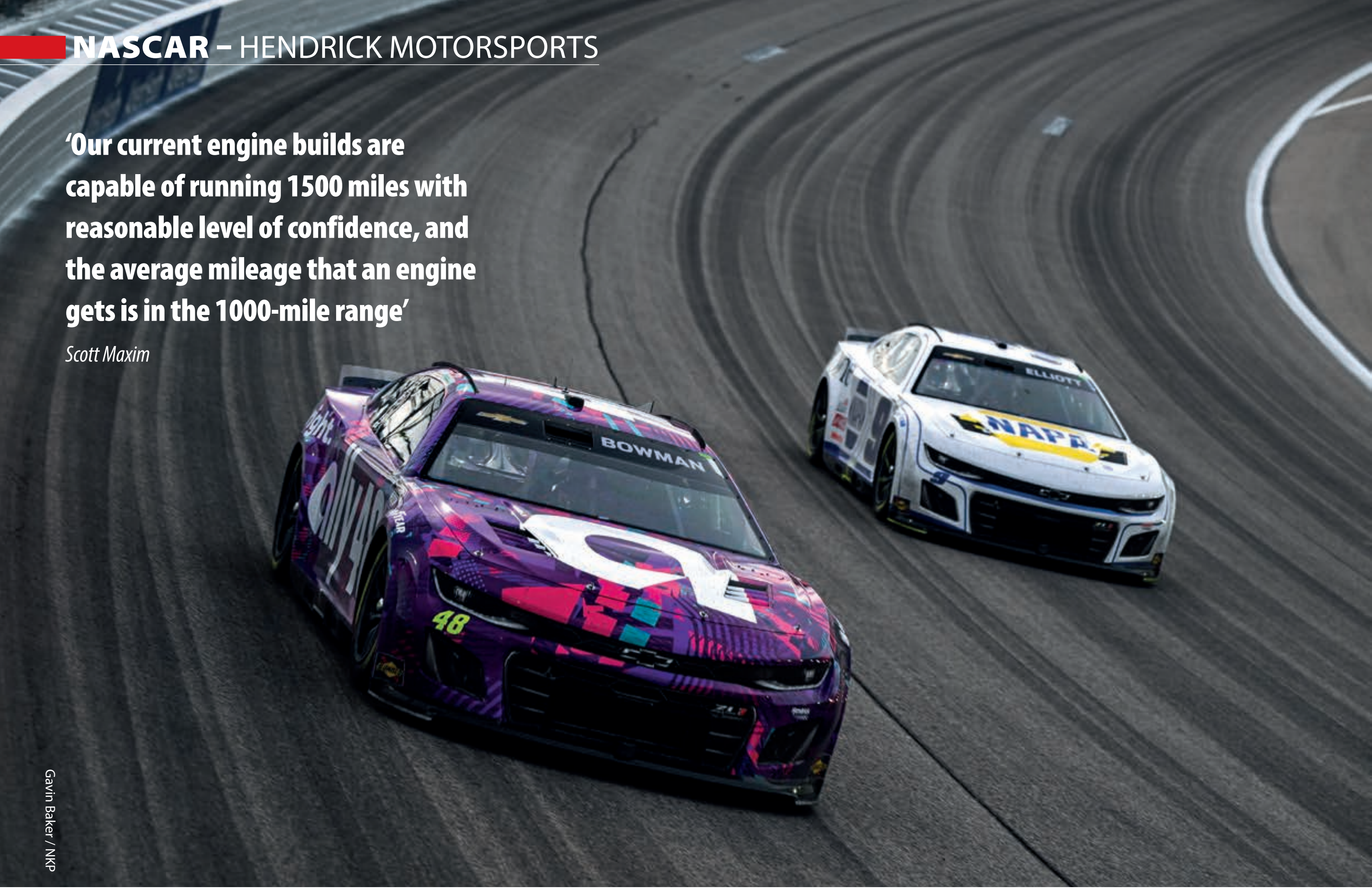
Scott Maxim, director of powertrain at Hendrick Motorsports

So, we have to try to be good stewards of purchasing in that regard, and to work with our vendors to do the best we can.'

Despite the high output, NASCAR rules mean that the majority of races during the season have to be contested with engines that have raced previously. Out of 38 Cup race weekends, 20 must be run with refurbished, or pre-raced engines. Not only does that reduce the cost to the customer teams, it also slows the rate of development, as any new components have to be introduced to all of the engines supplied, whether they are used by Hendrick's team or its customers.

Teams do have freedom to choose when those 20 engines can be run, but there are some limitations. The season-opening Clash at the Coliseum for example – in truth more of a showcase than true competition – has to be contested with a sealed engine that was raced the previous season. A sealed engine is mandated for the All-Star race too, while in

With engine regulation so tightly controlled by NASCAR, not only do all the power units for the various series have to be built on time, they have to produce exactly the prescribed power output



'Our current engine builds are capable of running 1500 miles with reasonable level of confidence, and the average mileage that an engine gets is in the 1000-mile range'

Scott Maxim

Gavin Baker / NKP

the Playoffs (the last four races of the series that decide the champion) cars must use sealed engines that have raced previously.

Power play

The strict regulations around engine use also mean Hendrick needs to ensure its engines do not lose large amounts of power over the course of their lifespan. That said, a fairly extensive rebuild can be undertaken without disturbing the seals around the engine that are mandated by NASCAR.

'We just ran about 600 laps around Bristol so, technically, that's just under 300 miles, but that's a little 0.533-mile [track] that we're running at an average of 7400rpm,' says Maxim. 'So, you are through a lot of cycles in a hurry there. That's a tough 300 miles, but one thing we've seen with respect to engine longevity is we're working with NASCAR as engine suppliers on this.

'Our current engine builds are capable of running 1500 miles with a reasonable level of confidence, and the average mileage an engine gets is in the 1000-mile range. The discrepancy there is because NASCAR is a contact sport. It's not a sterile form of racing, and what impacts our average [engine] mileage is wrecks, broken radiators, oil coolers and the like, that then lead to overheating. All things that are just a result of the type of racing we're in.

'That will take an engine that is half-life, or less, and relegate it to a full rebuild. There's just no way around that.

William Byron's win at the 2024 Daytona 500 was of particular note for Hendrick Motorsports as it marked 40 years to the day that the company made its NASCAR Cup Series debut

Gavin Baker / NKP

Kyle Larson's victory at Indianapolis in July signalled the 310th win for a Hendrick Motorsports-powered car in the NASCAR Cup Series

Nigel Kinrade / NKP

'We also get spins where the car is going backwards and, with the short exhaust pipes, you can easily get debris from the exhaust pipe outlet make its way up through the engine. It's a rough environment our cars live in, and our engines.'

Seal of approval

The engine shop therefore has to select the races where it thinks the engines are going to have the least wear and prepare them for others later in the season. The amount that is done during a rebuild – bearing in mind these are considered sealed units – is impressive.

'The first time it runs a race, we arrive at the racetrack with a fresh engine build,' explains Maxim. 'We have to install seals from NASCAR that seal the cylinder heads, both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the even and odd heads, so left and right, and the oil pan to the block. The camshaft also has a retention seal that does not allow it to be removed from the engine, and those seals must stay on.

'So after you one run one race, that engine is re-installed in a racecar, and that's essentially a sealed engine from the previous race. We've got to run 18 points-scoring events with a sealed engine, and then we've got the two additional races that are mandated to run a sealed engine in addition to that, for a total of 20.

'The one caveat is that, if you are fortunate enough to be in the Final Four at the championship race, those four engines have to be sealed units from a previous race. So, for those four teams, they've got to run a minimum of 21 sealed engines out of 38 events.

'We get those back to the shop and, in those situations where the engine is going to run again, we go through a comprehensive checklist: we clean the engine completely; change valve springs; inspect the valvetrain; run oil analysis; look for wear metals, or lack thereof.

Oil analysis

'The oil analysis will confirm that our wear levels for iron, aluminium, titanium, lead, indium and copper are consistent, and as we'd expect with an engine. If it's okay, the engine will go through its final peripheral systems checks and then go on the dyno. There, we run through all the vitals of pressures, temperatures, fluid flows, power output, crankcase depression and so on. Pending all of that being successful, and within range, the engine is signed off and ready to be delivered to a race team.'

Hendrick supplies eight full time cars in the Cup, so must have at least eight fresh engines for 18 races in the year. At each race, it also has a further eight fresh engines in the support truck, in case any are required.

Such attention to detail may seem common across the NASCAR landscape, but Hendrick has a particular claim to fame. During the 2024 season, it racked up its 520th race win in national motorsport, and the engine department is aiming to hit the 600 win mark as soon as it can.

'I think what helped get us there is a commitment across our entire shop for process, procedure and discipline,' says Maxim, 'and holding ourselves accountable to a high degree. It always has been. I think every race engine shop has that to some degree; you've got to have it to be successful.

'We've been blessed through the years to be able to put our engines in cars and race teams of the highest quality, and that is an honour. It's also a lot of pressure, though, to live up to those needs and expectations.

Starting from raw block castings bought in from General Motors, all machining tasks are done in-house for tight quality control

'We always strive to be a positive influence, and a contributor – our entire workforce does – to all the women and men out there racing. We're all driven by that'

Scott Maxim

Because we have many teams every week that are capable of outstanding performances, capable of winning, we need to be a positive part of that, not hindering them and not holding them back.

'We always strive to be a positive influence, and a contributor – our entire workforce does – to all the women and men out there racing. We're all driven by that.'

McLaren ECU

Despite all the regulations, there is always something to develop for the engine, and next year will see the new McLaren Applied TAG-510 ECU out track testing, with tentative plans in place for its race introduction in 2026. This will feature a more accurate digital signal than the current analogue system, offering benefits for both teams and engine builders.

'It's certainly more modern and capable, so there's much higher capabilities with respect to sensors, as well as throughput and telemetry, both in the vehicle and off-vehicle data transmission, be it via telemetry or wire,' says Maxim.

'Those capabilities, if there's future engine changes, or other manufacturers coming in, in addition to Chevy, Ford or Toyota, whatever options we have for engine architecture down the road, this ECU will be capable of managing those engines.

'It also offers the capability to provide for a safer and more robust racecar, which is something we always continue to strive for.

'In theory, I think it will be able to offer us higher quality data that we will be able to download in reasonable time. Right now, the data we can log is limited, and one of the reasons for that is having inefficient data offloads and transfers. With the more modern data transfer capabilities of the [McLaren] ECU, we will be able to download much larger amounts of data more efficiently.'

Mission statement

A walk around the Hendrick race shop is a humbling experience. The size and quality of the machines building the engines is almost dwarfed by the number of power units that sit in the shop ready to go. Pride of place is given to the engine that secured the company's 500th professional race win, mounted on a plinth to remind all the staff that work there of their successes.

'Our mission is consistency and quality, and we have that in our machines, our quality control, our metrology, our processes and our people,' says Maxim. 'Those are all areas we will continue to work on, to improve our infrastructure, our measuring and our testing capabilities, because we're getting to a point where that's the limiting factor.'

Maxim is clearly proud of the engine shop, and the team working in it to produce this high volume of powerful, reliable race engines. It speaks volumes that the Hendrick team has scored just over 300 of the 523 total race wins (at time of writing), while customer teams are responsible for the remaining 200+ victories. It's now only a matter of time before they hit the current goal of 600 race wins with Hendrick Motorsports power units.

City slickers

The Fastest Mini in the World competition has been attracting the most extreme examples of the famous city car for 30 years now. Racecar considers the top contenders at the 2024 event

By MIKE BRESLIN

The fastest lap of this year's FMitW event at Brands Hatch Indy was a 50.288s effort by Harvey Death (right), only 2.4 seconds off the British Touring Car Championship pole time

Note how far back the seat is positioned in Harvey Death's car, which helps with weight distribution across the spaceframe chassis. Many parts on this formidable machine were provided by former LMP1 outfit, Rollcentre Racing

When the Mini was launched in 1959, it was seen as what we now call a city car, something cute, cheap and convenient for pootling around town. What it was not seen as was a formidable competitor on a race circuit or rally stage. The cheeky little car was having none of that, though, and was quickly mixing it with the big boys, and winning, in both races and rallies.

Sports versions such as the Cooper were soon in production, while tuning companies dedicated to getting the maximum from Alec Issigonis' minimalist design proliferated, until the Mini was seen as the quintessential small competition car.

Meanwhile, the cars themselves just became faster and faster, many flying the flag high for front-wheel drive in special saloons and similar categories.

Photos: FMitW: Bresmedia

That development has never stopped, even when production of the original Mini ceased in 2000. The reason for this is partly the car's fanatical worldwide following, but also because for the last 30 years there has been an annual race event called the Fastest Mini in the World (FMitW). It caters solely for the old-style Mini, which in a motorsport universe of 'formula this' and 'class that' is a refreshingly just-what-it-says-on-the-tin title.

Mini Festival

The 2024 edition of FMitW was held at the Mini Festival at Brands Hatch in August.

'The Fastest Mini in the World is basically for any derivative of the Mini, or silhouette Mini,' says Nigel Death (pronounced Deeth), the race director, who also competes in a Mini Cooper S in Class D. 'Within the grid, we run four classes: A, B, C and D. Class A, which has no engine restrictions, attracts the silhouette, spaceframe cars, the really fast stuff.'

While rear-wheel drive, motorcycle-engined Minis have been allowed to compete in the past, the spirit of the competition is really about trying to get the most from the front-wheel drive format of the original car. That said, there are very few restrictions, beyond the usual safety regulations, but there are some spec elements. For instance, FMitW uses Sustain Racing fuel, which means a 35 per cent reduction in emissions, and even a small hike in performance.

'We've got evidence to prove it does make a difference,' says Death. 'We put it on the dyno at Swiftune [the renowned British Mini engine builder], and it delivers a 3bhp benefit.'

The event also uses Rowe synthetic oil, which has been proven to work well on the wide range of engines used in FMitW, while well known parts supplier, Mini Spares, is a 'massively supportive' long-time sponsor of the competition, says Death.

This year's 30th anniversary event attracted the biggest grid in 25 years, with 22 Minis entered, half of which were in the top class. As this is where the winner usually comes from, it makes sense to concentrate on a selection of Class A cars here.

Mini Cooper S V8

We'll begin with the car that currently holds the Fastest Mini in the World title, having won both 2024 races, and has done so four times in the past (2015, 2019, 2021 and 2022). It belongs to former Jaguar engineer, Harvey Death, who is organiser Nigel's brother.

The beautifully presented car has a spaceframe chassis with a T45 rollcage and carbon fibre bodywork. It weighs in at 630kg.

When Death bought the car, it packed a Vauxhall 16-valve Redtop engine, but he felt something a bit more 'Radical' was required.

'I spoke to Powertec, Radical's engine division, about their V8, and they agreed to loan me a buck engine,' Death recalls. 'I stripped the whole car to a frame and started to work out whether it could be fitted as a transverse engine driving the front wheels. It looked like it would work, or just about would.'

Now, with the 2.6-litre, 380bhp V8 squeezed into the car, it has a power-to-weight figure of around 600bhp per tonne. Naturally, to get the most out of an engine like this, the car needed an equally serious transmission, which presented Death with another packaging challenge.

'I did some research and worked out that the Xtrac six-speed sequential touring car gearbox would fit,' continues Death, 'though it needed some compromises to get it in. We ended up running the gearbox upside down so the driveshafts go out ahead of the block.'

Since then, a paddle-shift system has been added, while the car also uses a 'fairly locked up' Xtrac differential. Much of the work involved, which included beefing up the KAD-built spaceframe, was completed by former Le Mans LMP1 squad, Rollcentre Racing, and that pedigree shows.

'A lot of the content of the car was built from the redundant spares box from [Rollcentre boss Martin Short's] GT and Le Mans cars,' says Death. 'The four-way adjustable Öhlins dampers, for example, are off a prototype car.'

The big increase in power led to the Mini's radius arms being replaced because 'they were flexing, terribly,' recalls Death. 'We started off with aluminium ones and they were just dangerous. So we changed those to cast iron and they were still flexing too much. So we changed to upper and lower wishbones on the back, which gave the rear of the car a lot more control.'

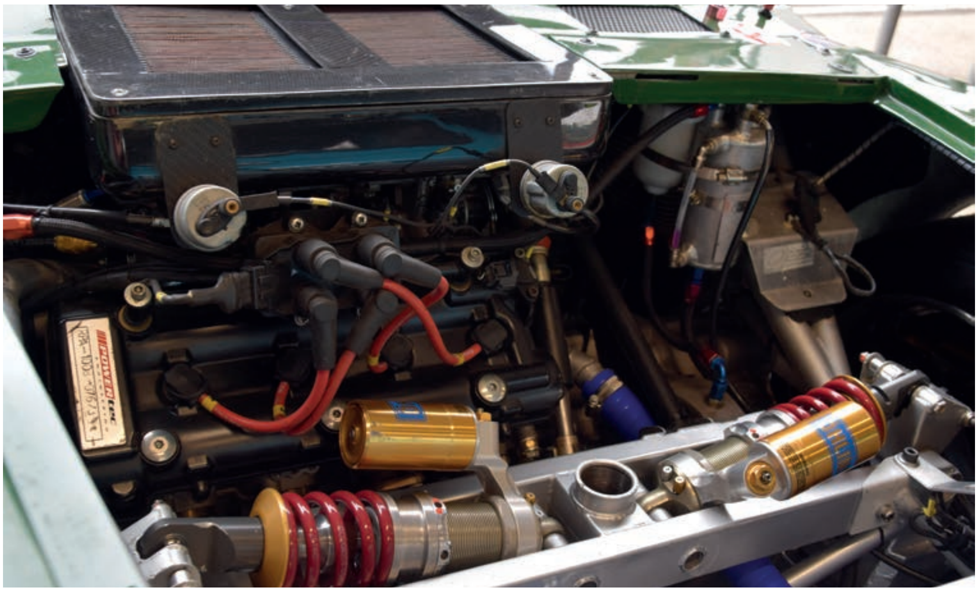
There's also an anti-roll bar at the rear and twin wishbones at the front.

Softly sprung

'We have done a lot of quite radical things with the suspension, like softening off the rebound, and it's quite softly sprung. We're doing everything we can to get the front wheels to stay on the tarmac. Although we've found that a lot of development on improving the front grip came from the rear of the car, which is often the trick with Minis. You get the maximum grip from the front, then you balance that up by reducing the grip on the back, so you don't get terminal understeer.'

Some of that rear grip is produced by a wing off a Mosler GT car – another Rollcentre contribution – cut down to fit within the Mini silhouette. Aiding this is a shaped floor, a decent-sized diffuser and a front splitter.

Rear wing on Death's Mini is from a Mosler GT car. Other aero elements include a shaped floor and a rear diffuser. That number plate is just for show - this car is certainly not street legal in the UK



Powertec V8 – the same as you'd find in a Radical sportscar – sits half in the engine bay and half in the cabin of Harvey Death's Mini. Suspension is double wishbone both ends, and its Öhlins dampers started life on an LMP car

Photos: FMitW; Bresmedia

One of the most noticeable things about this car, though, is the driver position, which is pretty much where the rear seat would normally be in a regular production Mini. This was chosen primarily to help with weight distribution, which also explains why the engine is located where it is – half in the engine bay and half in the cockpit. Essentially, it's pushed back as far as possible, while still keeping the car within the boundaries of a front-engined configuration. You'll note one bank actually protrudes into the cabin area.

This extraordinary Mini is capable of 163mph with the right gearing and on the right track, but Death is still considering making some modifications to the heads and cams, as these are currently Suzuki production parts (the Powertec V8 is basically two Hayabusa four-cylinder motorcycle engines in a v), and thinks these changes could push power up to 450bhp.

'It might mean we lose some driveability, which is part of the beauty of it at the moment. I don't think power is an issue, it's trying to use it that is the issue.'

'It's got a flat torque curve from 4000 to 11,000rpm. It's almost like driving an electric car'

Harvey Death

With that in mind, the car has traction control, although Death says it is probably only performing at about 35 per cent of its potential right now. It's driving style that's really the key with a Mini like this.

'It's got a flat torque curve from 4000 to 11,000rpm. It's almost like driving an electric car. It's pretty nice to drive, but it is still a grossly overpowered front-wheel drive car. If you drove it without thinking, it would understeer quite a lot but, if you drive it in a typical Mini type of way, it's quite neutral. Certainly, if you're just coming into a bend on lift-off with a trailing throttle, it does drive like a normal Mini.'

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Mini Honda K20

Another Mini that is far from normal is Peter Crudgington's pristine, Honda K20-powered example, which chased Death's V8 machine throughout the two FMitW encounters with Matthew 'Ollie' Howell at the wheel. At one point, the car was actually on pole with a 50.490s lap, though the fastest time of the event was Death's 50.288s.

Crudgington, an engineer in the aerospace sector, bought the glass fibre-shelled spaceframe car five years ago and then completely replaced everything at the front and rear and, as he puts it, 'about 80 per cent of the things in between.'

The spaceframe is CDS, and the car weighs 'in the 600s.' While the seat is set quite far back, it is not quite the extreme back seat driver approach of Death's machine.

Work on the 300bhp, 2.0-litre power unit, which is normally aspirated and runs on throttle bodies, was done in conjunction with Dave Yandell of DY Engine Services. He did the machining work, while Crudgington assembled the unit himself.

'It's different cams, pistons, rods, and the head's been gas flowed,' says Crudgington, who adds that the torque is exceptional for a K20. 'It's also a dry sump, to get the engine lower. The engine is actually set further back than quite a few of them, too. That's always a balance on front-wheel drive cars as you don't want the weight out the front, you want it over the axle line.'

The power goes through a five-speed Quaife gearbox and an LSD, and Crudgington has been very hands on with everything, even going as far as making his own loom and programming the dash and the Link Fury ECU, as well as producing all the body panels.

Bespoke floor

The really striking thing about this car, though, is how deep the rear diffuser is. This is fed by a bespoke floor, which starts just behind the door, and it works in conjunction with a Crudgington-made rear wing. 'They complement each other,' he says. 'The rear wing helps the diffuser because it kicks the air off it, which helps drag air through it.'

Interestingly, there are two fluorescent orange tabs marking the towing eyes at the rear of the car, and out on track these flick up, showing just how well this aero method works. Meanwhile, at the front there's a splitter / diffuser that's been located to funnel the air into the middle of the floor, flanked by mini wing / diffusers on each side, for more localised downforce around the front wheels.

Needless to say, none of this is original. In fact, Crudgington jokes that maybe only the door hinges are actually from a Mini.

'The Mini stuff is very weak. I thought, with the Honda in, we're going to be looking at 300bhp, so it needs big brakes [on the front], it needs different wheel bearings, different CV joints…' The list goes on. 'I fabricated the arms so it can run much bigger wheel bearings, but I've kept it as a trailing arm, so it still has the same roll-oversteer that Minis always have.

