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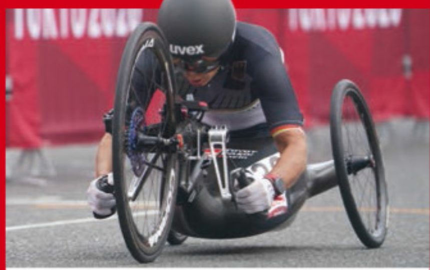

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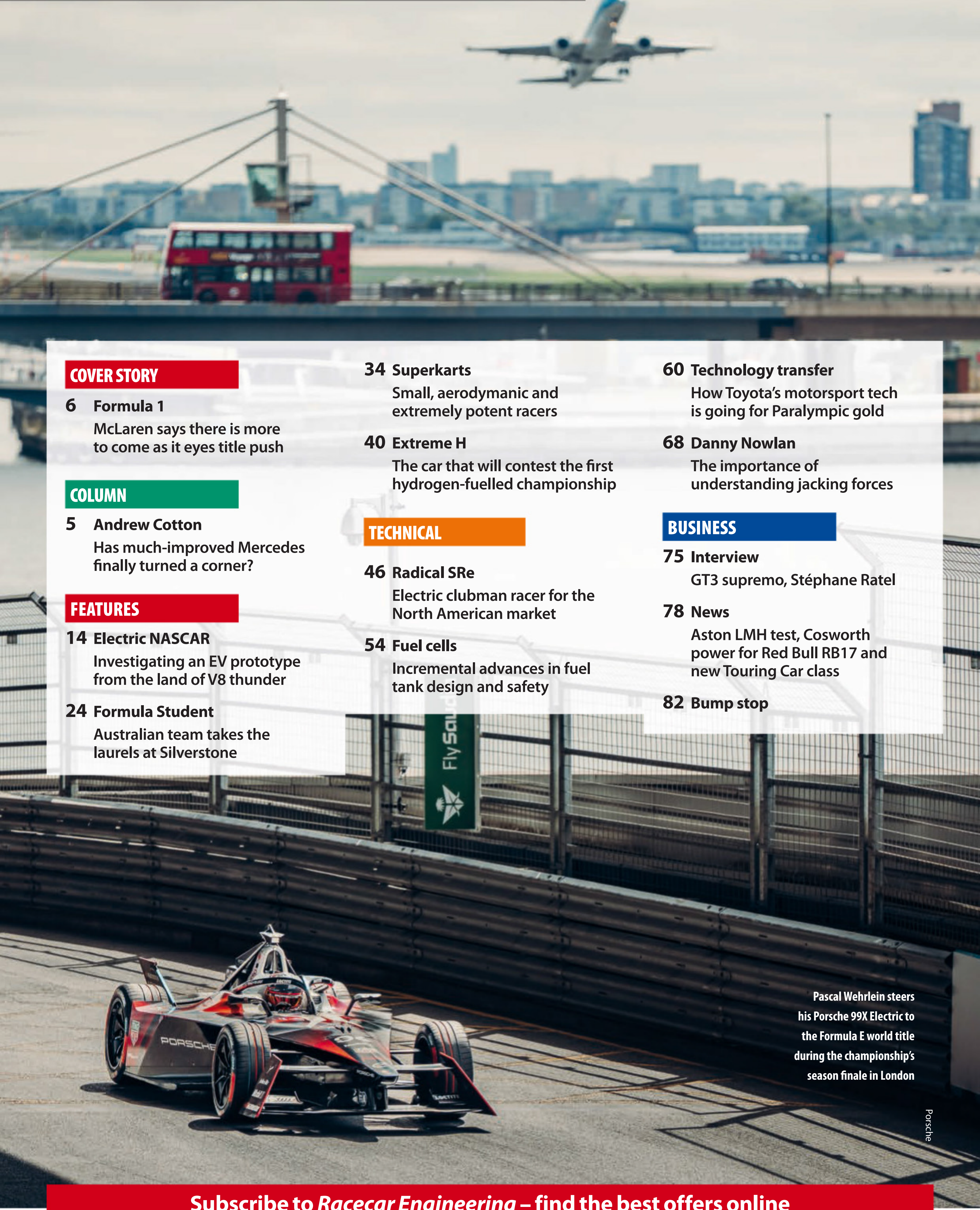

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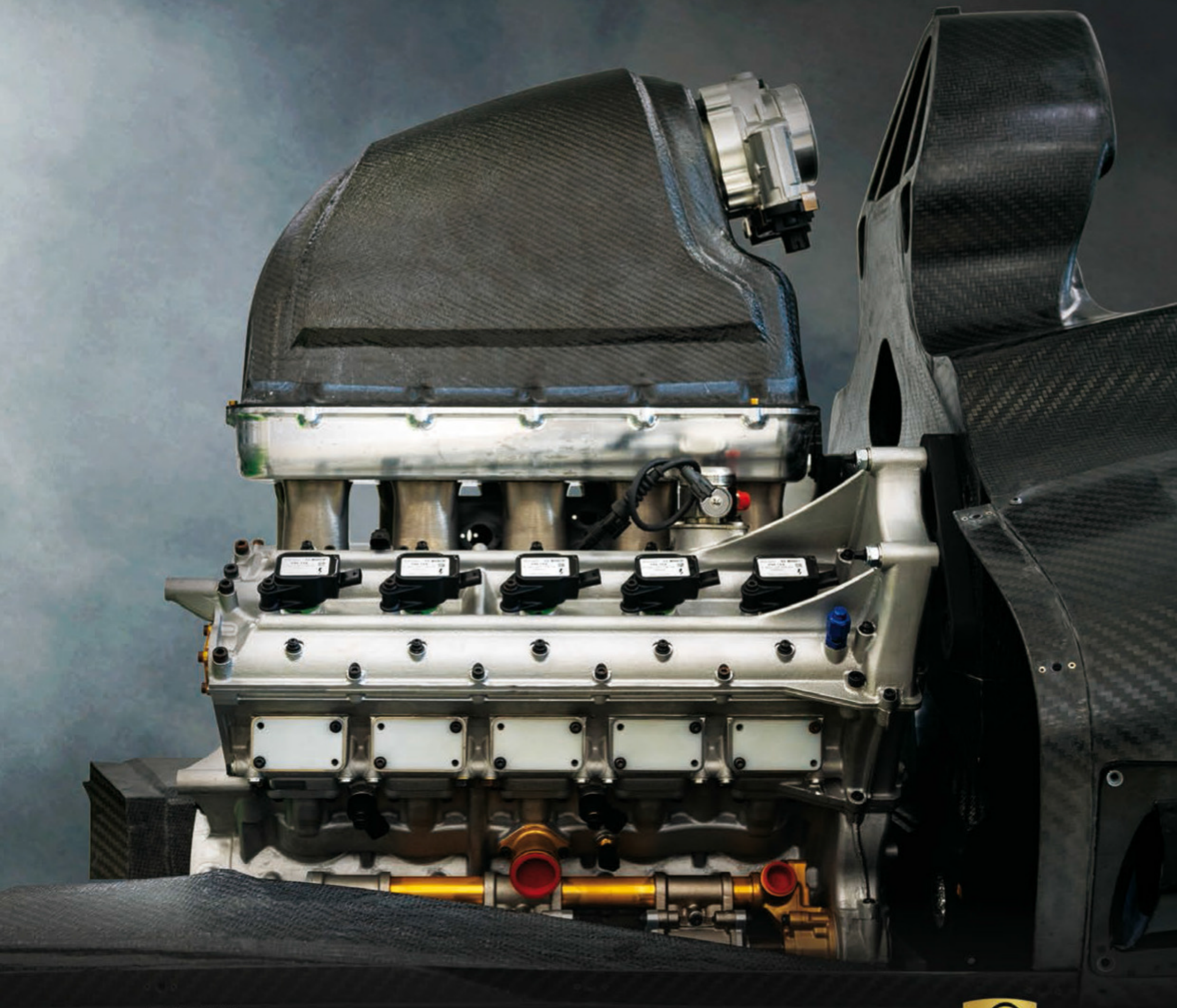

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On a knife edge

The minute difference between winning and losing in Formula 1 today

The Belgian Grand Prix at Spa saw George Russell lose a well-earned victory when his car was found to be underweight. The British driver in the Mercedes had taken a strategy call from the cockpit to stop just once for a change of tyre. That turned out to be correct, in terms of performance and race result, but the loss of rubber from the tyre, plus other normal losses from the car, meant a stunning drive was rewarded with disqualification.

It immediately reminded me of a conversation I had with our late contributor, Ricardo Divila (who was late in every sense of the word), after a 24-hour race at Spa. His car had finished a massive five laps behind the winning outfit, so was soundly beaten by any measure, yet, 'That's only one per cent off the winning car,' he pointed out.

The margins engineers at the track, and at the factories, are working to are miniscule, but they make a huge difference to the outcome of a race. *All* cars lose weight during a race through brake wear, tyre degredation, fluid losses and so on, and teams aim to be as close to the minimum weight limit at the end of the race as possible.

Working group

Russell's drive, and that of Lewis Hamilton behind him who inherited the win following the disqualification, marks an improvement of form for the Mercedes team this year that has been a long time in the making. The team appears to have found a set-up that worked.

The car was something of a horror show at the beginning of the year. In cornering, it was nervous on entry, had understeer mid-corner and then snap oversteer on exit. That proved alarming for the drivers, and led to slower lap times, poor results and a promise from the team to do better.

The team in the UK went to work, brilliantly. Upgrades made to the aerodynamics appear to have worked, as have modifications to the suspension to give the car the predictable turn in that drivers like.

According to some in the paddock, the current breed of cars is the most complicated to have been seen in Formula 1. Engineers have to find *exactly* the right balance between maximum downforce and porpoising, and the cars are on constant a knife edge between the two. What Mercedes has managed to do with its updates, and its work at the track, is find a sweet spot that allows the car to work as it should, even at places such as Austria where normally the car would not be expected to do well.

The disqualification of George Russell from the Belgian Grand Prix highlighted the precision that's needed in modern Formula 1 racing

The team now expects to carry its performance gain through the rest of this season, which, along with the resurgence of McLaren, will make the second half of the year rather more interesting.

What was also noticeable at Spa was the inability of teams to change their strategies once the race started. For Russell, once it was clear tyre degredation was lower than expected, and lower than what was seen during Friday's running, a one-stop strategy was the one to go for. Teams then focused on avoiding being undercut by another car on newer tyres, rather than their own strategy. So, when drivers stopped early in the race to shed the medium tyre, others followed suit, even those with life still left in their tyres, and a one-stop race was on.

Teams were paying the penalty for the unsettled weather during the practice sessions, which produced limited meaningful running, and very little data that pointed towards the lower degredation that was seen in the race conditions as the track rubbered in. The clues were there, however.

During the 24 Hours of Spa at the end of June, the first race on the new surface, degradation was lower than expected, and lap times improved incredibly for the GT3 cars.

Friday feeling

All of that also reminded me of a column written by Le Mans-winning engineer, Leena Gade, in this magazine, where she put forward a case for dropping Friday running altogether. Teams should have one practice session to make sure the car is straight, and then go straight to qualifying.

The unpredictability that led to the Belgian GP being such a good race can be replicated, if the FIA allows it. They have already once tried to drop a day from the schedule, without success.

Clearly, there are tickets to be sold on Friday, local business likes the extra day, and teams want to have as much data as possible ahead of the race, so there is very little chance from a commercial or sporting perspective that such a plan will be implemented. Gade also pointed out that it just pushes the pressure upstream to the factory, and getting the set-up right before the cars even arrive at the track.

However, with 24 races next season, having fewer days away from the factory must be something to be considered.

The margins engineers at the track, and at the factories, are working to are miniscule, but they make a huge difference to the outcome of a race

Title in its sights

After breaking out from F1's midfield last year, McLaren is starting to think about a title challenge as the current regulations mature

By DANIEL LLOYD

McLaren has become a leading candidate to topple Red Bull in the current regulations cycle, which started in 2022 and went through two seasons of domination from the RB18 and RB19

The numbers say it all. McLaren has produced one of the biggest turnarounds in form during Formula 1's current four-season regulation cycle, which started in 2022 and concludes at the end of next year.

In the first season of the rules, the British team scored 159 points, finishing a modest fifth in the World Constructors' Championship table. At the midway point of the current campaign, it had already registered 295 points, and was right behind Ferrari in second.

Even without factoring in sprint races, which have grown in number since 2022 and offer more chances to score points, McLaren was 127 points better off after 12 races this season than it was after all 22 races two years ago. In that time, the team has gone from being a mere observer of podium battles to a recurrent challenger.

It snapped a 57-race win drought when Lando Norris prevailed in Miami, and the team has since made inroads into addressing fundamental car concept issues that were obstructing lap time. There was even a one-two result in Hungary, that was only slightly tainted by a team orders row.

Having made reigning champion, Red Bull Racing, feel uncomfortable on several occasions, the question now is whether McLaren can mount a title challenge against what had, until recently, been considered an unstoppable force. The team is now starting to feel that what seemed improbable in 2022 could soon be possible.

'Moving on from what ended up being a very successful end to 2023, we looked at every area of the car,' says Neil Houldey, technical director of engineering at McLaren Racing. 'You've got your base aerodynamic performance and we saw from the upgrades that we were able to roll in some good lap time. But we knew that just aerodynamic or bodywork, wing-style aerodynamic upgrades weren't going to be enough. So we spent a lot of time looking at the entire car, where those performance opportunities were, to lock in base performance to the launch car [for 2024].'

'Moving on from what ended up being a very successful end to 2023, we looked at every area of the car'

Neil Houldey, technical director of engineering at McLaren Racing

Musical chairs

The launch version of the McLaren MCL38 displayed some design links to the upgraded version of the MCL60 that returned the team to frequent podiums in the second half of last year. That was natural considering it continued a roadmap set out by Andrea Stella, who replaced Andreas Seidl as team principal at the start of last year.

Stella, who played a key role under Seidl's leadership, oversaw an executive technical management re-shuffle in the spring of 2023, headlined by the departure of sole technical director, James Key, and the establishment of three departmental technical leaders: Peter Prodromou (aerodynamics), David Sanchez (car concept and performance) and Houldey (engineering and design).

McLaren then signed Rob Marshall from a 17-year stint at Red Bull to lead the engineering and design area from January, supported by Houldey. The picture changed again three months into the year when ex-Ferrari engineer, Sanchez, suddenly left, saying his role differed from his expectations when he agreed to join before gardening leave. Consequently, Marshall became chief designer, Houldey moved into his current role, Prodromou remained in charge of aero and Stella took interim charge of performance.

Despite the numerous movements at the top of Stella's technical structure,

Paolo Filisetti

The upgrade the team brought to Miami was a comprehensive package covering all areas of the MCL38. It coincided with the team's first GP victory in more than 50 races

Subsequent updates during the European season built on the successful Miami package, and included new cooling layouts and revised aerodynamic features on the front wing end plates

the development direction of the car has, crucially, remained stable.

At the MCL38's launch, McLaren refused to show its full hand, using just a basic looking front wing and obscuring the floor edge design. The car wasn't properly revealed until the pre-season test in Bahrain, one week before the opening round of the season.

Updated suspension

When it arrived, several evolutions from the MCL60 were apparent, including updated suspension designs at front and rear. On the front, the upper wishbone's rear arm was moved rearward and set lower in the chassis. The track rod was also pushed rearward, behind the front axle and in line with the rear arm of the lower wishbone. On the rear suspension, the inboard starting point of the pushrod was set higher compared to the wishbone arms.

'I would say there was just some base aerodynamic performance opportunity there,' says Houldey regarding the suspension. 'We carried over our front suspension from 2022 to 2023. We had seen lots of other teams exploring and developing in that area and we knew there was some opportunity there, aerodynamically, that we hadn't taken.'

Suspension wasn't the only area of the car McLaren looked closely at. The MCL38 appeared with re-shaped sidepod inlets, featuring a new element over the top edge and a rounder opening. This compared to the MCL60, which sported a thinner sidepod inlet with a distinctive undercut.

The sidepod was also re-modelled, with a deeper channel in its top side. Additionally, McLaren produced a more complex rear wing that dipped in the centre of the edge, compared with the flat edge of the MCL60.

'We found that going from front and rear suspension to cooler layouts, all of that added small amounts of opportunity, whether that was mechanical or aerodynamic improvement,' continues Houldey.

'Through the winter you do a lot of the bodywork and wing work. That again gave us that nice step in lap time we saw from 2023 to 2024. Really, we didn't change the process we had been using up to that point. We carried on working in exactly the same way as we had been working in the last two thirds of 2023, just focusing on where to put performance on the car. Everyone in the team worked towards those objectives.'

The McLaren MCL38 was the first F1 car to be developed in the team's new wind tunnel facility. Previously, McLaren used a wind tunnel at Toyota Gazoo Racing Europe in Cologne. Bringing aero testing closer to home has streamlined this area of work and is especially useful with the new technical regulations for 2026 fast approaching.

'We carried over our front suspension from 2022 to 2023… we knew there was some opportunity there, aerodynamically, that we hadn't taken'
Neil Houldey

Cornering disparity

Overcoming intrinsic problems with its car concept has been high on McLaren's list of priorities. When the MCL38 was launched, Stella, identified three key areas to work on: aerodynamic performance, mechanical grip and the interaction of the tyres with the track.

Lower-speed corners have been the team's Achilles' heel during the current rules cycle. The first version of the MCL38 suffered from poor aero balance in yaw, where the angle of airflow changes as the car rotates through a corner. Downforce is less important at low speed than at high speed, but still has a key role to play in keeping the car stable. It is therefore necessary for teams to set their cars low enough to generate the required downforce, but not so low it causes porpoising.

'We could even go back to previous car marks and say similar,' says Houldey. 'Low-speed performance, high yaw and high steer conditions are always hard to generate aerodynamic load in. You've really got to focus on that area to find the performance. We re-focused our efforts in CFD and wind tunnel on that low speed.

'It's taken a number of years, but that's been borne out by the changes we've seen in the last few events – since the [Miami] upgrade, really – for everyone outside of McLaren to feel we've made a bit of a step.

'Previously, we've always been working on trying to improve the low speed. It's just that it's not as easy, and therefore it's taken a while to get on top of,' admits Houldey.

Paolo Filisetti

The upper section of the sidepod inlet had a much deeper overcut in the Miami upgrade package

Team principal, Andrea Stella, identified three key areas to work on: aerodynamic performance, mechanical grip and the interaction of the tyres with the track

Overall, I think the package is about developing base car performance. Then we can start to play with the set-up to address the low-speed / high-speed discrepancy'
Neil Houldey

The first clear sign that McLaren was overcoming this fundamental performance issue came at round six in Miami, where Norris delivered the team's first grand prix win since Monza in 2021.

Miami milestone

At the Florida circuit, McLaren brought nine performance-related changes, including a new front wing, front suspension geometry and comprehensively revised floor. Norris ran the weekend with all the upgraded parts, whereas Oscar Piastri had everything except the floor and bodywork package, which was the most significant contributor to the change in performance. These were added to the Australian's car at subsequent events.

The new wing geometry yielded what the team described as a 'significant improvement of flow control.' The new suspension geometry and front brake duct were designed in conjunction with the front wing, tuning the rearward flow of air towards the floor, cooling inlets and rear wing.

The sidepod inlet's width was slightly increased to accommodate the change in onset flow from the revised suspension and wing. The floor, engine cover, cooling louvres and rear brake duct were also modified.

'The correlation between what we saw here and at the track was very good,' reflects Houldey. 'In terms of car set-up, we went into that weekend comfortable with where we were, and we learned a bit. We took a lot out of the package when it arrived in Miami and we've taken small amounts out of it since. I think our simulations are working well at McLaren and therefore we learn a lot prior to the events to enable us to exploit the car performance we have available.'

The upgrades, which were aimed at adding downforce, contributed to Norris taking McLaren's first win under the current regulations. It also marked the first win for the British driver, after several frustratingly close second places the previous year.

'Overall, I think the package is more about adding base car performance. Then we can start to play with the set-up to address the low-speed / high-speed discrepancy,' adds Houldey.

A comparison between the 2024 (above) and 2023 (below) front suspension clearly shows the change in position of the upper wishbone rear leg inboard mounting point, which has moved rearwards and down. The steering track rod was also moved rearward

'It's just the fact we've got more load that enables us to adjust a few more dials. That enables us to make the right trade between the high and the low speed at each event. There is less compromise that we need to make now, to get a competitive car.'

Balancing act

McLaren has been keen to avoid focusing too much on the MCL38's low-speed cornering that it detrimentally impacts the car's strengths, particularly in higher-speed turns.

'It's always a balancing act between low-speed performance, high-speed performance and porpoising risk,' notes Houldey. 'You can generate more low speed, but there is always the risk that you actually end up developing the car in other areas in a negative way. It feels like we've got a good balance there at the moment between all those aspects, and we've got a car that is performing nicely in almost all corners at almost every track.'

Top speed, or a lack of, has been another area for McLaren to address. It has been caused by the MCL38 carrying too much drag, which has left it weaker than its opponents on the straights. Looking at qualifying top speed data from each circuit's speed trap, the McLarens have often languished near the back of the pack this year. On average, one MCL38 ended up outside the top 15 in the qualifying speed trap table at each event in the first half of the season. Notable peaks came at Imola, where both McLarens placed in the top six (within 0.8 per cent of the fastest car through the speed trap) and at Silverstone where Piastri led the way.

Consequently, McLaren has been pushing to re-design parts that generate drag, but the numbers suggest it remains an ongoing issue.

'Again, it's the way we were developing the car initially, and the efficiencies we were working to earlier on,' says Houldey. 'We're obviously analysing and understanding what other teams are doing, and it was clear that we needed to put more efficient parts on the car and reduce the base drag.

'That was something we worked on through 2023 and into 2024. We had to accept that's another area we were behind,

like many things in 2022, but it's something we've been able to develop and put ourselves into a competitive position compared to our rivals.'

Speed trap figures aren't everything, though, and McLaren did not once fail to reach the final stage of qualifying in the first half of the season. Last year, the MCL60 was initially hit and miss on Saturdays, reaching Q3 at 45 per cent of rounds in the opening half. The fact the MCL38 has been impressive in qualifying, yet slower than its rivals through the speed trap, points towards it being stronger in other parts of the lap.

It has shown greater consistency over three sectors, even at circuits with some notable low-speed corner sequences such as Miami. At that track last year, Norris' deficit to the fastest car in each sector during qualifying was half a second, seven-tenths and half a second again. With the upgrades attached this season, the British driver was 0.145s off the leader in the first and second sectors, and under a tenth behind in the third.

Miami's first sector contains eight high-speed corners, while the second sector has a long flat-out section followed by a sequence of five low-speed turns. The consistent pace over a lap set the table for Norris' victory and demonstrated that work on taming the car's low-speed cornering deficiency cancelled out any lingering shortage in top speed.

Additionally, the MCL38 has been strong on its tyres during the races. A case in point was at Imola, where Norris reeled in Max Verstappen's seven-second lead over 20 laps, coming to within a second of the Red Bull driver at the chequered flag.

More to come

'We have progressed our understanding of tyre temperature management, improving the cooling of the rims and tyres through revised brake duct designs. At the same time, the drivers have added to this by modify their driving styles to improve overall tyre wear and degradation,' Houldey indicates.

In recent months, management figures at Red Bull have spoken of the diminishing returns that come with maturing regulations. However, McLaren feels there is still more pace to be extracted from the MCL38 heading into the business end of the season. Indeed, it expects to bring another major upgrade package to the final third of the campaign as it seeks to extract further lap time.

'We're still developing the car aerodynamically, and we will continue to do so in the tunnel for a while longer,' says Houldey. 'We're expecting at least one more big upgrade, and there will be some other upgrades on smaller parts such as brake ducts and front wing development. Some point after shutdown we'll be able to focus on next year's car, but we've done a decent amount already.'

New front wing, sporting a smoother downward curve than before, was introduced in Austria to 'improve flow conditioning'

'We need to be in the position where we can actually fight for the 2025 championship, but also at the same time develop a 2026 car that is right at the front again'

Neil Houldey

All F1 teams are looking ahead to the regulations overhaul in 2026, especially since the FIA published its new chassis blueprint in June. Equally, they are grappling with the problem of knowing when to shift the lion's share of resources to the future cars.

There are some guidelines, such as wind tunnel and CFD testing for 2026 being prohibited until January, but research on mechanical properties can be undertaken with the information that has been given.

In *RE* V33N7, RB's technical director admitted that, with the benefit of hindsight, the team would have switched attention from its 2021 car to the new 2022 machine sooner. McLaren has the same quandary; arguably more so if it wants to challenge for the title before the current regulations end.

Does the team sacrifice the start of the next rules cycle by going all out in pursuit of its first Constructors' Championship since 1998? Or does it hold what it has, in the hope its existing concept is competitive enough with minimal changes next year and that it can be among the best out of the gates in '26?

'We need to be in the position where we can actually fight for the 2025 championship, but also at the same time develop a 2026 car that is right at the front again,' says Houldey. 'That is no easy task for any team, but there is an opportunity now to start on certain aspects of the 2026 car.

'We can continue some of the mechanical layout work now. The aerodynamics side is a bit trickier because the regulations prevent us starting testing until 2025, and then we have limited CFD resource and wind tunnel time at our disposal. When January comes around, we're going to have to make some tricky decisions, but those decisions will only be made after a lot more discussion here, a lot more understanding of our competitiveness in 2025 and of where we see the opportunities in the 2026 regulations.'

Clearly, McLaren hasn't yet decided when it will shift focus fully to the 2026 car, though Houldey forecasts it will run the two projects in parallel 'for a significant period of time.'

'I think you need to be flexible with it and look at where you're sat,' he adds. '[Understanding] where the aerodynamic and mechanical opportunities lie on both cars and making flexible decisions as and when, nearer the time. It will be a discussion at set points during this year and next year, about whether we're doing the right thing and have the resources allocated in the right way, or whether we need to make a change and do something different.'

By keeping its options open for both regulation sets, McLaren hopes it can have a sustained presence at the sharp end of the grid, the like of which has not been seen since the late 2000s and early 2010s.

Electric avenue

NASCAR engineers explain how Next Gen car enabled them to produce an electric prototype

By ERIC JACUZZI, BRANDON THOMAS, CHARLES TOBIN

At the beginning of 2022, NASCAR was poised to embark on one of the biggest changes to the sport in its eight-decade history – the introduction of the Next Gen platform.

Next Gen marked a paradigm shift to reduce costs, increase competition and make joining the sport more appealing to global OEMs. While most of the 38-race calendar of its debut season was dedicated to addressing normal teething issues, a number of fringe projects were simultaneously under way using the Next Gen architecture at NASCAR's R&D Center in Concord, North Carolina.

