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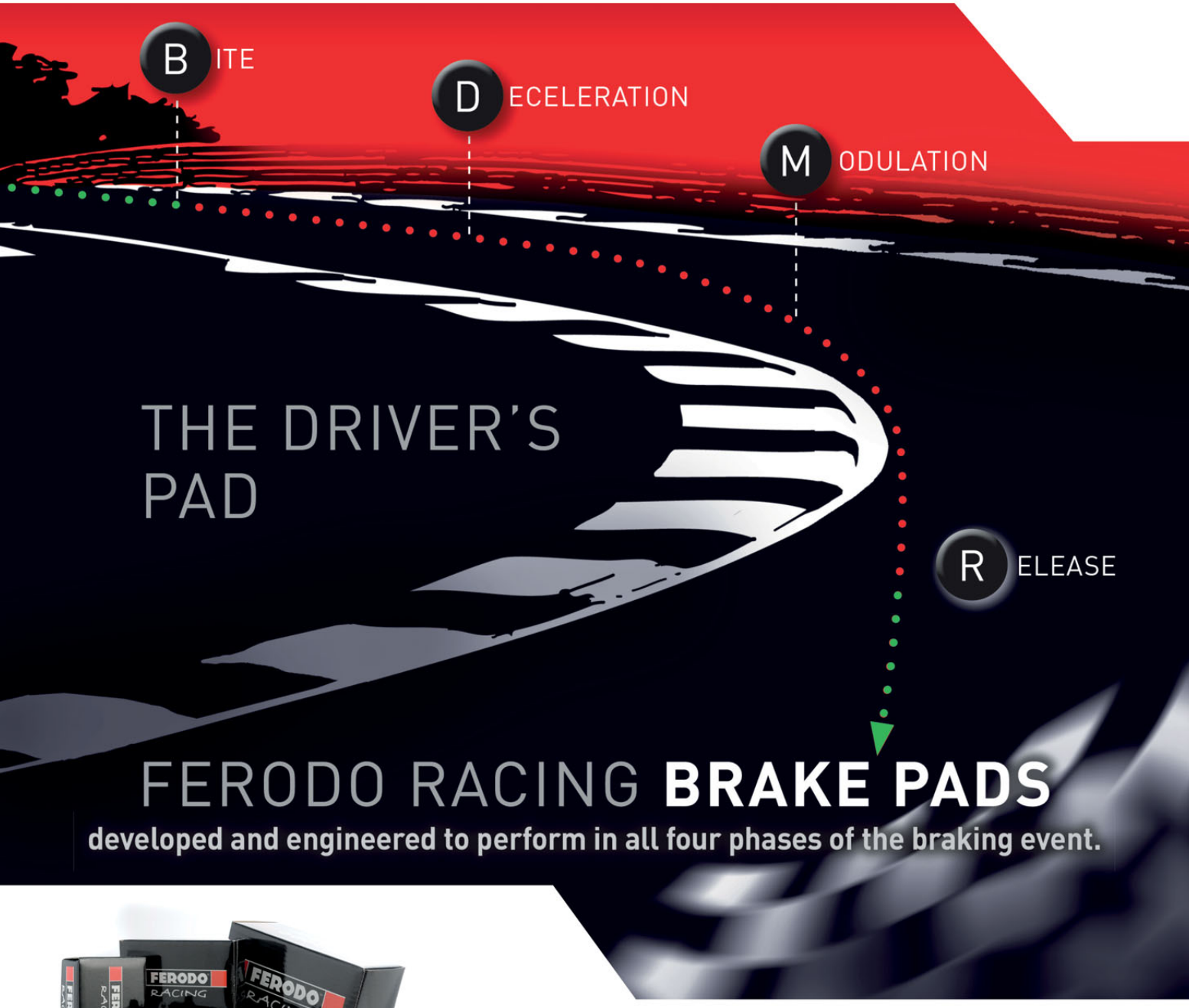

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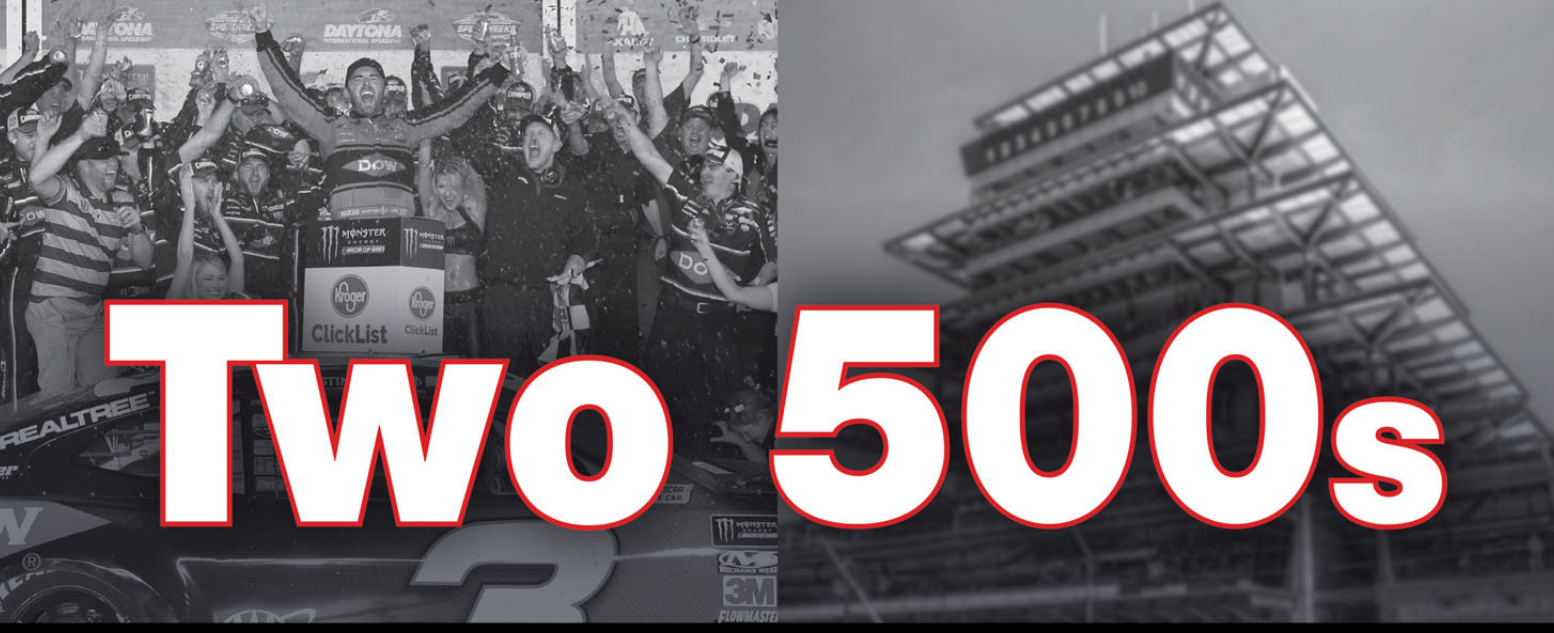

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Back to the Future

IN identifying hydrogen as a mobility energy source for the future, the Automobile Club de l'Ouest, organisers of the 24 Hours of Le Mans, has been very brave to push its agenda, especially in a world that's in a headlong rush to electrify everything. Volkswagen has recently released details of its new battery pack behind its global electric vehicle push and has a facility in Germany that will be able to produce around half a million a year. At the same time, every other carmaker is pursuing a similar programme. Battery electric cars will be a part of our future, but it's not the only solution.

As many of you will have read before, countless times actually, when I was at *Automotive Engineer*, all the talk in the late Nineties and early part of this century was about the forthcoming hydrogen fuel cell revolution. I was told by just about every automotive executive that by about now, they would be in full mass production. The cost of production would be in line with that of the internal combustion engine and we would have a bright future with just water coming out of the exhaust pipes. At the time, more than $3 billion had been spent by the carmakers developing hydrogen fuel cell vehicles.

Then came the recession of 2008 and it all went to pot.

However, when I joined *Race Tech* in 2006, it was still the bright future while to me motorsport was stuck in a time warp and was so far behind automotive technologies as to be out of sight and irrelevant. Formula 1 engine freezes and so on weren't helping at all. Fortunately, though, motorsport changed, led by the ACO and FIA so that suddenly hybrid technology became part of the offering, and while the dynamics of a racing car powertrain are quite different to that of a road car, lessons learnt in developing hybrid systems was of huge benefit to the carmakers involved in the upper tiers of the sport.

It is with this is in mind that the ACO has decided to promote hydrogen fuel cell cars as it knows that the development process demanded in motorsport will spin off to the carmakers. The question, though, is which ones will be brave enough to commit to it, diverting some of the R&D funds away from battery technology to hydrogen fuel cells. It's going to need one or two visionaries in different car companies to champion the cause and not be shouted down.

All this has caused me to re-read a book published in 2002 by Jeremy Rifkin called *The Hydrogen Economy* who talks about the worldwide hydrogen energy web (HEW) that he forecast would be the next great technological, commercial and social revolution in history. The time was coming when millions of small power plants would be connected into vast energy webs and through smart technology, people would share energy and sell it to one another. It would, he wrote, break the hold of giant energy and power companies, decentralise and democratise energy and recast commercial and social institutions along radically new lines.

This is a long way from the ACO's Mission H24 that aims to bring hydrogen fuel cell racing cars to Le Mans in their own class in 2024, but just perhaps one day, as it has successfully done so with other technologies, historians will look back and say that this was the initiative that restarted the stalled revolution of a few years ago. RT

William Kimberley
EDITOR

Jakob Ebrey

ABOVE The ACO believes that hydrogen is a viable alternative to answer future mobility needs and is promoting it in its Mission H24 project along with GreenGT Technologies

ACO commits to hydrogen future

William Kimberley

SPA, Belgium: On Saturday 22 September, Yannick Dalmas, four-time winner of the 24 Hours of Le Mans, drove a few laps that included a fuel stop demonstration around the Spa circuit in the GreenGT LMPH2G, a hydrogen-powered racing car. The intention was to demonstrate that the technology is safe, simple and promising.

Present at the demonstration run was Automobile Club de l'Ouest (ACO) president Pierre Fillon, Jean-Michel Bouresche, CEO of GreenGT Technologies and Henrik Hololei, the European Commission's director-general for Mobility and Transport, who said: "We need to make available zero-emission modes of transportation for a sustainable future and to develop new solutions. These are real challenges. I would like to congratulate and encourage ambitious people and projects like Mission H24."

This was the second stage of Mission H24 that was announced by the ACO prior to this year's Le Mans 24 Hour race in June when it was stated that the intention was to bring hydrogen-powered race cars to compete in the 24 hour race in 2024, in a special hydrogen class that will be created for a zero-emission race. The challenge seeks to speed up research and development around this fuel type, with the aim of taking it from track to road to achieve zero-carbon mobility.

The GreenGT LMPH2G is still in the experimental phase as engineering work and reliability tests continue, and has yet to begin its development and optimisation programme in the quest for more performance. An earlier version was due to start in the coveted Garage 56 spot at Le Mans in 2013 but was withdrawn a few days before the race as it was not ready for the tough endurance race. It was thought that the project had faded away. However, work has been continuing in the background over the last five years.

There are several ways of producing hydrogen, GreenGT and the ACO opting for 'green' hydrogen, one that is produced using a carbon-free process from the fermenting of bioresources such as biomass, waste or methane. It has a fuel tank capacity of 8.6 kg of hydrogen and a 2.4 kWh capacity. The dihydrogen (H_2), which is stored in three carbon filament tanks at 700-bar pressure, and oxygen atoms combine to form water molecules (H_2O). This reaction produces heat and electricity, which powers the car's electric motor. The

only emission is water vapour.

The Mission H24 initiative, the first determined step towards sustainable, responsible zero-carbon mobility, continues the long tradition of pushing technology boundaries that the ACO has established from the first 24 hour race in 1923. Apart from the racing spectacle itself and the marketing value to the winners, it was also a way for carmakers to test and validate the reliability and performance of their technologies. The ACO believes it will help develop less expensive, more effective solutions to sustainable power sources.

"Mission H24 embodies our commitment and our beliefs," said Fillon. "Last June at the 86th Le Mans 24 Hours, we announced our intention to create a hydrogen class for Le Mans 2024. Things are now starting to happen. We believe in hydrogen, just like we believed in hybrid technology and the introduction of a limited energy allocation. Today, hybrid cars are driven on public roads across the world. However, hydrogen is the future because we are aiming for zero-emissions and it's our role to develop high-performance, environmentally friendly technologies.

"Research is an ongoing concern for us as the organisers of the 24 Hours, and encompasses the fields of safety, performance, lower fuel consumption and environmental protection. At the ACO, we have always worked alongside manufacturers and other stakeholders in the automotive sector, and we see Mission H24 as a genuine commitment to future mobility."

"We had no hesitation in joining the ACO on Mission H24." said Jean-Michel Bouresche, CEO of GreenGT Technologies. "We have been convinced about the potential of hydrogen for several years now and have developed sound experience and recognised expertise in the field. Speeding up the research process via motorsport is a challenge that we are enthusiastically–but realistically–ready to accept."

"The ACO has always been open to new technologies, that has always been an important part of the 24 Hours of Le Mans and it's our mission and responsibility to continue this philosophy," said Vincent Beaumesnil, the ACO sporting director. "We are exploring many possibilities and when we created Garage 56 in 2012 for projects that are not part of the official competition and so did not need comply with the technical regulations, it allowed us to examine the different technologies. Our philosophy has always been open to look at new and future technologies that could be adopted by the automotive industry now and in the future.

"It's clear that over the last few years the big question has been how to reduce the dependency on fossil fuels and reduce emissions in general while becoming more ecologically sustainable. Hybrid technology, which we helped to stimulate its development, was fine for the short term, but we wanted a longer term strategy. While exploring all possibilities, we concluded that the future will not rely on just one solution, but on many. In other words, we don't think the future is just electric battery vehicles, biofuel or hydrogen, but a combination of everything.

"After the shock of dieselgate, the automotive industry has gone in a new direction with electric battery cars seeming to be the only option. However, at the ACO we have never been convinced that this is the only answer and that other technologies are relevant. The issue with an electric battery car is that in many cases power stations are not necessarily ecologically sustainable and current batteries have a very bad impact on the environment.

"There's no doubt that electric battery cars will be part of the mix in the future for specific use, but they won't meet all the needs of mobility and that hydrogen will play an important role as it addresses some of the major issues of our time, such as urban air pollution and the need to find new sources of fuel to replace conventional hydrocarbons. It unlocks multi-mobility potential as the technology suits every kind of journey, long or short, by car, bus or truck, or even by train, boat or plane.

"In the future it could be that the hydrogen used by vehicles will have been generated by wind and the sun which cannot be stored in batteries. We therefore know that we could have a real way to produce some stored energy due to hydrogen and it makes sense to use it in mobility.

"Another benefit of hydrogen is the refuelling time which on average takes around three minutes for a typical car with a range of about 500 kilometres in a normal driving cycle while an electric battery car takes much longer to recharge and the range is far shorter, especially when driven at higher speeds.

"Endurance racing is where we really want to promote long distance mobility and performance, we believe that hydrogen fits the bill."

At the start of the year, the ACO created a working group to look at the challenges of hydrogen fuel cell racing cars, of which there are representatives from five car manufacturers and three from interested tier one suppliers that are involved in the hydrogen industry. RT

Charles GUENANT

ABOVE The hydrogen fuel cell GreenGT LMPH2G did a few laps at Spa as well as undertaking a fuel cell stop

Virgin Racing to run Audi e-tron FE05 cars in Formula E's Season 5

William Kimberley

SILVERSTONE, UK: After a third place finish in the team's championship following a dramatic New York Season 4 finale, long-standing ABB FIA Formula E team Virgin Racing announced it would run Audi's new Gen2 challenger, the e-tron FE05 cars, during its Season 5 campaign.

"We are glad that in the new Formula E season together with Virgin Racing four Audi e-tron FE05 cars will fight for points and trophies," said Dieter Gass, head of Audi motorsport. "The team has been one of the key players in Formula E ever since the series was founded – both in terms of its racing performances and all off-track activities. This makes Virgin Racing's choice of using our powertrain a particular pleasure. This confidence also confirms the excellent work that our engineers are doing together with their colleagues from our development partner Schaeffler."

The Audi e-tron FE05 builds on the success of its predecessor, which was the most efficient car in many races during the fourth season. It peaked mid-July in New York City when the factory team Audi Sport ABT Schaeffler won the teams' championship.

The centrepiece of the new Audi e-tron FE05 is the Audi Schaeffler MGU03 motor-generator unit. While the rest of the car is specified for all teams, the manufacturers can demonstrate their technical expertise in the powertrain, which is bespoke. However, Formula E regulations require manufacturers also to make the complete car with its unique powertrain technology and related support available to other teams for a defined price.

The news follows Jaguar's unveiling of the all-new 'Gen 2' I-TYPE 3, its own Season 5 contender which has a new powertrain that has been developed in-house for the first time and also features over 800 new components. Jaguar Racing says it has managed to increase power by 25 per cent, (the 0-100 km/h time is now just 2.8 seconds, while a new battery provides a huge 85 per cent more usable energy over last season's I-Type car, all without any increase in weight.

Nick Rogers, executive director, product engineering at Jaguar Land Rover, emphasised how important Formula E was to developing electric vehicle technology and the importance of electric vehicles in Jaguar Land Rover's future product portfolio.

"Over the next five years we will see more changes in the automotive world than in the last three decades. The championship will enable us to engineer and test our advanced technologies under extreme performance conditions. We will apply this vital knowledge as part of our real-world development. At Jaguar Land Rover we employ 9,000 engineers and the team will draw on these engineers to extract data and push the boundaries of electric technology in a race environment." RT

ABOVE Virgin Racing is ending its successful relationship with DS Automobiles and entering a new multi-year agreement with Audi Sport as from Season 5

Audi withdraws World Rallycross programme

Hal Ridge

NEUBURG AN DER DONAU, Germany: German marque Audi will end its programme in the World Rallycross Championship after the final round of the 2018 season in South Africa, and will not participate in the series' transition to electric cars in 2021.

Audi, which has officially supported Mattias Ekstrom's World RX squad since the start of 2017, will instead focus its efforts on the DTM and Formula E in 2019. EKS won both the drivers' and teams' World RX titles in 2016 with minimal support from Audi, including giving Audi DTM driver Ekstrom blessing to run his rallycross programme since 2014.

"Basically, we will not take part with a factory involvement in future rallycross," said Dieter Gass, head of Audi Motorsport. "We have decided to carry on Formula E and DTM and at the end of the day it's a matter of the amount of big programmes that we can afford and work on at the same time. We are involved in Formula E so we already do have a programme in electric motorsport, even though we were very interested in the EWRX, at the end of the day it came very much down to a choice between DTM and EWRX. It was mainly a consequence of the positive decision to DTM rather than taking a negative decision to the EWRX."