'I spent about three months designing the suspension geometry,' Crudgington adds. 'Basically, it's got zero bump steer and zero torque steer. To make a racecar fast is quite straightforward, but to make one fast and easy to drive is really the key to it being competitive in races.'

The car has already been modelled in CAD and the suspension and other components examined with FEA, while over the winter the next step is a CFD assessment of the aero.

The Honda K20 in Peter Crudgington's Mini has been heavily modified, with different cams, pistons, rods and a dry sump oil system, which allows the engine to be positioned low in the car

Crudgington's Mini has a very deep diffuser and its rear wing helps pull the air through it. Note the orange towing eye marker tabs flicking up, even in a slow corner like Druids

'That's always a balance on front-wheel drive cars as you don't want the weight out the front, you want it over the axle line'

Peter Crudgington

A2Z Mini Sprint Honda

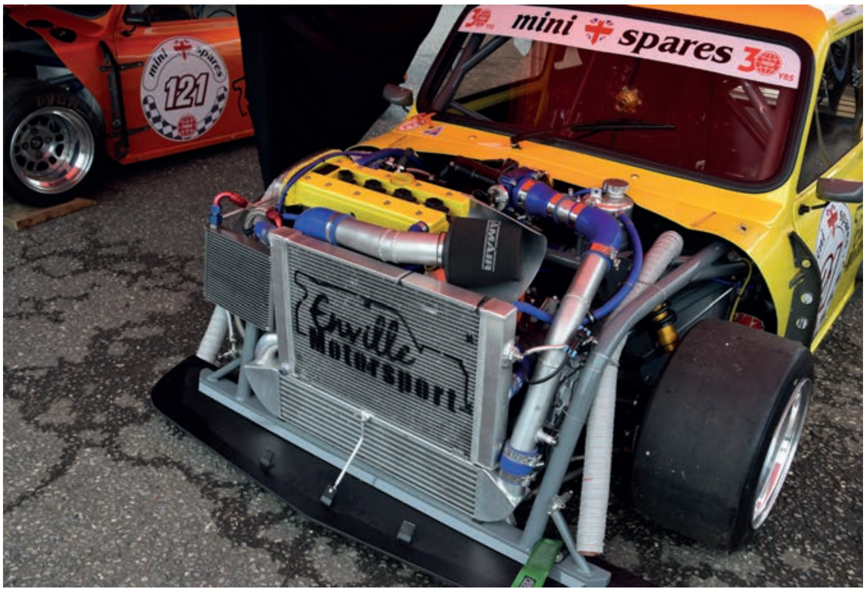
While Crudgington's car has very little original Mini left in it, Rohith De Silva has tried to keep as many Mini bits as possible in his, which is surprising, because at first glance it looks the most radical of all the contenders. This is because it's based on the proportions of a Mini Sprint, a limited run of roof-chopped and sectioned versions of the Mini, modified by a fellow called Neville Trickett. Reputedly, less than 100 were built and they are rare now but, because a silhouette of any type of Mini is allowed in Class A, this approach is fine.

The car, which was also driven by fellow Sri Lankan, Ashan Silva, at the FMitW event, is a spaceframe with a glass fibre bodyshell (the originals were steel). It has been developed by De Silva and A2Z Minis over many years and now utilises a 2.0-litre Honda K20 engine, similar to Crudgington's but closer to standard, except for the fact that it's supercharged. It's not been on the dyno yet, so power figures are unknown.

The blown engine is coupled to the standard H-pattern Honda gearbox and the car also has a limited slip differential.

Photos: FMitW; Bresmedia

This Richard Billington-built car, which won FMitW in 2023, has a full carbon fibre bodyshell and a very effective aerodynamics package, which includes a bespoke wing and shaped floor



Billington's Vauxhall VXR turbocharged engine produces 350bhp, even though the unit is close to standard. Though removed here, the car's boxy Mini Clubman front end offers more room for an effective cooling package

Rohith De Silva's extreme-looking machine is based on the proportions of a roof chopped and sectioned Mini Sprint, and is powered by a supercharged, 2.0-litre Honda K20 engine

Elsewhere, however, De Silva has kept the Mini faith so, 'all the suspension is out of the Mini, except for the Protech dampers,' he says. 'The steering rack is Mini, and the rear radius arms are from the Mini.'

Aerodynamics include a front splitter and rear diffuser, plus a modest rear wing, while inside the car the driver's seat is situated quite far back in the cabin, something of a theme with FMitW Minis.

Mini Clubman Vauxhall

Highly stretched cars like these can be temperamental, and there were one or two that did not make the start of the 2024 event because of mechanical issues. The reason Richard Billingham's 2023 FMitW winning car didn't run on race day this year, despite posting the third best time in qualifying (51.272s), was because it was sold to someone who had taken a shine to it in the paddock, the day before the races.

Billingham still had plenty to keep him busy, though, as he prepares a small fleet of five FMitW contenders through his Enville Motorsport organisation, all of them running with the Mini Clubman square front, a popular choice for modified Minis as it gives more room for a larger radiator.

The now sold car is based upon a CDS spaceframe chassis with a carbon fibre bodyshell and weighs 'probably just under 600kg,' says Billingham. With 350bhp on tap, that gives it an impressive power-to-weight ratio of 580bhp. That power comes from a 2.0-litre Vauxhall Astra VXR turbo engine.

Reliable power

'We used to have the Redtop [Vauxhall 16v] in before, but that's getting a bit rare now,' says Billingham. 'The VXR engine is reliable, and it's easy to get big power. It's got steel rods in it, but otherwise it's stock. There's really no need to go wild with them. If you do, you're either changing engines all the time or rebuilding them. I haven't touched this one for four years.'

Meanwhile, the gearbox is a Getrag F20 with an H-pattern manual shift, while there's also an LSD. Otherwise, he is another one that has chosen to utilise as many Mini parts as possible. 'We still run cast rear radius arms, all Mini front hubs, suspension top arms, steering rack… As much Mini as we can get in there, though it does have Protech single-adjustable coilovers all round.'

One aspect of the car that is certainly not Mini is the aero. 'Basically, the floor at the back comes up and then we put two end plates on to create a diffuser,' Billingham explains. 'The floor is also concave across the middle of the car, and there's a splitter on the front, too.

'We know the diffuser works because we were testing once at Mallory [Park] and the downforce produced actually bent it down.'

Because one of the few FMitW regulations is that the wing must fit within the width of the car, including wheelarches, finding an off-the-shelf rear wing for the diminutive Mini can be difficult. Consequently, most, including Billingham's, are bespoke items.

Maguire Mini Traveller Duratec

Bill Richards' Mini Traveller – as the estate version of the car was called – also has a bespoke wing, though this time the thinking behind it has more to do with straight-line speed than downforce.

The car started its racing life as an Arden 850-engined, regular-bodied Mini in the 1970s, originally built by special saloon guru, John Maguire. Richards bought it and then later converted it to something quite different, as he explains: 'When the Metro [Mini's replacement from British Leyland] came out, it had a lower drag coefficient than a Mini, so I raced it as a Metro for many years.'

However, Richards' long-time sponsor is Mini Spares, so a switch back to the Mini shape made sense commercially. 'It turned out that the Mini Traveller is exactly the same wheelbase as a Metro,' notes Richards. 'I also looked in the manuals and saw the top speed on the van was higher than the car – only by a handful of miles per hour, but still higher – so, it was one body off and one body on.'

Richards also started to brush up on his knowledge of aerodynamics, mainly from the NASA website, where he learnt about vortices. 'A vortex is what happens to the wind when it goes over the car,' he explains, 'and as it rolls down on the back of a Mini, it swirls, and it's like two anchors. But with a van, because it's a flat back, the vortex is further away from the back of the car.'

Never one to do things by halves, Richards made his own wind tunnel, using a fan from a rolling road mounted on an adjustable trolley and some smoke bombs from a friend who worked at British Gas, where they were used for testing ventilation.

'I made a wing in cardboard and started to experiment with vortices,' Richards recalls. 'Eventually, I got to the rear wing that's on the car now, which we made adjustable for different circuits, so I can move the vortex further back, or a bit closer, if I want.'

What downforce there is comes from under the car. 'The wing is nothing to do with downforce,' Richards says. 'Downforce is generated by John Maguire's genius. He made a slanted floorpan, so it's got a slant, and the body is straight [in relation] to the floor.'

That floor is made of aluminium, while the chassis is a full spaceframe and the body is glass fibre, all of which adds up to a total weight of 548kg. With a 'near standard' Ford Duratec 2.0-litre engine, which gives around 230bhp, 'Bessie', as this car is fondly known, has a decent power-to-weight ratio at 420bhp.

Bill Richards' Mini Traveller packs a Ford Duratec 2.0-litre engine and is based upon a spaceframe chassis originally built by special saloon guru, John Maguire

The rear wing on Richards' car has been developed for straight-line speed, rather than downforce. The estate body shape was chosen because of its lower drag and higher top speed, compared to a regular Mini saloon

Photos: FMitW; Bresmedia

'When the car goes light, the back will go round, so we back the [rear] braking right off to almost zero. That way, you can attack an apex of a corner and the car won't let go'

Bill Richards

The car also has a Sadev gearbox and an LSD, which, as many of the FMitW drivers attested, is hard work in a Mini. 'You need strong arms to drive it', confirms Richards.

Much of the suspension is original Mini-based, though there are wishbones at the front, lengthened radius arms at the rear and high-end Quantum dampers all round.

'All the bottom arms, the tie bars, they're all Mini. I mean, we've upgraded the material, but it's all Mini design,' notes Richards.

There are also AP brakes that are bespoke for this car at the front but, as is the case with most of these Minis, next to nothing at the rear when it comes to stopping power. 'That's because the back is so light,' explains Richards. 'If you are going into a corner, when the car goes light, the back will go round, so we back the [rear] braking right off to almost zero. That way, you can attack an apex of a corner and the car won't let go.'

Mini world

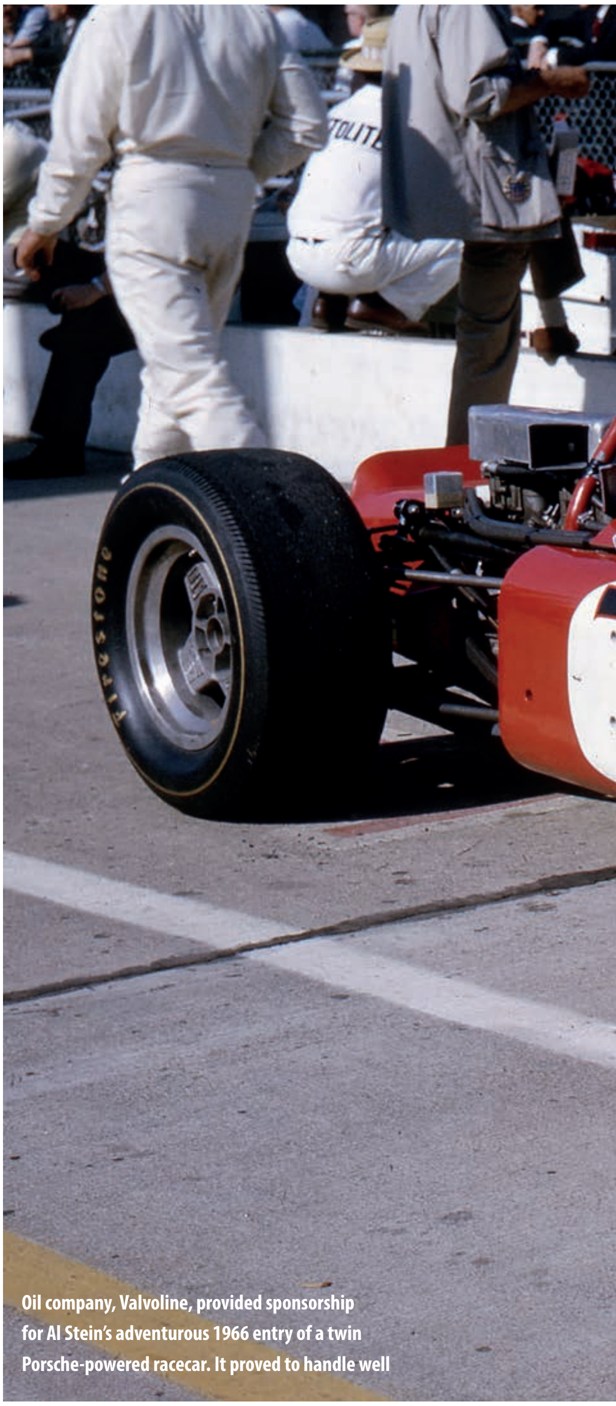
It's this typical Mini lift-off oversteer behaviour on track that makes these cars so entertaining, both from a driver perspective and to watch. This means there is a demand for more races – from spectators and competitors in the UK and overseas – and there is the possibility that other FMitW events might be held in the future.

Because of the huge international interest, a similar competition for these very cars, but held in the US, almost got off the ground in 2024, but was eventually scuppered by logistical issues. In truth, perhaps the appeal of FMitW is that it is a standalone event, with one single Fastest Mini in the World crowned each year. It's a format that's worked well for three decades now, so some might say there's no need to change it.

Double trouble

California's Al Stein looked to Porsche for twin powerplants for his all-wheel-driven attack on the Indianapolis 500, but was a year ahead of the curve

By KARL LUDVIGSEN



Oil company, Valvoline, provided sponsorship for Al Stein's adventurous 1966 entry of a twin Porsche-powered racecar. It proved to handle well

The decade of the 1960s was one of dramatic experimentation and transformation for the classic 500-mile race at Indianapolis. It witnessed the changeover to rear-engined cars, the surge of turbine power, spectacular tyre improvements and the triumph of turbocharging. Four-wheel drive was another feature of new cars, both successful and less so. None was more adventurous than Albert H Stein's Porsche-powered 1966 entry.

In fact, Stein's creation had both Porsche and Indy credentials. Its drive principle was the same as that exploited by Lou Fageol at the Speedway 20 years earlier and subsequently in his twin-engined sportscars. Al Stein powered his racer with two air-cooled Porsche sixes, each one driving the pair of wheels at its end of the car.

A mechanically precocious Californian machinist, Stein grounded his motorsport experience in the new and exciting arena of midget racing on the quarter-mile oval tracks of his native state. He and his home-built midget were on track and racing in the first ever event of the Midget Racing Association at Sacramento on 4 June 1933. Then just 20, Stein found his métier as both builder and driver of midgets, winning the Northern California Championship three years running from 1935. Crewing his racer were fellow East Bay residents, Richie Lukes and Harry Shorman.

Speed demon Stein inevitably came into the orbit of a like-minded, Oakland-area enthusiast in Fageol. 'Al and Lou were very close friends,' recalled Stein's wife, Patricia, 'always talking to each other.'

Wielding vastly greater resources, Fageol was first of the pair to make it to the 500-mile race at Indianapolis with his twin-engined car of 1946. Stein would later date the beginning of his Indy obsession to the early 1950s, an indication that it was Fageol's twin Porsche sportscars that started him thinking about a similar configuration for the Speedway.

Route to Indy

When Stein began mulling his mission to Indiana, his thoughts were concentrated on a pair of Porsche's air-cooled fours, similar to those used by Fageol in his sportscars. Two of these, at 1.5-litres each, would fit like a glove in the Speedway's 3.0-litre class for supercharged cars. Using Fageol's supercharging techniques would generate the kind of horsepower required to thrust Stein's special into the select, 33-car starting field.

However, as Stein's scheme progressed, Indy's rulers moved the goalposts. For the 1957 race, they reduced allowable engine sizes to 2.8-litres supercharged and 4.2-litres naturally aspirated. At 1.4-litres, the pushrod Porsche engines could still do the job, if equipped with forced induction.

[Harry] Shorman faced the same task Porsche was addressing in 1965, bringing the 911 engine up to more than 200bhp for racing

The outlook would be even better if a pair of four-cam Type 547 fours could be sourced and suitably downsized, but this would challenge Stein's modest budget.

Six of the best

New perspectives opened in the autumn of 1963 with the revelation that Porsche would soon produce a completely new model with a 2.0-litre, six-cylinder engine. This could be made bigger, not smaller, for two of these air-cooled engines to compete in the naturally aspirated 4.2-litre class. Although Porsche's declared output of 130bhp at 6100rpm was far from competitive – around 400bhp was deemed necessary – the overhead cam six was clearly capable of making higher power.

Thanks to the intervention of Fred Ernst, shop foreman at San Rafael's Johnson Pacific VW dealership, Stein could check out the latest Porsche power unit. The two men measured the engine in a factory fresh 911. Deciding this was the way to go, Stein acquired three of the early 911 sixes and their transaxles through Ernst's brother in Germany. Ernst would go on to provide useful advice and assistance to the project.

Stein had just the allies he needed to wring more power from a pair of Porsches. Finding they had both gravitated toward Zuffenhausen machinery, Harry Shorman and Richie Lukes teamed up at the end of the 1950s to form Lukes and Shorman (L&S) to prepare the popular Porsche Speedsters for racing. L&S modifications included lowering front ends, modifying carburettors, camshafts, valves and other engine components, altering gearbox ratios, improving brakes and stiffening anti-roll bars and shocks.

Two L&S-sponsored drivers, Walt Maas and Walt Benson, won numerous races and championships in their modified Speedsters.

The search for 200

In fact, only Shorman was running L&S because Lukes left the company after a year, albeit still keeping in touch as an advisor to Shorman and, later on, his son, Bill.

Shorman faced the same task Porsche was addressing in 1965, bringing the 911 engine up to more than 200bhp for racing. Heinz Hamster and Tom Manning at L&S assisted with preparation of the race engines.

Stein and Shorman planned an increase in cylinder bore to bring the 2.0-litre sixes closer to the 2.1-litres allowed by the 4.2-litre limit, but accounts are unclear as to whether this exacting task was carried out. One testament says the cylinders were 'overbored' to suit forged pistons that brought the compression ratio up to 11.5:1 to suit the use of methanol as fuel.

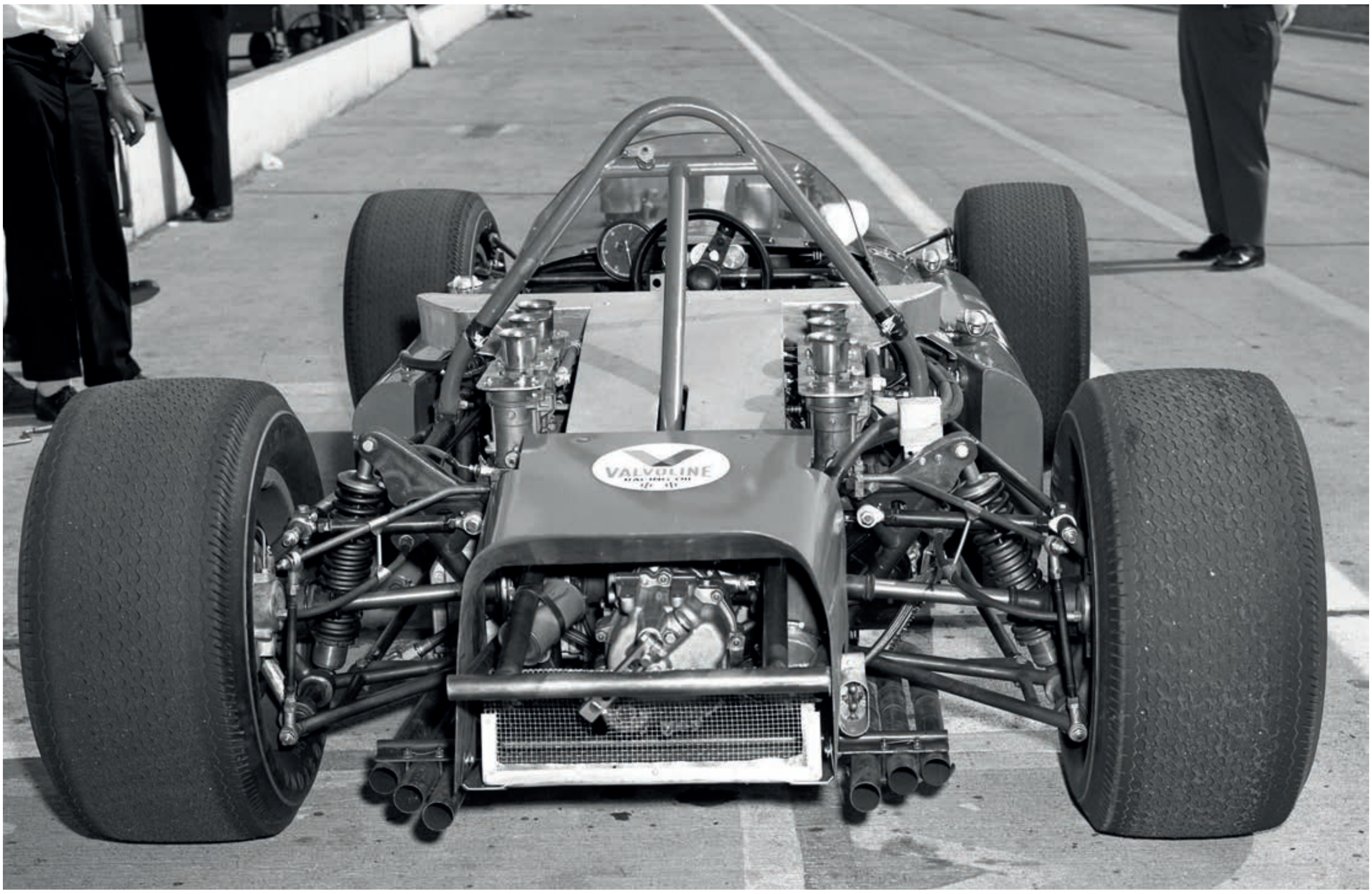
Ignition was converted to Mallory Mini-Mag systems, while carburetion was by eight 48mm twin-throat Webers, the same units used on big Maseratis and early racing Cobras. Basic mathematics tells us this left one throat at liberty on each bank, which was unavoidable because Porsche's bespoke triple-throat Webers were unavailable to Stein at the time. Simple boxes were fitted above them to give ram-air pressure at speed.

In case of emergency, the front engine could be shut down independently by a solenoid valve triggered from a steering wheel-mounted kill button.