One was the Garage 56 effort in partnership with Hendrick Motorsports that famously returned NASCAR to the 24 Hours of Le Mans last year. Almost in parallel, beginning in the summer of 2022, NASCAR and its OEM partners also agreed it was time to take a step into the battery electric vehicle (EV) arena. NASCAR's design and aerodynamics groups worked alongside each other to develop not only a novel powertrain, but also a new body style to go with it.

Design challenges

The two major system design considerations for the prototype NASCAR EV were electric powertrain selection, and how to package it in the Next Gen platform. With performance and reliability uppermost in mind, NASCAR began the search for an experienced group in the electric vehicle space to partner with.

This venture did not last long before it was decided that STARD would be the supplier of the powertrain for the vehicle. The Austrian-based company's track record for providing cutting-edge electric powertrain technology spoke for itself. For the past two years, it has partnered with Ford Performance on its SuperVan 4.2 and SuperTruck that competed at the Pikes Peak International Hill Climb.

With the powertrain partner secured, the design of the vehicle itself could begin.

One of NASCAR's key partners in developing the Next Gen platform, Dallara, began the initial work of packaging the powertrain into the base car design. The first substantial obstacle the group encountered was the lack of space available for the rechargeable energy storage system (RESS).

Rather than undertake a complete chassis re-design toward a skateboard configuration, as would be optimal, it was decided to continue with the existing platform to reduce costs to all partners. The logical choice was to put the 1300lb (590kg), 78kWh RESS on the right side of the car, where it would occupy a large portion of the available space. Due to the existing design, it would also need to be installed from underneath the vehicle.

This being the first electric stock car, and knowing all too well the style of racing it would be subjected to, the RESS casing needed to be robust enough to withstand high-speed contact with a wall, and other cars. Consequently, the RESS sits at approximately elbow height to the driver, in a carbon casing that can withstand a 40*g* hit without penetration to the RESS pack cells.

To the casual spectator, opening the front or rear of this prototype would raise a few questions. Primarily, they would ask where the traditional, OEM-specific, pushrod V8 went, and what happened to the Xtrac sequential gearbox they're used to hearing run through its gears at races every Sunday.

In the front of the car is a single STARD six-phase UHP motor and accompanying single-speed gearbox, nestled in a modular front clip in the familiar Next Gen chassis.

Rather than undertake a complete chassis re-design… it was decided to continue with the existing [Next Gen] platform to reduce costs to all partners

NASCAR wants to showcase its sustainability efforts and building an EV prototype is one way of doing that. Discussions about the project between NASCAR and its OEM partners started in mid 2022

With the re-design of a few components on the chassis… the prototype EV weighs around 4000lb (1814kg), or approximately 600lb (272kg) more than a race-spec Next Gen

NASCAR vice president of design, Brandon Thomas, displays the NASCAR EV prototype during its Chicago debut in July

To accommodate the new front driveshafts of what is now an all-wheel-drive racecar, the lower shaft end of the stock, Next Gen Öhlins damper features a 'fork' design. The next change a spectator will notice is that the steel firewall has been replaced with a carbon version that supports the inverter for the front motor and the DC-DC converter.

Look in the rear of the NASCAR EV and you'll see another carbon firewall, this time supporting two inverters for two further STARD six-phase UHP motors. Unlike the front, though, here an integrated rear clip supports the motors and gearbox.

This rear clip is similar to that used in the Garage 56 Le Mans project. Without the need for a fuel cell, though, the clip could be shortened to help with weight reduction and bumper structure packaging.

The road car inspirations for the body style of the NASCAR EV prototype

With the re-design of a few components on the chassis and accompanying systems, the EV prototype weighs in at around 4000lb (1814kg), or approximately 600lb (272kg) more than a race-spec Next Gen.

To help slow down the additional weight, the Next Gen-spec Heavy Duty (HD) brake package from AP Racing was selected, while NASCAR's tyre supplier, Goodyear, was tasked with developing a EV-specific tyre. The company worked for nearly a year on the project, coming up with a tyre capable of withstanding the unique demands placed on it by the prototype car.

Some of the challenges Goodyear faced included designing a tyre that experiences greater loads, higher torque and, in particular, the all-wheel drive arrangement, which adds drive torque at higher slip angles on the front tyres compared to what the rears are used to.

Goodyear drew upon lessons learned from its road car division in designing for the unique characteristics of the electric NASCAR. For example, on the materials side, sustainable materials from its roadgoing tyres were incorporated into the race rubber, which was based on the 70 per cent sustainable material tyre from Goodyear's EcoReady line of passenger car tyres.

Finally, Goodyear integrated the next generation of its SightLine TPMS system, which made its debut on the Garage 56 programme at Le Mans last year.

In this application, however, system weight was reduced by over half, while it also achieved the same level of reliability.

The design team says it reflected on current automotive purchasing trends in the US so, while the EV uses the Next Gen chassis, the body design is based on a generic Crossover Utility Vehicle

With the CUV-style body shape, aerodynamic performance was a concern, so the prototype was investigated at Windshear in North Carolina and at Stellantis' wind tunnel for its yaw angle capability

One of the most striking features of the NASCAR EV prototype is the body style, designed to mimic a Crossover Utility Vehicle, or CUV. Over the past few years, CUVs have come to represent a substantial portion of the North American vehicle market, and this trend looks set to continue with the introduction of new models from OEMs.

Raising the roof

To obtain the CUV shape, the roof line is a compromise between Chevrolet's Blazer EV, Ford's Mustang Mach-E and the Toyota bZ4X. NASCAR and its OEM partners defined the important areas to ensure there was enough design freedom in the body to adequately capture the differences in each of the three manufacturers' designs.

NASCAR worked with Craig Kember and John Dixon, two freelance automotive designers, to create the so-called generic body for the EV prototype, running through upwards of 10 iterations that blended the styling of all three vehicles, while also meeting the proposed rule set.

Once all parties were satisfied with the general proportions and areas of design freedom, NASCAR set to work on the aerodynamics of the vehicle.

One of the big mysteries to NASCAR's aero group was how this body shape would behave at the speeds of almost 300km/h that current stock cars are capable of. Like in the Next Gen project, parallel investigations into performance of the aero package, and the lift-off safety performance, were undertaken.

A rear wing was considered more effective than a traditional NASCAR spoiler, a major departure for the sport's aerodynamic concept

On the performance side, higher minimum ride heights were selected to keep the CUV appearance intact when racing. This reduced the effectiveness of some of the underbody aerodynamic devices, but the deficit was mostly felt at the rear of the car. The very high lift generated by the tall greenhouse and rear section produced a big challenge for the aerodynamicists, who were tasked with offsetting that lift without drastically changing the body shape, or adding massive spoilers.

One of the most striking features of the NASCAR EV prototype is the body style, designed to mimic a Crossover Utility Vehicle… to represent a substantial portion of the North American vehicle market

It was determined that a rear wing would offer several advantages over a conventional NASCAR spoiler. These include higher lift coefficients, a common solution for all three of the OEM bodies, and a tunable element to balance performance if needed.

Wing placement was such that it could accommodate varying roofline lengths, which was permissible in the design guidance developed between the OEMs and NASCAR.

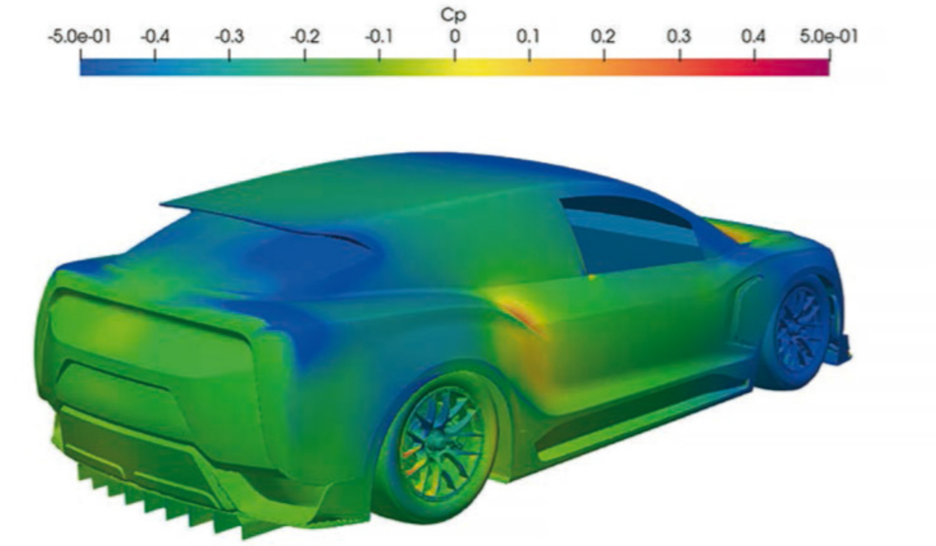
Erratic behaviour

In addition to higher than expected lift, the body style also has some peculiarities at the rear. It was found early on that the rounded edges at the rear of the vehicle were particularly sensitive. They not only reduced lift and increased drag, but also made for some erratic behaviour in CFD.

As is typical for NASCAR, body appearance is very important for maintaining fidelity to the production cars, so aggressive vents and performance shapes were largely avoided, unless they were subtle in nature.

On the lift-off safety side, the protoype EV performed very well from the beginning, even prior to adding the usual components of hood flaps, roof flaps and roof rails.

Initial CFD modelling predicted the concept would have the highest lift-off speed of any NASCAR vehicle, and the team was pleasantly surprised when this was backed up during a visit to the Stellantis Aero Acoustic Wind Tunnel at Chrysler's headquarters in Auburn Hills, Michigan.



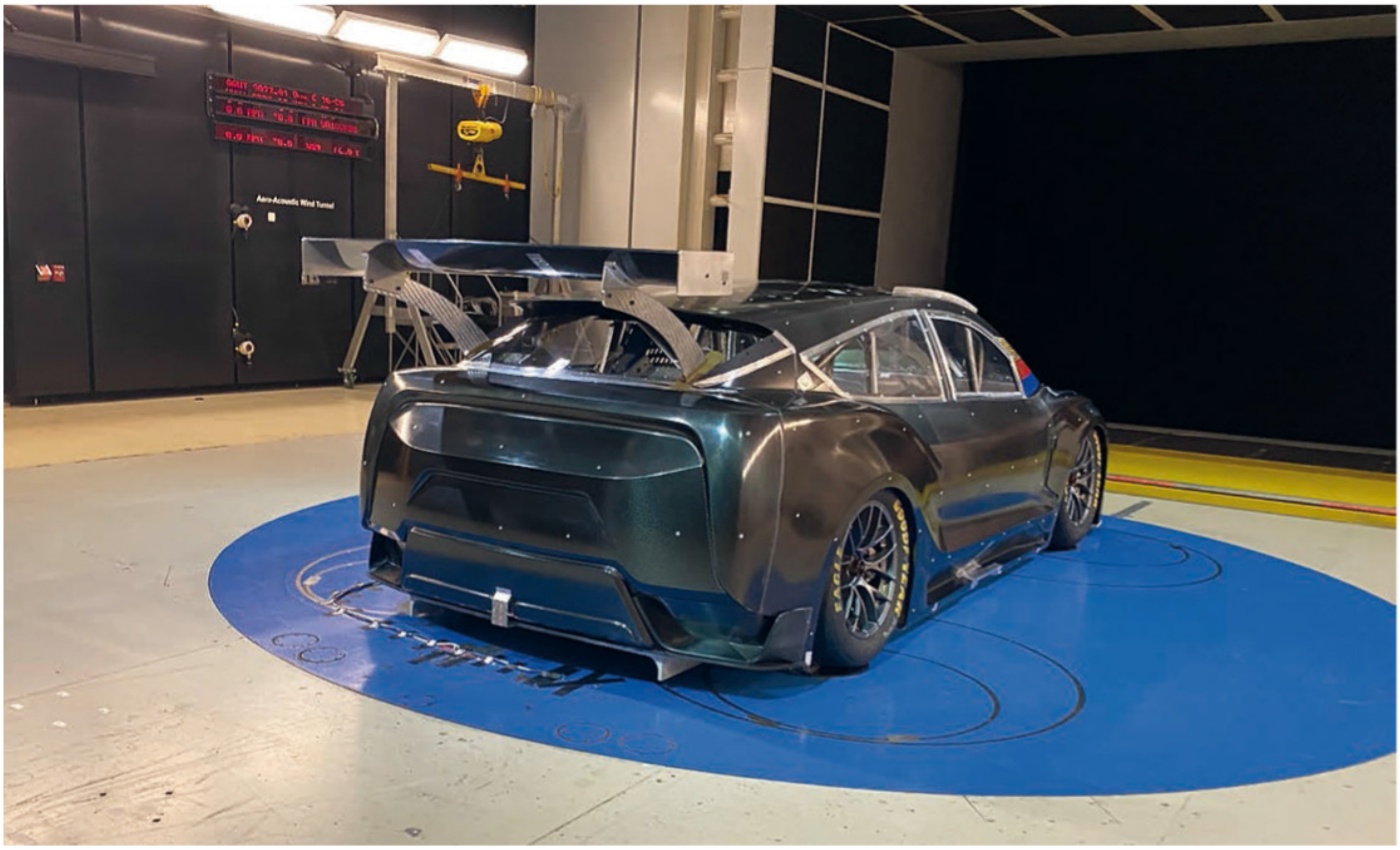
Initial CFD with no body treatments showed some concerning behaviour around the rear quarters and greenhouse

NASCAR studies lift-off by measuring the lift on either the side or rear of the vehicle and then calculating at what speed that lift will equal the weight of the vehicle, hence lift-off being reported in miles per hour.

The Stellantis wind tunnel can yaw from zero to 180 degrees in either direction, a unique feat for a full-scale wind tunnel and a great advantage for a project such as this.

With lift-off testing checked off, aero development concluded and work began on constructing the running vehicle prototype.

Initial CFD modelling predicted the new prototype would have the highest lift-off speed of any NASCAR vehicle



The aero test mule undergoing investigations at Chrysler headquarters in Michigan. Engineers were surprised to find the vehicle shape performed unexpectedly well in lift-off safety tests

Rain delayed the official launch of the prototype from February to July this year, when a crowd-pleasing burnout was performed ahead of the Chicago Street Race after months of testing

The first step in the testing process was selecting the correct Rechargeable Energy Storage System capacity for the defined performance targets of the car

With Martinsville Speedway used as the benchmark track for simulation, it was only right track testing should take place there, too

The final point of interest for the body is the material used in its construction. NASCAR spotted an opportunity to incorporate more environmentally friendly materials, as well as evaluate them for use in regular NASCAR racing, and so worked with Swiss company, Bcomp, to use its flax-based composite pre-preg and PowerRib stiffeners on the production vehicle (the aerodynamic test car used regular carbon fibre).

NASCAR anticipates that more sustainable fibres will be incorporated into production stock cars in the future, while it will also continue the carbon fibre recycling programme it has established with the cooperation of existing NASCAR teams.

Validation testing

Testing and simulation for the EV began almost a year prior to the first chassis being built. The first step in the process was selecting the correct RESS capacity for the defined performance targets of the car.

Together, STARD and NASCAR ran numerous simulations on different RESS capacities to compare how they would perform on some of the defined benchmark tracks the traditional NASCAR Cup Series races on, given an array of power levels and regen' strategies.

Along with the simulations, NASCAR leaned on its OEM partners to help execute driver-in-the-loop (DIL) test sessions to fine tune powertrain and vehicle specifications.

After months of extensive simulation runs, a specific RESS was chosen, based on its power density, energy content and the trade-off of RESS weight.

Using Martinsville as the benchmark track for the simulation work, it was predicted that the chosen RESS at full race power would be able to manage more than 55 laps at, or around, the same lap times as the current Next Gen cars are capable of.

Table 1: Performance specifications

Peak power	1000kW
Race power	600kW
Energy content	78kWh
DC voltage level	756V DC max

Real life testing began at the drag strip beside Charlotte Motor Speedway in October 2023 for systems checks and low-speed running. With the shakedown complete, focus shifted to running the car in anger.

14 November marked the first time the EV would run fast laps at any NASCAR track. The three-day test aimed to gather and verify data on RESS, systems and tyre performance.

Day one of the test focused on RESS and regen' management and vehicle system performance. In total, the car ran over 100 laps with nine different power and regen' settings. These laps were not only imperative in understanding the powertrain and chassis set-up on the engineering side, but also for driver acclimatisation to the vehicle.

NASCAR veteran and Ford test driver, David Ragan, had carried a heavy load in the earlier DIL work, so he was deemed the perfect fit when the EV took to the track.

In stock car racing, the most heightened sense for fans attending has always been the sound of a pushrod V8 holding over 8000rpm. It is distinct and unlike any other race series. This also holds true for the drivers' audible experience inside the cockpit.

With the EV prototype, this experience is flipped on its head. As Ragan learned in the early laps of testing, he could now not only feel how the car was performing, but could also hear what he was feeling.

By all accounts, the chatter of the tyres as he rolled the corners and the squeal of the brakes on entry took some getting used to.

At the same time, he was also learning to understand what regen' did for his braking performance, and how the all-wheel drive system helped compensate for the heavier car on corner exit.

Day one of testing was a huge learning experience for the entire group on the facets that make an all-electric vehicle different.

By the end of the test, the prototype NASCAR BEV had completed over 300 laps, and ran within a few tenths of a Next Gen car qualifying time at the same track

Day two of testing was primarily focused on tyre development. Goodyear performed an outstanding job, bringing several different stagger and compound options to test. The car ran over 130 laps around Martinsville on day two, finalising the tyre selection.

In addition to this, the laps also verified the simulation work done in the months prior.

The longest continual run of the day was 65 laps. Having achieved most of the targets for the day, this allowed the team to go into day three with the ability to throw a few more development options into the mix.

The first run of the final day was again used to verify RESS management, and to afford the driver more seat time. The 57-lap session went as expected, and was a further great learning experience for all involved. The car exceeded expectations and the team moved onto stretching the prototype's legs.

One of the major perks of an electric vehicle is the fact that the powertrain is tunable with nothing more than strokes of a keyboard. Dialling up the power for Ragan, a few qualifying runs were conducted at close to the full 1000kW. Again, all went to plan.

By the end of the test, the prototype NASCAR EV had completed over 300 laps (338km) and ran within a few tenths of a Next Gen car qualifying time at the same track.

The public debut was initially planned for The Clash at the Los Angeles Memorial Coliseum in February, but rain forced the event to be run a day early. The EV was instead revealed in Chicago on 6 July, followed by a showcase of its capabilities, including performing a huge, crowd-pleasing burnout and demonstrating the speed and acceleration of the all-electric vehicle.

Future plans

While the internal combustion engine has a long road ahead of it in NASCAR, the sport is committed to exploring future powertrain options to remain relevant with the automotive industry. There are no competition plans for the EV at this time, but NASCAR and its OEM partners will instead use the project to educate fans about the potential of electric vehicles.

Whether the future of stock cars includes electric technology, hydrogen combustion or sustainable fuels, NASCAR plans to be in the driver's seat on the cutting edge.

Despite successful test sessions, NASCAR's EV will not be used in competition but will instead be put into service to educate the sport's considerable audience on the potential of such technology

Aussie rules

Perth-based Edith Cowan University blitzes homegrown competition in latest edition of Formula Student UK

By DANIEL LLOYD

The fact Edith Cowan University (ECU) transported its car from Australia to the UK by air freight shows just how seriously it took this year's Formula Student contest at Silverstone. Not wanting to lose weeks of vehicle access to a time-consuming sea freight voyage, the Perth-based institution chose the more expensive, but much quicker, option of flying. The car arrived two weeks prior to the competition, giving enough time for customs checks and preparation by the team.

ECU last contested the British version of the inter-university racecar design competition in 2016. Its return came after winning Formula Student Australia with the WR-7, an internal combustion engine-powered car sporting wings for downforce and a unique rear suspension layout. Being able to then compete against electric and hybrid-powered cars in the British event, rather than being in separate classes as the competition is in Australia, was one of the major draws for ECU to make the trip.

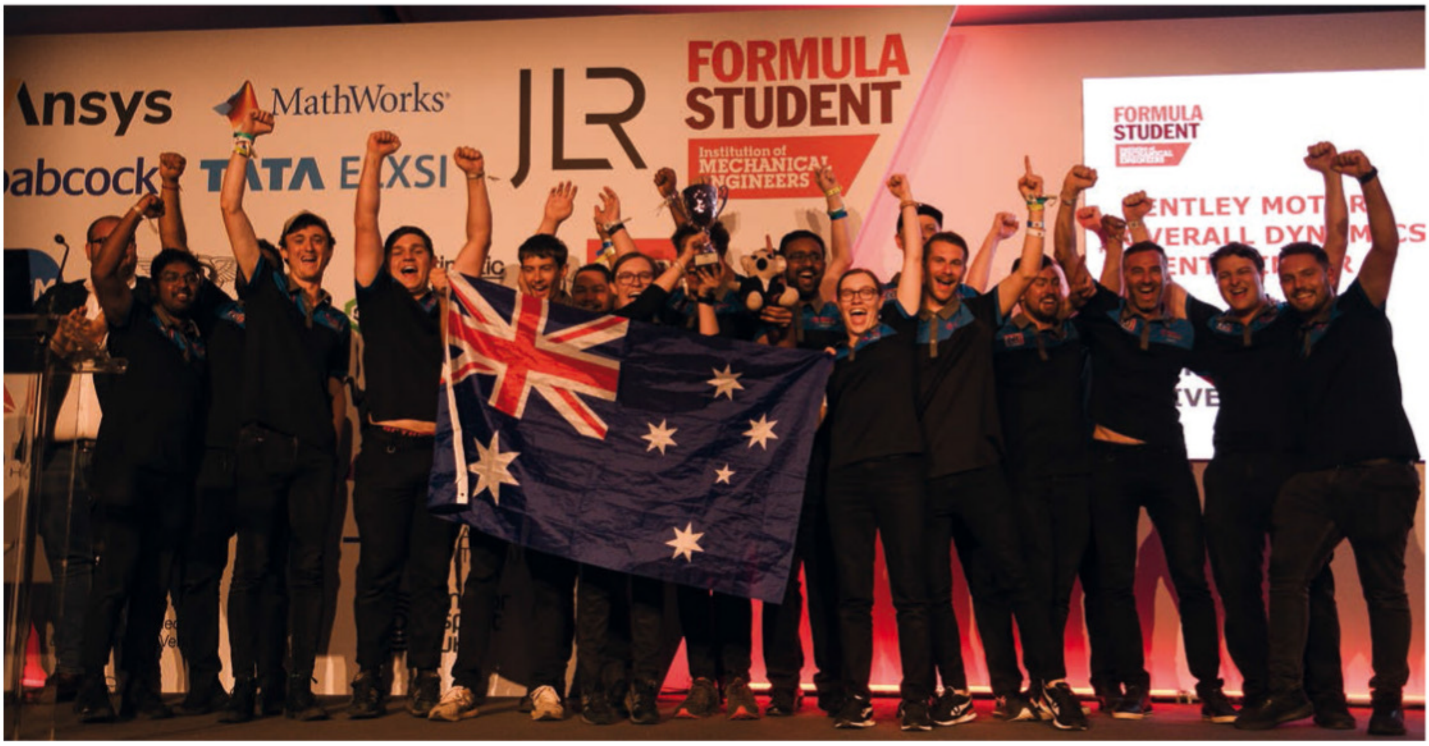
After four days of scrutineering, judging and dynamic trials at Silverstone, the Australian team won by 200.4 points, the biggest margin achieved in 21 years.

The 26th edition of Formula Student UK (FSUK) attracted 121 entries. A record 21 of those competed in the FS-AI competition for autonomous vehicles (see box out on p32). There were also 37 entries in the Concept Class, which did not involve any track running but was based on judged presentations and simulation.

Beyond that, the main competition between 63 teams comprised nine disciplines, four of which were static (scored by judges) and the rest dynamic (against the clock).

The winning car, which achieved the highest FSUK score since 2007, was air freighted from Australia to the UK and tested on Multimatic's four-post rig before the event

IMechE



Edith Cowan students celebrate becoming the third Australian team to win the British version of Formula Student, after Royal Melbourne Institute of Technology in 2007 and Monash in 2018

Achieving a full circle of scrutineering stickers is just one part of the battle at FSUK, and qualifies a car for entry in the dynamic events

After four days of scrutineering, judging and dynamic trials… the Australian team won by 200.4 points, the biggest margin achieved in 21 years

Different powertrain types were permitted and encouraged, ensuring a breadth of engineering storylines across the paddock.

As always, the hardest test to pass was scrutineering, which involves detailed checks to ensure car safety and compliance with the rules. After two days of technical inspections, only six had passed all scrutineering stages – tech, safety, chassis, tilt, noise and brakes – and were therefore qualified to take part in the dynamic events. Although 14 more cars subsequently passed scrutineering, the six teams fastest out of the blocks were expected to be overall victory contenders.

'The way it works in terms of getting around a corner is very kart-style'

Ashley Ure, team leader at ECU Racing

ECU was among them, along with Cardiff University, Coventry University, University of Aberdeen, University of Warwick and University of the Basque Country. By the end of the competition, only ECU, Cardiff, Aberdeen and Staffordshire University had completed all four dynamic challenges.

Maximising its points scoring opportunities across the dynamic events helped ECU on its route to victory, because they made up 60 per cent of the total points on offer. However, the Australians also did well in the earlier static events, laying solid foundations for their car's impressive showing on track over the weekend.

The static side of the competition, making up 40 per cent of the total, was based on the hypothetical scenario of each team pitching a car concept to a manufacturer. Design, Cost, Business Plan and Lap Time Simulation assessments were all carried out.

ECU finished top of the table in Design, seventh in Business Plan, ninth in Lap Time Simulation and 20th in Cost, so it didn't have everything its own way. After all static events were completed, the team was second in the standings behind University of Glasgow, but went on to claim the overall crown with an excellent performance in the dynamic disciplines, leading both the Sprint and Endurance time trials, which took place on a laid-out course at Copse corner.

ECU also placed second in Acceleration, Skid Pad and Efficiency, the latter measured during Endurance. Strength across both parts of the competition was integral to its success.

Winning solution

The ECU student-built WR-7 weighed in at 164.5kg, making it one of the lightest cars at FSUK this year. Its carbon fibre monocoque was reinforced with aluminium honeycomb sandwiched between an inner prepreg skin.

ECU's winning 'Integrated Powertrain Suspension' system had the powertrain connected to the rear axle, not the chassis

This arrangement was pressed and bonded together before going into the university's on-site CNC router to define the shape.

Power came from a single-cylinder Yamaha YZ450F motorcycle engine; the unit's small size meaning the car's speed relied on a high power-to-weight ratio.

