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THE BATTLE IN WHICH WE CAN NEVER DECLARE VICTORY

I **ALWAYS** smiled when William's editorial column trumpeted its arrival in my Inbox for a sanity check. "Okay, Kimbo. Who are we offending this month?"

A hard act to follow. Not least because he always knew whose cage to rattle, and how hard.

If you detect a tone of melancholy in my editorial voice this issue, it's with good reason. There can be no lambasting of gormless politicians; even the EV evangelists are safe this month. (Well, perhaps not *all* month: see our lead news story on Goodwood's staging of its first sustainably-fuelled race at its Revival meeting.) Instead, there's just the head-shaking disbelief that always accompanies motorsport's sudden, unexpected loss of one of its own.

World Rally star Craig Breen's business was to win stages, but it's no exaggeration to suggest that he also won hearts wherever he went. He wore his own heart on his sleeve and a smile on his face – a rare combination in elite sport these days.

How on earth could he be gone? This generation of hybrid World Rally Cars are spectacular, but we congratulated ourselves on the fact that they were the safest cars in rallying history.

No longer based on bodyshells that roll off the production line, the cars introduced last season can absorb up to 115% more energy in an impact on the roof than their predecessors, as well as ensuring 51% less protrusion in a side impact and 70% less in a frontal impact. The hybrid unit itself is designed to withstand impacts of up to 70G.

We have become used to the sight of the drivers scrambling out after the most hideous accident, and walking away.

They are fine cars. But Craig died in testing, when his Hyundai slid off the road at relatively low speed, only for a pole to seemingly go through the driver's side window. It is a chilling reminder that the quest to improve safety never ends, for this is a battle that can never truly be won.

From HANS to helmets, seat nets to spectator fencing, and from new materials to marshalling equipment and medical response, motorsport has made such staggering progress in recent years. Elsewhere in the magazine, Tino Belli, director of aerodynamic development for IndyCar – where cars can be lapping at nearly 240 miles per hour – reveals that in technical discussions the engineers describe their priorities as "safety first, safety second, safety third and entertainment fourth".

Across the board, motorsport has never been safer. But we can never relax. The relentless work in every single area must continue, identifying new weaknesses and addressing them.

If the task seems arduous, sometimes overwhelming, then it's worth recalling Craig Breen's huge smile, his sheer joy at doing the job he did, and his mantra: it's a privilege to work in this sport. RT

Mark Skewis
EDITOR

Jochen van Cawenberge

GOODWOOD DECISION GIVES eFUEL FOR THOUGHT

For the first time in Goodwood's 75-year history, this season's Revival 2023 meeting will feature a 100 per cent sustainably-fuelled race. Is this the way to go? By **Mark Skewis**

GOODWOOD has taken a step towards solving one of the dilemmas haunting historic motorsport, revealing that this September's Fordwater Trophy will see a grid of 20 pre-66 Porsche 911s race on synthetic fuels – the first time a race like this has been held.

"At Goodwood we are passionate about sustainability," the circuit said in a statement. "It is key to our ability to continue celebrating the iconic cars of the past.

"To that end, we are incredibly excited to announce that for the first time ever, the Goodwood Revival will in 2023 feature a race with cars entirely powered by synthetic fuels. The Fordwater Trophy will be a race of 20 pre-1966 Porsche 911s, each running without a drop of fossil fuels in them. As a sustainable fuel-powered historic motor race, it will be the first of its kind.

"It will prove quite the way to both celebrate 75 years of racing at Goodwood and 25 years of the Goodwood Revival, while giving a heartening look at how we can continue to do so long into the future, reducing our impact and helping to further-develop sustainable fuel options."

The Fordwater Trophy will act as a crescendo of Goodwood's year-long celebration of the world's most famous sports car, the Porsche 911. The Revival race list is completed by a further 14 races for everything from pre-war Grand Prix cars to sports cars of the early 1960s; the races join the previously-announced Carroll Shelby Centenary and 75 years of Lotus celebrations.

The announcement came weeks after the EU granted sustainably-fuelled cars an exemption from the forthcoming ban on the sale of new ICE vehicles. It was a decision that divided opinion: welcomed by some as the voice of reason; criticised by environmental group Greenpeace as "a lazy compromise" and denounced by others as a move that undermined the electrification of the automotive sector.

For some time now, motorsport has been championing the switch to sustainable fuels. From rallying to endurance racing, and from IndyCar down to karting, carbon-neutral fuels have been seen as the way forward. They are also a central part of the sustainability drive contributing to F1's resurgence in popularity.

Haru Oni trailblazer

It was fitting that Goodwood's announcement targeted the Porsche race, for the German sports car manufacturer has been a key protagonist in the move to eFuels: synthetic fuels that have the potential to be nearly carbon neutral and are made from CO2 and hydrogen using renewable energy sources. Porsche's 'Haru Oni' pilot plant in Punta Arenas, Chile, has been seen very much as the poster-child of the move towards the production of synthetic fuels.

"We will only meet our ambitious decarbonisation goals if we factor currently existing vehicles into the decarbonisation effort as well and operate them as close to net carbon neutral as possible," said Porsche's sustainability Team Lead Karl Dums last month of the manufacturer's objectives. "Worldwide, there are roughly 1.3 billion vehicles with combustion engines and our vehicles in particular are known for their longevity.

"So we've developed various different ideas for operating combustion engines as near to net carbon neutral as possible. It was clear to us that renewable energy will play a major role in solving the problem. And that's the basis for the concept of eFuels, which enable nearly-carbon-neutral operation of combustion engines.

"In their fundamental properties, they

LEFT No fossil fuels will be used in this year's Fordwater Trophy race

RIGHT Karl Dums, Porsche's Team Lead, sees a big future for eFuels

are no different than kerosene, diesel or petrol produced from crude oil. Porsche was one of the first companies to address the issue on political, regulatory and business levels – and we wanted to communicate that from the outset and create incentives for other companies to get involved."

Dums has been working at Porsche since 2008 and involved in innovative projects in the powertrain area from the very beginning. Initially with the electrification of the first Porsche vehicles, then with drive concepts. Most recently he headed the department for advance drive development and aggregate strategy, where the eFuels project was launched.

"For me, the topic of eFuels ideally embodies the combination of my passion for engines, sustainability, and Porsche's aspiration to be a technology driver," he said. "In the project, we are breaking new ground every day and have been able to see that Porsche is not afraid to consistently explore new paths."

"Renewable energy sources are not evenly distributed around the world," he explained. "In Germany we have rather too little, but in other places in the world they have more than they can use locally. The highest energy densities in the form of sun and wind are found in desert regions, for example, or in southern Chile. So the energy that exists there has to be transported to where it can be used. The production of eFuels makes that possible.

Industrial scale

"We at Porsche AG, in collaboration with HIF Global, Siemens Energy, ExxonMobil and other international partners, have decided to build the 'Haru Oni' pilot plant in Punta Arenas, Chile. We take advantage of the outstanding local conditions to exploit wind energy to produce eFuels."

With both the automotive and motorsport industries seemingly at a crossroads – exploring with hydrogen combustion and fuel cells, while pursuing EVs and eFuels – the big question is: what next?

> *"With eFuels we have blazed a technological trail that offers added value to the cause of sustainability around the world"*

BELOW Porsche is part of a group pioneering eFuels at Haru Oni, which is expected to be producing 550 million litres per year by 2027

"We have recognised the demand for and, above all, the benefits of eFuels and had the courage to embark on a new path, to develop a solution, and demonstrate that it's viable," said Dums. "The important thing now is for other players to pick up the ball and follow in the footsteps of Porsche. We believe that with eFuels, we have blazed a technological trail that offers added value to the cause of sustainability around the world.

"At the same time, there is also potential for other applications: beyond road transport, eFuels could also be used in the aviation sector, shipping or even the chemical industry. The key here is implementation on an industrial scale. We at Porsche will be involved in it through our investment in HIF Global.

"Electrification is not quite as easy to implement in the aviation and shipping sectors as it is in road transport, for example, and will therefore happen more slowly," he said. "I hope that we can manage to create true added value through the use of eFuels. It will allow us to demonstrate that Porsche is striving to be a pioneer in climate protection as well and that we're in the driver's seat." RT

Rallycross Promoter GmbH/Red Bull Content Pool

Loeb returns to rallycross in Delta Evo-e RX

NINE-time World Rally Champion Sébastien Loeb will make a full-time return to the FIA World Rallycross Championship this year behind the wheel of a Lancia Delta Evo-e RX, after joining forces with countryman Guerlain Chicherit in a two-car line-up at Special ONE Racing.

Loeb competed in World RX in a Peugeot 208 WRX from 2016 to 2018 – yielding a brace of victories and 15 further podium appearances from 36 outings. His ratio of top three finishes to starts is the third-best in World RX history, and in his final campaign, he was the only driver to prevent Johan Kristoffersson from taking a clean sweep of event wins.

Five years on from his departure, the Haguenau native is back, and in a uniquely compelling partnership, he is linking up with another icon in the shape of the Lancia Delta Evo-e RX – a car that channels the spirit of the much-loved Lancia Delta Integrale, which ruled the WRC roost in the late 1980s and early 1990s. Between them, Loeb and the Delta Integrale can lay claim to no fewer than 17 WRC titles.

"I'm from a generation that was brought up seeing wins by Lancia Deltas in rallying, so naturally I have a weakness for this car," the 49-year-old acknowledged, "but when Guerlain spoke to me the first time about tackling a rallycross season with it, I thought he was mad! Then I tried the car last December and was immediately won over by its dynamic qualities. I have great faith in this project and I can't wait to champion it on tracks around the world.

"I'm very motivated for the challenge, and I think rallycross is the ideal discipline for electrification because we have a lot of power and the races are short. These cars are exciting to drive, and World RX is the perfect platform to promote their evolution. The show on-track is just amazing, with great fights and even more spectacular action than before, and now we have the opportunity to attract a whole new generation of fans."

The team behind the project – Special ONE Racing – was born out of GCK Motorsport, whose founder, four-time Free Skiing World Champion Chicherit, gave the Lancia a promising debut in the 2022 World RX season finale at Germany's Nürburgring. Like Loeb, fellow Frenchman Chicherit is an experienced rallycross protagonist, with more than 40 starts to his name at the highest level and a trio of top five finishes.

"It's a dream of mine to be able to align two cars from my own brand with World RX, one of which is entrusted to a sporting legend," he enthused. "The scene is set to see Special ONE Racing become a top-notch team. From this season, we'll have the opportunity to make history, becoming the first to have a retrofitted car win a World Championship event. Let's get going!"

As a new player in the mobility landscape, Special ONE's aim is to manufacture and distribute exclusive, eco-friendly retrofits of classic sports vehicles, with the team's brace of new-generation, 500 kW (680 bhp) electric rallycross beasts – designed and built by GCK Performance and capable of out-accelerating a Formula 1 car to 100 km/h – based on the road-going Delta Evo-e. Special ONE Racing has committed to run its pair of Delta Evo-e RXs in World RX for at least three seasons. RT

ABOVE Loeb was impressed by his test in the Special ONE Racing Lancia Delta Evo-e RX


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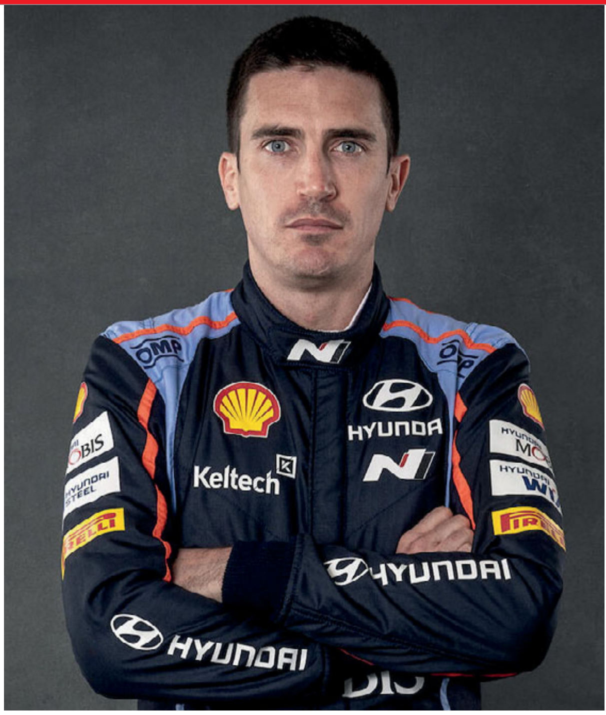

FIA reviewing fatal WRC crash

HYUNDAI Motorsport and the FIA are working together to review all aspects of the incident that cost rally star Craig Breen his life while testing ahead of last month's Croatia WRC event.

The new generation of WRC cars, believed to be the safest rally machines ever built, had already withstood a number of huge accidents since their conception for 2022. Rigorous safety tests on the new cars, ahead of their introduction to the WRC stages, revealed they can absorb up to 115% more energy in an impact on the roof, as well as ensuring 51% less protrusion in a side impact. However, the freak nature of the accident, which occurred at relatively low speed during a pre-event test on Croatian roads, was explained by Hyundai team principal Cyril Abiteboul.

Abiteboul confirmed that the Hyundai World Rally Team i20 N Rally1 had collided with a wooden fence, which had intruded the cabin of the car through the driver's side window.

"It's been a very emotional time for all of us," said Abiteboul. "Emotions are still raw and there has been an amazing outpouring of grief for Craig, who was an incredible person to know, as a team-mate, competitor and friend.

"Regarding the accident, road conditions were slippery and the car slid off the road at a relatively low speed and made contact with a wooden fence. A post from this fence intruded into the cabin through the driver's side window.

"The stage was closed immediately and the on-stage medical team was rapidly on the scene.

"We must mention that James Fulton [the co-driver] was unhurt in the crash and our hearts go out to him. We are doing everything we can to support James at this time.

"Craig was taken to hospital from the stage. As far as can be determined, Craig's passing was instantaneous.

"As far as can be ascertained, there was no issue with any element of the car, the tyres or the safety equipment. The local police completed a report at the scene."

Breen, 33, was well-known for his infectious enthusiasm and quick wit which won the hearts of fans across the globe. He began his second stint with Hyundai Motorsport earlier this year and had amassed an impressive nine podiums over 82 WRC starts.

Hyundai team-mate and close friend Thierry Neuville also shared a heartfelt message on social media, saying: "Today I've lost a team-mate but more than anything, I've lost a friend. Craig, your passion for rallying was immeasurable, your joy behind the steering wheel was beyond any of ours, your emotional stage end comments were in a league of their own. All this will stay deep in my memories. I will miss you! Rest easy my friend."

After careful consideration, which included discussions with Breen's family, surviving co-driver Fulton, and Hyundai Motorsport's crews and team members, the team decided to compete in Croatia but with a reduced two-car line-up. The cars carried a special tribute livery to honour Craig, his Irish roots and his beloved Irish rally community.

Kris Meeke, who drove alongside Breen during his early years with Abu Dhabi Total World Rally Team, was one of many to pay tribute, saying: "Craig, this morning you woke up the happiest man alive, living your dream. My lasting memory of you won't be as a top-class rally driver, but as the guy who took time with my kids and made them laugh more than I could. You were a larger-than-life character and battled your way to the top with pure passion. Can't believe it. Keep 'er lit up there... You will be sorely missed." RT

ABOVE LEFT & BELOW WRC crews paid tribute to Craig Breen in Croatia

Jaanus Ree / Red Bull Content Pool


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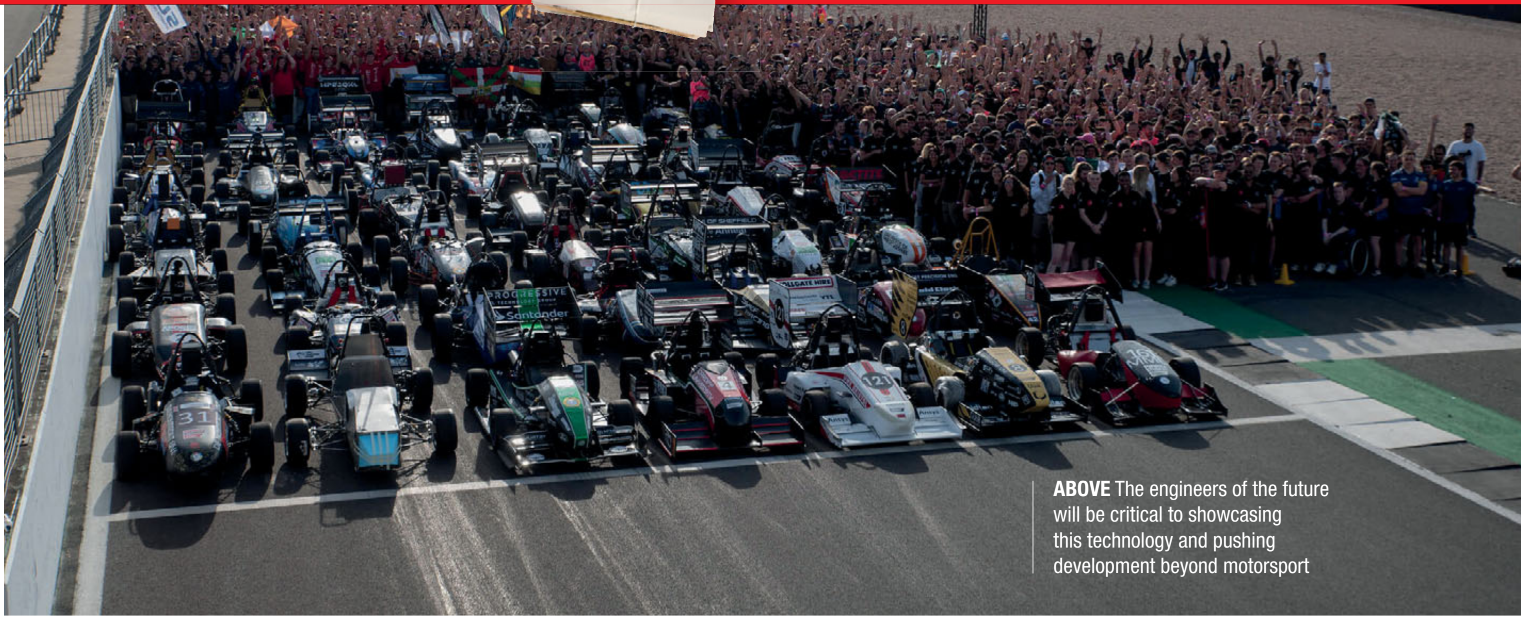

ABOVE The engineers of the future will be critical to showcasing this technology and pushing development beyond motorsport

Motorsport UK grant secures sustainable fuels for Formula Student

FOR the first time, Formula Student will offer sustainable fuel options for teams developing internal combustion vehicles in the upcoming competition, which celebrates its 25th anniversary this year.

Motorsport UK, the governing body for motorsport in the UK, has provided a grant for entrants to use Coryton sustainable fuels in ICE powertrains within the Formula Student competition.

The sustainable fuels provided by Coryton will offer an 80% reduction in greenhouse gas emissions for the combustion vehicles using it at Formula Student, when compared to fossil fuel-based equivalents, without sacrificing performance. It will also bring the competition in line with Motorsport UK's objectives to achieve greater sustainability across all motorsport series.

Organised by the Institution of Mechanical Engineers, Formula Student challenges teams of university students to create a functional prototype of a single-seater race car, enabling them to become well-rounded engineers with practical experience in addition to their academic studies.

First announced during the 2022 finals event, teams running internal combustion vehicles will now have the chance to use one of two 100% sustainable/non-fossil fuels – an E85 and a 95 RON E10 – as well as the standard 99 RON that has traditionally been provided. The sustainable fuels are second generation biofuels, made from agricultural, forestry and food processing waste. The carbon in the fuels is effectively recycled from the atmosphere, rather than additional CO_2 being released from fossil fuels.

Hugh Chambers, CEO of Motorsport UK, commented: "The 2023 Formula Student competition is a fantastic opportunity for the automotive and motorsport engineers of the future to experience and deploy leading edge technologies in a stimulating motorsport scenario. By funding the use of sustainable fuels for those teams that choose an internal combustion engine, we hope to inspire the next generation of engineers to have a broad view of the future technologies of propulsion."

David Richardson, business development director at Coryton, said: "We're delighted to be involved with Formula Student and to get the opportunity to showcase the potential of sustainable fuels when it comes to the continuation of the ICE. As we often say – the ICE in itself is not 'dirty', it's only the fossil fuels used within it. Sustainable fuels are here and ready now, and should be used alongside every available technology to help tackle climate change.

"Obviously F1 and other motorsport organisations see the potential of sustainable fuels and it's important that the next generation of engineers have the opportunity to be involved. We feel passionately about securing the future of automotive engineering at the grassroots level. Electric-only courses very much have their place but it's vital to show that mechanical engineering can also have a clean future ahead too."

While the number of university teams developing electric cars for the competition mirrors the same trend in the automotive industry, the provision of these new sustainable fuels is part of Formula Student's commitment to support teams of students that are not able to make a change to electric powertrains in the near future, whether due to economic or technical limitations.

"Offering sustainable fuels for the IC entries is a key part of our broader strategy to remain technology agnostic and keep the barriers to entry as low as possible," said Dan Jones, Chief Judge for the Formula Student competition. "This ensures that as many students as possible have the opportunity to take part in Formula Student, as well as demonstrating that combustion powered motorsport has a sustainable future."

This development follows the growing trend across all motorsport series, with race series such as Formula Two and Formula Three also debuting a 55% mix fuel in 2023 and Formula One working to develop a 100% sustainable fuel as a key part of its commitment to reach Net Zero Carbon by 2030 and full use of sustainable fuels by 2026.

This year's Formula Student will take place between 19-23 July 2023 at Silverstone. RT


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LEFT & BELOW A total of 4.97 kg of ballast will be redistributed to the rear of the Camaros to match the Mustang's CoG

Supercars defends CoG changes as it sticks to parity pledge

SUPERCARS has moved swiftly to ratify a centre of gravity (CoG) change to equalise the two Gen3 models fighting for the 2023 Repco Supercars Championship crown.

CoG testing took place after the Beaurepaires Melbourne SuperSprint last month. Nine cars from a number of teams were tested at Tickford Racing's Campbellfield headquarters. A difference of 2.3 mm was measured between the average of the Gen3 Ford Mustangs and Chevrolet Camaros.

In response to the difference, Supercars has ratified an adjustment of 4.97 kg on the bar just behind the fuel cell of the Camaro. The changes are in line with the adjustments seen on the Gen2 Ford Mustang in 2019.