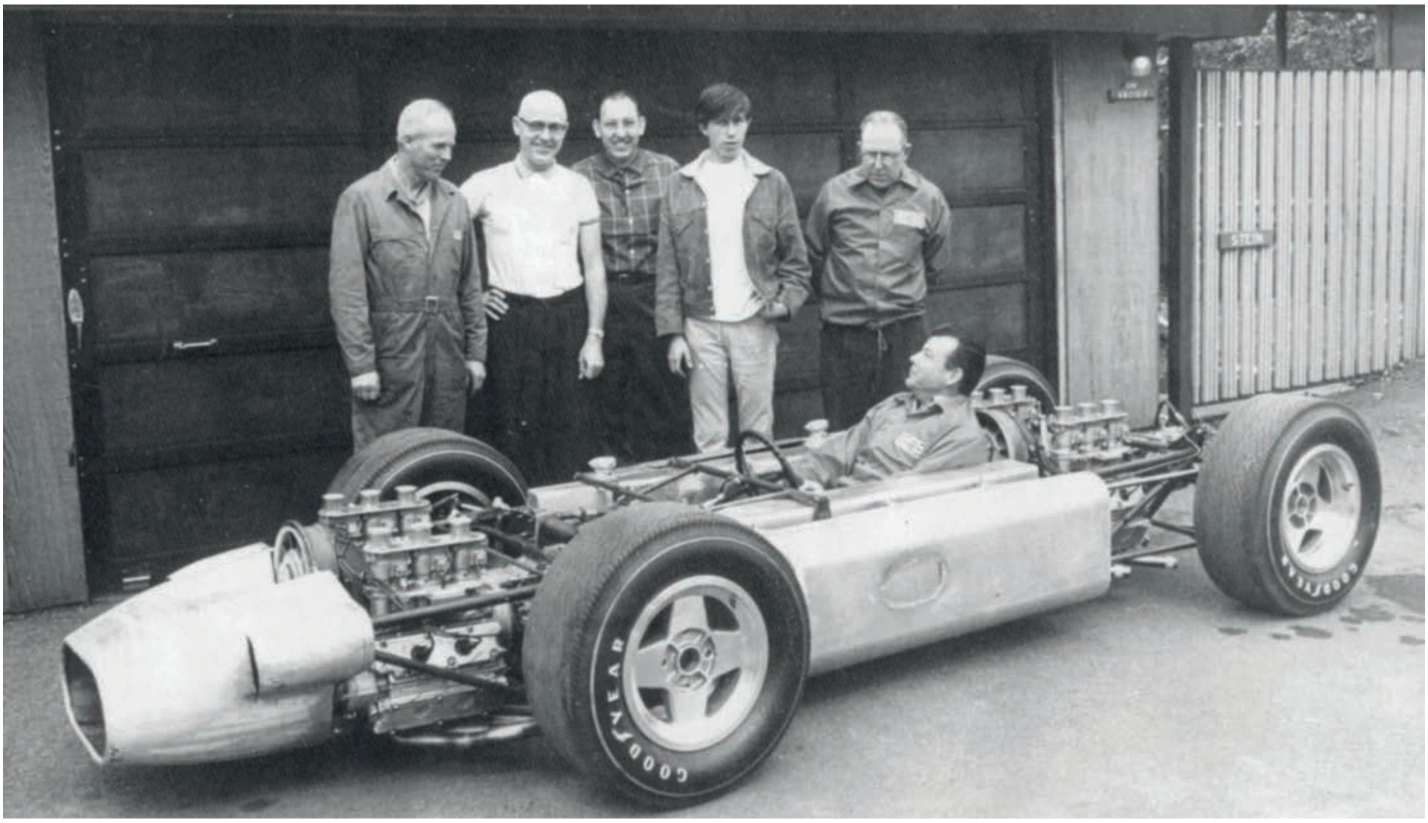
Cam challenge

Special camshafts were essential to extending the Porsche's rev range to gain power. This proved a major challenge. Possibly apocryphal was the report that racing cams ordered from Ed Iskenderian had to be put aside because he had overlooked the fact the Porsche's cams rotate in opposite directions. In fact, they don't, but as viewed from the

At Indianapolis in 1966, interest was considerable when the Twin Special and its veteran driver, Bill Cheesbourg, prepared to tackle the historic 2.5-mile Speedway. However, camshaft problems and a lack of outright power hampered its efforts in testing



A rear view of the Twin Special showed the design and construction talents of Joe Huffaker. Note the Weber 48IDA carburettors are not fitted with their forward-facing ram air scoops here



Al Stein (right) and his team were all smiles at the completion of the car. Its low lines promised good handling and modest aerodynamic drag, though the high driver position countered that

anti-clutch end, the 'front' in a normal car, the crankshaft and cams do turn counterclockwise instead of the more common clockwise. This may potentially have disorientated Isky, known as 'the camfather'.

Departing from the layouts used by Porsche and Fageol, Stein elected to place both engines forward of the wheels they drove. To achieve this, he turned their transaxles upside down, which had the effect of placing the ring gear on the other side of the pinion to restore forward drive. Although Lukes and Shorman suggested using lighter Halibrand transaxles, Stein remained loyal to Porsche original equipment, which in its upended state set the engines lower in the chassis. Ernst worked out the knotty shift linkage required between the two transmissions.

Knitting the Twin Special together was a tubular steel spaceframe built by San Rafael's experienced Joe Huffaker. Stein arrived at his shop, Huffaker told David Colman, 'with everything laid out in line form. We just did the final drawings and worked from those.'

'We have an advantage, that the Fords have to put 250bhp through each rear tyre while we can spread our 440 [bhp] into four tyres, all working'

Al Stein

'Huffaker had worked for Stein when Joe first came to California from Indiana in 1949,' Colman explained. 'He respected Stein's savvy as a tool and die maker, race driver and car preparer.'

'It was sort of a work in progress,' Huffaker said of the Stein project. 'I was preparing our own MG Liquid Suspension Specials for Indy and had to squeeze in working on Al's project at the same time. I was a bit puzzled by the logic of his project but there is no question that his design was certainly different.'

Taking the finished chassis back to his workshop in Orinda, California, Stein set about making it into a racing automobile.

Advantage four

Suspension at all four corners was traditional racecar parallel wishbone style with concentric dampers and coil springs, plus adjustable anti-roll bars. Drive to the front wheels was carried through uprights and hubs from a Lancia-built 4x4 vehicle, as recommended by Ernst, instead of the DKW parts originally envisioned by Stein.

Fuel tankage was either side of the driver, both inside and outside the longitudinal frame trusses.

Huffaker's Genie four-spoke aluminium wheels carried 11.90 x 15 Firestone Indy tyres, narrower than the usual Speedway rubber in view of the car's more balanced drive loadings.

'We have an advantage,' Stein explained, 'that the Fords have to put 250bhp through each rear tyre while we can spread our 440 [bhp] into four tyres, all working. With narrower tyres, less wind resistance and four-wheel drive, we should be the fastest car through the turns.'

His engine builders told Stein that each six-cylinder powerplant should develop at least 210bhp.

As for 'less wind resistance', Stein's concept envisioned a low profile for his racer, thanks to the horizontally-opposed Porsche sixes. In essence, this was achieved in the body built for him by the Albany, California duo of Leo Titone and Bob Feehan, although an anomaly was its front-end air scoop, surely an augmenter of drag.

The layout also left little room for the driver, whose erect position behind a tall windscreen contrasted with the ultra-low seating of the latest mid-engined cars, as pioneered by Lotus. A general lumpiness of the result hinted at many drag inducers degrading the benefit of the car's low profile.

First impressions

Initial impressions were positive when the unpainted Stein creation was taken to Vaca Valley Raceway, near Vacaville, for a shakedown on its 1¼-mile oval track early in April 1966. Contracted by Stein to pilot his creation was Bill Cheesbourg, an Indy veteran who first competed at the 500-mile race in 1957. Previously, the Tucson, Arizona resident piloted both generic Offy-powered roadsters and such exotics as the supercharged Novis. Experienced he may have been, but he achieved only erratic results at the Brickyard.

Reaching 140mph on the Vaca Valley track, Cheesbourg was satisfied with the car's handling. However, he and Stein both felt that more horsepower was required. The answer, Stein felt, lay in better camshafts though, with only a couple of weeks remaining before practice began at Indianapolis at the beginning of May, time was running out.

Camshaft creation, which Stein outsourced to L&S, became nightmarish. Having urged his pattern maker to abandon plans for a holiday to create patterns for new camshaft castings, Shorman received a report from the foundry that a shift in the moulds meant the castings were unusable. In a rush, Shorman contacted specialist, Weber Engineering, asking it to add metal to the original Porsche camshafts and give them a more radical grind.

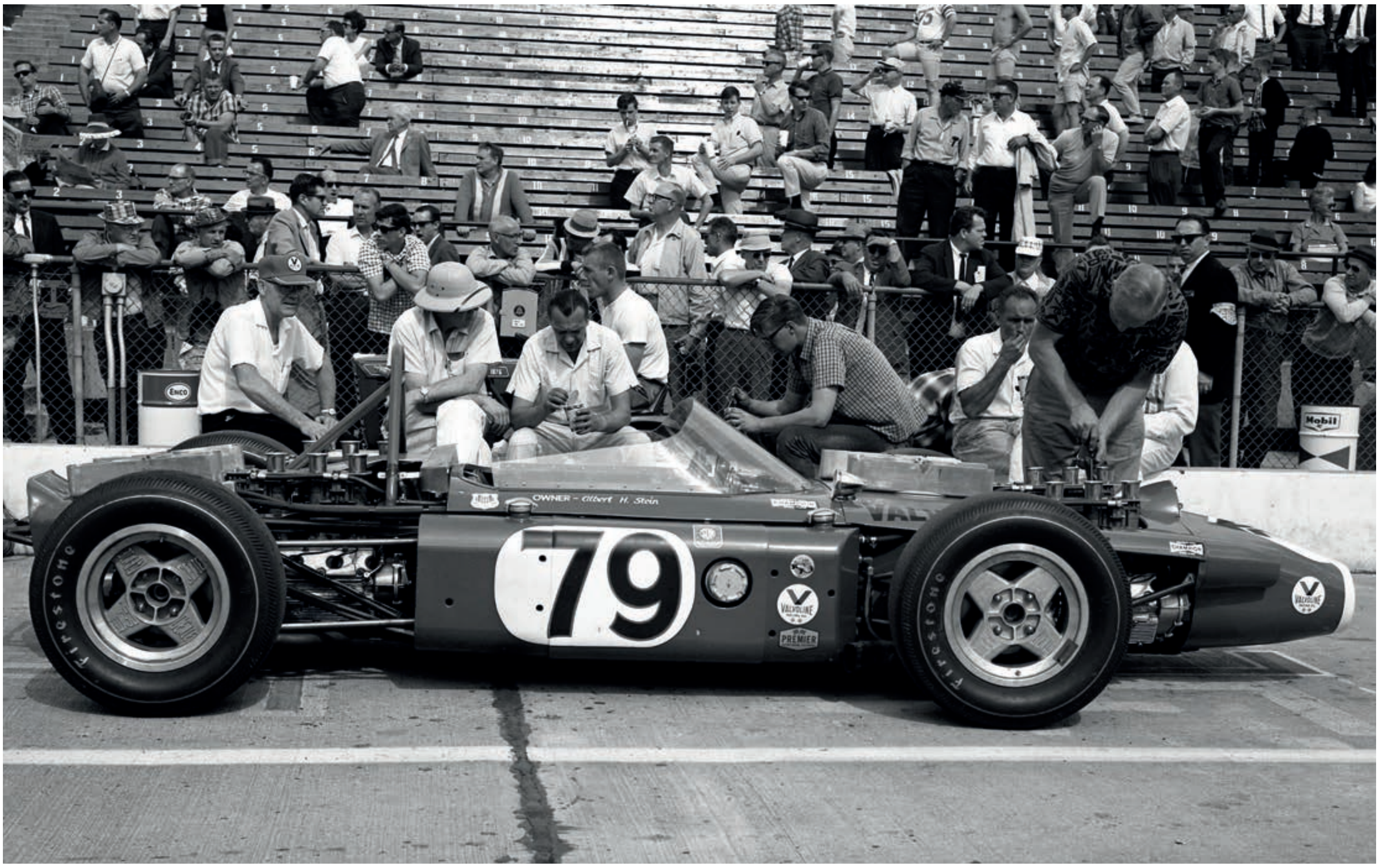
Air freighted from California, the Stein machine arrived at the Brickyard on Sunday, 8 May, a week after the early birds had made their appearance. This left a limited amount of time to get up to speed before the first day of qualifying on 14 May. Unfortunately, preparations were further compromised by rain stopping play on multiple occasions.

'The chassis seemed good,' recalled Tom Manning. 'The hydraulic throttle worked well, and Cheesbourg liked the way the car handled. The complicated shift linkage wasn't very good so it would jump out of gear, and we had constant problems with the engines.'

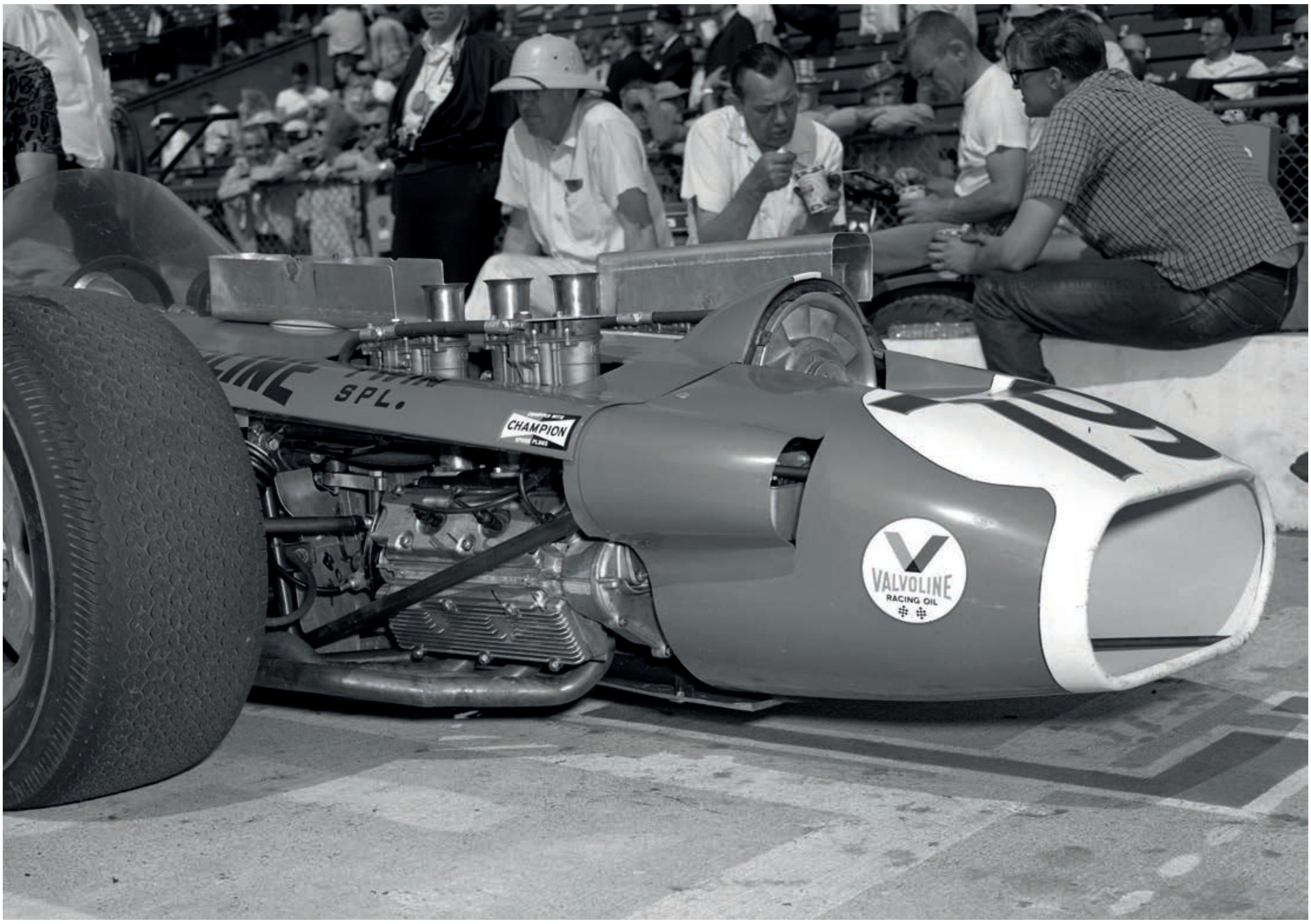
Aiming for a ground-hugging profile, Stein was largely successful. Cockpit space was at a premium, however, and the front air scoop contributed to drag

'The chassis seemed good, the hydraulic throttle worked well and Cheesbourg liked the way the car handled [but] the complicated shift linkage wasn't very good… and we had constant problems with the engines'

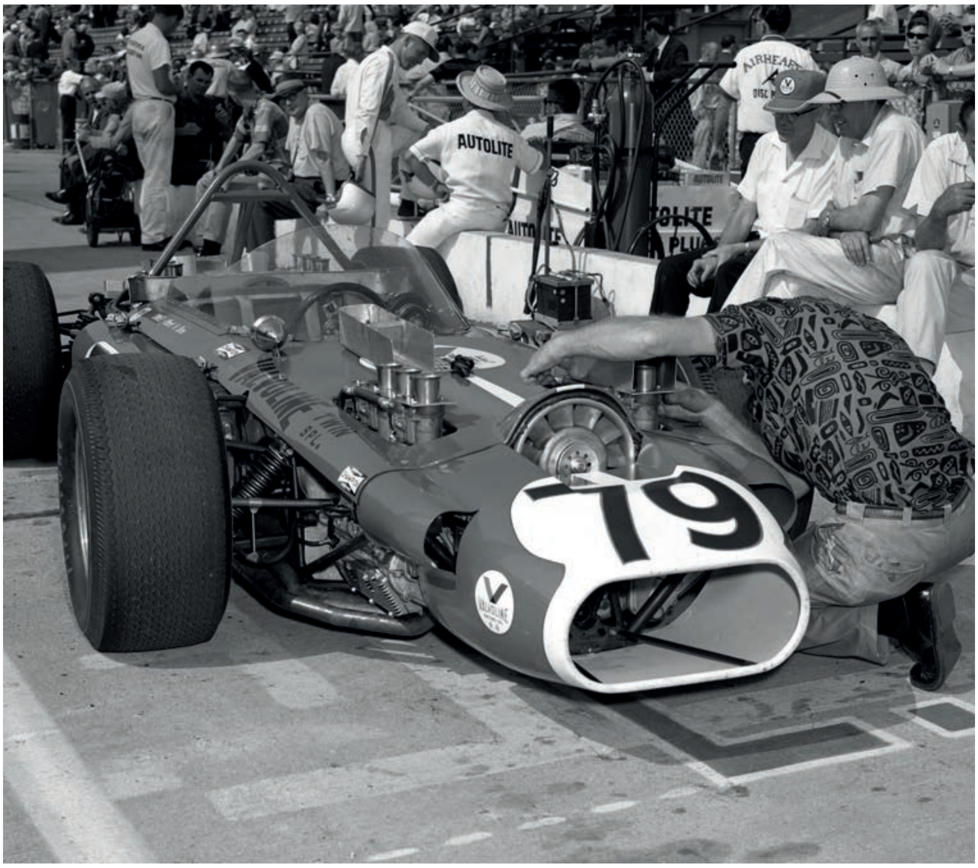
Tom Manning



Powering the Twin Special were two standard 1965 Type 901/01 Porsche sixes and transaxles, modified with special camshafts, higher compression ratios and non-standard Weber carburettors



Both Porsche engines in Stein's special were mounted ahead of their driven wheels with their transaxles inverted, not only to provide correct wheel rotation but also to lower the car's c of g



Lacking only the power to perform well against the competition, Stein was a year or two early with his twin-engine concept. The 220bhp Carrera six-cylinder engines Porsche offered in 1967 would have made a significant difference to the top speed of the car

At the Speedway, the Weber-modified camshafts were installed under the direction of crew chief, Welton 'Skeets' Jones, but 'the lobes began to break up almost immediately,' crewman Manning recalled. 'They were a disaster.' To add insult to injury, the resulting debris circulated through both engines because Stein, against some advice, had installed a single reservoir serving the dry sump lubrication systems of both engines.

Poor performance

The net effect was the sixes achieved just 7500 useful revolutions at Indianapolis. Output was boosted by the addition of 60 per cent nitromethane to the methanol fuel. Although the engines were dyno tested by Manning, and reportedly by Champion Spark Plug at their Long Beach facility, their actual output at Indy is open to speculation.

Although much was later made of the effect of the Twin Special's putative high drag on its performance at the Speedway, where it showed little in the way of speed on the straights, odds are high that lack of power from the Porsche sixes was more to blame than aerodynamics. In fact, only the Eagles, Brabhams, Lotuses, and their imitators of that era, achieved much in the way of low-drag design.

With disintegrating camshafts robbing the team of vital running time, Cheesbourg and the Twin Special made few runs during the week before the second qualifying weekend. The driver then switched to another radical mount, Norm Demler's GE turbine-powered roadster. Although its speed of a reported 260mph on the straights contrasted starkly with at least 100mph less for Stein's creation, that car too failed to make the starting line up.

Proof of concept

The twin Porsche was wizard in the four turns, said Cheesbourg: 'We had the fastest cornering speed of the meet. I could run through the turns flat-footed.'

This comment validated Stein's concept, which combined the high polar moment of inertia given by its widely disposed engines with a low c of g and four-wheel drive, a harbinger of things to come in the turbine-powered cars of 1967.

The weight aspect of the unique car's power-to-weight ratio was also disadvantageous. One citation of 'a bit over 2000lb' would mean the Stein car was carrying several hundred pounds more than the usual Speedway racers. The Twin Special was 'unnecessarily heavy in lots of places' according to Manning. The twin production car transaxles were just one example.

Contrary to reports that the Valvoline-sponsored Twin Special 'didn't qualify' in 1966, no attempt to qualify it was made. Its best time just broke the one-minute barrier at 59.3 seconds. This would have been a big deal in 1962, when Parnelli Jones made history by being the first to qualify with four laps at less than a minute apiece for an average better than 150mph. However, by 1966, the field's slowest qualifier averaged 56.6 seconds per lap for 159.01mph, while the average speed for 1966's 33-car field was 160.251mph.

In Stein's favour is that this result was no embarrassment for a radical new concept at the Speedway. 22 entries failed to make the race that year, including one of two new cars built expressly for Indy along the latest lines by Huffaker. Stein's car foreshadowed interest in four-wheel drive that flourished in 1967 through 1969. Indeed, Cheesbourg tried to interest Stein and Demler in joining forces to field a 4x4 turbine car in 1967 but both declined, citing exhausted resources after their unrewarding 1966 season.

Early bird

Stein was a year or two early. Had his dream machine been targeted at the 1967 season, he could have obtained a brace of fuel injected 901/21 Carrera 6 engines. These would have given him a total of 440bhp at 8100rpm on petrol, with factory quality camshafts. Recalibrated to run on methanol, and with a tip of the nitro can on top, it would have had much more power for qualifying, albeit at the expense of some fuel economy.

The sixes would have run reliably throughout May, giving Stein and his team the time they needed to lighten the vehicle and improve its aerodynamics, time that was stolen from them in 1966 by their last-minute struggles over camshafts.