Audi has been a key player in Technical Working Group meetings between a group of manufacturers, the FIA and World Rallycross promotor IMG with regards to the planned switch to electric cars, which has been delayed until 2021. Gass has not ruled out the possibility of entering electric rallycross in the future. "I never say never. I still think rallycross is a very interesting concept, we will keep on looking at it and then we will make a decision. Obviously it's too early to say yes we will, but we will keep an eye on the situation for sure." RT

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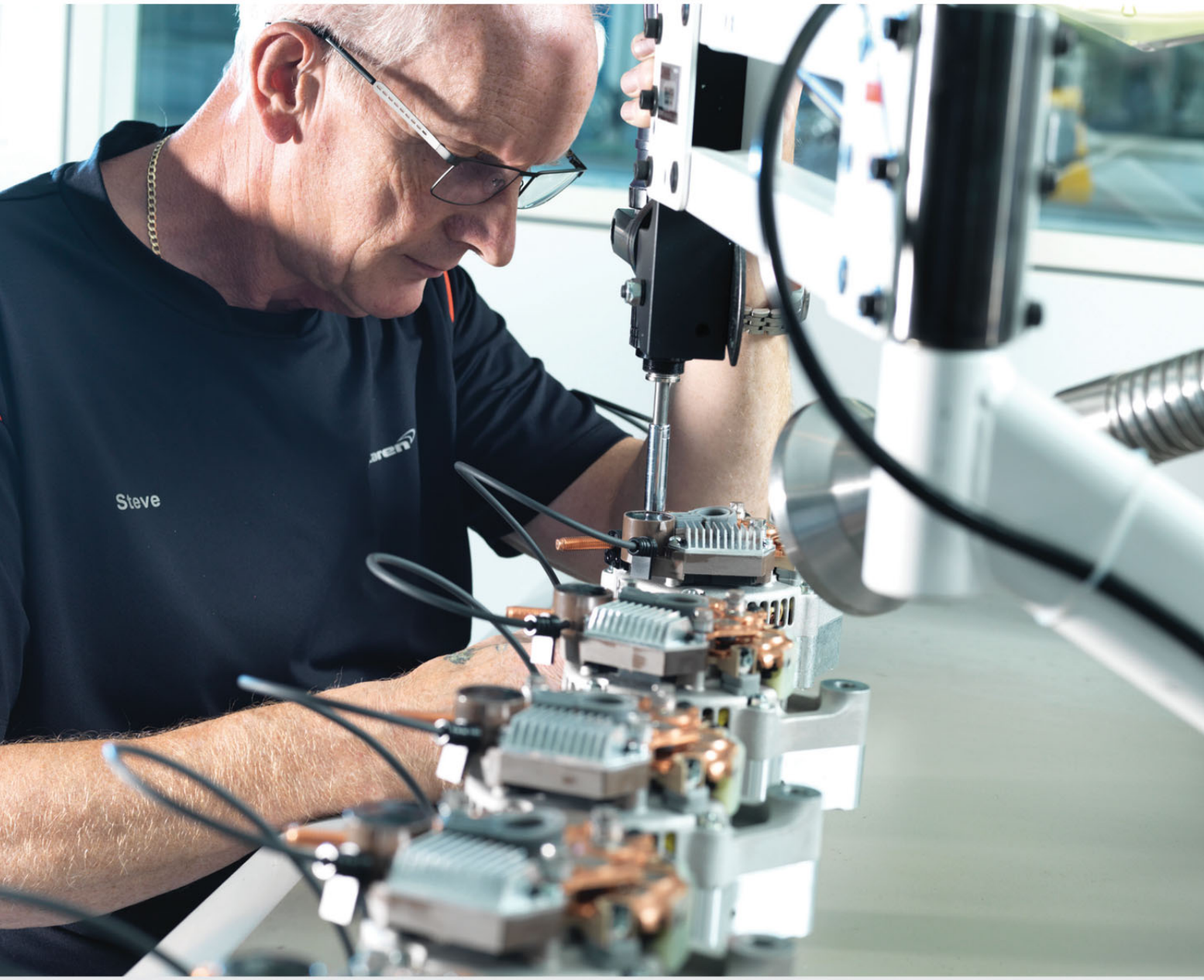

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ABOVE A suggested look at the future design of F1 cars as put forward by Formula One Management

Formula 1 releases design concepts for 2021 racers

William Kimberley

LONDON, UK: Formula One Management has released images of some design concepts for future Formula 1 cars that could be seen on the track by 2021. The idea is to deliver better racing with the looks to match. The design will continue to evolve over the next year but this is a first look at the concepts set to shape F1's future.

High on the agenda is a solution to allow cars to follow each other more easily, which in turn should increase the opportunities to overtake. There is also a desire to have cars that look so good that kids will want to have posters of them on their walls.

"When we started looking at the 2021 car, the primary objective was to enable the cars to race well together," says Formula 1 motorsport boss Ross Brawn. "What we established early on in our research is the cars we have now are very bad in following each other.

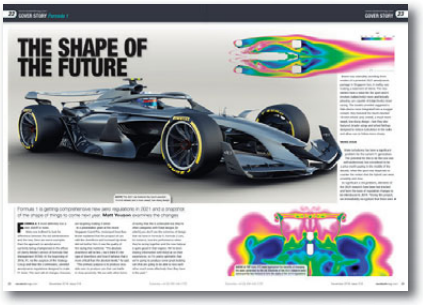
"Once the cars get within a few car lengths of each other, they lose 50% of their downforce. That's a substantial amount of performance lost, so we set about understanding why that was and how we can improve it. I'm pleased to say we're at about 80%.

"As time has gone on, another of the primary objectives was to make great looking cars. We want cars that look better than what you see in a video game, cars that kids want to have up on their walls. At each stage, as we have been evolving the car, we've had someone we are working with create a graphic representation to give us a feel of what the car could look like.

"That is not to control the development, because it's critical this development achieves its objectives, but why shouldn't we have great looking cars as we're evolving the cars? We want a car that is inspiring.

F1 is the pinnacle of motorsport and the car should look sensational." RT

See The shape of the future page 20



Williams GP Holdings makes small loss but Advanced Engineering stays robust

William Kimberley

GROVE, UK: Williams Grand Prix Holdings PLC, the holding company of the Formula 1 team, has announced a £2.7m loss for the six months ending June. The Formula 1 team's revenue fell from £65.5m to £60.7m although it made a profit of £2.2m. Williams Advanced Engineering posted an increase in revenue of £1.6m to £21.5m with a moderate profit of £0.2m, which was down on the £1.1m it made in 2017. However, increased expenditure on Williams Heritage and the Williams Conference Centre saw the group make an overall loss of £2.7m.

"We have delivered a solid set of financial results in what has been a challenging half year for our Formula 1 operations, whilst continuing to demonstrate growth in our Williams Advanced Engineering Business, which continues to grow following a robust performance in 2017, generating revenues across a diverse range of projects and attracting new customers with its growing reputation for outstanding delivery," said CEO Mike O'Driscoll. "The reduction in profitability in the first half is all related to the timing of various projects. Its focus remains on providing energy-efficient and technically advanced performance solutions in sectors as diverse as motorsport, aerospace, defense and healthcare.

"We are also excited about the prospects of our recently announced joint venture with Unipart (Hyperbat Limited) which will produce batteries for premium future hybrid and electric vehicles in a high-tech facility based in the UK.

"However, revenue and earnings before interest, tax, depreciation and amortisation (EBITDA) in Formula 1 reduced in the first half of 2018, reflecting the challenging financial environment we operate in as an independent team.

"We are enduring a tough 2018 season on track, which has demanded additional investment to tackle performance issues, and we have been working through these while also turning significant attention to the design of next year's car.

"There continues to be a large gap in competitive expenditure between the leading teams and the rest of the grid, and we remain hopeful that the future of the sport under Liberty Media will bring about a fairer, more level playing field for all teams.

"Although we continue to face challenges in a very dynamic environment, we are well placed to respond. With world class facilities and a strong and talented organisation, Williams remains determined to succeed." RT

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BELOW The car has already undertaken test mileage and has even been demonstrated in public

PWR Racing reveals electric Swedish Touring Car prototype

Hal Ridge

VIKMANSHYTTAN, Sweden: Swedish Touring Car Teams' champions PWR Racing has revealed a 100 per cent electric STCC prototype called the PWR 001.

The squad launched its prototype at the Mantorp Park season finale on 22 September, following secret testing of the car, which features an electric drivetrain in a Cupra TCR chassis, the type of the car the SEAT Dealer-backed squad fielded to win the teams' championship this season.

The new concept has three motors, revving to 8000 rpm and driving the rear wheels, producing 450 kW (612 hp) and over 1000 Nm torque. The car is believed to reach 100 km/h in less than three seconds, with a top speed of 300 km/h.

The 41 kWh batteries, which make up 366 kg of the 1,510 kg total weight of the car are constructed of over 350 cells "that can be fully charged in approximately one hour with a maximum capacity of 15 minutes at maximum power output," said a statement from the team. With the batteries located in the middle of the chassis, the PWR 001 has a 44/56 per cent weight distribution.

"The biggest revolution within the automotive industry since the combustion engine and the assembly line is currently happening and we are launching our part in this," said Hans Baath, project manager for PWR 001 as chairman of STCC AB.

"We have already begun to get used to electric, connected and autonomous cars in different stages of development. Virtually all car companies have some sort of strategy for how to deal with this on a larger scale. At the same time, the technology is far from ready and the need for the development of robust technology is vast. Therefore, we choose to take this initiative to work with our partners' combined expertise and technology. We think it's obvious that electric cars have a place in motorsport in the foreseeable future."

STCC 2018 race-winner Mikaela Ahlin Kottulinsky has conducted test mileage and drove the car in a demonstration on its public debut. The STCC is yet to confirm if or when it might consider a switch to electric cars, while the project is unconnected to the SEAT's planned Cupra e-Racer E-TCR concept. RT

Volkswagen Polo R5 set for Catalan debut

Hal Ridge

HANOVER, Germany: Volkswagen's long-awaited debut of its Polo GTI R5 rally challenger will be at the mixed-surface Rally Spain on 25-28 October in the WRC2 category. The four-time World Rally Champion's new car is intended solely for customer racing and the German marque has stated that the Catalan event, where Frenchman Eric Camilli and former World Rally and World Rallycross Champion Petter Solberg will drive, will be its only works outing.

Homologation of the car is expected to take place on 1 October by which time it will have completed 10,000 test kilometres. Volkswagen has revealed that it has already sold 15 GTI R5s to customers in Austria, Belgium, Finland, Italy, Paraguay, Portugal and Sweden.

"The Polo GTI R5 has completed around 9,000 test kilometres to date, half of which were on gravel and half on asphalt. The entire development team has worked hard and delivered a first-class result, which has been confirmed by the initial reactions of customers," said Volkswagen Motorsport director Sven Smeets last month, after customers visited VW Motorsport's Hanover base to see the new car.

"When defining the specification, we took great care to ensure that it would be easy for professional privateer teams to master the technical support of the Polo GTI R5," said Jan-Gerard de Jongh, technical project manager for the Polo GTI R5.

Volkswagen World Rallycross driver Solberg is looking forward to returning to the WRC, in which he won the title in 2003. "The opportunity to make a WRC comeback with Volkswagen is a unique one and I was very happy to accept the offer," he said. "When I drove the car in January in Sweden, I didn't want to stop. Everything about the Polo GTI R5 worked from the very beginning. I am really looking forward to Rally Spain. I always used to like the combination of gravel and asphalt. I obviously want to get the R5 Polo off to a good start with a good result." RT

ABOVE Petter Solberg is one of the drivers that has put the new Polo R5 through its paces

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LEFT Furniture Row Racing won the NASCAR Cup series with Martin Truex Jr last year

Winning NASCAR Cup team to cease operations

DENVER, CO: In a bombshell announcement, Furniture Row Racing, which won the NASCAR Cup Series with Martin Truex Jr last year, is to close its doors at the end of this season. This is despite team owner Barney Visser insisting in late summer that not racing in 2019 wasn't an option. However, a lack of firm sponsorship for next season crippled the team, particularly with primary sponsor 5-Hour Energy deciding not to renew its sponsorship for 2019, despite Truex winning 16 races since 2016 and is currently sitting in third this year with four victories.

"This is not good for anybody," said Visser in a statement. "The numbers just don't add up. I would have to borrow money to continue as a competitive team and I'm not going to do that. This was obviously a painful decision to arrive at knowing how it will affect a number of quality and talented people.

"We've been aggressively seeking sponsorship to replace 5-hour Energy and to offset the rising costs of continuing a team alliance with Joe Gibbs Racing but haven't had any success. I feel that it's only proper to make the decision at this time to allow all team members to start seeking employment for next year."

"While I am saddened by this announcement, I totally understand the decision," said Truex, who joined the team in 2014. "Barney Visser, Joe Garone and the entire Furniture Row Racing team took me in while my career was in a bad place, and together we reached the pinnacle of the sport. I will forever be grateful to each and every one of them, and also to Furniture Row, Denver Mattress and the Visser family."

While the loss of the team, which began fielding Cup cars in 2005 and earned its first win in 2015 is a huge blow to Toyota and NASCAR, the sanctioning body issued a statement indicating that it is trying to address the financial stability of its teams.

"NASCAR wishes the very best to Barney Visser and his family. Barney has been a successful owner and an amazing champion, and his presence will certainly be missed. NASCAR will continue to work on growing the sport and working with the race teams on competitive and operational excellence.

"Much of those efforts have already been put in place, and will continue to be a focus." RT

Hybrid boost to replace ballast in BTCC

LONDON, UK: The British Touring Car Championship is likely to use the hybrid power unit to boost power rather than add weight to even out the grid once the series goes to hybrid in 2022.

Series boss Alan Gow has told the touringcartimes.com that "The hybrid adds weight, and if you add weight, you can't have as much ballast as you've got, and because we don't want to make the cars have to run with bigger wheels and tyres, the hybrid will probably replace the success ballast.

"So the leader of the championship might have slightly less power available to them during the weekend, there's tons of ways we can go about it, but yes, I don't want to add something to the number of systems we've already got – I don't want to add number of passes from the hybrid system to success ballast, so we'd probably just use the hybrid to replace it."

Gow also said that the new hybrid power unit will enable teams to play around with strategy during a race. "The drivers will have a certain amount of power available to them during the race, and it's up to them how they use it. They can use it for defence, or attack – there will be a certain amount of power that each car will be capable of having for each race, and how a driver uses it and when he uses it will be up to them." RT

Unilever steps up to support Williams Engineering Academy

Alan Stoddart

GROVE, UK: Unilever has stepped in to support the Williams Engineering Academy that was formed three years ago with the support of Randstad. Unilever has been a partner of the Williams Formula 1 team since 2015 in a collaboration that includes marketing and promotional rights, as well as offering a strategic way to activate the sponsorship – The Unilever Synergy Programme. The programme forms a central pillar of the partnership activity, using engineering expertise from the Formula 1 environment and Williams Advanced Engineering, and aims to drive efficiencies, sustainability and cost savings via multiple work streams and maximising the two-way relationship.

The 10 students will be selected at the F1 in Schools World Final in Singapore. F1 in Schools is a not-for-profit organisation which encourages the development of STEM skills by allowing schools to take on the role of a Formula 1 team. The Unilever Williams Engineering Academy will be open to those aged between 16 and 18 who have made it through to the World Finals with successful candidates being selected following a series of assessments. Gradually, the number will be reduced on an annual basis with the potential for two students to graduate to full-time roles.

"I am delighted to see our partnership with Unilever extend to include a rewarding and exciting initiative such as this," said Claire Williams, deputy team principal. "Education is extremely important to us in terms of finding the next generation of engineers. We've been running the academy since 2015 and we're thrilled to see Unilever help take this forward to find the young engineering talent of the future." RT

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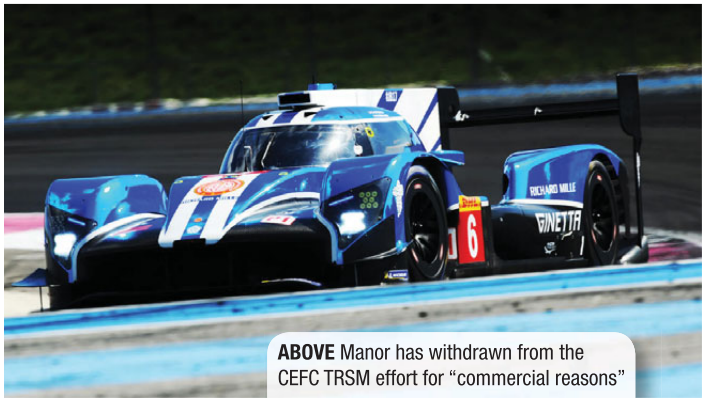
Manor ends LMP1 involvement with Ginetta project



ABOVE Manor has withdrawn from the CEFC TRSM effort for "commercial reasons"

Alan Stoddart

SILVERSTONE, UK: Manor has confirmed that it has ended its involvement with CEFC TRSM Racing's World Endurance Championship campaign. The news followed CEFC TRSM's announcement that it would return to the series and run a single Ginetta race car at the upcoming Six Hours of Fuji following its no show at the Silverstone round of the World Endurance Championship amid a last minute switch from Mecachrome to AER engines.

Manor made its decision to withdraw from the effort for "commercial reasons", although it also follows a tumultuous year which has seen problems at every round of the championship.

"Manor provided equipment, expertise and experienced people into the LMP1 project, managing the team and trackside operations starting from the car build through to after Le Mans," explained Manor team principal, John Booth. "However, for commercial reasons we are not involved now."

TRSM is now expected to be run by Ginetta, although this has not been confirmed. RT

MSA to optimise cost of safety equipment for competitors

Alan Stoddart

COLNBROOK, UK: The Motor Sports Association (MSA) has committed to an in-depth review of competitor safety equipment over the next two years. This will explore a raft of initiatives, including strategies to reduce the burden on competitors of the unnecessary replacement of seats and harnesses, while ensuring suitably high standards of safety are maintained in the sport.

Part of this new initiative will be to provide greater education for competitors in respect of their own safety and to place more responsibility on the competitor to maintain a level of safety equipment, above a defined MSA minimum standard. As a first step, the MSA will recognise an extended life for certain FIA-homologated seats and harnesses in the UK.

The MSA will also be publishing new guidance on installing seats and harnesses, while giving scrutineers further training. The governing body will also be reiterating scrutineers' powers to retain or invalidate homologated equipment if they have serious concerns regarding its condition or know it has been involved in a major accident.

Looking ahead, the MSA is also investigating new ways of tracking homologated components as well as evaluating more cost-effective accident data recorders for wider use.

"As the governing body, one of our principal roles is to grow motorsport at grassroots level while promoting safety within the sport at a realistic cost for competitors," said MSA chairman David Richards. "I firmly believe the time has come for a wholesale review of our approach to safety across the entire motorsport landscape and this review will be delivered by 2020. It's therefore appropriate to allow our competitors to continue using their recently purchased seats at least until then, when the outcome of this review will be published." RT

PERSONNEL

Steve Phelps has been named NASCAR president, effective 1 October, 2018. **Brent Dewar** has elected to step down and will remain with the company through the end of the 2018 racing season, transitioning to a senior consulting and advisory role in 2019. Phelps will assume the duties held by Dewar and will report to **Jim France**, NASCAR chairman and chief executive officer. As president, Phelps will have responsibility over all competition and business operations for the sanctioning body. Joining NASCAR in 2005, Phelps has played a key role in significant initiatives, such as negotiating key partnership agreements with Coca-Cola, Monster Energy, Comcast and Camping World, the acquisition of NASCAR's digital and social rights and leading industry collaborative efforts such as the Industry Action Plan and industry-wide marketing platforms. He brings more than three decades of experience to the role, including senior leadership roles at the National Football League and Wasserman.

Pat Fry is returning to McLaren as its new engineering director. He had originally left the team eight years ago to join Ferrari where he worked his way up to director of engineering before leaving in 2014. His last position in Formula 1 was with the now defunct Manor team.