Its signature feature was a custom-made arrangement called the Integrated Powertrain Suspension (IPS) system, comprising an A-frame mounting the engine and axle. Toe rods retained the frame in position.

The hollow live axle came from an American micro sprint car, cut down to the width of the Formula Student machine. According to the team, it saved 5kg over the De Dion rear beam of the WR-7's predecessor.

The IPS was also easily serviceable as the entire rear end, including the engine, exhaust and air intake, could be removed as one.

'Our previous iteration of this car was an evolution from the triangulated, four-link De Dion we did in 2019, but using trailing arms with a Watt's linkage,' said ECU team leader, Ashley Ure. 'That meant we had the engine mounted to the chassis, and the wheelbase was longer. We essentially had twist between both sprockets because the axle was moving independently from the engine. If we wanted to shorten our wheelbase [to the desired 1550mm] we couldn't have a short chain and still be twisting it, otherwise it would come off. In shortening the chain length, the whole birth of [the idea to] mount the powertrain to the suspension originated.'

This allowed the rear axle to be brought forward, accommodating a shorter chain and repositioning the car's c of g to balance out a heavily front-biased weight distribution.

As the results show, the system ended up working soundly, as ECU produced a car that was quick and agile through the turns, and durable, too. Agility is a desired trait at FSUK, particularly in Sprint and Endurance, due to the course's tight and twisty nature.

'The way it works in terms of getting around a corner is very kart-style,' said Ure. 'We rely on the inside rear wheel to jack. That gives us our speed and rotation, so we have a nice torque steer effect going on.'

Formula Student UK results

Position	Team	Static points (max 400)	Dynamic points (max 600)	Total (max 1000)
1st	Edith Cowan University	344.3	570.9	915.2
2nd	Cardiff University	286.7	428.1	714.8
3rd	University of the Basque Country (EV)	340.4	374.2	714.6
4th	Staffordshire University	241.2	445.1	686.3
5th	University of Aberdeen	180.2	270.8	451
6th	Oxford Brookes University (EV)	343.6	106.3	449.9
7th	Coventry University	192.5	244.8	437.3
8th	University of Salford	191.2	220.4	411.6
9th	University of the West of England (HY)	246.5	138.2	384.7
10th	University of Glasgow (EV)	374.6	0	374.6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The University of Glasgow scored highest in the static part of the competition, but its car only passed two of the scrutineering phases and was therefore ineligible to advance into the dynamic part. This prevented it from challenging ECU for top honours and the Scottish team ended the event in 10th position overall.

Electric success

While ECU took a dominant win, the battle for second was much closer. Cardiff University edged out the University of the Basque Country by just 0.2 points, having overturned a 53.7-point deficit after the static events. The Basque Country team beat Cardiff in three of the five dynamic categories, but its absence from the Sprint event due to an electrical fault proved costly.

The Basque Country team beat Cardiff in three of the five dynamic categories, but its absence from the Sprint event… proved costly

Despite slipping to third overall, the Basque contingent designed the highest-ranked EV in the competition. Its car featured a 35kW electric motor on each wheel, powered by a 600V battery storing 7.25kWh. FSUK forbids batteries over 600V and the Basque team suggested its unit could go up to 640V.

Additionally, the motors were unable to run at their full potential due to an 80kW limit set by the rules. Nonetheless, the Basque car did well in the Acceleration challenge, leading with a 4.364s run over 75m.

Several EV teams opted for simpler, rear-wheel-drive-only systems, but those that could manage a more complex, all-wheel-drive package fared well.

Aerodynamics were extensively studied for the Basque car's design, which incorporated venturi tunnels under the floor to generate downforce through ground effect; the floor fed through a small opening between the nose and the front wing.

IMechE

Best EV came from the Basque Country, which opted for 4WD to give independent control of the four motors onboard

Coventry University opted to ditch its wings after it was unable to turbocharge its new, smaller Kawasaki 400cc unit

'In our simulations, the downforce of the entire underfloor was around the same as the downforce the front wing and rear wing generated separately,' said Basque Country student, Imanol Salvador, who worked on aero.

Aero debate

The extent to which aerodynamic features are needed in Formula Student is debated among the teams, although the top three cars overall each sported substantial wing packages. The reason for the debate is the cars rarely exceed 70km/h in competition, but that doesn't stop teams from trying to make the air work to their advantage.

'It does definitely make a difference,' said Prescott Campbell, team lead at Oxford Brookes University, which produced a complex aero package for its EV that included Formula 1-inspired sidepods. 'We did lap time simulation to compare how fast the car would go without [the aero] but lacking the downforce vs having it on, and proved to ourselves that it would be worth having on the car. We're less concerned about drag as we are about creating downforce at low speed, just because of the average speed of the vehicle in competition.'

Some teams decided to try and optimise mechanical grip rather than seeking major aero developments

Runner-up, Cardiff University, also dabbled with some interesting aero, including a double drag reduction system on its two-fold rear wing. The wing comprised two parts: the front beam generated downforce from air being thrust over the top of the car, but also accelerated the air that passed underneath it and towards the rear beam. That rear beam had two DRS flaps that were manually engaged before a session.

On the other hand, several teams decided to try and optimise mechanical grip rather than seeking major aero developments. Often, this was resource-led, but the art of basic set-up cannot be underestimated. Coventry, which was the first team to pass scrutineering this year, previously fielded a winged car design but discarded it when plans to turbocharge its new Kawasaki Ninja 400cc engine fell through.

Going for a smaller engine than before saved a little over 20kg, but the absence of the envisaged turbo boost was set to compromise the car's power-to-weight ratio. Therefore, Coventry deemed the wings surplus to requirements, taking off yet more weight in a combined saving of around 50kg.

'We've got all the mounts for aero, but we're not running it because if we're going naturally aspirated, we just want to take all the weight out that we can,' said Chris Bradley, fourth year motorsport engineering student at Coventry University. 'This year, we're at 172kg, so we're significantly lighter than before. The car accelerates harder, it corners better, even without the wings.'

That was discovered during a test at Sutton kart track, where Coventry laid out a Formula Student-style course and found its winged solution with the new 400cc engine was two seconds slower than without.

Coventry also introduced new Multimatic dampers, replacing the Öhlins product that was popular among FSUK teams this year.

'We've got adjustment for high speed, low speed, rebound and compression,' added Bradley. 'We've taken it on the shaker rig at Multimatic, which came as a package with buying the dampers. That's drastically improved how it handles this year.'

Furthermore, Coventry brought a compressor for its pneumatic gear shift system. In fact, there were several interesting solutions around the paddock in this area. For example, ECU had a SodaStream canister to store the CO_2, but Coventry's decision to add a compressor stemmed from the team's engine change that led to a requirement for the driver to perform more frequent shifting.

'Running the old engine, we had so much torque that we would do everything in third,' explained Bradley. 'Now we really have to use all the gears. We had a CO_2 bottle on board, but we don't have enough capacity to shift as much as we need with a CO_2 tank. So, rather than go to a bigger tank, we went to the compressor. It's good because you don't have any pressure drop off and it's tucked away behind the firewall. It was quite a late design shift, but it's been working nicely.'

This year's FSUK event was the first in which all IC-powered cars ran on sustainable fuels

One of the teams that arguably punched above its weight at this year's event was University of Aberdeen, whose 15-person crew was smaller than most at the sharp end of the competition.

Like Coventry's wingless effort, the Scottish squad focused on getting the basics right with its IC-powered car, built around a steel spaceframe chassis with carbon fibre bodywork. At 216.5kg, it was heavier than the likes of ECU, Cardiff and Coventry, but still contained some neat weight-saving measures, including a 3D-printed airbox (one of many in the paddock) and tubular, rather than solid, wishbones.

Aberdeen completed around 350km of testing at a kart track in Scotland prior to the event. Indeed, several teams forged tactical partnerships with karting venues for when they needed to shake down their cars. Virtual testing was also paramount for many, and teams with more sophisticated aero packages spoke of lengthy simulation programmes to define the best shape.

Sustainable fuels

This year's FSUK event was the first in which all IC-powered cars ran on sustainable fuels. Coryton brand, Sustain Fuels, supplied a third of the eligible cars in 2023, but the partnership was quickly ramped up after that initial trial ran successfully.

Aberdeen worked its chassis frame around the chain and developed a diffuser, but removed it for the dynamic events

This year, Sustain again brought its Racing 100E biofuel (107 RON octane rating) and E10 (95 RON) products, the former having 83 per cent ethanol content and the latter having 10 per cent. The ethanol, known as bioethanol, is sustainably sourced from second-generation non-food biomass such as agricultural waste. This is deemed to be more environmentally responsible than first-generation biomass, which is directly derived from crops such as rapeseed oil, corn and sugar cane and therefore eats into land that could have been used for food production.

'I think there's two primary reasons why we're interested,' said Suresh Nahar, brand manager for Sustain Fuels. 'The future of motorsport is the younger generation, so there is a big push in the industry to get this message across about sustainable fuels into that sector. More generally, everything we're trying to do for sustainable fuels as an industry-wide programme requires communication and engagement with all levels. We're trying to capture a wide breadth of audience so everybody can get talking about this in the right way.'

Although the FSUK sustainable fuel products were 'drop-in' solutions requiring no major engine modifications, some teams still needed to adapt. For example, ECU had to re-map the fuelling in its Yamaha dirt bike engine, having been accustomed to running the WR-7 on 98 RON octane content fuel.

Teams were offered a choice of both fuels in advance and selected their preference prior to the competition. Six of the 27 teams using IC power registered for the E85 and the rest opted for the E10, which is closer to a premium forecourt product.

'They're both 100 per cent sustainable, but those products differ in two ways,' added Nahar. 'One is ethanol content and, as a byproduct of that, [the other is] octane rating. We've got a really nice range of something that is more forecourt-like, and another that is more racing-focused, to prove these fuels can work in a number of different applications."

Having sustainable fuels is obviously a good marketing exercise for Sustain Fuels and Coryton, putting their name in front of future engineers, but it could also help to keep powertrain variety in the competition.

Teams need to get sponsors (and their universities) on board to achieve the budget required to participate, and environmentally friendly mobility solutions are an obvious selling point. Having a way to use ICEs that doesn't add new carbon to the atmosphere is useful for teams that want to run them.

Last year, FSUK attracted more EVs than IC-powered cars for the first time. That trend continued this time around, although it was only a slight majority. Three cars had hybrid systems, the best of which from University of the West of England finished ninth.

There were no alternative fuels entries outside of the Concept Class, although hydrogen solutions are being developed for other Formula Student competitions around Europe. Altogether, there was decent variety in the propulsion systems used.

The 26th edition of FSUK demonstrated that the competition remains an important training ground for potential motorsport engineers. Many were clearly proud of their designs and inspired by the chance to compete. They were given further inspiration during the first day of scrutineering by the soundtrack of an Alpine A522 testing on the Silverstone GP circuit. One could observe a Formula Student car undergoing technical checks and then look up to see the F1 machine charging through Copse. No doubt many of the students present had similar thoughts in that moment: this is where I am, and that is where I could be one day.

IMechE

FS-AI element of the event grew further as additional funding enabled the organisers to double their car count from two to four

Autonomous growth

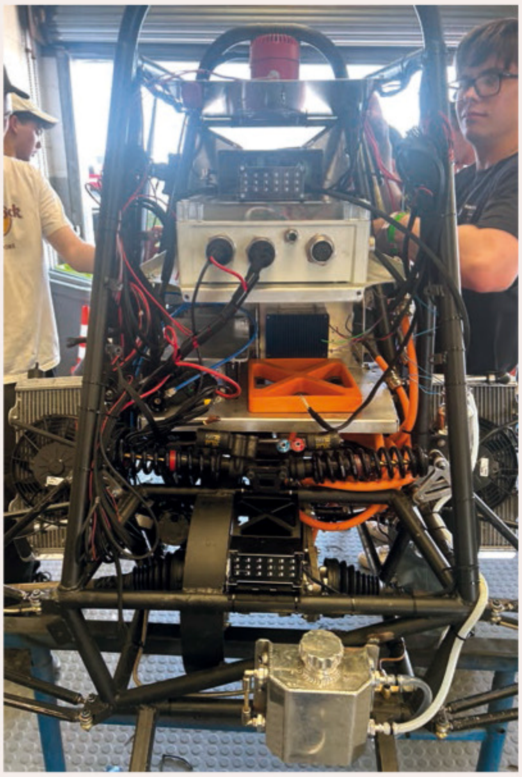
Formula Student UK first organised an autonomous car competition in 2018, but this year marked the biggest edition to date as 21 teams took part. Increased funding from the Centre for Connected Autonomous Vehicles (CCAV) enabled FSUK organiser, the Institution of Mechanical Engineers (IMechE), to provide two more driverless EVs in which teams implemented their AI technology. It was also possible for teams to build their own autonomous cars. Only the University of Edinburgh took up that challenge this year, although others are aiming to join the fray.

The in-house IMechE car, called the ADS-DV, contained an onboard computer which ran the AI software that students had written, stored on a plug-in, solid-state drive (SSD). Students then uploaded the pre-written mission for the challenge at hand. The car also featured a ZED 2 stereo camera that provided an image of the course and information about the depth of real-world objects, as well as GPS for data logging. Teams were then free to add their own hardware, such as additional sensors and computers with specific programs and algorithms, in the quest for accuracy.

Sensors elsewhere on the car fed wheel speed, brake pressure, acceleration and steering angle data to the teams, though most brought their own extra GPS and IMU (Inertial Measurement Unit) sensors to measure the car's behaviour.

Automotive technology powerhouse, ZF, worked with the IMechE on developing and building the ADS-DV and provided support to the teams at Silverstone. Most were given two weeks to practice with the in-house car.

The FS-AI category gave a chance for computer science students to shine, although other courses such as motorsport engineering and robotics were also represented



Edinburgh developed its own AI car from a rear-wheel-drive EV and passed scrutineering. Camera and LIDAR sat between roll hoops, as a tall rear end carried computer systems, battery and accumulator

For those that were unable to borrow a car in advance (such as the eight overseas institutions), ZF arranged an integration day on the week of the event. ZF and driverless technology company, IPG Automotive, also built a simulation suite that several teams used to try out their algorithms in a virtual setting. Both companies hope that all teams will use the simulation program next year.

'The simulators replicate the CAN interface and the dynamics,' explained Adam Heenan, technology group leader of intelligent algorithms and control at ZF. 'They are effectively a virtual car that reacts exactly like the real car does. It's the same computer connected to it, so the teams can show up with their SSD and plug it in.'

The competition consisted of four static and four dynamic challenges. Edinburgh took the win, scoring 822.1 points out of a possible 1000 – this came with a separate team that used the IMechE supplied car. Oxford Brookes (665.9) and University of Glasgow (594.8) completed the podium.

Naturally, the FS-AI category gave an opportunity for computer science students to shine, although other courses such as motorsport engineering and robotics were also represented.

'It's a double skill set,' said FS-AI head judge, Emma Penney, also head of business development at IPG Automotive. 'Students have to understand that it's an EV, but also how their vehicle is communicating with the sensors, LIDAR or whatever they decide to use. It's also transferrable to the automotive industry, which has evolved so much in the last 10 years. Students will learn so much by applying their software and competing.'

‘Just don’t call it a go-kart’

Superkarts can lap some tracks as fast as F3 but, with no suspension and unusual aerodynamics, they present a unique engineering challenge

By MIKE BRESLIN

Photo: Steve Addison

Some years ago, Patrick Depailler, the rather wild but very quick Formula 1 driver, tried a superkart out for size. After a few laps he pitted and declared he could ‘put one of these on pole at the Monaco Grand Prix.’ Or words to that effect, in French.

Whether or not that was true is up for discussion over a beer, but what’s not in doubt is that these spectacular little machines are very fast indeed.

How fast? These days, 0 to 60mph is around 2.3 seconds for the top class, while they can hit speeds of close to 145mph on some circuits. However, it’s on the tight and twisty tracks they really come into their own. Places such as Cadwell Park in the UK, where a superkart holds the outright lap record.

‘It depends on the length of the straights, as the lap time does come from the corner speed,’ says Ian Rushforth of the British Superkart Racing Club (BSRC). ‘But I would say we’re very rarely at a race meeting where we aren’t the quickest on the day.’

Yet it may well be this impressive performance that’s held this category back, in a way. For, while it was hugely popular in the late 1970s and early ’80s, it has since dropped off the radar a little bit, and some believe this might be because these machines make many other racecars look a bit, well, slow. Consequently, it’s sometimes difficult for British Superkarts – as the UK series is called – to find slots at regular car meetings.

It’s debatable whether the on-track performance is the only reason for this, but it is interesting to note that this year’s British Superkart Grand Prix was held at a motorcycle event – though the series does usually race at car meetings.

Healthy grids

Superkarts is still relatively healthy in the UK, though, and while entry levels for this year’s Grand Prix were nowhere near the category’s heyday (there were 362 entries across all classes in 1985!) it is still at a decent level, with 59 listed for the Donington Park event. This, too, was across all the classes, however they now race as one grid.

That’s a very big grid, but then there’s a lot of room for karts on a regular race circuit. This use of long tracks does mean it can be difficult to figure out just what is

Superkarts use six-speed gearboxes, have very effective aero and are among the fastest vehicles to lap UK circuits. The works Anderson is pictured here

a superkart, though Rushforth is very firm on this point: 'Just don't call it a go-kart.'

He has a point, for these machines are very different from fun karts and even top-level, short-circuit karts. For a start, they have longer wheelbases, use gearboxes and aerodynamic packages, making them more like racecars than regular karts, and the level of engineering reflects this.

Race-kart engineering

Superkart regulations are relatively open and, while Anderson Racing Karts make up the bulk of the current field in British Superkarts, other manufacturers are involved. There is also room for technical ingenuity, as Russell Anderson, boss of Anderson Racing Karts, explains: 'It's the development I like. We manufacture everything on it, and I like to be in control of our own destiny. So, if we need a part, we're going to make it.'

The amount of engineering freedom depends very much on the class, of which there are four, including 250 Mono (single-cylinder 250cc engines), 450 National (450cc four-stroke motocross engines) and 125 open (highly modified 125cc engines). The quickest and most popular class in terms of entrants, though, is Division 1, so we will concentrate on that here.

'Division 1 is the fastest,' confirms Rushforth of the 250cc, twin-cylinder, two-stroke class. 'The engines are 100bhp [with a minimum weight of 218kg, including driver] and they do 140mph and more. It is a common formula across the world, but we've probably got the most competitors here in the UK.'

One of the defining elements of any kart is a lack of suspension, but this doesn't mean there is no adjustability.

'Altering the caster and the camber makes a massive difference,' says Steve Parker of superkart team, Parker Motorsport. 'Then you can alter the width and the track, front and rear, though once they're set, they don't usually change too much.' Toe can also be adjusted.

Frame work

With no suspension, and very little deflection in the walls of the tiny tyres, there has to be a certain amount of 'give' somewhere, and this tends to be in the kart's frame.

'The chassis needs to flex,' says Mark Allen, who builds the Jade superkart. 'If it's too stiff, it just won't work because it won't turn, and it won't ride the bumps. Obviously, without suspension, you get to somewhere like Cadwell [Park] and it'll just take off over the bumps.'

Allen adds that the flex in the chassis, and its waisted shape, helps with 'lifting the inside rear wheel when you turn into a corner, otherwise it just understeers everywhere. The shape of the kart is what makes it work. That, and getting the flex right.'

'It's a bit of a black art to get the chassis spot on,' adds Anderson. 'That changes with different tyre compounds as they evolve. So we always have to evolve the chassis. There is the give [in the chassis], and that really becomes your suspension. It flexes diagonally, and it's a combination of various diameters and thickness of tubes that gives you this.'

Anderson was not especially keen on divulging what steel he uses in his chassis, other than saying it was 'very high-tech,' but Allen was more forthcoming: 'It has to be magnetic. You cannot have any aluminium tube, and you cannot have a carbon fibre chassis. We use T45 – most people use this – or 4130, or something like that.'

The most common tube sizes used tend to be 32mm and 30mm.

Twist and pitch

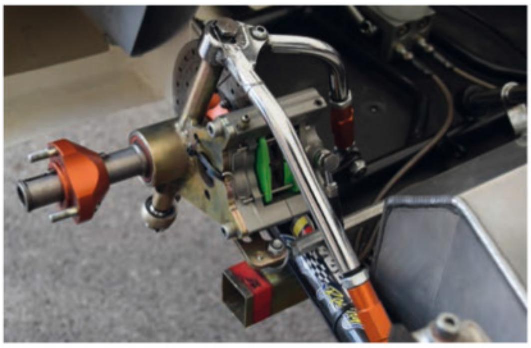
'You're relying on the twist of the chassis as you pitch it into the corner,' says Rushforth, who also builds the Spyda superkart. 'I use T45 aircraft steel for the main chassis rails and the front axle; the rails that bear the weight of the engine, they're also T45. The rest of it will just be ordinary CDS.

'Generally, I've found that if you use T45 it takes time to bed in. Whereas if you built the whole chassis out of CDS, it would be at its best from the moment you put it on the circuit, but then would decline as it becomes tired. I'm not talking about declining over a few weeks here, but over quite some time.'

There is a certain amount of adjustability in the chassis, too, as Stuart Parker, who works alongside his brother Steve at Parker Motorsport, explains: 'You've got three chassis rails at the back. We find if we take the centre rail out, we can alter the back-end geometry, just to soften it up if we need to. Typically, we'll run the three chassis rail configuration, but other people prefer to run with two chassis rails.'

Weight distribution can also be adjusted, by moving the seat, but this is not generally done during a meeting. Because the driver is in a set position – almost lying down and tight in the seat – there is also no moving around to shift weight along the chassis while driving, as there is in conventional karting.

The frame is so much more than a chassis, as it must also provide the 'give' that would normally be the work of the suspension on a traditional racecar. Chassis tend to be made from high-grade steels such as T45; carbon is not allowed



Having no suspension is a defining characteristic of any kart, and superkarts are no different. Camber, caster, toe, tyre pressures and tracking are the main areas of adjustability

Bodywork material is free, with both carbon fibre and GRP used. Aerodynamic approaches differ, with a wide range of nose, rear wing and diffusers on show at any meeting, producing plenty of variety. A PVP superkart is shown here

While the adjustable nose is designed with low drag in mind, it's also a very effective downforce producing device. Note the ram-air snorkels either side of the driver compartment on this twin-engined Jade superkart

While Andersons make up the bulk of the Division 1 field, there are other makes involved. Here a Spyda flies high at Cadwell Park, where a superkart holds the outright lap record

Clamped to these compact chassis – a superkart can be no larger than 210cm by 140cm – is a bodywork package, which tends to be glass fibre, although carbon is allowed.

'Some use [carbon],' says Anderson. 'It depends on driver weight more than anything. If they've had too many hamburgers, they tend to want to buy carbon fibre, but [the works Anderson] kart is all GRP.'

Aero packages

Carbon can also be used on the wings, which brings us to the most visibly obvious way that superkarts differ from regular karts.

'In the 1980s, the karts had a full body,' says Allen. 'A twin [cylinder] then would do 160mph. Now, the best twin won't really do more than 145mph but, thanks to the aero, around the track it's four seconds faster.'

The current bodywork packages do still aid straight-line speed, largely thanks to the sculptured nose, which is a downforce producing device that can be tilted with the use of adjusting bolts.

'It can make an enormous difference on the front, just lowering or raising it up,' confirms Stuart Parker. 'Not only does it put more aero on the front, it also controls the aero that goes on to the wing. It lifts the airflow over the kart.'

It's this over-kart aero that contributes the most to overall downforce. 'It's generated both from on top, plus the air that's passing under the kart into the diffuser,' says Steve Parker. 'I would say it's more about the aero on top, but the floor also contributes. It's probably 65 per cent on top and then 35 from the underneath.'

Stable platform

'Obviously, our ground-to-floor clearance remains pretty static, so we're quite lucky,' says Allen. 'With a racecar, it goes up and down.

'In the 1980s, the karts had a full body. A twin [cylinder] then would do 160mph. Now, the best twin won't really do more than 145 but, thanks to the aero, around the track it's four seconds faster'

Mark Allen, Jade superkart builder

With a superkart, you do get a bit of deflection in the tyres, and it will squat a bit when it's flat out, but it's hardly anything.'

Despite this stable platform on all the karts, there is still quite a wide variety of aero approaches, particularly when it comes to the diffusers and wings.

'Ours is really skinny,' says Allen of the rear wing on the Jade. 'Most people have much bigger rear wings, but we have found that if you get the profile right, you don't particularly need a massive wing. And you get more drag with a big wing.'

Wings have a height restriction of 60cm, and many of them are curved in the centre, which is partly to do with one aero complication that is perhaps unique to superkarts. That is the driver sits in the airstream, usually offset to the left to balance the weight of the engine positioned on the right, choking off much of the airflow to the wing.

'The driver is probably sitting in front of more than half of the wing width,' says Rushforth. 'I have tried separate little winglets that fill the space either side, but they aren't as good. The full rear wing definitely works better.'

Clearly, a very low seating position is a vital attribute. 'We aim to keep the shoulders below the wing,' says Steve Parker. 'So we try to seat the driver as low as we can, with their eyeline just above the nose fairing. You're basically trying to keep them out of the wind.'

While the aero packages will obviously produce drag, as well as downforce, Division 1 superkarts are blessed with plenty of power to help counteract this. With around 100bhp on tap in a 218kg kart, that equates to around 460bhp per tonne. In the majority of cases, this is produced by twin-cylinder, two-stroke, 250cc engines, though there is another approach, which we will come to soon.

Czech mate

The most popular engine is the Czech-built VM, 'an inline, tandem twin based on the old Rotax from the late '70s and '80s,' says Steve Parker. 'It kicks out about 100bhp, with 42mm carbs. It also has a full ram-air system and custom pipes. It's all custom for a kart, both the engine and the set-up.'

Unsurprisingly, engine tuning is one of the most crucial things about running a superkart, particularly ignition and jetting.

'Obviously, you're jetting it to suit the conditions of the day, the circuit, etc,' says Rushforth. 'So you need the knowledge to set up the carburettors. The person who has a good handle on that will be quicker on the day. Some don't understand it thoroughly, so they'll keep the thing a bit rich, and won't push the boundaries, whereas the people at the front probably do.'

The twin-cylinder engines rev to between 13,500 and 14,000rpm, but even they are outdone by the Jade which, a little confusingly, packs 'twin' IAME engines. That's a 50bhp, 125cc unit on either side of the kart, both of which rev to 15,000rpm.

'The fuel systems are separate,' explains Allen, 'but they're joined on the gear change, and obviously the throttles, so it all doubles up. Most superkarts have just one rotary valve, disc valve engine on the right side, but these are reed valve engines. The reed valve engines have a bit more torque, but none of them have a huge amount of torque at the bottom end. It's once they start seeing 10,000 [rpm], they start singing.