The Twin Special made one more appearance in 1966 on the weekend of 19-20 November. This was the final USAC race of the year, the Bobby Ball Memorial 200 Miles on the one-mile oval at Phoenix, Arizona. Don Meacham and Cheesbourg are listed as its pilots during practice but, contrary to some reports, there is no indication the car competed in the race.

Stein's concept… combined the high polar moment of inertia given by its widely disposed engines with a low c of g and four-wheel drive, a harbinger of things to come in the turbine-powered cars of 1967

'Al didn't put much work into it before Phoenix,' said crewman, Byron Feldhaker. 'He did it mainly as a tax write-off.'

Contrasting with this is the report that Stein took the car back to Vaca Valley for pre-Phoenix testing, taking the wheel himself.

The sordid aftermath of the 1966 Indy effort was a welter of lawsuits among Stein and Lukes & Shorman over the camshaft re-grind fiasco, and the reluctance of Stein to pay for same. Some evidence shows Stein had recognised the shortcomings of his car's body and had fashioned a less wind-catching nosepiece, but this was never tried in anger for Stein let his twin Porsche brainchild languish in his Orinda, California garage until he died in 1980. R

Whether coming or going, the Twin Special left its mark at the famed Indianapolis Motor Speedway. Some of its forward-thinking concepts turned up on other cars in '67, including four-wheel drive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The win is not enough

Rod Pobestek's RP968 World Time Attack challenger has been steadily improving for a decade now. Racecar *examines the changes made for 2024, and the results*

By DEJAN NINIC

Changes to the Porsche 968-based machine have been incremental in recent years, mainly focusing on aerodynamic efficiency by reducing drag and cleaning up airflow in critical areas

Much investigation work has also been done on the car's braking system, including introducing Bosch M5 ABS and pressure and temperature sensors. The next development will be twin calipers

'I just want to build the fastest car possible.' Those were the words of Rod Pobestek, the owner and visionary of RP968, who goes on to say he doesn't consider winning the World Time Attack Challenge (WTAC) event at Sydney Motorsport Park five times in a row a measure of success.

'It's nice to win WTAC, but the car can go faster. I am going to keep learning, making improvements and finding the next gain.' That *raison d'être* has driven the development of the RP968 every year since its conception in 2014. Every area of the car has had at least one major overhaul since the first version competed in 2015, and further upgrades are constantly being investigated. *Racecar* introduced the RP968 in the V30N2 issue after it set a new standard for WTAC in terms of evolution and track performance. More than four years have now passed since that feature so, as the RP968 turns 10, it is worth revisiting the project to discover how recent upgrades have resulted in further gains and which new ideas are being evaluated.

Beyond the tyre

WTAC has always been, fundamentally, a competition for highly modified road cars using road legal tyres. The control tyre for the Pro class, Yokohama's A050 R-Spec, performed very well for more than a decade but, as the competition grew in popularity, so too increased the power and downforce of the cars up to what appeared to be the limit of the A050 rubber.

Tyre blistering was noticed on the loaded tyre from the driven axle on several Pro cars as early as 2015. While in only very few cases did the blisters ever lead to a structural failure of the tyre, resulting in a loss of pressure, data gathered by tyre technicians over several years showed blistering was more likely to occur as the track temperature increased. Therefore, for WTAC 2022, the Pro class was scheduled to run much later in the day, and into the evening, in an attempt to mitigate the risk of blistering.

However, the tyres experienced a different form of damage that year. The blistering was no longer evident, but the tread of the tyre appeared to separate from the carcass. This type of damage was seen on enough cars for some competitors to abort further attempts.

Rod Pobestek confers with a clearly elated Barton Mawer. The car has steadily improved since its debut in 2014, and this year was helped by the switch to Yokohama A060 medium compound slicks

Mawer celebrates after posting a 1m16s lap. The goal is now 1m15s

Aerodynamic iterations made to the RP968 have been influenced in some areas by developments in Formula 1 aero

The new slick tyres are better suited to the high loads of the Pro cars and [Pobestek] feels the next level of performance seen in 2023 was only permitted by the construction of the slick tyre

Many observers at the time noted that, before the Pro class session, an exhibition event with cars drifting and doing burnouts to the destruction of their tyres had left debris, including steel wires, on the track, which could have altered the track surface and potentially caused punctures in the tyres of the competition cars. Regardless of the reason, Yokohama decided it would be best to consider a different tyre, better suited to the evolving competition.

Subsequently, a technical committee, comprising WTAC technical officers, tyre technicians and race engineers, came to the agreement that a more robust slick tyre should be evaluated as an alternative. Some of the experienced race engineers involved also strongly recommended using tyre blankets to ensure tyres on the cars were always above a minimum threshold of pressure during competition.

In May 2023, the RP968 conducted the first test on the new slick tyre proposed by Yokohama, the A060, in a medium compound. The test showed the tyre, heated by blankets prior to entering the track, could be used for two sessions without any signs of damage. Performance was deemed equivalent to its predecessor and it looked to have the capacity to allow Pro cars to push to find more speed without risk.

Using tyre blankets for pre-heating was not made mandatory by WTAC, but a minimum tyre pressure of 24psi (1.65bar) was set for the Pro class to mitigate any possibility of structural damage during warm-up laps.

Pobestek, like many others, believes the new slick tyres are better suited to the high loads of the Pro cars and feels the next level of performance seen in 2023 was only permitted by the construction of the slick tyre.

Aero efficiency

The major upgrade to airflow management for the RP968 came prior to the 2018 event. Since then, the design focus has been primarily on adding, or modifying, body parts to improve aerodynamic efficiency. Reducing drag and cleaning up airflow in critical areas has been considered more important than increasing downforce.

On track, meanwhile, the focus has been on quantifying that aerodynamic performance, specifically at each section of the track and relating it to the attitude of the body (rake, roll and heave) at each of those moments in time. Set-up changes that introduced more static and dynamic rake (nose down) tested this year showed a remarkable gain in total downforce for the car with a corresponding shift forward in balance, sometimes highly responsive to steering inputs. To assist with this, the team is making some suspension upgrades that will allow better control of front wing ground clearance during a lap.

Figure 1 shows the components that have been added to the body over the last few years, specifically to improve aerodynamic efficiency. These include front floor extensions, re-designed barge boards, vortex generators ahead of the floor expansion section and shrouds over the rear lower control arms that are in the volume of the diffuser.

Since 2019, significant attention has also been given to gathering data from the car and the environment at each track session. Extracting the ultimate aerodynamic performance of the RP968 is only really limited by the number of opportunities the team has to test the car on track.

Sammy Diasinos of Dynamic Aero Solutions, the ongoing aerodynamicist for the RP968, is now focused on fine tuning a new floor section design. The inspiration came to Pobestek following recent changes made to Formula 1 cars, and he has been encouraging Diasinos to run iterations in CFD. Early results are promising, but the iterations are still ongoing as each result is opening up further understanding and ideas for better flow management.

Brake consistency

In 2019, the RP968 used carbon-ceramic brake discs (rotors), weighing approximately half that of the previous cast iron discs. While there were obvious advantages from the reduced mass and rotating inertia, the team struggled to find a pad material that performed well with the ceramic matrix surface. After a period of time in use, the ceramic discs also showed signs of premature cracking, while the driver, Barton Mawer, found a lack of braking consistency an issue as the ideal operating temperatures of the components could not be achieved.

For 2023, then, cast iron discs were put back on the car during testing, and it was decided to retain the set up this year. For the 2024 season, Competition Friction supplied alternative Pagid RS racing pads for the team to investigate, although by the end of the season all involved agreed that custom pad materials may need to be developed.

Alongside that, with significant evolutions made in caliper design since the RP968's debut, the team is also investigating new calipers with the potential for dual use on a return to carbon discs.

Similarly, ABS technology has also entered the mix. The RP968 was upgraded to Bosch ABS M5, which has played a silent but significant role. The unit can apply a precise intervention to the pressure delivered to each individual caliper, giving Mawer the confidence to search for the limit in braking with the knowledge that the car will continue to decelerate with full control. The addition of brake pressure sensors on the four exit ports of the unit has given engineers crucial information on individual braking performance of each corner, which has been especially useful in understanding variations in braking performance during a run as brake disc temperatures escalate.

Again, to assist with this, infrared brake rotor temperature sensors were also installed for this year and the information gathered added further insight to Mawer's frequent references to inconsistency in braking behaviour. As can be seen in **figure 2**, it is common to see front disc temperature rise from 400degC to 730degC during the first brake application on a competitive run, with peak temperatures above 800degC registered later in the lap.

In contrast, the rear discs only achieve a peak temperature of 300degC. Just as the rear pads achieve a temperature for high friction, the front pads achieve thermal saturation and rapid wear begins just before the lap is completed. Note front and rear brake disc temperatures are never phased.

A further development being considered for the future is brake drums with adjustable vents for thermal management. Converting to carbon-carbon friction products is also under consideration, but the potential detriment to

Set-up changes that introduced more static and dynamic rake (nose down) tested this year showed a remarkable gain in total downforce for the car with a corresponding shift forward in balance

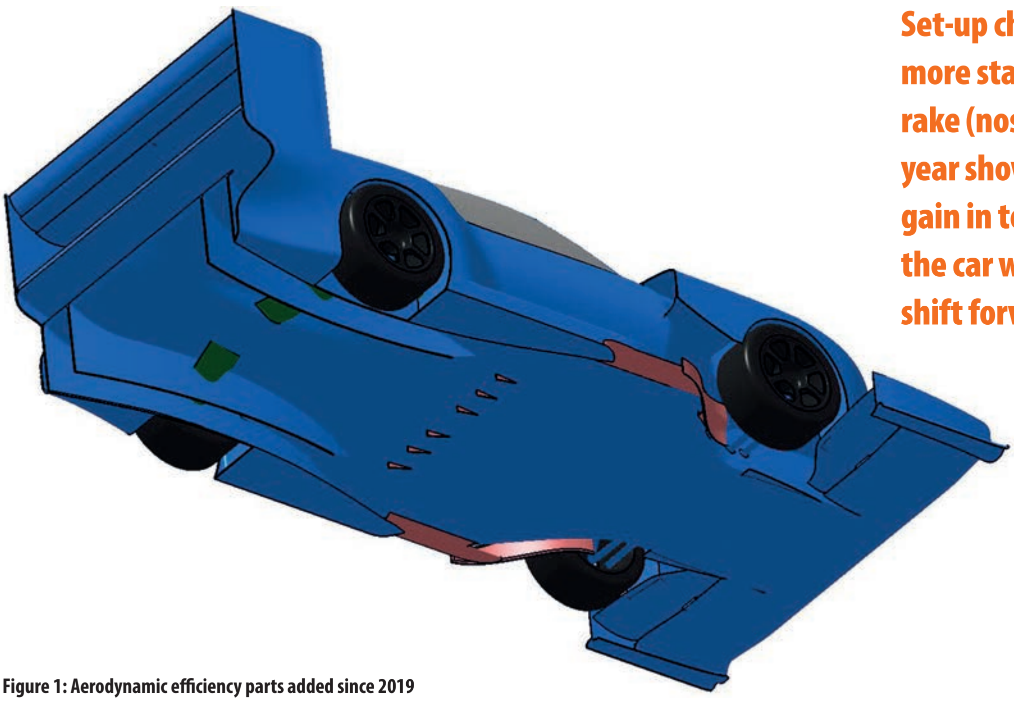

Figure 1: Aerodynamic efficiency parts added since 2019

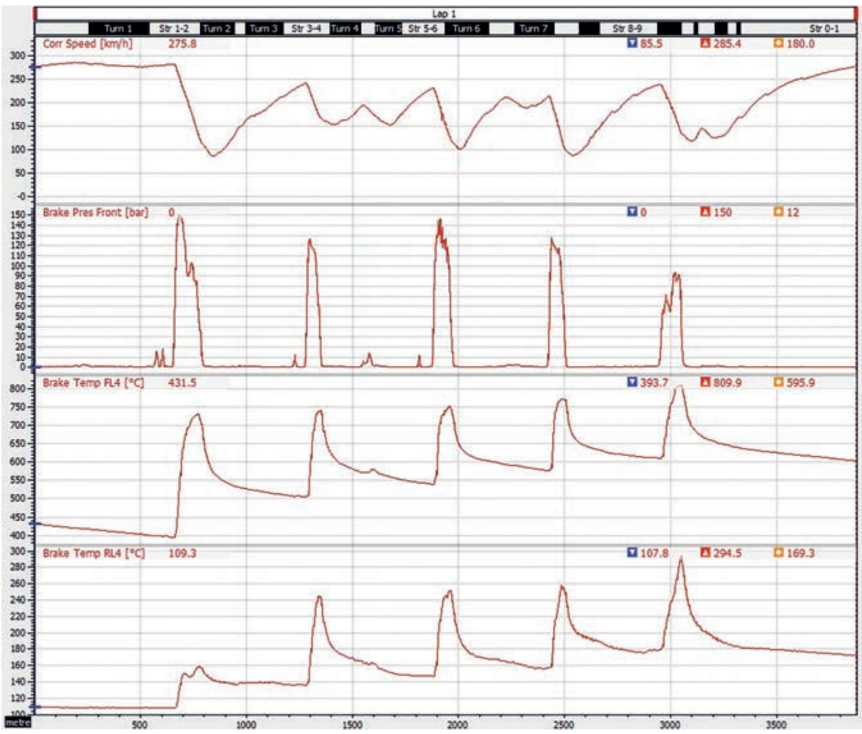

Figure 2: Comparison of brake disc temperatures over the course of a lap

operation of all the components in close proximity to the 1000degC+ friction elements must be taken seriously.

Also, the simple practicality of not having enough time during a single warm-up lap to put the required energy into carbon-carbon brakes may be enough of a limitation, if the cost of the carbon brakes alone isn't.

Suspension tweaks

There have not been any major changes to the RP968's suspension since 2019, the team instead choosing to focus on optimising the existing active suspension system to improve tyre performance and platform control.

A minor change for 2024 was an extension to the rear damper eyelets to allow for a taller rear ride height and the resultant increase in static rake. As mentioned earlier, this change proved effective in creating a better balance of ride height and pre-load in the rear.

The lessons learnt from the effect on body control gained with pre-loaded suspension encouraged the team to determine if such gains also existed at the front.

To this end, a new front upper control arm (**figure 3**) has been designed and, at time of writing, is through the final stages of manufacturing. The new arm offers a ride height adjustment through the offset bushes that locate the lower mount of the front spring / damper assembly.

Steering overhaul

As corner speed, braking and acceleration has all steadily increased, so have the demands placed on the steering system. The existing electric power assist assembly, which had offered exceptional control and adjustability, was saturating at high loads and dropping assist at critical moments on track. With the help of Chris Petch at Racer Products in New Zealand, a custom hydraulic Woodward steering rack was designed. Head mechanic for the RP968, Trent Murphy, and Mawer faced the challenge of the steering overhaul in the short time before WTAC 2024.

To provide clearance to the oil pump and crank pulleys, the steering rack design features a left-hand offset pinion with the steering column path re-positioned above and across the engine. The column then uses a bevel mitre joint to re-direct the steering column down past the engine. The assist of the hydraulic rack was beyond expectations, and the team is now working closely with Woodward Manufacturing to fine tune the configuration of this custom rack.

For 2024, the RP968 retained the Elmer 4.0-litre petrol engine, Garrett G42 turbo and Albins ST6 transaxle. The Emtron KV8 ECU has seen progressive firmware upgrades, thanks to support from the manufacturer, and engine tuner, Matt Gillmer, of Gillmer Tuning, has worked closely with Emtron to re-define the architecture of the firmware as he pushes the limit on control methods.

Currently in development is a torque demand-based engine map architecture, which is using the control needs of the driver as the demand variable. Pobestek explains: 'Matt has really got the engine humming along well and very reliable. We had more power this year, but the wind masked how good it was. You can see in that data that the car has much more speed from turn three to turn four.'

'I have had to focus on the details of the traction control, as the torque from the engine is climbing,' adds Gillmer. 'I am only really able to put more power in from fourth gear and up, until we can find more traction in the lower gears.'

Performance comparison

Table 1 summaries the fastest laps recorded in the last three WTACs, with 2019 included as a reference (due to Covid restrictions, the event was not held in 2020 and 2021). This year, the RP968 repeatedly lapped in the 1m17s bracket, creating the expectation that

Figure 3: New front upper control arm currently undergoing investigation for future development

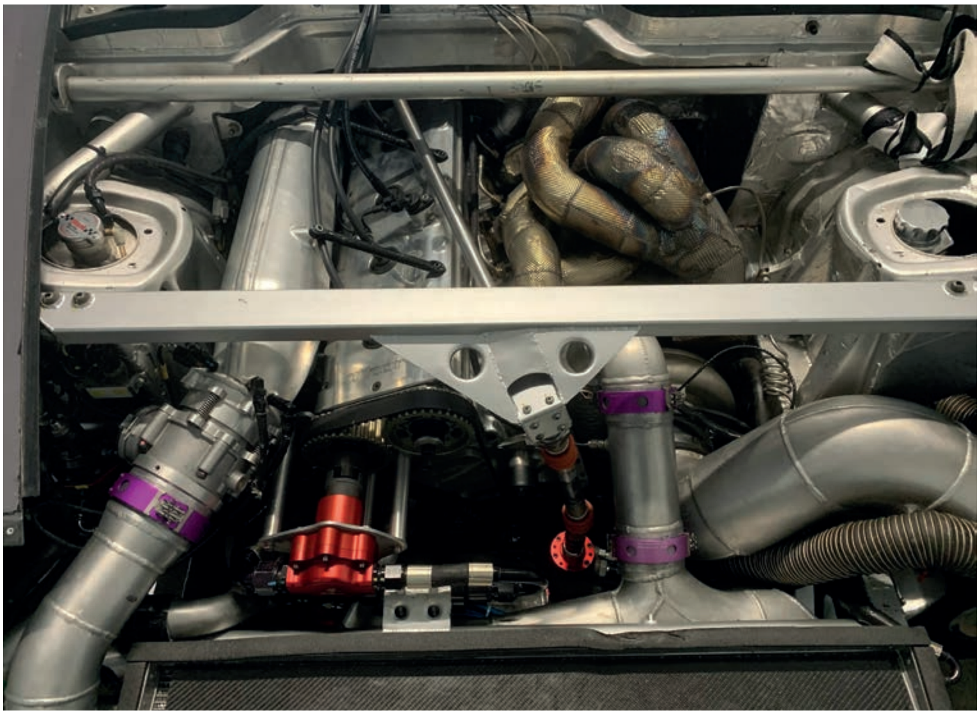

Figure 4: The revised steering column with mitre joint above and across the engine, which remains the turbocharged Elmer 4.0-litre

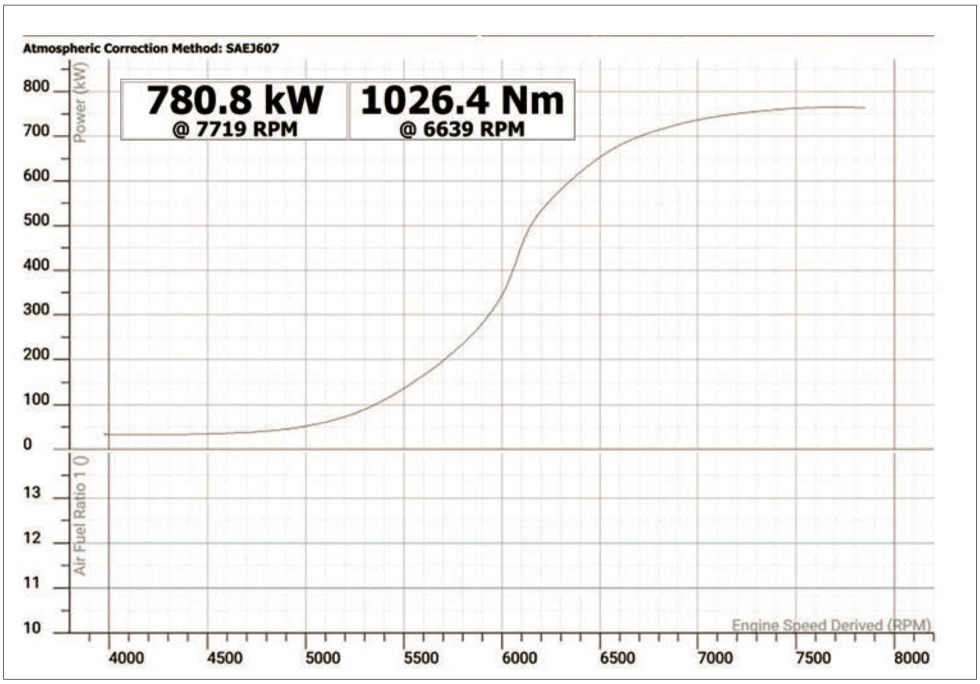

Figure 5: Engine power output remains strong (results here show rear wheel power on a hub dynamometer) - traction is the issue


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Table 1: Lap time summary

Year	Best lap time
2019	1m19.2s
2022	1m20.1s
2023	1m17.8s
2024	1m17.4s

the car could break into the 1m16s in the final shootout run. However, the final run of 1m17.4s left many observers and team members somewhat deflated.

Thankfully, enough data was collected to determine if a lap in the 1m16s zone was possible, even if it didn't actually happen on the day. **Figure 6** displays the speed traces and variance for each lap, with the 2024 lap as the reference. If a particular lap shows an increase in variance, then it is going slower, or losing ground, relative to the reference lap.

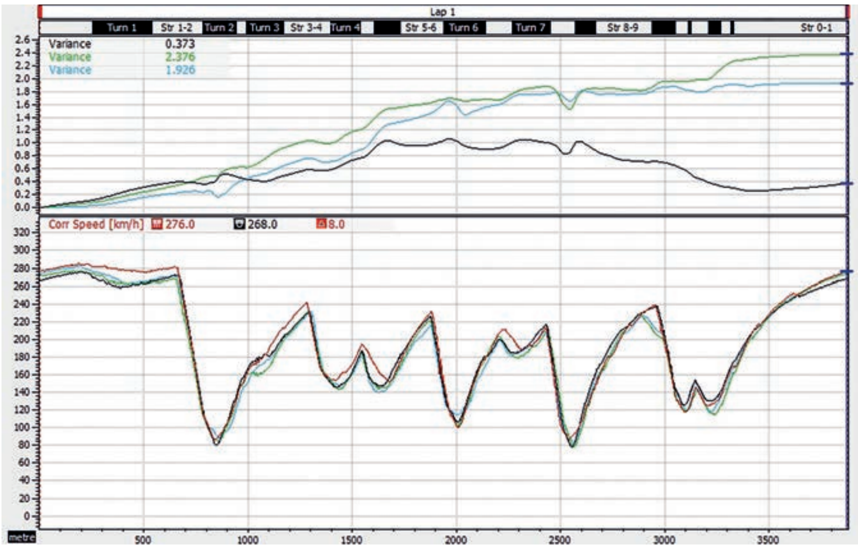

Figure 6: Comparison of car speed over a lap since 2019

Conclusion

It is evident there has been progressive improvement each year throughout all sectors of the 3.91km track. Of specific interest, though, is the loss of performance compared to 2023 in the last sector. Relative to 2023, this year the car was tracking at a one second advantage, but then lost ground from the exit of turn eight, and some more while braking for and through the last two turns. Mawer gives his interpretation of what happened: 'We were experiencing an inconsistency with the braking throughout the event, so I did under-drive the last sector. The braking into turn eight was early, and my correction forced the car wide at the exit and I got a bad run. I was then just focused on finishing the lap without making any mistakes, and as a result probably didn't get the best out of the car in the last two turns.'