All 14 Camaros will now compete with redistributed weight in a move designed to raise their centre of gravity to match that of the Mustangs.

The changes do not affect the overall 1335 kg minimum weight for each car – 4.97 kg of ballast is simply being moved to the rear of the Camaro.

"To be clear, this isn't adding a new 4.97 kg – this is redistributing existing ballast in the car," Supercars Head of Motorsport Adrian Burgess explained. "It's not a major adjustment by any means, it's a small number – but this is a parity series.

"In comparison, 10 kg of fuel is far more powerful than the adjustment we've just made for the CoG."

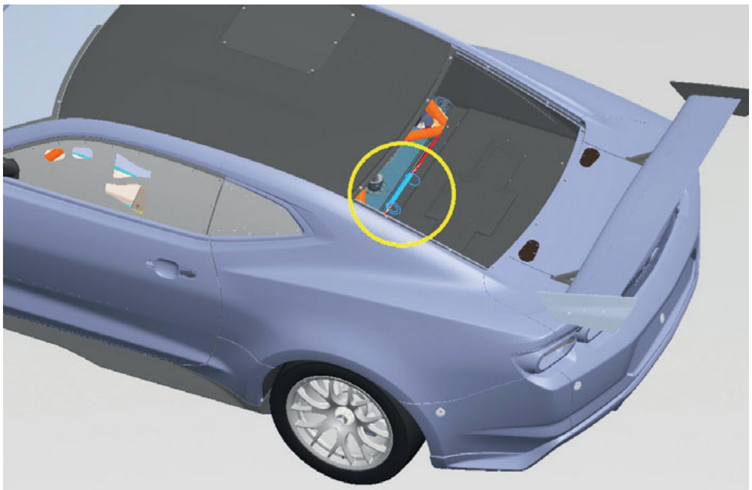
Such was the small difference between the cars going into the test, that the Gen3 changes equate to six per cent (1.8 kg) of the 28 kg ballast total from the 2019 changes.

Burgess reiterated that while it is a small number, Supercars was determined to uphold the championship's technical parity formula. "Coming into this, we knew the cars were already very close," Burgess added. "We did the test at Tickford, and there was 2.3 mm difference in CoG.

"In 2019, we needed to put 28 kg of weight as high as we could get it on the roof bar of the Mustang. On this occasion, if we needed to put weight in the same place, it would only be 1.8 kg.

"It's better for the teams to put the weight further back, because that will bring the front axle weights closer together."

The latest move came after changes to the Gen3 chassis were recently signed off by the Supercars Commission and Technical Working Group. The TWG approved some modifications to the front and rear clips, and chassis, to improve the impacts of damage learnt from Albert Park. RT



"Gladiator" Allison tasked with leading Merc out of the wilderness

JAMES Allison, hailed by Mercedes colleagues as "a gladiator", is to return to the Technical Director role as Mercedes seeks to reverse its fortunes.

Allison joined Mercedes in 2017, initially working as Technical Director before becoming Chief Technical Officer four years later, which led to him combining F1 with other projects such as the INEOS Britannia America's Cup team.

Mike Elliott succeeded Allison as Technical Director in 2021, only for 2022's major 'ground effect' regulation changes to signal a shift in the F1 pecking order, with Mercedes going from perennial title winners to a distant third in the championship.

BELOW Allison returns as tech director as Merc looks to change the philosophy of its F1 car

Elliott now takes the Chief Technical Officer role, in a job swap that Mercedes boss Toto Wolff suggested was proposed by Elliott himself.

"This was very much driven by Mike Elliott owning the process. So, we have reversed the roles," Wolff told *Autosport*. "Mike has moved up to CTO, as he has a brilliant switched-on scientific mind. And James Allison has returned to his Technical Director position, reporting into Mike.

"What Mike's assessment was, and the introspection is really admirable, is that with James we have a gladiator on the field and the troops are going to go through the fire for him and with him.

"Mike came to the conclusion that the way he approaches things, his skill set, is best utilised in developing the organisation going forward: from technical capabilities to human capabilities and putting together the structure that can be successful for many years to come."

Glittering record

Allison boasts a wealth of F1 experience beyond his championship-winning time at Mercedes, also picking up drivers' and constructors' titles at Renault and Ferrari in a career that started back in the early-1990s.

He had oversight of the 2022 design, the W13, but he was not in overall control.

Mercedes was caught out by porpoising last season as it pursued encouraging downforce figures in aero simulations as F1 reintroduced ground-effect. It weighed a switch of aero philosophy for this year's W14 challenger, but instead opted for an evolution of last year's model, which has proved too slow. The car has been rid of its terrible bouncing, but at the cost of outright pace.

Following the disappointment of this year's initial races, there have been calls for a switch in philosophy, most likely towards the Red Bull-style design that Aston Martin has pursued this year with early success.

That kind of fundamental shift, especially working under a cost cap, takes time and most likely dooms Merc to another poor campaign. If the team does bounce back, it will be in no small way due to Elliott's lack of ego.

He is a talented engineer, who played a key role in Mercedes' success as it dominated the start of the turbo hybrid era. But to acknowledge that the switch to Technical Director did not necessarily suit his skillset was indeed, as Wolff admitted, an "admirable" call. RT

LEFT The WEC is pursuing a tyre development roadmap

Goodyear wins tender for new WEC GT3 class

GOODYEAR will become the exclusive tyre supplier for the FIA World Endurance Championship's incoming LMGT3 class.

The appointment of the American tyre manufacturer, which is already an exclusive supplier to FIA WEC's LMP2 class, was approved by members of the FIA World Motor Sport Council via electronic vote. It covers a three-year period, starting from the 2024 season.

LMGT3 is set to replace cars built to LMGTE technical regulations that have been on the FIA WEC grid since the series' inaugural season in 2012. The new GT class will be based around the FIA's existing GT3 technical platform and will continue to focus on gentlemen drivers who have always been an integral part of the FIA WEC.

As part of the WEC tyre development roadmap, any form of tyre heating has not been permitted since the beginning of the 2023 season, while the amount of available tyre specifications in the Hypercar class has been reduced to two per circuit (and three for the 24 Hours of Le Mans) from 2023. A move to a single specification per circuit (and two for Le Mans) is the next short-term target, while the LMP2 class has already shifted to single specifications for both dry and wet tyre types.

Richard Mille, FIA Endurance Commission President, said: "Tyres are one of the key areas which will evolve over the next couple of years. We have already moved away from tyre heating and we will be gradually reducing the number of available tyre compounds, therefore having an experienced partner that already knows both the FIA World Endurance Championship as well as GT3 racing is an asset. The fact that LMGT3 cars will run on commercially-available, off-the-shelf tyres is also a positive development that will bring down the costs for competitors."

Pierre Fillon, President of the Automobile Club de l'Ouest, said: "We are delighted to have a highly reputable tyre manufacturer on board as the LMGT3 class prepares to hit the track next year. The teams will benefit from Goodyear's expertise in supplying quality tyres at a competitive cost. Thanks to Goodyear for their commitment to endurance." RT

Audi's F1 drivetrain to run by year's end

AUDI has revealed that its first full hybrid F1 drivetrain unit, consisting of the combustion engine, electric motor, battery and electronic control unit, is scheduled to run on the test bench before the end of this year.

By that point it will have recruited in excess of 300 specialists to work on the project, which races for the first time in 2026.

The F1 show car, with striking launch livery, was a central element of the brand's presence at Auto Shanghai. There, with the Chinese GP cancelled for a fourth time by the pandemic, Audi CEO Markus Duesmann provided an insight into the current progress of the project.

"Motorsport is an integral part of our DNA," said Duesmann, Chairman of the Board of Management of Audi AG. "We are convinced that our Formula 1 commitment will strengthen Audi's sporting focus. The racing series is continuously increasing its global reach, especially among young target groups and in our most important sales market: China."

"The Audi Formula 1 project has really taken off in recent months," revealed Oliver Hoffmann, Member of the Board of Management for Technical Development at Audi AG. "In the ongoing concept phase of the power unit, the foundation of our drivetrain for 2026 is being laid today. We attach great importance to detail work, for example on materials or manufacturing technologies, and we also focus on topics such as the energy management of the hybrid drivetrain. After all, efficiency is a key success factor for Formula 1 and the mobility of the future, these approaches will advance both worlds." RT

ABOVE Audi gave Chinese F1 fans a preview of its GP project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FE report: high performance and sustainability can co-exist without compromise

FORMULA E has published its Season 8 Sustainability Report, entitled Racing For Better Futures, which details the most impactful year to date of the first sport in the world founded with sustainability at its core.

The highlight of Season 8 was the launch of the Gen3 in Monaco, regarded by fans as the spiritual home of motorsport. It is the fastest, lightest, most powerful and efficient electric race car ever built.

The Gen3 is powered by electric motors that are, notes the series, substantially more efficient than internal combustion engines (ICEs), converting more than 95% of the electrical energy compared to approximately 40% in the high efficiency ICEs of other motorsports.

Likened to a 'power station on wheels', the Gen3 produces more than 40% of the energy it consumes in a race through regenerative braking. It is also the first formula car aligned to life cycle thinking, with a clear path towards second life and end of life for all tyres, broken parts and battery cells.

It is the first formula car to use linen and recycled carbon fibre in bodywork construction, with all waste carbon fibre reused for new applications. Natural rubber and recycled fibres make up 26% of new Gen3 tyres which are fully recycled after racing.

Jamie Reigle, Chief Executive Officer, Formula E, said: "As we publish our Season 8 Sustainability Report, interest in motorsport has never been higher. The global reach of the sport provides a powerful platform to engage hundreds of millions of fans across the world in taking positive action to combat climate change. At Formula E we take our leadership role seriously by driving the agenda and setting the benchmark for sustainable sport. We are delighted to see others across the sports spectrum follow our lead.

"We are proponents of an electric future and are adamant that elite sport, high performance and sustainability can co-exist without compromise. Formula E is committed to pushing boundaries at the cutting edge of technology, performance and sustainability. The launch of the Gen3 race car during Season 8 is evidence of our commitment. The Gen3 is the world's most efficient race car and described as a machine created at the intersection of high performance, efficiency and sustainability. The Gen3 made its racing debut this year, grabbing the attention of audiences and showcasing an exciting, electric future for motorsport."

The new report highlights more key social projects over 2021/2022, including ongoing work through the charity partnership with UNICEF and its Safe and Healthy Environment Fund; the FIA Girls on Track activations; and legacy projects in race locations that directly benefit the communities where races take place.

Key initiatives and commitments that benefit the planet are also highlighted, with a continued commitment to maintaining the championship's net zero carbon status from inception. Formula E was the first sport in the world to achieve such status and last season announced a 24% emissions reduction on Season 5's baseline – well ahead of the science-based target of a 45% reduction by 2030.

Formula E was also independently ranked and recognised as the most sustainable sport in the world by the Global Sustainability Benchmark in Sports (GSBS) in

addition to maintaining the International Standard for Sustainable Events (ISO 20121) and the FIA Three-Star level for Environmental Accreditation.

Metrics of the positive impact that its sustainability initiatives have had include the partnership with UNICEF benefiting nearly 700,000 children around the world affected by climate change; hosting 450 girls as part of the FIA Girls on Track programme; investing more than €500,000 in multiple philanthropic causes globally; and over €110,000 on a variety of community engagement initiatives in all host cities.

Julia Palle, Sustainability Director, Formula E, said: "Season 8 was another significant year for Formula E in maintaining and progressing our ambitious sustainability strategy. With a dual focus on using the ABB FIA Formula E World Championship to benefit both people and the planet, we developed additional initiatives that go above and beyond some of the world-leading work we've completed to date. Whether it's focusing on children, local communities, gender diversity, environmental excellence or developing cutting-edge technology that will transform the future of the EV market, we're committed to using our core sustainability purpose to mitigate the impacts of climate change and accelerate sustainable human progress for all." RT

ABOVE All emissions associated with the development and production of the Gen3 race car have been offset

IMS quest to become "most sustainable motorsport venue in the world"

INDIANAPOLIS Motor Speedway (IMS), home to the largest single-day sporting event in the world, the Indianapolis 500, has celebrated another landmark in its quest to become the "most sustainable motorsport venue in the world". It recently revealed that it had become the first sport facility to achieve organizational certification through the Council for Responsible Sport.

Organizational certification became available for the first time in August 2021. The new standard is based on the recognition of the following core principles: power of sport, resolution of climate change, enablement of social justice and business of sport.

IMS was the first to commit to the new framework, implementing year-round tracking of environmental and social impacts for the more than 300 events hosted at IMS annually. Previously, in 2021, the Indianapolis 500 presented by Gainbridge was certified a responsible event.

> *"This should be celebrated as vigorously as any chequered flag waved on the famous Yard of Bricks"*

The Council provides a structured approach for event hosts and organizers to measure, implement, validate and improve the social and environmental sustainability of their events and venues. Certification is earned by taking action spanning five categories: planning and communications, procurement, resource management, access and equity and community legacy. IMS ultimately accomplished 210 credits across these categories, earning silver level distinction as a Certified Organization.

"IMS' commitment to embrace social and environmental realities and to implement a systematic approach to setting goals, adapting operations and measuring progress is outstanding," said Rico Tesio, Council for Responsible Sport board chair. "Achieving Responsible Sport certification at an organizational level is not only a real milestone in the venue's own storied history but also demonstrates leadership in motorsport and beyond and should be celebrated as vigorously as any chequered flag waved on the famous Yard of Bricks."

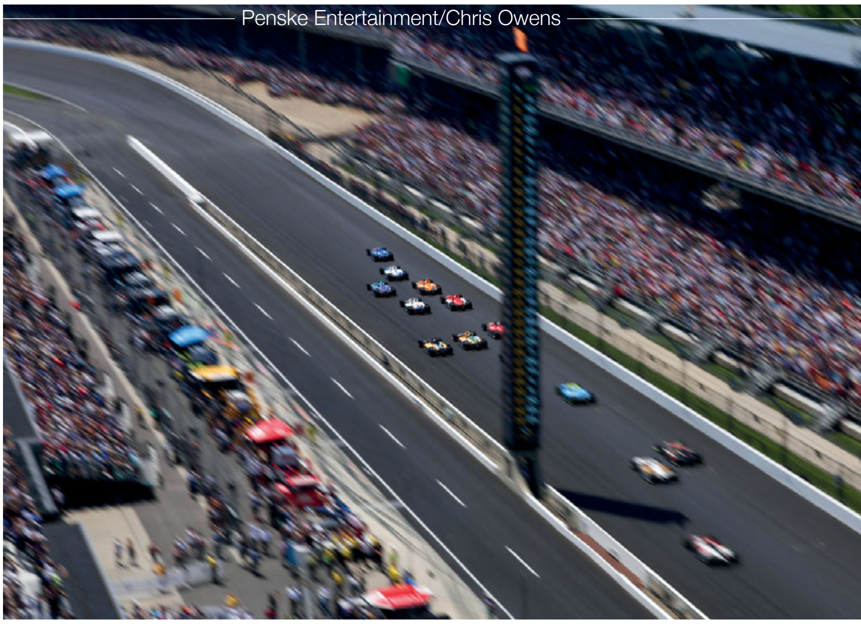
Key partnerships and the implementation of new tracking technology helped IMS achieve this landmark goal. With the addition of the new organizational certification, the Council implemented ReScore, a system designed to help venues track their progress. WM Sustainability Services was critical in IMS' sustainability journey, providing support by documenting a variety of resource management credits relating to emissions calculations, waste diversion and energy consumption.

"This is a monumental and impactful achievement for the Indianapolis Motor Speedway, earned through a comprehensive commitment to innovation and hard work that safeguards our community and leads the way in our sport," IMS President J. Douglas Boles said. "We learned a lot in 2021 when we received our event certification for the Indy 500. That process helped us get to this moment, where we are now tracking the impact of our events throughout the year and implementing systemic programs that yield results.

"We remain committed to becoming the most sustainable motorsport venue in the world, and we are grateful for the support and enthusiasm shown by our fans as we continue to identify new opportunities to encourage their participation in this journey."

As part of the new certification, IMS implemented new standards and procedures. This includes the development of a diversity, equity and inclusion plan, along with a public commitment to the measurement and mitigation of environmental impacts. IMS expanded waste diversion efforts beyond the Indianapolis 500 to include events hosted at IMS year-round. Additionally, IMS adopted new procurement policies and protocols, eliminating single-use plastic and Styrofoam in office spaces, in addition to prioritizing purchases from women- and minority-owned businesses and businesses with sustainability related certifications. RT

BELOW IMS, the world's largest spectator sporting facility, is the first sport venue to receive Silver Responsible Sport Certification


Penske Entertainment/Chris Owens

RIGHT OEMs are keen to showcase battery technology that is improving in leaps and bounds, but how will that impact motorsport's future role?

IS THE WAY AHEAD CRYSTAL CLEAR?

With the electrification of motorsport shining the spotlight on battery technology, **Chris Pickering** talks to one of the country's leading experts on the subject, Professor David Greenwood

CRYSTAL balls must have been in great demand over the past decade in the motor industry. Even now, with the UK and the EU set to ban the sale of new fossil-fuelled cars by 2035, there appears to be a degree of back-tracking around the regulatory minefield that is vehicles designed to run solely on synthetic fuel.

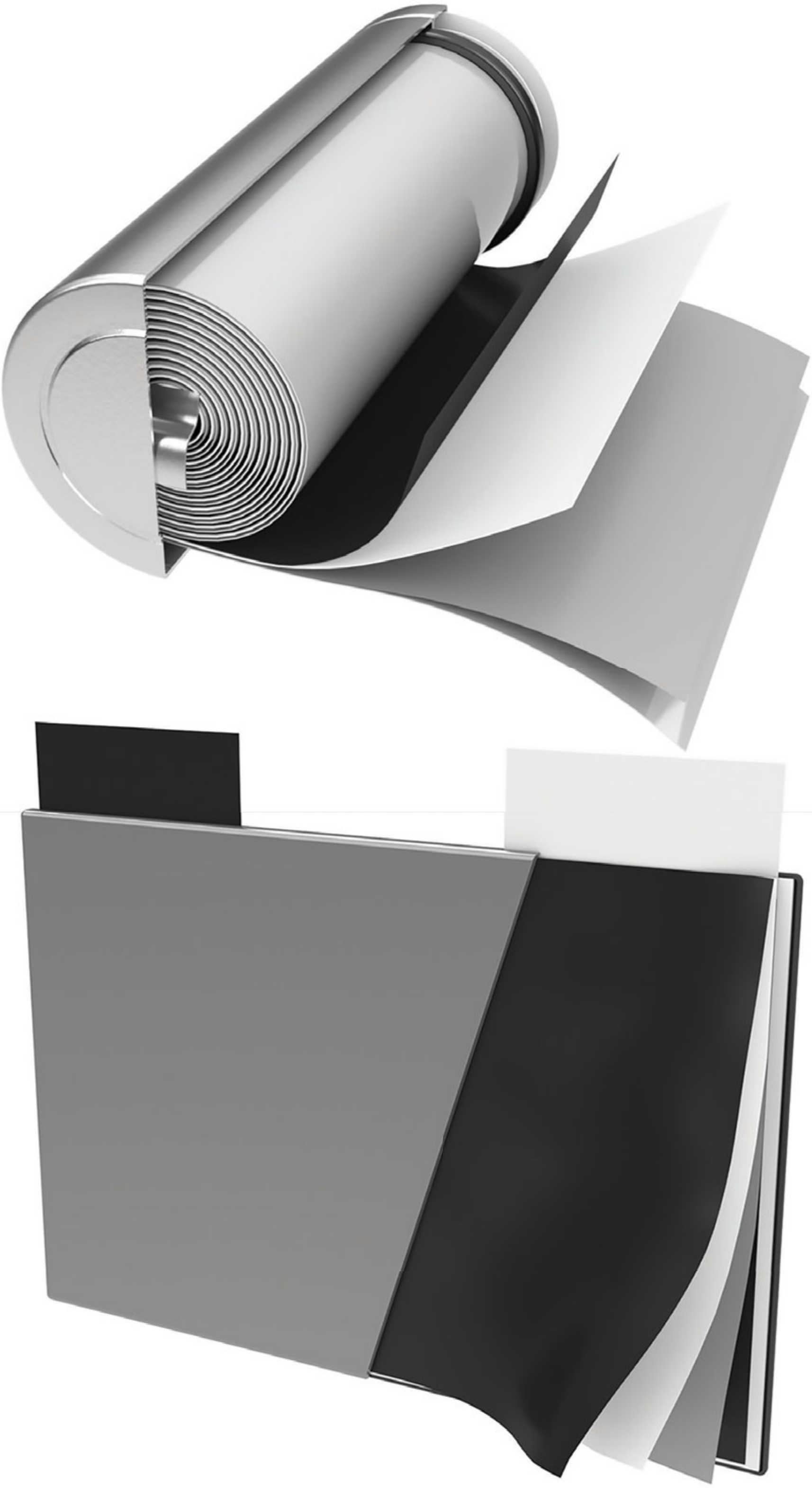
Could the combustion engine still be granted a reprieve in the mainstream? It's hard to say, but the political will – driven by air quality concerns as much as climate change – still seems to be very much focused on battery electric vehicles.

And that's hugely significant for motorsport. We could spend all day debating the relative strengths of fuel cells, hydrogen combustion and synthetic fuels, but if the OEMs and the key sponsors are keen to attach their name to electrification, it's where a substantial proportion of professional-level motorsport will continue to head.

Race Tech doesn't have a crystal ball either, but we have enlisted the help of the next best thing. Prof David Greenwood from Warwick Manufacturing Group (WMG) is one of the country's leading battery experts. His previous credits include work on the original generation of Formula 1 KERS systems and a stint as head of Hybrid and Electric Systems at Ricardo.

To fully understand the situation facing electric motorsport, you must first look at its context within the wider world of battery production, he points out: "We've seen a huge reduction in battery costs over the last decade – pretty much by a factor of 10, from $1,000 per kWh in 2012, down to roughly $120 per kWh if you're buying in huge volumes for passenger cars now. Part of that is thanks to less expensive materials, but a big part of it also comes from economies of scale and massive improvements in manufacturing technology. Both are significant if you want to make a small batch of batteries for motorsport."

With traditional powertrains, motorsport has been able to manufacture highly specialised components largely independently of other industries. A single well-equipped machine shop could still produce the majority of a Formula 1 engine in a small and comparatively affordable facility. Cell manufacturing, on ▶



the other hand, is generally tied to vast facilities that are beyond the means of even the wealthiest organisations in the sport. And the same goes for most of the research and development work that's being poured into cell chemistry.