'One of the advantages [of a twin engine] is you can put the seat in the middle, so the balance of the kart, if you get it right, is the best thing going,' adds Allen.

Maintenance men

Whether it's twin-cylinder or twin-engine, maintenance is not too onerous.

'After a session, we take the plugs out, have a look in the top for the burn pattern to make sure the jetting is thereabouts,' says Steve Parker, 'but basically, it's just cleaning, making sure everything's right. Preventative maintenance more than anything.'

During a season, most engines will receive a bottom end rebuild, 'probably twice a year,' says Anderson. 'We put new pistons in every second meeting.'

In terms of development, most of this is done by the engine manufacturer, though 'we do a little bit to it,' says Anderson. 'It's mostly just preparation and set up. We have an in-house dynamometer that takes the whole kart and engine. We're just tinkering with the ignition, and the exhaust. It has a big diameter pipe, and that's important.'

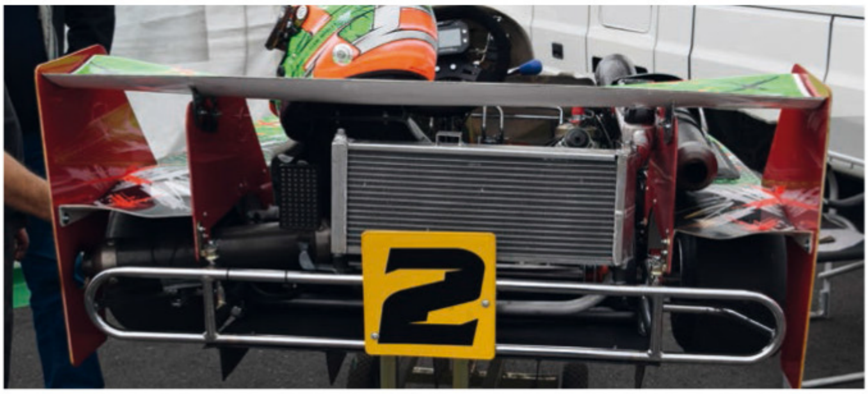
Both types of engine configuration require plenty of cooling, and most superkarts use twin radiators, one at the side and one at the back for the twin-cylinder machines. As forced induction is permitted, ram-air snorkels also feature.

Chain gang

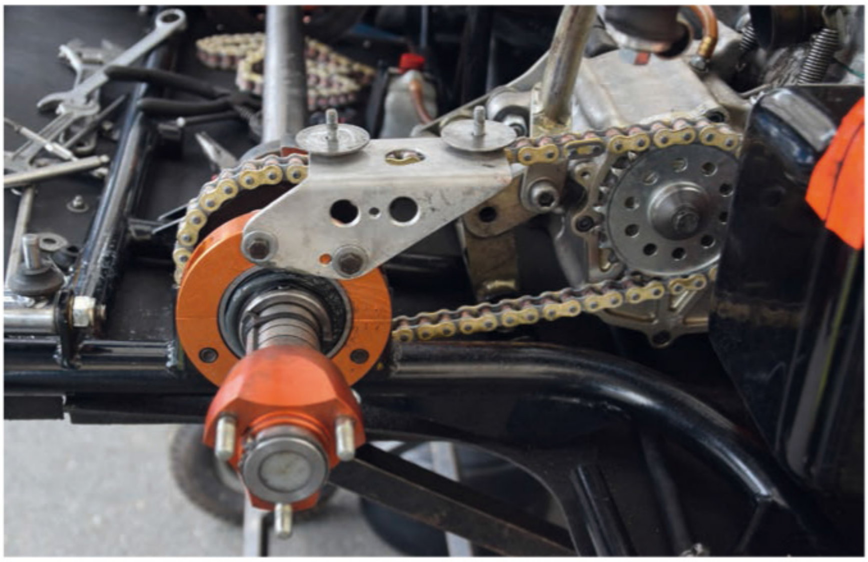
Those snorkels, slightly reminiscent of the old F3 restrictors, are a reminder that the natural habitat of a superkart is a regular race circuit. For this reason, they're also often called long-circuit karts, which means gearboxes are a necessity. These tend to come with the engine and, in Division 1, are six-speed sequential motorcycle units.

Drive is via an uprated chain onto a live axle, which is basically a 40mm shaft. However, with small wheels and sprockets, compared to the motorcycles these 'boxes were originally designed for, there's a lot of force going through the transmission.

'They are on cush drives,' says Steve Parker. 'The drive is straight onto the actual sprocket, but the sprocket on the axle does have cushioning to protect the gearbox a little bit. That's called a cush. Basically, this absorbs some of the shock from the direct drive.'



The works Anderson kart from the rear, showing the pronounced curve in the centre of the wing. Note also the extra winglets over the rear wheels and the diffuser strakes just visible beneath the rear nudge bar



Drive is via an uprated motorcycle chain onto a live axle. To help protect the motorcycle-sourced gearbox, a 'cush' attached to the sprocket absorbs some of the shock from the direct power input

Most of the Division 1 machines use the inline, tandem, twin-cylinder VM engine, which produces around 100bhp. In a 218kg kart, this equates to a power-to-weight ratio of 460bhp per tonne

The Jade, on the other hand, uses two 125cc, 50bhp IAME engines, both of which rev to 15,000rpm. This approach means the seat does not need to be offset to counteract a single engine, which helps with chassis balance

Superkarts are very physical to drive, thanks to the full-on aero packages, lack of suspension and grip from the slick tyres. They're also very rewarding

The clutch control is either a lever on the steering wheel or a pedal, depending on driver preference, but it's only really used at the start. After that, gearshifts are clutch free, and there's no throttle blipping required on the downshifts.

While the clutch sees little use during a race, the brake pedal is rather more important. This typically operates twin discs on the front, with four-pot calipers, and a single disc with six-pot caliper at the rear, with most karts running adjustable brake bias. The discs are mounted inboard, as the wheels are tiny, in comparison to anything else that goes out on a long circuit at least, which means very small tyres, too.

These are six-inch wide slicks from either Dunlop or Hoosier (short-circuit karts use five-inch rubber). The top drivers tend to run two sets over a weekend, one for qualifying and race one, and the second set for the other two races. Pressures 'are generally around 10 or 11psi, maybe 12 on a cold day to get some heat into them', says Rushforth.

Hard drive

The tyres may be small, but there is still a lot of contact patch on the road, in relation to the size of the kart. This, coupled to the fact these karts have no suspension and very effective aerodynamics, makes driving a superkart quite a challenge, physically.

Johnny West, a sprightly 69-year old who flies in from the US to compete in British Superkart rounds, gives his opinion: 'I run pretty well for about four or five laps, and then, oh, my neck! I'm just not as young as some of these guys, but I still have a great time. We have these in the States, but the competition here is tougher.'

'They're very exhilarating… once you've driven one, you're probably going to have to go up to at least Formula 3 performance to experience anything like it again'

Ian Rushforth, British Superkart Racing Club

Even the younger drivers find superkarts hard work, as Steve Parker – who was a driver before committing to the engineering side – confirms: 'It's amazing how much arm pump you get as a driver. And it's all in the forearm. You need a lot of strength to hold onto them.'

Some superkart racers, like F1 drivers, will do neck exercises to help counter the *g* force from the aero, while there's also the bumps to think about, because even circuits with surfaces that seem smooth in a racecar feel like a farm track in a machine with no suspension.

On top of this, superkart drivers are not held in with seatbelts, most believing it's safer to part company with the kart in an accident, as racers always used to.

It's not just the physical side of driving, though, and Parker Motorsport invests much of its time during a meeting in driver development.

'We go through the data logger, work with the drivers, try to find out where they're losing or gaining time,' says Stuart Parker. 'I can use onboard footage, and also the onboard telemetry, to try and analyse areas where they can improve. I try and work on one or two things every session, to keep it simple rather than flooding them with too much data.

'With these twin-cylinder karts, they've got around 100bhp and they're very light, so throttle control is very important. With a solid axle, you have to use the throttle to let the back end of the car float. Without using the throttle, it will understeer. So, at the turn-in point you need to be at, say, 10 per cent throttle and by the apex, you're about 50 per cent, feeding it in.'

Bang for buck

Presenting both a driving and an engineering challenge, British Superkarts has a lot to offer and, on top of this, it's also relatively cheap to compete.

'The basic kart is around £8000 to £9000 without the engine,' says Anderson. 'The engine's around £11,000, so you're at £20,000 (US$25,700) for a top-of-the-line superkart.'

'Once you've bought the kart, I would say you need to budget for about £1500 a meeting,' says Steve Parker. 'So you're probably looking at about 10 to £12,000 a season. That's being competitive, though. You can do it for a lot less than that.'

That is excellent bang for buck, in terms of performance. It would be hard to even come close to this level of speed with something else for similar money. 'They're very exhilarating,' concludes Rushforth. 'I think once you've driven one, you're probably going to have to go up to at least Formula 3 performance to experience anything like it again.'

So, as to Depailler's assertion that a good driver could put one of these karts on pole at Monaco, perhaps they could – for the F3 race at least.

Extreme H

Pioneer 25

The car that will be used in the first hydrogen-fuelled championship next year takes a conservative approach to fuel cell power delivery

By DANIEL LLOYD

Hydrogen has been part of the future fuels debate in motorsport for a while now, but its stock will rise considerably next year when the first hydrogen racing series kicks off. Hydrogen-fuelled demonstrator cars have appeared in series such as Le Mans Cup and Super Taikyu, but those have been individual cases. By contrast, the FIA Extreme H Championship will pit identical hydrogen-fuelled cars against each other over the course of a five-round international season.

The series is the latest brainchild of Alejandro Agag, the Spanish politician and businessman who introduced us to Formula E a decade ago. Extreme H will supersede Extreme E, the all-electric off-road series that, during its four-year lifespan, has held races in locations where the damaging impacts of climate change can be highlighted.

Agag said shortly after the Extreme H car launch on London's River Thames in June that the genesis of the championship resembles the early days of Formula E: 'Full of adventure and uncharted territory.'

When Extreme E started in 2021, it appeared to be piggybacking on the groundwork Formula E had carried out. Electric racing was nothing new by that point. This time, however, Extreme H has the chance to become a trailblazer for a different type of low-emission technology.

Odyssey to Pioneer

That opportunity to break new ground is reflected in the name of the Extreme H car: Pioneer 25. It has been developed by Spark Racing Technology, the same company that manufactured the Odyssey 21 for Extreme E and the fleet of Formula E cars. Spark factored in the learnings and shortcomings of the all-electric Odyssey 21 when designing its hydrogen replacement. For instance, it has used flexible carbon fibre and Twintex composite bodywork rather than flax fibre, which proved brittle in rough and tumble racing and needed to be replaced often.

The championship and Spark both acknowledge the Extreme H bodywork is more traditional to racing, and less environmentally friendly, but its strength and increased modularity are supposed to offset the expense and emissions incurred by regularly replacing the flax fibre parts.

The cockpit layout is also different. The Odyssey 21 was designed under a draft race format that involved drivers and co-drivers sharing the cabin, rally-style. That format was abandoned before the inaugural Extreme E season in favour of single-driver heat races, but only after the original cockpit design had been finalised. This meant drivers raced solo in two-seater cars that compromised their visibility, comfort and adjustability.

With the transition to Extreme H, Spark jumped to make the Pioneer 25 a single seater, improving the overall driving experience. It also made it easier to have a fully adjustable interior, which is crucial in a series where drivers of different heights and builds take turns to drive.

The Extreme H car uses a fuel cell system to generate electrical power. Symbio, a French company owned by the Stellantis automotive group, has developed the system.

A hydrogen stack consists of several cells, each of which has an anode on one side and a cathode on the other, separated by a membrane in the middle. Symbio is using a proton exchange membrane (PEM) for Extreme H, the same technology found in its commercial vehicles, with some minor adaptations for racing.

In the Pioneer 25, hydrogen gas molecules are injected from a pair of Toyota-built, 1kg storage tanks into the anode, but only the protons are allowed to pass through the membrane to the cathode side. The electrons are re-directed outside the cell through an electrical circuit.

This circuit route is where electrical power is generated and then shipped to the rest of the powertrain through a converter.

Many of the existing Extreme E component suppliers have been retained for the transfer to hydrogen, including Fortescue (battery), Helix (motors) Fox (suspension) and Alcon (brakes)

Once the electrons return to the cathode, they marry up with the protons and oxygen (which is allowed into the cathode side only).

The reaction of electrons, protons and oxygen in the cathode generates water vapour and heat. These are emitted from the car as waste products, instead of carbon dioxide as in a typical petrol-driven, combustion engine car. The electrical energy is then transferred to the battery and a pair of Helix electric motors, which deliver up to 400kW combined power to both axles.

Extreme H is planning to use green hydrogen, which is produced by a renewable energy-powered electrolysis process that splits the hydrogen and oxygen from water. Green hydrogen has already been used to charge Extreme E car batteries and power the infrastructure at race events.

The Pioneer 25's fuel cell stack is positioned behind the driver, above the battery and below the hydrogen storage tanks. Symbio projects the fuel cells will be able to last a complete championship season at minimum, although it has ensured the cells are accessible in case parts need to be replaced during an event.

However, a quick-change solution wasn't deemed necessary because Extreme H cars have time between races to undergo maintenance, unlike a circuit racecar, which requires fast action at pit stops.

'On such a car, running in very severe conditions, you need to find a way to dismantle parts in an easy way,' says Symbio motorsport director, Serge Grisin. 'We need to dismount the fuel cell system very easily. The proposal was to have a plug and play packaging system so, if we have to do

'The first mission of the fuel cell in Extreme H is to provide energy to charge the battery'

Serge Grisin, motorsport director at Symbio

something on the fuel cell, we can just swap the complete system and work quietly in controlled conditions. You need to have very specific conditions to open the hydrogen loop. For example, no dust.'

The Pioneer 25 has been in the works for two years now. Mule testing of a downsized stack took place last summer using the Odyssey 21 chassis, before the new tubular spaceframe chassis for Extreme H underwent its first shakedown in December and its maiden off-road test in January. Since then, the Pioneer 25 has amassed around 1600km to configure the various systems and determine its reliability, visiting off-road proving grounds such as Château de Lastours and Fontjoncouse in France. Delivery to the teams is the next major milestone to hit, in October or November of this year.

Battery supporter

There are different ways of using a fuel cell system in racing. The H24 EVO sports prototype that Symbio also works on, for example, has a 300kW capacity for endurance racing purposes and a battery that delivers some boost and power from regenerative braking. Conversely, the Pioneer 25 relies more on battery power for its short, 10-minute or so, races, whereas the 75kW fuel cell stack operates as support for the 325kW battery. The stack will charge the battery when the car is stationary and on the move.

'You can come from one situation where there is a small fuel cell, acting like a range extender, to a fuel cell that provides the complete power of the car with a very small battery for accessories and starting,' explains Grisin. 'In Extreme H, the fuel cell is a power generator. It interacts mainly with the battery. Sometimes it can provide additional power like a boost acting directly to the electric motor, but the first mission of the fuel cell in Extreme H is to provide energy to charge the battery.'

The battery pack lies flat on the floor of the Pioneer 25, in contrast to the Extreme E approach of stacking cells vertically in a cuboid, Formula E-style arrangement. The change, made due to the fuel cell occupying space where the original Extreme E battery pack once sat, has helped to lower the car's centre of gravity, and increase inertia.

In Extreme E, the car pivoted around the battery's mass centre, making it very unstable at speed. The lie-flat Extreme H design is intended to make the Pioneer 25 easier to drive, and seems to have worked successfully.

Extreme H

Neatly packaging the hydrogen components has been a priority. The Pioneer 25 is only four per cent longer and wider than Odyssey 21, despite being almost 15 per cent heavier. However, improvements in drivetrain efficiency make it as fast as its electric predecessor

One of the test drivers reported at the car's launch that it is less prone to the extreme pitch and dive phenomenon known as 'tipping' that made Extreme E cars so hard to control over jumps, which are a frequent feature of the courses.

The Extreme H battery is supplied by Fortescue (formerly WAE), which has also provided the Extreme E pack. Several parts have been carried over for ease of integration reasons, including the battery cells, module configuration and cooling concept.

Dynamic drive

'Fuel cells are great, but they're not dynamic,' says Doug Campling, motorsport director at Fortescue. 'When you put your foot on the throttle, it might take 20 seconds to spool up. That's not nearly dynamic enough. Most of the power going to the electric motor comes from the battery, because the battery can respond quickly. We then use the fuel cell to feed the battery. The battery is smaller than in Extreme E, but we still deplete it from full SOC [state of charge] to zero in an Extreme H race. In many ways, it's analogous to an EV with a range extender.'

The tanks are designed to store enough hydrogen for a single Extreme H race, which is expected to last around 10-12 minutes. Hydrogen will be stored as a gas at 700bar and injected to the fuel cell. The 2kg combined capacity of the fuel tanks was made for range and temperature reasons.

'If you empty a tank from 700bar to 50bar in 10 minutes, you will probably lose 70degC and have a good chance of freezing it,' says Spark motorsport director, Pierre Prunin. 'If you do it too fast, you freeze everything. With the tanks, it's like you are dividing the rate of depletion by two. You are reducing the chances of freezing. That was also an important parameter.'

Extreme H is set to retain a variation of the 'Hyperdrive' push-to-pass mode used in Extreme E. This will unlock the full 400kW potential of the Pioneer 25, engaging the fuel cell as a direct power source to the motor and not just as a charging device. Looking further ahead, Extreme H is considering ways of increasing the initially conservative share of power delivery from the fuel cell.

'We've got a framework that exists, predominantly evolving around how the balance of technology will shift,' says championship technical director, Mark Grain. 'We've got 75kW in the fuel cell and 325kW in the pack. Over time, we want to shift that and allow that to balance out.'

Tipping the scales at 2200kg, the Pioneer 25 is a heavy beast. With the fuel tanks, fuel cell system and multi-fan cooling arrangement factored in, it weighs 305kg more than its all-electric predecessor. However, it boasts similar performance attributes, such as matching the Odyssey 21's ability to do 0-100km/h in 4.5 seconds.


Andrew Ferraro Extreme E

Floor-mounted battery has reduced c of g and the amount of pitch variation that made Odyssey 21 so hard to handle over jumps

'That's probably the biggest surprise we had,' admits Prunin. 'The car is heavier, and the level of power is the same. However, thanks to some internal modifications to the drivetrain and gearboxes, we can use the full potential of the motors. We have 25 per cent more torque than we currently use in Extreme E. This is compensating significantly for the additional weight.'

Having more torque – up to 450Nm according to the series – puts more stress on certain mechanical components, but Spark is working on a torque limiter to manage this. A limiter device was present on the launch car in June, although it had not been fully developed or tested and so the championship was not ready to officially confirm it.

Having a torque limiter will avoid the need to enforce torque cuts, which were introduced in the first season of Extreme E to save the driveshafts after several were broken during the testing phase.

'We are planning to introduce a torque limiter later on,' confirms Prunin. 'We are developing a solution with the torque limiter to save the driveshaft and the transmission between the motor and the wheels. [It is necessary] for very specific cases where you have a huge peak of torque. For example, when you land after a jump.'

Suspension options

The Pioneer 25 sports a more advanced suspension geometry with greater adjustability than the Odyssey 21, which Prunin identifies as a key area where car performance has improved. American supplier, Fox, has also brought its Live Valve electronic suspension adjustment technology to Extreme H. This software reads data from sensors measuring acceleration, braking, steering and other parameters and independently adjusts the compression and rebound damping accordingly, on the fly.

Determining the best suspension set-up from a much wider range of options will be crucial, considering testing time is limited and races are short

'You have different maps you can set up in the car,' indicates Prunin. 'It will act dynamically on the car's damping characteristics and can detect when the car is jumping, braking and accelerating. For example, when you are accelerating, you can make the rear stiffer. You can [create] all sorts of situations.'

This contrasts markedly to Extreme E where the suspension was purely mechanical. The Odyssey 21 has double wishbone suspension with a three-way adjustable mono-damper. The Pioneer 25 also sports the double wishbone layout but with twin front and rear coilover dampers that have four-way adjustability, plus the new Live Valve technology on top. Determining the best suspension set-up from a much wider range of options will be crucial, considering track time is limited and races are short.

'Maybe we will limit that a bit, just to avoid them going in the wrong direction,' Prunin suggests regarding the electronic set-up tool. 'At least in the beginning [because] it requires a lot of mileage and experience to set up. We are really happy to do that with Fox. They have provided an interesting challenge for race engineers. I also think it will be a challenge for [competitors] to learn all the procedures around the car.'

A visual difference between Extreme E and Extreme H is the prevalence of vents on the rear bodywork for cooling the fuel cell. The Odyssey 21 had no such gaps in the bodywork; temperature regulation mainly came from a liquid cooling plate for the battery, which has been carried over. On the Pioneer 25, five large fans behind the cockpit draw air towards the fuel cell stack.

'The cooling of the fuel cell is pretty challenging because you have about 50 per cent efficiency,' says Prunin. 'It means that if you provide 1kW [from fuel cells] to the battery, you need to evacuate 1kW of heat. The challenge is that, compared to an IC engine where you can have water at 90-95degC, with a fuel cell, the water temperature is lower. It means you have less delta with air temperature and ambient temperature. You need a bigger radiator and bigger fans to cool down the fuel cell.

'On this car, we have four different cooling circuits: one for the front motor, one for the rear motor, one for the fuel cell and one for the auxiliary systems – the compressor, DC-DC converter and so on.'

Developing a pioneering hydrogen racecar has required a rigorous crash test programme that has continued through this summer. Spark has worked to ensure the hydrogen tanks and fuel cells can withstand the rigours of off-road racing, per the requirements laid down by the FIA.

'There are some static tests, but there are also dynamic tests, which are quite new for rally raid cars in general,' explains Prunin. 'When you have a rollcage, all you have to do is some static push-off tests to ensure you can put 10 tonnes on the 'cage. Here, they have imposed a sidepod impact, where you hit the side of the car with a pole at a certain speed. Another one we had to do is a rock impacting the roof of the car at a certain speed, [towards] the reservoir of the tanks. There were many discussions and iterations had with [the FIA]. It has been a good challenge for us. It was pioneering. The same with Formula E in the beginning.'

The sense of adventure at launching a world-first hydrogen series, which could get

'The cooling of the fuel cell is pretty challenging because you have about 50 per cent efficiency'

Pierre Prunin, motorsport director at Spark Racing Technology

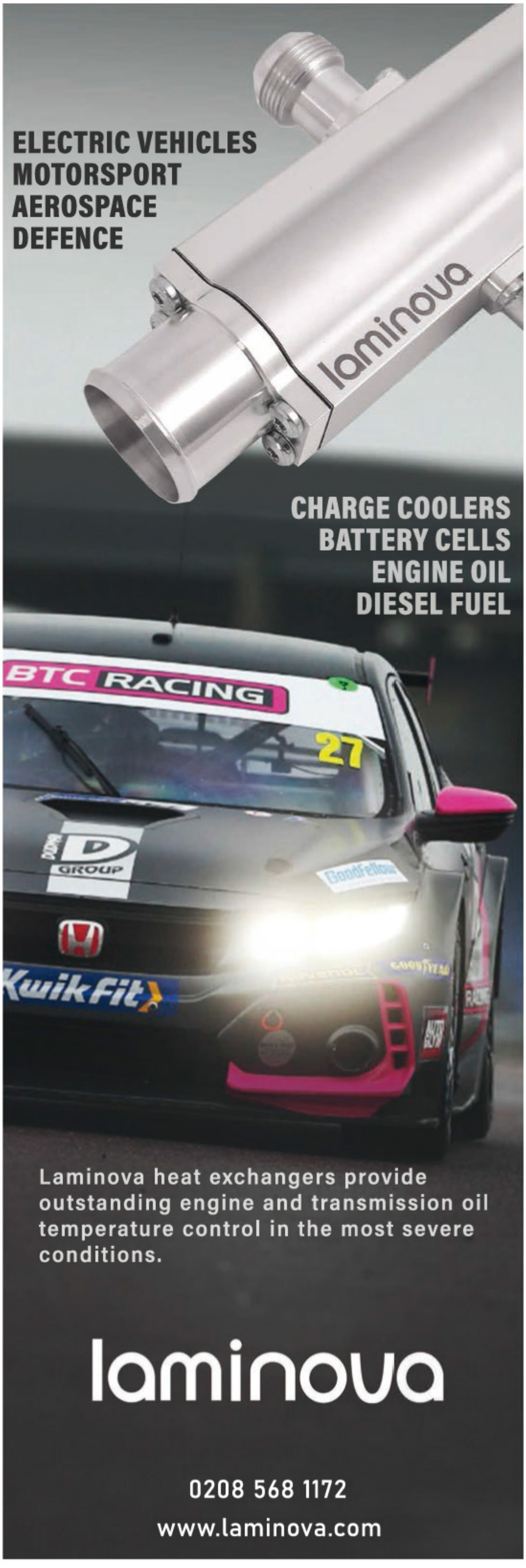
Jack Hall Extreme H

A tyre supplier has not yet been finalised and the car has tested on different options, according to Spark. Rather confusingly, it was launched on Continentals due to the ongoing Extreme E supply deal

FIA World Championship status in 2026, is clear among those involved in Extreme H. Yet they are also benefiting from four years of experience with the Odyssey 21. Placing heavy focus on the battery for power delivery in the early stages of Extreme H is testament to that. It represents a cautious approach, but also leaves room for development.

The team behind the Pioneer 25 knows the eyes of other series will be on their vehicle next year because the concept is a world first.

If all goes well, it may earn a lasting place in the history of motorsport trailblazers. Ⓡ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Game on!

How a computer games wizard opened the eyes of North American drivers to the possibility of an electric club level racecar

By TOMMY PARRY

Before Richard Hilleman established himself as a big name in the computer gaming industry, as co-producer of the renowned Madden American football series, he was a motorsport fanatic. His obsession with all forms of motorsport, and its emphasis on cutting-edge technology, dovetailed nicely with his ambitions as a gaming pioneer.

After releasing nearly 40 titles in the mid-1980s, Hilleman helped expand the then tiny sphere of racing games as producer of 1989's Indianapolis 500: The Simulation, hailed as the first to move the racing video game away from the arcade and towards the budding world of realism. Some 15 years later, he made his first foray into real-life motorsport by electrifying a CRG go-kart with a motor from an electric motorcycle. Putting this new powertrain in a lightweight, proven package felt better than doing something more complex that could bring teething problems.

'It seemed wise to try and infiltrate electric motorsports from the bottom up,' he says.