Frédéric Lénart has stepped down from his position as general manager at the Automobile Club de l'Ouest after six years with the club. The appointment of his successor will be announced shortly. RT

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Pat Symonds, Chief Technical Officer, Motorsport Division | Formula 1

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The evolution of motorsport regulations

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The challenge of Roborace and what it means to the motorsport industry

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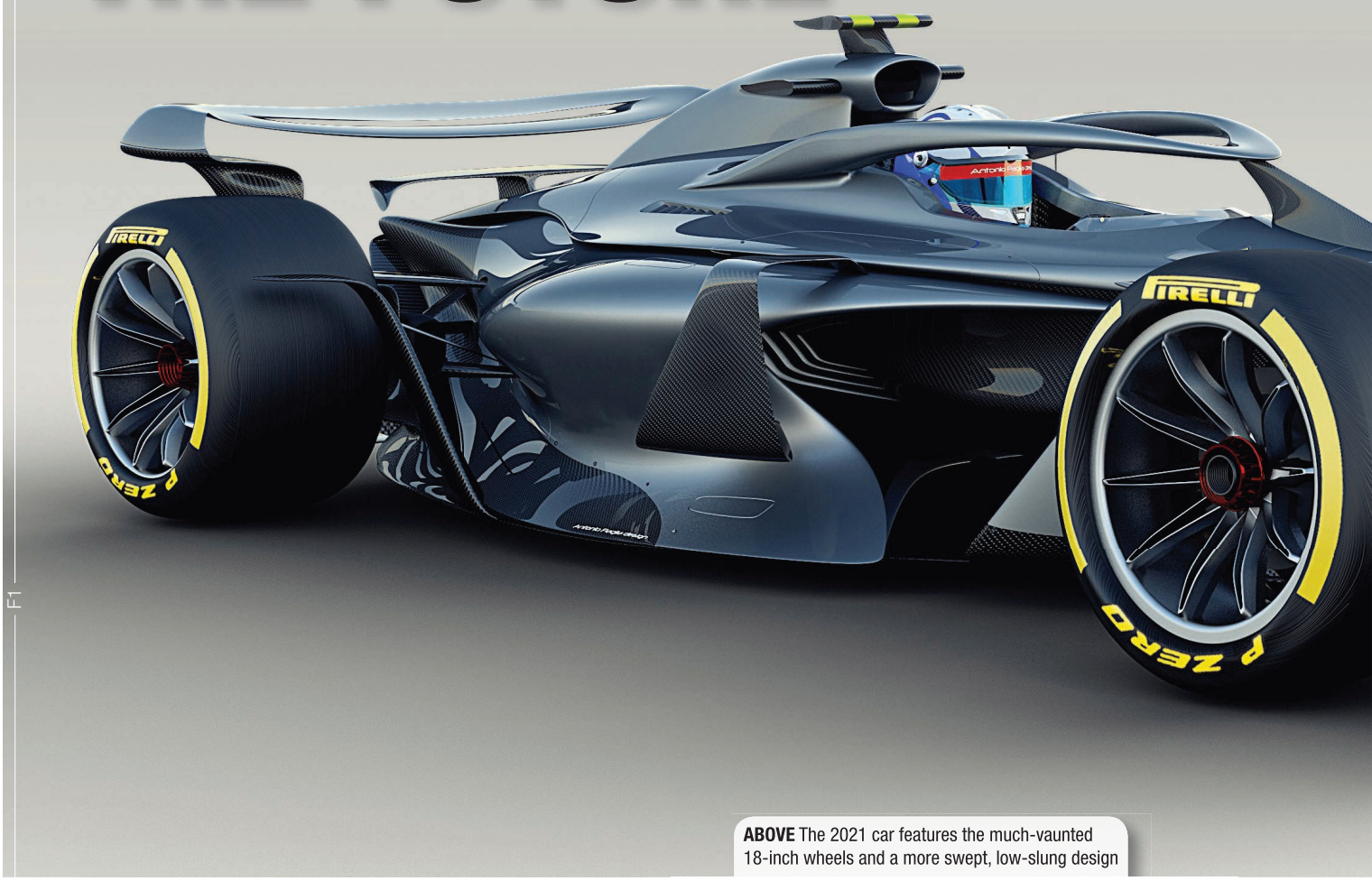
THE SHAPE OF THE FUTURE



ABOVE The 2021 car features the much-vaunted 18-inch wheels and a more swept, low-slung design

F1

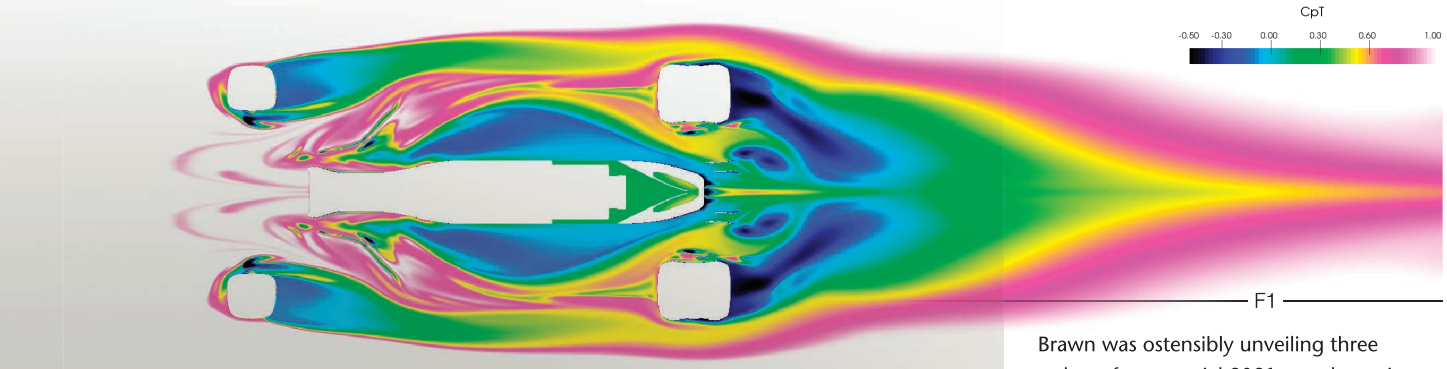
Formula 1 is getting comprehensive new aero regulations in 2021 and a snapshot of the shape of things to come next year. **Matt Youson** examines the changes

FORMULA 1 most definitely has a new sheriff in town.

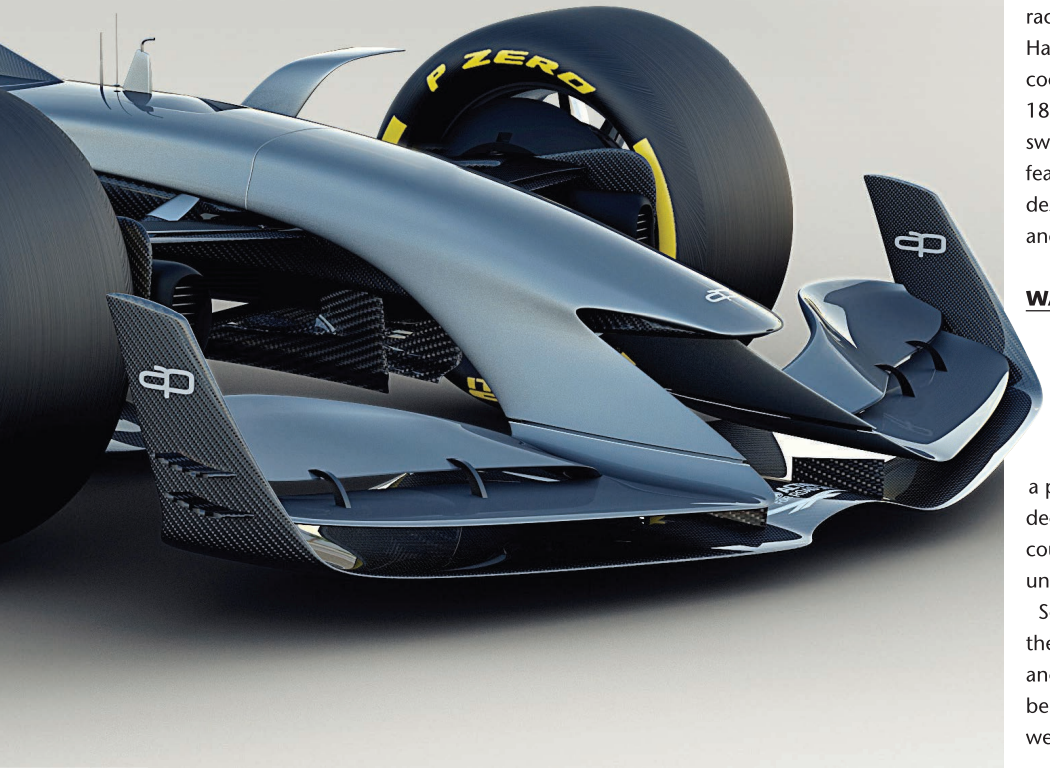
Were one inclined to look for differences between the old administration and the new, there are worse examples than the approach to aerodynamics currently being championed in the offices of Liberty Media's version of Formula One Management (FOM). At the beginning of 2016, F1, via the auspices of the Strategy Group and then the Commission, unveiled aerodynamic regulations designed to make F1 *faster*. The next raft of changes, however, are targeting making it *better*.

In a presentation given at the recent Singapore Grand Prix, motorsport boss Ross Brawn explained that the prospect of cars with less downforce and increased lap-times did not bother him: it was the quality of the racing that mattered. "The absolute downforce will be less – but I think it's the type of downforce and how it behaves that is more critical than the absolute levels," he said.

"The primary purpose is to produce race-able cars: to produce cars that can battle in close proximity. We see with other forms of racing that this is achievable but they're often categories with fixed designs [in which] you don't see the extremes of design that we have in Formula 1. Formula 2 cars, for instance, lose less performance when they're racing together and the new Indycar is quite good in that respect. We've been sharing information with IndyCar on their experiences, so I'm pretty optimistic that we're going to produce some great-looking cars that are going to be able to race each other much more effectively than they have in the past."



F1

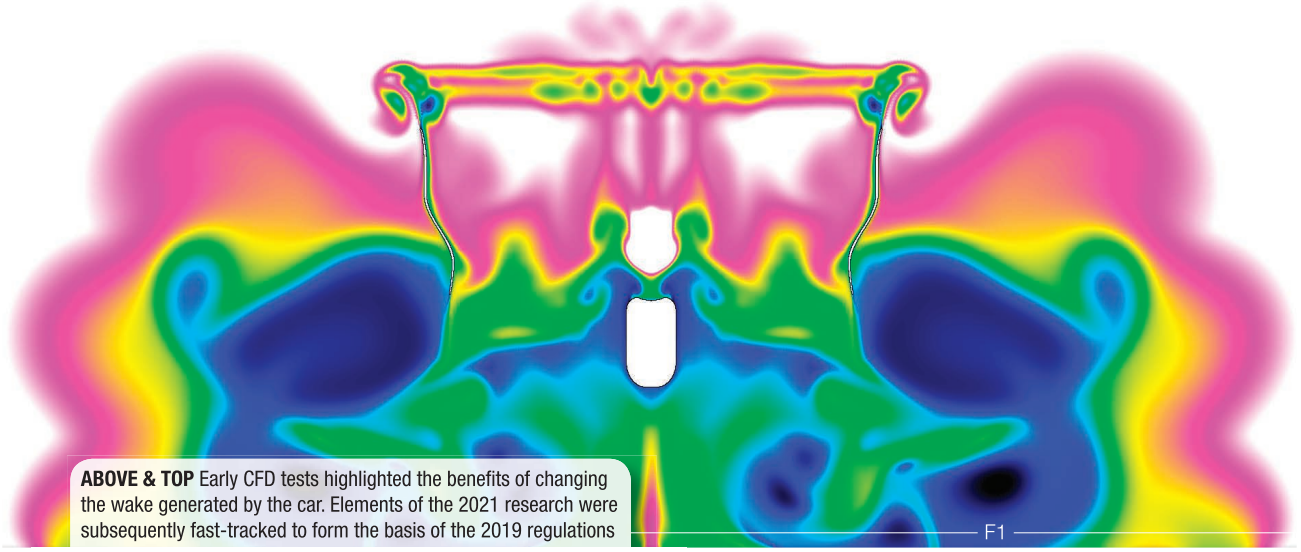


Brawn was ostensibly unveiling three renders of a potential 2021 aerodynamic package in Singapore but, in reality, was making a statement of intent. The new owners have a vision for the sport and it involves (subjectively) more aesthetically pleasing cars capable of (objectively) closer racing. The models unveiled suggested a Halo device more integrated into a snugger cockpit; they featured the much-mooted 18-inch wheels and, overall, a much more swept, low-slung design – but they also featured simpler wings and wheel fairings designed to reduce turbulence in the wake and allow cars to follow more closely.

WAKE ISSUE

Wake turbulence has been a significant problem for the current F1 generation. The potential for this to be the case was well-understood, but considered to be a price worth paying in the middle of the decade, when the sport was desperate to counter the notion that the hybrid cars were unwieldy and slow.

So significant is the problem, elements of the 2021 research have been fast-tracked and form the basis of regulation changes to be introduced in 2019. "Doing this project, we immediately recognised that there were ▶



ABOVE & TOP Early CFD tests highlighted the benefits of changing the wake generated by the car. Elements of the 2021 research were subsequently fast-tracked to form the basis of the 2019 regulations

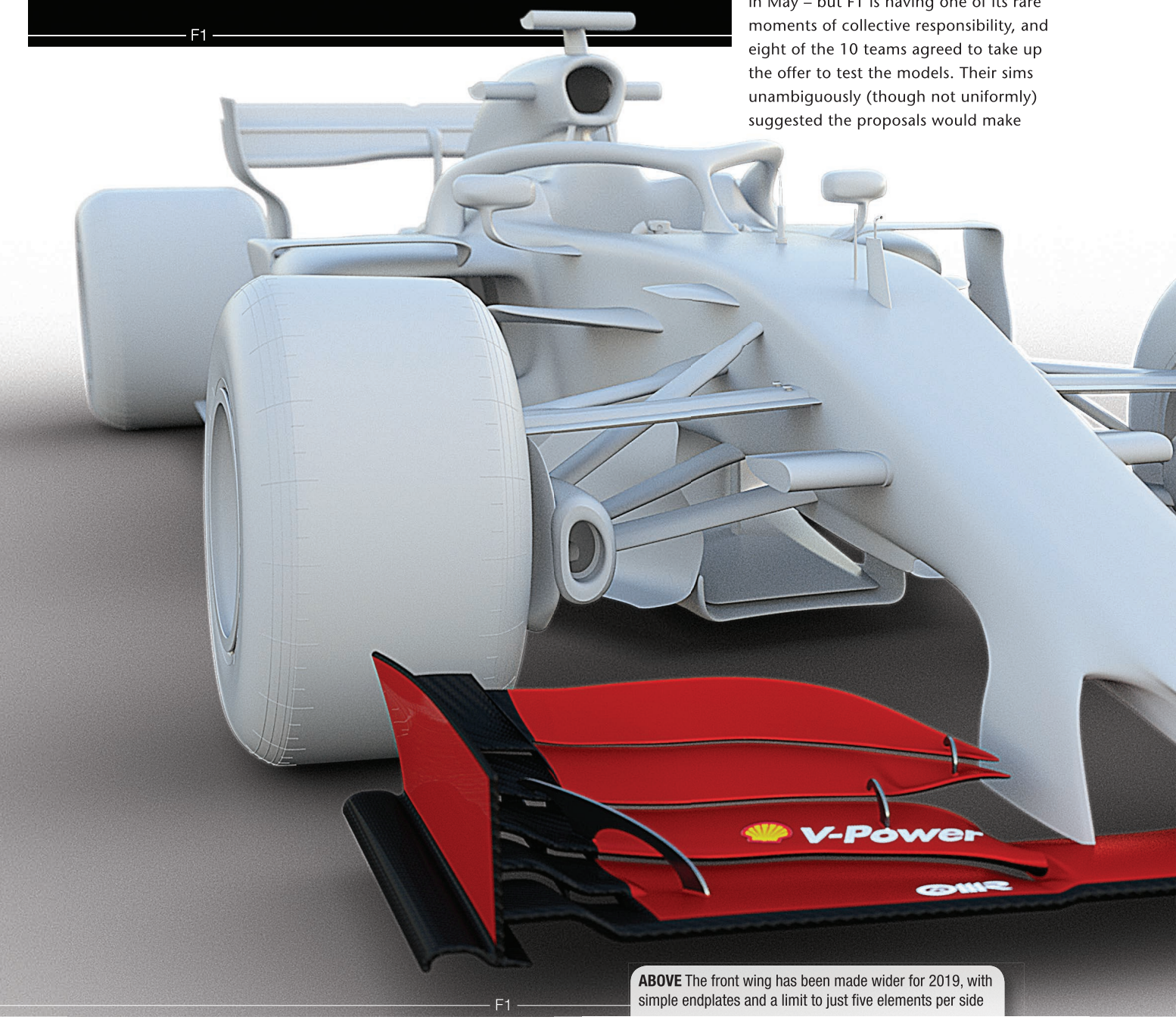
F1

BELOW Could this be the shape of F1's brave new world in 2021?

F1

some features which immediately gave some benefit in terms of the sensitivity between the cars," says Brawn. "Next year's car, as a step in the right direction, is, I think, a very important barometer for us to see how much impact it has on the ability for the cars to follow."

That there are new aero rules for 2019 is surprising. F1's technical regulations tend to have an inertia all of their own, and the desire for change can be a slow-burning affair. Thus, when the aerodynamic proposal was presented to the teams at the end of March 2018, it seemed unlikely the green light would be given in May – but F1 is having one of its rare moments of collective responsibility, and eight of the 10 teams agreed to take up the offer to test the models. Their sims unambiguously (though not uniformly) suggested the proposals would make



ABOVE The front wing has been made wider for 2019, with simple endplates and a limit to just five elements per side

F1

ABOVE The furniture that used to populate the front wing has been eliminated, with just two vertical strakes permitted underneath

racing closer – and, no-one could think up a good reason to not have that.

The aerodynamic direction taken by the current cars produces a *very* turbulent wake, with teams using front wing vortex generators and blown axles to fling turbulent air wide of the car, allowing smoother air to infill and work more effectively with surfaces behind the front wheels. The wide wake is problematic for a following car. Assuming a total pressure coefficient equal to 1 for the leading car, a car following very closely may have a TPC as low as 0.5 or 0.6, losing between 40 and 50 per cent of downfore.

> *"A car following very closely may lose between 40 and 50 per cent of downforce"*

Formula 1 Chief Technical Officer, Pat Symonds, one of the experts at the heart of the project, explains the problem succinctly: "Look at the current front wings, there are a lot of appendages and elements sitting on top of the wing. Each one is designed to produce a vortex, to control that wake. Unfortunately, when you start pushing the front wheel wake out a long way, you create a very, very wide area of low-energy air behind the car, which reduces the downforce on the following car."

The intention with the 2019 regs is to reduce the 'outwash' wake from the front wheels by changing the shape and the nature of the front wing, and simplifying the front brake ducts. This will make the airflow follow a more natural path over and around the car. Bad for the car; better for the following car.

"The first thing to do was reduce the number of elements that were producing these big vortices – and so the rules will now limit cars to just five elements per side," explains Symonds. "On top of the wing, we have eliminated the furniture that currently sits there, and underneath the wing, we'll have just two vertical strakes. At the same time, the wing has been made wider. It's gone out to the full two-metre width [of the car] and we've made the endplates into a very simple shape, limited to an angle of 15°. It will give a much cleaner airflow and limit the outwash."

Behind the front wing, the new regs will also simplify the front brake ducts. These have become convoluted into sculpted crenulations, the purpose of which has little to do with cooling the brakes, and a great deal to do with generating more vortices and channelling air out and away. "These are changing too," adds Symonds. "What we're going to be left with is a smaller brake duct that is essentially just a simple scoop, without the complex vortex-shedding winglets and elements that have been appearing over the last few years."