"We often talk about battery factories operating at giga-scale," comments Greenwood. "A gigawatt hour (GWh) is 1,000 megawatt hours (MWh), so a gigafactory is one that can produce thousands of megawatt hours' worth of batteries per year. A 10 GWh factory will supply about 160,000 cars a year, which is roughly what a premium automotive manufacturer like Jaguar Land Rover or BMW might need for a single model in its line-up. In contrast, the total volume for motorsport would probably be measured in megawatt hours at best."

At very large scales, this becomes a very cost-effective way to produce batteries, but the upfront investment remains huge. A full-scale battery factory for a car company costs somewhere in the region of £2-4bn. An F1 team could build one big enough to suit its own needs for about £20-30m – but still way outside the reach of most motorsport formulae.

Even the aerospace industry – traditionally seen as a volume market compared to top-end motorsport – may struggle to make its voice heard over the demands of the far more lucrative passenger car segment. WMG is understood to be working with some of the biggest names in aerospace, and it's said that their annual requirements for battery supply could be covered by a single gigafactory in just one week.

"I think it's possible that we could see the emergence of some specialist cell providers catering to the needs of industries like aerospace and motorsport. But they're going to be low-volume, high-value products, so I would expect them to be coming in at 10 times the $120 per kWh that we're seeing for passenger car batteries or possibly more. It's going to be an expensive game to play," comments Greenwood.

An easier and more cost-effective solution would be to work with the cell chemistries developed for mainstream applications. Here, motorsport has already demonstrated a talent for repackaging off-the-shelf cells with battery management systems (BMS), cooling systems and structural designs that are far better optimised for the industry's unique requirements. Greenwood points out that these are also areas where there's some genuine potential for technology transfer from motorsport back into other industries.

A tale of two chemistries

If motorsport is to make use of the R&D work and manufacturing facilities set up for mainstream automotive, we come back to the question of which technologies this industry is likely to pursue. At present, Greenwood explains, there's something of a divergence between two ends of the market.

"We're seeing a tendency for long-range premium vehicles to use a high-nickel chemistry, which is generally nickel-cobalt-manganese (NMC)," he comments. "Whereas, with the charging infrastructure

LEFT The anode-electrolyte-cathode sandwich can be rolled into a cylindrical cell (above) or stacked like layers of lasagne to form a pouch cell (below) or a prismatic cell

BELOW The original KERS concept was criticised at the time but its balance of power and energy, which was pitched cleverly, did contribute to the development of battery technology

rapidly improving, the market for suburban commuter vehicles is moving towards cars with a shorter range of perhaps 150 to 180 miles at much lower costs. If you don't need the very high energy densities of the premium cars you can do it with much cheaper chemistries, like lithium ion phosphate (LFP)."

LFP chemistry can be used for very high-power batteries as well as very low-cost ones – in fact, the first KERS cells were LFP. Unfortunately, the form of LFP the car industry is interested in is the cheaper, more energy dense version.

NMC-type chemistries are far more promising for motorsport, and the market there is certainly big enough to sustain production, but these are still far from perfect for competition use.

There is an inevitable trade-off between power and energy in a battery. In a lithium ion cell, the anode is typically graphite, while the cathode is made from a layered metal oxide. Between them sits a polymer separator that's soaked in a liquid electrolyte (at least, it is for the moment, but we'll get onto that later).

During discharge, the lithium ions flow from the anode to the cathode, while the opposite is true during charging. In either case, the power of the cell is theoretically governed by the speed at which these ions can pass into or out of the electrode materials. This, in turn, comes down to the materials' internal structure.

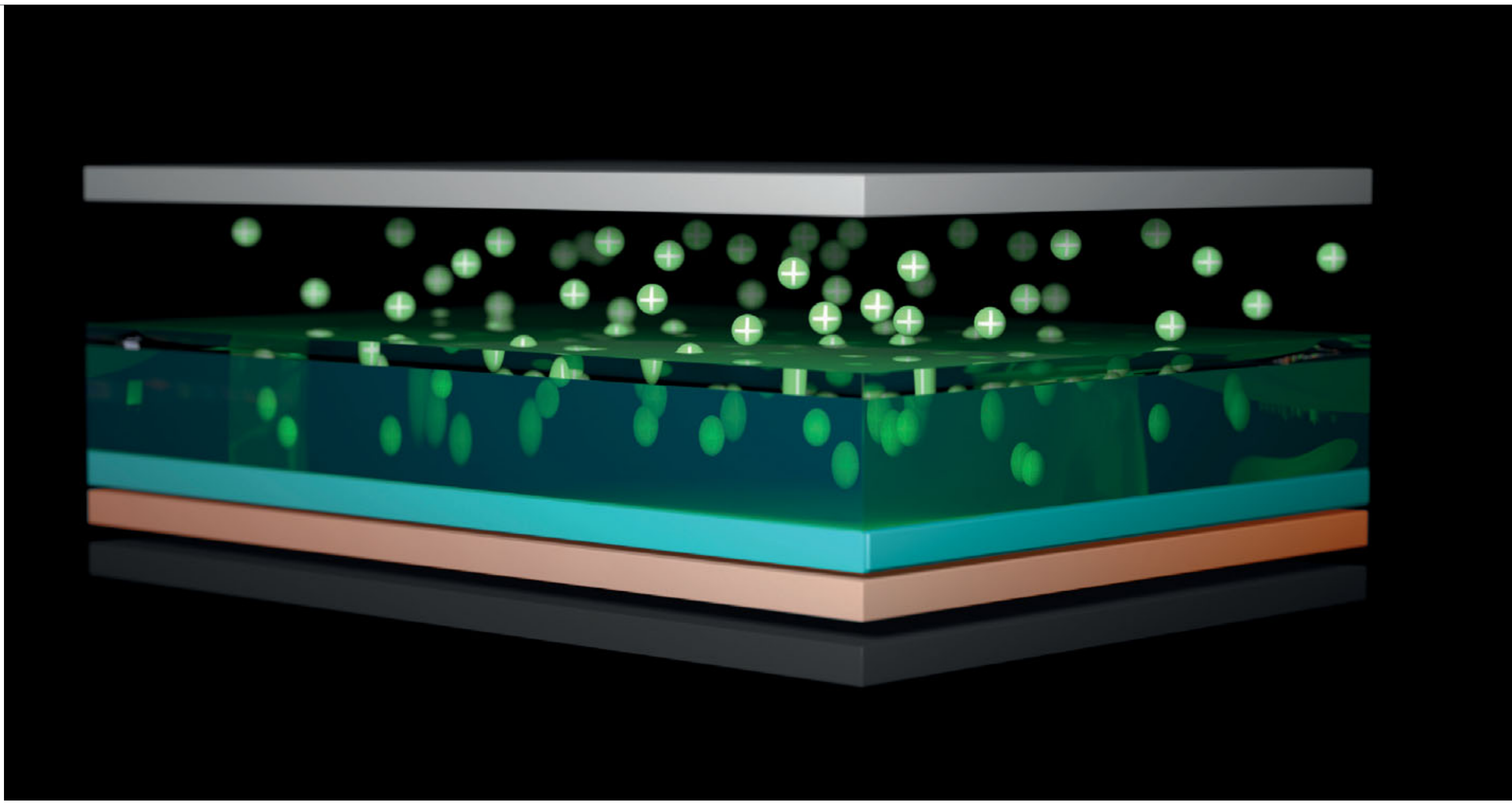
> *"The KERS systems were cleverly pitched just outside the trade-off capability of any battery technology on the market at the time"*

Loosely speaking, the more porous the material is, the more power it can produce. Unfortunately, when it comes to energy density, the material needs to be packed as tightly as possible, which reduces the internal surface area and limits its power capability. As such, there is a fundamental trade-off between the two.

"A key characteristic of any cell is its power-to-energy ratio, which is the amount of power it can supply as a proportion of its energy," explains Greenwood. "In a typical motorsport application, we're mostly interested in the power, which puts the cells into the top corner of this power-to-energy chart. Some chemistries will give you a better trade-off between those two attributes than others, but you'll never escape it completely."

Interestingly, this is one of the areas where motorsport has already played a significant role. ▶

Ferrari



ABOVE Could solid-state technology find its way into categories like Formula E and Extreme E?

The first generation of KERS systems in Formula 1 allowed up to 60 kW of power output and 400 kJ of energy storage, which posed a particularly interesting problem for the engineers working on the project.

"That balance of power and energy was pitched really cleverly, as it put the KERS systems just outside the trade-off capability of any battery technology on the market at the time," Greenwood recalls. "Formula 1 teams have huge budgets – far higher than virtually any other form of motorsport – and through their parent OEMs they were able to access some of the companies that had this technology. They then took those battery designs and applied the mindset of mechanical and thermal engineers rather than an electrochemist's mindset, and they increased the power-to-energy ratio of those batteries by a factor of four. That played a really significant role in battery development."

Greenwood can foresee the potential for motorsport to feed into cell development like this in the future, but he acknowledges that it's likely to be the preserve of big-budget teams backed by wealthy OEMs: "If there is enough commercial interest from the battery companies, then motorsport could play a really interesting role. There is a market requirement for high power density batteries – it's just not one that most of the battery companies are focused on currently."

As with traditional powertrains, there are limits to which technologies could realistically make their way onto road cars, but the potential is out there, he emphasises: "Even the work on the high-power batteries could potentially flow down into road cars, as long as it becomes affordable. If it's reliant on things like high-cost carbon fibre composites that can't be recycled at end of life, then that's unlikely to happen. But if we do it by developing new cell formats and cooling systems that enable better use of space and lower cost solutions, we could see that trickle down to the mainstream."

No silver bullet

Energy density will remain a key topic for motorsport. Mass-produced lithium ion batteries currently lag behind the energy density of liquid gasoline by a factor of around 50 to one, and while this is expected to improve, it will never come anywhere close to parity. As such, it's extremely unlikely that the current Formula 1 template of very high speeds and durations of nearly two hours will ever be possible with battery electric vehicles.

"The challenge at the moment is that the Formula 1 regulations aren't moving in the same direction as passenger cars in terms of technology," notes Greenwood. "They're still very much focused around internal combustion engines with liquid fuel providing the main energy source, and a level of hybridization that pushes the battery into a very high power-to-energy ratio. Replicating that format with a pure battery electric powertrain won't be possible for a very long time."

Every so often, you see a headline that suggests otherwise, with the promise of a miraculous new battery technology that will lead to a step-change in ▶

> *"I'm not convinced motorsport would be an immediate application for solid-state"*

energy density when it arrives. Unfortunately, the reality is that there's no such 'silver bullet' on the horizon.

"Often the root of these claims is a university that's done some really good research at a material level, and they've discovered that you can make a 10-micron particle work really well," comments Greenwood. "If someone then takes a calculator and multiplies that up to the size of an EV battery it can lead to these incredible predictions. What that omits is all of the engineering challenges involved in scaling that up to the final product. So unless those claims are made by an organisation that has got visibility of all those challenges, they definitely need to be taken with a pinch of salt."

Another point to bear in mind is that none of these technologies exist in isolation. They can take many years to perfect, during which time other chemistries will have inevitably emerged too. The end result is that even those that did represent a genuine step-change from the state-of-the-art when they started off in the laboratory may simply be another incremental improvement by the time they reach the market.

Solid-state

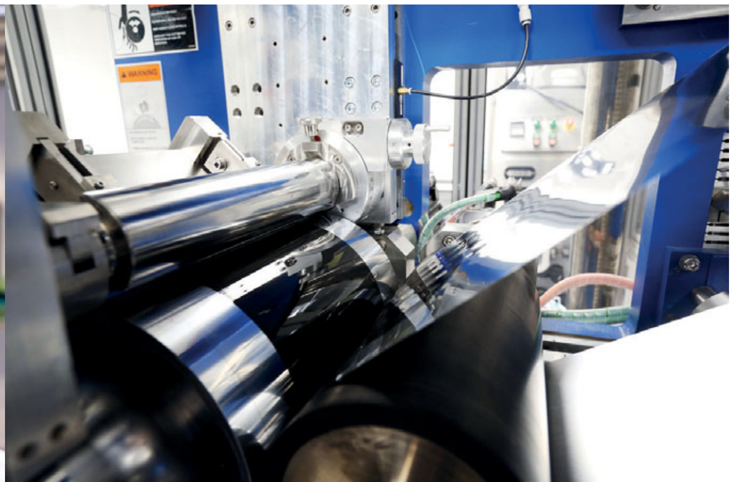
One of the most eagerly-awaited technologies at present is the solid-state battery. Here, the liquid electrolyte between the two electrodes is replaced by a thin layer of solid material – hence the name. As with conventional batteries, the anode-electrolyte-cathode sandwich can then be rolled into a cylindrical cell or stacked like layers of lasagne to form a pouch cell or a prismatic cell.

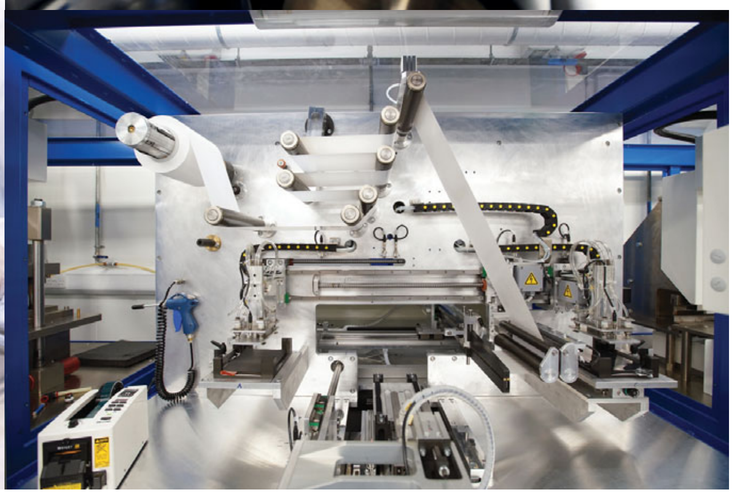
The use of a thin layer of material for the electrolyte means that the cells can be smaller and lighter for a given energy capacity. But where things get really interesting is when this technology is combined with another concept commonly known as the anode-less battery. This term, Greenwood points out, is something of a misnomer as the cell still has an anode. However, instead of the usual graphite acting as a sponge to absorb lithium, it's just a thin film of lithium metal.

"When you do that, you can get a really big change in energy density, because you're getting rid of pretty much a third of the material in the cell, so we're talking about perhaps a 30 per cent improvement on the current state of the art," he comments.

Predictably, there's a catch: "There are two types of an anode-less battery right now. There are the ones that we can make that don't work. And there are the ones that do work, but which we can't make," quips Greenwood. "What we don't yet have is a working battery that we can produce in volume. That's probably about eight years away." ▶

BELOW The University of Warwick's research focuses on the design and manufacture of innovative battery concepts across multiple sectors





There are prototypes that have shown promise in the lab, but not at the sort of temperature, pressure and physical format that would be needed for use in a car. Some designs, for instance, need to be held at elevated temperature and pressure. As such, the energy density improvements seen at a cell level would be outweighed by the extra hardware required to maintain these conditions once you get to a systems level.

"Once we reach the point where anode-less batteries no longer require these special conditions, I suspect conventional high-nickel batteries will have evolved to a level where they're not that far behind," comments Greenwood.

"I'm also not convinced that motorsport would be an immediate application for solid-state, because the technology tends to lend itself to batteries that are very good on energy density, but not so good on power density. And if you try to work it really hard in terms of power, it breaks quite quickly. So, I think it's unlikely to be a really high-power application like Formula 1 ERS that would push for solid-state, but we might see it in something like Formula E or Extreme E where greater energy density is required."

Less relevant to motorsport but a huge question in road car development is what could potentially replace the more affordable LFP chemistry. Here, one of the most promising candidates is the sodium ion battery (usually referred to as Na Ion Batteries or NIBs). As the name implies, this replaces the lithium found in lithium ion batteries with more abundant and environmentally-friendly sodium, which can be extracted from seawater or any number of natural sources. The cathode chemistry also tends to avoid problematic materials like cobalt, which has been linked to human rights abuses.

Shifting demographic

Without a miracle cure for the limitations of battery energy density, some forms of motorsport may have to find a more creative solution to the problem. Formula E is close to the current limits of battery technology, but it has already demonstrated an impressive development curve from marginal performance and cringe-inducing car swaps to genuine single-seater pace and over 45 minutes of continuous racing. The energy management side of the competition has become a critical factor for drivers, teams and fans,

ABOVE & BELOW Formula E's impressive development curve has carried it from embarrassing car swaps (below) to genuine single-seater pace and over 45 minutes of continuous hard racing

> *I'm hopeful that we lower the barrier to entry for people doing their own customised electric cars for club-level competition"*

thanks in part to highly-visible initiatives like Attack Mode.

"We have to respect that Formula 1 is not the same as Formula E and they each have their own following," comments Greenwood. "My personal view on this is that the long-race format is going to be more and more difficult to market over time, as the demographics shift.

"I work with a lot of extremely bright, committed students who follow Formula 1 avidly from a technology perspective, but they watch the race itself on the YouTube highlights because they can fast-forward through all the processional bits. And if you think about what might have to happen to Formula 1 for it to be able to attract and retain a younger audience, it's probably the kind of things that also make it more accessible for electrification."

Of course, there are other options. Prior to the ban on refuelling at the end of 2009, Formula 1 cars had to stop multiple times in order to complete the full race distance. The current V6 hybrid cars are a triumph of engineering, but their ability to race for two hours without stopping is unique in modern motorsport, and it's questionable as to whether this actually adds anything to the spectacle.

Another area that tends to generate fantastical claims when the tabloids get hold of press releases from battery researchers is the idea of super-fast charging ("Electric cars could be charged in just nine seconds with new quantum tech" reads the first headline when I search on Google). As Greenwood points out, the ability to charge and discharge rapidly, is extremely relevant to high-power hybrid systems, where the total capacity of the battery might potentially be filled in one or two braking zones. But he's sceptical of the idea of in-race recharging.

"There's definitely a requirement for fast charging in road cars. However good the charging infrastructure is at home or at work, people don't want to be sat at a motorway service station for an hour if they have to stop in the middle of their journey," he notes. "The target in the industry is to get these stops down to around 15 minutes. But I'm not sure how relevant that is to motorsport. Even with the fastest charging technology we can see on the horizon, we're talking minutes rather than seconds, and I think a 15-minute pitstop would be a hard sell."

A more practical proposition might be battery swapping. This has long been talked about in road car circles. EV brand NIO already has nearly 1,400 automated swap stations operational in China, which can exchange the old battery for a fully-charged and pre-conditioned replacement in as little as three minutes. The brand's research shows that customers typically choose this option over recharging in the areas where it's available.

RIGHT Could battery swapping ever find its way into motorsport? EV brand NIO's automated swap stations can complete the process in as little as three minutes

"Battery swaps make sense where you want a really high utilisation of the vehicle, like buses and taxis," comments Greenwood. "I could imagine something like that coming into a motorsport environment wouldn't be cheap, but it would be doable."

Other formulae

Fear not if all this talk of multi-billion-pound battery facilities and pit stop robots sounds a little bit esoteric. National and club-level motorsport is unlikely to experience the same pressures to embrace electrification and be seen to do so. But Greenwood believes there could be opportunities here too.

"There's not much you can do to a modern IC engine unless you've got access to the ECU and the expertise to operate it," he comments. "You need a different set of skills, and you need high voltage training if you're going to do something similar with an EV, but actually it's a much easier thing to do. There are companies out there who will supply an electric powertrain off the shelf, which you could put into a spaceframe chassis or an existing production car.

"It's never going to be as straightforward as swapping a carburettor, but for someone with the right skills it's probably a similar level of complexity to, say, building a Mini with a Hayabusa engine in the back. I'm really hopeful that we could start to see that lowering the barrier to entry for people doing their own customised electric cars for club-level competition."

It's the top end of professional motorsport where electric and hybrid powertrains are likely to make the biggest impact, however. As Formula 1 and Formula E have already proven, the combination of a motorsport engineer's mindset and a global OEM's resources can go a long way in battery and motor development. Whatever the future holds for these industries, it's sure to be an interesting time. RT

WHY 'TURBULENCE' HAS BECOME A DIRTY WORD!

Last year's NTT IndyCar Series boasted the most on-track passes in seven seasons but a raft of new technical changes are intended to make the racing even better. **Chris Pickering** talks to Tino Belli, IndyCar's director of aerodynamic development

As taglines go, The Greatest Spectacle in Racing is certainly punchy. And to ensure that this month's Indy 500 lives up to its spectacular billing, IndyCar has introduced a comprehensive series of aero upgrades.

Some are mandatory, some are optional, and some were previewed at the first oval round of the season last month at Texas Motor Speedway, but one thing unites all of these changes: they're designed to help cars further down the pack compete in turbulent air, and give them a shot at moving forwards.

"We can follow pretty close at Indianapolis Motor Speedway. The spacing is maybe five car lengths, but when you have a train of 25 to 30 cars that means the drivers at the back are in really, really dirty air," comments Tino Belli, IndyCar's director of aerodynamic development.

Put simply, IndyCar's response has been to give the drivers that start further back the option of running greater downforce to restore grip in the turbulent air. Although available to all, it's not anticipated that drivers starting at the front will need to make use of most of these options.

The first of these changes is that the teams are now allowed to run as much as +5° rear wing angle (up from the previous limit of +2°). The wing itself is unchanged and can technically go up to +9°, but the limit is there to prevent the cars becoming excessively bunched up.

New pillars (the vertical supports that hold the wing) are required to run the increased wing angles, but the teams can switch between the two. This allows the cars to be run with negative wing angle during qualifying and with the revised pillars put on to allow a greater wing angle and more downforce during the race. As before, the teams will be allowed to adjust their wing settings in the pit stops.

"The idea is that if a driver qualifies out of position, but they have a good car setup, they can try to work their way up through the field," notes Belli. "Until now we've only allowed +2° on the rear wing, and then people would run wickers on the trailing edge. The disadvantage of the wickers on the trailing edge is that if you start the race with them, you're going to end the race with them. They could still trim out in the race by going into negative numbers, but it's much easier this way."

In isolation, adding wing angle to a car will cost you speed on the straights, but things are a little more complex when you've got 25 other cars up ahead.

"As Formula 1 found out when they went to ground-effect last year, a cleaner wake allows the cars to follow more closely in the corners, but it means they don't get the same tow down the straights. The two go hand-in-hand," comments Belli. "Increased rear wing angle is a bit better than a wicker, which tends to create more dirty air. We're hoping that by encouraging people to use wing angle rather than wickers, they're not going to create quite so much turbulence behind them."