The new motor from Zero Motorcycles provided 115Nm of torque, enough to propel the 136kg motorcycle it normally powered to a maximum speed of 131km/h (81mph). The prospect of putting the same lump in a streamlined kart weighing just 200kg, with driver, was motivating, to say the least, and preliminary testing would demonstrate that the on-demand torque available from an electric powerplant would outrun some of the fastest petrol-powered karts around, which all weighed considerably less.

Krista Casey

After several iterations, the concept settled on the Radical SR8, primarily because it was designed to take, and stop, a 380bhp V8 engine, so offered the best platform on which to develop the SRe

Matt Cresci

It started with a kart, and Hilleman quickly learnt that cooling was an absolute priority in any electric racer

Richard Hilleman

Richard Hilleman (in cap) and Memo Gidley of IndyCar and sportscar fame pose with the rest of the Rattlesnake Electric Sport team

Achieving basic functionality was easy, but keeping temperatures in check required ingenuity. As Hilleman learned, topping his battery pack with a container full of dry ice became an indispensable part of his pre-cooling regimen on sweltering summer days.

Rattle and roll

Once the kart had proven itself capable of running in 35degC ambient, he began a shakedown at Sonoma Raceway's technical kart track. Despite its technical layout, it still managed to clock 91mph down the front straight, roughly 8mph faster than the fastest shifters that weighed some 30kg less.

The track organiser wasn't pleased at the safety implications of his new invention and urged Hilleman to never repeat such a demonstration. That was fine; he had proven his kart's ability and it was time to publicise it.

After making his passion project legal, and printing several sheets of stickers for his new Rattlesnake Electric Sport-branded karts, Hilleman replaced the ageing CRG with an Aluminos chassis and debuted his e-kart at that year's Refuel, an EV-only event held annually at Laguna Seca in California. Hilleman invited local hot shoe, Matt Cresci, then making a name for himself in Mazda MX-5s, to help develop his new creation.

A fleet of electric cars developed on a budget that dwarfed Hilleman's outpaced a punchy kart around a high-speed track, but his snakeskin-liveried kart stole the show, for the first few laps at least.

One oversight kept Rattlesnake's debut from being the fairy tale start it could have been. Zero Motorcycles had designed the motor for 12V contactors, and the 24V contactors that Hilleman had fitted failed just feet before Cresci entered turn seven on his fourth lap. Gravity could carry Cresci downhill to the pits, but this was an unfitting end to an otherwise sensational premiere.

The silver lining was lucrative, however. By March of the following year, Hilleman was under way building a half dozen new karts after his demonstration. Profits from those sales had provided him with the confidence to take a leap and explore a faster platform.

He felt the right move was to combine his electric powertrain with a lightweight, proven and well supported racecar.

Matt Cresci

When time came to step up to a car, a Radical SR3 was initially chosen as the base vehicle. This is an early incarnation of the SRe concept


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That same early incarnation of the SRe in hot pursuit of a 700bhp DL Eagle SL-C at Sonoma Raceway in California

With over 800 examples then in use in the United States, he settled on the Radical SR3. Weighing only 680kg and powered by a 1.5-litre RPE-Suzuki engine making 200bhp – roughly the output he anticipated his e-motor would make – it seemed perfect. Finding parts and support would be easy and, when learning about his plans, Radical offered to assist with the integration of the powertrain.

At first, the plan was to use two Zero Motorsports motors and belt drive the Quaife differential that came standard with the SR3. However, Radical suggested Hilleman use the chassis from the company's V8-powered variant, the SR8, as it featured suspension components and brakes designed to deal with greater weight and power.

After he accepted the proposal, Radical made a number of 'pipe changes' to an SR8 chassis to accept a new motor package, as well as a 24kWh battery pack, which took the place of the old fuel cell. The 'SRe' was born.

Meeting of minds

In the spring of 2014, right as the SRe's development began, work took Hilleman to London, UK. While waiting for his return flight leaving from Heathrow, Hilleman spotted someone at his gate leafing through an issue of *Racecar Engineering* and felt instant kinship.

'Two types of people read that magazine: nerds and industry people,' he quips.

Hilleman suddenly found himself locked in technical conversation with Craig Daniels of Formula E's China Racing, at the time wading through the murky waters of the series' inaugural season. China Racing (now ERT) had hired Daniels from Omni Powertrain Technologies as a technology provider.

'I suspect they considered the SRe as a training tool for their drivers, which might have influenced their decision to provide support'

Richard Hilleman

When he realised Hilleman was no dilettante, he decided to divulge some information about how his team planned to sort out the mechanical gremlins from that trying first season.

Hilleman enquired about the team's battery cooling strategies, knowing the potential for thermal issues. After hearing Daniels' ideas, Hilleman sensed they might not be sufficient for the hotter weekends on the calendar and suggested the dry ice cooling method that had helped him sort out his karts on blistering August afternoons in California. And so went the chin-wag until it was time for Hilleman to catch his flight.

After the two went their different ways, they couldn't have known they'd be sharing technical insights again very soon.

As Hilleman had predicted, China Racing suffered from cooling problems at the following Beijing E-Prix, where the ambient temperature soared to 32degC. He watched the television coverage of the following race in Putrajaya, Malaysia, with a smirk, noting how China Racing's cars had subsequently been equipped with dry ice cooling.

Celebrity squares

A few months later, Daniels invited Hilleman to join the team at the 2014 Formula E season finale in London, where China Racing's Nelson Piquet jnr secured the Drivers' title.

There, Hilleman felt like a celebrity. 'I knew someone in nearly every pit,' he laughs. Among those were Benoit Vareille and Carsten Clausnitzer, two of the clever minds from Rational Motion brought on by Daniels to help China Racing. Not only had the pair developed Toyota's Formula 1 KERS system, but had also built its Radical-based EV P002, which claimed first prize in the Electric Car class, and sixth place overall, at Pikes Peak International Hillclimb in 2012.

Hilleman mentioned his plans of running an electrified Radical in North American club racing and the plans he had for it, and the three Formula E men decided there and then to invest. They pulled a few strings and made several rare parts available to Hilleman. The small team was clearly eager to move the SRe in the right direction.

'I suspect they considered the SRe as a training tool for their drivers, which might have influenced their decision to provide support,' Hilleman surmises.

Daniels would help Hilleman integrate the new powertrain, and even supplied him with a modified Hewland gearbox. Clausnitzer and Vareille offered him a used Formula E car from one of China Racing's earlier efforts.

CaliPhotography

Having the backing of Radical, and three notable names from the world of Formula E – Craig Daniels, Benoit Vareille and Carsten Clausnitzer – helped Hilleman enormously in the project

This, a complete Formula E motor package, came with the McLaren Applied ECU, as well as hundreds of hours of dyno and track testing, all for a very reasonable price.

'I'm extremely grateful for all they offered, as I couldn't have afforded to develop the powertrain on my budget,' says Hilleman.

As Hilleman adapted the Formula E Hewland single-speed gearbox to function within the Radical's confines, Daniels helped machine a transmission mainshaft to fit the new pancake motors.

Cooling control

The motor came with several batteries, and the one chosen was the 600V unit used in the aforementioned P002. However, this lacked adequate cooling apparatus for longer runs, and Hilleman had to plan for accumulated heat over the day.

'I had a hot pack and my test driver, Enzo Prevost, had a cool one. The battery pack just doesn't disperse heat very well because you've got a big stack of batteries sitting on top of each other and minimal airflow over them,' Hilleman explains.

A rudimentary approach perhaps, but one which helped start a deeper understanding of heat management in electric racing.

'EV racing is about thermal management in three specific places: the battery, the motor and the inverter / controller. How these areas accrue and discharge heat over the course of the race dictates pace more than any other factor. If you understand the systems well, you can drive so as to equalise heat across the entire system. Lifting and coasting, using more or less regen', or altering throttle and brake inputs will drastically affect the system's overall stamina,' he notes.

'EV racing is about thermal management in three specific places: the battery, the motor and the inverter / controller. How these areas accrue and discharge heat over the course of a race dictates pace more than any other factor'

Richard Hilleman

'Because the inverter is heat reactive to constant loads and the motor is heat reactive to peak loads, throttle application can be altered to move heat from one area to another. For example, a smoother throttle application out of the corner will transfer heat from the motor to the inverter. A more forceful throttle application will transfer heat from the inverter to the motor.'

Energy transfers, regardless of their direction, have an impact on the battery. 'When you pass electricity through a battery, either in or out, the resistance from the cells creates heat – something like one to two per cent of the total amount transferred. So, if you're pulling 300kW out of a battery, you inevitably produce about 3kW of heat in the process.'

In order to appreciate the ideal rate at which a battery should be discharged to maximise performance over the course of an afternoon, two terms need defining. There is the C-rating of the battery, or the discharge rate relative to a battery's nominal (or rated) capacity. The nominal (or rated) capacity is the amount of energy that can be withdrawn from a battery at a particular constant current beginning from a fully charged state.

'Essentially, you want to keep the discharge rate below the C-rating of the battery for as much time as possible. A higher discharge current than the C-rate at which the nominal capacity was determined will result in lower capacity removed from the battery before it is fully discharged. For a 32kWh pack, that rate is about 40A. Whether it's charging or discharging, as the current rises, some of the energy is lost to heat,' Hilleman explains.

With a working car at his disposal, and many small items still to address, Hilleman sought out a sanctioning body to support his brainchild. Not only did it have to welcome new technology, it had to offer both time trial and sprint racing classes to better understand the powertrain's limitations.

'I chose NASA (National Auto Sport Association) because they gave me a home. I believe the old spirit of Can-Am, of open-class racing, lives on through them.'

Driving an electric vehicle forces a driver used to combustion engines to do more than just manage temperatures, and Hilleman's test driver, Prevost, adapted his technique to the system's regen' demands quickly.

In order to run the full 20-minute sessions in time trials at Sonoma, a track with moderate braking demands, Prevost softened his brake application.

Driving experience

'Full digressive braking didn't harvest energy as well as a linear ramp rate would. This lengthened the braking zones, but it definitely helped charge the battery, and that made the biggest net difference in regards to lap times,' Prevost elaborates.

The powertrain could, however, simplify the driver's role in other areas. Prevost was pleased to see the SRe worked better in high-speed direction changes than the four-cylinder SR3, a car in which he'd logged many laps. Even with its wings trimmed, the SRe was more stable, since it did not require mid-corner upshifts – the beauty of a single-speed gearbox. He could therefore avoid inducing that momentary driveline shock while the car was laterally loaded in the middle of Sonoma's high-speed, turn eight chicane.

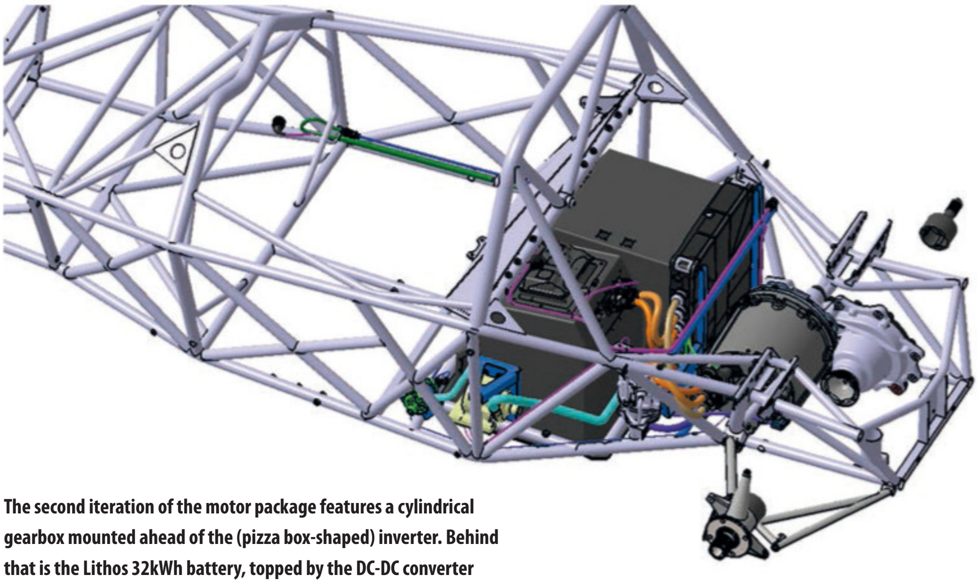
When Cresci piloted the SRe in a short race at Laguna Seca, the day's schedule and his race length made it possible to disregard regeneration and go flat out. Interestingly, he found he managed the inputs in a very similar fashion to when he drove the SR3, with one exception – throttle tip-in: 'I was a little more progressive with the throttle due to the extra torque, but that was it,' he notes.

Despite the apparent similarities, though, Cresci admitted to finding the experience of driving an electric racer alien.

'I realised then how much I'd depended on a combination of shift points, revs and vibrations from the engine to get a sense of speed. Without those, I had to rely more on my vision and my reference points to get a better sense of how quickly I was going.'

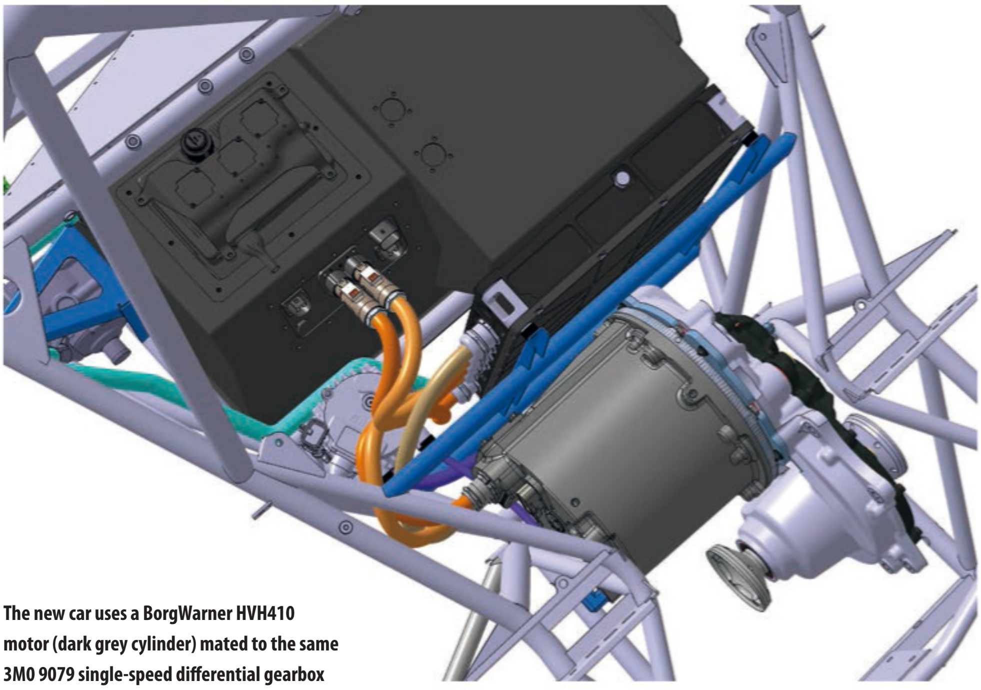
In late 2018, Hilleman took the SRe to the NASA Nationals to compete in the Time Trial Unlimited class, in which he took seventh. The car continued to run dependably for three years until a miscalculation led to its demise.

After Hilleman prepped his batteries with an eight per cent margin for a 12-lap race one weekend at Sonoma, the front runners' unexpected pace extended the race distance by another lap. His 12V battery had fallen below the point where it would hold the contactors closed and, on the 13th lap, the main relays opened and the car slowed as he crested the blind turn three. The car behind could not stop in time and punted Hilleman almost 25 metres down the track. He emerged unscathed, but the SRe needed a new powertrain, a new frame and bodywork.



Richard Hilleman

The second iteration of the motor package features a cylindrical gearbox mounted ahead of the (pizza box-shaped) inverter. Behind that is the Lithos 32kWh battery, topped by the DC-DC converter



Richard Hilleman

The new car uses a BorgWarner HVH410 motor (dark grey cylinder) mated to the same 3M0 9079 single-speed differential gearbox

Richard Hilleman

Hilleman's Rattlesnake Electric Sport and Radical SRe have opened a lot of people's eyes to the potential of an electric club level racer

> **With the [charging] network a fixed variable, future improvements to the SR3 will likely come from perfecting current systems, improving race day strategies and waiting for the aftermarket to innovate what Hilleman cannot**

Hilleman kept the winter blues away by going back to the drawing board and rebuilding his damaged Radical with a new Cascadia controller, Borg Warner HVH410 motor, Lithos 32kWh battery and the 3M0 9079 single-speed differential gearbox built specifically for the motor. At the cost of another 32lb (14.5kg), the new package improves stamina, adds 100bhp and raises the car's top speed from 100 to 112mph.

'The new powertrain doesn't have a total loss 12V battery. Instead, it has a DC-DC converter, which provides a solid 13.5V at 100A to run the rest of the car. This ensures it won't shut down on track again.'

Richard Hilleman

After the unfortunate incident at Sonoma, Hilleman rebuilt the car with a new chassis and improved powertrain with DC-DC converter

Richard Hilleman

The second iteration of the SRe weighs 14.5kg more than the first, but has an additional 100bhp and a 12mph higher top speed

Hilleman's improved cooling system functions similarly to a cool suit but with six times the volume, using dry break hoses to cycle 3M Novec, a non-flammable, non-conductive fluid, through the system, which keeps the battery temperature below ambient prior to leaving the pits.

Day rate

When running in time trials, Hilleman's main concern now is ensuring he has sufficient power to carry him through the day. The local charging rate determines his daily run plan but, for example, the 6kWh charge rate he can expect at Sonoma allows him to put in an out lap, a single hot lap, a cool down lap, another hot lap and an in-lap. Such a schedule allows him to recharge between sessions and maintain optimum performance across an eight-hour day of running.

'Before we figured out an ideal schedule, we waited for our 'happy hour', when the track temperature was ideal, usually some time in the late afternoon,' he says. 'There were two distinct advantages to this: finding a clear lap was easier with fewer cars out, and our car would accelerate better. Because we didn't need a denser intake charge, track temperatures were our deciding factor.

'Plus, we were already trimming the wings to minimise drag, so we didn't suffer from reduced downforce. Hotter ambient temperature means thinner air, which means better acceleration.'

While several circuits in Northern California have introduced commercial Series 2 chargers (capped at 19.2kWh), the charging infrastructure in North America cannot support unfettered competition yet.

Future evolution

With the network a fixed variable, future improvements to the SRe will likely come from perfecting current systems, improving race day strategies and waiting for the aftermarket to innovate what Hilleman cannot.

In the meantime, to better understand the intricacies of the technology currently available to him, Hilleman has built a simulator using the same ECU as the SRe to practice his energy strategies.

'I practice at maximum power and adjust regen' until I find a better strategy, including yellow flag scenarios and the like so I have a few options in any given situation and I have to do less mental arithmetic in the car.'

Thanks to the input from a few brilliant minds, in less than a decade, a dream revolving around a golf cart battery-powered go-kart has blossomed into a remarkably fast and versatile club racer that has opened many North American eyes to the potential of the EV. Rattlesnake Electric Sport and its Radical SRe has set a new standard at national club racing level, and it's still early days.

Cell mates

Racing fuel tanks have not changed significantly in over 20 years, but there have been incremental improvements, particularly as new fuel types arrive on the scene

By LAWRENCE BUTCHER

The humble fuel cell (the petrol holding device rather than the proton exchange membrane, hydrogen-eating type) rarely makes it into the headlines unless something spectacular happens. Romain Grosjean's fiery escapade at the 2020 Bahrain Grand Prix being the perfect example. Most of the time the unsung hero that is the fuel cell goes about its business, keeping drivers safe from an inferno, despite being subjected to incredible forces during high-speed crashes.

It is a testament to the high specification of fuel cells that the regulations governing their construction have remained largely unchanged since 1999. That's right, FIA standards FT3, 3.5 and 5-1999 have been around for a quarter of a century, but work is currently (albeit slowly) under way to update the standard, as detailed in the sidebar on p57.

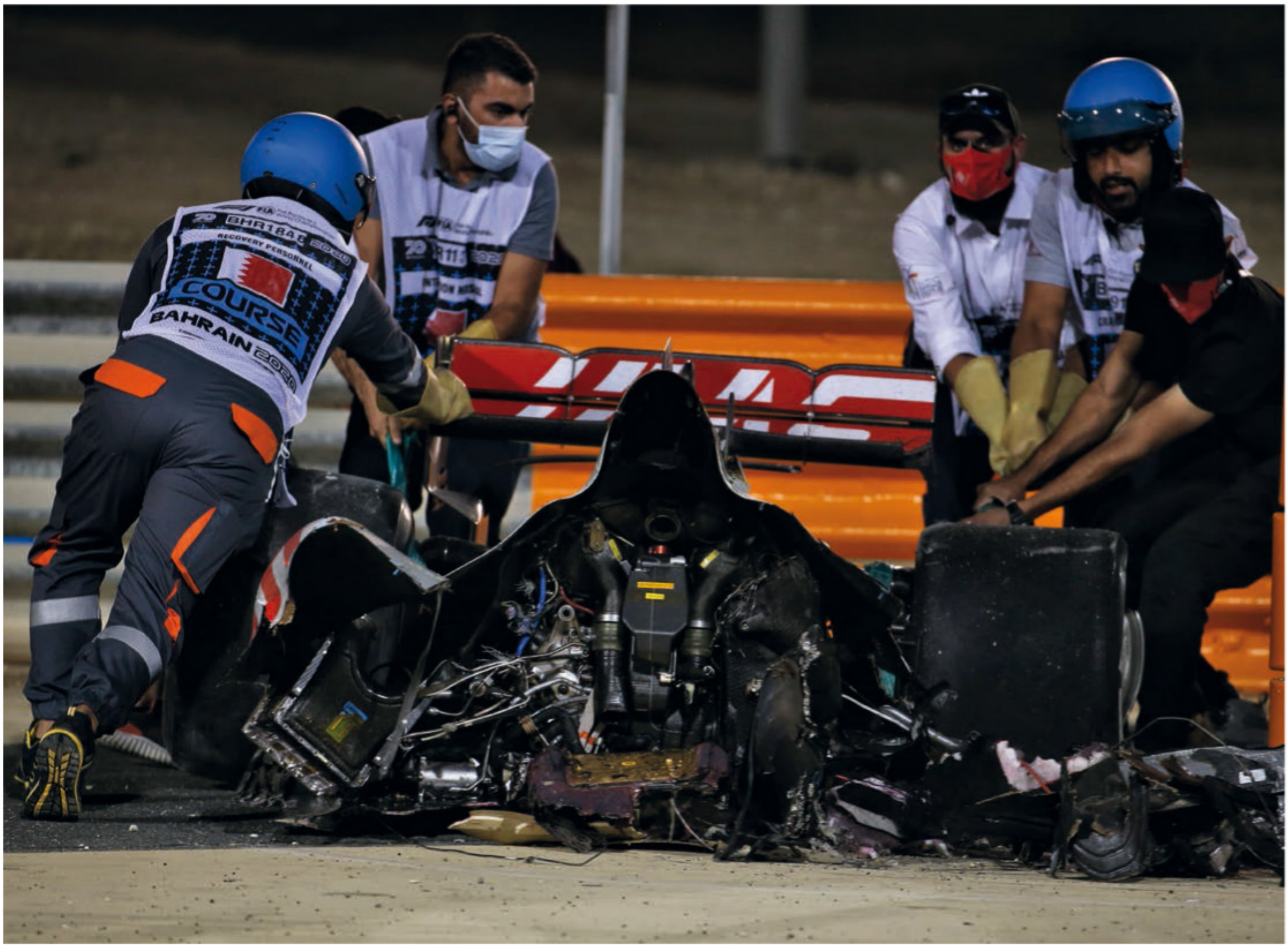
A history of safety

Scroll back 60 years, however, and fuel tanks used in racing were simple aluminium structures with a few internal baffles to control slosh. Any crash severe enough to rupture the tanks almost guaranteed a fire. Bladder-type, or flexible, fuel tanks were in existence, pioneered for use in military aircraft, and some teams did start deploying them in the 1950s, but it would not be until the 1970s that the FIA mandated their use in Formula 1, and even later across lower formulae and other racing disciplines.

Across the Atlantic, Indianapolis 500 organiser, USAC, was ahead of the curve developing safety measures to minimise the risk of tanks splitting, and resulting fires. In the mid-1960s, it set out to find a safer means of fuel storage on racecars and enlisted the help of the Firestone Rubber Company, which was producing bladder fuel tanks for aircraft.

Interestingly, the result of the research and development project (covered in a period safety film called *Ounces of Prevention*), was not a bladder tank, but rather a foam filling, which could be used with any tank type.

Firestone found its solution to minimising the chance of ignition of fuel with the Scott paper company, which produced a reticulated polyurethane foam – later dubbed safe foam.



The investigation following Romain Grosjean's crash at the 2020 Bahrain GP concluded the impact ripped a fuel cell inspection hatch and supply fitting out of the tank, which led to the fire

It may look like a crumpled bag, but this Proflex Formula 1 fuel tank is designed for maximum efficiency in the limited space available

Modern racing fuel cells are largely bespoke items, produced for specific vehicles. This Proflex cell fits an Audi GT3 car

Above and below: two further examples of Proflex Formula 1 fuel cells, showing subtle modifications to the design to fit different chassis.

The effect of the foam when inserted in a tank was to prevent the formation of an explosive fuel-air mixture and stop any flame reaching liquid fuel, without inhibiting flow of fuel to the pumps and, at the same time, mitigating slosh in the tank. To this day, the latest variants of reticulated foam are used in many, though not all, racing fuel tanks.

By the early '70s, the FIA took notice and a 1969 safety study referenced the developments made by USAC and its standards for bladder tanks, replete with reticulated foam filling. At the time, USAC-compliant tank construction used a woven 'bag' made from nylon or 'Dacron' impregnated with fuel resistant elastomer, enclosed in either a steel (0.5mm) or aluminium (1.5mm) housing.

The idea of using a flexible bag of tough fibres was that it would deform rather than rupture in the event of an accident. The only major issue was ensuring resistance to puncture, a very real possibility given that most cars at the time still carried their fuel in exposed, side-mounted tanks.

It was Colin Chapman who pioneered the use of a single large tank, rather than several smaller tanks, mounted behind the driver in the Lotus 79. The development was an inadvertent safety advance resulting from a performance-related change, as it removed the possibility of link pipes and unions between tanks failing in an impact.

The idea of using a flexible bag of rough fibres was that it would deform, rather than rupture, in the event of an accident. The only major issue was resistance to puncture

Recent advances

The general principles of racing fuel tanks have remained almost unchanged since those innovations of the 1960s and '70s, though the concept has been greatly advanced with the advent of new reinforced tank materials, almost completely mitigating the puncture issue, and ever more complex designs.