'MUSHROOMING'

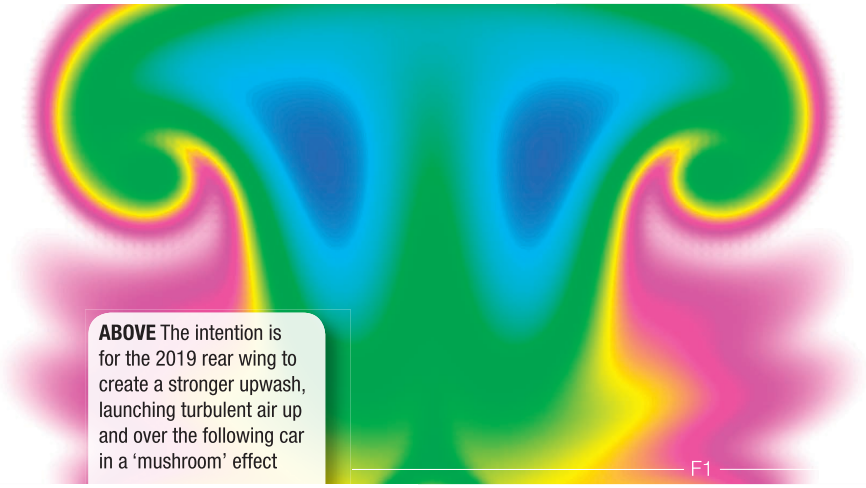
Limiting the outwash will, in effect, create a narrower field of turbulence trailing the car – but this would still impact a following car trying to tuck into the slipstream. This is where a rear wing 50 mm wider and 20 mm deeper will aid the creation of a stronger upwash, launching the turbulent air up and – it is to be hoped – over the following car in an effect the aerodynamicists refer to as 'mushrooming'.

"The rear wing helps us when we're ▶

trying to promote closer racing," explains Nikolas Tombazis, the FIA's head of single-seater technical matters, who while previously working for FOM, was one of the aerodynamic leads on the project. "It has two strong, trailing vortices which pull the flow up from close to the ground into the 'mushroom'. This mushroom is pushed upwards quite violently and quite quickly, allowing clean air to be pulled in from the sides to take the place of the turbulent air being flung upwards. This clean air tends to be higher energy, which has a beneficial effect on the aerodynamics of the following car."

How big an improvement will this make? There is a clamour for numbers but forecasting the real-world performance for cars half a year and more away from launch is an exercise that is more art than science.

> *"Cars should be able to follow within a second – the magic number that triggers the DRS"*



ABOVE The intention is for the 2019 rear wing to create a stronger upwash, launching turbulent air up and over the following car in a 'mushroom' effect

F1

The teams that chose to simulate the new geometry all agree it delivers results that should be a boon for closer racing, though by how much is a question that won't properly be answered until next season gets underway.

One reason for this is simply that every car is different, and thus has a unique level of sensitivity to the wake. Tombazis believes it is realistic to expect this natural variation to remain – simply stepped down a level across the board: "We consider the critical position to be approximately 15 to 20m between the cars. That's the distance we would expect to see separating cars that are running half a second apart, approaching a medium-speed corner. With the current generation, the following car is losing about 30 per cent of downforce in this scenario. We hope to reduce that by 10 per cent.

"It's difficult to provide an exact number. What I would say is that there is a general trend for teams to develop more downforce, which would exacerbate the problem. If we ▶

ABOVE F1 has traded information with IndyCar in its quest to develop good-looking cars that can actually race in close proximity to each other

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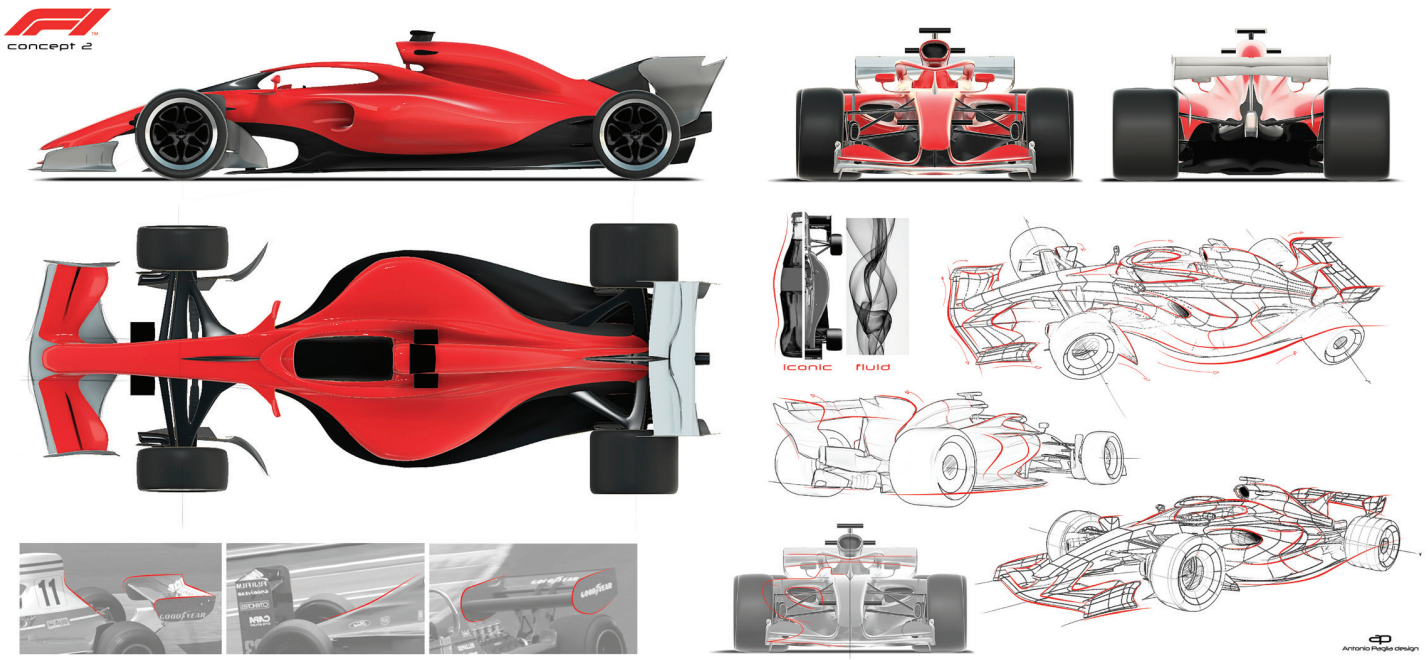


ABOVE Simpler wings and wheel fairings on the 2021 cars are designed to reduce the turbulent wake

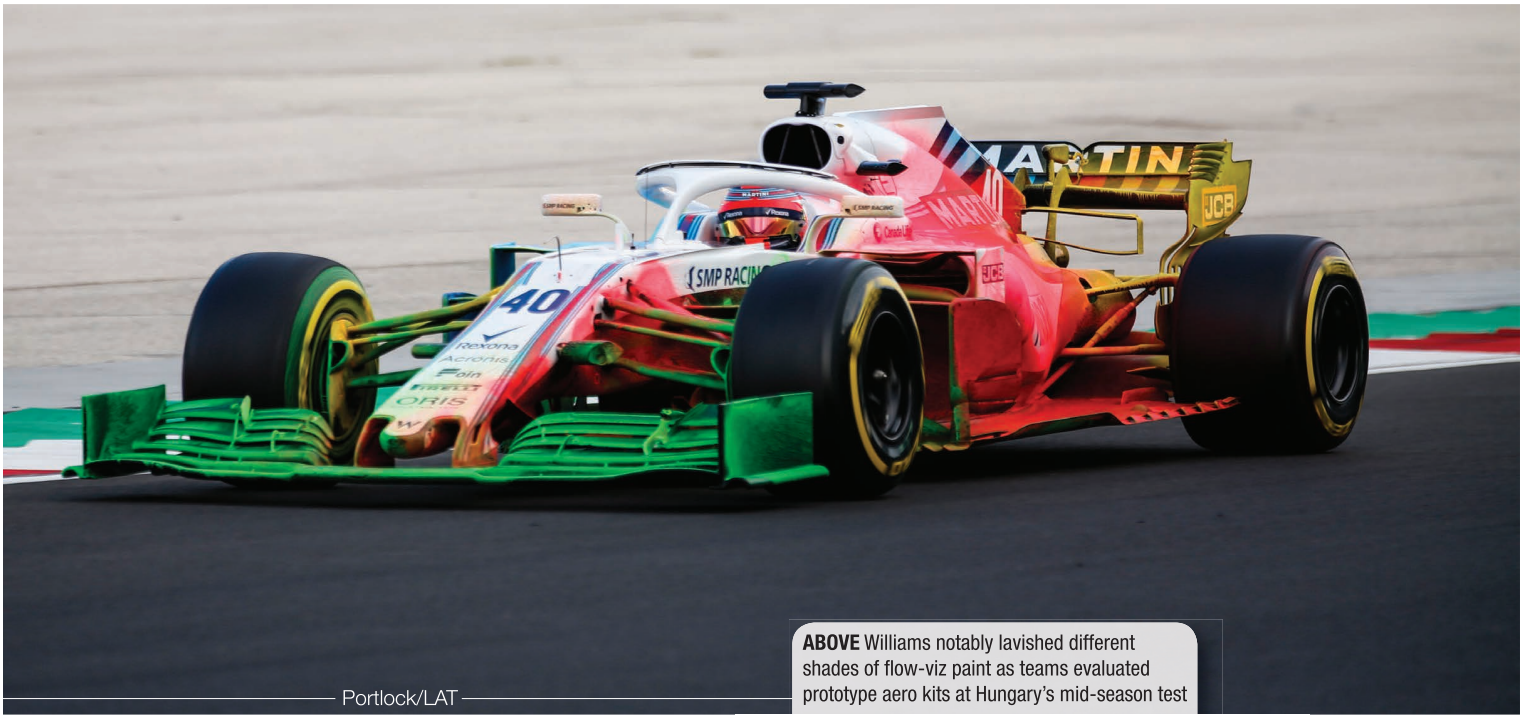
had not intervened, we feel that 2019 would be worse than 2018 and 2020 would be worse than 2019. We believe that 2019 will now be better than 2018 – but no-one is expecting F1 cars to be fighting like touring cars."

Everyone involved in the project is keen to stress that the point of the changes is to promote closer racing. It is not to make overtaking artificially easy. The numbers generated by the project, however, suggest cars should be able to follow within a second – which, of course, is the magic number that triggers the drag reduction system.

A decade after being first mooted, the DRS is still a subject of contention. There is an outside possibility the wholesale 2021 reboot may see the device rendered obsolete, though in the short term the 2019 changes will give it a power-up. The gap between the DRS flap and the main plane of the rear wing will increase by 20 mm. Race Director Charlie Whiting believes this change will make the DRS useful on a wider range of circuits, specifically on tracks where the maximum length of straight has proved too short to allow drivers to get full value currently.

"We will be able to make the DRS more effective on shorter straights," he confirms. "At the moment, we're trying to lengthen zones where we can, [but] circuits like Melbourne for example [where the DRS is already at its maximum length], those are the sorts of places that with the extra power from the DRS we should be able to make it work a bit better."

There is, of course, a cost. The new regulations, both in 2019 and the bigger change planned for 2021, are expected to ▶

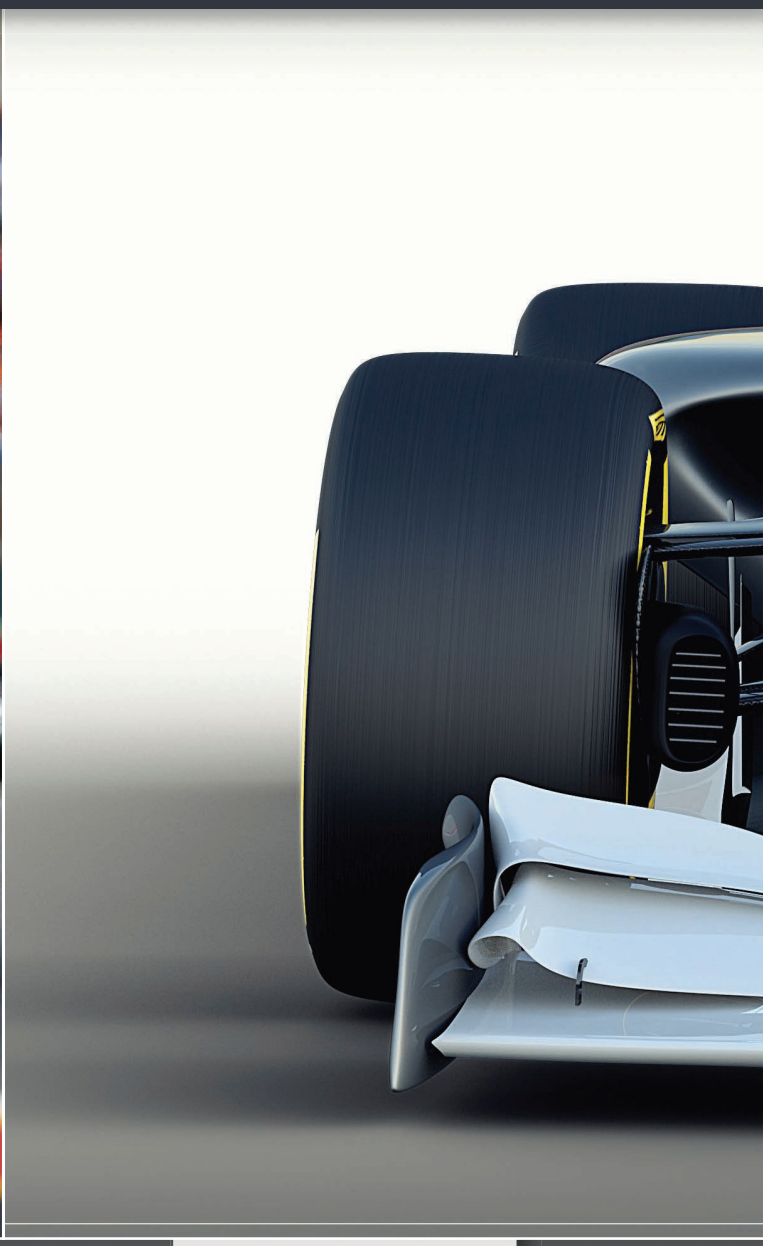


Portlock/LAT

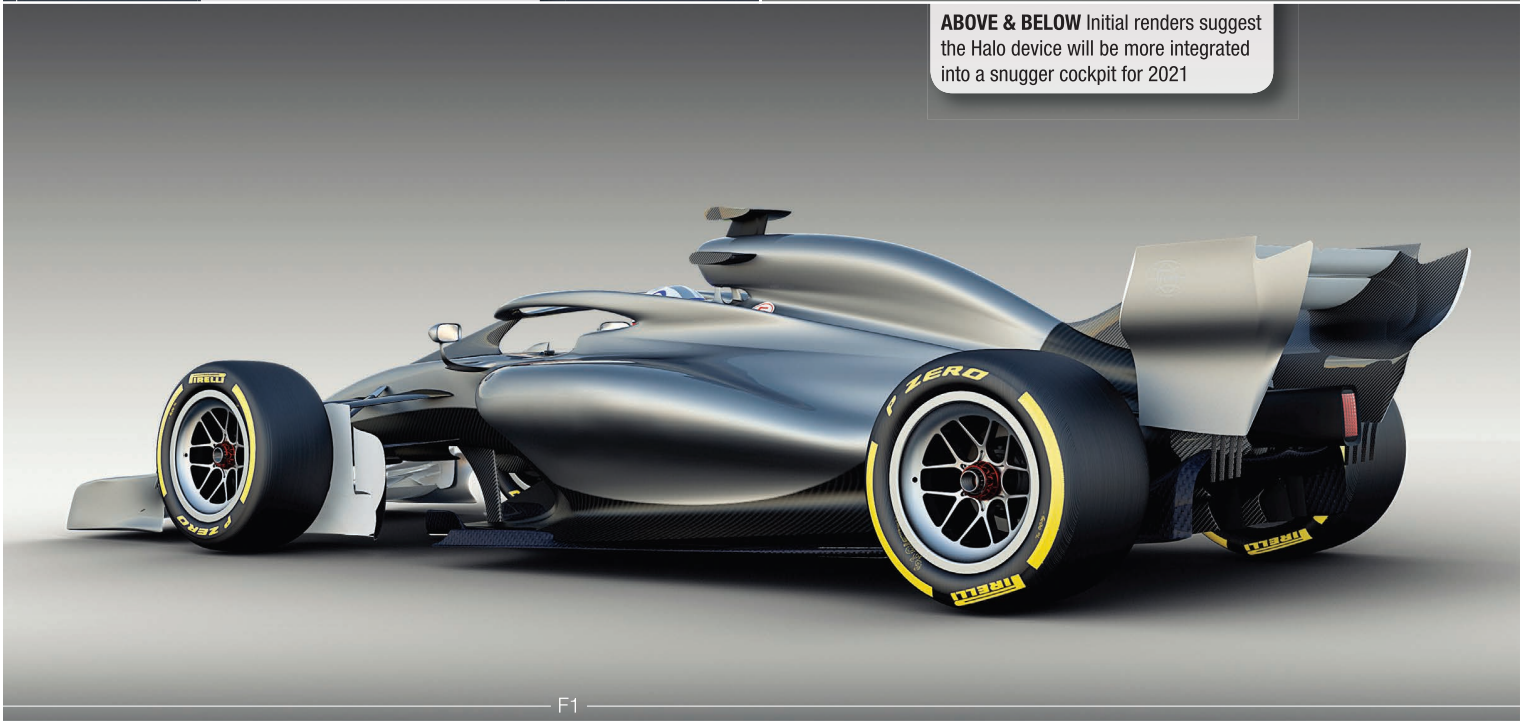
ABOVE Williams notably lavished different shades of flow-viz paint as teams evaluated prototype aero kits at Hungary's mid-season test

Dunbar/LAT

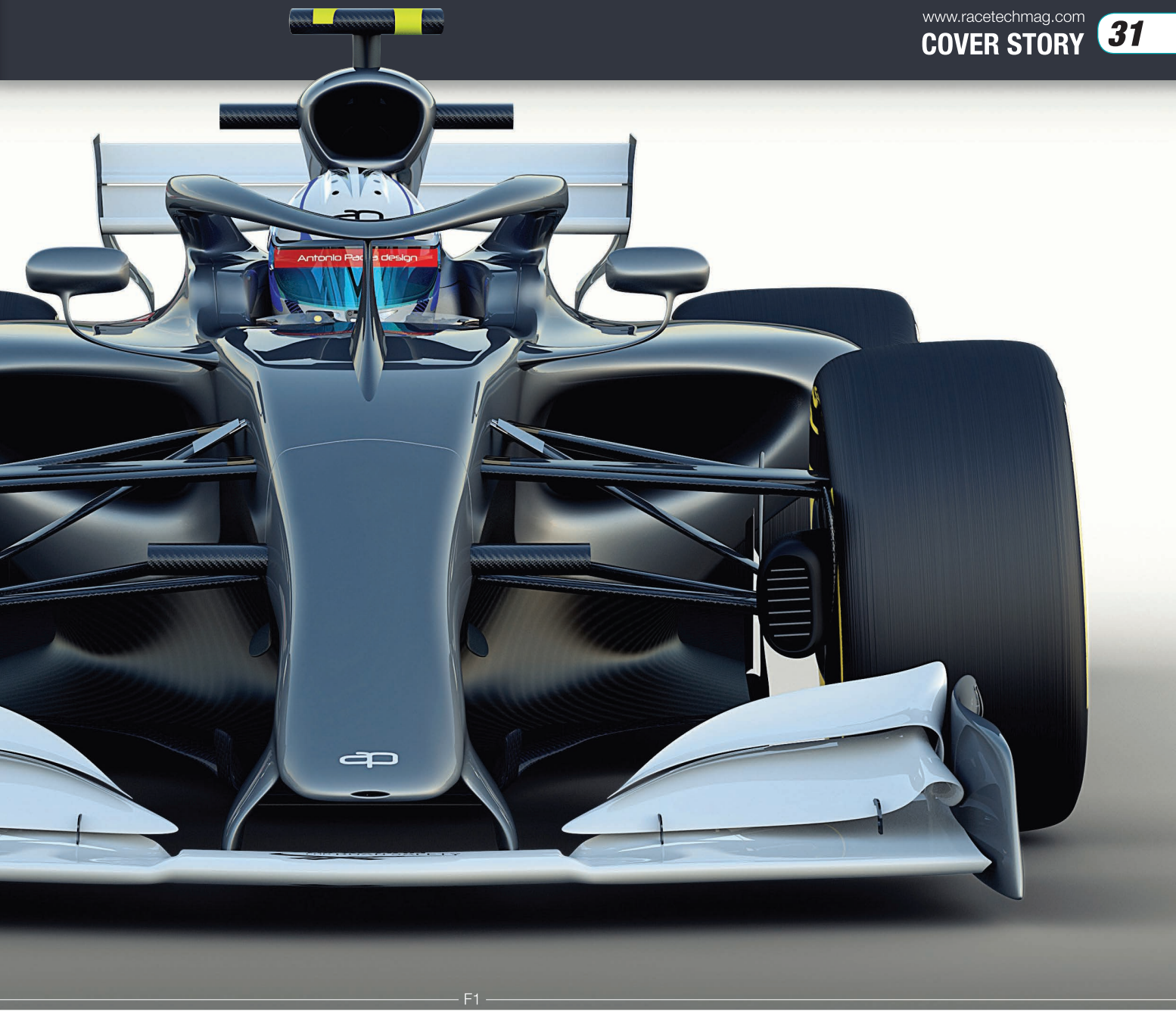
ABOVE The primary objective for 2019 is to deliver cars that can follow each other more closely than the current crop



ABOVE & BELOW Initial renders suggest the Halo device will be more integrated into a snugger cockpit for 2021



F1



F1

> *"A plan for long-term development rather than short-term gain"*

result in slightly reduced downforce levels and concomitant increases in lap-times, perhaps 1.5 seconds slower around a notional average track next year. Brawn is keen, however, to emphasise the positives in this.