> *"We're hoping that by encouraging people to use wing angle rather than wickers, they're not going to create quite so much turbulence behind them"*

CFD pioneers

The impact of turbulent air on following cars is not an easy thing to predict. IndyCar has been carrying out multi-car Computational Fluid Dynamics (CFD) studies since 2014 in an attempt to limit this effect, but it's a fiendishly difficult task.

"Even with a zero downforce car it wouldn't be possible to completely ignore negative effects on the cars behind," points out Belli. "You see people on social media saying we should go to cars without wings to improve the racing … well, we're almost there. We have very small wings for the speedway events. In qualifying, the rear wings are pretty much at zero downforce, with most of the downforce coming from the front wing and the underside of the car."

Lapping Indianapolis at more than 230 mph inevitably requires a significant degree of aerodynamic assistance (although the extremely high speeds need to be taken into account – the actual coefficient of downforce is comparatively low). Lap speeds without downforce would be down to something like 170 mph, Belli notes, and simply wouldn't generate the same spectacle.

"I've been coming here since 1986, and it still blows my mind," he comments. "I was out there yesterday, and every time it still makes me think 'how do they do it?'"

Ground-effect has been part of this recipe for a very long time. When Formula 1 banned ground effects at the end of the 1982 season, IndyCar persevered with the technology. Initially it had to be toned down slightly for safety reasons – back then the cars still used aluminium monocoques with the drivers positioned right at the front – but structural advances since then have allowed the speeds to be pushed back up. Last year's Indy 500 saw the event's fastest ever four-lap average for a pole position qualifying session at 234.046 mph, set by Scot Dixon in the Chip Ganassi Racing Honda.

"That's a tribute to the strength of the monocoque, the retention of parts in an impact, the Aeroscreen, the top frame, the foam we use in the cockpit and the head restraints. That's all improved to such an extent in recent years that we felt we could start increasing the speeds," comments Belli.

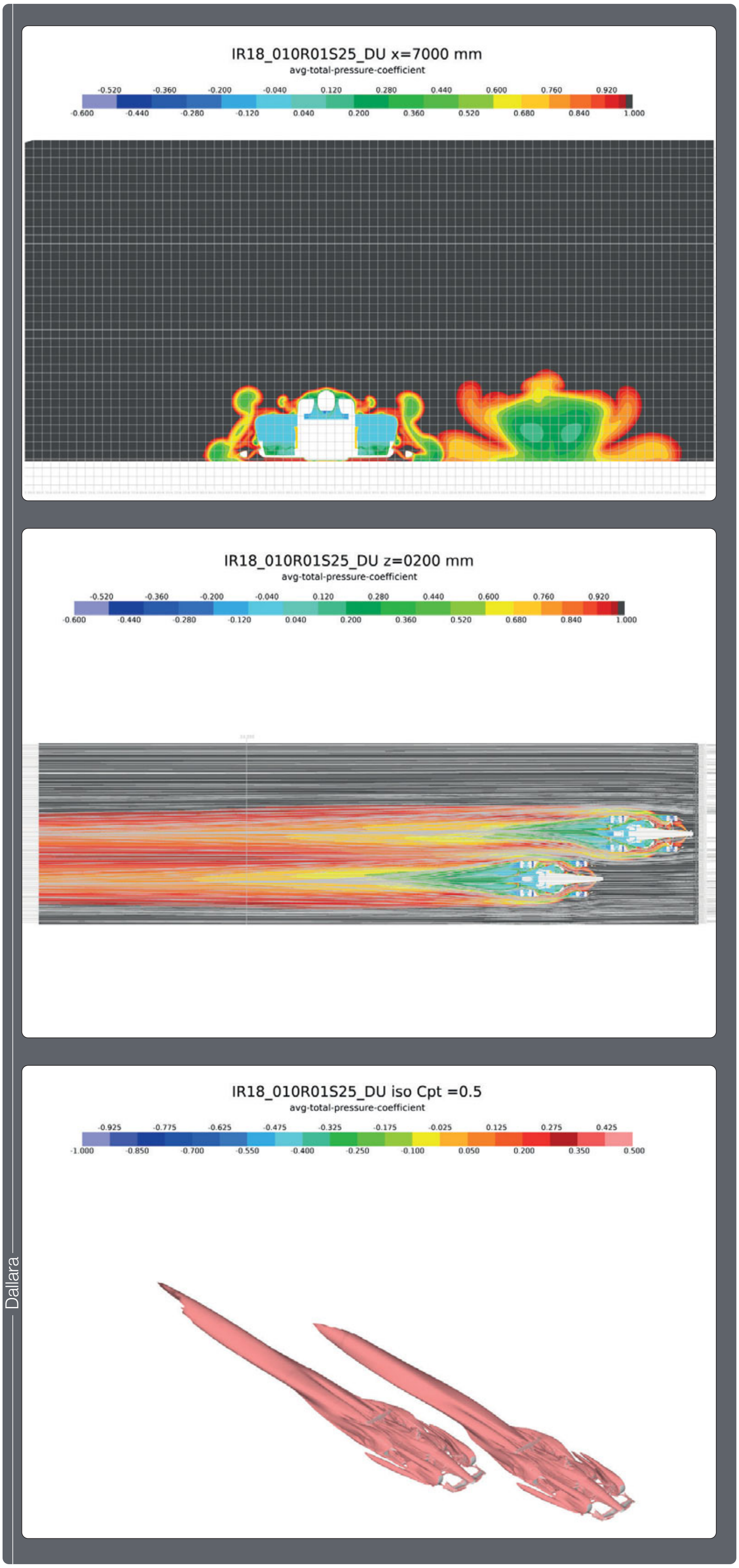
During qualifying, the target for the drivers is to be able to hold the throttle wide open for four laps. Tyre scrub brings the speeds down by a handful of miles per hour through the corners, but it is essentially flat-out. As such, it's unlikely that any of the new optional parts will be used in qualifying, where the cars generally run with the downforce backed off as far as the grip levels will allow.

Attitude

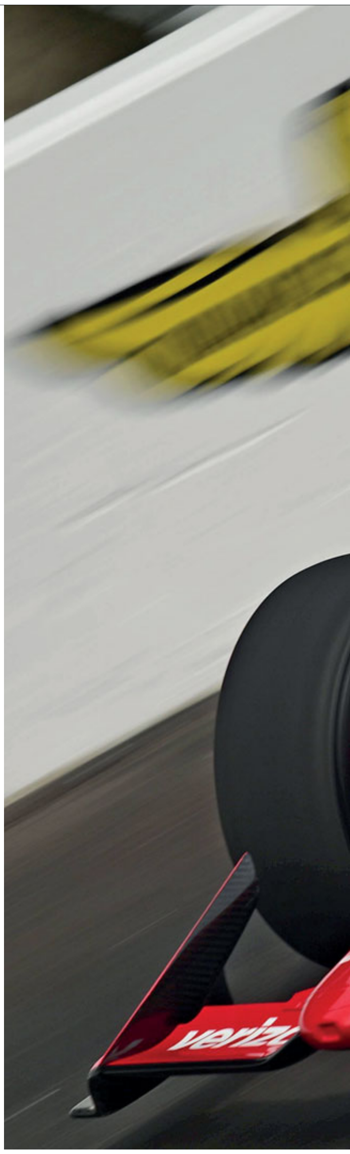
Another area where IndyCar has been at the forefront of aerodynamic safety for a long time is running CFD simulations beyond the normal aero map. Since the mid-2000s, the series' technical team has been looking at scenarios such as the risk of a car flipping backwards if it runs over debris and ends up nose-up at high speed. Around that time, the engineers also started running simulations at very high yaw angles, starting with cars at 90 degrees, followed by additional tests at 130 degrees and 180 degrees (with the ▸

ABOVE Drivers in the pack at the Indy 500 will be able to run up to 10% more downforce than last year

Penske Entertainment/Karl Zemlin



RIGHT Josef Newgarden topped the timesheets at the weather-disrupted Indianapolis 500 Open Test, lapping at 227.686 mph



LEFT Multi-car CFD studies, notoriously difficult to conduct, have helped the series limit the effect on cars running in turbulent air

car travelling backwards).

Dario Franchitti and Scott Dixon's coming together at Michigan in 2007, which saw the Scot's car slew sideways and flip over horizontally, led to the introduction of domed skid plates on the underside of the car. These accelerate the air under the car and dramatically increase the level of downforce at high yaw angles to reduce the risk of it becoming airborne.

Domed skid plates proved difficult to police, allowing for variables such as wear rates on bumpy tracks and unplanned changes in ride height due to ambient conditions. Aerodynamic advances elsewhere in the design have allowed IndyCar to abandon this technology but it continues to be used in sportscar racing.

"Every time we change the aerodynamics of the car – the bargeboards, the rear wings, the front wings – or the mass and the weight distribution, we have to go back and look at those scenarios again," comments Belli.

Penske Entertainment/Chris Owens

Safety first

In technical discussions, we're told, the IndyCar engineers describe their priorities as "safety first, safety second, safety third and entertainment fourth". It's this mantra that guides the aerodynamic development, with most of the downforce generated under the floor, where it will theoretically have the least impact on potential overtaking opportunities.

The underwing is also the most efficient area to pick up downforce. Two years ago, IndyCar introduced a device that's somewhat misleadingly referred to as the outer bargeboard. This, in fact, acts more like a vortex generator, creating a pressure differential from one side to the other and spinning the airflow, which then generates low pressure underneath the car.

"We like those. They're very efficient, so they give downforce without really increasing the wake of the car," says Belli. "And they give downforce towards the front of the car. That reduces the ▶

The future

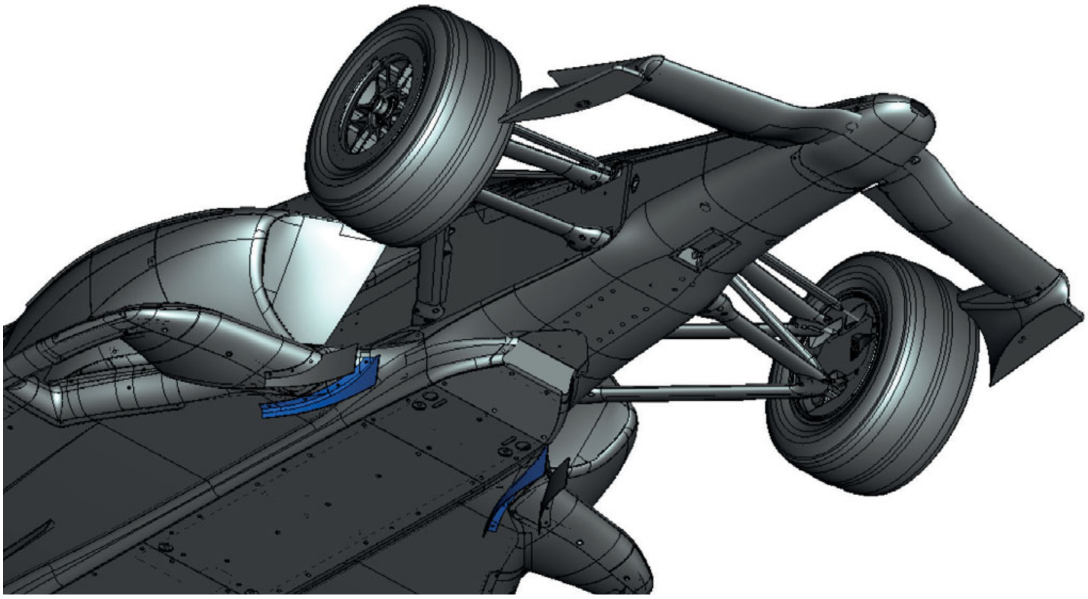
AERODYNAMICALLY, the core concept of the car will be unchanged for 2024, and the current updates are likely to be carried through. There will be a series of detail changes to the aerodynamics, however, to support the new hybrid powertrains.

The cooling for the hybrid system will be added to the oil cooling system in the right-hand sidepod (the left-hand side being used for water cooling). In this new configuration, the bottom portion of the heat exchanger will feed the engine, the middle is for the gearbox and the top feeds the hybrid system. The physical size of the sidepods won't change, but the cooling requirements will increase.

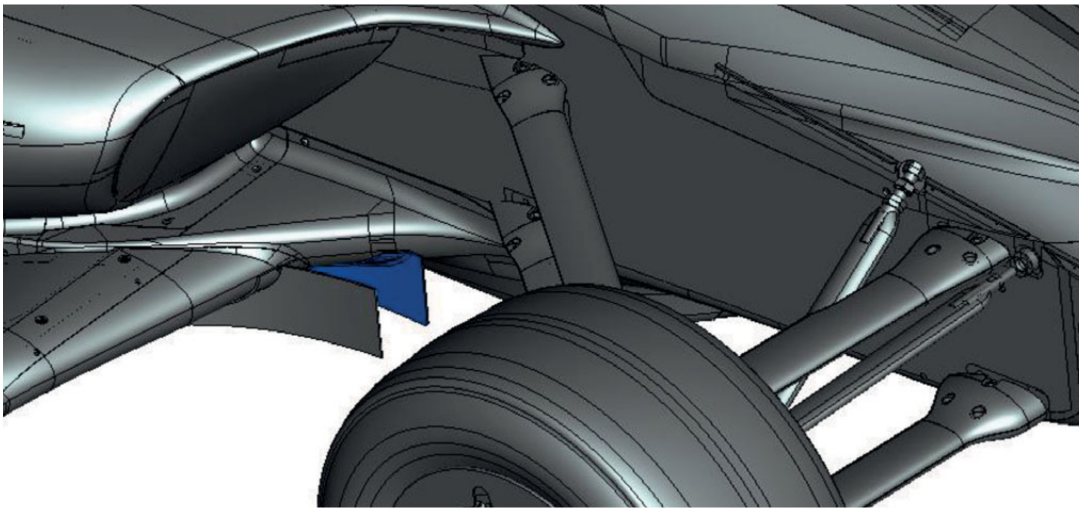
There will be new front and rear wings for the Indy 500 in 2024. The rear wing will essentially be a scaled-up version of the current design, with a larger chord and span. It will retain the rolled-off endplates, which were introduced in 2018 to reduce vorticity and increase downwash on the front wing of the following car.

The changes at the front are somewhat more complex. When the current wing was originally developed in 2018, the first iteration that the aerodynamicists evaluated struggled with stability on the 5° nose-up safety test. As such, it was re-designed with a short chord and a high camber, which was something of a compromise.

Since then, detail improvements to the front of the sidepods and other areas of the car have overcome the previous issues on the nose-up test, allowing IndyCar to adopt a larger chord and a lower camber. This reduces the pressure gradient around the wing and lowers the chances of separation. RT



LEFT The extra bargeboards can reduce the dependency on the front wing, which is the first part to hit the wake from the car in front



BELOW The option of a new additional underwing strake and infill wicker give the teams more tools to work with

dependency on the front wing, which is the first part to hit the wake from the car in front. As you get closer, you tend to get a bit washed out on the front end of the car because the front wings lose a tonne of downforce. So anything we can do to minimise how much front wing we need to run is usually good for following cars."

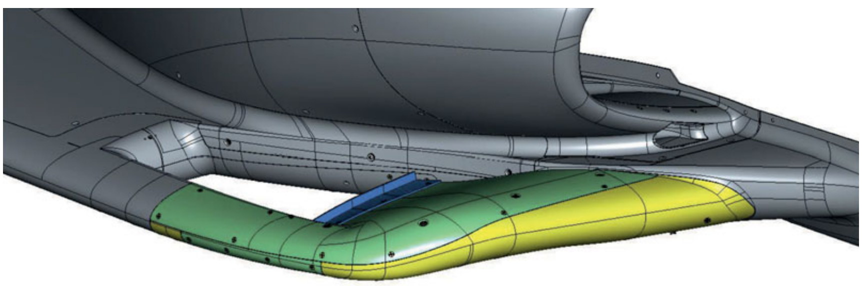
A degree of this front-end washout is inevitable, and it leads to an interesting effect. As the driver lifts off the throttle to encourage the nose to tuck back in, the weight transfers to the front and the car pitches forwards slightly. This places the bargeboards lower to the ground, increasing their effectiveness and shifting the centre of pressure forwards.

Typically, the front right tyre is very close to saturation when running on an oval. Shifting the centre of pressure forwards increases the vertical load on the tyre and can help to offset the loss of front downforce when following close behind. To accentuate this effect, IndyCar has now opened the option of a second bargeboard slightly further inboard.

"It'll be very interesting to see how many people take that up," says Belli. "The teams had that option in Texas this year, and about a quarter of the field chose to use it. But every track has its own nuances. Turns three and four at Texas have quite steep banking, which tends to push the car into the ground and give more front downforce. Whereas, they have to lift for turns one and two, so there the car might rise up and lose front downforce. So if your car's pinned on the front in turns three and four, and understeering in one and two, you might not want to use these bargeboards.

"But Indianapolis is a different track with different characteristics. Here, we have more of this tendency for the front end to wash out on the second half of the corner, which we don't want because the drivers then have to lift, and it reduces their chances of catching a tow down the straights."

Another optional addition is a set of lower strakes for the underwing. These can interact with the flow around ▶



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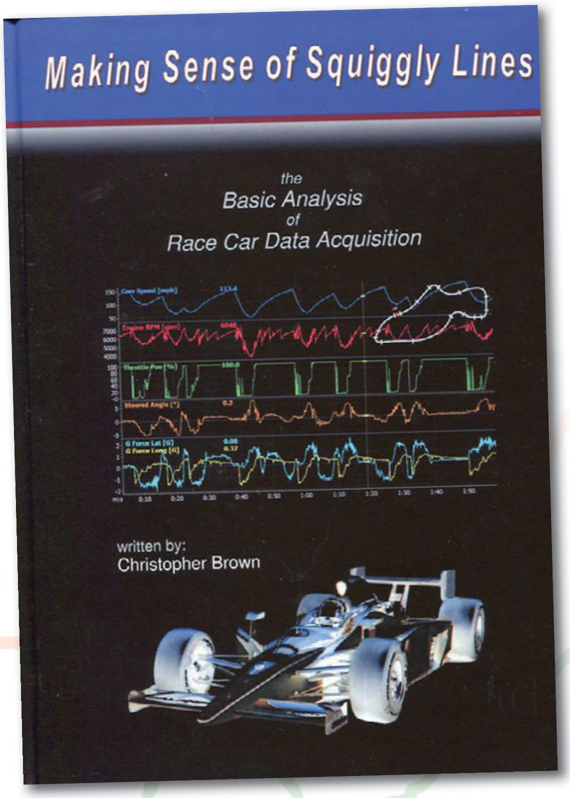

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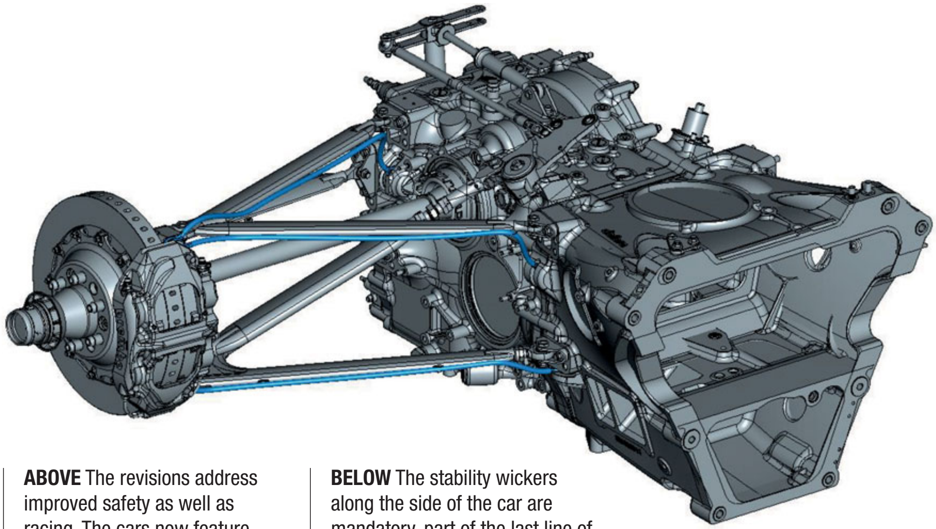
the bargeboards, so teams will need to decide whether they prefer the rear downforce of the strake or the front downforce of the bargeboard. Similarly, the strakes can stall if they get too close to the ground, which means that the setup needs to be carefully considered. The pitch sensitivity mentioned previously also feeds into the teams' choices for front springs, dampers and anti-roll bars (the latter being cockpit-adjustable in IndyCar, unlike virtually any other major international series).

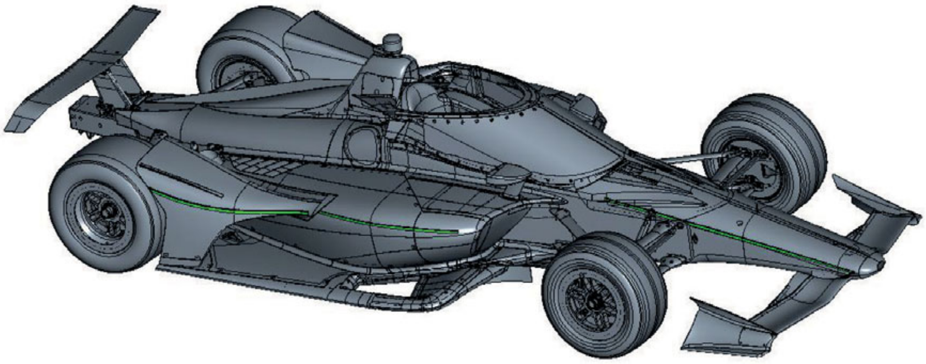
In contrast to most of the downforce-enabling changes, teams will now also have the option of removing the wicker on the underwing opening, which was previously mandatory. Conversely, they also get the option of a trailing edge wicker right at the back of the diffuser ("We suspect everyone will go for that, as it's super-efficient," notes Belli).