Moving to the current day, the past 40 years have seen many refinements in fuel tank construction, while the use of new materials such as ballistic nylon, Aramid and oriented polyethylene materials have added remarkable toughness without reducing the deformability of racing bladder tanks, necessary in many cases to permit installation through small access flanges in chassis.

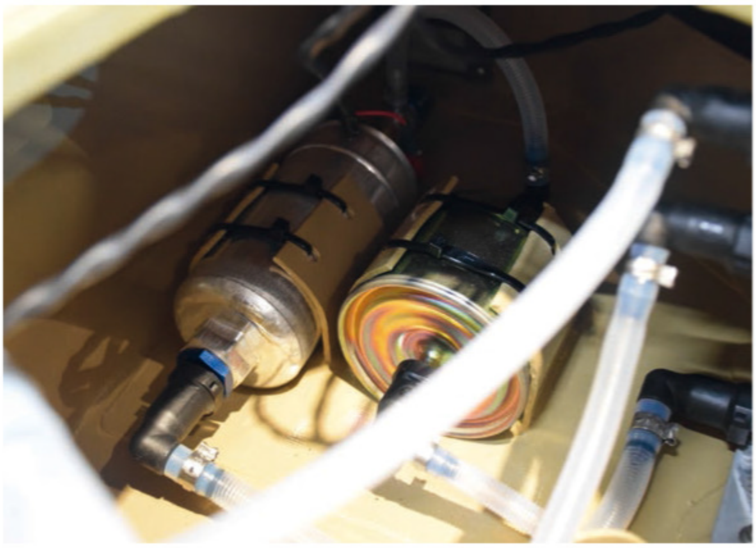
The development of improved fill and vent roll-over valves, and more effective safety foams, have all contributed in reducing the occurrence of fuel spills, fires and explosions in motorsport across the globe.

Tanks built to the highest FIA FT5 are used in major series such as F1, IndyCar and the FIA World Endurance Championship. The materials used to construct these cells must have a tensile strength greater than 2000psi and are subject to exceptionally stringent tests to measure resistance to puncture and shear loadings, with samples being immersed in fuel for at least 75 hours prior to testing.

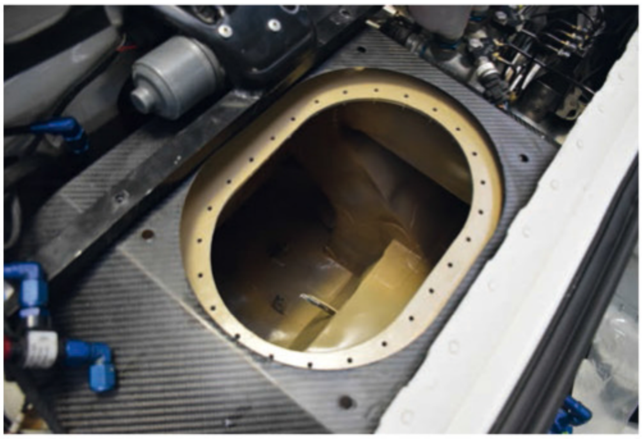
'The strive for performance is equal across the motorsport spectrum,' says Giles Dawson, CEO of Aero Tec Laboratories (ATL). 'The difference is resource led. In F1, weight is everything, but in WEC, for example, the focus is far more on cost effective development.'

To keep fuel cells light in weight, yet still meeting the required standards, producers have introduced new, high-strength fibres and developed means of plying, twisting, tie-coating, impregnating and corona treating

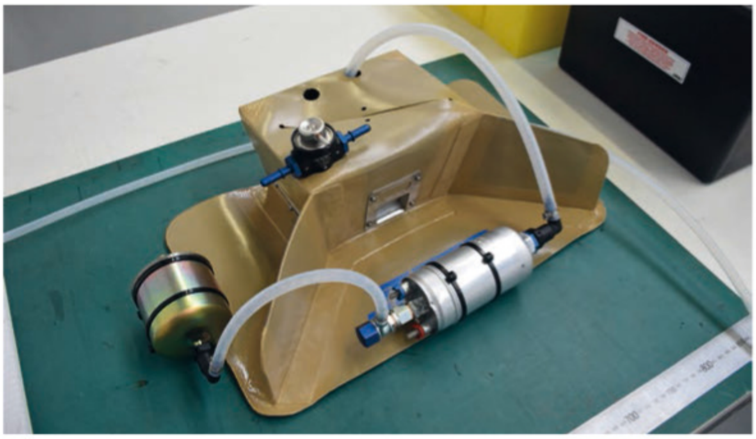
This cutaway of an ATL tank shows the inner compartments and reticulated foam filling



Almost all motorsport tanks now feature high volume, submersible lift pumps. This is a BTCC car unit



Most tanks also need to have an inspection hatch so pumps can be serviced or replaced



Ensuring every drop of fuel is available to be used in a race is the job of the collector. Here an ATL design

the yarns to derive remarkable puncture strength from bladders that are both lighter and thinner than their predecessors.

Even for the lower specification tanks used in other series, built to comply with FT3 and 3.5 standards, there are constant performance evolutions, as Kevin Molloy of Proflex Fuel Tanks, explains: 'There are combination nylon-based fabrics available, but we also use Kevlar in FT3-approved tanks; the strength is the same but the tank is a lot lighter.

'Some teams chose Kevlar purely for the weight, but it is also more flexible. That can be a real benefit, for example, in a historic racer where you need to squeeze the bladder through a small aperture.'

Dawson agrees. 'There have been some really interesting advancements happening at F1 level,' he says. 'Leading up to 2024, we made significant progress in driving down weight. This has been possible with new materials, but also the introduction of innovative new manufacturing techniques. Looking to the next 12-18 months, you'll start to see another significant leap forward in the use of even stronger, lighter and higher-performing materials.

'What is really exciting, though, is being able to cascade these new materials down into lower formulae. One of the three key objectives of the development has been enhanced compatibility with renewable and synthetic fuels.'

Each fuel cell manufacturer works with their own materials supplier to develop bespoke products. For instance, additional coatings can be added to the fibre yarns to reduce the level of fuel permeation through the tank. Similarly, the elastomer blends can be tailored to improve abrasion resistance.

'It's about finding the sweet spot, more or less abrasion resistance, keeping it thin, keeping it lightweight, but also still cost effective,' says Molloy.

While the primary purpose of the fuel tank is to keep its contents safe, it also has an important role to play in vehicle performance.

While the primary purpose of the fuel tank is to keep its contents safe, it also has an important role to play in vehicle performance

At a basic level, it must ensure fuel is always available to the engine, in addition to which the packaging of the tank, and its location within the chassis, are critical considerations from a vehicle dynamics and aerodynamics angle.

With package space at a premium, those responsible for designing the fuel tank are expected to fit it in the smallest volume possible, even if the shape of that volume isn't ideal for fuel distribution. The aim is to ensure that only the fuel necessary to complete a race distance, plus any sample required by regulators, is carried. The tank design must therefore be such that every drop of fuel can be picked up by the pumps.

Structural design

The layout and structure of the compartments within will therefore be carefully optimised using CFD to simulate the movement of fuel under representative accelerations, with the flow between compartments often controlled by one-way flaps. Molloy does caution that in series where refuelling speed is also important, the inner structure mustn't restrict incoming fuel flow: 'You wouldn't put a catch tank at the entrance from the filler neck, for example,' he notes.

Multiple low-pressure lift pumps will be placed in strategic positions around the tank to ensure consistent fuel pick up. In most applications, these pumps are now brushless units controlled using pulse width modulation (PWM), which allows for their speed to be precisely varied with the motor controller. These lift pumps normally feed into a smaller volume catch tank, while a larger lift pump will feed the fuel to the engine.

Sustainable fuels

The past decade has seen the arrival of new fuel types in racing, featuring bio-content and, latterly, full synthetic fuels. Fuel tank suppliers need to account for these fuels in the development of their tanks, though it is notable that the FIA standards for homologating tank materials still use regular petrol (gasoline) as the 'control' fuel.

'The landscape for synthetic fuels is ever changing and will gather pace as we head towards a carbon neutral future,' says Dawson. 'There has been some focus over recent years on understanding the effects of current and future fuels by the FIA, and we have played a part in assisting them in their understanding, but at this point we are driving development through our vision of where things are going.'

'The landscape for synthetic fuels is ever changing and will gather pace as we head towards a carbon neutral future'

Giles Dawson, CEO at Aero Tec Laboratories (ATL)

The ethanol content in bio-fuels, for example, is notoriously aggressive towards components such as rubber seals and tank liners, so bladder manufacturers must ensure the fuels being used in their products in no way compromise the integrity of the cells.

'The construction methods aren't impacted as such,' adds Dawson. 'It's more consideration for the effect of high ethanol content fuels on seals (static and dynamic). This was first felt in the FIA World Rally Championship with the expansion of Viton seals when exposed to synthetic fuels. Mixing, or alternating, fuels can also drastically reduce the life of tank internals, and certainly increases the degradation of baffle foam when fuels of differing polarity are used.'

Changes in regulation to account for new fuels have a knock-on effect on racers, too.

'The challenge is supporting the regional ASNs as new regulations are introduced into championships,' says Dawson. 'When you look at the changes needed to some of the component... for example, the cost of a dynamic seal in Viton A vs perfluoroelastomer needed for many of the new fuels can be more than 10 times as much, so the seal can be more expensive than the component, and that is hard for customers to understand.'

Similarly, changing to new blends of synthetic elastomers for use in bladder construction, which are immune to even the most aggressive fuels now on the market, has a significant cost implication.

According to Molloy, Proflex's current advice to customers is to flush tanks filled with biofuel using regular E5, and to not leave them standing for long periods.

'If a customer asks if they can use 100 per cent biofuel in one of our tanks, all we can do is give them that advice and say the tanks are only homologated with the FIA test fuel.'

As with so many aspects of motorsport technology, development of fuel cells is in the incremental improvement stage these days. However, there are still issues to be addressed and, to keep the excellent safety record, new standards need to come sooner, not later.

Future safety changes

Following Romain Grosjean's fiery 2020 crash, the FIA set up a research project to see where the current FT-1999 regulations could be improved upon. In that example, it was determined that the force of the extreme impact with the metal barrier ripped both a fuel tank inspection hatch and the engine supply fitting out of the fuel cell, allowing fuel to escape.

In April 2021, the FIA held an Industry Working Group meeting to lay out areas of research for formulating new fuel tank regulations. These would draw on the lessons of both Grosjean's crash and others, while also updating the testing procedures and standards to suit the very evolving demands of racing, and the fuels now in use.

The research looked at the effect of different bio and synthetic fuel types on tank materials, while also investigating the impact of fuel and elevated ambient temperatures on tank integrity. The proposed standard also suggested materials should be more rigorously tested, with a minimum tensile strength of those used in FT5 tanks set at 8.9kN, with the same requirement set for the seams between material sections.

Further improved tests for puncture and abrasion resistance were also proposed, as well as new tests to ascertain permeability of the materials. Coupled with the revised tank construction regulations, the development of new standards for installation of tanks in vehicles were also within the remit of the project.

The FIA has been working with all the major fuel tank suppliers in formulating these new regulations. However, despite a timeline issued during that initial meeting suggesting the standard be released by the end of 2021, they are still yet to appear. *Racecar* approached the FIA for comment on the current status of the project for this feature but the federation had not responded at time of writing.

Romain Grosjean's fiery crash at Bahrain International Circuit in 2020 caused a research project to be launched by the FIA, but updated fuel cell regulations have still yet to be released

Going for gold

Within the depths of Toyota's factory racing headquarters, a band of engineers is producing equipment for Paralympic medal contenders

By DANIEL LLOYD

Activities at the Toyota Gazoo Racing Europe (TGR-E) headquarters in Cologne mainly focus on the Japanese company's factory racing programmes in rallying and sportscars. However, behind those loud and proud halo projects, a small band of engineers is working away in the background on a niche mission that has delivered wins at one of the world's biggest sporting events.

For 12 years, TGR-E has housed a parasports division, responsible for developing racing wheelchairs, handbikes and prosthetic limbs for Paralympic athletes.

At the 2016 Games in Rio de Janeiro, Germany's Andrea Eskau won gold in the H5 category road race aboard a handbike fitted with a seat insert developed in Cologne. This summer in Paris, Eskau will go for Paralympic gold again using Toyota's updated version of the handbike, which uses motorsport engineering techniques and expertise. Last summer, she used it to win the H5 time trial at the Euro Para Championships in Rotterdam.

Toyota isn't the first motorsport or automotive manufacturer to be involved in parasports. Honda has been developing racing wheelchairs since 1993, introducing a carbon fibre tub in 2002 and starting a commercial business in the last decade.

BMW's North American car division worked with the US Paralympic team to develop racing wheelchairs and Italian motorsport constructor, Dallara, built the carbon fibre handbike in which two-time CART champion, Alex Zanardi, won three medals (two gold, one silver) at London 2012 and Rio 2016 respectively.

Companies such as these, with experience in the production of lightweight and strong components, are a natural fit for parasports, especially the wheeled disciplines. This is

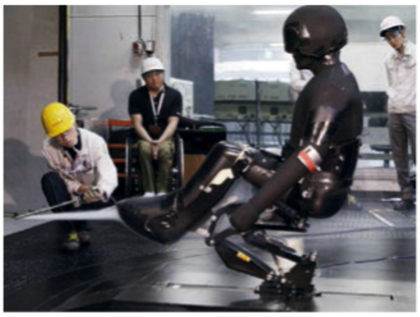
TGR-E

Three examples of TGR-E parasports projects: Andrea Eskau's latest handbike (left), Alhassane Baldé's racing wheelchair (back) and a Nordic ski sled for Eskau's winter programme

Toyota

The motorsport engineering influence is clear in the design of Andrea Eskau's handbike that she will use in Paris this summer

Toyota



TGR-E

Toyota's European motorsport hub in Cologne is well known for its factory and customer racing operations, but less so its parasports work

Eskau's Nordic ski sled behind one of two Winter Paralympic gold medals she won at Pyeongchang 2018

Parasports is a way of showing the versatility of TGR-E's motorsport engineering facilities

because parasports athletes require high quality, bespoke equipment that moulds to their physical requirements and enables the peak of their physical strength to shine.

For Toyota, parasports is small fry compared to its big budget factory motorsport programmes. There isn't a department dedicated to such projects at Cologne; its engineers have full-time jobs in other parts of the TGR-E company and dip into parasports work as and when required.

'It's really a case-by-case project, depending on an inquiry, or an athlete who has a certain request and, of course, depending on available capacities on the design and production sides,' says Norbert Schäfer, project manager of TGR-E parasports. 'The good thing is that all our projects have, and had, top management back up. With certain exceptions, I think we can say we have a freedom to work in a concentrated way and be straightforward on the projects.'

The core parasports team at TGR-E consists of around 15 people, from departments such as design, CNC machining and composites. Central to each project, though, is the athlete, whose physical requirements and preferences are at the heart of developing comfortable, adjustable and manoeuvrable equipment.

Companies such as these, with experience in the production of lightweight and strong components, are a natural fit for parasports

Chance encounter

TGR-E's parasports venture started in 2012 with Eskau, who has been paraplegic since a bike accident in her 20s. The partnership began with a chance encounter: Eskau lived on the same road as a TGR-E employee (when it was called Toyota Motorsport GmbH) and highlighted some issues with her handbike at the time. During subsequent meetings at the factory to produce a new seat insert, Toyota learned that Eskau was also a successful Nordic skier. The two parties started looking at ways of improving her ski equipment and ended up developing a new sled. Eskau went on to win three Winter Paralympic golds with her Toyota-designed equipment, one at Sochi 2014 and two at Pyeongchang 2018.

'She showed us some pictures of her [original] sled,' recalls Schäfer. 'One of our colleagues gave the comment, "It looks not so bad… but we can do better." The team in the composites department spent their private time, mainly, to quickly design and produce the first Nordic skiing sled made from carbon fibre, using some special components to create a one-off for her, which made her quite successful, to be honest. That was the start of the business.'

Schäfer runs the commercial side of Toyota's parasports programme, serving as the link between the engineers and the rest of the company's motorsport business, as well as the parasports regulatory bodies.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TGR-E

'The old handbike with massive wheels at the rear is something we wanted to avoid. We wanted to deliver something with a lower c of g and much neater, compact packaging'

Roger Kirschner, lead engineer at TGR-E parasports

Eskau's current handbike has much smaller rear wheels than its predecessor, helping to improve its handling characteristics and shortening the wheelbase to increase stiffness

The technical side is spearheaded by Roger Kirschner, a senior composite design engineer at TGR-E. Kirschner, was born with the left side of his body paralysed, has gone on to have a long career in motorsport, including stints as an aerodynamics engineer for the Sauber and Toyota Formula 1 teams.

'What is crucial is that there is a strong link between the athlete and me,' he says. 'When I have their opinion, I cast this into a first concept. I always go to the dedicated departments, especially from production, and say what I would like to do. They explain if I need to do it [differently]. I then make a second concept and take that into 3D design. Then, we release the components.

'We make sure we have their opinion, to allow us to use new techniques, such as machining components more efficiently.'

The TGR-E parasports programmes obey the same organisational philosophy as Toyota's factory motorsport projects, in terms of parts design and production.

'It's the same professional way of project management: initiation, feasibility, briefing, kick-off, second round, concept and so on,' adds Schäfer. 'What we are doing here, in Paralympics, is absolutely the same as, for example, the door or seat of a racecar. We are using really up-to-date motorsport engineering experience, equipment, materials, design background and empathetic capabilities to discuss on a perfect level with the athletes. If we combine all this in a proper way, the outcome should be almost perfect.'

This means Kirschner's team can react quickly to an athlete's request, for example if they experience discomfort in one area.

At this year's Paralympics, two athletes will be using Toyota equipment designed at the company's motorsport factory. Eskau will bid for a fifth career gold medal in hand cycling, while Tyrone Pillay will represent South Africa in men's shotput. Pillay, who works as an IT technical manager in Toyota's South African regional office, uses a prosthetic carbon fibre left leg that TGR-E produced last year.

Racing systems

More analogous to motorsport, though, is Eskau's handbike, not least because it's used for racing. Most of the components, except the chain, gear shift system and wheels, have been designed and built in-house at TGR-E.

Development of Eskau's latest handbike started in 2018 ahead of the Tokyo Paralympics that took place in 2021. It replaced the previous model in which she won gold in the H5 road race at Rio de Janeiro.

'What we are doing here, in Paralympics, is absolutely the same as, for example, the door or seat of a racecar. We are using really up-to-date motorsport engineering experience, equipment, materials [and] design'

Norbert Schäfer, project manager of TGR-E parasports

Despite it being successful, Eskau's old handbike suffered from high-speed instability and was difficult to handle in the corners. Kirschner and his colleagues went to the suspension department at TGR-E to re-design the trailing arm for the wheel, which opened the steering angle and reduced its turning circle by three degrees. The updated version also featured adjustable steering damping and force feedback, while its weight was reduced by 19 per cent, from 12.2kg to 9.9kg.

'If the handbike is stable in a corner, it is also stable in a straight line,' says Kirschner. 'Packaging-wise, the old handbike with massive wheels at the rear is something we wanted to avoid. We wanted to deliver something with a lower c of g and much neater, compact packaging. The rear wheels are now lighter and better to package. You can put them closer to the [athlete's] arm, and reduce the overall length of the handbike.'

The rear wheels on the updated bike carry more negative camber than the previous version, too. This is to match the natural camber of Eskau's arms as she propels the bike, leaning forward and using the hand grips. Smaller wheels helped reduce the wheelbase, contributing to the weight reduction and increasing structural stiffness.

TGR-E also modified the front section of Eskau's seating compartment, bringing the monocoque closer to her body for a tighter fit, while still keeping the seat adjustable. According to Kirschner, Eskau is able to take corners at much higher speeds than before.

Olympic and Paralympic events are about showcasing individuals' pure strength, harking back to the event's ancient Greek origins.

Parasports, on the other hand, introduces engineering into the mix. In motorsport, engineers focus on making things faster, lighter and more compliant. By applying this approach to a handbike, or racing wheelchair, how much of the individual's performance can be deferred to technology?

The answer should be none, if you consider that rules are in place to ensure the athlete is what makes the difference. The broad category of para bike racing follows the same equipment regulations as the UCI, cycling's global governing body. The UCI's overarching stance is that, for road racing categories, 'no technical innovation may be used until approved' by the federation.

Rules to obey

While handbike racing has the benefit of an Olympic counterpart that also uses machinery (cycling), wheelchair racing as a form of athletics does not. Bespoke regulations define what can be done technically there. Mechanical gears and levers for propelling the wheelchair are banned, as is the use of fairings or other devices for aerodynamic purposes. Only hand-operated mechanical steering devices are allowed. No element of a wheelchair, or attachments, can incorporate energy storing capacity, such as elasticity, to enhance performance.

Devices built to aid aerodynamics are also banned in handbike racing, though this presents a grey area with regards to other parts of the handbike. Aero might not be as important here as in a racecar, but handbikes can go surprisingly fast in a straight line. According to Kirschner, speeds of up to 100km/h are achieved on certain downhill sections in favourable conditions.

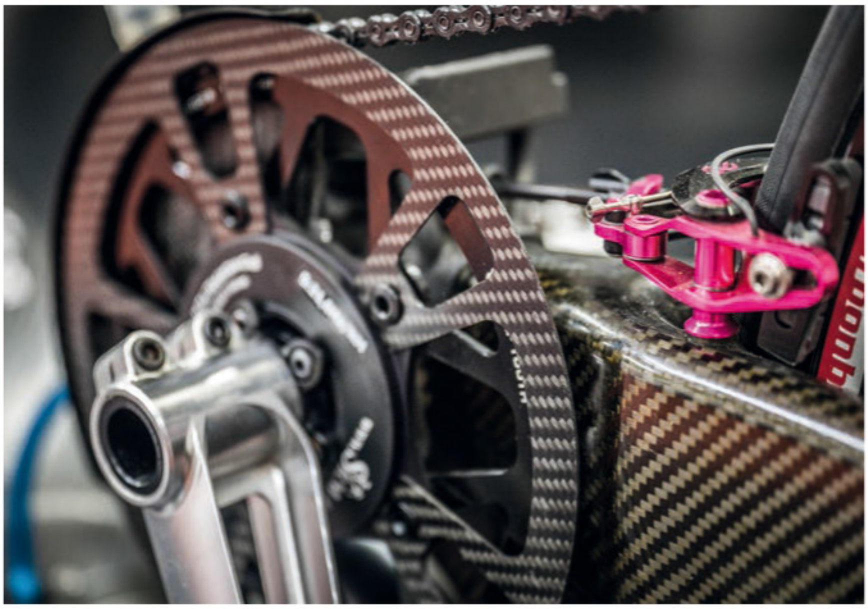
'In the regulations, it says that if a device has one purpose and that is to be aerodynamic, it is forbidden,' he says. 'But if you have a lever for the steering, it can *look* aerodynamic. So, you must balance this right.'

TGR-E has an aerodynamics department at Cologne, and Kirschner acknowledges that the people there can be a useful resource for the parasports team, even if they can't design any purpose-built items for the handbike.

'Of course, they can give their opinion,' says Kirschner. 'Maybe we should open or close an area, make a corner sharp or rounded. There is nothing wrong with this. It is just aero efficiency from a theoretical point of view. Putting devices into the wind tunnel for hours is too much for us. Not because we cannot do it, but because our understanding is this is not how it should be done.'

The power of stiff

In creating Eskau's new handbike from carbon fibre reinforced plastic (CFRP), Kirschner's team sought to increase the structure's stiffness to best support her physical input.



TGR-E

The team worked with TGR-E's composites department to develop Eskau's handbike with low weight and high stiffness

This was seen as more important than reducing the handbike's weight. Creating a lightweight handbike did result in less mass for the athlete to propel, but stiffness reduces as weight comes down, so there was a delicate balancing act at play. Drawing on TGR-E's existing in-house composites expertise, the parasports team set to work on the handbike's geometrical properties.

'Here, performance is driven more by the pure stiffness of the product,' explains Kirschner. 'The power the athlete can give is limited. In the end, the stiffer product should lead to more transition [of strength] into speed. With speed, you are more competitive.

'Stiffness is the key. It is usually done by geometrical stiffness and not the choice of material because you use carbon where possible. Carbon is very low on flexing, but in a racing wheelchair, the geometry will allow the beam to flex. Usually, people misunderstand, saying that by using carbon you will make it stiff. This is wrong. It's about geometry. Of course, carbon will contribute to this, but not in the way that geometry is.'

Safety is also a key factor in the handbike's design, considering the high speeds that can be achieved. Crash testing of the TGR-E handbike was not feasible, due to financial reasons more than anything, but Kirschner and his colleagues carried out finite element analysis (FEA) to ensure the structure would protect Eskau in the event of an accident. This also highlights one of the key differences between para cycling and its Olympic cousin.

'They are sitting in a monocoque,' he explains. 'If you compare this to a motorcycle, or bicycle, the idea is different. In a crash, you try to disconnect the rider from what they are riding. We don't have this. We have them encapsulated in the monocoque, like our racing drivers, so we have to make sure they are well protected.'

'Stiffness is the key. It is usually done by geometrical stiffness and not the choice of material because you use carbon where possible'

Roger Kirschner

Contribution to racing

The development of Eskau's handbike, and the other parasports equipment that TGR-E has made, has been possible due to the existing motorsport engineering practices at Cologne. However, the benefits don't just flow in the direction of Kirschner's team.

The parasports division has a part to play in helping Toyota's sportscar and rally programmes, through its ability to take on the risk of small-scale prototype parts and engineering processes. If they are successful in producing a part for the handbike, they can be applied in the manufacturing department for racecars, on a larger scale. It's a feedback loop of sorts: parasports uses the rapid production capabilities of the motorsport department to develop its parts and can be the guinea pig for new methods or components that could benefit the race teams.

'Paralympics can always say, let's go for that, we'll test it,' says Kirschner. 'We have no problem with this. For example, machining a part from both sides using a new technique developed in the production department was used for the first time in Paralympics. When it proved a success, it went into things such as customer and works motorsport.'

Kirschner can't give all the details of the technique parasports devised and tested, since it may yield a competitive advantage.

'Imagine you need to machine a component on one side, and then you need to flip it over, onto the other side,' he describes. 'When you flip it over, you need to have a reference, a jig. But we have a different method to do this, which is very efficient for us. We came up with this in-house, the production guys then developed the idea and we, as the Paralympic team, jumped on that opportunity to try it.

'The first time we did it was on the handbike. And the racing wheelchair immediately had the same [technique]. This is something that spread out through all the projects in the company.'