INDYCAR INSIGHT

"I think [performance] will be less than where we are now – but if the cars continue to develop at the rate they're developing there will be a need to pull it back," he says. "Next year's regulations will be… an adjustment back but, as inevitably happens in F1, that will creep up again.

"It's interesting to look at IndyCar. They've reduced the downforce considerably and, at least on the road circuits, the drivers are very positive about the style of racing. They have some issues on the ovals but that's a unique environment. On the road circuits, there's pretty positive feedback from the teams and the drivers, even though they've got substantially less downforce than they used to have."

While both FOM and the FIA are keen to stress the 2019 update can be adopted to the current chassis with minimal disruption, the prevailing view in the paddock, unsurprisingly, suggests otherwise. For the bigger change coming in 2021, the intention is to provide rather more than eight months' lead time.

"This is the FIA's domain but realistically the end of next year [2019] is when we should be looking to issue the principal regulations," says Brawn. "That gives everyone a year to work on the car. What we mustn't do is leave it so late that those with the maximum resource can do the best job. There will always be a benefit of having experience and good resources – you can't move away from that – but if the regulations are issued too late, then you end up favouring the bigger teams."

While several technical directors remain to be convinced of the value the first set of changes will make, there is an unusual amount of goodwill and willingness to give it a go. In recent years F1 has perhaps lacked a clear road-map but the sense at the moment (despite a deafening silence on the subject of engine regulations) is that it now has a plan for long-term development rather than short-term gain. The new boss is most definitely not the same as the old boss.

COOL RUNNING

Motorsport companies have a lot of innovations to offer the transport industry's low-carbon revolution, says **William Kimberley**, with Equipmake's spoke motor among them

THE Cenex Low Carbon Vehicle event at Millbrook has grown exponentially over the 11 years of its existence, both in terms of number of exhibitors and in developing a fine reputation as the place for the low carbon mobility industry to showcase its products and expertise. A growing trend, and one that was most apparent this year, was the major presence of motorsport companies. As the automotive industry is in the throes of a revolution with the advent of enforced electrification due to future governmental directives and regulations, no longer can the carmakers follow their traditional roadmaps. Everything is up in the air, which means that all options are open and being explored.

According to Professor Lord Bhattacharyya, chairman of the Warwick Manufacturing Group in 2015, "The global energy storage market will be worth $50bn by 2020; of this, $21bn will be in transportation. Automotive is well on its way to displacing consumer electronics as the biggest user of energy storage."

DISRUPTION

No industry understands disruption better than the motorsport one. At the highest level, its whole being is based on building, designing, testing and importantly, crash testing, and then racing prototypes in a ridiculous timeframe and these are the skills that the automotive industry needs. With its recently acquired knowledge in both fully electric as well as hybridised powertrains, many of those companies involved, such as Williams Advanced Engineering, McLaren Applied Technologies, Prodrive, RML Group, Ricardo, AVL, Bosch, Claytex, rFpro, Mahle and Integral Powertrain have become the go-to for the OEMs, and were very much in evidence.

Williams Advanced Engineering announced that Hyperbat, its joint venture with Unipart, is to go into low-volume production in a purpose-build factory in Coventry to provide a secure future supply chain for UK-based carmakers as their vehicles transition to electric power. The result of a collaboration with Integral Powertrain, Williams Advanced Engineering was also showing the

ABOVE From buses to hypercars, Equipmake has made a motor that can do it all

newly announced Aston Martin Rapide E powertrain prototype on its stand, the British carmaker's first all-electric model which will be built at a dedicated facility at Aston Martin's new St Athan site in South Wales.

Integral Powertrain, McLaren Applied Technologies and Hewland Engineering also announced a collaboration on a new innovative CTU 400 E_Axle system. "There's no doubt the future of the automotive industry is in electric powertrains," said Simon Mead, Integral Powertrain's development manager. "This collaboration, utilising the expertise of all three companies, has produced an impressive technical solution that is cutting edge in terms of technology, can be made competitively in small and high volume and is scalable in design. I think you will struggle to find anything as power dense on the market that is not a motorsport application."

SHORT LEAD TIMES

Benefitting from the knowledge it has gained in motorsport, Ricardo was showcasing a range of products, including its own E-Axle, a new family of electric vehicle transmissions that can be configured to suit specific requirements and are available on remarkably short lead times.

While not exhibiting at Cenex, Equipmake's managing director Ian Foley did give a presentation on 'The cost-effective electric bus – cheaper than a diesel without subsidy'. He will be a name known to many in the motorsport world as he was behind the development of a novel electrically driven high-speed flywheel energy storage system that was spun off into Williams Hybrid Power.

This technology was chosen by Porsche Motorsport as an alternative to a battery option for the energy storage medium on its 2010 911 GT3 R Hybrid endurance racing car that was campaigned that year, including at the 24 Hours Nürburgring race where it famously led before retiring in the final few laps due to an engine-related failure, a problem unrelated to the hybrid system. The following year it secured its first victory in the VLN race at the Nordschleife, making WHP's flywheel a race-winning technology. It then made further history as it was a vital part of the equation that enabled Audi's R18 e-tron quattro to become the first hybrid car to win Le Mans in 2012.

A couple of years later Williams sold the hybrid part of the business to GKN, Foley initially going along with it but then leaving to become managing director of Equipmake. The company has been in the news very recently, announcing that it has formed a partnership with Brazilian bus chassis manufacturer Agrale to jointly develop a low-cost electric bus that will be based on the Agrale MT17, a 12m single-decker with a maximum capacity of 70 passengers. The overall weight of the new electric bus will be the same as the diesel version, according to Equipmake.

> *"Automotive is well on its way to displacing consumer electronics as the biggest user of energy storage"*

The drivetrain will feature two Eqiupmake APM200 motors, that weigh around 40 kg in a 318 x 247 mm package, can run at 10,000 rpm and have peak power and torque figures of 220 kW/450 Nm and are mounted on a bespoke two-speed gearbox. The unique spoke architecture makes it the highest power/torque dense automotive electric motor in the world says Foley. The same APM200 motors will also power the forthcoming Ariel HIPERCAR which he hopes will show the potential of the technology at ▶

ABOVE Ariel says that four Equipmake APM200 motors mean that its HIPERCAR will offer 1,180 bhp and hit 100 mph in 3.8 seconds

ABOVE The Hyperbat, which will power Aston Martin's first electric effort, was made jointly by Williams Advanced Engineering and Unipart

> *"The scrabble to buy technology-ready answers is a microcosm of the whole automotive industry in getting electrified"*

the extreme edges of the performance map.

The HIPERCAR, which stands for High Performance CArbon Reduction, is a joint project that Equipmake has joined along with Delta Motorsport to develop an ultra-high-performance sportscar with advanced carbon reduction technologies. It is due to go into production in 2020.

The car is a range extended EV featuring a 750 Volt, 42 kWh or 56 kWh, lithium-ion, cooled and heated battery pack that forms a semi-stressed member of the chassis. It's charged, when required, by a 35 kW micro-turbine range extender developed by Delta Motorsport, negating any range anxiety issues and making the vehicle independent of any charging infrastructure. Its electrical architecture consists of high and low voltage systems linked by multiple CAN networks enabling the powertrain controller, vehicle dynamic control interface and battery controller to communicate and interact with 12V and safety systems.

It will be available as a 4-wheel or 2-wheel rear drive, full bodied car. Powered wheels are driven by Equipmake's inboard motors via integral, single speed step-down gearboxes direct to the driven wheels, with each individual motor developing 220 kW (295 bhp) and 450 Nm (332 ft/lb) of torque. In 4-wheel drive, the total power is therefore 880 kW (1,180 bhp) and 440 kW (590 bhp) in 2-wheel drive form.

Total torque is 1,800 Nm (1,327 ft/lb) at the motor and 9,900 Nm (7,301 ft/lb) at the wheels in the 4-wheel drive version and 900 Nm (664 ft/lb) at the motor and 4,950 Nm (3,651 ft/lb) at the wheels in the 2-wheel drive car. Ariel claims that it will accelerate from 0-100 mph in 3.8 seconds and 0-60 mph in 2.4 seconds.

What makes the car so unique, though, is the APM200 motors' spoke technology where the magnets are arranged radially around the outside of the rotor like the spokes of a wheel. This is claimed to improve the torque density by as much as 25 per cent to make it the highest torque density architecture for a permanent magnet motor. A sophisticated water-glycol cooling system features channels running up and around the rotor itself, close to the magnets, and back down again. ▶

ABOVE A man well known in motorsport, Ian Foley, now with Equipmake, has been instrumental in previous hybrid technologies

Ensuring the liquid keeps to a maximum 60°C enables the motors to run at high outputs for a prolonged period.

"The core technology of the spoke motor is well known as its architecture gives a better use of magnetic flux giving a higher torque density," says Foley. "However, nobody had really managed to work out how to manufacture and cool it properly, so what we've done is work out how to manufacture it cost-effectively and cool it very effectively.

"There's a big difference between the continuous power and the peak power of all electric motors. The more heat you get out, the closer you can run it to peak power so all our development is really focused on how to improve cooling the motor. It's easy to get peak power for a short period of time, it's hard to have sustained peak power, because you run the risk of overheating. Typically, all motors have roughly a 50 percent difference in their peak power and their continuous power because of the cooling, so that's an area in which we are putting a lot of work into, so it's an area where we're going to see big developments in the next few years."

Another challenge that had to be met was that the rotor needed to be non-magnetic and very strong but also thermally conductive. The answer, according to Foley, was aluminium. "This was because we can keep it cool and therefore it retains its strength. We also use neodymium iron boron magnets as we can keep them cool. They become more expensive the higher temperature rating but because of the cooling system, we can use the cheapest grade of neodymium but get very high magnetic strength.

"Most permanent magnet motors can be made where the peak efficiency is very high, but we have a significant volume benefit over the conventional motor. We've compared it to a comparable conventional motor and it's about 50 percent of the volume and 80 percent of mass which obviously has packaging benefits."

Although postponed for a year, Foley ▶

ABOVE & BELOW Hard to believe it may be, but both Ariel's electric hypercar and Agrale's green bus depend on the same APM200 motors

> *"It's hard to have sustained peak power… you run the risk of overheating"*

believes that the new all-electric FIA World Rallycross Championship that's coming in 2021 offers huge opportunities for Equipmake as the electric motor/gearbox supplier, working with an OEM. "Although I think our APM200 motor is very close in meeting the requirements in terms of power density, weight and packaging, we could still perform any necessary modifications to meet the needs," says Foley. "One of the reasons we are getting interest from manufacturers that need to electrify their racing cars is because of the packaging benefits our motors offer.

ATTRACTIVE

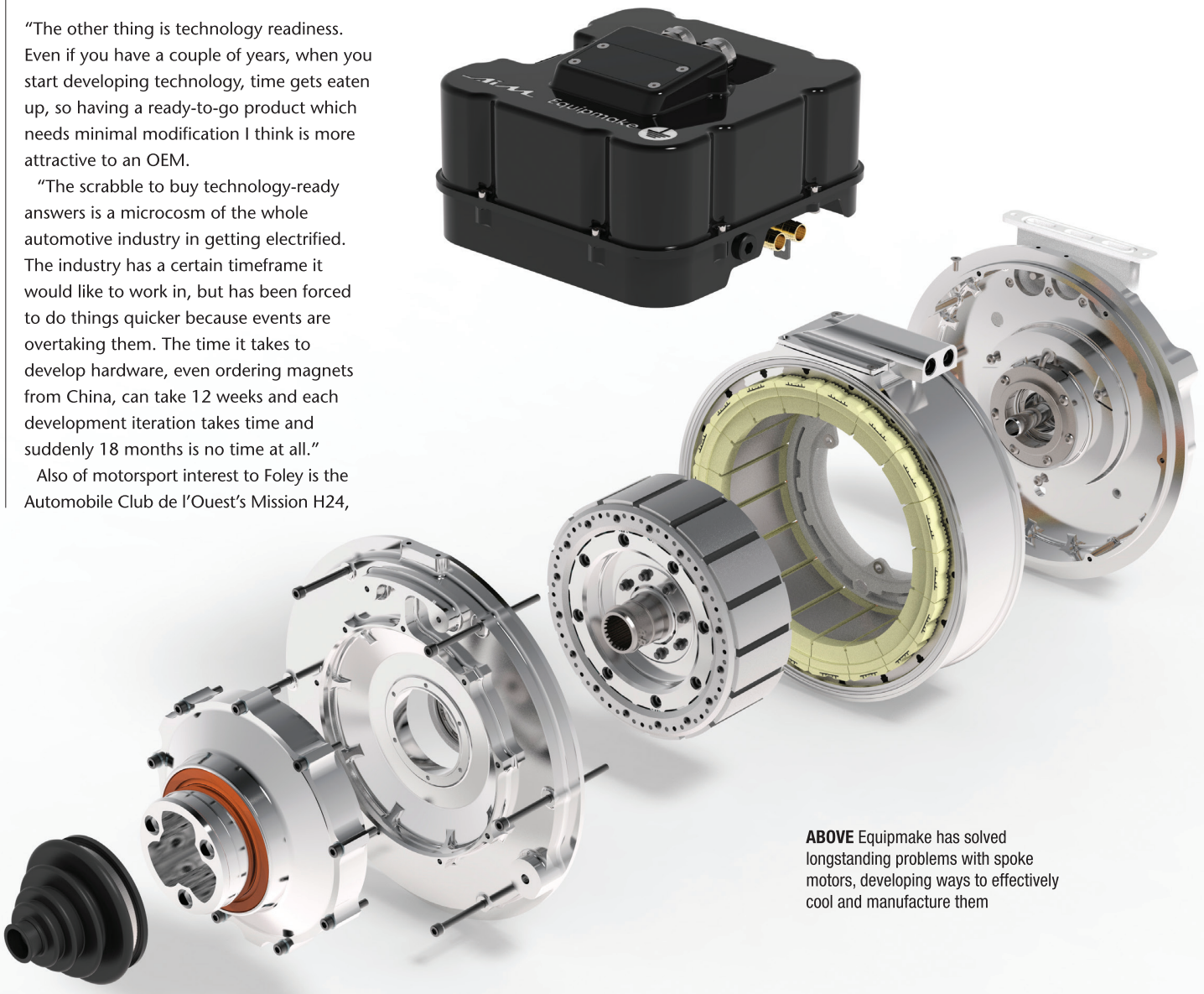
"The other thing is technology readiness. Even if you have a couple of years, when you start developing technology, time gets eaten up, so having a ready-to-go product which needs minimal modification I think is more attractive to an OEM.

"The scrabble to buy technology-ready answers is a microcosm of the whole automotive industry in getting electrified. The industry has a certain timeframe it would like to work in, but has been forced to do things quicker because events are overtaking them. The time it takes to develop hardware, even ordering magnets from China, can take 12 weeks and each development iteration takes time and suddenly 18 months is no time at all."

Also of motorsport interest to Foley is the Automobile Club de l'Ouest's Mission H24, and its push to promote hydrogen fuel cell racing cars. "From our point of view, the fuel cell would look very much like a battery that would give a continuous, relatively low output interfaced with a high-power energy store that could be a flywheel or a high-powered battery to provide the transient, so by the time the motor inverter is seeing that, it looks very similar to the battery. I don't think there would be a lot of change in terms of what we would provide, but we'd be very happy to be part of any such project."

Located on an industrial park adjacent to Lotus Cars in Norfolk, Equipmake is currently looking to expand as it will be manufacturing the electric drivetrains for its customers. "Originally we wouldn't look to anything like this, but with the relatively low volumes we are talking about, around 5,000 units a year, that's something we can accommodate."