One of the few additions that is mandatory is the set of so-called stability wickers that run down the side of the bodywork. This is another element of what IndyCar terms its spin-stability measures. ▶



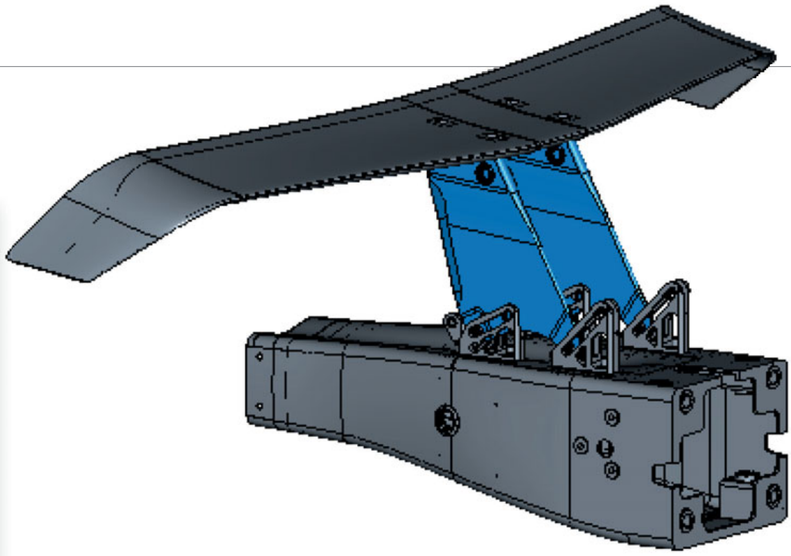
ABOVE The revisions address improved safety as well as racing. The cars now feature stronger rear suspension tethers

BELOW The stability wickers along the side of the car are mandatory, part of the last line of defence to avoid lift-off incidents



Penske Entertainment/Chris Owens

RIGHT A number of the parts have already been trialled at Texas Motor Speedway



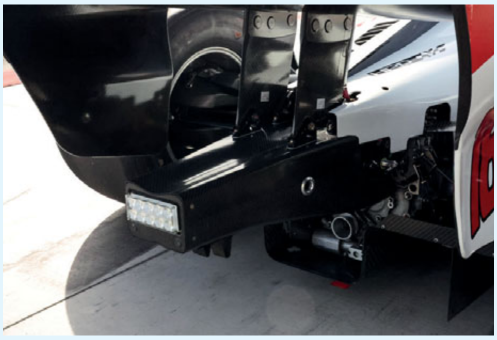
ABOVE A new rear-wing pillar specification will allow three degrees more adjustability range for the rear wing on the IMS oval

Safety, safety, safety

ALONGSIDE the aerodynamic upgrades, there are a series of changes to improve safety. These include stronger rear suspension tethers, taller headrest sides and reinforced tyre ramp attachments.

Another significant change is the adoption of a new rear crash attenuator, developed in collaboration with chassis manufacturer Dallara. This has its roots in the new attenuator design that will come with the revised bellhousing for the hybrid system next year. However, with the 2024 design completed nearly 18 months ago, IndyCar took the decision to adapt it for the current gearbox and release it in time for Indianapolis.

The main premise of the new design is to spread the crush over a greater distance. It stands 4.3 inches (110 mm) longer than the previous design, despite being around 1.5 lb (0.7 kg) lighter. Sled tests have shown it to reduce both the average and peak decelerations in the event of an impact. RT



ABOVE The new rear crash attenuator was developed in collaboration with chassis manufacturer Dallara

"Contrary to what you might expect, it tends to break the left-hand side suspension when a car hits the wall here at Indy," comments Belli. "The left rear suspension breaks and the car falls down on that corner, lifting the right front wheel into the air. The left front wheel breaks away as well, and the wings are somewhat designed to break away from the car (although they're tethered)."

The stability wickers are part of a last line of defence if the car finds itself in that stricken condition at high speed. They're designed to trip the flow off the bodywork and prevent it becoming a lifting surface. Again, this is modelled in CFD at a variety of extreme yaw angles (complete with broken car).

Aeroscreen

Less subtle but arguably even more important than the current round of aerodynamic updates was the introduction of IndyCar's Aeroscreen device in 2020. In that short time, it has already been credited with saving several drivers from serious injury, including Ryan Hunter-Reay and Callum Ilott.

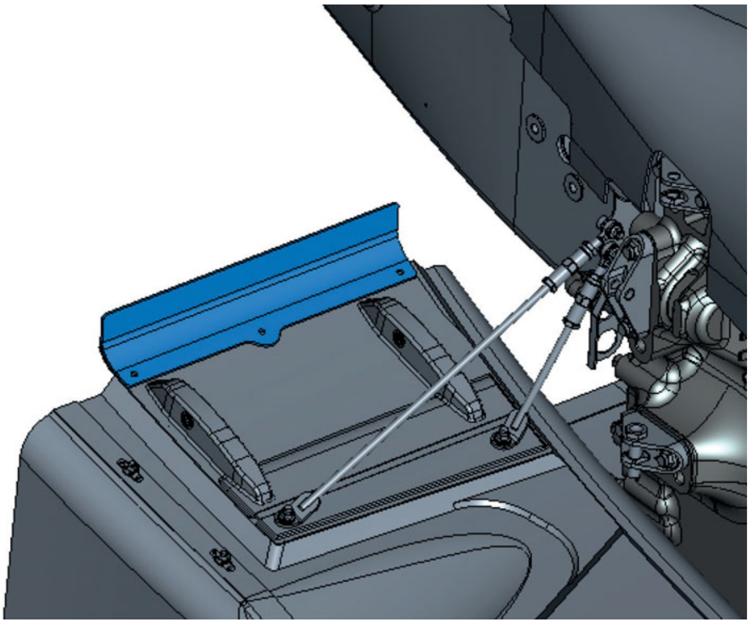
The shape of the Aeroscreen is designed to follow the natural streamlines over the bodywork, and its aerodynamic impact is said to be small.

"The Aeroscreen doesn't make a huge difference aerodynamically," comments Belli. "Had it been lower, it would probably actually have had a positive aerodynamic impact. But, of course, we have to get it high to make sure that any large objects can't hit the driver on the head, and the top part of the screen has a small negative impact as a result."

A bigger challenge, he explains, is the mass. The Aeroscreen's top frame is made from 3D printed titanium, while the screen itself is 9 mm thick polycarbonate. It's an impressive piece of engineering from Red Bull Advanced Technologies, which has kept the weight down to a comparatively svelte 53 lb (24 kg). Nonetheless, that's a fair amount of mass to add to a lightweight single-seater, and much of it comes from the frame of the screen, which sits at pretty much the highest point on the car.

"This transfers more weight onto the right front tyre, which is already the most heavily-stressed tyre on an oval circuit," comments Belli. "Any additional weight transfer to that tyre has the potential to make

BELOW The underwing trailing edge flap wicker, a new part for Indy 2023, is optional



the temperatures rise faster and increase degradation. This has been the biggest challenge with the Aeroscreen – the mechanical impact rather than any changes to the aerodynamics."

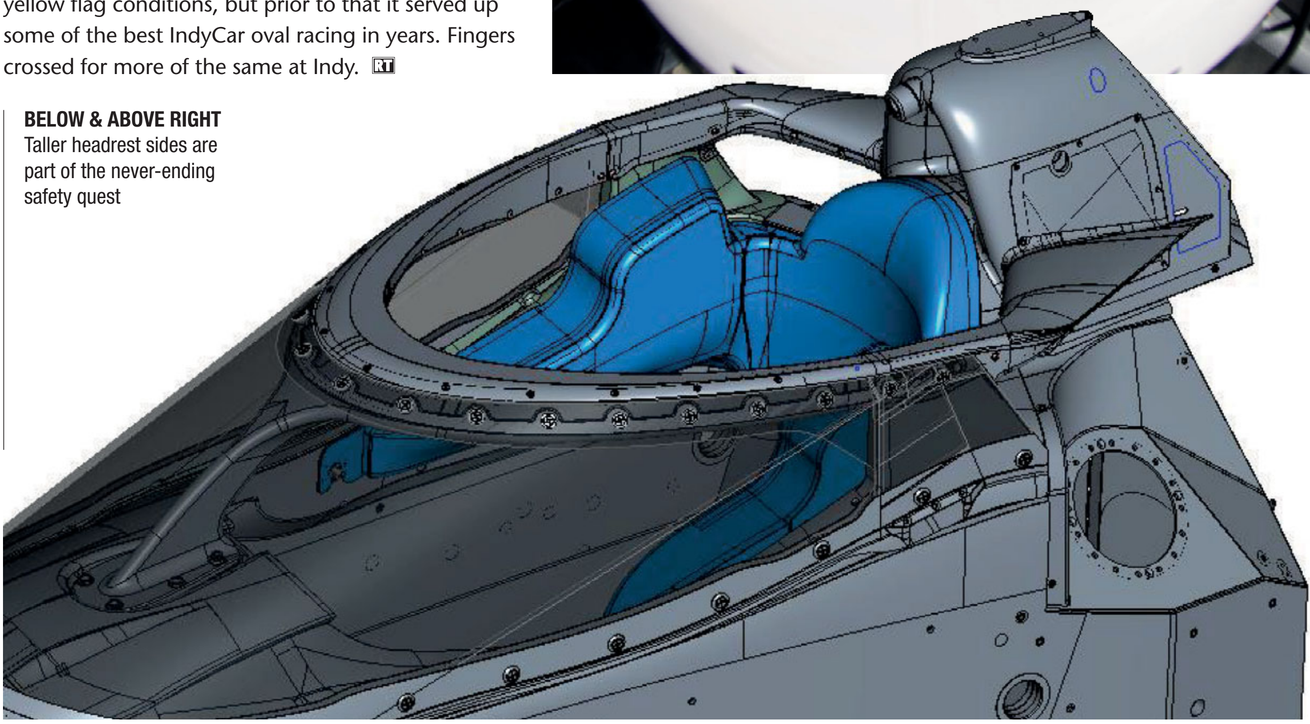
If the right front tyre reaches saturation, the driver will have to lift. The bargeboard modifications mentioned previously may assist in this scenario, by shifting the centre of pressure forward, but they don't cure the problem. Next year, however, IndyCar and Pankl will introduce a new iteration of the top frame design that refines the 3D printed concept with an intricate, topologically-optimised internal structure that should save 11 lb (5 kg) while maintaining the same level of protection.

> ***"The biggest challenge with the Aeroscreen has been the mechanical impact rather than any changes to the aerodynamics"***

IndyCar also has a lightweight windscreen waiting in the wings, which would shed more mass. For the time being, the plan is to use this on road and street courses, but the series' engineers are currently evaluating whether it would be suitable for ovals too.

Of course, we won't have to wait that long to see the new aero kit in action. This year's Indy 500 is almost upon us, although a number of the parts have already been trialled at Texas Motor Speedway. The race there, at the beginning of last month, finished under yellow flag conditions, but prior to that it served up some of the best IndyCar oval racing in years. Fingers crossed for more of the same at Indy. RT

Penske Entertainment/Chris Owens



BELOW & ABOVE RIGHT
Taller headrest sides are part of the never-ending safety quest

THE GREENEST INDY 500 IN HISTORY

One of the biggest changes for this year's Indy 500 is something the fans and drivers won't even notice. **Chris Pickering** talks to the man who has overseen the development of Shell's 100 per cent renewable fuel

MOTORSPORT is all about chasing the numbers. Entire careers can be spent chipping away at hundredths of a second or tenths of a per cent. And yet when the cars line up for the start of this month's Indy 500, they will be burning a fuel that slashes CO2 emissions by upwards of 60 per cent compared to conventional gasoline. That's not an incremental improvement: it's a step change. And it can be achieved with minimal alterations to a conventional spark ignition engine.

Admittedly, IndyCar was already well ahead of the curve on alternative fuels. The series was the first in the world to introduce a 100 per cent ethanol fuel under the old V8 formula in 2007. When the turbocharged V6 engines arrived in 2012, it switched to E85 (85 per cent ethanol and 15 per cent gasoline) in an attempt to make it more road-relevant to the 'flex fuel' vehicles that are popular in some parts of the United States.

The new fuel was introduced at the beginning of this year, when Shell took over from Speedway as the official fuel and lubricant supplier to IndyCar. Thanks to the series' unique history with sustainable fuels, it could be argued that this is an evolutionary step. But with the majority of the world's passenger cars still burning conventional fuels, the comparison to fossil-derived gasoline is still just as relevant, and the benefits just as dramatic.

"The objective was to develop a 100 per cent renewable fuel that would work as a drop-in solution for the current engines," explains Shell's technology manager for motorsports, Bassem Kheireddin. "Our scientists worked with engineers from Honda and Chevrolet to understand their requirements, and based on decades of R&D knowledge, you know, harnessed within Shell, we were able to come up with a formulation that consists of a significant percentage of second-generation bioethanol that's derived from sugarcane waste."

The bioethanol is combined with another renewable component, also extracted from waste, to create a fully-sustainable blend, although Kheireddin and his colleagues are remaining tight-lipped as to exactly what that might be. We can only speculate, but biomethanol can be captured from methane taken from agricultural slurry and can be used to produce common fuel additives such as methyl tert-butyl ether (MTBE).

Crucially, the ethanol that forms the bulk of the mixture is taken from a second-generation source that doesn't compete with food production. It's taken from Raízen, a Brazilian joint venture created in 2011 by Shell and Cosan. The Brazilian enterprise is one of the largest sugarcane ethanol producers in the world, and owner of the first commercial second-generation ethanol plant.

> *"What was previously considered as a waste stream is now used to produce ethanol"*

"What was previously considered as a waste stream is now used to produce ethanol," notes Kheireddin. "So when you look at the sugarcane and you extract the juice, the remaining portions that were discarded are now used to produce the ethanol. That's what distinguishes it from first generation ▸

ABOVE IndyCar has ushered in a new era of sustainability with a fuel that enables at least 60% greenhouse gas emissions reduction compared to fossil-based gasoline

RIGHT IndyCar's experiments with ethanol have kept it ahead of the curve in recent years

LEFT It took Shell a little over a year to develop the fuel, which contains a significant mix of second-generation ethanol combined with another renewable component

RIGHT The NTT IndyCar Series became the first United States-based motorsports series to power racing with 100% renewable race fuel at St Petersburg's season-opener

biofuels. You're now dealing with the fibre component or the cellulose component of the sugarcane and through chemical modification of the molecules you can produce ethanol."

Wish list

The development process began with a list of specifications drawn up by IndyCar and its two powertrain suppliers, Honda and Chevrolet. This included burn rates, lower heating value, vapour pressure, distillation profile and octane numbers.

"Ultimately, this fuel, to meet the demanding needs of the IndyCar engine, has to be a high-performing fuel. And we were successfully able to do that," comments Kheireddin. "So the octane number, for instance, is close to 100 and did not require any significant modifications to the engine. That was the first thing the teams looked at, after which the focus moved onto durability testing."

> *"IndyCar was already well ahead of the curve on alternative fuels"*

The knock range of the fuel can be determined by running various sweeps on the dyno, varying parameters such as ignition timing. Other factors were examined using extended mileage tests, after which the engines were stripped and checked for wear and deposits. No issues were reported by either manufacturer.

The key requirement was that the fuel had to be compatible with the existing engines. In order to achieve that, some of the specifications were kept close to those of the previous E85 blend, while others are understood to be quite a departure. The end result, however, is much the same. Indeed, while the fuel is now 100 per cent sustainable, the ethanol content is said to be around 80 per cent.

"The ethanol content is not wildly different to the previous fuel," comments Kheireddin. "The key difference is that we use a renewable component for the remainder of the fuel, in place of the [fossil] gasoline component that was used previously." ▶

IndyCar

Small changes to fuel composition can make a big difference, so the teams were understandably cautious.

"Our job was to convince them through data about the fuel's properties, that it would work for them," says Kheireddin . "And, you know, we tried a couple of other formulations – I can't say how many – but this was the one that we picked."

Following the teams' own dyno testing, the first track test of the new fuel came at IndyCar's annual pre-season gathering at the Thermal Club motorsport resort in California.

"It's been neat watching this come from a lab test a little over a year and a half ago, through the dyno testing and onto the track in quite a compressed timescale, and then seeing it racing for the first time at St Pete," comments Kheireddin. "It was great to see it performing on the track. The feedback from the drivers was great. They're not necessarily technical folks, but they understand performance and they will know if it's been affected. When I had a chat with them, a lot of them remarked that they hadn't noticed any change."

Team perspective

It's a sentiment that appears to be echoed by the teams. Honda Performance Development's technical director, David Salters, certainly regards it as a success: "The whole transition has been pretty seamless, which is really the main thing you want

RIGHT Bassem Kheireddin is Shell's technology manager for motorsports

> *"Racing needs to become sustainable. We need to be responsible"*

IndyCar

BELOW The Indy 500, the jewel in IndyCar's crown, provides a fantastic showcase for the championship's sustainability drive

IndyCar

with something like this. So hats off to IndyCar and hats off to Shell. It's a big statement to be able to say you've achieved a 60 per cent CO2 reduction, and it's been an extremely satisfying journey to get here."

According to Salters, "a few bits and bobs have been changed" to optimise the engine for its new fuel, but overall, the process was said to be extremely easy. What's more, the discussions around the introduction of the fuel were understood to have been very harmonious.

Electrification

"It's been a great collaborative effort, and a credit to everyone involved," he comments. "We will continue to work together and share data. Racing needs to become sustainable. We need to be responsible."

In some respects, it's a particularly tricky question for IndyCar. The series is going hybrid next year, and there will be plenty of opportunity to harvest energy on the road and street courses that now make up two-thirds of the calendar. But oval racing is still a defining element of the series – not least in its blue riband event, the Indy 500 – and, here, it will be harder to showcase electrification, with very limited scope for regenerative braking. As such, sustainable fuel arguably holds even greater importance in IndyCar than it would elsewhere.

"The thing is, it's still entertainment. And people like the look and sound of racing cars. If you can maintain that in a sustainable way, that's a good step forward," comments Salters. "Looking at the sustainable fuel aspect is a great opportunity to investigate something different, and we do lots of combustion modelling so we can really understand what's going on. That helps us to develop that technology, which is what racing should be used for."

Shell says it has no imminent plans to introduce a fully sustainable fuel for the road car market, but it is pressing ahead with E15 and E85 ethanol blends in parts of the United States, so there's the potential for genuine technology transfer.

""It's in Shell's DNA to innovate, and we believe the racetrack is a proving ground from the high speeds, the high temperatures, the extreme conditions," comments Kheireddin. "We take those learnings from the track and transfer them to road-going products. Obviously, the fuel composition has to be different to reflect the design differences between a road car engine and a racing engine, but the fundamental principles are the same."

Just as important is the message it sends out. The Indy 500 is celebrated as The Greatest Spectacle in Racing, and it's lost none of that sparkle. This year, however, will be the greenest Indy 500 to date, and proof that speed and sustainability can go hand-in-hand. RT

ABOVE Shell worked with Honda and Chevrolet to ensure the transition to 100 per cent renewable race fuel went without a hitch

BRAKE WITH TRADITION

More than 125 years after Ferodo's first experiments with composite friction materials, the company remains at the cutting edge of braking technology. By **Chris Pickering**

BACK in the pioneering days of the motor car, the problem of how to make these new-fangled contraptions go was inevitably followed by another question: how to make them stop?

Horse-drawn carriages already had rudimentary braking systems that pressed a block of material – usually rope soaked in tar – onto the solid surface of the wheel. As speeds rose, this approach began to prove hopelessly inadequate.

Various other systems were put forward, but most of these focused on the mechanics of how the braking pressure was applied. In 1897, a Yorkshireman named Herbert Frood decided to take a different approach. He focused on the friction surface itself, initially experimenting with a mixture of horsehair and bitumen, but soon switching to woven cotton impregnated with natural resin.

Frood was still working with horse-drawn vehicles at the time, but his resin-bound braking material was about to take off in the new world of motoring. Here, the use of rubber tyres had forced manufacturers to abandon rim brakes. In 1902, Louis Renault patented the drum brake, which quickly became the default option for the rapidly expanding number of car manufacturers. The same year, Frederick Lanchester took out his own patent for the first disc brake.

In the meantime, Frood had set up shop on the outskirts of Manchester, before moving to Chapel-en-le-Frith in Derbyshire in 1902. Two years later, he would name his company, taking an anagram of his surname and adding an 'E' as a nod to his wife, Elizabeth. The Ferodo trademark was born.

Frood's resin-bound material couldn't have come at a better time. He began manufacturing linings for drum brakes in 1902, and he's credited with inventing the modern brake pad. Lanchester's own experiments with copper linings and iron discs had resulted in an ear-splitting screech as the two metals made contact. Frood's composite materials solved this issue, although the disc brake wouldn't reach mainstream automotive use for another half a century. When it did, in 1956 with the Triumph TR3, it was Ferodo that made the first disc brake pads for road car use.

The early days

More than 125 years after Frood's first experiments with composite friction materials, Ferodo remains at the cutting edge of braking technology. The company now has more than 330 grands prix wins to its name, not to mention land speed records, Le Mans victories and a dominant presence in motorcycle racing.

One of the first major milestones on the racing side came in 1930 with the introduction of Ferodo's MZ linings. This quickly became the material of choice for manufacturers such as Alfa Romeo, which was sweeping all before it in grand prix racing at the time.

After the war, the next big breakthrough was the DS11 material. Originally intended for heavy-duty trucks and industrial applications, it was to become a game-changer in the world of motor racing. The material's exceptional fade resistance and

high temperature tolerance meant that the discs could be made smaller and the amount of cooling could be reduced. This meant that the cars weren't just better under braking; they had less unsprung mass, which improved handling, and lower aerodynamic drag, which improved straight-line speed.

DS11 was used in all types of racing, but its record in Formula 1 was particularly impressive. Between 1961 and 1981, all bar two grands prix were won by cars using Ferodo's seemingly invincible material.

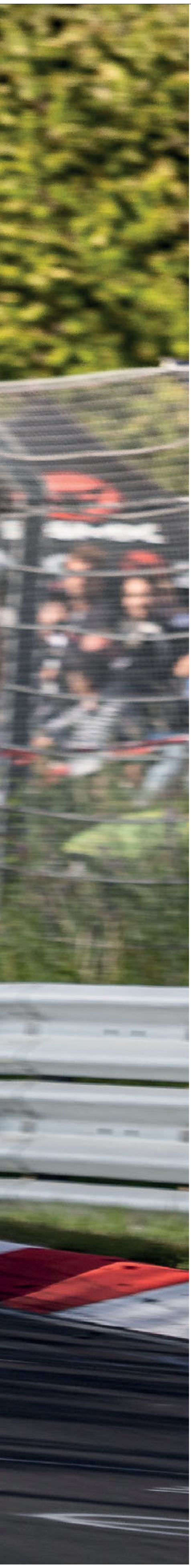
But the company's dominance was about to come to an abrupt end. The early 1980s saw carbon-carbon brakes come of age in Formula 1. The technology behind these was – and still is – owned by a handful of aerospace companies. As with most motorsport pad materials of that era, DS11 also relied heavily on asbestos, which was about to be phased out. This meant its days were numbered in other series too.