Enough data was collected to determine if a lap in the 1m16s zone was possible, even if it didn't actually happen on the day

Whilst Mawer isn't a driver looking for excuses, there is strong evidence that the wind at this year's competition did have an effect. Steady winds of 25km/h were recorded and regular gusts over 40km/h. The direction of the wind would have assisted the car for braking into turn eight, forcing a tighter line through the turn, but **figure 1** shows the headwind onto the final straight slowing the car's acceleration until it shifted into fifth gear, where the increased power recovered a small fraction of the ground lost. More significantly, the crosswind evident through the last two turns undoubtedly de-stabilised the car throughout the entire 2024 WTAC event.

There's no doubt Pobestek sets a very high standard, and lives to see the improvements. And they continue to come. The data recorded this year shows that with the existing performance of the RP968, the list of proposed upgrades applied and, with luck, more favourable track conditions, setting another lap record in the 1m16s zone *will* be possible. From there, the 1:15s is not an overly ambitious expectation. Rod Pobestek's determined pursuit of speed continues. R

Data captured at the 2024 event shows unexpectedly strong winds did have an impact on car behaviour, so the team didn't quite reach its lap time goal. However, with further upgrades planned, the RP968 will return to contest the WTAC in 2025 and has a 1m 16s lap time in its sights

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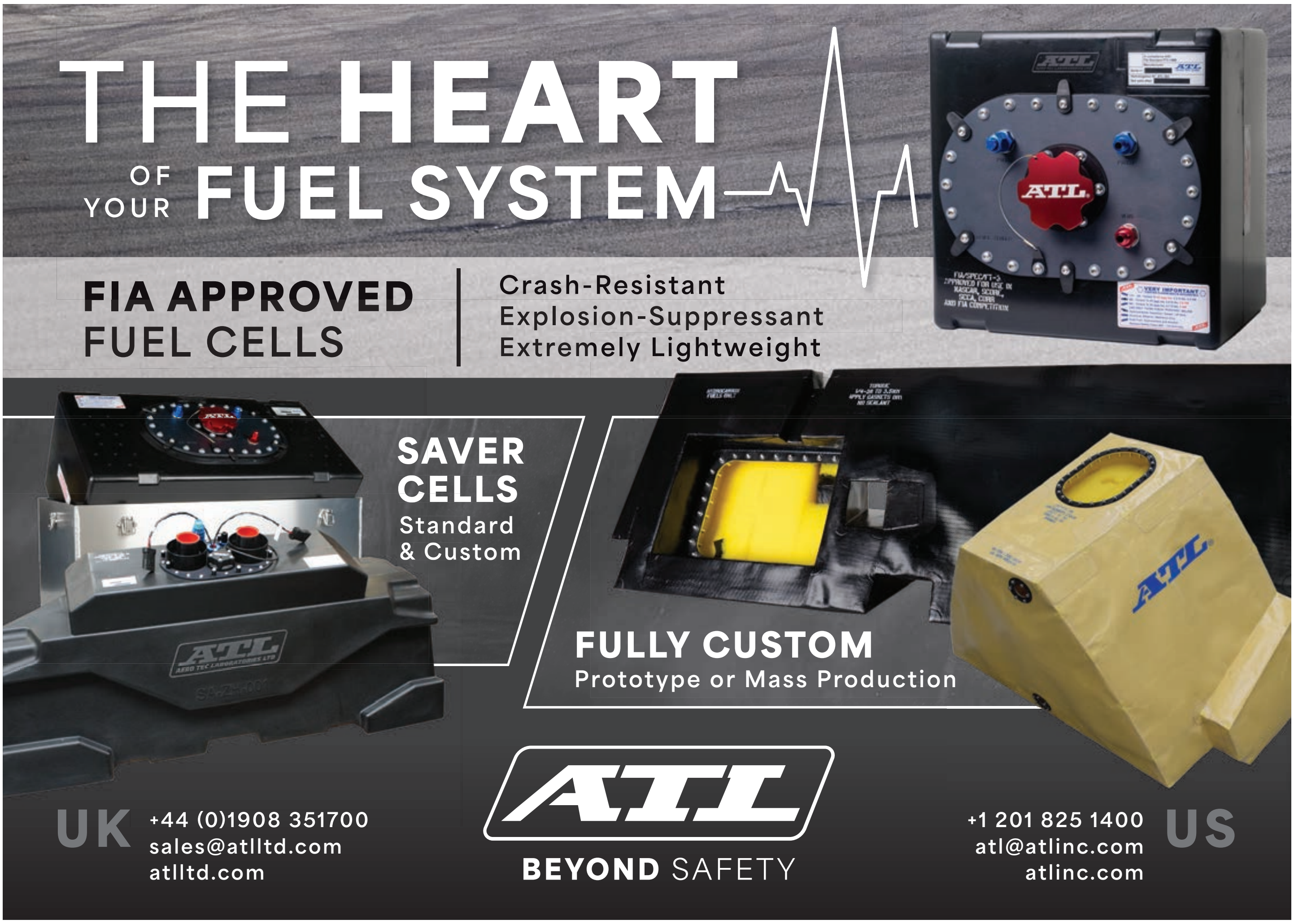

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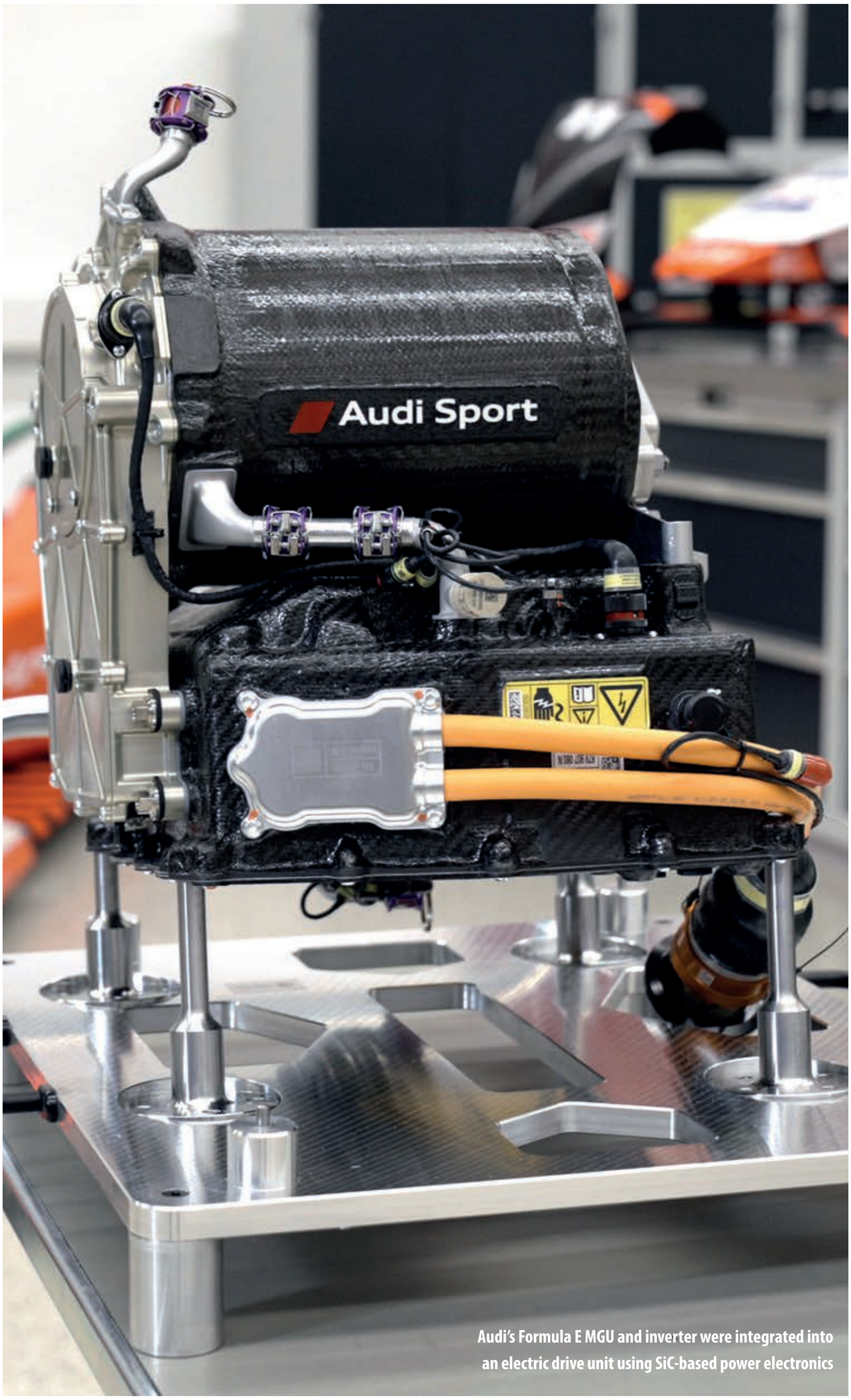
Code of conduct

Investigating the current state of play in the world of high performance power semiconductors

By LAWRENCE BUTCHER



Audi's Formula E MGU and inverter were integrated into an electric drive unit using SiC-based power electronics

Electrification is steadily gaining ground in motorsport, mainly via hybridisation, but also through all-electric race series. Regardless of the power mix, both hybrids and pure electric vehicles (EVs) require the use of inverters to control their electric motors, and the development of these devices has been almost as important to performance progression as gains in motor technology.

Control systems for electric motors, be they incorporated into a pure EV or a hybrid drive system, are a key part of ensuring overall powertrain efficiency. The control must be precise, switching current at sometimes very high frequencies and with minimal electrical losses. Losses mean inefficiency and a reduction in the amount of battery energy that reaches the wheels, while also contributing to deficits in other areas of vehicle performance.

For example, an inefficient controller will generate considerable heat, which in turn increases the need for cooling and, in turn, adds to the aerodynamic drag of a vehicle. It is therefore in the interests of anyone developing high-performance electric vehicles to have the most efficient motor controllers possible, while also ensuring they are lightweight and in a compact package.

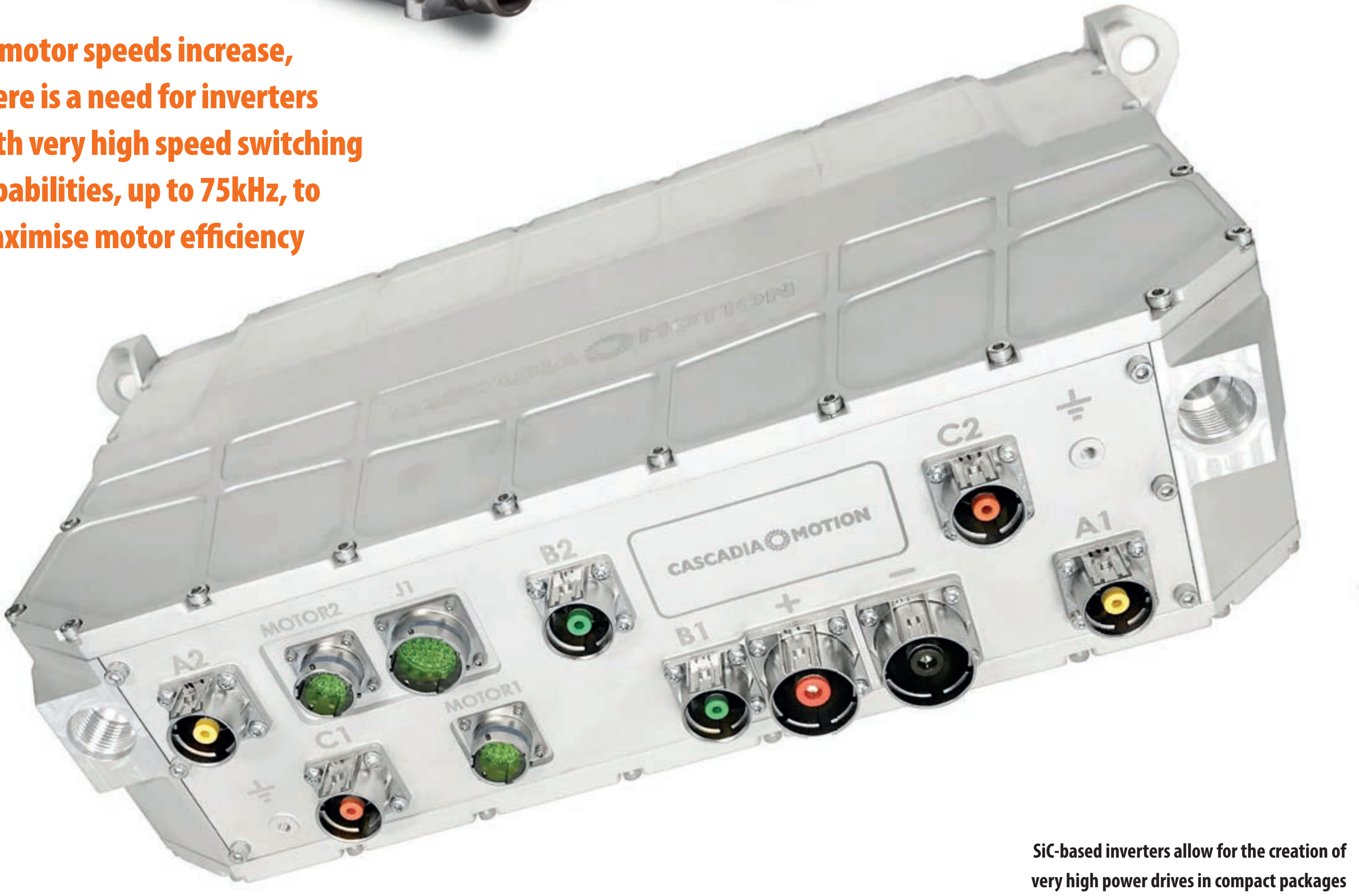
Reversing the flow

An inverter converts electricity from a DC (direct current) source – normally a battery, but also in some cases supercapacitors and fuel cells – into AC (alternating current), to drive a motor. DC current is fed to the primary winding of a transformer in the inverter and is 'sliced' using an electronic switch, comprising a series of power semiconductors, which these days are either insulated gate bipolar transistors (IGBTs) or metal oxide semiconductor field effect transistors (MOSFETs). The electrical charge travels into the transformer's primary winding, reversing, and then flowing back out. The result is an alternating current within the transformer's secondary winding, which then feeds the motor.

For both racing and road car applications, efficiency is king for both motor and inverter operation. As motor speeds increase (most

Equipmake's HPI-800 inverter, a SiC-based unit that its manufacturer provides efficiency gains with the potential to reduce the size of an EV's battery by around 10 per cent (for a given range)

As motor speeds increase, there is a need for inverters with very high speed switching capabilities, up to 75kHz, to maximise motor efficiency



SiC-based inverters allow for the creation of very high power drives in compact packages

Formula E powertrains, for example, now operate at more than 30,000rpm), there is a need for inverters with very high speed switching capabilities, up to 75kHz, to maximise motor efficiency, while balancing the efficiency and losses of the inverter.

To meet these demands, inverter manufacturers have turned to silicon carbide (SiC) power semiconductors, and there is also growing interest in gallium nitride-based (GaN) devices. Both are wide-bandgap (WBG) materials, which references the energy difference in semiconductors found between the top of their valence band and the bottom of the conduction band. Having a WBG enables such devices to operate at higher voltages, temperatures and frequencies than traditional narrow-bandgap materials.

Silicon limits

The development rate for power electronics in recent years has been ferocious. A decade ago, the only real solution for high power inverters were silicon-based IGBTs.

An IGBT combines aspects of a bipolar junction transistor (BJT) and a MOSFET to create a switching device capable of handling large currents but requiring a low current (the gate drive current) to initiate switching. The speed at which a controller can switch is dictated by the capabilities of the power semiconductors. This is referred to as the pulse width modulation rate, and the more switching operations per second, the higher the rate.

IGBTs were initially used for electrified powertrains because they share many of the traits of a MOSFET, but can operate at higher frequencies with lower losses. This is because they have a lower on-state voltage drop owing to their conductivity modulation, which is the change in conductivity of a semiconductor material due to, for example, an increase in temperature.

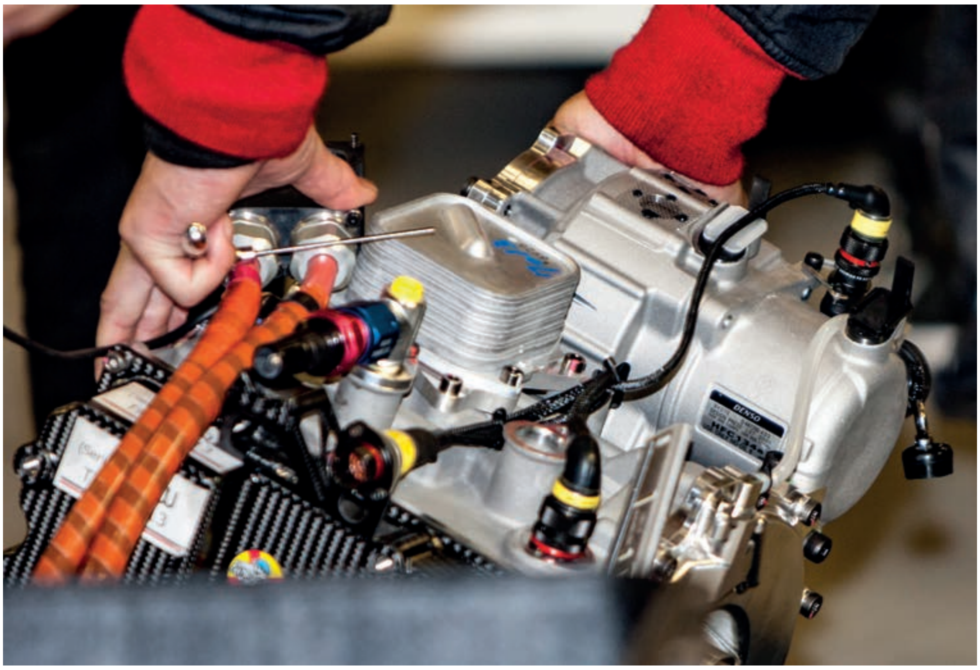
For a similar current and voltage rating, an IGBT could be made much smaller. Broadly speaking, MOSFETs were more efficient in applications below 250V, while for those over 1000V, IGBTs were the best choice. Between these points, MOSFETs or

IGBTs could be used, with factors such as cost, size, speed and thermal requirements dictating which was favoured.

Before the arrival of wide bandgap materials like SiC, the big disadvantage of MOSFETs was that to handle high voltages, they required a much thicker voltage 'holding' region (the N- drift region), which increased conductive losses and generated greater heat. Hence why silicon semiconductor-based IGBTs were the most popular choice for controlling traction motors, thanks to their ability to handle high voltages and currents (owing to the high breakdown voltage of the material), while offering low resistance. However, this high voltage capability comes at the expense of switching speed.

Also, Si devices can only operate at relatively low temperatures, which presents problems when they are subject to high current draw when packaged in confined spaces with minimal cooling (ie in a racecar).

As the level of control demanded by motor developers rose, and as more powerful motors that require higher voltages and currents came along, so the limits of silicon-based transistors were reached. That spurred development of new devices using SiC or, most recently, GaN.



Toyota was one of the first to utilise SiC MOSFETs in its TS050 LMP1 car, which made its debut in 2016 and won Le Mans three times

The power of SiC

SiC is a compound semiconductor made up of silicon and carbon. Its potential as a power semiconductor material has been known for some time and serious research into its practical application began in the 1990s. However, it has taken the best part of 25 years for the processes by which viable crystals can be grown and manufactured into devices to mature. This effort has been worthwhile as the material's advantages over Si are considerable.

SiC has a very high dielectric field breakdown strength, necessary to provide a high breakdown voltage. It is also able to resist heat far better than Si and has a superior electron saturation velocity. These benefits are countered by the crystals growing far slower than Si and their higher strength makes processing them harder, both of which add cost.

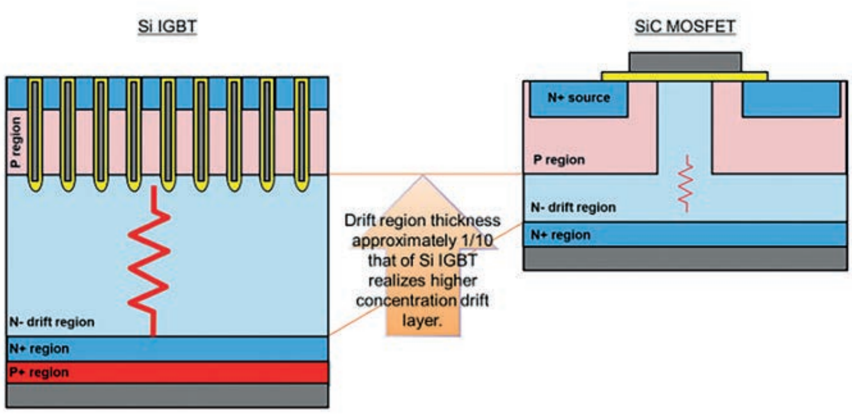
SiC devices have largely now been supplanted by Si-based options in high-performance applications (though they are still viable in road cars and, from a cost efficiency perspective, often a better option). Initially, this was in the form of hybrid Si IGBTs, which also incorporate SiC components.

Motorsport was an early adopter of SiC-based inverters. For example, in the 2016-17 Formula E season, supplier Rohm, working in conjunction with the Venturi team, used a hybrid inverter design that paired an Si-based IGBT with SiC Schottky barrier diodes.

The result was an inverter 2kg lighter and 30 per cent smaller than the team's previous system, which relied on just Si IGBTs. However, with improvements in SiC-based MOSFETs, previously limited by relatively low voltage tolerance, pure SiC devices have become readily available and offer higher switching speeds in a smaller package.

The very high dielectric breakdown voltage of SiC makes high-power MOSFETs feasible as the resistance of the drift region of the device can be kept low. Additionally, unlike an IGBT, there is no accumulation of charge in the drift region, which means no 'tail' current when switching, meaning greater speed and efficiency.