Another area where Equipmake is blazing a trail is in additive manufacturing. "There have been huge advantages in additive manufacturing in recent years and it's really down to the speed in which layers can be applied, and what used to take days to create now takes just hours or even minutes in some cases. However, it's not currently viable for motors other than in some niche applications in medicines and aerospace but you can see the way it's going which is why we are doing our R&D now and working with a partner in additive manufacturing, so I think we will continue to see the size of motors come down, that will ultimately lead to cost reduction." RT



ABOVE Equipmake has solved longstanding problems with spoke motors, developing ways to effectively cool and manufacture them

PORSCHE'S MINIATURE MARVEL

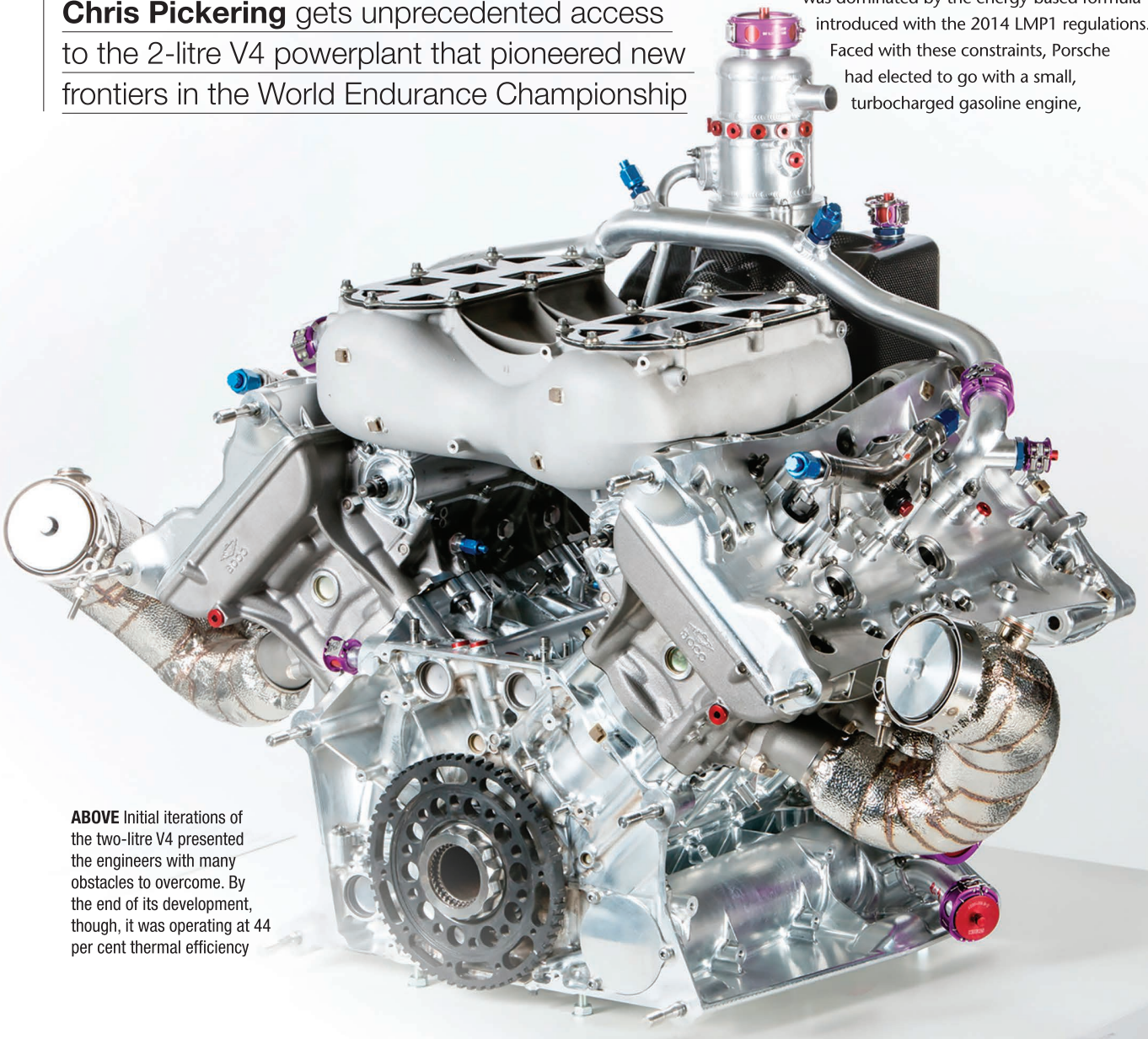
Chris Pickering gets unprecedented access to the 2-litre V4 powerplant that pioneered new frontiers in the World Endurance Championship

THE Porsche 919 Hybrid's 2-litre turbocharged V4 is the most efficient combustion engine that the company has ever made.

Winner of six world championship titles and three outright victories at Le Mans, it's one of the most successful racing engines of recent years. Through the 919 Tribute tour it's also helped us to answer a question that has been bugging racing fans for years: Just how fast could a modern LMP1 car go if it was freed from the series' fuel and energy restrictions?

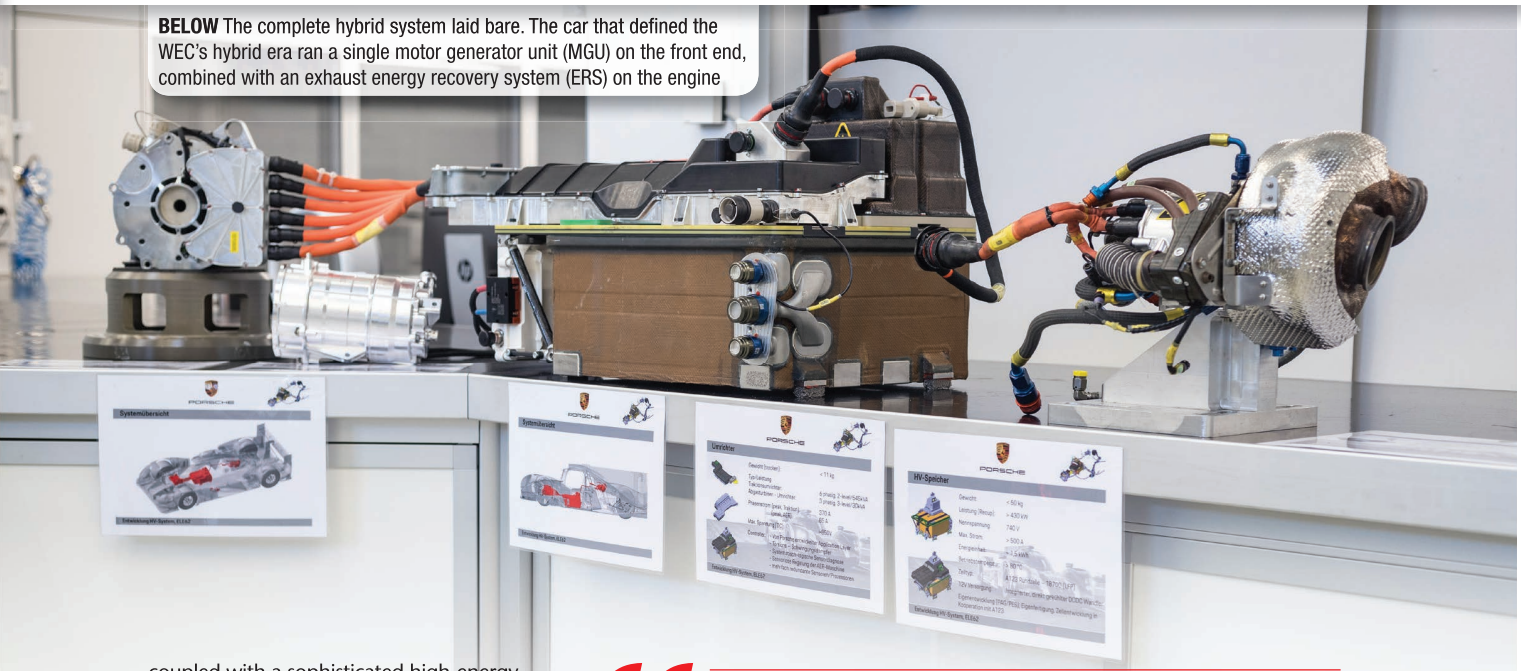
The latter has proved a fitting tribute to these record-breaking cars and the engineers who worked on them. But there's also a certain irony here, because the design of the 919 Hybrid – and above all its powertrain – was dominated by the energy-based formula introduced with the 2014 LMP1 regulations.

Faced with these constraints, Porsche had elected to go with a small, turbocharged gasoline engine,



ABOVE Initial iterations of the two-litre V4 presented the engineers with many obstacles to overcome. By the end of its development, though, it was operating at 44 per cent thermal efficiency

Photos: Porsche AG



BELOW The complete hybrid system laid bare. The car that defined the WEC's hybrid era ran a single motor generator unit (MGU) on the front end, combined with an exhaust energy recovery system (ERS) on the engine

coupled with a sophisticated high-energy hybrid system. This was very much a holistic decision, not just balancing the fuel flow and energy requirements for the powertrain, but also freeing up packaging space for the aerodynamicists to exploit, as well as reducing the size and mass of the combustion engine. To a certain extent there was also the desire to explore an alternative solution to Audi's turbocharged diesel engine and Toyota's comparatively large naturally aspirated gasoline unit.

"We wanted to go for the smallest engine we could practically achieve, which we believed was a 2-litre V4," explains Porsche Motorsport development engineer Christian Eifrig. "The vee configuration was a natural step for packaging and structural rigidity; an inline engine [which is longer and narrower] would have required an additional subframe to reinforce it. This wasn't necessarily the optimal decision for the engine in isolation, but it was definitely the right concept for the car as a whole."

> *"A new engine package included the addition of Formula 1-style jet ignition"*

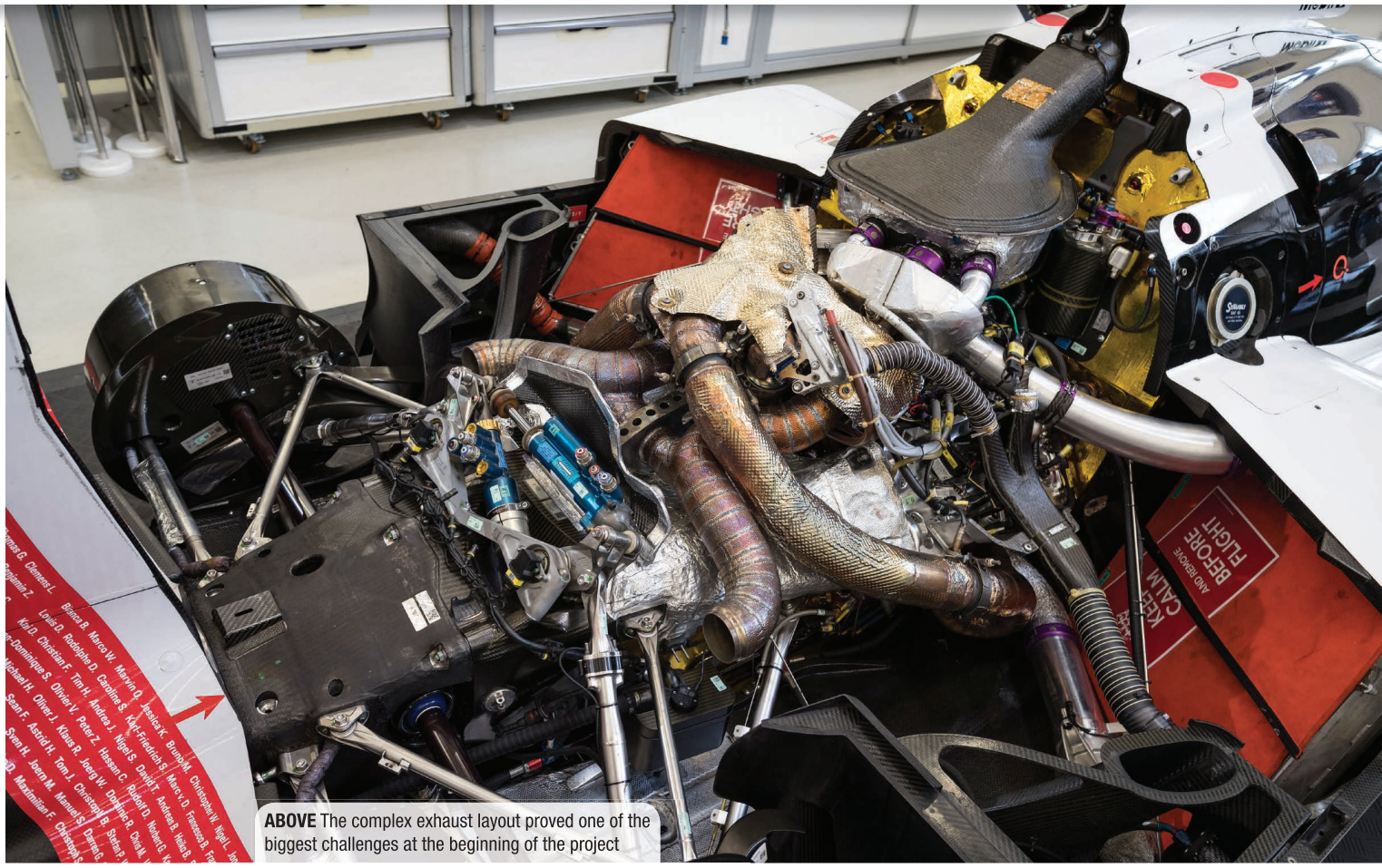
This approach wasn't without its challenges. For a start, a four-cylinder engine is still subject to the same loads as a V6 or V8 of a similar output, but it has fewer bearings, fewer pistons and fewer connecting rods to distribute them over. Plus, while a 90-degree V4 has theoretically perfect primary balance (and better secondary balance than the equivalent inline engine) it's a configuration that can suffer with vibration issues. Nonetheless, the team's determination to overcome these challenges paid off with a dominant performance in the top class of the World Endurance Championship (WEC).

Although the system would be scaled back to 6 MJ for the first season, the target had always been to run in the 8 MJ category, maximising the engineers' freedom to capture and exploit waste energy. Given that most of the braking takes place on the front axle, allied to the fact that LMP1 cars are potentially quite heavily traction-limited, it was a no-brainer for a car running in this class to use a kinetic energy recovery system on the front end. Both Audi and Toyota had followed this approach to varying degrees, but Porsche elected to run a single motor generator unit (MGU) on the front end, combined with an exhaust energy recovery system (ERS) on the engine.

The idea of running an exhaust ERS – sometimes referred to as a heat energy recovery system – had been talked about in LMP1 circles before. It was similar to the MGU-H units that would be introduced in F1 the same year that the 919 made its WEC debut. However, the fundamental difference was that the Porsche system would be a separate generator unit, used in combination with a conventional turbocharger. It would also be used for energy recovery alone, without the ability to operate as an electrically-assisted turbo.

One of the boldest decisions was to go for an 800-volt architecture for the hybrid system. Already mooted as a future solution for high performance road-going hybrids, it would allow the 919 to charge and discharge at very high power levels. To put things in perspective, if your smartphone battery was ▶

ABOVE Innovative high power cells were key to the battery system



ABOVE The complex exhaust layout proved one of the biggest challenges at the beginning of the project

to charge at the same rate, it would be full in well under a second. The downside was that there were virtually no motorsport-grade components on the market at the time that would cope with such high voltages.

There was also the question of what type of energy storage system to run. Porsche had already experimented with an electromechanical flywheel system developed in conjunction Williams Hybrid Power on the GT3R Hybrid racer and the 918 RSR concept that followed. However, Audi was already using a similar system on the R18. Similarly, supercapacitors, as used on the Toyota TS040, were considered but rapidly discounted on the grounds of energy density. Instead, Porsche formed a partnership with automotive cell manufacturer A123 Systems in Boston to develop a bespoke lithium ion battery pack.

"A battery offers more storage capacity than a flywheel or a supercapacitor system. The potential obstacles were the current that it would have to handle and the ageing of the cells, but we decided we could overcome those challenges," comments Jens Maurer, head of systems at Porsche Motorsport. "The A123 cells were a big step forward. The company agreed to supply the cells to us exclusively for the duration of the LMP1 project."

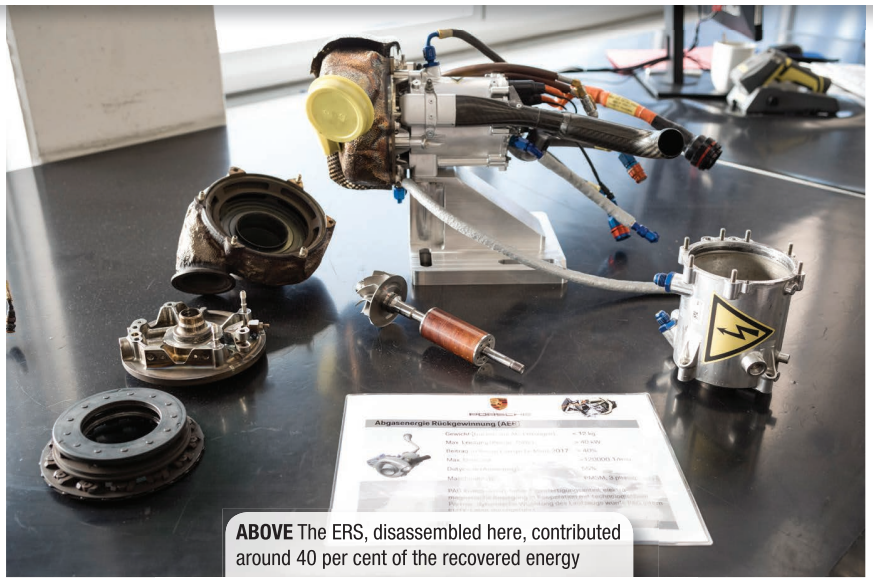
It's worth noting that 8 MJ was the cumulative amount of energy that the car was allowed to recuperate over the course of one lap. The battery itself is said to hold 'approximately 1.5 kWh', which equates to around 5.4 MJ. Nonetheless, over the course of a 24-hour race it could capture and discharge more than 800 kWh – based on NEDC figures that would be enough to propel the 35.8 kWh Volkswagen e-Golf from London to Indianapolis.

TEETHING TROUBLES

Development work began at Porsche's Weissach facility in 2012, while the bulldozers were still clearing what was to become the LMP team's new home on the opposite side of the site. Some 260 new personnel and a cluster of buildings big enough to accommodate a small F1 team were added to the facility, not to mention a state-of-the-art simulator.

In April 2012, the first single-cylinder test engine ran in the lab. Three months later the complete V4 roared into life. Everything appeared to be going to plan until May 2013 when the engine was first run in the car. The moment the clutch was released, the shaft going into the gearbox sheared off due to a torsional vibration issue. A temporary fix was found in the form of a raised idle speed, but more problems were to come.

"We started with an even firing order. This was the best solution for the gas exchange and the engine itself proved reliable, but there were a lot of frequency issues elsewhere in the



ABOVE The ERS, disassembled here, contributed around 40 per cent of the recovered energy

car," recalls Eifrig. One of the problems was that the vibration was interfering with the resonant frequency of the car's suspension. Worse still was the effect on the drivers, who complained of breathing difficulties, eyesight problems and dizziness.