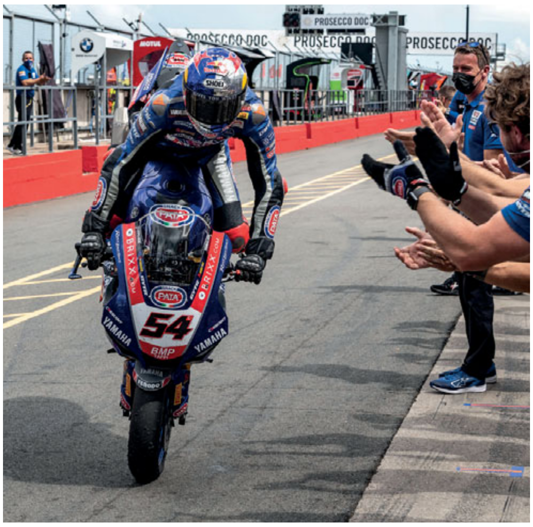
Reborn

Ferodo's racing activities took a back seat for the next decade and a half. On the road car side, the original site in Derbyshire remains active to this day, with other Ferodo production sites spread around the ▶

BELOW Ferodo's seemingly invincible material won all but two grands prix between 1961 and 1981

1VIER





RIGHT Ferodo is racing on two wheels as well as four, as technical partner of Pata Yamaha Prometeon in WorldSBK

LEFT One important outcome of this winter's testing is the development of a new compound, TL163, specifically engineered for the rear axle of GT cars. It has a friction level and torque shape that make it compatible with ABS and wear characteristics that will make it a key player during the 2023 season

world. The motorsport division, Ferodo Racing, was revived and transferred to Mondovi, in northern Italy, in the mid-1990s.

Since then, Ferodo Racing has been run by Sergio Bonfanti, while technical manager Edward Little was drafted in from the UK to lead the R&D operation.

"We wanted to drag ourselves back to the forefront of motorsport," recalls Little. "At the time, the leading company in the field was one that had taken a material originally developed for mining vehicles and added a lot of abrasives to bring the friction levels up. It was not dissimilar, in a way, to what Ferodo had done with the DS11, and it effectively defined the modern racing friction material outside of Formula 1."

Ferodo developed its own material along a similar concept, known as DS3000. In use to this day, it has proven successful in a wide range of applications from touring cars to rallying, with a reputation for a strong initial bite and good modulation.

"I think a large part of the success of DS3000 comes down to the fact that it's a very capable all-rounder," comments Little.

Brake pad formulation is a science, but it's not an exact science, he points out: "There can be anything from 10 to 30 components in the material, ranging from fairly obvious ones – like carbons, graphites and ceramics – to some fairly exotic stuff. Friction dust, for example, is cashew nut oil, which is cured and ground up, and it has a particular effect because of its surface area. On top of that, there is a vast number of interactions between those components. So maybe 75 per cent of it is science and 25 per cent is a mixture of cookery and black magic. There is a degree of luck involved too, and I think with DS3000 we got it right for the requirements at the time."

While there might be a degree of sorcery that separates the good from the great, the majority of the work in brake formulation comes down to methodical testing, Little explains: "We had a very good structure for developing the materials. For instance, we had techniques for analysing which was the strongest iron powder that we could put in; which was the most heat-resistant graphite that we could use, and so on. From that point onwards, a lot of it comes down to statistics. If you have enough time to test 100 brake pad formulations rather than 50, you've got twice the chance to find something that really stands out." ▶

BELOW With sales of eBikes rising more than 500% over the past nine years, Ferodo Racing has launched a specialized range of brake pads, discs and brake fluid for both conventional and electric bikes

Ceramic resins

For over a century, phenolic resins, similar to those used by Frood, remained the base material of choice for most braking applications. The mid-2000s saw the introduction of ceramic resins. Once again, this technology had emerged in other industries before being brought into motorsport, where the ceramic materials' excellent wear resistance and broad range of operating temperatures were significant benefits. Ferodo harnessed this technology for a new generation of pad materials, starting with DS1.11, which was later joined by DS Uno. Both have found success across a broad range of disciplines, including touring cars, one-make championships and single-eaters, with DS Uno also doing well in rallying.

GT racing

While DS1.11 and DS Uno had brought Ferodo back to the forefront in tin-tops and the junior formulae, the company was keen to tap into the fast-growing GT racing market. To do this, Little and his colleagues on the racing side in Italy once again collaborated with the road car engineers back in the UK. Together, they went back to basics, stripping the brake pad formulation right down and building it up again from first principles.

"This required quite a long-term approach, because we weren't just tweaking the materials, we were stripping it back and building it up, and evaluating new materials along the way," he notes. "As well as developing the new formulation, it gave us a huge library of materials and properties that we're still working with."

This project led to the launch of DS3.12 in 2019, which is Ferodo's halo product, covering the upper echelons of GT racing, stock cars and other heavy-duty motorsport applications. However, it's also started to establish a broader family of materials developed around the same work.

> *"Originally intended for heavy-duty trucks and industrial applications, the DS.11 material was to become a game-changer in the world of motor racing"*

"Subsequently, the development work we did for DS3.12 has come to help us in other applications. We came to realise, for example, that the way that the ABS is engaged and released can be just as important as the outright friction level in some GT classes and on some circuits," comments Little. "We've had that feedback through our relationship with the teams, and we realised that we had materials that seemed to offer exactly the sort of characteristics they needed when we had dyno tested them during the development process. So that means we sometimes have ready- ▶

ABOVE The DS.11 friction material was conceived for industrial applications but went on to dominate in F1, winning 265 times in 267 races

BELOW The launch of DS3.12, Ferodo's halo product, won it a foothold in the upper echelons of GT racing. The research involved is also helping establish a broader family of materials that have proved popular in touring cars, one-make championships and single-seaters

made solutions to problems like that, which enables us to react very quickly."

Fundamentally, the development process hasn't changed a great deal, he points out. With so many variations within the pad material itself, the engineers try to minimise the external variability by picking a single disc and caliper setup to use as a baseline for the initial testing.

The metallurgy of brake discs has become somewhat more complex over time. Most are still made from grey cast iron, which uses flaked graphite to improve the stiffness, thermal conductivity and heat capacity of the iron. Over the last 30 years or so, a growing number of brake disc manufacturers have started offering spheroidal cast iron, which is sometimes claimed to offer improved wear resistance. The impact on the pad material, however, is negligible, so it can be neglected during the initial development.

Once track testing commences, the formulation can be refined to suit small differences in pad metallurgy and brake system design. Still, the variables are relatively small: most high-end GT cars, we're told, use one of two brake systems on the front axle. Generally, it's the layout of the cars themselves that poses a greater significance, with a wide range of vehicle weights found in GT racing, allied to a mixture of front, mid and rear-engined configurations.

Counter-intuitive thinking

The most significant change in GT car braking systems in recent years has been the adoption of ABS.

"The arrival of ABS was a big step," comments Ferodo Racing's general manager Sergio Bonfanti. "It forced us to look at our dyno results in a different way before putting the friction material on a racecar. We have to look far more carefully at things like how the friction level changes throughout the braking event. The friction coefficient of a traditional brake pad tends to rise as the car slows down, so that's something we've had to iron out."

This constitutes a fundamental rethink of the brake pad formulation. In the past, the friction material had three key tasks: it needed to provide very high friction to slow the car; wear resistance to provide sufficient durability; and fade resistance to ensure consistent performance at high ▶

ABOVE Ferodo harnessed its expertise with ceramic resins to develop a new generation of pad materials such as DS1.11 and DS Uno (pictured). Both found success across a broad range of disciplines, with DS Uno also doing well in rallying

LEFT The science and the facilities (Ferodo's dyno hall, prototype shop and vehicle testing workshop are seen here) continuously evolve, but there remains one constant: 125 years of innovation

Giorgio Piola

FORMULA 1

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(with 2019 preview)

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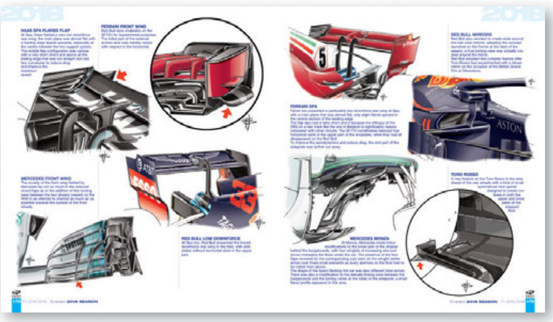

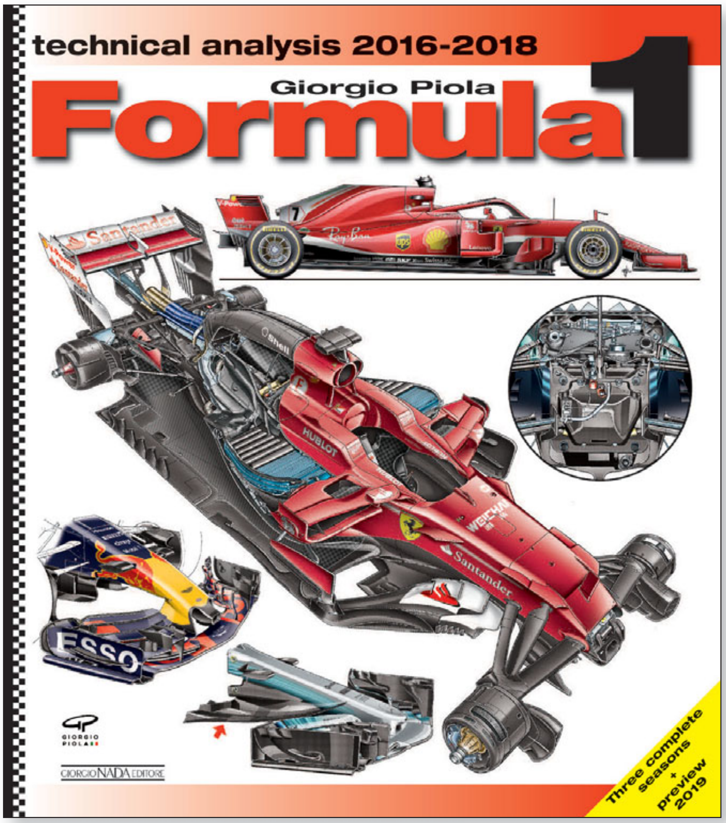

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temperatures. The advent of ABS means that outright friction levels are actually less critical than they were before. Instead, it's about ensuring that the ABS engages and disengages smoothly.

ABS has also changed the balance between the front and rear braking systems, Little points out: "In the past, it was generally the front brake pads that did most of the work. The rears would just need to be a capable material that could prevent fade and offer high-ish friction. Now, we're developing materials for the rear pads that are deliberately very low in friction. They have a very flat friction profile, so the relationship between the pressure you put into the pedal and the torque that you get from the brake is completely linear."

> *"Friction dust is cashew nut oil, which is cured and ground up, and has a particular effect because of its surface area"*

Even a few years ago this approach would have seemed highly counter-intuitive, he admits: "Until recently, if you'd suggested this to a motorsport brake formulator they'd have thought you were mad. But that's what the market requires these days to get the right balance, because lockup is so prevalent on the rear wheels. That means that rear wheel performance is almost more critical than the front now – or at least there's now a strong synergistic relationship between the two. It's changed the way we think about the rear brake completely."

The trend towards these so-called digressive brake pads has prompted Ferodo to return to the dyno testing of the 150-or-so materials that it catalogued in the lead up to the launch of DS3.12. Ironically, it's often materials that were towards the bottom of the pile originally that are now coming into their own with the new requirements.

To put things into context, a front pad would perhaps have a friction coefficient of around 0.5, whereas the rears would now be something like 0.3. Relatively speaking, this translates to more lubricants in the pad formulation and less abrasives. This front-to-rear friction split also plays an important role in loading the rear tyres and keeping them up to temperature, which benefits traction and cornering as well.

"The most difficult part of the braking is the combined phase, where you're still braking but you're starting to turn in," comments Bonfanti. "You can gain several tenths each time by really optimising the braking. Even at somewhere like Monza you're potentially talking about a second a lap just from the braking. So we're trying to avoid any interference from the ABS when you first get onto the brakes and when you release them going into the turn."

The car is also effectively coasting while the ABS is engaged, he points out. Almost by definition this is lost time – neither shedding excess speed nor driving out of the corner – and it also gives the driver less control.

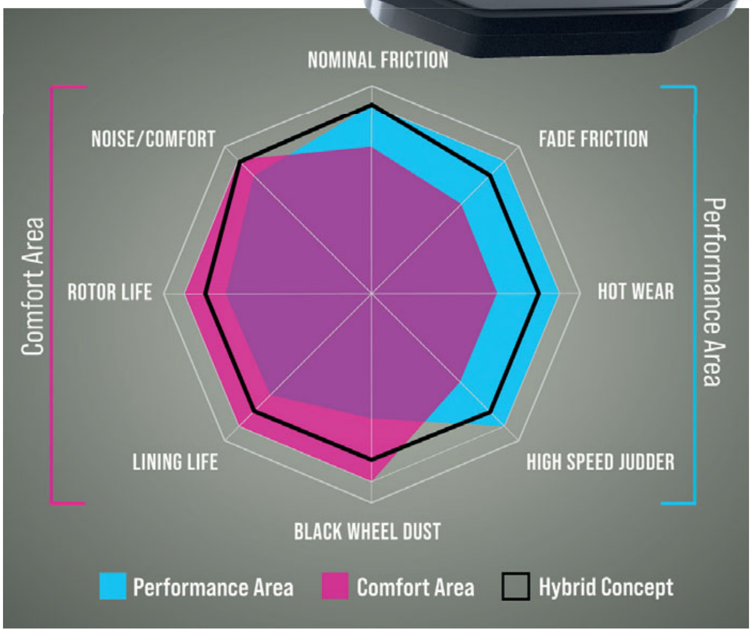
"While the ABS is active, you're not driving the car – at least as far as the brake input is concerned – the car is driving you," Bonfanti observes.

The future

While ABS optimisation might be the biggest talking point in GT racing at the moment, there's an even greater challenge on the horizon. Hybridisation is largely the preserve of top-tier prototype and single-seater categories at the moment, but the arrival


Jaguar

ABOVE Electrification is increasingly a factor. Ferodo provided the brake pads for Formula E's Jaguar I-PACE eTrophy support series



BELOW Leveraging its comprehensive material science expertise, Ferodo's OE business has introduced advanced copper-free hybrid friction material composites that simultaneously serve braking performance and comfort requirements in both ICEs and EVs

LEFT Years of painstaking work in the laboratory underpin the breakthroughs made on road and track

of road-going hybrid supercars like the McLaren Artura, the Ferrari 296 GTB and the Honda NSX – all of which have racing variants currently running IC-only powertrains – begs the question of whether we might see electrification start to play a bigger role on the track.

"We need to understand how the electrification is going ahead, because, for sure, that is driving a lot of development work on the discs," comments Bonfanti. "Cast iron has been very stable for the last 25 to 30 years, but we're now seeing a lot of pressure to take away weight in other areas of the car as electrification brings additional mass to the powertrain. Any changes to the discs as a result of that will surely prompt a change to the pad materials as well. That's something we've already seen on road cars, but not yet in the racing industry."

Clearly, the role of the friction material would change too. On the road car side, Little points out, peak friction levels have become less critical, as brake-by-wire systems have prioritised regenerative braking. Instead, wear resistance and noise levels have come to the fore. Even challenges such as stiction corrosion are starting to emerge as road cars use their mechanical braking systems less.

Currently, there's a degree of divergence between increasingly electrified road cars and predominantly IC-only competition cars. However, that might not always remain the case, and there are already exceptions. Ferodo provided the brake pads for Formula E's Jaguar I-PACE eTrophy support series, for instance, and it's understood that the low noise levels were part of the reason that the material was chosen. After all, if you're looking to showcase the refinement of your new EV, you don't want each car squealing as it rolls down the pitlane.

RIGHT Environmental concerns will inevitably influence motorsport, as they have the automotive business. Ferodo has been supplying low- and zero-copper friction products since 2012. Its formulations were developed using a tribological fingerprinting process to identify alternative materials that can provide the same stopping performance, noise, vibration and harshness (NVH) characteristics and durability performance as traditional copper brake pads

Environmental concerns are also likely to play an increasing role in the motorsport industry, from brake dust emissions to manufacturing impact. In the United States, copper, which can be toxic if it accumulates in the environment, will effectively be banned from road car brake pads as of 2025. Currently, the proposed ban doesn't apply to motorsport products, but it's something that Ferodo is keeping an eye on as it seeks to reduce its impact. Elsewhere, the brand has reduced the use of plastics in its packaging by 98 per cent, and the majority of the energy used in the factory is now taken from solar panels on the roof.

It's all a far cry from Frood's Patent Brake Blocks. But in other respects, the methodology and even some of the materials used in the formulation, haven't changed that much. It does make you wonder what the next 125 years might bring. RT

IT'S PROBABLY JUST SPAM…

From fixing bikes to winning the Young Engineer of the Year accolade – **Peter Innes** finds out how an email from Lewis Hamilton inspired a kid from Peckham on a quest to democratise access to STEM opportunities

THINK of the key venues for scientific education down the ages, and the images that spring to mind might include America's Ivy League universities plus Stanford and the Massachusetts Institute of Technology. On this side of the Atlantic we have Oxbridge and the great London seats of learning. Then, of course, there's the Peckham branch of Burger King.

It was here – in one of the most deprived areas of South-East London – that two great minds found they were thinking alike in 2015, leading to a venture that could have a huge impact on STEM teaching long into the future.

Local sixth-former George Imafidon had just won a scholarship from Southwark Council that was to pay his way through a degree course in mechanical engineering and programming at UCL, when he agreed to meet mutual friend Muizz Almaroof. Why Burger King? Neither of them had access to an office, and the Peckham McDonald's was usually too busy to have a meeting in peace…

"When we sat down, Muizz just started pitching this vision to me," says Imafidon. "He hoped to answer the question: 'What's the motive?' which is a colloquial phrase meaning 'What is there to do today?' I connected to that because I'd used the phrase throughout my childhood.

"Motorsport's competitive arena means it still has the power to drive innovation quicker than anywhere else"

"Given the personal and professional development support I was now receiving thanks to my scholarship, I wanted to play a part in giving others access to the same kind of events outside the area. We started out with an app, so instead of them messaging me saying: 'What's going on?' they could find it all in a few clicks. The rest is history."

The big idea was to help others find similar support to break into STEM careers, which were about as far off the average Peckham kid's radar as space exploration. Their new company Motivez was soon much more than an app, turning into a community aimed at helping show people "STEM is more sexy than they think".

Eight years on, Motivez has already helped over 10,000 young people onto the career ladder via a range of programmes. Prospering Peckham encourages 14 to 16-year-olds to develop STEM-based solutions for tackling local pollution. Older teens are offered work experience, internships and help with applying for jobs in areas they may never have considered before. Anyone up to the age of 25 can also take on bespoke programmes with specific organisations such as McLaren, a link that led to one of Imafidon's personal Motivez highlights so far.

"While the kids were doing this showcase at the end of our Prospering Peckham programme, we brought out a McLaren Supercar," he smiles. "It was special to bring something like that to Peckham and for them to see: you can be the ones designing a car like this, or potentially even buying the car one day. It's about showing them they can access all these things – and education is a big route to get there. But we don't just want you to be a consumer, ultimately we want you to be a creator – and the means to get there could well be through engineering, because I think engineers are like rock stars."

Imafidon himself is proof positive of that. Still only 26, his career path already reads like a fairytale, leading to the 2022

ABOVE Prodrive engineer George Imafidon celebrates the dramatic title win at the 2022 Extreme E finale with Cristina Gutiérrez

Young Engineer of the Year award. And it all started as an eight-year-old fixing his friends' rusting bikes in his Mum's back garden so they could ride together round the same Peckham streets and car parks. He later sated his need for speed at the local kart track, but it was when it closed down that he first turned his thoughts to designing cars instead of driving them.

Charged with murder

Even so, Imafidon admits he was nothing special academically – until his family was rocked to the core when his brother Kenny was wrongfully charged with murder and imprisoned for six months in the Feltham Young Offenders Institute, a tale told in a book to be published by Penguin in July entitled *That Peckham Boy*.

"Kenny's a massive inspiration to me," adds Imafidon. "But his story seriously motivated me because I realised you can be wrongfully accused of something and put in that position, and I know what this environment can lead to. Growing up here meant I had to be as resourceful as possible. When I saw people go down pathways I didn't see as favourable, I said to myself: 'What is my way out?'

"Academia was a way I could visibly see, but one that hadn't been tried by many others I was growing up with, who may have been excluded from school for example. Still, no other route I could see around me seemed to be working, so academia seemed like the best thing; not just academia but to do it all-in, no distractions, just go for it.

"That was a big driving force to get out of my current environment, and a great opportunity for me to change the narrative and inspire my community ▶

Coryton Advanced Fuels

that there's another way."

True to his word, Imafidon gave it his all, even persuading his science GCSE teachers to start coming into school on Saturdays for extra lessons to help him get ahead of the game. Under the guidance of inspirational education specialist Patricia Lamour MBE, he set up the Aspire Prep Group to help other keen students in a similar position.

Once Imafidon found out Southwark Council offered scholarships to pay university tuition fees, his motivation went into orbit. He earned funding from a total of six different sources in the end – including the Amos Bursary, which he more than repaid by taking a year out of his course to raise a total of £1 million.

Reaching that target was no easy feat and Imafidon admits it took a toll on his mental health, but neither that nor the demands of running Motivez

ABOVE The success of Prodrive's Dakar and Rally Raid campaigns has helped shine a light on the case for sustainable fuel

RIGHT Driven by the disappointment of narrowly missing out the previous year, winning the Extreme E title with Lewis Hamilton's X44 was payback for all involved could prevent him gaining a first-class degree. He also spent his first two years at UCL competing in Formula Student, which offers young engineers all over the country the chance to design and build their own racing cars.

Rejection

Stung by the rejection when he was overlooked for Formula Student in year three in favour of someone who had grown up fixing classic cars – miles away from his own life experience – he took an internship at Rolls Royce, where he redesigned a jet engine fixing to make it more aerodynamic. This has since been widely adopted in passenger aircraft, saving the company a staggering estimated £50 million.