Growth limited

Toyota's parasports projects have helped its athletes achieve success in their respective fields. Schäfer says he would love for it to expand into a commercial business, selling handbikes, prosthetics and other specialist equipment on a wider scale, but the nature of the parasports division is not conducive to such growth. For one, it works on designs tailored to an individual's requirements. Also most of its project members are working for other TGR-E engineering departments already. Some serious re-structuring would be required if parasports was to expand beyond its current form.

'The number of athletes who would fit perfectly from motivation, age and personal viewpoints into such a project is quite limited.

TGR-E

The user of a TGR-E parasports product is treated as the 'engine', with everything else designed to seamlessly integrate

> **'Paralympics can always say, let's go for that, we'll test it'**
>
> *Roger Kirschner*

I think it will stay as a case-by-case [basis] in the future,' reckons Schäfer. 'The idea is really to even more establish a Paralympics team to always be present, one that is embedded in the strategic mobility thinking of TGR-E.

'Even though our main DNA is motorsport, we are well known and well received in this business. Also, the Toyota organisation is now more aware about the possibilities and positive impacts from a marketing point of view.'

Even if a commercial expansion of TGR-E's parasports activities is currently out of reach, the small group of engineers seems to thrive on its underground reputation. When called upon, it has a small but significant part to play in the operation of Toyota's racecar manufacturing activities. It also showcases the diversity of motorsport engineering processes in a different sporting arena.

While most at Toyota will be eyeing up titles in the FIA World Rally Championship and FIA World Endurance Championship this autumn, a small number of staff at Cologne will be just as keenly tuned in to the Paralympic Games, as they watch the fruits of their labour go for gold in Paris.

Handbikes can reach speeds of up to 100km/h, depending on the topography and conditions, so safety of the athlete within the monocoque is a vital consideration, too

dpa picture alliance / Alamy Stock Photo

Jacking forces

Investigating where they come from, and how they are applied

By DANNY NOWLAN

If there is one topic guaranteed to start a bar room brawl with racecar performance engineers, it is suspension geometry. Of all the articles I have penned over the years, the ones that have generated the most interest are the ones concerning this aspect of racecar set-up. Particularly those where I have mentioned force application points vs kinematic roll centre.

However, if there is one big blind spot in the subject of suspension geometry, it is jacking forces. You regularly see the term thrown about, and there is a lot of mystery about what it actually is. That is what we'll be discussing in this month's article.

The penny dropped

To kick things off, I want to start with an apology. I really didn't take this subject too seriously until about 2013 or so when I started dealing with formulae that had outrageous levels of downforce and used crazy values of anti-dive to control it. Once the penny dropped, it forced me to reconsider a few things.

However, as we are about to see, what appears straightforward on paper isn't always quite so clear cut when the rubber hits the road.

Where jacking forces come from is the vertical component of the suspension geometry linkages that are applied to the sprung mass. This is illustrated in **figure 1**.

What is shown in **figure 1** is our common or garden variety double wishbone suspension. To keep things simple, I've shown the lower control arm parallel to the ground, purely to make things easier. It's worth noting here that in my book, *The Dynamics of the Racecar*, I go to great lengths to explain that the 2D case is actually a subset of the 3D case.

As can be seen from **figure 1**, the jacking force is the vertical component of the force in the linkage 3-4. This is what drives the force to the tyre, but is also applied directly under the sprung mass. The reason I can state this is (as per chapter three of my book) we have already taken into account the moments, which is what drives the force application points.

Fig 1: The mechanism that drives jacking forces, laterally

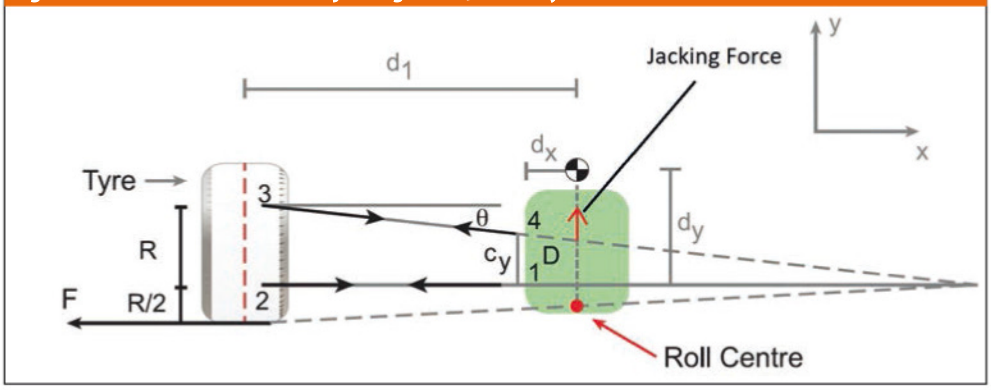
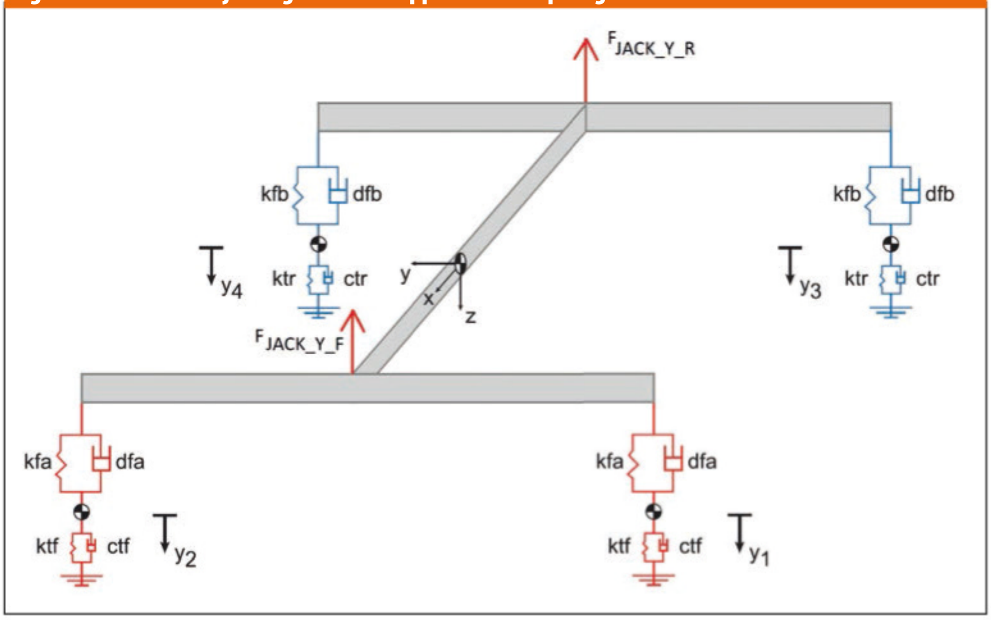


Fig 2: How the lateral jacking forces are applied to the sprung mass



The great news is we can readily relate the roll centre to the jacking force. The formula for this is simple, and shown in **equation 1** below.

$$F_{JACK\_Y} = \frac{F_y \cdot rc}{0.5 \cdot t} \qquad (1)$$

Where,

F_{JACK_Y}	=	Lateral jacking force
F_y	=	Applied lateral force
rc	=	Force-based roll centre location
t	=	Track width

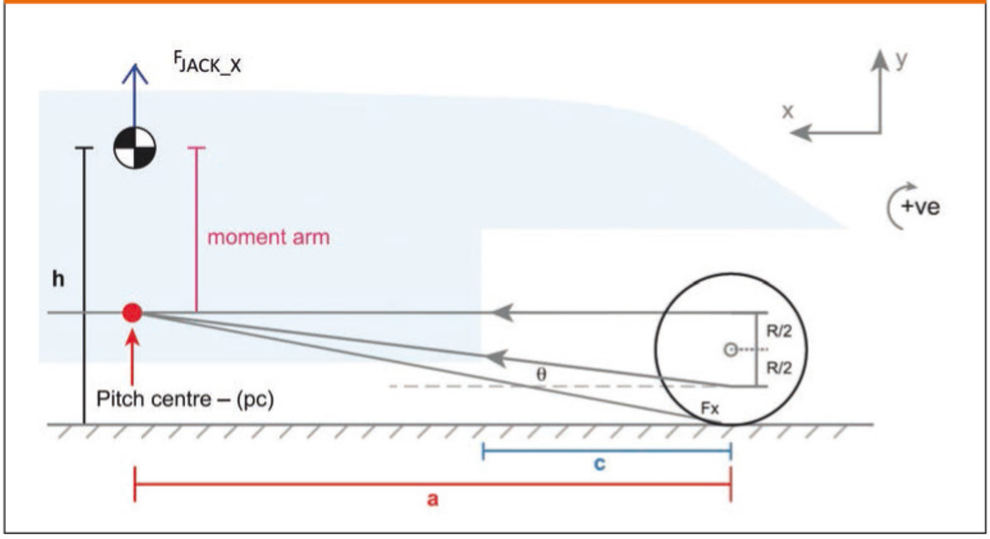
Again, I refer you to chapter three of my book, where I go into the explanation of this in great detail. So much so, there is no point repeating myself here, other than to add that the reason we have the 0.5t term is I am assuming the c of g is located symmetrically.

With lateral jacking forces, where things become interesting is in how they are applied to the sprung mass. They are actually applied per axle, as illustrated in **figure 2**.

The reason for this becomes more obvious when we look at where the forces come from.

Where jacking forces come from is the vertical component of the suspension geometry linkages that are applied to the sprung mass

Fig 3: Longitudinal jacking forces origin



When the forces are equally distributed left to right, the lateral jacking forces are bystanders since the terms cancel out

If we review what is going on in **figure 1**, it is not hard to see how this happens at each axle, which is why we have the formulation we see in **figure 2**. Now, in terms of what these numbers look like, we need to consider the numbers shown in **equation 2**:

$$F_{JACK\_Y\_F} = \frac{F_{y1} \cdot rc_1}{0.5 \cdot tf} - \frac{F_{y2} \cdot rc_2}{0.5 \cdot tf} = 2 \cdot \frac{(F_{y1} - F_{y2})}{tf} \cdot rc_f$$
$$F_{JACK\_Y\_R} = \frac{F_{y3} \cdot rc_3}{0.5 \cdot tr} - \frac{F_{y4} \cdot rc_4}{0.5 \cdot tr} = 2 \cdot \frac{(F_{y3} - F_{y4})}{tr} \cdot rc_r \quad (2)$$

Where,

$F_{JACK\_Y\_F}$	=	Front lateral jacking force
$F_{JACK\_Y\_R}$	=	Rear lateral jacking force
F_{y1}	=	Lateral force front left (positive to the right)
F_{y2}	=	Lateral force front right (positive to the right)
F_{y3}	=	Lateral force rear left (positive to the right)
F_{y4}	=	Lateral force rear right (positive to the right)
rc_1	=	Force-based roll centre front left
rc_2	=	Force-based roll centre front right
rc_3	=	Force-based roll centre rear left
rc_4	=	Force-based roll centre rear right
rc_f	=	Effective front-based roll centre
rc_r	=	Effective rear-based roll centre
tf	=	Front track
tr	=	Rear track

There are a number of interesting things that pop out from **equation 2**. Firstly, when the forces are equally distributed left to right, the lateral jacking forces are bystanders since the terms cancel out. Where they make their presence felt is at the middle of the corner with large load transfers or asymmetric set-ups. That said, there is a curve ball to be aware of here, but we'll come to that shortly.

Longitudinal forces

The longitudinal jacking forces are driven by exactly the same mechanism as the lateral case, and this is illustrated in **figure 3**.

As with the lateral jacking forces, we have assumed a simple 2D visualisation that can be a four-link or double wishbone suspension. The reason we have done it this way is simply for ease of illustration. As per the lateral case, what drives the longitudinal jacking force is the vertical components of forces in the longitudinal suspension linkages.

Again, we only need add this to the c of g since (as per the lateral force application point) we have already taken into account the pitch centre of the longitudinal force application point by resolving the moments.

Also, as with the lateral case, we can readily relate the pitch centre location to the longitudinal forces. Your guiding principle here is **equation 3**.

$$F_{JACK\_X} = \frac{F_x \cdot pc}{t} \quad (3)$$

Where,

F_{JACK_X}	=	Longitudinal jacking force
pc	=	Pitch centre location
t	=	Moment arm from the axle to the c of g
F_x	=	Applied longitudinal force

Where things deviate, though, is with the longitudinal jacking forces, provided they are symmetric. Unlike with the lateral case, they are applied straight to the c of g and *not* per axle. This is a very important distinction, and an easy trap to fall into for the inexperienced.

What drives this is we have already taken into account the moments, thanks to the pitch centres. So now, in terms of an overall formulation for the longitudinal jacking forces, we have that shown in **equation 4**.

$$F_{JACK\_X} = \frac{-F_{xf} \cdot pc_f}{a} + \frac{F_{xr} \cdot pc_r}{b} \quad (4)$$

Where,

F_{xf}	=	Front applied longitudinal force (positive forward)
F_{xr}	=	Rear applied longitudinal force (positive forward)
pc_f	=	Front pitch centre
pc_r	=	Rear pitch centre
a	=	Distance from front axle to c of g
b	=	Distance from rear axle to c of g

Jacking forces are an important part of the pantheon of suspension geometry, affecting both tyres and sprung mass

One further thing we do need to discuss here is where the longitudinal forces are asymmetric. This kicks in with very badly conditioned suspension geometry, or asymmetric running. In any such cases, **equation 4** becomes **equation 5**.

$$F_{JACK\_X} = \frac{(-F_{x1} \cdot pc_1 + F_{x2} \cdot pc_2)}{a} + \frac{(F_{x3} \cdot pc_3 + F_{x4} \cdot pc_4)}{b}$$

$$M_{JACK\_X\_ROLL} = \frac{(-F_{x1} \cdot pc_1 + F_{x2} \cdot pc_2) \cdot tf}{2 \cdot a} + \frac{(F_{x3} \cdot pc_3 - F_{x4} \cdot pc_4) \cdot tr}{2 \cdot b} \quad (5)$$

Where,

$M_{JACK\_X\_ROLL}$ = Rolling moment due to the jacking force (positive to the right)
pc_1 = Pitch centre front left
pc_2 = Pitch centre front right
pc_3 = Pitch centre rear left
pc_4 = Pitch centre rear right
F_{x1} = Longitudinal force front left
F_{x2} = Longitudinal force front right
F_{x3} = Longitudinal force rear left
F_{x4} = Longitudinal force rear right

In all cases, the longitudinal forces are positive forward and, to keep the maths simple, I've assumed the c of g is located in the middle of the car. I should also add that the reason we have a rolling moment due to the asymmetric effects of pitch centres is exactly the same reason we needed to take into account the front and rear lateral jacking forces' effects on the sprung mass. The mechanisms driving this are identical.

However, what this shows is that for asymmetric set-ups, such as sprint cars and late model dirt cars, you can manipulate this to get the result you want.

Bridge the gap

So, the next question ask is what roles do jacking forces play in load transfer? What they do is bridge the gap between what is going on with the sprung mass and unsprung mass, so all the familiar load transfer equations work out.

The lateral case here is straightforward, and works out simply. The longitudinal case, though, is more surprising, particularly if you have the load transfer happening on just one axle, for example during the acceleration phase in a rear-wheel drive vehicle.

Here, the rear load transfer equation is just the reaction of the moment of the sprung mass combined with the jacking force applied at the rear tyre. However, what happens at the front is the jacking force that is applied at the c of g (which is going vertically upwards) tidies the load we see on the front axle. The important thing to remember here is that the jacking forces make sure the numbers all add up.

Now that we have discussed the principle behind what drives all this, we need to talk about the wildcards in the pack. For jacking forces, where these wildcards come in is how the spring / damper unit is mounted to the vehicle. Let's start this part of the discussion by looking at the longitudinal case, as illustrated in **figure 4**.

Fig 4: Spring mounting, longitudinal case

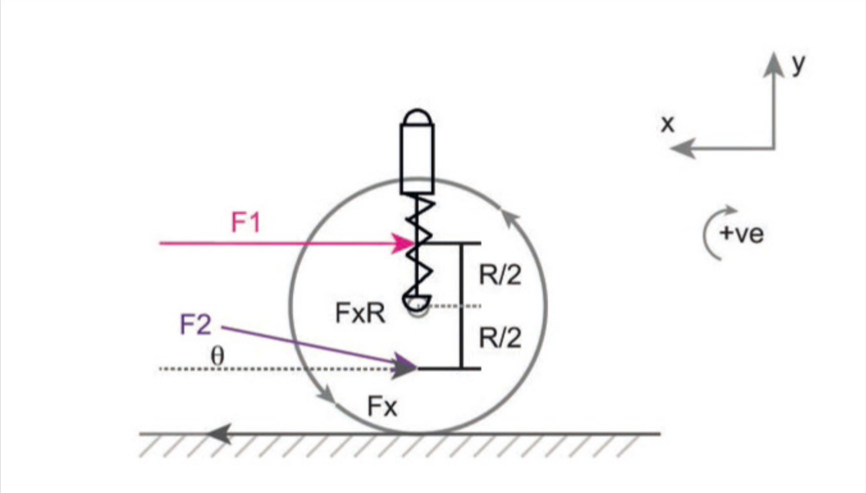
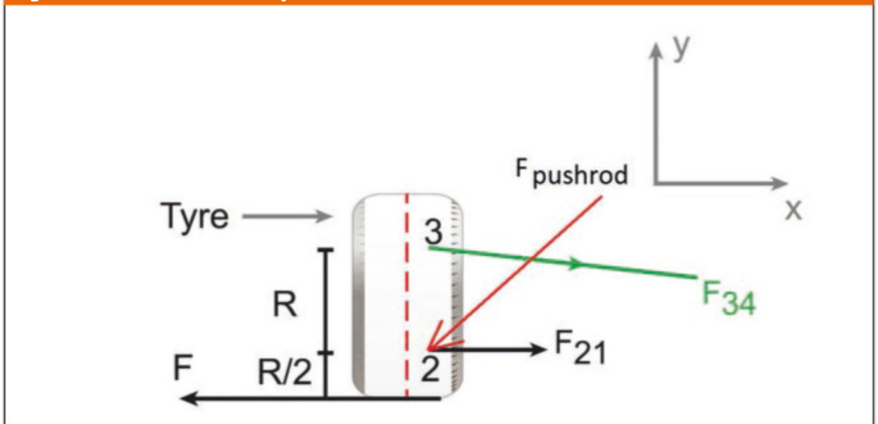


Fig 5: Pushrod-mounted suspension



Here, we see the spring / damper unit mounted vertically. In this scenario, we have zero cross-pollination between the sprung mass and the jacking forces and, when it comes to correlation, the jacking forces in the longitudinal case are very straightforward.

The lateral case

Things are not so clear cut in the lateral case, though, because nailing that vertical mounting can be rather more tricky. Let's consider this for a pushrod-mounted suspension, as illustrated in **figure 5**.

In this case, what happens when we resolve the forces and moments about the hub for the lateral case becomes statically indeterminate. This doesn't mean the jacking forces go away. On the contrary, they are *always* there. What it shows is that it's not going to work out quite as advertised.

Before you start to panic, I should add here that, in the case of a lower control arm mounting, the lateral jacking forces will behave much closer to the ideal case.

So, to wrap things up, I'll give you some rough rules of thumb when jacking forces make their presence felt. In the lateral case, with anything less than 25 per cent of the c of g height for the lateral roll centre, you can get away with not taking into account jacking forces. This is not perfect, but allows you to do quick approximations to get into the ballpark.

In terms of anti squat / dive, if you are over 50 per cent, jacking forces definitely make their presence felt.

Remember, the final arbiter on this is always the data. Ignore that at your peril, and don't end up in a ditch over a textbook!

In conclusion, jacking forces are a very important part of the suspension geometry kaleidoscope. Not only do they impact on the tyres, but also on the sprung mass. I have given you a few things to watch out for, but what jacking forces do is tidy up the load transfer numbers that we see. If you are clever about it, quite a few things can be done to exploit this, but *never* forget your data when it comes to your correlations.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Halo product

Brake fluid is an important, if underrated, aspect of racecar performance. Halo By Orthene demonstrates its importance

This year's LMP2 race at the 24 Hours of Le Mans was decided by a winning margin of just 18.651 seconds. When a gap that small determines such a prestigious race result, it's important that all aspects of the car perform at their peak through all stages of the event. That means considering every little detail, including brake fluid, which is perhaps an overlooked area of racecar performance.

At Le Mans, teams can choose the brake fluid they use, which is significant in a class such as LMP2 where all teams run identical cars. The United Autosports Oreca 07 Gibson that prevailed this year was using P1, a product from Halo by Orthene that was launched earlier this year and piloted to great effect by the Anglo-American squad.

'We have been looking for ways to improve brake pedal stiffness and consistency, testing various options in fluid and system components,' said Gary Robertshaw, United Autosports LMP2 chief engineer. 'Our testing showed that Halo P1 provided increased pedal stiffness and consistency over long runs, so the decision was made that we would use Halo P1 across all our endurance racing activities.'

At Le Mans, there are several long straights on which the brakes cool off, followed by tight corners where brake temperatures rise dramatically. Plus, there are occasional hard stops, including at every pit visit, which incur heat soak from the metal parts of the brakes into the brake fluid. A fluid that can maintain its key properties through such extreme temperature variation is key, especially in an endurance race.

Brake fluid basics

Brake fluid transfers the force of a driver pressing the brake pedal through to the calipers, which slow each wheel. When the driver hits the pedal, pistons in the master cylinder compress, releasing brake fluid under pressure towards the braking components of the system. There are several characteristics whose properties a brake fluid must sustain over the temperature range to ensure the brakes give consistent, predictable feedback to the driver. The main ones are boiling point, compressibility, lubricity and viscosity.

Brake fluid needs to have a high boiling point, otherwise vapour lock can result, causing the calipers to no longer respond to the driver's action due to the presence of a gas in the braking system. Potentially, this could result in a high-speed accident, due to lack of deceleration.

The Halo brand was launched in December 2023 by Orthene, a leading brake fluid manufacturer since its establishment in the 1970s

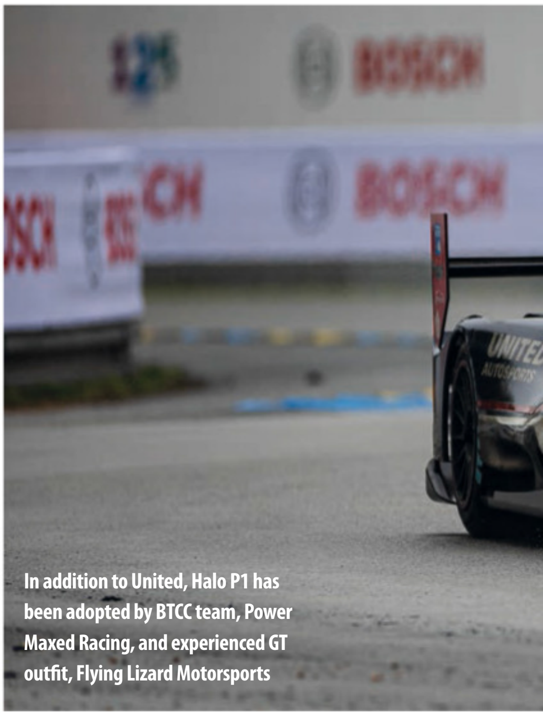
Most racing brake fluids have a minimum dry boiling point of 300degC, although Halo P1 pushes that up to 341degC. This additional capacity ensures the fluid can handle the high temperatures, which have increased across several series in recent years due to the addition of heavy electric and hybrid powertrain components that add stress to the brakes.

Research continues regarding racecar brake fluids that can exceed the current maximums. Halo's parent company, Orthene, once set the boiling point record at 320degC, but that has since increased by more than 20degC with the P1 product.

'I think there is potential to develop it quite substantially,' says Daniel Stafford, chief development chemist at Halo by Orthene. 'Cars are getting heavier, but drivers still need good pedal feel, regardless of powertrain. We will have a second-generation product that will undoubtedly have a higher boiling point, though the main focus is on maintaining low compressibility across the operating envelope, rather than a super high boiling point.'

Higher brake fluid compressibility results in a spongy feel to the brakes, which is undesirable in any car, but particularly so in motorsport where drivers want a firm, predictable pedal feel with limited travel. Inconsistency here can lead to slower lap times, or mistakes.

Low compressibility is an inherent property of all hydraulic fluids, including the brake variety, but compressibility increases as brakes get hotter.


In addition to United, Halo P1 has been adopted by BTCC team, Power Maxed Racing, and experienced GT outfit, Flying Lizard Motorsports

Halo's Fade Resistant Technology makes the P1 brake fluid highly polar, meaning its molecules avoid sharing the same space and are therefore more resistant to compression. Halo P1 has registered less than 8mm of piston travel at 293degC, compared with 14mm at the same temperature for another leading brand on the market.

Lubricity and viscosity

High lubricity is required to prevent wear of the braking system's mechanical parts. Additives are implemented to Halo P1 to ensure the fluid retains lubricity at high temperature. Motorsport brake fluid also needs to have low viscosity, meaning the liquid needs to be kept thin. This enables it to flow smoothly through the system. Halo P1 has a kinematic viscosity of 1400 centistokes (cSt) at -40degC and 2.63cSt at 100degC.

'With the GT3s and Hypercars, for example, there are a lot of electronic assists in the brakes now,' notes Stafford. 'Lubricity and viscosity are playing a more important role. It's a juggling act: you want high temperature resistance, but you also want low viscosity and high lubricity. We're starting to have to juggle the performance of the products as the systems become more developed. Especially with hybrids, because you're having to electronically integrate the braking system with the regenerative system of the motor. When you have a lot of electronic assistance working together, that puts demands on the brake system and brake fluid.'

Brake fluid is made from chemical combinations. Halo P1 is made from a type of combination called an ester, specifically containing boric acid and glycol ether.

'The idea of a racing brake fluid is that the compressibility should remain relatively constant, no matter what the temperature is'

Daniel Stafford, chief development chemist at Halo By Orthene

Other types are available, such as non-hygroscopic (water-resistant) ones based on silicone, though those are deemed to have lower lubricity than a fluid derived from a methyl borate ester such as Halo P1.

'With Halo P1, that borate ester is bespoke to the product,' explains Stafford. 'We design and manufacture that chemical to get the high performance. You have to refine the components as high as you can as any impurities will degrade the performance.

'So, to have the highest boiling point and lowest compressibility, you have to start with very pure ingredients. We refine our ingredients first on an analytical level. Most raw materials for brake fluids are about 90 per cent pure, but we purify up to 99 per cent, which is as much as we practically can. That's what gives the higher performance.'

Temperature ranges

Racecar brake fluids are different to those used in road cars because of the temperature ranges in which they operate. While racecar brake fluids need to retain their chemical properties at over 300degC, roadgoing fluids top out towards 260degC. The same applies to minimum operating temperatures. For racecar brake fluid, that is around 100degC, while road products have a starting operating temperature below freezing. Despite this, Halo tests its racecar products down to as low as -80degC.