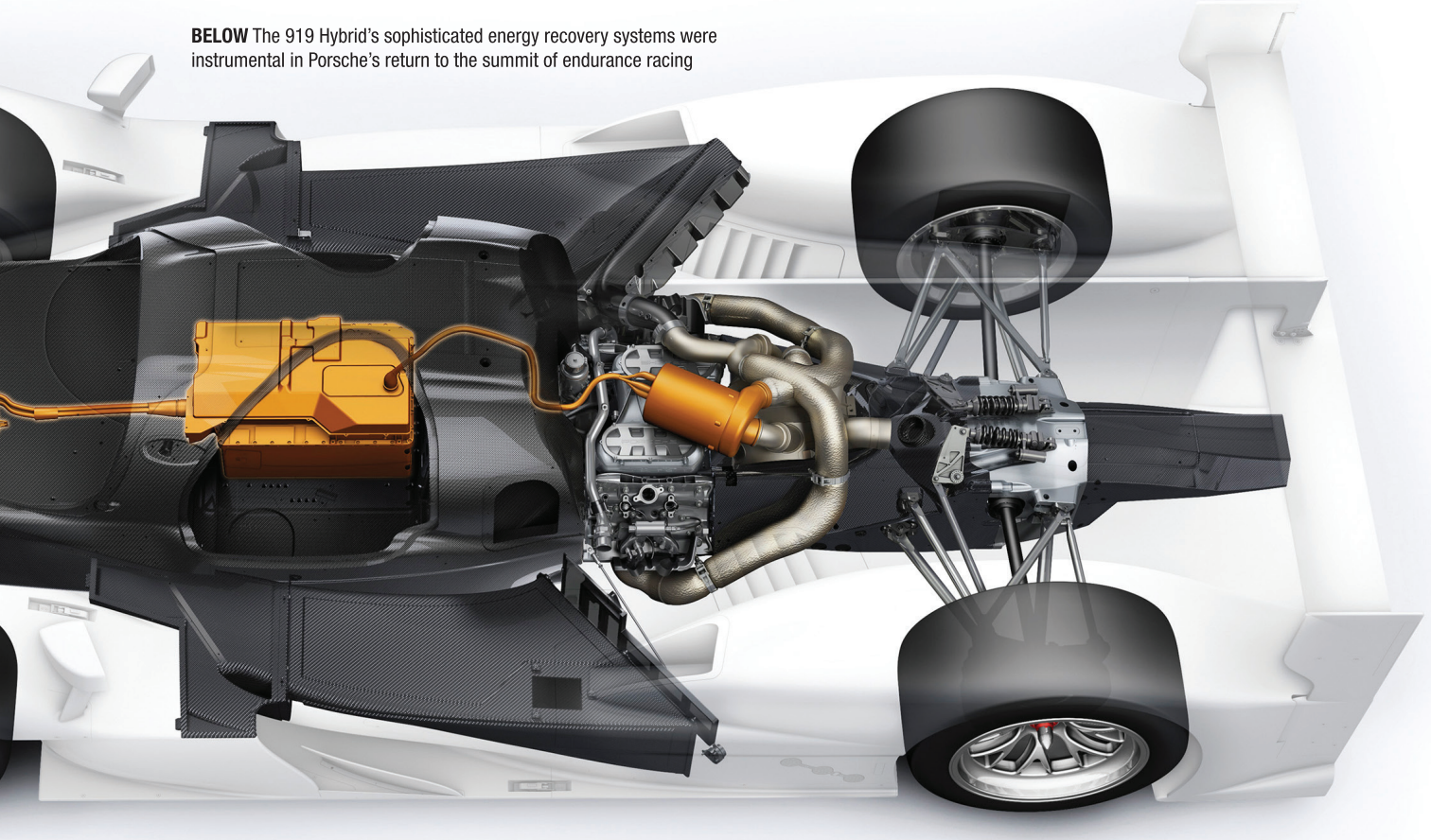
Porsche's response was to switch to an uneven firing order (similar to the 'big bang' configuration used on some motorcycle engines) with a new crankshaft design to suit. This cured the frequency issues, but introduced a new set of challenges, with the cylinders firing more or less as two pairs. One of the problems this creates is that the two pulses are travelling down the exhaust at more or less the same time, leading to problems with both scavenging and turbo management. Porsche's response was a new exhaust design with asymmetric primary pipes that aimed to restore the interaction of the pressure pulses.

The exhaust system follows a complex design, linking the turbocharger, the ERS, the wastegate and the tail pipe. Stood next to the car with the rear bodywork off, the system resembles a spoonful of spaghetti draped over the combustion engine. It was equally complex to engineer, Eifrig explains: "The exhaust design was quite difficult to handle. You had a lot of temperature and a lot of vibration, but you also wanted to make it light and, of course, it has to be reliable. It's also expanding with temperature in all sorts of different directions. This was one of the biggest challenges in the beginning of the project."

At the heart of the system lies a single Garrett DualBoost turbocharger. This is understood to use an axial turbine, in place of the radial layout found in normal automotive turbochargers. A conventional turbine housing is used, but a specially-profiled shroud channels the exhaust gasses through the turbine axially, rather than at 90 degrees, improving efficiency. The 'dual' part of the name derives from the use of a small diameter double-sided compressor wheel. Compared to a conventional (larger diameter, single-sided) item, this is said to reduce rotational inertia, as well as further increasing efficiency. In production applications, Garrett says the DualBoost technology can result in double the acceleration rate of a conventional turbocharger, plus lighter weight and a packaging size that is 10 to 20 per cent smaller.

But the turbocharger itself is only the beginning of the story. Mounted on the wastegate is a variable geometry turbine, ▶

BELOW The 919 Hybrid's sophisticated energy recovery systems were instrumental in Porsche's return to the summit of endurance racing

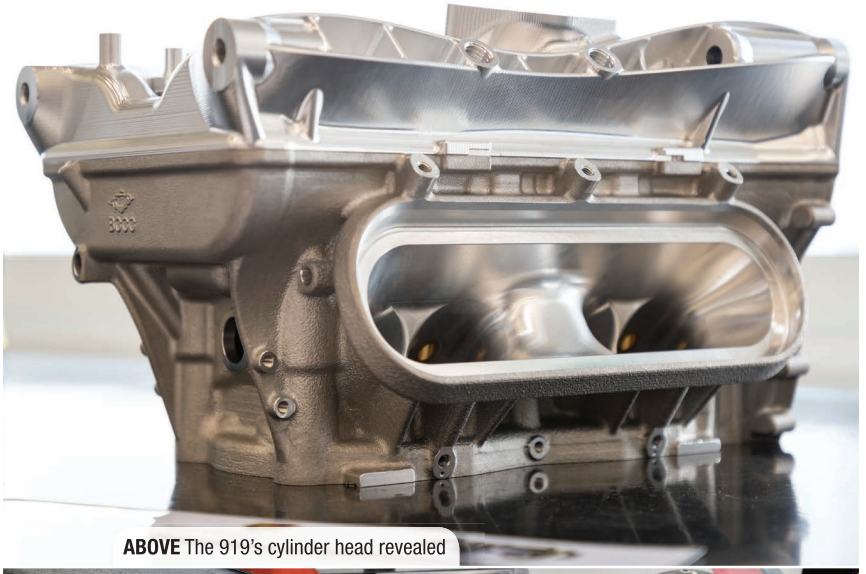


which drives the ERS generator. Under normal circumstances, this effectively takes the role of the wastegate, varying the pitch of the blades to control how much gas bypasses the turbocharger and thus modulating the boost pressure.

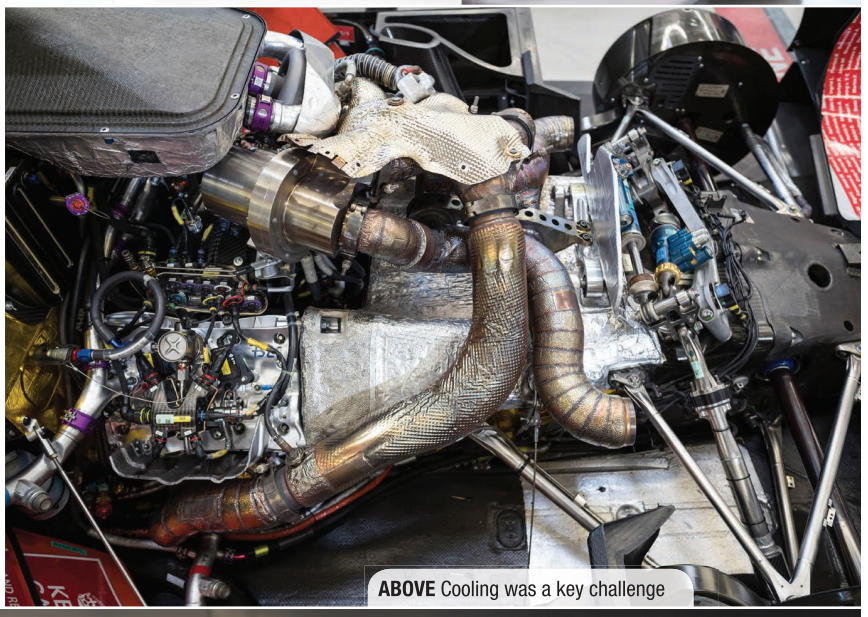
"We've still got a conventional wastegate, but it is more or less just a failsafe," comments Eifrig. "Most of the time the ERS fulfils that role, but if the system is not running then the wastegate can be used instead. Similarly, if the battery is full we can use the wastegate without loading the ERS. We can use the two interchangeably with no effect on the engine; our primary goal is still to generate the optimum boost pressure."

Perhaps the obvious question is why the Porsche engineers went down this route rather than coupling a motor-generator unit to the turbocharger, as is done in Formula 1. The simple answer, Eifrig explains, was that they could achieve the required boost response without assistance: "We carried out some studies and for our specific configuration we found that a [one-way] thermal energy recovery system would be the best option. There could have been benefits [to using electrical assistance] if we'd run a really big turbo and we needed to overcome a lot of lag, but we didn't have that problem. You also need to bear in mind that adding an e-machine to a turbocharger will increase its inertia, which makes it harder to achieve a fast response time."

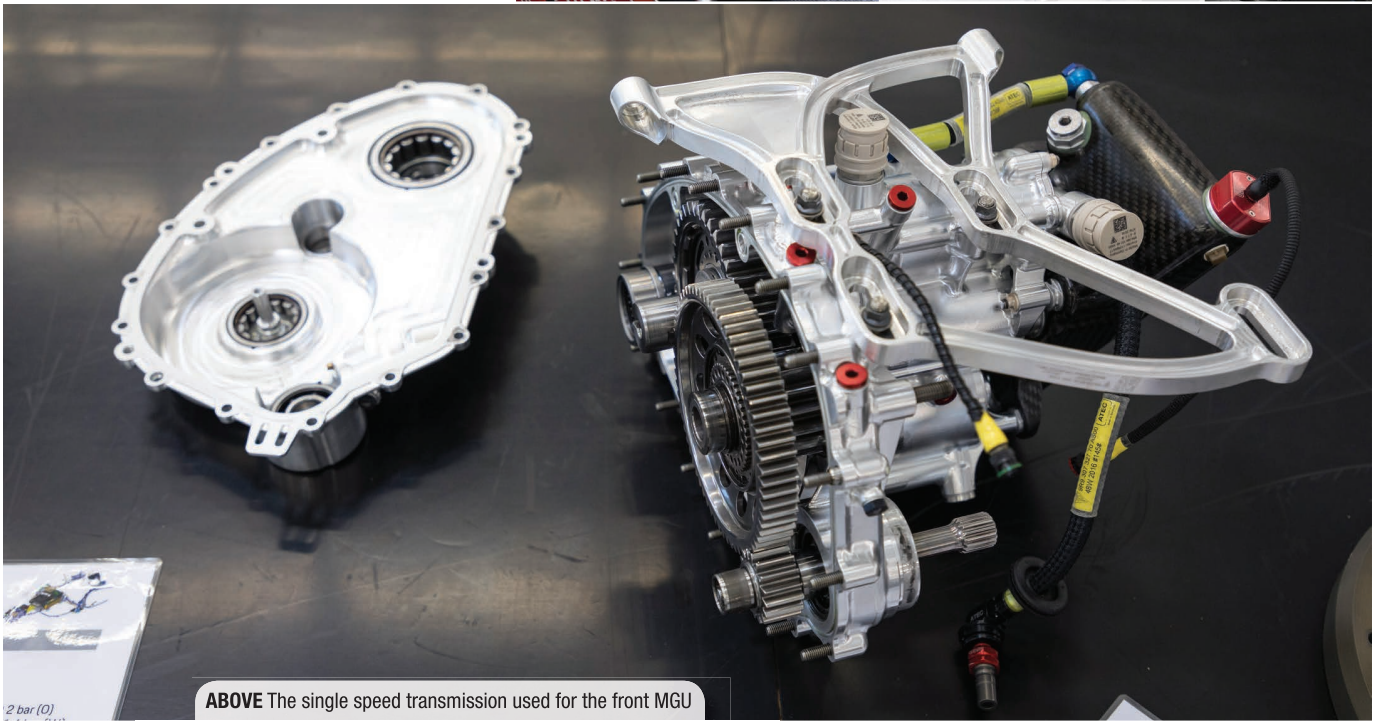
The idea of running a turbine on gasses ▶



ABOVE The 919's cylinder head revealed



ABOVE Cooling was a key challenge



ABOVE The single speed transmission used for the front MGU

ABOVE Porsche responded to initial vibration issues by changing the crankshaft to accommodate a new firing order

vented from the wastegate might sound like a token gesture, but Porsche says the ERS contributed around 40 per cent of the recovered energy. It's also worth noting that it operates – to some degree – almost constantly while the engine is running. For circuits like Le Mans, where nearly 75 per cent of the lap is spent at wide open throttle, that's a major advantage.

STAYING COOL

Cooling was to be a key priority. The heat rejection of the hybrid system is roughly one tenth that of the combustion engine, but it still represents a significant cooling demand. Part of the challenge is that the electrical components need to be kept at a much lower temperature; while the combustion engine can run at 150 degrees, the battery – its cells immersed in dielectric fluid for direct cooling – operates at around 60 degrees. As such, the radiator area for the hybrid system is only 50 per cent less than that of the combustion engine, despite a 10:1 difference in heat rejection.

"The engine is extremely sensitive to intake temperature, so we needed to keep the intercooler as cool as possible," comments vehicle integration specialist Ivan Botti. "We were running a very high compression ratio [13:1] – not far off a diesel engine – so the knock limit was very close. Every extra degree of cooling you can provide allows you to be a little bit more aggressive on the ignition timing. We were restricted in terms of engine water temperature – we would have liked to run the radiators smaller for aerodynamic reasons, but that would have led to knock."

Radiative heat transfer was a major consideration in the engine bay, with the ERS placed so close to the exhaust pipes, which experience internal temperatures of nearly 1,000 degrees. Likewise, the ERS itself could spin at more than 130,000 rpm, with the tips of the turbine blades going supersonic. At such speeds, the oil system's ability to cool the bearings becomes critical, as does the heat transfer from the turbine into the ERS generator.

The exhaust system is awash with different heatshield materials, while the layout of the intake system has been carefully designed to reduce inlet temperatures. The air is sucked in through a scoop above the cockpit, down into the compressor and then into the intercooler, mounted on the right-hand side of the engine bay. What happens next is rather unusual, with the cooled, high pressure air routed back *through* the engine block and up into the airbox. This results in the shortest possible distance between the intercooler and the intake, reducing heat transfer along its length.

The engineers set out to reduce the engine's internal heat rejection as much as much as they could. As such, the water jacket was designed to be as small as possible – we're told it's around a fifth of the thickness of a typical road car design. An Inconel-like material was used for the liners, which allowed their thickness to be greatly reduced as well. In total, Botti explains, the heat rejection from the 919's Le Mans-winning combustion engine is lower than that of a base-spec Boxster.

"You only cool where you need to cool in order to last 24 hours," he notes. "We had some hot spots in areas where we knew we could tolerate them for that sort of duration."

EVOLUTION

In its debut season, the 919's combustion engine produced around 500 bhp, running in the 6 MJ class with a fuel flow allocation of 4.79 litres per lap at Le Mans. For 2015, a higher compression ratio, a new turbocharger design and a revised twin-exit exhaust system saw the power climb to between 520 bhp and 535 bhp depending on the ambient conditions. That's despite moving up to the 8 MJ class, which saw the fuel flow allowance reduced to 4.76 litres per lap.

The forces inside the engine started to go up as the power output increased. "Soon the weak point became the bearings in the connecting rods, as is often the case in a highly turbocharged engine," comments Eifrig. "Every year we re-designed the connecting rods several times. Each time we managed to get more power we would go to the design department and ask for more

> *"If your smartphone battery was to charge at the same rate, it would be full in well under a second"*

strength or stiffness. Sometimes you can get power in a few hours on the dyno, but you have a much longer lead time on hardware changes, so we were limited on reliability until the new parts came through."

The Porsche engineers turned to a new simulation technique to push the connecting rod bearings even further, he explains: "We used a technique that combines finite element modelling and computational fluid dynamics to give you both the forces on the bearings and the interaction with the oil film."

A reduction in fuel flow allocation for 2016 brought the combustion engine's power figure down to less than 500 bhp (although total system output remained at around 900 bhp). Then, ahead of the 2017 season, Audi withdrew from the WEC, taking the series' only diesel engine with it. Free from the requirements to balance diesel and gasoline, the FIA adjusted the fuel flow allocation once more, taking it down to 4.3 litres per lap. Porsche maintains that this handed an advantage to the larger six-cylinder Toyota engine, but the German team fought back with a new engine package, which included the addition of Formula 1-style jet ignition.

Here, a small pre-chamber is added around the spark plug to create a localised rich zone, from which a jet of burning mixture shoots out to ignite the rest of the cylinder. Eifrig is a little coy about the exact configuration and even with the parts laid out on the bench it's not entirely clear how the system works. We're told there are no visual differences to the cylinder head and that the same heads could, in fact, be run with conventional ignition. This implies the spark plug design may have incorporated the pre-chamber.

These revisions clearly did the trick. By this point, the engine is said to have been operating at some 44 per cent thermal efficiency (having started at around 40 per cent). For the third year in a row, Porsche picked up not only victory at Le Mans – taking the company's tally to 19 in total – but also the WEC drivers' and manufacturers' crowns. It was to be the end to an illustrious competition career for the 919 Hybrid, but not quite the end of the story.

In December last year, Porsche announced it would be taking a modified version of the car, dubbed the 919 Hybrid Evo, for a series of demonstration runs in 2018. The powertrain is mechanically identical, but calibration changes, and being unshackled from the LMP1 regulations, have seen power rise to 720 bhp from the combustion engine and some 440 bhp from the front axle's motor generator unit, giving a faintly surreal 1,160 bhp in total. Anything that wouldn't be required in a short daytime sprint was jettisoned, including the air conditioning, headlights and windscreen wipers. At the same time, a heavily revised aerodynamics package and a set of specially-developed Michelin tyres help to give the car its F1-beating pace.

Our meeting with the engineers at Porsche's competition department in Weissach comes the day after the 919 Hybrid Evo was flown off to Laguna Seca for the final circuit stop on its farewell tour. It's business as usual in the Motorsport department, where most people have either returned to the company's GT racing projects or transferred to the forthcoming Formula E car. The latter is said to benefit extensively from experience gained with the design of the 919's motor and power electronics.

Likewise, expertise from these projects is filtering down into the company's road cars, including the all-electric Taycan, which is due next year, and a plug-in hybrid version of the new 911. While these mark the start of Porsche's electric era, the 919 Hybrid – in some respects – marks a turning point. We can only hope there are more great combustion engines to come.

Porsche 919 Hybrid 2017/Porsche 919 Hybrid Evo 2018

Monocoque	Composite material structure consisting of carbon fibre with an aluminium honeycomb core
Combustion engine	2,000 cc 90° V4, turbocharged, 4 valves per cylinder, DOHC, direct injection, fully load-bearing aluminium cylinder crankcase, dry sump lubrication
Connecting rods	Pankl
Maximum engine speed	Approx. 9,000 rpm
Engine management	Bosch MS5
Output	Combustion engine (rear axle) circa 500 bhp and MGU (front axle) over 400 bhp in LMP1 form. Combustion engine (rear axle) 720 bhp and MGU (front axle) 440 bhp in Evo form
Turbo	Garrett DualBoost
Fuel filler	Staubli
Fluid fittings	Sobek Motorsporttechnik
Hybrid system	KERS with a motor generator unit (MGU) mounted on the front axle; ERS for recuperation of energy from exhaust gases. Energy storage in a liquid-cooled lithium-ion battery with cells from A123 Systems
Drive system	Rear-wheel drive, traction control (ASR), temporary all-wheel drive at the front axle via the electric motor when boosted, hydraulically operated sequential 7-speed racing gearbox
Chassis	Independent front and rear wheel suspension, pushrod layout with adjustable dampers and Pitch Link System, actively controlled lockout system
Brake system	Front-rear brake-by-wire system, variable control of torque distribution front to rear, monobloc light alloy brake callipers, ventilated carbon fibre brake discs front and rear, 4-wheel brake-by-wire system, variable control of individual wheel torques to optimise the car balance
Wheels and tyres	Forged magnesium wheel rims from BBS; Michelin Radial tyres, front and rear: 310/710-18 Specially developed Michelin tyres for higher loads on the Evo
Weight	888 kg (including driver ballast), 849 kg in Evo trim
Length	4,650 mm, 5,078 mm
Width	1,900 mm
Height	1,050 mm
Fuel tank capacity	62.3 litres

All photos: Porsche AG

SMASHING FAREWELL

With the Nordschleife lap record shattered and the car's Tribute Tour at an end, **Alan Stoddart** gets the opportunity to bid Porsche's 919 Hybrid Evo goodbye

UNLIKE many successful racing cars, which are sold on to privateers or simply mothballed in a museum, Porsche decided to take a different tack with the three-times Le Mans-winning 919 Hybrid. As previously detailed in the pages of Race Tech, the German marque elected instead to see what its car was capable of when it wasn't hampered by the regulations governing the WEC's top class.