"It's just nuts and bolts," he deadpans. "But it just happened to be a part that hadn't changed in 40 years. This fixing has to withstand the stresses on it, so you've got a few constraints, but we completely redesigned it. Everyone else was focused on the sexy components, whereas I barely knew about a jet engine before I started. So it just goes to show it's not always about doing things as they've always been done, or focusing on what everyone else is focusing on, because you just don't know where the performance is going to come from."

Weeks after Imafidon graduated, his own career took off for real when he received an email – which he originally dismissed as spam – from one ▶

BELOW George has learnt from experienced Prodrive colleagues in motorsport and advanced technology

Extreme E

Lewis Hamilton. The Formula 1 legend needed board members for his newly-created Hamilton Commission, aimed at increasing the amount of black people working in UK motorsport. Hamilton had heard about Motivez and reckoned Imafidon perfectly fitted the bill.

Better still, Hamilton was on the lookout for personnel for his new X44 team, which was to compete in the inaugural season of Extreme E racing using the resources, management and experience of motorsport veterans Prodrive. Imafidon went to Spain in November 2020 for the initial testing of the ODYSSEY 21 E-SUV car, and by the first race in March 2021 he was on the plane to Saudi Arabia as the team's performance engineer.

"Like a sponge"

As the series sailed to Senegal and Greenland aboard its St Helena ship, Imafidon set about learning "like a sponge" from his more experienced colleagues. The seven-person limit for race teams, reminiscent of the early days of F1, meant his learning curve about all areas of the operation went into overdrive.

"That total of personnel includes mechanics, so on the engineering side there was just me and lead engineer Gus Sanchez," he says. "I was responsible for running the car from a data and electrical/electronic perspective. In the first year I was observing the car and learning how all the components work, but by the second year I was responsible for all the implementation on the car. It was a big step up and a proper responsibility.

"It's not always about doing things as they've always been done"

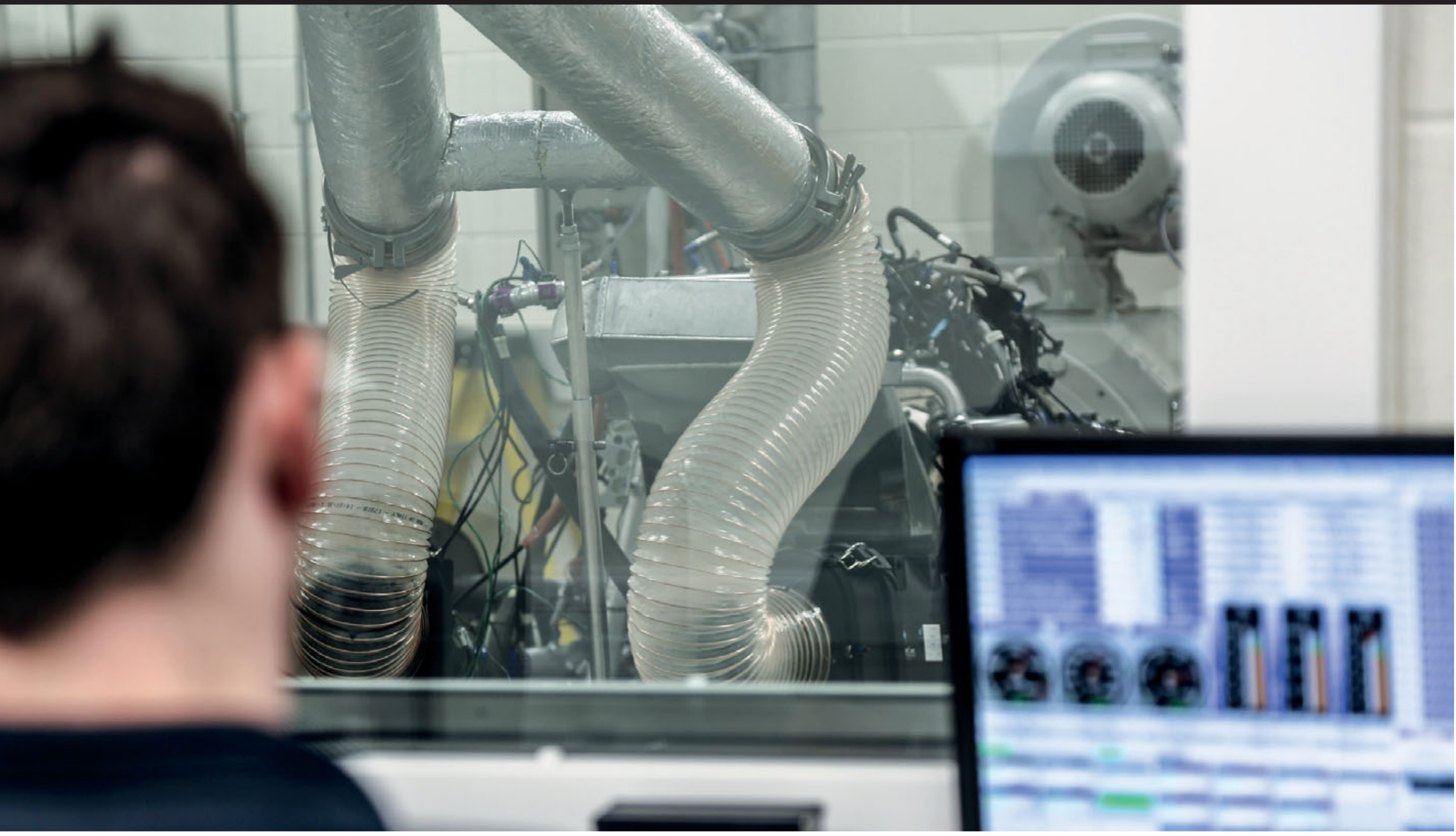
"The attention to detail was immense because there's no one else to look over everything, so you have to learn every single thing about the car, dot all your I's and cross all your T's. Gus was mainly responsible for making sure the drivers were happy and the general management of the team, so it was all down to me."

Prodrive is well known for the amount of simulation it invests in its motorsport projects, and Extreme E made for an intriguing test of its pre-event capabilities. The race venues were not only new to the teams but scattered all over the planet on diverse environments and surfaces. So how much could Imafidon plan in advance?

"I was responsible for gathering as much data as possible on each new terrain," he adds. "I'd make a report and then discuss that with Gus, looking at things like elevation and the profile of the track to go through what that meant for setting up the car. But it's always hard to do things from pictures. So it was usually only when we got there and saw the actual track that we'd manage to adjust the set-up for real.

"We raced on everything from snow to sand. You

BELOW Imafidon is now working across tech such as sustainable fuels, hydrogen and electric powertrains



may say: 'It's a soft, springy floor for sand' but all types of sand are different in terms of the surface. In fact, one of our biggest challenges was the first time we raced on grass. That involved working on a very slippery surface where the track was evolving massively, and it wasn't just the first time I'd ever done it, but the first time for many of the team as well.

"It all means Extreme E is not like other series where you have months on end to decide your set-up for each track. You really only have between the track walk and free practice to make the decisions and get everything done. The set-up evolves over the course of the sessions, but every single change we make could have a drastic impact. So we were always looking for ways to extract the most performance from the car – and also the drivers."

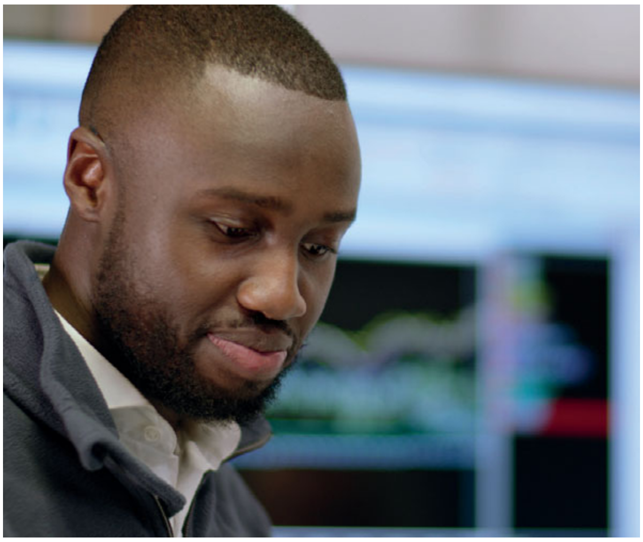
Ah yes, the drivers: Spain's Cristina Gutiérrez, only the second woman ever to win a stage of the Dakar Rally, alongside French rally legend Sébastien Loeb. Not a bad pairing, especially in a single-make formula where the drivers can inevitably make more of a difference. Part of Imafidon's role even involved driver coaching, but there are limits…

"With a nine-time World Rally Champion there's not much you can coach," he smiles. "The great thing about Seb is that he makes your job easier. If he had a particular area of the track where he experienced an issue he'd say: at waypoint 21 I felt the car doing such-and-such. Then we can look at the data, and by qualifying or the final we might suggest things. But Seb really knows what to do – and he always has something hidden up his sleeve in terms of line. So our job was more about translating what Seb was doing to Cristina, while making sure it fitted with her driving style."

They must have done OK: the gap between the male and female drivers initially averaged 10 seconds a lap, but come the Season 2 finale at Uruguay's Punta del Este Gutiérrez was fastest overall across the whole weekend.

That race also led to the ultimate payback for everyone at X44 and Prodrive. A year earlier they ended tied on points with Rosberg X Racing, losing the title only on countback of wins. This time they overcame a huge points deficit with two races left to prevail – by 0.6 seconds.

"To win the title, it was like: Whoah," says Imafidon. "I was still only 25, so to be able to do something like that with a team was big for me. The emotions we went through after missing that first championship were so powerful, they gave ▶



ABOVE Prodrive's new powertrain facility at Banbury will help accelerate the development of a new generation of alternative-fuel and hybrid propulsion units

LEFT Imafidon is passionate about providing a brighter future for young people, no matter their background us so much motivation for continuous improvement. It's about the prize but the process is more important.

"You say you're going for it but realistically you can only focus on one race at a time. That's what we did. I just became very present on what can I do right now to make the most of this. It showed every single little detail matters, including strategy and improving team operations.

"I saw all the conversations that led up to that big moment; for example where we'd use the hyperdrive in the final, which was a very strategic move. It was all those small things that added up to that split second at the end. Even then we didn't know straightaway if we'd won the whole championship, so it took a while for it all to sink in. But yeah, it was phenomenal."

Prodrive isn't running the X44 team in 2023 but Imafidon has stayed on as a race engineer to help smooth the handover. That puts him in a good position to assess how the ODYSSEY 21 car has developed, and how individual teams can get the most out of it.

"Everyone has the same dampers but the window you work in is entirely up to you," he says. "The car's high centre of gravity makes it easy to roll, so you want to run the car low if you can. At first teams would run the suspension fully closed because going over the bumps was having a large impact and the drivers were feeling it. So you'd run it as stiff as you can, and it still wasn't enough for that weight of car.

"The second variety was similar, but now we have Fox dampers which have lots of variation in how you can set up the car, which makes it a bigger technical challenge. We've gone from single dampers on all four corners to an internal bypass on the two fronts and an external bypass with two dampers on each of the rears, so a total of four on the rear, two at the front.

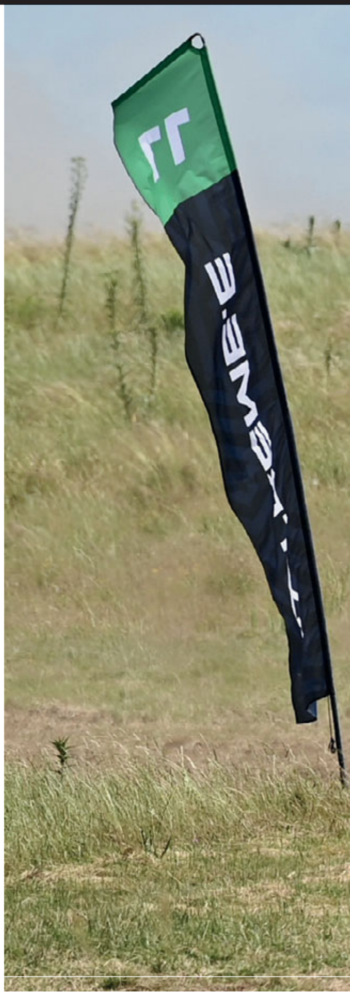
"We can also configure the toe, how much power you distribute to the front and the rear, plus tyre pressure and a few other things. So we have much more room to explore what's possible now, which makes it more fun from an engineering perspective."

"Humanitarian engineer"

Imafidon is also grateful for the change from air-cooled to water-cooled batteries, which are no longer temperature-limited, particularly while running at 275 kW in the heat of the desert. That has led to more charging between sessions, but teams prefer it because it means drivers get more time in the car, leading to a better show.

Away from Extreme E, Imafidon's immediate focus is to help Prodrive expand its research into sustainable models of motorsport. This self-declared "humanitarian engineer" has long aimed to seek out new ideas to improve people's quality of life – and he insists motorsport's competitive arena means it still has the power to drive innovation quicker than anywhere else. But the solutions are more complex than governments might have us believe.

"The truth is the future of motorsport



RIGHT The nature of Extreme E means every change the engineers make can have a dramatic impact

BELOW The award-winning app Motivez, for which he won the Diana award in 2019, is helping young people level up and pursue careers in STEM

is more eclectic; it's not just electric," states Imafidon. "Everything is driven by government policy, which largely advocates for electric. But while electric can thrive for inner city driving, it isn't the best solution for every single application. When it comes to heavy-duty vehicles, hydrogen is a lot more feasible – maybe even taking the existing internal combustion engine and changing components to get the range needed for the vehicle's mass.

"E-fuels are another exciting field but one challenge is understanding supply, so it might be better for more niche applications. That's what we're looking at now. Prodrive were one of the first to run e-fuel, EcoPower, in our Rally Raid and Dakar programmes. It reduces carbon emissions by 80 percent and can be used in almost any IC engine with no loss of performance or range. So I want to exploit all these cleaner solutions to extend the life of the ICE – because that's the most sustainable thing we can do, rather than just throwing them all away…"

Loeb's record run of six straight stage wins at this year's Dakar Rally is proof that e-fuels can get the job done at the highest

Extreme E

level. Meanwhile hydrogen has been touted as the coming holy grail for decades – and the Extreme H series proposed for 2024 could finally get it cooking with gas. But will the future be hydrogen fuel cell or hydrogen combustion?

"Fuel cells have been used in motorsport but there's a long way to go," adds Imafidon. "So hydrogen combustion is an effective bridge until fuel cells mature, using existing technology if we can retrofit it with other components. That is achievable right now, because it has been done before. There's been lots of research and development but because of all the investment in electric, it hasn't lived up to its potential. All you're doing is reducing the NOx emissions to minimal levels by running the car leaner. So hydrogen combustion is interesting, especially for fans who still love that atmosphere it brings while doing it in a cleaner way."

If we're looking for the ideal energy solution for the future, frankly we could do a lot worse than work out whatever it is that powers George Imafidon.

He thinks nothing of combining the demands of running Motivez with his Prodrive job – all because he doesn't know anything different; it's the way it's always been for him ever since sixth form. He considers his "best and highest use" isn't merely to be an engineer, nor just to serve young people, but to do both.

Imafidon insists he is standing on the shoulders of giants, not least the mentors who entered his life at critical times – from his teachers and benefactors through to Lewis Hamilton. The message he is keen to pass on is about "serving your way to the top" by helping others along the way.

> **"Helping kids dream again"**

And, just as engineering boils down to coming up with a vision and creating it, that's exactly what he now wants the kids he mentors to do with their own lives.

"Our work is about helping kids dream again," he says. "The power of dreams is all we have. One thing my brother always taught me is when we lose hope, there's nothing left. The dream is what keeps that fire burning and that hope alive.

"It doesn't come without its challenges. I nearly gave up on my motorsport dream after the Formula Student rejection. That was a big knock. But when I look at what it led to with Rolls Royce… everything happens for a reason. I never gave up on the dream that I could be the best engineer I can be, and use the gifts I've been given to improve my community.

"The power from failures has definitely been more than the power from successes. In order to produce anything great, it takes time and continuous iterations. These are the values I teach the kids – many of whom will face more rejections than me. But if I hadn't failed, there's no way I could teach that. So yes, stuff like that can happen, yet you can't give up on dreams. If you keep plodding away, you might just get the opportunity.

"I don't want to be the exception to the rule any more. And, through Motivez, I'm showing that's not the case because now we're producing a large community of people from different backgrounds who are all designing their future too. All we do is put the pen in their hands. Here's the pen, write your story…" RT

FORMULA 1 TECHNOLOGY *THE ENGINEERING EXPLAINED*

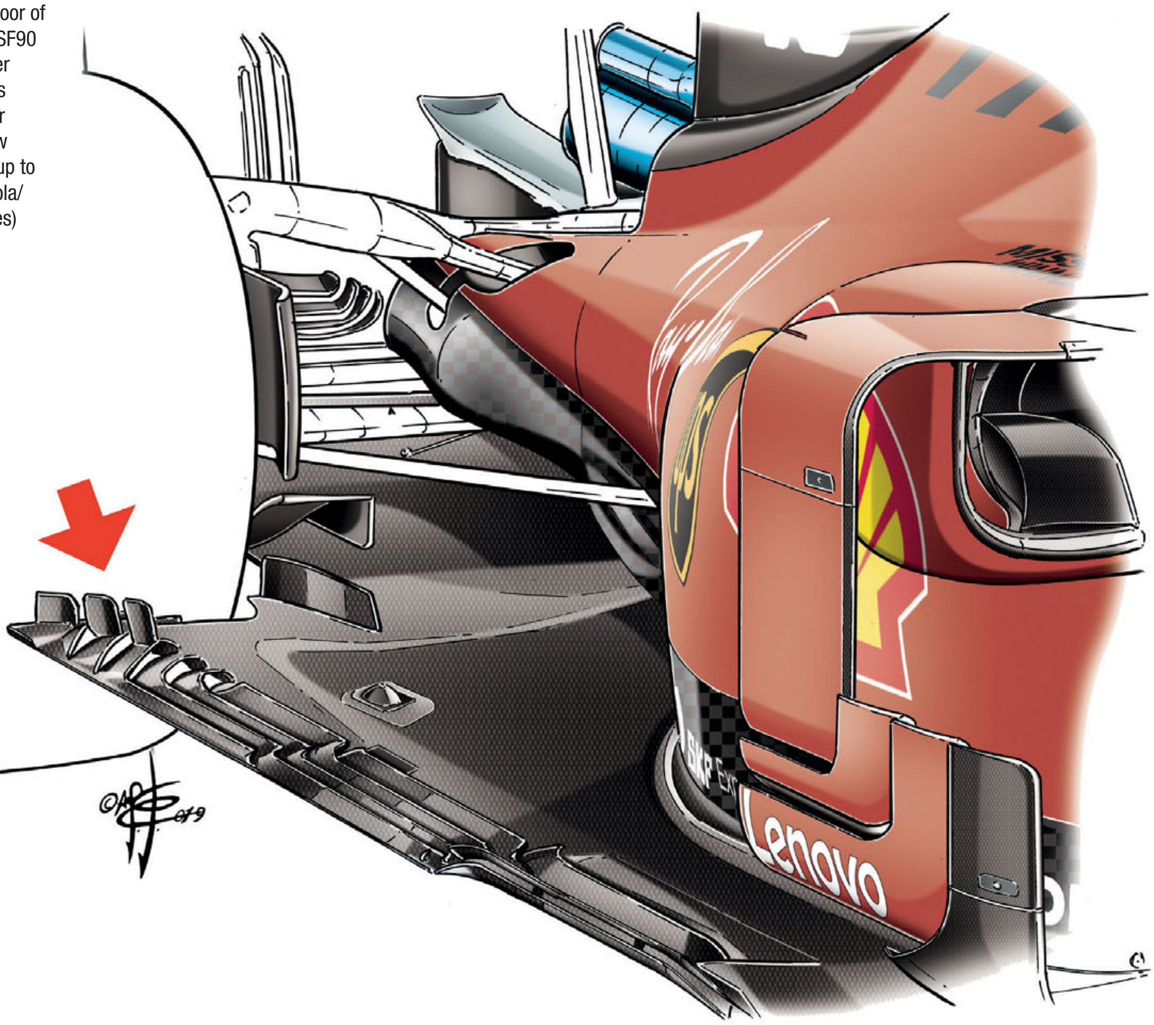
In this extract from his new book, **Steve Rendle** examines underfloor aerodynamics, one of F1's biggest battlegrounds

THE floor has become a complex aerodynamic component and is the most efficient downforce-producing part of the car, providing a high level of downforce for a minimal drag penalty. In recent years, various slots, holes and vanes were used near the edges of the visible upper surfaces of the floor to help to fine-tune the airflow, improving downforce.

Floor configuration up to 2021

Until the end of the 2021 season, the floor of an F1 car was stepped. This was to meet an FIA regulation that was introduced in 1995 to reduce the levels of downforce. In simplified terms, the rules stated that:

- All the parts of the car from a point 330 mm behind the front-wheel centreline to the rear-wheel centreline must lie on one of two parallel planes – the 'reference plane' and the 'step plane'.
- The reference plane dictates the lowest surface of the car (the surface closest to the track). Without the FIA regulation 'plank' fitted, the lowest surface of the car is on the reference plane.
- The step plane must be 50 mm above the reference plane.
- The parts lying on the reference plane must extend from a point 330 mm behind the front-wheel centreline to the rear-wheel centreline, and must have a minimum overall width of 300 mm and a maximum overall width of 500 mm, and must be symmetrical about the car's centreline.