'Generally, all brake fluids have a low compressibility,' says Stafford. 'On the road, it's important for modulation, but racecars take it to an extreme. The idea of a racing brake fluid is that the compressibility should remain relatively constant, no matter what the temperature is.'

Roadgoing brake fluids are designed to last for many years, whereas racing ones are replaced at each event, so longevity is less of a concern than performance. Still, performance durability is valuable at an endurance race like Le Mans.

'You have longer pit stops in endurance racing where the car is stationary for one or two minutes,' says Mike Biscoe, Halo by Orthene chief marketing officer. 'It gets a massive amount of heat soak, goes back out onto the track and, very often, the driver will lose the brakes in the first few laps until that heat soak dissipates and the feel comes back.

'United Autosports reported back to us that they didn't have that problem. They still had enough bite in the brakes to get back on it aggressively, as soon as they're out the pits.'

The sub-20-second winning margin for United at Le Mans this year equated to just 0.062seconds per lap. It's hard to quantify how much time was saved by the brake fluid alone, but its contribution is highly likely. The result was certainly close enough that a brake fluid less capable of dealing with the wide temperature range of a 24-hour race may not have facilitated such an edge.

Javier Jimenez / DPPI

Interview – Stéphane Ratel

Crest of a wave

The GT3 category continues to remain strong around the world. Stéphane Ratel talks through its success and challenges

BY ANDREW COTTON

Any GT3 series able to boast an average grid of more than 50 cars for over 10 years has to be deemed a success, and that's precisely what the GT World Challenge Endurance Cup has achieved since 2011. This is backed up by large grids in other GTWC series run by the same promoter, SRO Motorsports Group.

However, there are several threats to the GTWC global structure, which also operates in Asia, America and Australia. The first is the prevalence of GT3, which became part of the FIA World Endurance Championship this year. Not only has this increased pressure on the competing car manufacturers (and on where they spend their marketing budgets), but it also has also led to scheduling issues.

Talking the torque

One of the main challenges, though, is cost. Here, SRO founder and CEO Stéphane Ratel has been adamant; while others are looking at introducing torque sensors to help balance the cars, the GTWC cannot. Already, teams in the IMSA series, which will introduce torque sensors next year, are considering jumping ship and racing in a non-torque sensor controlled environment because of the high cost involved.

So far, the only FIA-approved torque sensor is developed by MagCanica in California. While the sensor and calibration itself is not a high cost, at around US$9000 (approx. £6985) per sensor, two are needed per driven axle, and the driveshafts themselves are made especially to accommodate the sensor.

Multiple shafts are also required during a season to accommodate servicing of the sensor and driveshaft, plus spares from damage or failure. Manufacturers may be able to swallow many of the costs incurred, but customer teams cannot.

Ratel believes he could lose up to half his grid if he were to introduce torque sensor technology into his series, so he relies on more traditional methods of balancing performance.

Cost control, calendar clashes and an electric future are all on Ratel's mind

Ratel believes that he could lose up to half his grid if he were to introduce torque sensor technology so relies on more traditional methods

On top of this, he sees another problem regarding costs, based on the arrivals of Ford and Chevrolet.

Both compete in the WEC and are pushing customer programmes as much as Ratel might have hoped, but the Mustang and Corvette models are significantly more than his target purchase price of around €500,000 (approx. $542,500). That has put pressure on the others to match it.

'The very important point is what will be the cost?' asks Ratel. 'The manufacturers look at the Ford and Corvette and say, "we are a super prestigious brand, this car costs €800-900,000. How can we sell our cars for €500,000?" It is almost marketing positioning, and that is dangerous. For me, even the BMW has jumped up quite a lot.

'The new Lamborghini, the new Mercedes, the Lexus… these are the cars that will position whether or not we can still have cars in the region of €500-550,000, with running costs to match. If the [price of the] cars go up, then the writing is on the wall.

'I have lived through this boom and bust because maybe the marketing value was not there. Now we are

The arrival of Ford and Chevrolet in GT3 has caused a stir, the two cars being significantly more expensive than existing prestige counterparts attracting more money into it. Maybe with Ferrari in Hypercar, young drivers with budgets shift out of single seaters earlier because they see a career in Hypercar and they want to come to GT. Maybe the cost can be sustained because the goal is higher.'

The FIA and ACO's move to introduce GT3 cars to the WEC had a visible effect on the GTWC paddock at Spa for the Endurance Cup's flagship 24-hour race. Although the event saw 67 cars take the start - slightly down on the more usual 70-car grid - it was behind the garages where the marketing spend had clearly dropped.

Empty spaces that normally housed hospitality units were filled with cars there to celebrate the centenary of the 24 Hours of Spa.

'If you look at it, the paddock looks empty,' says Ratel. 'It's obvious the money is going to WEC. The manufacturers' marketing spend is not with us any more, apart from Ford.'

GT3 grids remain healthy, but the manufacturer marketing spend has been noticeably reduced at events like the 24 Hours of Spa

Clash of the calendars

Adding GT3 to the WEC has brought a further complication next June. Although the SRO's Intercontinental GT Challenge global series is intended for manufacturers to help local teams with engineering and driver support, next year sees a significant scheduling problem for manufacturers. In June, GT3 cars will complete on consecutive weekends at the Le Mans test day, the 24 Hours of Le Mans, the Nürburgring 24 Hours (which is always held on the Corpus Christi holiday), and then Spa. The latter two are IGTC rounds.

Some IGTC manufacturers also support the IMSA series, which has a clash with the Nürburgring race. For Porsche, there is a Formula E round taking place on that weekend, too.

The situation has led to BMW considering dropping its support of some of the races during that congested period to protect its drivers and engineers. For Ratel, the constantly changing date of the Nürburgring race to follow a religious festival doesn't work either. This year was the first in which cars racing there also scored IGTC points.

'I am investing in this event, and we want to build it,' he says. 'It was always a one-day event but is now a four-day event with more camping and entertainment. We cannot keep changing the date.

'Also, the weekend after that is [usually] Norisring [DTM]. What do you do with Norisring? You cannot move that or you clash with WEC and they don't want to do that either. The problem is we are dealing with [date of] a religious weekend and that doesn't work because it moves.

'There is so much on the global motorsport calendar these days, so you need to set a date, and then keep to that date. The good thing is that the three following years Easter will be in May, so there will be no problem. Maybe they should look at another date because of fog anyway. Maybe July... Me, I would recommend they have a [fixed] date, not a flying date that creates chaos.'

GT3 has been carefully curated by the SRO since it was launched in 2005, and the company has overseen growth in major territories such as the US and Asia, where grids of more than 40 cars are now becoming common.

Asia has been one of the SRO's success stories, having grown GTWC Asia, co-promoted the Asian Le Mans Series and promoted the FIA GT World Cup in Macau, which has become a must-attend event for manufacturers again supporting local teams.

Next year, the plan is to restore the Suzuka 1000km to the IGTC after a multi-year break. The Japanese race will run alongside the Bathurst 12 Hour, the Nürburgring and Spa races and the Indianapolis 8 Hour.

'Asia is our biggest success, with 41 GT3 cars between the two platforms,' says Ratel. 'There are 49 GT cars [racing] in total - it is the best championship in Asia. For manufacturers that want to develop and have potential for growth, they should support a little at least the best GT class in Asia.'

There is a plan to turn the Asian Le Mans Series into something more serious than what is currently perceived a winter version of the European Le Mans Series. Ratel wants to convert it into a championship to complement its European cousin, using teams and drivers from Asia. Ultimately, he wants Hypercars to compete, believing local teams will soon be at a level to run them.

Electric vision

However, he is also focusing on electric racing, and has a plan to develop his GT Experimental World Tour concept, which was first announced back in 2019. Ratel does not yet have the support of enough manufacturers to do it, but says once he has four signed up, he has a programme waiting for them.

'We are talking to seven manufacturers, and there are two more actively working on projects. I need four. It will happen,' says the Frenchman. 'You *have* to do something with electric cars these days.

'We are talking to seven manufacturers. I need four. It will happen. You *have* to do something electric these days'

'The Electric GT [series] was not reality. Ours is reality. Pumped-up road cars, realistic in the length of the races, the rally stages, the hillclimb. It is made for electric cars. With the eco rally in between to measure performance, it all just makes sense.'

The problem is that, since having his fingers burned in the Mercedes and Porsche era of the late 1990s, Ratel has focused on customer racing. Now, he actually cannot launch GTX without the manufacturers, and getting them interested has proven to be a challenge.

'My only problem is that even if a motorsport director is convinced, he has to sell it to the marketing department and the board,' says Ratel. 'What do the board know? Formula 1, Le Mans, World Rally, IndyCar, DTM maybe? The rest they don't know.

'That is the difficulty. For the first time, it is a project that is impossible to start without manufacturers. No privateer can do this. It is initiated by manufacturers, designed for customers. I have tried to get them to commit to two cars per manufacturer for two years. On the third year, you will find clients and they will love it.

'The Targa Florio, then Enna, and then you go up Mount Etna. Everyone would like that who likes motorsport, whether it is electric cars or not. That is something that is sellable to clients. These electric cars are fun and fast, and it is customer racing.'

Ratel has never been one to rest on his laurels, and even in this ever-changing world of racing, he still has his path clearly mapped out.

Aston's V12 Hypercar hits track

Aston Martin has begun track testing its Valkyrie AMR Pro-based LMH car in preparation for the 2025 FIA World Endurance Championship and IMSA seasons. Aston Martin factory drivers have tested the car at Silverstone and Donington ahead of next year's opening round of the IMSA series at Daytona in January.

The Valkyrie features a version of the carbon tub taken from the road car, and a lean-burn development of the Cosworth V12 engine that has been de-tuned to meet the FIA's performance window. The aerodynamics have also been re-designed to fit within the lift / drag window prescribed by the regulations.

'The Valkyrie AMR-LMH sets its own standard as a thoroughbred endurance competition car,' says Adam Carter, Aston Martin head of endurance motorsport. 'While it is very early in the testing cycle, from what we have witnessed so far, we are satisfied that it is achieving the targets and criteria we have set out for it to accomplish.'

The race programmes on either side of the Atlantic will be run by the British Heart of Racing team, which conducted the tests in the UK.

'We are competing at the pinnacle of sportscar racing. The competitors are formidable and they have been doing it for a long time,' said Heart of Racing team principal, Ian James. 'Some of them also have endless resources. We know we are going up against the very best, so we intend to represent Aston Martin at the same level.'

Aston Martin Racing

Developed from the impressive, carbon-tubbed Valkyrie AMR Pro, the LMH racing variant features revised aerodynamics and a de-tuned version of the production car's Cosworth V12 engine

Cosworth V10 power for Red Bull RB17

British engine manufacturer, Cosworth, has been selected to provide the engine for Red Bull's RB17 Hypercar, which made its debut at the Goodwood Festival of Speed in July.

Development of the 90-degree, V10 engine started in 2023, and is lifed to 24,000km, due to the imposed 15,000rpm rev limit.

The engine uses the same air valve technology as grand prix racing engines, and meets the Euro 6 vehicle emission standard.

Cosworth's latest engine sits alongside the 6.5-litre V12 that powers the Aston Martin Valkyrie, the 3.9-litre V12 in Gordon Murray's T.50 and the 8.3-litre V16 power unit in Bugatti's Tourbillon.

'Developing this V10 for a multiple Formula 1 world championship-winning business such as Red Bull is fantastic for the Cosworth brand, especially when we can let this one ring out all the way to 15,000rpm,' says Dr Florian Kamelger, CEO at Cosworth. 'We're thrilled to be building on our relationship with Red Bull and bringing together some of the greatest minds in the industry to produce a truly world-class machine.'

The Adrian Newey-designed RB17 made its debut on the world stage at this year's Goodwood Festival of Speed, with Cosworth supplying the power as it does for several recent hypercar offerings

Michelin delays new tyre

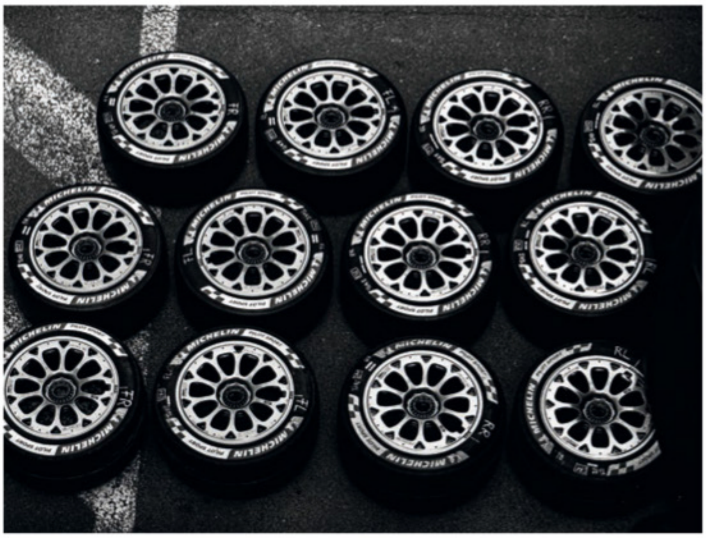
French tyre company, Michelin, which has the contract to supply the top classes of the WEC and IMSA, has delayed by one year the introduction of a new tyre that was originally set for 2025.

First reported by *Endurance-Info*, the new tyre's test programme has been blighted by poor weather, first at Portimão in March and then at a back-up test at Austin in late July. This restricted Michelin's real-world data and meant it couldn't produce the final tyre in time for official series tests at the end of the year.

A new schedule includes testing in Bahrain after the WEC season finale in early November, and at various rounds next year to allow teams to prepare fully for the new tyre in 2026.

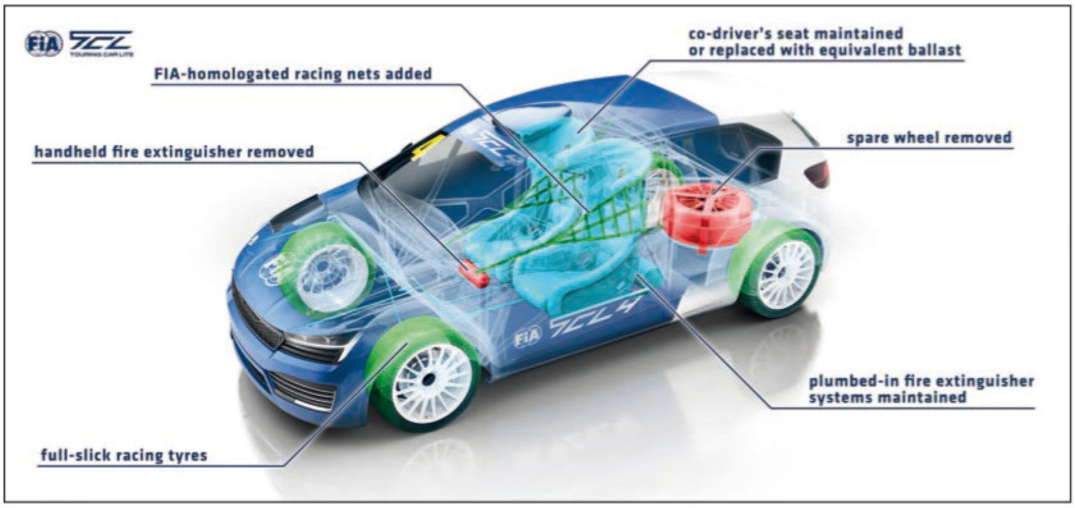
The new product aims to increase the amount of sustainable material used from 30 to 50 per cent, and so Michelin and series organisers are keen to push through the change as soon as possible.

It is also expected to help with warm up as neither the WEC nor IMSA now permits tyre warmers.



Michelin's test programme for a new LMH / LMDh product has been hampered by rain this year

New touring car tier to share rally traits



TC Lite will use the Rally4 and Rally5 regulations as a starting point, supplemented by modifications to make the cars fit for circuit competition

The FIA has launched a pair of new classes, collectively called TC Lite, aimed at providing a low-cost entry point into touring cars by utilising an existing rally car architecture.

TC Lite will sit below the global TCR platform and will consist of two tiers: TCL4 and TCL5. These will share base technical regulations with the Rally4 and Rally5 classes.

The convergence means that Rally4 and Rally5 cars, such as Ford Fiestas and Renault Clios, can race on the track as TC Lites with only minor modifications, which will be laid out in an appendix to their rulebook.

The minimum weight will be reduced to take into account the loss of a spare wheel, hand-held fire extinguishers and other tools that are carried in a rally car. TC Lite versions will be fitted with homologated racing nets and slick tyres.

TCL5 vehicles will have 6kg per bhp in power-to-weight and the quicker TCL4s will be rated at 5.1kg per bhp. Both will change gears through sequential transmissions.

'Having the same cars in rallying and touring car racing has plenty of benefits,' says the FIA's Touring Car Commission president and CEO of the British Touring Car Championship, Alan Gow. 'It is cost-effective, sustainable, provides the competitors with a level playing field and creates opportunities for more available seat time.

'At the same time, manufacturers and their customer racing programmes will be able to grow their business as the market of these cars will naturally broaden.'

TCL5 will also accommodate Rally5 kit cars, which will allow National Sporting Authorities to approve cars prepared and homologated by local tuners for domestic competition.

IN BRIEF

Former Ferrari technical leader, **Enrico Cardile**, will join Aston Martin's Formula 1 team at an as-yet unspecified date in 2025. Cardile will join former Mercedes engine guru, **Andy Cowell**, at the squad. Cardile was Ferrari's chassis technical director and will be a valuable asset to the team in preparation for the 2026 chassis and engine regulations.

One of the worst-kept secrets in racing was confirmed when **Acura** announced that the **Meyer Shank** team will run its IMSA programme next season. **Wayne Taylor Racing (WTR)** will be confirmed to switch from Acura to **Cadillac** in early August. WTR ran both Acuras this season but made the decision to switch back to Cadillac having left GM's stable in 2021.

Audi says it has completed simulated race distances with its 2026 F1 engine and will soon run the same programme with the entire drivetrain. The circuits selected were Spielberg, Singapore and Las Vegas, the latter featuring slow corners and a long straight, ideal for energy recovery system development.

ADESS has developed and built an LMP3 chassis that will enter the marketplace alongside other new cars from **Ligier** and **Duqueine**. Testing took place at Portugal's Estoril circuit in July.

Gearbox manufacturer, **Xtrac**, has reached automotive levels of cyber security, achieving the standard of international TISAX. 'By protecting the company's information assets, we are defending the interests of all stakeholders, including, most importantly, our customers, as well as our employees and suppliers,' says Xtrac chief executive, **Adrian Moore**.

Mahle Powertrain has expanded its UK facility in Northampton to include a dedicated hydrogen powertrain testing facility. Upgraded engine dynos support 900kW and 4000Nm nominal capacity and will be used to develop IC engines for the heavy duty and marine sectors. The facility is already used in the development of fuel cell systems and hydrogen-fuelled vehicles.

IN BRIEF

Isotta Fraschini, the Italian car maker competing in the top class of the WEC, has parted company with its sporting director, **Claudio Berro**, and replaced him with new company CEO **Miguel Valldecabres**. Berro will remain close to the programme, according to the manufacturer.

Alpine's factory WEC team has confirmed engine updates will be implemented before the end of this season after an embarrassing double failure at Le Mans. Both cars completed just over 1000km during the race before retiring. Engine supplier, **Mecachrome**, has updates being prepared but there is no firm date as to when they will be ready.

Liqui Moly has been confirmed as the official oil and lubricant partner to the **British Touring Car Championship**. The three-year deal starts immediately for the remainder of the 2024 season.

The **National Motorsport Academy** has partnered with the **Global Karting League** to create educational opportunities for young people aged 6-16 within the motorsport industry. Racers will receive free formal education, including race coaching and data analytics, and undertake training modules in science, technology, engineering and maths. In addition, the NMA will engage with GKL racers on selected events to cover topics such as racing technology and practical mechanical skills.

Symbio is working on a hydrogen fuel cell demonstrator for Formula Student as part of a push to make more students familiar with the technology. 'The idea is to have something create momentum around the fact we need talent for hydrogen,' says Symbio motorsport director, **Serge Grisin**.

Williams has bolstered its F1 staff with hirings including Alpine's former technical director, **Matt Harman**, and head of performance, **Richard Frith.** Harman will start his new design director role after the summer break. Williams has also recruited a new chief aerodynamicist, **Juan Molina**, from Haas.

McLaren Applied selected for MissionH24

McLaren Applied's VCU-500 vehicle controller, ATLAS data analysis software and tyre pressure monitoring systems have all been selected for the latest generation MissionH24 concept that aims to develop hydrogen technology for endurance racing.

MissionH24 revealed its latest iteration of the car, which is based on an LMP3 chassis, at the 24 Hours of Le Mans in June, and it is set to run during the event next year.

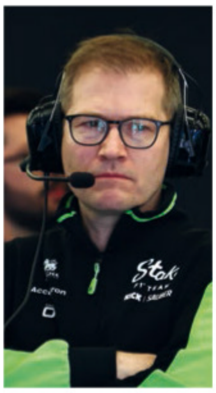
The project is not intended for competition, but rather as a test bed in preparation for the top-class cars that will compete in 2029.

The likelihood is that the class will run with hydrogen as a fuel in an internal combustion engine after rumours abound that manufacturers are moving away from the fuel cell idea in technical working group meetings.

'Our VCU-500 analysis package, tyre pressure monitoring system and ATLAS GT will provide Mission24H with the latest control systems and analysis tools to optimise the performance of the H24EVO,' says Sam Guest, head of telemetry, control and analysis at McLaren Applied. 'We look forward to seeing the car on track and supporting our MissionH24 colleagues in achieving their exciting goals and demonstrating the future of hydrogen mobility in the most demanding of endurance races.'

The latest incarnation of MissionH24 broke cover at Le Mans in June and will run there next year, aided by a number of McLaren Applied systems

Ex-Ferrari F1 chief joins Audi project



Out goes Andreas Seidl, who joined Sauber in 2023...

...and in comes Mattia Binotto, Audi's new F1 lead

Audi has shaken up its senior management team ahead of its Formula 1 entry in 2026. Andreas Seidl and Oliver Hoffmann have both left the project, replaced by former Ferrari boss, Mattia Binotto. Hoffmann was previously chairman of the board of directors at Sauber, which Audi is taking over for its F1 venture. Seidl was CEO of Sauber Motorsport and Sauber Technologies.

Gernot Döllner, who became Audi CEO in July last year, commented only that, 'I would like to thank Oliver and Andreas for their important work in establishing our entry into Formula 1 and their commitment in preparing it.'

Binotto will be the chief operating and chief technical officer in the leadership team of Sauber AG, with responsibility and accountability for the team's operative management and sporting success. The Italian will report to the board of directors of Sauber Motorsport AG.

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Into the melée

Toyota comments on the BoP process results in a slapped wrist

Stewards' Decision no.7 at the 6 Hours of São Paulo had, unusually, absolutely nothing to do with the race itself. Instead, it concerned comments made by senior Toyota personnel regarding the FIA World Endurance Championship's Balance of Performance process for the Hypercar class.

The penalty of a suspended €10,000 fine was a situation just waiting to happen, as the FIA and ACO have battled to create a system that is both robust and open enough to cope with the scrutiny that inevitably follows. They have created a set of sporting regulations that bans teams from talking about BoP, while also hiding the exact criteria that they use to balance the cars.

Naturally, teams that calculate themselves to be quicker than others say it's a fair system, one that recognises the strengths and weaknesses of each car. Those that calculate through their simulations that their cars are slower generally lambast it. Ultimately, it's cheaper to win an argument than it is to go testing.

Toyota team director, Rob Leupen, and team representative, John Steeghs, were both hauled up before the stewards in Brazil for comments made by Leupen to a journalist. The organisers felt his comments contravened the rule that teams cannot publicly talk about BoP, although some have found clever ways of getting their point across without drawing any wrath.

Toyota has a recent history of BoP grievance. Last year's Le Mans was controversial in that the FIA and ACO broke a promise they made to the teams that the BoP would not be changed until after that event. The promise was important, as it encouraged teams to race rather than hide performance, but it was undone.

Toyota felt punished by this decision and, politically, there was some fall out. Its chairman, Akio Toyoda, refused to accept a special award from the organisers, and re-wrote his speech to comment on the system. Ultimately, the re-write was funny, and the award was accepted later, but it was an uncomfortable time for the governing bodies.

Falling foul

Toyota's public position went unpunished, but skip ahead to 2024 and it was at it again, this time crossing the FIA and ACO's line. Leupen was quoted as saying the process 'is not transparent' and that 'in the future, honesty is required,' according to the stewards' report. He is correct on both points. The process is *not* transparent, but deliberately so.

A lot of what is decided for the BoP is communicated with the teams, discussed and then actioned accordingly. How the BoP engineers arrive at their decisions is a mixture of data categories such as fastest laps (over 20 per cent, 40 per cent, or 60 per cent, depending on what they are looking for) and top speeds, but the data spread being taken is not disclosed. The reason for this is that the teams have more resource than the FIA or ACO, and can play a more complex game if they know the parameters. Also, the FIA and ACO can change the rules if they wish. They promised me faithfully in May they would not implement a rule that allows them to reduce power to a car over 250km/h, but then did exactly that at Le Mans.

Honesty policy

On the honesty comment, Leupen is also right. The FIA and ACO *must* be honest, and *must* make the right decisions. By not revealing their measure of the cars, they are open to criticism if there is a mistake anywhere along the way. The inference the stewards took in Brazil was that Leupen had accused them of dishonesty.

The warning was that there would be no such leniency in the future

Notable was the comment, 'these statements call into question the impartiality of the FIA, cast suspicion on its integrity, and thus causes moral harm, particularly given that the press article in question was disseminated in multiple countries.'

This last comment I found particularly interesting. On track, an offence is punished according to cause, not effect. If a driver causes a rival's car to retire, the effect that has is not taken into account when deciding the punishment.

Did Leupen's punishment take into consideration the dissemination of the story? Rival teams were cross that Toyota seemed able to comment on BoP without penalty when they were not but, while Toyota was given a slap on the wrist in terms of a suspended sentence, the warning was that there would be no such leniency in the future.

Applying BoP to a top class is never straightforward as the prize is too big, the cars too complex and the teams too well resourced. Personally, I'd love to see BoP gone from Hypercar. But then I'd also like to see hybrid dropped in favour of lighter weight, steel brakes instead of irrelevant carbon /carbon ones, and the return of h-pattern gearboxes. However, the key statistic for me at this year's Le Mans was that previously, no more than two cars had ever finished on the lead lap. This year, nine did.

ANDREW COTTON Editor