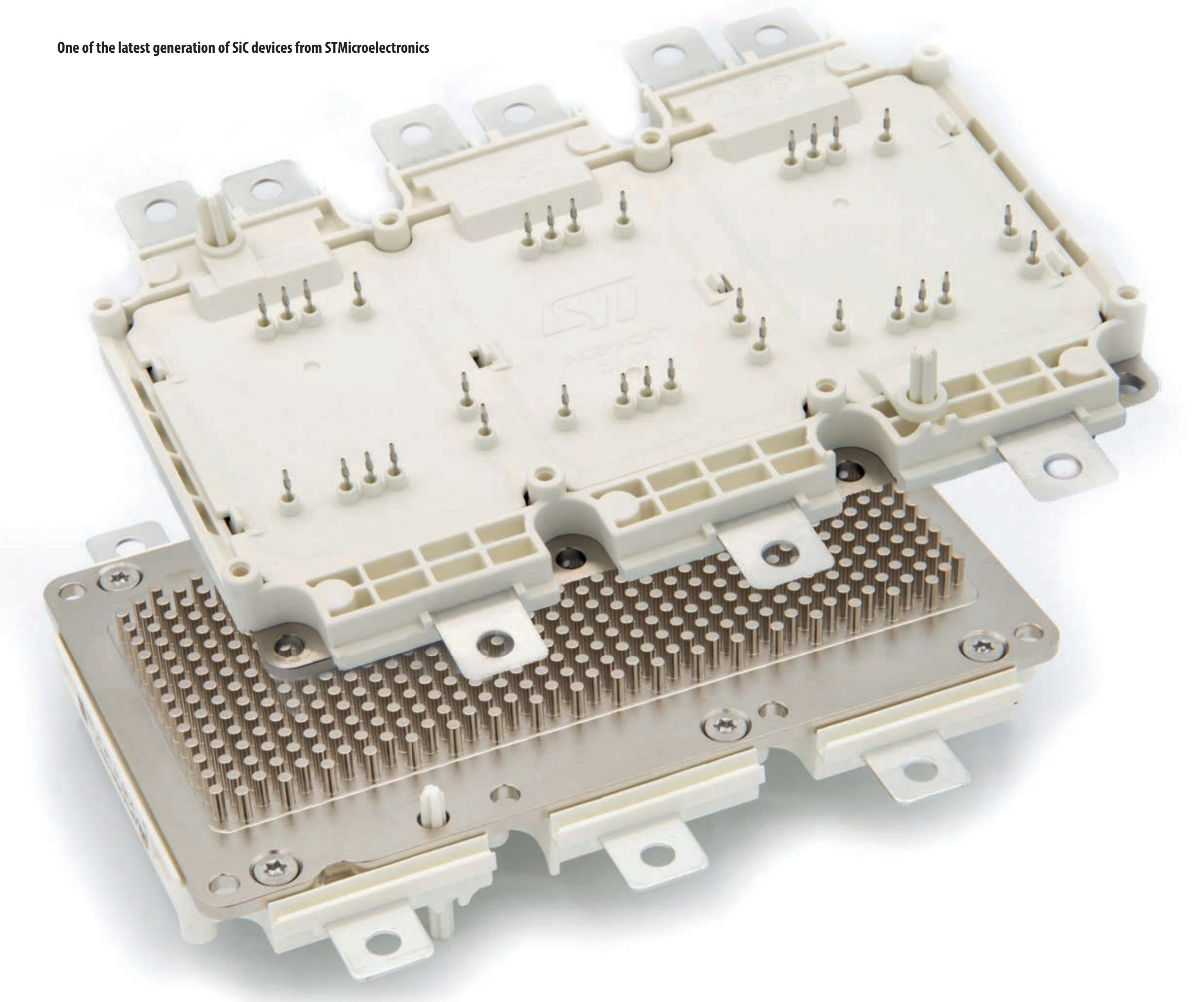
Toyota, which has been working with its partner, Denso, on SiC for many years, was one of the first to use SiC MOSFETs in competition, introducing them in the TS050 LMP1 car on the rear hybrid system motor controller. For Venturi, the team switched to SiC MOSFETs in 2017 and saw a further 4kg saving and 30 per cent size reduction compared to its hybrid IGBT solution, with a drop in switching losses of 75 per cent relative to its older Si-based inverter.



A comparison between the structure of an Si IGBT and SiC MOSFET

Si devices can only operate at relatively low temperatures, which presents problems when they are subject to high current draw when packaged in confined spaces with minimal cooling (ie in a racecar)

One of the latest generation of SiC devices from STMicroelectronics



GaN [gallium nitride] is only just starting to gain prominence as a suitable semiconductor material for high-voltage power electronics, but has the potential to further increase the performance and efficiency of inverters

Since their arrival nearly a decade ago, semiconductor manufacturers have continued to push the development of SiC devices, reducing losses ever further while also shrinking them in size and increasing switching speeds. Strides are also being made in their manufacturability, making them accessible beyond the realms of the top race series. This is evident in the fact that even relatively mundane production EVs now sport 800V electronics architectures and SiC inverters (take Hyundai's Ioniq 5 N for example, which puts out 650bhp and is able to maintain sustained track sessions without running into issues).

GaN on

GaN is only just starting to gain prominence as a suitable semiconductor material for high voltage power electronics, but has the potential to further increase the performance and efficiency of inverters. GaN is a WBG material, so it is capable of very high switching speeds and has a high breakdown voltage. It also has around 50 per cent lower losses, thanks to minimal reverse recovery charge, than SiC, making it an attractive option for high-performance motor drives. However, it is currently at a much earlier stage of development.

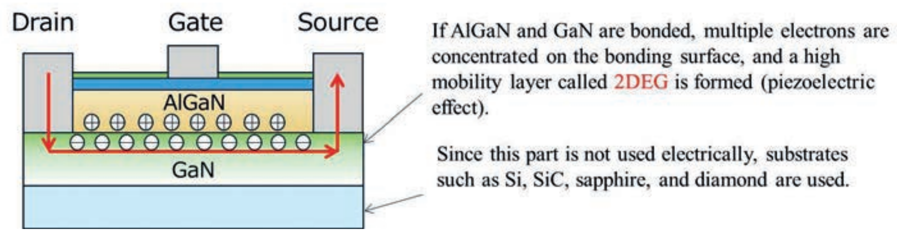
When comparing GaN to SiC, one of its main benefits is that it can form a high electron mobility transistor (HEMT) when used as a lateral semiconductor. A HEMT is made by forming a wide bandgap aluminium gallium nitride (AlGaN) film onto GaN crystal. If electrons accumulate at the bonding surface between these two materials (called a two-dimensional electron gas layer) and current is applied, a transistor is formed with substantially higher electron mobility and density than SiC, and able to operate at much higher frequencies than a traditional MOSFET.

There are two main types of GaN device, the first being the lateral HEMT, examples of which are already deployed in consumer electronics. The second is vertical GaN power semiconductors. The former are fabricated on large Si substrates, which makes mass production easy. However, they are generally limited in their breakdown voltage, which restricts their use in high power applications.

That said, there are various efforts under way to produce high voltage inverters using GaN on Si technology. For example, an Israeli company, VisIC Technologies, has been developing devices that employ lateral GaN transistors but with a Normally Off state (one of the issues with pure lateral GaN chips is they are Normally On). It has tested these in traction inverters and offers products up to 650V, with further developments in motion.

Moving to vertical GaN devices, these are far less developed and rely on the formation of a thick layer of material to increase the breakdown voltage. This means the crystals need to be grown on a GaN substrate, which introduces a host of manufacturing problems. Various processes also need to be applied to create a diffusion layer, and that can lead to flaws in the crystals. Techniques are currently being worked on to combat these challenges.

Presently, applications of GaN are limited to DC-DC converters, rather than traction motor drives in motorsport. In this role, GaN-based converters are in widespread use in series such as Formula E. However, some manufacturers are actively investigating the use of devices such as GaN HEMTs (high electron mobility transistors) and FETs (field-effect transistors) for motor inverters.



The structure of a GaN-based HEMT

For example, Marelli is currently working on 950V GaN devices with the Polytechnic University of Turin in Italy, and others such as Hofer Powertrain are looking at the implementation of GaN into three-level inverters targeted at high-performance automotive and motorsport applications.

Future options

There are various other power semiconductor technologies at differing stages of research that could hold potential for use in the motorsport market. For example, gallium oxide (Ga2O3) has a Baliga performance index (which expresses the theoretical potential of a material as a power semiconductor) five times that of SiC, while also exhibiting lower losses. Unfortunately, commercial production of such devices is still some way off as producing large enough wafers to make them viable is difficult. The fabrication of the material into a functioning device – such as forming the various layers – is also far from a straightforward process.

Beyond the hardware, the software underpinning the operation of electrified powertrains is subject to intense development

Interestingly, diamond also has potential as a semiconductor, with breakdown voltages, electron mobility and heat dissipation capabilities far exceeding any currently used materials. Again, the main challenge at present is growing sufficiently large crystals, synthetic diamonds tending to be only millimetres wide.

Of course, the power semiconductors are only one of the elements needed to create a high-performance, high power density inverter. The overall structure of the devices, and especially the cooling system, also play an important role. Here, reducing the thermal resistance between various components is key, so that coolant (most inverters in racing are liquid cooled) can be used more effectively.

Standard practice is to indirectly cool the semiconductors via a structural base plate, through which coolant is flowed. That said, Marelli has been working on an inverter that eliminates the base plate with a claimed overall device efficiency of 99.5 per cent and a 50 per cent cut in both package size and weight, compared to a more conventionally cooled SiC inverter.

Beyond the hardware, the software underpinning the operation of electrified powertrains is subject to intense development. You can have the most efficient semiconductor out there but, if it is poorly utilised, or the motor it is controlling is run outside its operating limits, its potential will not be realised.

Despite rapid progress in the past 15 years, and since hybrid came to F1, we are still early in the curve for high-performance BEV and hybrid systems, but motorsport is ideally placed to provide a valuable proving ground for emerging technologies.

Italian engineering company, Marelli, is working on the development of a 950V, multi-level inverter using GaN

Hot property

The ongoing thermal management challenges posed by hybrid and electric powertrains

By GEMMA HATTON

The adoption of hybrid and electric vehicles has introduced new sources of heat that engineers now must manage. Batteries, motors, inverters, and the associated cabling that make up the high voltage arm of modern powertrains, all have electrical current flowing through them. As Georg Ohm discovered in 1827, wherever there is current, there is resistance, and this resistance generates heat.

The need for speed in racing translates to a push for power, forcing even more electrical energy through these components. Take the motors used in Formula 1, for example. The original KERS system in 2009 used 60kW motors, whereas the MGU-K system of today uses motors with double that power. It's a similar story in Formula E. The Gen1 cars of 2014 had a maximum regeneration capability of 100kW, and a battery power output of 200kW. Now, the latest Gen3 cars regenerate up to 600kW, with a battery power output of 350kW.

Although impressive, these power figures come with a downside. More current means more resistance and more heat. You may be thinking, but electric powertrains are notoriously efficient, so surely there is not much energy wasted as heat? Well, yes and no.

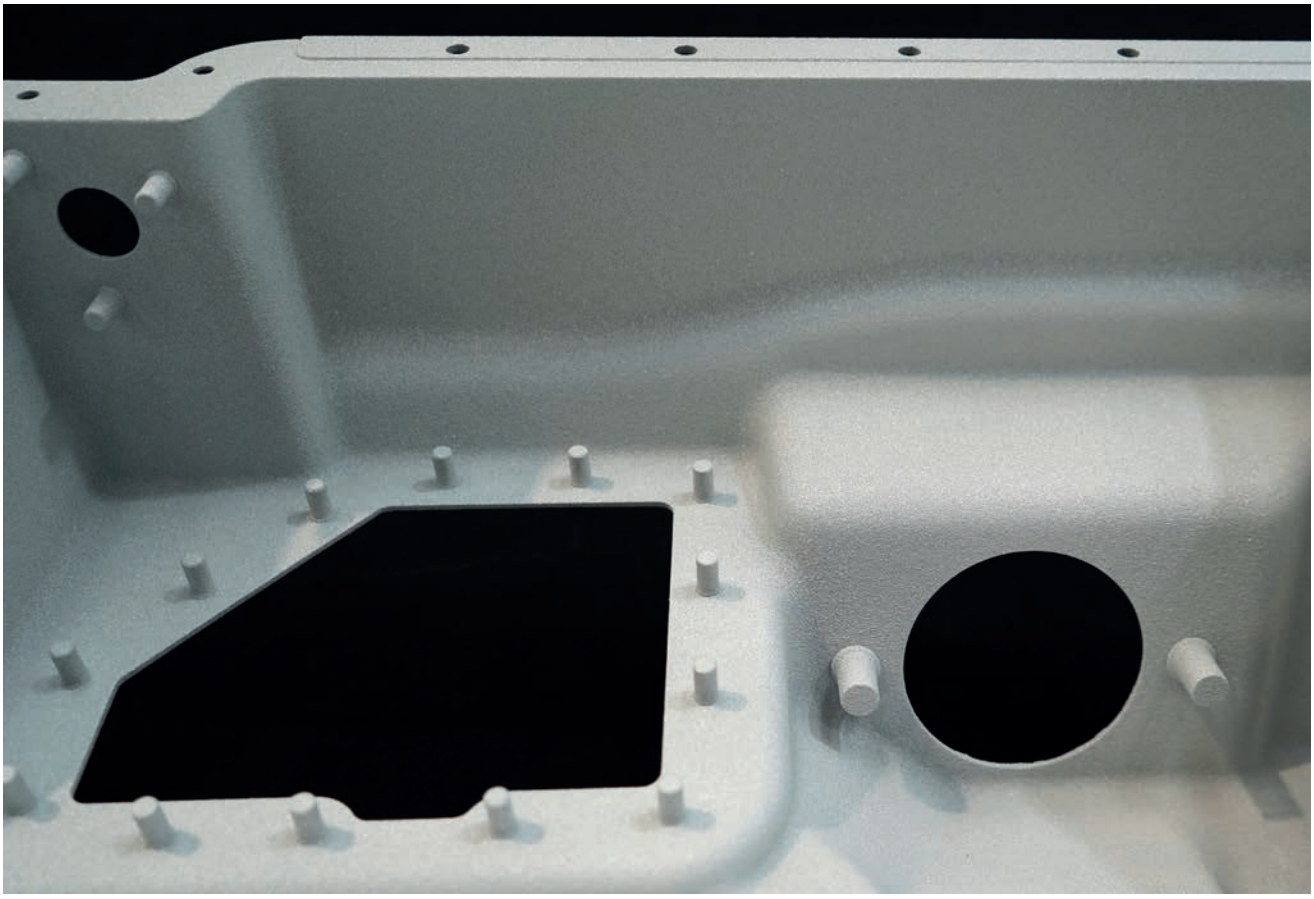
Today's silicon carbide inverters are now achieving 99 per cent efficiency, with the latest motors close behind at 98 per cent efficiency. However, a small percentage of a much higher power number still translates to a substantial amount of temperature that must be dealt with. Which is why there are still plenty of heat management headaches with modern powertrains.

You may be thinking, but electric powertrains are notoriously efficient, so surely there is not much energy wasted as heat? Well, yes and no

Optimum range

Just like an engine, batteries, motors and inverters achieve their highest performance when they operate within a specific range of temperatures. Outside of this, performance drops and degradation takes hold.

The optimum working range of a high voltage battery is typically around 80-90degC. Any lower than this and the chemical reactions within the battery slow down, preventing the battery from delivering energy efficiently. Furthermore, if the battery temperature is too cold during charging, lithium plating can occur. This is where lithium ions build up on the anode because they cannot be quickly stored within the anode's microstructure. These deposits are known as dendrites and they increase the cells' resistance, reducing its voltage. At low voltages, lithium stays in



As the power of electric motors and batteries in racing has increased, so has the heat generated by them. This battery enclosure is coated in Zircotec's ceramic flameproof coating

It is not just the batteries and motors that have to be considered, but also the inverters and all the associated cabling, for wherever there is current flow, there is resistance, which in turn creates heat

its metallic form and therefore continues to build up on the anode, reducing the battery's capacity and life whilst increasing the risk of short circuits.

However, if the cells of a battery exceed their maximum temperature limits, this triggers exothermic chemical reactions, which generate large amounts of heat. This heat feeds these exothermic reactions further and the cell enters a continuous loop of destruction, otherwise known as thermal runaway.

When it comes to motors, there are two main losses: internal resistance within the copper coils and hysteresis losses due to the sinusoidal waveform, which changes the direction of the magnetic field. Both are emitted through heat, causing problems for both the rotor and stator. Rotors typically reach temperature peaks of 150degC, with temperatures higher than this causing the magnets to de-magnetise. The coil windings of the stator have a maximum temperature limit of around 160 to 180degC and, if this is exceeded, the insulation of the wires starts to melt, leading to failure.

The final component in the EV powertrain trio is the inverter. This device converts DC (Direct Current) power from the battery to three phase AC (Alternating Current), which is required by the motor to generate continuous torque and motion.

To transform the constant DC signal into a sine wave AC signal, the DC source is switched directionally across high-frequency, high-power switches. Traditionally, IGBT (Insulated Gate Bipolar Transistors) are used, but are only capable of switching frequencies of 10kHz.

However, a new switching technology has arrived on the scene: silicon carbide (SiC). These inverters achieve higher efficiencies and switching frequencies of over 100kHz, triggering manufacturers to shift to silicon carbide technology.

If the cells of a battery exceed their maximum temperature limits, this triggers exothermic chemical reactions, which generate large amounts of heat. This heat feeds these exothermic reactions further and the cell enters a continuous loop of destruction, otherwise known as thermal runaway

A further benefit is that these devices operate at higher temperatures, but that in turn increases their heat management requirements.

'Whether it's an IGBT or SiC MOSFET [Metal Oxide Semiconductor Field Effect Transistor], each time these transistors switch between frequencies, energy is dissipated,' reveals John McKeen, technical director of Dow MobilityScience. 'This generates quite a bit of heat, particularly as companies continue to move to higher temperature SiC inverters. So, we're working on materials that provide a thermally conductive pathway away from the component to ensure these electrical devices are reliable when operating at high temperatures.'

Battery deterioration

To protect themselves from the rapid deterioration cycle triggered by too low or too high temperature, electric components enter something called derate. This is where the component effectively limits the amount of power it can discharge or charge. In the case of the Formula E battery, for example, exceeding the maximum temperature limit by only 2degC drops the power level from full power down to zero, significantly reducing the amount a driver can accelerate or regenerate energy.

To remain performant, batteries must be kept in a strict temperature window. In the case of those used in Formula E, exceeding the maximum temperature limit by just 2degC can lose the race

In Formula E, this drop in power is so significant, it can mean the difference between finishing on the podium and not. The Andretti Formula E team suffered this fate at São Paulo earlier this year, when the battery started to derate for Jake Dennis, dropping him from third to fifth position in the last two corners.

'The battery definitely needs a bit of nursing [in Formula E], because it operates best within a specific temperature window,' explains Dorian Boisdron, team director at Nissan Formula E Team. 'The battery is cooled with dielectric fluid in cold plates that are attached to the battery pack. Heat is extracted from this fluid by water to air radiators.

'We use an external device to pre-heat this fluid and circulate it through the cold plates so that when the car leaves the garage the battery is at a minimum temperature of 42degC. On track, we need to make sure the battery doesn't exceed around 80degC, otherwise it will derate and drop off in power.'

Brake energy

It's a similar story for the motors and inverters that make up the regenerative braking system. You would be forgiven for thinking that converting kinetic energy under braking, which otherwise would be wasted as heat, into useful electrical energy would reduce the amount of heat generated.

'Brake temperatures are now much more variable with the introduction of regenerative braking'

Dominic Graham, head of engineering at Zircotec

Unfortunately, engineering is not that kind. Although the overall temperature at the brakes is less under regeneration, passing electrical energy through the motors, inverters and battery generates temperature. This, combined with the shift to smaller braking components and fluctuating energy recovery levels, makes controlling brake temperature a key concern.

'Brake temperatures are now much more variable with the introduction of regenerative braking,' says Dominic Graham, head of engineering at coatings specialist, Zircotec. 'Before, the brakes would experience peaks and troughs of temperature throughout a lap but, over the course of a race, the overall brake temperatures would remain relatively consistent.

'Whereas with regenerative braking, temperature is effectively being pulled out of the system to be recovered into electrical energy that can be stored in the battery. On laps where the driver is recovering a lot of energy, the brakes will run much cooler than on laps where the driver is deploying energy, as this warms the motors and inverters up. So now, the brakes tend to go through more extreme hot and cold cycles throughout the distance of a race, which puts quite a lot more varying stress on the brakes themselves.'

These temperature troubles are further exacerbated by the smaller size of modern brakes. As the regenerative system recovers most of the temperature into electrical energy, teams can get away with running smaller discs, pads and calipers, helping them save weight and space.

Although fine in most cases, on laps where drivers reach the maximum amount of energy they are allowed to recover, they then have to rely on the mechanical brakes. As these are now effectively undersize, it doesn't take much to make them overheat.

'That's been a big area of development for the likes of Formula 1,' says Graham. 'Increasing the size of the wheels to 18in as part of the 2022 regulations actually helped a lot with this, as it allowed much more space for cooling around the brakes.'

Managing the temperature of the warmer motors and inverters during regenerative braking is essential as, just like the battery, these components can also go into derate, limiting their available discharge power.

'Motors typically generate much more heat during regeneration than traction,' says Boisdron. 'Due to weight transfer, you are

always decelerating more with the front axle than the rear, so we use the FPK [Front Powertrain Kit] as the main braking unit for regeneration. We have had more races where the FPK temperature is more of a problem than the battery, so we try to take care of it as best we can.'

Duty cycle

Whether it's the battery, motor or inverter, arguably the best strategy to cooling these components down is to avoid heating them up in the first place. This is achieved by reducing the duty cycle. In hybrid and electric racing, when a driver brakes, they effectively charge the battery, and when a driver accelerates, they discharge the battery. Each of these charge and discharge events are referred to as a duty cycle, which surges high current through the electrical components. This, combined with internal resistance, generates the high temperatures.

There are several ways to reduce the duty cycle and therefore maintain components within their temperature window and avoid derating. The first is to reduce the total energy consumed throughout the race, as this will lower the amount of energy discharged from the battery, and the need to recover energy. Although effective from a temperature perspective, this involves driving slower and finishing the race with excess energy, which could have been used to finish further up the order.