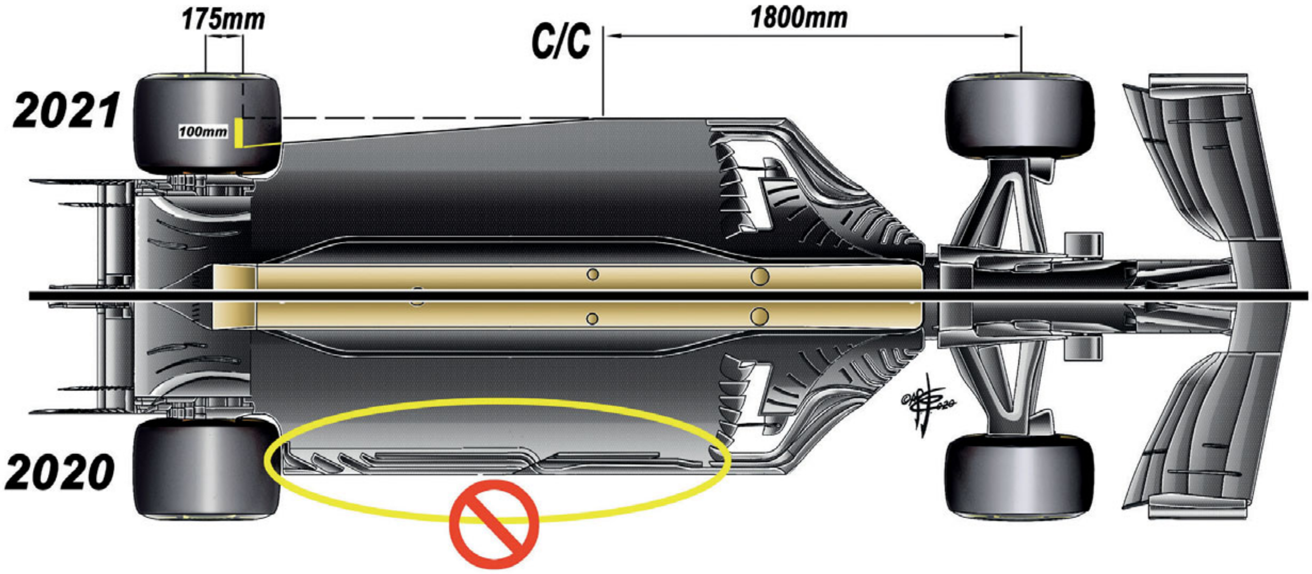
RIGHT The rear floor of the 2019 Ferrari SF90 featured a number of slots and vanes typical of the floor designs in the few seasons leading up to 2022. (Giorgio Piola/ Motorsport Images)

In practice, this meant that the cars had a low central rectangular surface, running from behind the front-wheel centreline to the rear-wheel centreline, to which the ‘plank’ was fitted, and the surfaces either side of that rectangular surface were positioned 50 mm higher, resulting in a stepped floor.

Until the end of the 2020 season, the floor extended from a point a prescribed distance behind the centreline of the front wheels almost all the way to the back of the car. This was still the case for the 2021 season, but for the start of that season new regulations were introduced with the aim of decreasing the level of downforce available. The changes included reducing the floor area by effectively cutting off a triangular section from each rear outer edge of the floor. Whereas previously the floor was rectangular, for 2021 the floor had diagonal tapers at the rear corners, tapering inwards towards the longitudinal centreline of the car when viewed from above. The various slots and holes in the edges of the floor mentioned previously were outlawed for 2021, the regulations stating that the floor must be solid.

The forward section of the floor, which extends forward from the sidepod area under the chassis, is ▶

LEFT This view of the Alpha Tauri of Yuki Tsunoda being recovered after an accident at the 2021 French Grand Prix clearly shows the stepped flat floor and plank. (Motorsport Images)



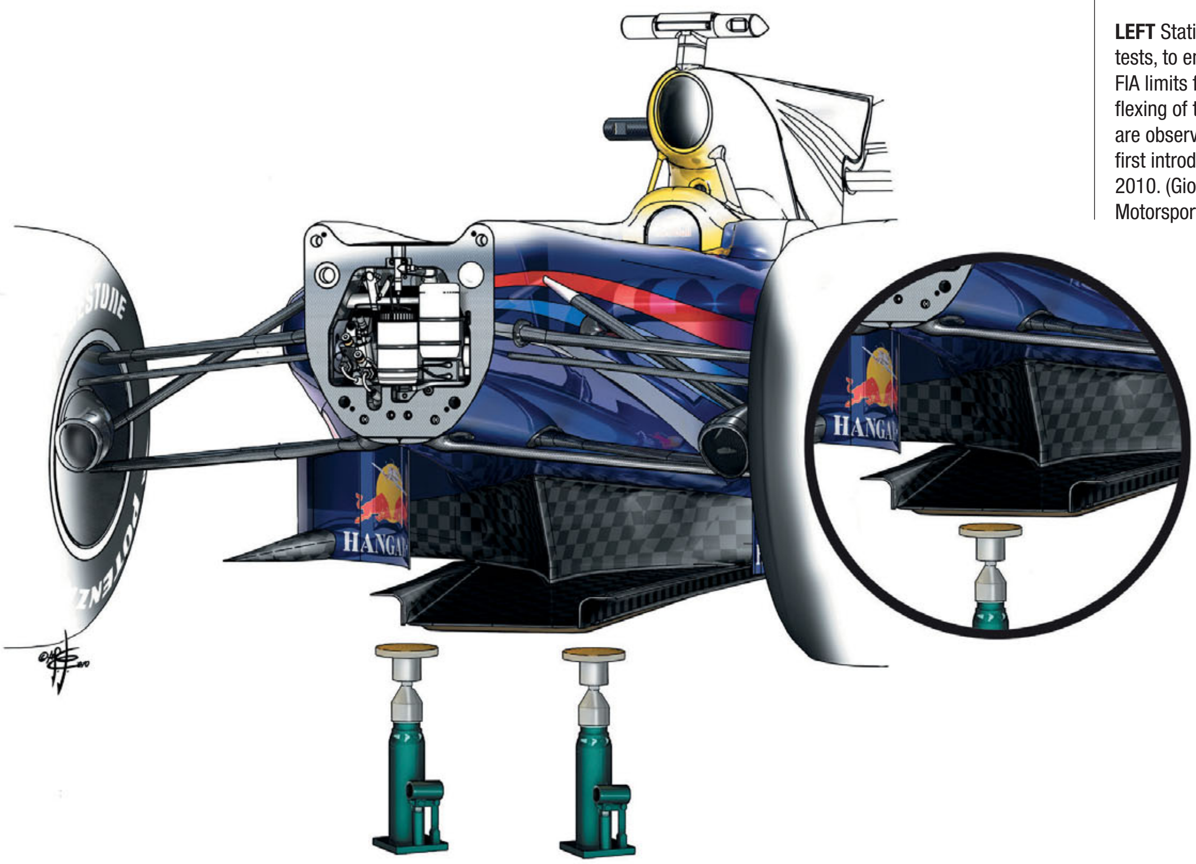
known as the 'tea tray'. As it is theoretically possible to gain an aerodynamic advantage from a flexible floor – specifically in the tea-tray area – FIA limits for the flexing of the floor (checked using static load tests) have been specified, and regularly revised, in recent years. This prevents teams using a tea tray that can twist significantly under aerodynamic load, helping to increase downforce.

Floor configuration from 2022

As part of the heavily revised regulations introduced for the 2022 season, the floor is no longer stepped, and there is a return to the use of underbody tunnels – which have not been seen on F1 cars since the 1980s 'ground-effect' era. The reason for reintroducing these tunnels is to improve the 'stable' downforce available when closely following another car, reducing the reliance on the wings – the downforce produced by the underbody is less affected by the aerodynamic wake of cars ahead.

These underbody tunnels run on either side of the car below the sidepods, forming two separate venturis. The size and shape of the tunnels is closely regulated. The rear ends of the tunnels form

ABOVE An illustration depicting the revised floor regulations introduced for the start of the 2021 season – see text for details. (Giorgio Piola/ Motorsport Images)



LEFT Static load tests, to ensure that FIA limits for the flexing of the floor are observed, were first introduced in 2010. (Giorgio Piola/ Motorsport Images) the diffuser (see later), and the diffuser exit is around 30 per cent narrower than that for the 2021 cars, although can be much deeper – nearly 80 per cent deeper than for 2021.

On the outer, upper edges of the floor, towards the rear of the sidepods, longitudinal 'edge wings' can be fitted to help to direct the airstream away from the edges of the floor in order to reduce disruption to the air flowing through the rear of the tunnels towards the diffuser.

The 'tea tray', or 'bib', is far smaller ▶

RIGHT A typical 'tea tray' at the front of the floor, seen here on the 2011 McLaren MP4/26. (Motorsport Images)

Ground-effect

THE term 'ground-effect', as originally used to describe the 'skirted' high-downforce cars that dominated the sport during the 'ground-effect era' of the late 1970s and early 1980s, has become somewhat distorted over time.

The term 'ground-effect' actually refers to a physical phenomenon that occurs when an object is moving in close proximity to the ground. Taking an aircraft wing as an example, when an aircraft is flying close to the ground, it experiences reduced drag over the wing surfaces (due to the vortices from the wingtips and the aerodynamic 'downwash' behind the wing being disrupted), and as the aircraft moves closer to the ground, the air pressure under the wing increases, effectively increasing lift (and forward speed), which enables the aircraft to 'float' just above the ground. This is often evident during landing, when, depending on the aircraft type, a good pilot can use the effect to allow the aircraft to 'sink' gently onto the ground. Ground-effect can also be used to allow an aircraft to accelerate just above the runway during take-off before reaching the specified safe climbing speed.

In an F1 context, inverted wings have been used to generate downforce since the late 1960s, but it was almost by accident that the power of underbody ground-effect was discovered during wind-tunnel experiments by Peter Wright and his team at Lotus when working on the design of the Lotus 78.

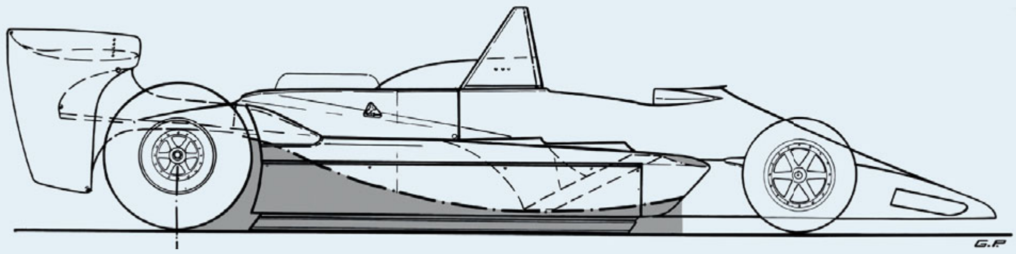
As Wright recalled in an interview with Andrew Cotton for his book *Haynes Lotus 79 Owners' Workshop Manual*, team personnel were exploring new cooling techniques in a wind tunnel when they noticed that the gap between the surface of the rolling road and the model's sidepods was shrinking under load. This was the pivotal moment in the discovery of venturi ground-effect, which was the principle on which skirted ground-effect cars were based.

Once the principle was better understood, the geometry of the underfloor venturi tunnels was refined, and skirts were added to seal the 'leakage' of air from the gaps between the edges of the sidepods and the track, significantly improving downforce, by up to 50 per cent.

Development was rapid, and Lotus stole a march, with the ground-effect Lotus 79 dominating the 1978 season, winning both the constructors' and drivers' championships (with Mario Andretti and Ronnie Peterson taking first and second places respectively in the drivers' championship).

By 1983, the use of skirts coupled with underbody venturi tunnels was banned after growing safety concerns, and it is generally stated that 'the ground-effect era' ended. However, the ground-effect principle continued to be relevant in F1, and any car that uses part of the underbody to generate downforce due to its proximity to the ground is in reality making use of ground-effect. Ground-effect has been harnessed in recent years by using the front wing, floor and powerful diffusers to create a venturi effect (see 'Using the floor to produce downforce (the venturi effect)'), lowering the air pressure under the car and producing downforce.

So, when it is sometimes stated that the 2022 season saw a return to ground-effect cars, this is not strictly true, as F1 cars have continued to make use of ground-effect, via floors designed to generate downforce, ever since the end of 'the ground-effect era'. RT



LEFT A Giorgio Piola illustration showing the ground-effect tunnels under the sidepods of the Lotus 79 of 1978. (Giorgio Piola/ Motorsport Images)

from 2022, greatly reducing its aerodynamic effect.

FIA deflection tests are carried out on the floor, with prescribed loads at specified positions at the front, outboard edges and centre, and the deflections measured must be within specified limits.

Using the floor to produce downforce (the venturi effect)

Let's look at how the floor of the car can be used to produce downforce.

In conjunction with the front wing and the rear diffuser (and to an extent the rear wing), the floor forms a 'venturi'. On pre-2022-season cars, the entire floor formed part of the venturi, but from 2022 the cars feature two separate venturi tunnels, one on each side of the car, effectively increasing the contribution provided by the floor to the overall level of downforce produced on the car.

In its simplest form, a venturi is a tube with a constriction partway along its length. The area where the fluid (air is a fluid) enters and flows into the tube, before it passes through the restriction, is known as the 'inlet', the restriction is known as the 'throat' and the area downstream of the throat is known as the 'diffuser'. When a fluid flows through a venturi, the fluid accelerates as it passes through the throat and its pressure drops.

If we apply the venturi principle to the floor of an F1 car, what we actually have is a venturi tube with a flat bottom, formed by the surface of the track.

On pre-2022-season cars, the area ahead of the front of the floor (where the airflow is controlled mainly by the front wing) is the 'inlet', the area under the floor is the 'throat', and the area behind the flat floor (where the airflow is controlled by the diffuser and rear wing) is the 'diffuser' – which is why the diffuser is so-named.

From 2022, exactly the same principle applies, except that two separate venturis are used – one on either side of the car. ▶

ABOVE This view of the Alpine A522 of Esteban Ocon being recovered at the 2022 Miami Grand Prix clearly shows the typical shape of the underside of the floor on 2022 cars, with the underbody ground-effect tunnels and heavily upswept diffuser. Note also the long vanes at the front of the tunnels. (Motorsport Images)

BELOW Another view of the recovery of a 2022 car, this time the Ferrari F1-75 of Carlos Sainz at Imola, again showing the shape of the underfloor tunnels and the deep diffuser. (Motorsport Images)

LEFT During the first ground-effect era in the late 1970s/ early 1980s, 'skirts', clearly visible here on John Watson's 1979 McLaren M28, were used to seal the edges of the sidepods to the track. (Motorsport Images)

For each venturi, the inlet, throat and diffuser are effectively integral with the floor, which is shaped to form the venturi. The longitudinal centre section of the floor (under the cockpit) is flat, with the regulation 'plank' fitted to that section.

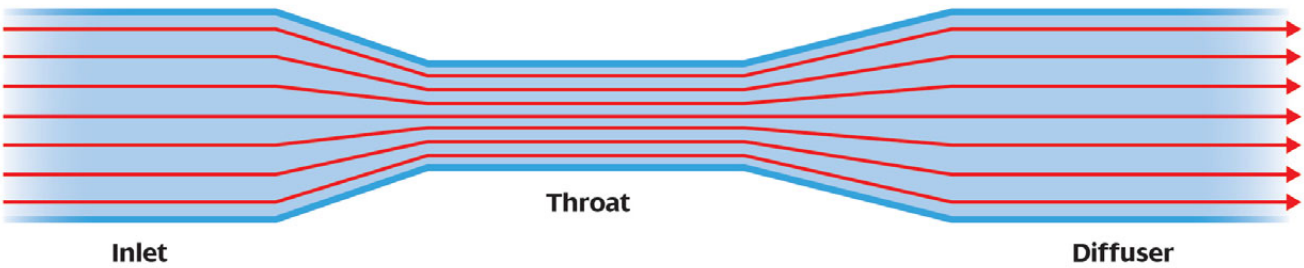
If the air pressure under an F1 car is lower than the air pressure acting on the upper surfaces of the car, downforce is generated. So, by controlling the airflow upstream and downstream of the floor in order to accelerate the air under the car, it is possible to obtain higher levels of downforce.

In isolation, the floor would generate little downforce, but the front wing, diffuser and rear wing allow it to work effectively. For this to happen, the maximum amount of clean air must be directed under the car, and this air must be accelerated as much as possible. One way of increasing the venturi effect is to run with the floor inclined upwards towards the rear (known as 'rake'), and this is why, for the past few seasons, some cars have run with the rear ride height noticeably higher than the front.

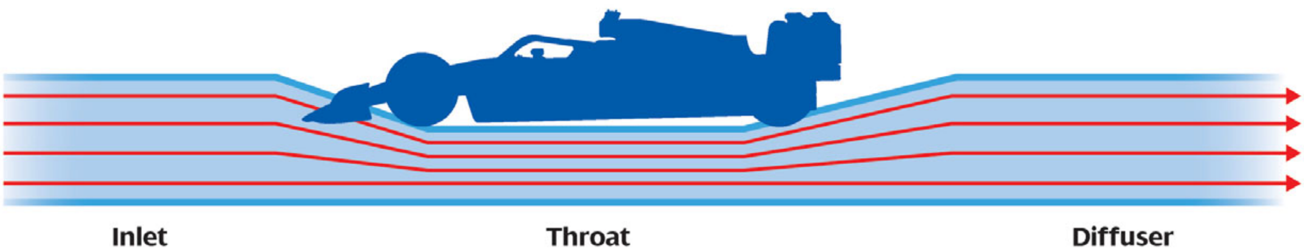
During the 1970s/1980s ground-effect era, the designers 'sealed' the sidepods (and hence underbody venturis) to the track surface using 'skirts' that made contact with the track surface. This prevented air from 'leaking' along the edges of the bottom surfaces of the sidepods. Skirts cannot be used in F1 today, but the designers aim to achieve a similar effect by 'sealing' the lower edges of the sidepods using vortices generated along the edges of the floor. If this can be achieved successfully, it improves downforce, but perhaps more importantly can be used to reduce the sensitivity of the car to ride-height change, in turn contributing to the reduction, or even elimination, of the 'porpoising' phenomenon seen during the early part of the 2022 season, which proved particularly troublesome for Mercedes and Ferrari.

The vortices are generated by various devices at the lower edge of the floor, between the front and rear wheels, and during 2022 pre-season testing, it was apparent that McLaren in particular had taken the lead in successfully generating these vortices to seal the floor. The challenge for other teams, as ever, is to integrate the various aerodynamic devices so that they interact to optimum effect, which is not always easy if they were not designed as an integrated package from the outset.

The floor is shaped to deal with the wake from the front wing, and to interact efficiently with the diffuser and rear wing. In 2010, teams discovered that the introduction of the double diffuser actually improved the downforce available from



ABOVE & BELOW A schematic of the venturi principle, showing the 'inlet' (equating to the area around the front wing), the 'throat' (the car's floor) and the 'diffuser' (the car's diffuser)



ABOVE Mechanics carry the floor for a 2021 Alfa Romeo C41, showing the plank at its centre. (Motorsport Images)

BELOW Various devices, such as the slots and raised hoops visible here on the Ferrari F1-75, are used to generate vortices along the edges of the floor on the 2022 cars to help to 'seal' the edges. Note also the bracing stay to reduce the flexing of the floor under load. (Motorsport Images)

the forward floor, by allowing the front of the floor to work harder due to the improved airflow beneath it. This helped to maintain the aerodynamic balance of the car, because, without this effect, the double diffuser would have resulted in a large increase in downforce at the rear of the car, with no corresponding increase forward of the diffuser.

The 'plank'

The FIA's regulation skid block ('plank') is attached to the bottom of the floor. From the start of the 2022 season, it must extend longitudinally from a point 430 mm behind the front-wheel centreline to a point 600 mm ahead of the rear-wheel centreline. The plank is 250 mm wide, and must be 10 mm (± 0.2 mm) thick along its entire length when new, with a minimum thickness of 9 mm at the end of the race. The plank therefore dictates the minimum possible ride height of the car.

The plank contains holes into which FIA scrutineering gauges can be inserted to check the minimum thickness. Although a team can choose the material used for the plank, its density must be within specified limits. The usual choice is a manufactured beech-wood product called Jabroc, which comprises thin veneers bonded together with a high-strength resin. The manufacturing process is carefully controlled to ensure that each finished plank is identical in terms of wear rate and material density.

Watching the mighty BT52s turn back time at Goodwood prompted former Brabham designer **Sergio Rinland** to ask the question:

WHEN IS THE POWER *ENOUGH* POWER?

A **FEW** weeks ago, at the Goodwood 80th Members' meeting, I was reminded of what the great Mark Donohue once said when asked if his 1,000 HP (1,500 HP with 2 bar boost!) Porsche 917/30 Can-Am had enough power: "If you can leave two black stripes from the exit of one corner to the braking zone of the next, you have enough horsepower."

Formula 1 came close to that 'enough power' in the early '80s when, after ground-effect was banned, Gordon Murray of Brabham and Paul Rosche of BMW teamed up to create the fabulous Brabham BMW BT52 which allowed Nelson Piquet to win the 1983 F1 World Championship. We enjoyed seeing those machines in action at the 80th Members' Meeting, thanks to the efforts of former BT52 pilot Riccardo Patrese, ably assisted by the man bearing the surname of the team: David Brabham.

During qualifying at the 1983 French Grand Prix, Rosche brought in what is arguably the most powerful Formula 1 engine ever, developing close to 1,300 HP; similar to that 5L flat 12 turbo Porsche of 10 years earlier, but with a nimble four-cylinder 1,500 cc road car-derived masterpiece.

I was privileged to design my first Brabham (the BT56, together with David North and John Baldwin) with a derivative of that engine, the notorious 'laid down' BMW.

While Donohue's Porsche would run for a whole 200-mile Can-Am race with that amount of power, Nelson had to be content with 'only' 850 HP in race trim. Looking back at the 1983 Formula 1 season, it is no wonder the BT52 was such a dominant car.

When a sudden rule change by the FIA at the end of 1982 banned ground-effect in the governing body's quest to reduce what was perceived to be unsuitable cornering speeds for the tracks of the time, Gordon Murray scrapped his already-built ground-breaking Brabham BT51. That would have been the ultimate ground-effect Formula 1 car, with pit stop refuelling in mind to reduce the size of the car and gain an advantage at the beginning of the race by carrying only half of the fuel load of their competitors – close to 100 kg lighter!

ABOVE & BELOW Turning back time: the BT52s at Goodwood (above) stirred memories of the original monster back in 1983 (below)

Joe Harding/Goodwood

While everybody else just fitted a flat-bottom floor and bigger wings to the well-advanced 1983 ground-effect designs, Gordon rethought the whole concept in record time and came up with the perfect compromise of a huge front wing and rear diffuser, moving weight back to be able to put all those BMW horses on the ground without the help of the aerodynamic downforce they were used to up to then. Just trying his best not to spin the rear wheels, as remarked upon by Mark Donohue...

Bearing in mind that no time was available for any aerodynamic or tyre development to react to this sudden rule change, Gordon's approach was a stroke of genius.

That was the last time, in my humble opinion, that Formula 1 had 'enough power'. After that, the FIA started to limit turbo boost, first to 4 bar and subsequently to 2.5 bar, before banning turbos altogether in 1989.

The next rules revolution came 30 years later with the turbo hybrid engines and, ultimately, 40 years later with the return of ground-effect in the quest to recover the capacity of the cars to race closer together. Full circle! But thanks to the tight rules and the high level of technology available today to hone the available power, we don't have Donohue's kind of 'enough power'. RT

Newspress