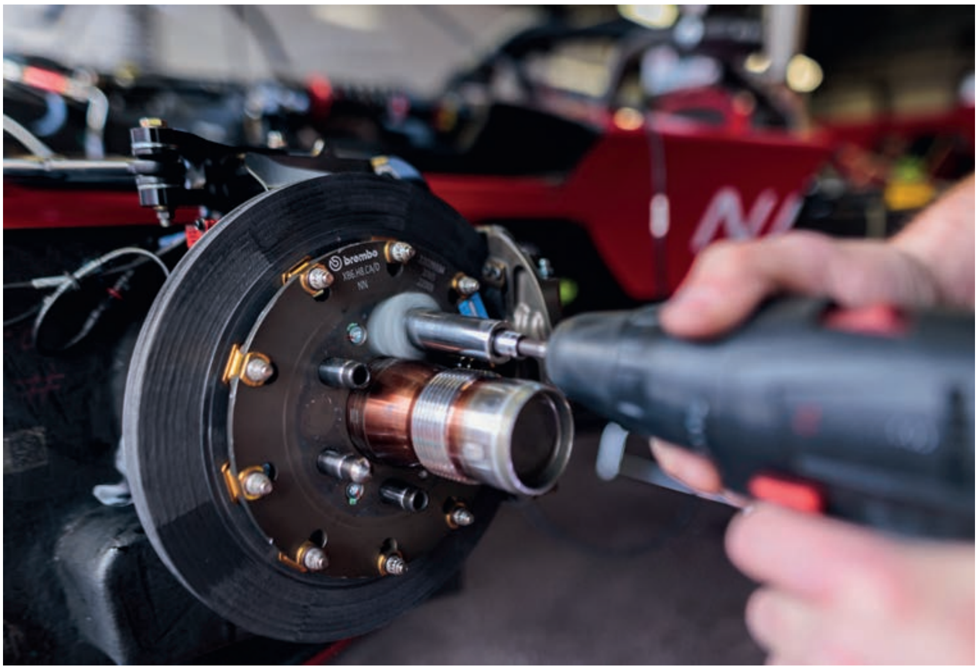
'As soon as we run the car for sure, we play a bit with the flow of this dielectric fluid through the cooler, but the biggest effect on temperature is reducing the duty cycle of the battery,' explains Boisdron. 'We manage the maximum regeneration power to limit the stress on the cells and the amount of energy we are pushing into the battery, as this is where it's most critical in terms of heat.'

The second approach is to try and minimise the discharge (acceleration) and charge (braking) phases of each corner whilst achieving the same lap energy target. In other words, lift and coast – just like drivers do when saving fuel.

'We can also choose to use the energy over a lap in a different way,' continues Boisdron. 'So we run a different energy consumption / speed profile from one lap to another.'

Another tactic is to switch to the hydraulic brakes more, as this maintains braking capability without edging the motors and inverters closer to the derate limit. Of course, this reduces the amount of energy that can be recovered during a lap, which in turn effects a team's overall energy management strategy.

'Using the hydraulic brakes more impacts the regeneration capability of the car,' confirms Boisdron. 'Because you regenerate less, your energy consumption across a lap increases, which in turn has a big impact on your strategy. So we try to reduce the temperature of the FPK as much as possible to start with the biggest margin we can before hitting the derate limit.



The introduction of regenerative braking is causing components in the brake system to experience more extreme hot and cold cycles

'This is a big difference from previous generation cars because these were all about multi-hydraulic braking, whereas now we can choose between the FPK and standard braking. For energy management purposes, we want to use the FPK as much as possible, but to achieve that we have to manage its temperature. We also have to pay attention to the brake discs and the brake-by-wire temperatures, too. The car is not designed to do long runs using mainly the mechanical brakes, so it is all about finding a good balance between the different braking systems.'

'We manage the maximum regeneration power to limit the stress on the cells and the amount of energy we are pushing into the battery, as this is where it's most critical in terms of heat'

Dorian Boisdron, team director at Nissan Formula E Team

Thermal tactics

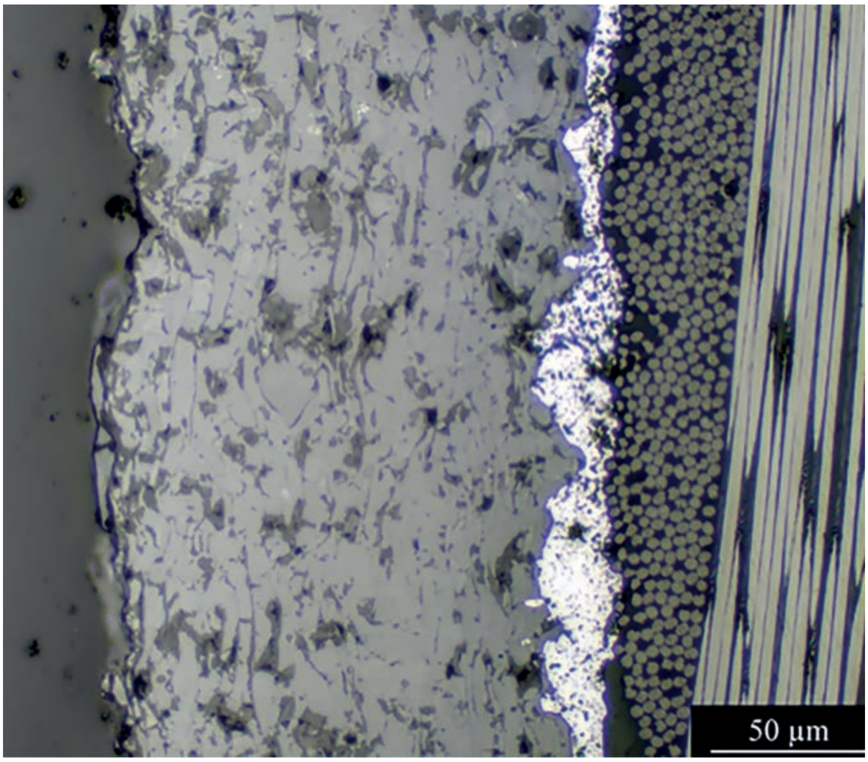
Alongside the complex cooling systems now common in modern racecars, other techniques such as heat shields, coatings and adhesives can also be used to mitigate heat.

'To cope with these fluctuations in brake temperature, you need to effectively cut off the temperature peaks and avoid any excess heat in the surrounding airspace that could damage the inside of the wheel rim or tyre,' explains Graham.

'The air intakes and brake drums are typically made from carbon fibre composite, which has an upper temperature limit of around 100 to 120degC. Anything above that and the carbon starts to either delaminate or burn. So we apply our thermal barrier coatings to the inside of those parts which helps prevent excessive heat build up, allowing the composite to withstand up to 200degC. The other advantage, particularly around brake components, is that our coatings also help keep the heat in, which can be important when it comes to warming the brakes.'

This coating is a blend of ceramic powders, which is plasma sprayed onto composite parts. First, the component is media blasted to roughen the surface, helping promote mechanical adhesion. A plasma plume then melts the particles of the ceramic powder, which are then propelled towards the part at twice the speed of sound. As the particles move through the air, they cool down from around 10,000degC to 100degC across a distance of approximately 100mm. By the time they reach the part, they are molten enough to embed into the surface, but not so hot as to melt it. The result is a layer of thermal barrier coating.

'We build up the coating in layers to capture air in between,' explains Graham. 'This allows us to achieve a temperature reduction of 35 per cent across a 0.3mm thick coating. We can also increase the number of



The microstructure of Zircotec's ThermoHold ceramic coating. The composite part can be seen on the far right, followed by the bond layer, ceramic coating and, finally, the colour top coat

The thermal challenges of electric and hybrid powertrains… are already significant [but] are then further compounded by regulations, cost caps and the increasing demand for parts used in motorsport to last longer

layers, depending on the application, and blend different materials throughout the depth of the coating.

'Quite often the coating will start off with a base of pure metal, such as aluminium, to improve durability. It's a tricky balance to adhere enough molten aluminium to the substrate without melting it but, once that initial layer is down, we then gradually integrate ceramic powder to achieve the high temperature resistance.'

Thermal pathways

As well as protecting the surface of parts by applying coatings, the joints of parts can also be made thermally resistant with the use of thermal adhesives. These can be utilised within battery packs to transfer heat from inverters, or from battery cells to cooling plates.

'Our thermal adhesives are essentially thick pastes and glues that we can tune to the specific application,' says McKeen. 'Where heat is the priority, we develop adhesives that aren't electrically conductive to ensure the electrical components are isolated from the cooling plate to avoid shorting. The mechanical properties might also be different, so the approach is very dependent on the application. In some cases, such as when we need to fill a large gap, we tune the formulation to deliver an adhesive that retains elasticity when cured.

'We've integrated our materials into the Jaguar TCS Racing Formula E car for the last four seasons. Our thermal adhesives are used in the inverter and other powertrain components, helping remove heat from these electrical components and improve efficiency.'

Due to the extreme temperatures involved, Zircotec uses robots to plasma spray the ceramic coating onto composite components

The thermal challenges of electric and hybrid powertrains, which as we have seen are already significant, are then further compounded by regulations, cost caps and the increasing demand for parts used in motorsport to last longer.

'In the past, some components that were damaged by heat would simply be replaced for the next race,' notes Graham. 'Now, with the introduction of the cost cap, parts need to not only withstand high temperatures, but withstand these temperatures for much longer.

'Take the example of a Formula 1 exhaust. These components would typically only be on the car for a single race, and then maybe a practice or qualifying session. Today, teams are running their exhaust systems to last the full life of the engine, because there's a new pressure to keep costs down and ensure parts are re-used as much as possible.'

Calculator risk

Why simulators are not the be all and end all, and how to use them properly in motorsport engineering

By DANNY NOWLAN

Cranking up the front wing of an F3 racecar might produce better lap times on the simulator, but no human can drive the car set up that way. Reality has to kick in at some point in the process

One of my favorite quotes from the film *The Karate Kid* comes when young Daniel gets his licence and Mr Miyagi, the human Yoda, says, 'Just remember, licence never replace eye, ear or brain.'

The reason I open with this here is because one of the more disturbing trends I have witnessed in recent times is the over reliance on CAE (Computer Aided Engineering) tools, leading to young engineers boasting about how they have done thousands of simulations, only to then be shocked and shaken when things don't work out as they expected on track.

Going hand in hand with this is the abandonment of first principles in engineering education and practice. To illustrate this point, let's wind the clocks back a little over six decades.

The SR-71 Blackbird, a strategic military aircraft capable of Mach 3+, was designed by 35 guys with slide rules and drawing boards. We went to the moon on the back of slide rules and computers less powerful than an iPhone. Clearly, we – as human beings – had the capability to achieve quite extraordinary feats of engineering using our brains and some simple tools. With the advances made since in CFD, FEA and vehicle / flight mechanics simulation software, we should be punching these sort of achievements out with near reckless abandon. But let's look at the track record.

For example, the Airbus A380 airliner arrived three to four years late, and that cost the programme dearly. Back in the world of motorsport, let's not forget how certain high-end motorsport engineering groups were seemingly oblivious to what ground-effect cars would do as they got close to *terra firma*.

The problem is when you just blindly simulate, it invariably exploits the simulator's weaknesses. There are some exceptions that prove the rule on this. Take FEA for example.

We went to the moon on the back of slide rules and computers less powerful than an iPhone. Clearly we – as human beings – had the capability to achieve quite extraordinary feats of engineering

Most people would take one look at this and say simulation is rubbish. Strictly speaking, that is not true, because since the simulator is driving the car it can exploit its low stability aspects to maximise performance

Where there are well-defined boundary conditions, it is an extraordinarily powerful tool. Likewise, the ChassisSim shaker rig toolbox, provided the model isn't too silly. However where things can start to get diceyis with CFD in regions that aren't well understood, or lap time simulation where you go off the reservation.

To illustrate, let me give you an example of how lap time simulation can easily go very wrong: if you don't give active consideration to stability, the car will appear to just get exponentially better as you add front wing.

Table 1 is a great example of this, taken from when I talked in a previous issue of *Racecar Engineering* about using the stability index on a Formula 3 car.

Let's first take a look at the standard result where we have no stability correction. Unsurprisingly, as we crank up the front wing, the car just gets better and better. Now, most people would take one look at this and say simulation is rubbish. Strictly speaking, though, that is not true, because since the simulator is driving the car, it can exploit its low stability aspects to maximise performance.

Up the garden path

However, if you haven't taken driveability into account, this can quickly lead you up the garden path. Put the stability index correction in and, all of a sudden, it brings things back under control. Omit this final step, and blindly rely on lap times alone, and you'll find yourself in a very black hole.

An even starker example was when I ran the ChassisSim race engineering competition in 2021. This was centred around a GT3 car running at Bathurst. One of the competitors ran a ridiculously soft set-up, as shown in **figure 1** (the baseline set-up is coloured, the soft set-up is black).

Take a close look at the bottom two traces, which are front and rear roll. You have 6.8mm vs 17mm roll at the front and 6.88mm vs 13.9mm roll at the rear. On paper, this makes the car 13km/h faster. Impressive.

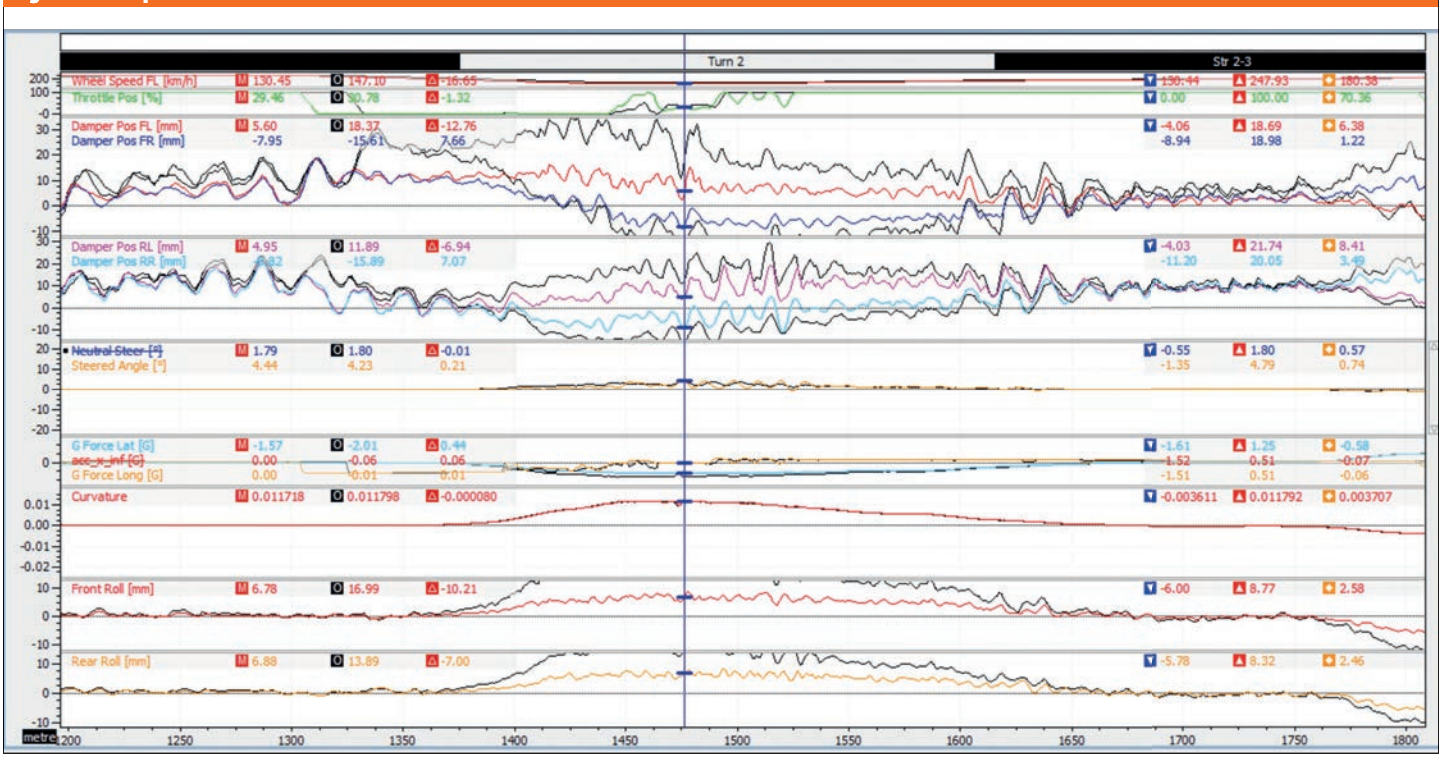
The problem was, the moment this set-up went on to the driver-in-the-loop simulator, it failed miserably. As the car started to ascend Mount Panorama, it didn't even make it past The Cutting. In other words, only a computer could drive the car with this set-up because it was moving around too much.

This is just one example – and believe me, I have many others – to illustrate the perils of relying on lap time simulation alone. For me, it also reveals the real danger of bigger motorsport operations recruiting

Table 1: Lap times for an F3 car around Queensland Raceway

Change	Standard	STBI correction
Baseline	61.96s	62.262s
Aero balance + 5%	61.84s	62.48s
Aero balance – 5%	62.4s	62.8s
Rear bar 600N/mm (std bar 1200N/mm)	62.265	62.58s
Rear spring 900lbf/in (std spring 800lbf/in)	62.0s	62.3s

Figure 1: Comparison of the standard GT3 car vs one with anti-roll bar rates halved

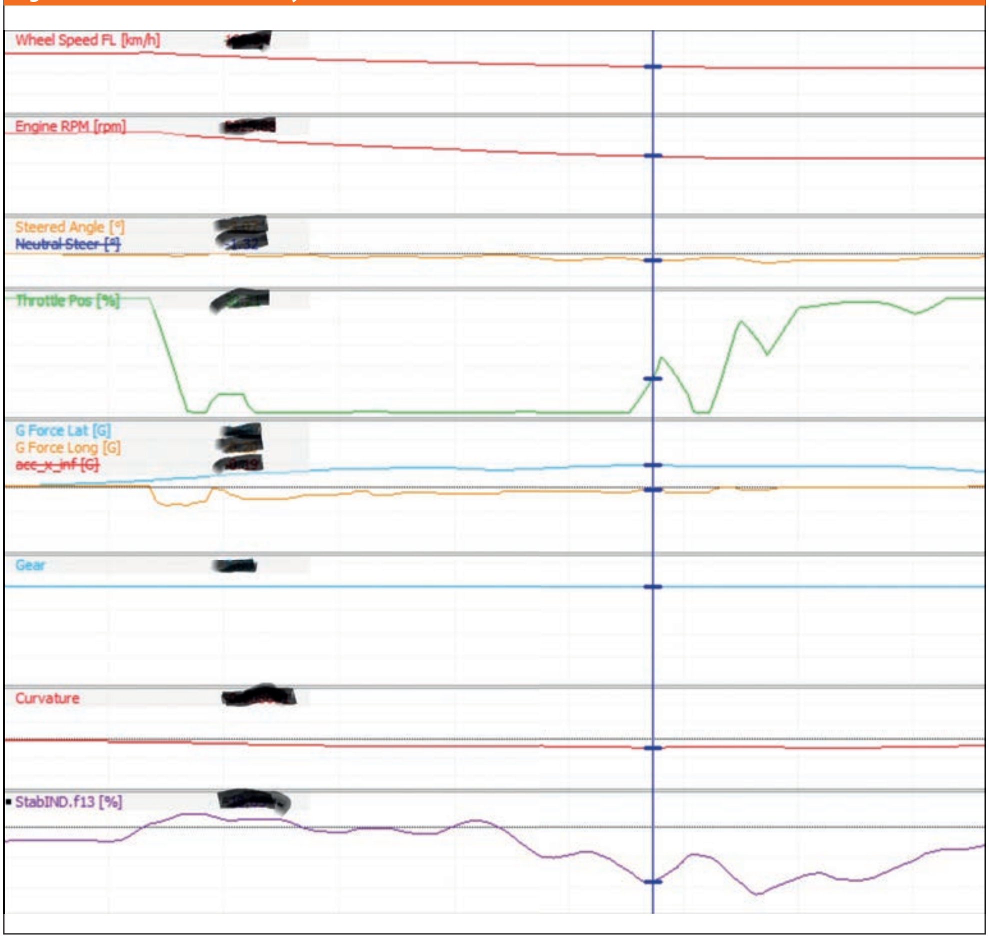


engineers straight from university who haven't done their time in junior formulae.

Now, one could contend that this is mitigated somewhat by using key performance parameters, but even this is not a guarantee. To illustrate this point, let's look at an open wheeler with some very badly conditioned stability issues that come from sub-optimal choices of suspension geometry. This is shown in **figure 2**.

As can clearly be seen, the stability index (the last trace) is varying significantly in the mid-corner section. Now, if you think a single average is going to approximate what is really going on mid-corner then you are dreaming. This neatly also explains why, nearly 30 years ago, when ChassisSim was in its formative stages, I rejected the pseudo static simulation approach and went the transient route from day one.

Figure 2: Variation of stability index mid-corner



Six commandments

For the reasons discussed, I can understand why a simulation company wouldn't provide an optimisation function. Multisim, for example, is a company that has taken this approach. That being said, there are some important caveats to consider. The first is what I like to call my six commandments of how to use racecar simulation; lap time simulation in particular. They are as follows:

1. Use logged simulated data as per actual data.
2. Always make a record of it.
3. Always, without fail, look at the data, and consider it critically.
4. Only do global sweeps once the model is fully sorted.
5. Focus on small, sensible changes and only change parameters where you have modelled.
6. What you are looking for is small, consistent changes.

It is for these very reasons that the ChassisSim set-up sweeping feature has a data logging section to it and a result summary. By doing that, I'm actually forcing you to review what you have just created.

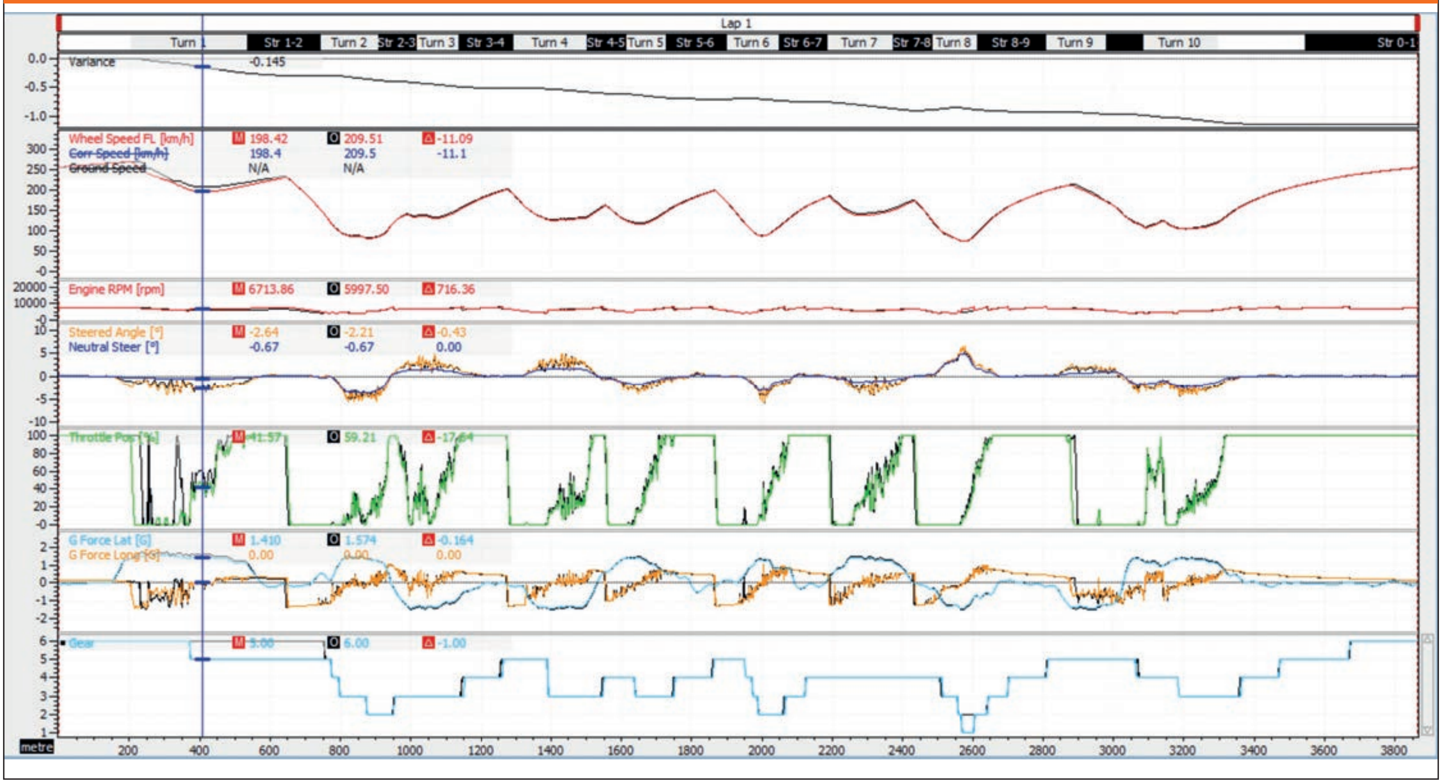
The other important caveat comes from my UK dealer and good friend, Mike Pilbeam of Pilbeam Racing Designs Ltd. Mike has been actively involved in motor racing for a very long time and made the incisive observation that if you don't have a firm grasp of what you are doing in terms of racecar engineering *before* you turn on your computer, you are already lost. Often, the low-hanging fruit with simulation packages is energy optimisation strategies, where you have a given amount of regen' energy to discharge and want to figure out how to properly utilise it. Here you can have a lot of fun because this is where lap time simulations really shine. Granted, it won't completely translate to what is on track, primarily because of the inconsistencies inherent in the nut behind the wheel, but it still gives you a great starting point.

Multisim shines in this area. It is also very good at track replay simulation work and shaker rigs. The latter I have experience with because it hasn't just

Figure 3: Shaker rig log results

Set-up	Heave res freq	Heave resp	Cross pitch	CPL front	CPL rear	Comments
Baseline	4.45	5.39	3.7	163.1	218.9	One word – awful
Spring damper package 1, RSP 330N/mm LS DR 1, HS DR 0.5	4.65	3.77	1.51	161.4	208.2	Significant improvements everywhere, but more work to be done. Rear can be tuned down a bit
Rear LSB 20K, rear LSR 15K	4.65	3.76	1.48	161.5	208.1	Slight improvement but nothing dramatic
Rear LSR 12K	4.65	3.76	1.52	161.5	207.8	Cross pitch response worse, but rear CPL better at 207.8kgf
Rear LSR 20K, rear HSR 7K	4.65	3.78	1.46	161.4	208.7	Contact Patch Load (CPL) is worse but the shape of the cross pitch response is definitely better
Rear spring 350N/mm	4.77	3.94	1.42	161.9	209.7	Heave and CPL response is worse. That said, another step forward in the cross pitch mode response
Front LSB 25K, front HSR 8K	4.73	3.89	1.45	162	209.7	Overall not a step forward
Front LSR 15K, front HSR 8K	4.69	3.94	1.27	161.8	209.2	Heave response is worse but the cross pitch mode is a massive step forward
Front HSB 25K	4.69	3.86	1.33	161.9	209.3	Heave response is a bit better but the cross pitch is worse

Figure 4: Podium simulation for the NA Autosport Evo 6 for World Time Attack Challenge 2016



been me using the shaker rig toolbox. In fact, I came to the shaker rig party quite late but, as a case in point, let's take a look at a shaker rig simulation log.

As you can see in **figure 3**, shaker rig simulation lends itself to the Multisim approach. In particular, the key performance parameters make it easy to sift through the results. Track replay simulation is also a very similar creature and you can get away with this, provided the model is sensible, since the boundary conditions are well defined. You still need to look closely at the results though.

First principles

So, how *do* you find the big competitive advantages? Well, simulation can certainly help you quantify, and will point you in the right direction, but where it really comes from is knowing your first principles, and being on top of your game.

If we look at things like ground effect aerodynamics, active suspension and semi-automatic gearboxes, their fundamental tenets are not just sound: you take one look and ask yourself, why didn't I think of this earlier? This also illustrates a fundamental simulation principle that I was taught by of my motorsport mentors, Brian Ireland, when he was using ChassisSim in anger. He said if it makes sense on the sim' and it makes sense in real life, put it on the car.

So, how do you know you are dealing with a real change that you *should* put on the car? This question is particularly pertinent when you have

The final thing to keep in mind is that a simulator is not a magic wand… it is still only a calculator; a tool to enable you to get the job done. It's up to you to make sense of the results, it won't do that for you

found a big chunk of improvement in lap time. In this case, you just can't rely on a bunch of key performance parameters, you *must* look at the data. **Figure 4** is an example of a genuine race-winning change found on the sim'.

Here, coloured is the baseline and black the simulated change, which was adding front dive planes to the car. Even though this made it 1.5s quicker, take a look at the top trace, which is the compare time. Note how continuous the change is. That is the screaming green light to put it on the car.

To round off our discussion, we must also consider why using simulation is bad news for motorsport. To do so, let's wind the clocks back to the late 1980s / early 1990s.

Back then, engineers had significant technical freedom and could test until the wheels dropped off. Consequently, young engineers coming into the sport received a proper apprenticeship. Nowadays, the junior formulae are so tightly restricted, the testing so limited at the big end of town, and the new recruits are coming straight from university. Consequently, the safety nets – ie hands-on experience – that used to be in place are no longer there. So, when the simulator leads you up the garden path, there is nobody there with enough experience to smell a rat. Remember, simulation without validation or experience is nothing more than speculation.

Motorsport calculator

The final thing to keep in mind is that a simulator is not a magic wand. ChassisSim is one of the most sophisticated motorsport calculators ever created, but is still only a calculator; a tool to enable you to get the job done. It's up to you to make sense of the results, it won't do that for you.

In closing, then, while simulation certainly has its place, it must be grounded in real-world experience and application. If you become too reliant on simulation, and just focus on lap times or key performance parameters, you run the serious risk of getting sucked into the simulator's pitfall.

It might seem like the tempting thing to do, but it is likely to send you down the wrong path and lead to a car that is slower or harder to drive. This is why you still *need* to know your fundamentals, and your simulation experience *must* be matched to real-world experience. Forget this, or worse, ignore this, and you are doomed to failure.

Toyota links up with Haas

Toyota Gazoo Racing has entered a technical partnership with the Haas Formula 1 team to provide a training facility for young engineers and drivers, while also sharing technical expertise between the two outfits.

During the announcement made in October, Toyota president, Akio Toyoda, stressed that the Japanese company has *not* returned to F1, but is instead increasing the opportunity for young Japanese talent to be involved in grand prix racing.

Toyota fielded a works F1 team from 2002 until 2009, but didn't win a race. In a speech at the Haas partnership launch, Toyoda admitted he regretted the decision to withdraw, but said it was not wrong.

That was seen as an indication that the relationship with Haas marks a first toe back in the water for Toyota in F1. However, it does not seem likely that TGR will take over the supply of the chassis, as Dallara is a long-term partner with Haas. Nor will Haas cease using Ferrari's wind tunnel in favour of switching to the Toyota facility in Cologne. Haas is registered as a Ferrari power unit customer until the end of 2028.

'We, Toyota Gazoo Racing, and the Haas F1 Team have agreed a technical partnership concerning the cultivation of young drivers and others, and Haas F1 Team vehicle development,' said Tomoya Takahashi, Toyota Gazoo Racing company president.

Young engineers will be involved in the design and manufacture of small carbon parts in simulated high pressure environments, in order to prepare them for life in F1.

'Through this partnership, TGR aims to learn Haas F1 Team's strength of data utilisation, such as the vast amount of data collected during races with various locations around the world, immediately analysing it and promptly using it in a next race's strategic planning,' added Takahashi.

Though at pains to say Toyota has not returned to F1, Akio Toyoda did admit he regretted withdrawing from the championship in 2009, and wants to give young Japanese talent a taste of working in it

Wind tunnel up for grabs

Property management company, Peer Group, is offering for sale the former Lola 50 per cent wind tunnel for a guide price of £2.5m+VAT. The tunnel originated at British Aerospace before it was relocated and updated by Lola, opening in 1998. It was then leased to the new Lola Cars business in 2021 on a three-year contract.

The tunnel has been upgraded to provide pre-programmed, automated testing with full model motion control and integration with the latest sensor technologies, all controlled by Cosworth's wind tunnel-specific Diablo software.

The tunnel is of steel modular construction, designed to be easily dismantled and relocated globally.

Ride height controversy in GP paddock

Technical controversy erupted at the United States Grand Prix when it emerged that Red Bull Racing had developed the capability to adjust its car's ride height in *parc fermé*.

The reigning champion squad admitted to having a device in the cockpit that could alter the height of the undertray's leading edge.

F1 teams pursue low ride heights to enhance their cars' aero efficiency whilst trying to minimise side effects such as plank wear and porpoising.

The FIA found no conclusive evidence that Red Bull's tool was being used under *parc fermé* conditions, which would be illegal, nor was it able to confirm whether it had been used in the past.

'While we have not received any indication of any team employing such a system, the FIA remains vigilant in our ongoing efforts to enhance the policing of the sport,' an FIA spokesperson told *Autosport*, which broke the story. 'As part of this we have implemented procedural adjustments to ensure the front bib clearance cannot be easily modified.'

Red Bull RB20 undertray, pictured at the United States GP. F1 teams cannot make changes to cars between qualifying and the race under *parc fermé*

Formula 1 2026 regs adjusted

The F1 regulations are still being fine tuned, in an attempt to ensure all cars hit the track with parity in 2026. Pre-season test days have also been increased to help teams hit the power window

The new regulations that will govern Formula 1 from 2026 have received a significant overhaul since they were first introduced in June. The change is mostly to the structure of the sporting regulations, which are to be laid out more simply and with less conflict between different articles, but work has also been undertaken to increase the performance of the cars when they hit the track in 2026.

As featured in *Racecar Engineering* V34N8, the cars will have more power from the hybrid system throughout races, and work has been undertaken to revise the aerodynamic rules to allow for the cars to manage that energy better. For example, if energy from the battery is spent, the adjustable aerodynamics are intended to allow the speed to be carried for longer.

Aerodynamically, the cars will perform to a higher level, meaning reduced lap times, while also managing the wake to allow a following car to more easily run in the slipstream. This has been a fundamental focus of the work to aid overtaking and 'the show'. Management of the adjustable aero devices has also been regulated differently to what was first made public in 2024.

According to sources in the paddock, the simulations show that the cars will theoretically perform within a second of each other around Bahrain International Circuit when they all hit the track in testing.

Also approved at the FIA World Motor Sport Council meeting was an increase in the number of pre-season test days, from two to three. These, too, will be managed slightly differently to originally planned, in order to generate the right lap time and speed, coupled with more power.

Also agreed at the WMSC were changes to the 2025 sporting regulations, removing the point for fastest lap set by one of the top 10 finishing drivers, and increasing the number of times a young driver is allowed to compete in the first free practice session of a grand prix weekend, from one to two times per season.

Historic racing widens its net

Cars that raced between 1991 and 2000 are now eligible to compete in historic racing, the FIA World Motor Sport Council has confirmed.

The update will bring many of the world's most iconic race and rally cars back to competition. These include Formula 1 cars from the turbo era that were previously only approved for demonstration runs, along with grand prix cars built between 1987 and 2000. Also now eligible to compete are Le Mans cars of that era, including the Mercedes Benz CLK GTR, McLaren F1 GTR and the Ferrari F40 LM.

Fans of super touring will soon be able to see Audi, Opel, Renault and Alfa Romeo back in harness, as well as hugely popular Group A rally cars, including the Subaru Impreza and Ford Focus WRC.

Fan favourites such as Nigel Mansell's FW12 from 1988 could soon be back in competition

BMW and Ansys enter partnership

Ansys, the US-based engineering software and simulation company, is now a partner of BMW M Motorsport.

The German marque's racing division will benefit from using Ansys products, as part of the deal.

'At BMW M Motorsport, we already work closely with Ansys, especially in the area of drivetrain design and construction,' says Franciscus van Meel, CEO of BMW M. 'The flexibility and performance of Ansys solutions enable us to quickly implement innovations and accelerate our product development – from design to final validation.'

Ansys is also a partner of Ferrari's sportscar racing activities.

Rodin buys Dynisma sim

Rodin Motorsport will take delivery of a new Dynisma Motion Generator (DMG) driver simulator for its plethora of junior single-seater programmes.

The UK-based, New Zealand-owned team, formerly known as Carlin, will use its new DMG-1 rig for car set-up, tyre strategy, driver training and circuit familiarisation. Rodin runs cars in FIA Formula 2 and 3, as well as F1 Academy, GB3 and Spanish F4.

Dynisma works with many top-level race teams and has also supplied its simulator technology to automotive OEMs. The DMG-1 has a motion latency of 4-5ms and a bandwidth of 50-100Hz.

'Having a simulator on site of the standard of DMG-1 is going to be a game changer internally for how we approach our seasons,' says Rodin F2 team manager, Benn Huntingford. 'Not only will we be able to continue our push with our driver preparation, but it allows us the opportunity to really look at our car set-up and evaluate things in a landscape where testing just isn't possible.

'We've already seen from Callum [Voisin] testing the simulator that it is an incredibly useful tool, so we're very much looking forward to working with Dynisma and getting the simulator on site next year.'

Rodin Motorsport races in F2 and F3 and will use Dynisma's DMG-1 to prepare for its '25 campaign

Ash Warne, CEO at Dynisma

McLaren rumoured to be closing in on WEC

McLaren, which has long courted an endurance racing programme, could be on the cusp of finally entering the top class of the FIA World Endurance Championship in 2027, according to paddock rumour.

However, the British supercar manufacturer is understood to want to win the Formula 1 World Championship first before making a commitment to endurance racing.

LMDh chassis constructors, Dallara and ORECA, have both said they are talking to several manufacturers which are interested in joining the global prototype rule set. McLaren and Ford are known to have made approaches, while Mercedes is thought to have completed a feasibility study, but ruled out a prototype programme, at least in the short term.

Next year will mark three decades since McLaren won the 24 Hours of Le Mans with the F1 GTR, a result that helped catapult the brand into the global phenomenon it is today. The company already runs the 720S GT3 Evo model in the WEC's LMGT3 class, courtesy of United Autosports, which is co-owned by McLaren Racing CEO Zak Brown and Richard Dean. It also races in IMSA with Pfaff Motorsports.

FIRST LOOK AT DS E-TENSE FE25

DS Automobiles was the first manufacturer to release images of the new, Spark-built, Gen3 Evo Formula E car that will debut in December. The French brand, which partnered with Penske Motorsport in 2022, unveiled the more powerful next generation car, which it calls the DS E-TENSE FE25, in Paris. The Gen3 Evo has refined aerodynamic bodywork and features four-wheel drive, which will give it better acceleration

IN BRIEF

Xtrac, the British transmission systems manufacturer, has achieved Two-Star FIA Environmental Accreditation.

'We're delighted to receive this certification. It's a big step forward for us and a significant achievement for a tier one motorsport supplier,' says Xtrac's chief executive, Adrian Moore. 'It recognises our long-standing commitment to achieving net zero.'

Cadillac is changing its management structure in racing, with Laura Klauser and Christie Bagne moving back to GM production activities. Jessica Dane, who sold her share of the Triple 8 Australian Supercars team last year, will be at more IMSA races next season in her new role as GM's programme integration manager.

IMSA SportsCar Championship GTD cars will run with torque sensors for the first time in a November test. Many of the car manufacturers have already used the devices through their teams racing in the FIA World Endurance Championship. The test is indicative only, and IMSA will gather data from each of the cars ahead of the 24 Hours of Daytona in January.

The **Lamborghini Super Trofeo** series will return to the GT World Challenge undercard next year after a season supporting the WEC. Racing on WEC tracks proved to be a double-edged sword, particularly at Le Mans, where reliability concerns regarding the tyres saw the second of two races postponed.

After recently announcing his retirement from driving, **Nicolas Lapierre** will take over as sporting director of Alpine's WEC team, supporting team boss, Philippe Sinault. They both report to Bruno Famin, VP of Alpine Motorsports.

GT World Challenge Asia has introduced a new street circuit in Beijing. The 4.9km track uses public roads that wind between modern architecture and the Tongming Lake Park. China has a historic link to GT street racing, having hosted the BPR series at Zhuhai in 1994 and 1995, before switching to the city's purpose-built circuit.

MIA recognises industry leaders

AP Racing, Fortescue Zero and Jota were among the winners at the 2024 Motorsport Industry Association Business Excellence Awards, held at Silverstone in October. The ceremony highlighted the achievements of key players in the global racecar supply chain in front of more than 400 guests.

Brake manufacturer, AP Racing, collected the MIA Business of the Year award for companies with sales over £5 million (US$6.5m). The company launched its entry-level Pro Sport caliper range earlier this year.

Fortescue Zero, previously WAE, won the MIA Technology and Innovation award for its efforts to accelerate the commercial decarbonisation of industry across many sectors, including motorsport.

Jota, the British race team that will run the factory Cadillac programme at Le Mans next year, received the MIA Teamwork award based on its success at the 24-hour race in different classes, leading up to its graduation to Hypercar last year with a customer Porsche 963.

Other companies to collect prizes included Alcon, Autosport Bearings & Components and Hypermotive.

The ceremony was held after day one of the CTS24 trade-only show where companies showcased their products, and discussed motorsport industry developments and pathways to wider application.

'The MIA Business Awards allows us to collaboratively recognise and reward those who have made significant contributions to our industry,' said MIA CEO, Chris Aylett. 'The calibre of both our winners and nominees this year is a great example of the high levels of excellence that continues to be reached by our members year on year.'

Global Logistics Management's Peter Joyce accepted the award for Service to the Industry

Hypermotive won the New Markets award, collected from Shiftec by Brad O'Nians

Alcon received the Export Achievement award, picked up by Jonathan Edwards

Fortescue's Doug Campling was on stage to take the Technology and Innovation award

The MIA Teamwork award was received by Jota co-owner, Sam Hignett

Lee Sinclair of Autosport Bearings picked up the Business of the Year under £5m award

AP Racing's Richard Gregory collected the award for Business of the Year over £5m

MIA CEO, Chris Aylett, addresses the 400+ guests ahead of the awards ceremony

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Full house?

Why sportscar racing continues to appeal to manufacturers worldwide

The Petit Le Mans at Road Atlanta remains one of the great events of the year. The 10-hour race around the 2.5-mile, undulating circuit is always spectacular, and this year was no different. After hours of green flag running mid-race, it was the battle between Acura and Porsche separated by less than two seconds that kept the crowd entertained, right up until Ricky Taylor's Acura hit a stranded Ford Mustang GT3 in the middle of the track. After that, the cudgels were taken up by Cadillac, which sometimes had lights switched on in the dark, other times not. A brave move at turn one saw the pink Cadillac move ahead of the no.6 Porsche 963, which was then hit by a BMW that had picked up a puncture.

The array of manufacturers involved in sportscar racing at the moment is mind boggling. The talk of the paddock was that the situation cannot continue, and some manufacturers are in trouble, while others spoke of new manufacturers interested in joining. But who, and why?

Good concepts

A record crowd at Road Atlanta was brought about by a few different concepts IMSA has tested. Firstly, the race has been held at the same time every year since 1998. That means that fans can plan ahead to attend. Secondly, the racing is streamed on the series' own website, and is freely available around the world in areas that do not have television deals in place. Thirdly, the racing is good, despite the introduction of hybrid systems that have escalated costs, but brought in manufacturers.

One representative told me that whatever the capability of hybrid, just having the technology is an enabling factor in the discussions at boardroom level of an OEM. It is clear the system is not practical and applicable for road car function, nor is it an environmental thing. It makes the cars heavy, is not used to extend range or to increase power. It is a vehicle dynamics tool that improves lap times in the corners by helping the car on the brakes, which is a big area of development for all the manufacturers; rotation at the mid-point of the corner and acceleration.

Fourthly, the cars have individuality. With open engine regulations, manufacturers have been able to bring whatever they want, so you have normally aspirated V8s, turbocharged V6s and, next year, a normally aspirated V12.

Sound is just one thing, though - styling is another. With the aero numbers tightly managed, the road car designers can put the styling cues in place to make the cars look different. Even in the dark around Road Atlanta, the light configurations make the cars easy to identify.

So, not only do the spectators get to see and hear differences in the cars competing, but the paddock, teams and drivers are all accessible, and the regulations are stable.

Interest rates

That last point has brought manufacturer interest. Many OEMs in Europe have issued profit warnings in the last few months, and there's no doubt there are some in sportscar racing with a question mark over their heads as to whether their programmes will continue. Yet, depending on who you speak to, there are three or four more manufacturers interested, although that could mean anything.

When you think about it, though, there aren't many places for a manufacturer to race. Most series are now either a closed shop due to the misguided idea that a single supplier is cheaper, or not well enough promoted.

Just having [hybrid] technology is an enabling factor in the discussions at boardroom level

Honda is evaluating the new engine regulations when they come to NASCAR, but there is no guarantee the Japanese manufacturer will switch allegiance from IndyCar, to which it remains firmly committed, at least for now.

Mercedes is considering building a prototype, and has apparently completed a feasibility study with a manufacturer, but with all the re-organisation in Germany at the moment, coupled with the development of new product and racecars, it is not likely to arrive any time soon. Ford's name is also in the ring, some saying it has made a decision already, others that it might do so in the next few months, while others suggest it's nowhere near ready.

McLaren is considered the most likely candidate, but we have been saying that for years. Some say it is ready, others that it has to win the Formula 1 World Championship first. Either way, if – or when – it comes, it will not be a surprise.

It is interesting to chase these stories, even if they turn out to be nothing more than hot air. At least people are talking about new manufacturers being interested, and can see a logical reason for them to join. We are also talking about the technology that will come in the future. Sportscar racing is in a good place right now. Even though the major manufacturers in Europe are experiencing lower than anticipated car sales, the racing is still relatively affordable, and the LMDh formula continues to draw attention.

ANDREW COTTON Editor

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