This meant removing the fuel flow limitation from an otherwise unchanged powertrain, which alone was enough to raise the output of the 2.0-litre turbocharged V4 an impressive 220 hp up to 720 hp. This was further aided by the lifting of restrictors governing the amount of energy that could be deployed from the hybrid systems, which increased the e-machine's output by 10 per cent from 400 to 440 hp.

According to Nick Tandy, speaking to Race Tech in between demonstration runs at Brands Hatch, all this extra power results in an experience that is "mega".

Although Porsche's factory driver was completing the runs on demonstration tyres, and being demo runs the team hadn't spent days perfecting the car's set up for the track, Tandy is emphatic about the Evo's performance. "The car, when it is on full power and full boost, is unbelievable actually," he says. "I mean you always get this feeling when you leave the pitlane for the first time, when you have been out of the car for a couple of weeks, and you accelerate out of the pitlane and the hybrid system kicks in you think, 'Wow, this is quick', but with the Evo version it's like driving the car for the first time. It's something special."

DOUBLE DRS

The other biggest differences between the 919 and the Evo were the changes to the aero package, the most notable of course being the addition of the huge rear wing and the implementation of both front and rear drag reduction systems. These, along with the side skirts to improve the level of downforce generated through ground effect,

LEFT The 919 Hybrid Evo demolished the Nürburgring-Nordschleife lap record. Timo Bernhard's 5m19.55s lap beat Stefan Bellof's mark, which had stood for 35 years, by a remarkable 51.58 seconds

contribute to a total increase in downforce of more than 50 percent compared to the competition 919 Hybrid, but still allows the car to reach the scarcely believable 229.5 mph top speed that it hit on its record-breaking Nordschleife run thanks to a 63 percent improvement in aero efficiency.

Getting to this point with the 919 Evo provided a new set of challenges to the Porsche team. Regulation could be ignored but the constraints of time and budget mean that efficiency was not just an aero problem. "Being so restricted in terms of time meant that we couldn't come up with completely crazy concepts, but we were able to select some key areas which we thought would have a big impact on the performance of the car," explains Olivier Champenois, Porsche's test engineer. "We developed the car mainly on computers in CAD and on the simulator, but we got enough as to be happy to bring it to the track for the first time at Spa in April.

> *"We were able to take Eau Rouge and Blanchimont with the DRS open"*

"A big part of the gain in performance was from the moveable aero devices. So we've got an F1-like drag reduction system on the rear wing and aero balance compensation at the front. So although we call it DRS, it actually enables the car to have good balance in the corners at high speed. This was useful at Spa for example, where we were able to take Eau Rouge and Blanchimont with the DRS open, and the car was still OK to drive."

The design process also depended on Porsche's engineers looking at the improvements in a holistic way, because as Champenois highlights, all of the changes have to work together. For example, simply increasing the downforce would not automatically improve lap times because it would just add pressure to the tyres which could dramatically reduce the amount of traction they could offer. It is only by considering the design as a whole that shifts the car into what he calls "a completely different level of performance".

Tandy adds that the drivers were also a key part of the transformation from the LMP1-winning car to the Evo version. While increases in power and grip were obvious things for the engineers to work on, other aspects to do with the manageability of the car came from those who had experienced its traits in the heat of battle first hand.

"I, for example, asked for help from the electrical system to help with the braking," he says. "So effectively having an ABS system without having an ABS system and all the additional weight, and wiring systems that go along with it."

Driver-side additions like this were important to ensure that the pilots could get absolutely everything out of the car during the record attempts, and were a key aspect of upgrades like the brake-by-wire system, which offers dynamic yaw control to improve the Evo's ability to dive for an apex.

"They have tried to make it so the driver is independent from the system," Tandy explains. "So as much as possible you don't actually feel it. The individual braking forces on each wheel are applied automatically so from my point of view it doesn't feel different. It feels like you would expect from this car.

"And that was the idea. It was to give the driver the ability to drive normally, while the systems behind it are working in the background making the car faster, and that's how it feels. You, as a driver, don't notice the different braking forces going into each wheel underneath you or in the pedal, it's all happening in the background."

WINNING FORMULA

Getting the 919 to the stage it is at now has also relied on engineers outside of Porsche itself. This is evidenced by the red stripe that adorns the full length of the 919 Evo, made up of the names of people heavily involved with the car's development. Among these names is that of David Tsurusaki, ExxonMobil's global motorsport technology ▶

ABOVE The red stripe consists of the names of people heavily involved with the 919's development

> *"Very lightweight oils that also have cooling capabilities"*

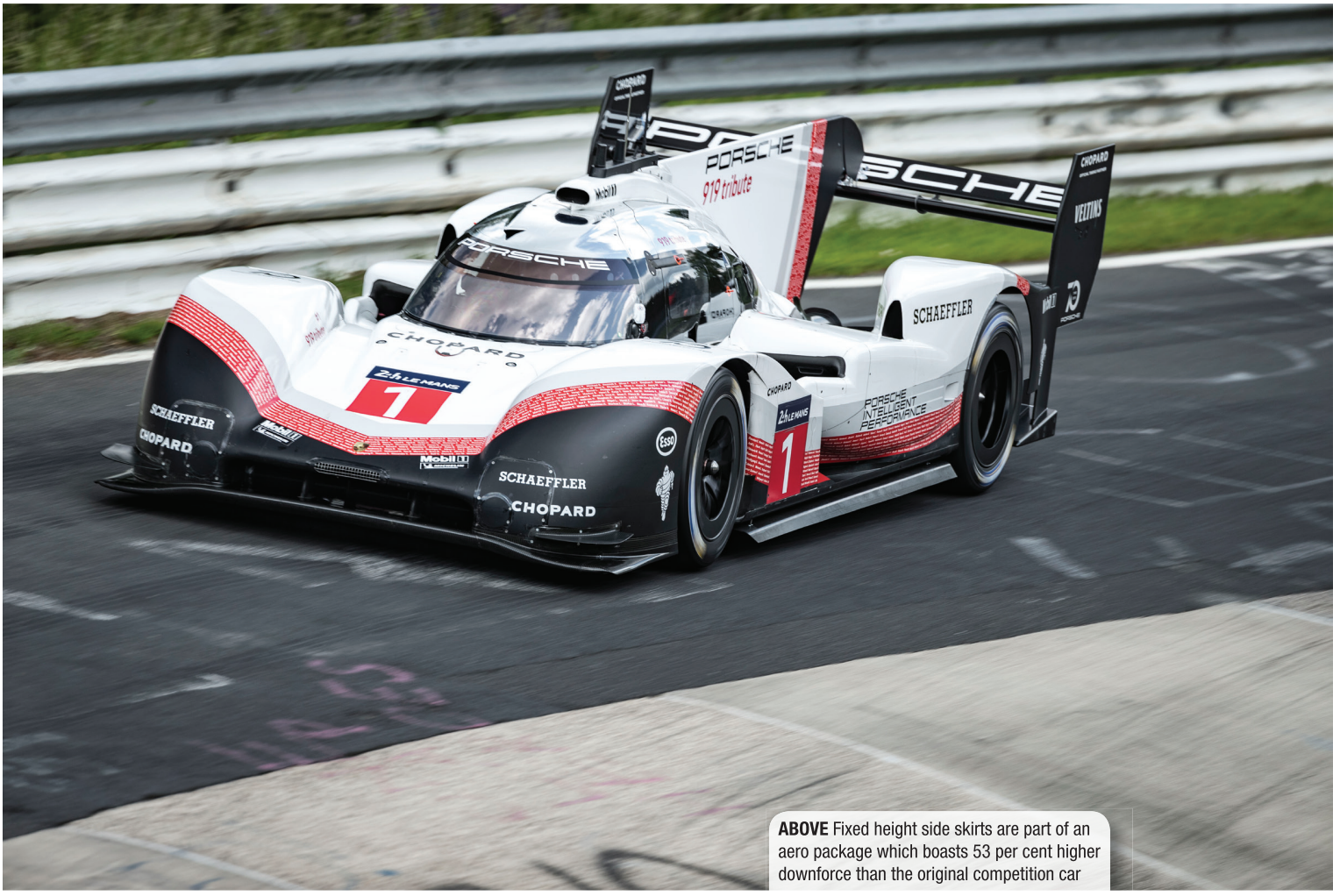
manager, and stands as a testament to the importance of the role Mobil 1 oil played in enabling Porsche to achieve its lofty goals.

Mobil 1 is the factory-fill oil for every Porsche car that has rolled out of its Stuttgart factory in the last 22 years, and surprisingly, the oil that has chalked up three wins at the Le Mans 24 Hours isn't that different to the one you'll find in the Boxster parked on your drive.

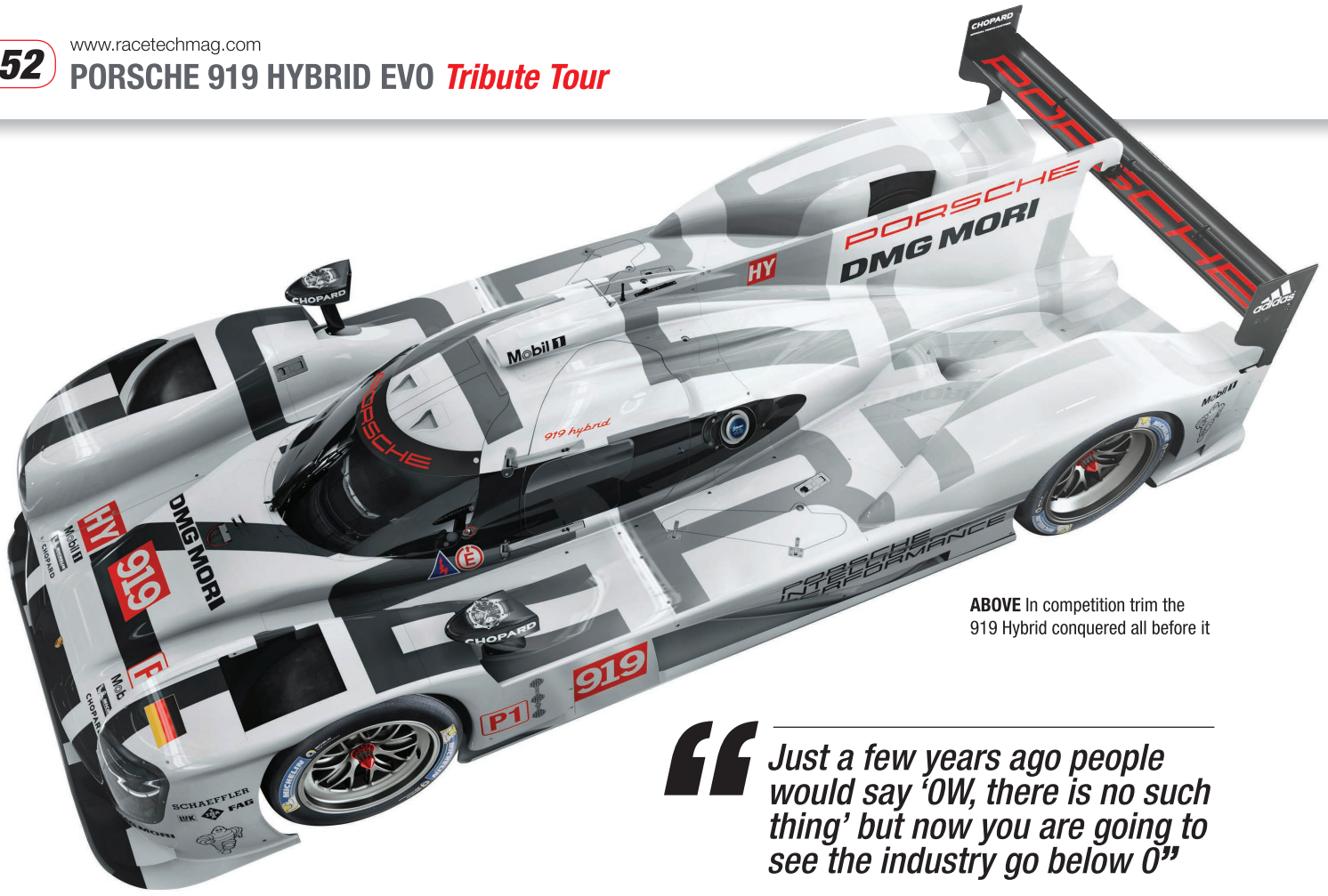
One of the things that makes an oil successful in both a 24-hour endurance race and a lifetime of commuting, touring and weekend racing is the oil's base, says Tsurusaki, which is key to keeping a highly tuned engine running sweetly. "The best way that I've explained the importance of the base to people is that if you think of a lubricant as me laying balls of different sizes on the floor, then if I were to push an object across the floor it'll push the big balls out of the way rather than rolling on them.

"In a lubricant, if you can make the molecules the same size, or in this case, make the balls that I put on the floor exactly the same size, and I push an object across the floor it'll just glide across them. So you get the lubricity by building the molecules in a particular way, and that's what we do in an oil."

While historically, Porsche's teams have simply used off-the-shelf oils, the 919 presented a chance to test out some different ideas based on feedback from the LMP1 team. This offered the team itself immediate benefits, allowing it to tweak the performance of the oil based on the results of its testing, but it also enables ExxonMobil to improve the formulation of its oils for road use in the future. So for example, if there was a bearing wear issue. Even if ▶



ABOVE Fixed height side skirts are part of an aero package which boasts 53 per cent higher downforce than the original competition car



ABOVE In competition trim the 919 Hybrid conquered all before it

> *"Just a few years ago people would say '0W, there is no such thing' but now you are going to see the industry go below 0"*

nothing failed and the engine and its oil was performing well, but Porsche's engineers saw after a 12-hour race the opportunity to improve protection for Le Mans, then ExxonMobil's technical motorsports team is able to alter the characteristics of the oil to deal with specific issues or offer other specific improvements.

In the case of the 919, some of the changes the team has set its sights on have been better wear protection, minimising oxidisation deposits and of course, improving the engine's power output. In all of these cases Mobil 1 has been successful. The gains might not necessarily be huge, but as Tsurusaki points out, "The ways that we can elevate performance by small percentages is the difference between winning and losing sometimes."

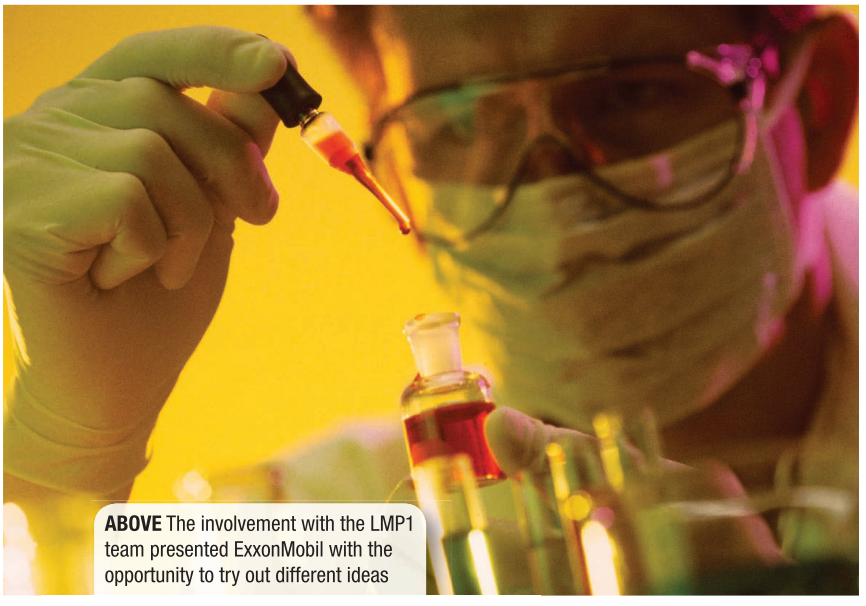
MOLECULAR MAKEUP

Even elevating performance by small percentages isn't an easy task, however. Changes to the base oil technology and additive technology sometimes required ExxonMobil's chemists to build up bespoke molecules with particular properties.

"A chemist can draw the molecular makeup that he needs, and he might say that he needs it to be 99 per cent pure, which would allow it to offer a particular benefit," he says. "Then it would be soluble and work with the other parts of the oil and it would all fit together, but then you realise no-one can make it, so we have to do it ourselves."

Although the 919's life as a cosseted museum piece is approaching, and there will be no further changes to the oil in the multiple title-winning racer, ExxonMobil is still looking to the future and is continuing to develop its range of oils. In the consumer world a lot of this work is around efficiency, which is obviously a huge priority for OEMs given regulation and market demands. This, as Tsurusaki points out, is essentially the same as getting more horsepower from a racing engine. If a car can complete a lap faster than before with a different oil, but with everything else the same, including the amount of fuel used, then that is doing more with less, which is improved efficiency. That is really just the same as a road car returning better fuel economy.

"There is a lot of emphasis on it," he says, "that is why you see 0W-20 oils and 0W-16 oils, while 0W-30s are common oils now. Just a few years ago people would say '0W, there is no such thing' but now you are going to start to see the industry go below 0... they are going to have to



ABOVE The involvement with the LMP1 team presented ExxonMobil with the opportunity to try out different ideas

ABOVE Green Hell: The car averaged 233.8 km/h (145.3 mph) on a circuit revered by race drivers, engineers and enthusiasts alike

recalibrate the ratings system.

"What's more we are already testing that sort of oil in racing, we are testing oils that you can't categorise because a standard API, ACEA scale stops at 0."

EV INNOVATION

Away from the internal combustion side of things, ExxonMobil is, like many motorsport and automotive companies, looking at leveraging its expertise with electric vehicles, particularly as more and more electric series are being announced. Much of the work for these vehicles centres on the electric motors and the gearboxes of these new racers.

"You don't necessarily look at the gearbox the same way as you would in a typical car," notes Tsurusaki, "but it is one of the key areas of the car you can improve efficiency in. It's one of the only things you can look at, and we think we can push the envelope on the efficiency of future gear oils.

"The other thing that I think you are going to see is an evolution combined gearbox and motor cooling as the housing for both becomes one and the same. The potential of this is that the oil will be cooling and lubricating all in one, so you are going to get very, very lightweight oils that also have cooling capabilities, which we think is a valuable future technology.

"So electric and hybrid powertrains are something that we'll still be very much involved with."

The Porsche 919 Evo has now had its last outing, completing some demonstration laps at Laguna Seca's Rennsport Reunion at the end of September; meanwhile the car's extraordinary and headline-grabbing 'faster than F1' Spa lap has already been surpassed in this year's F1 qualifying. Despite this though, the 919 Hybrid and its Evo derivative will loom very large in the memory as an astonishing example of what can be achieved when some of motorsport's finest engineers let their hair down.

And of course, aside from a plaque and a plinth in Porsche's museum, the 919's Tribute Tour seems likely to leave one other yardstick around for some time to come: its absolute obliteration of the Nordschleife lap record, with its time of 5:19.55 already the stuff of motorsport legend. RT

BRINGING DRIFTING TO THE PEOPLE

Dismiss it at your peril, because Drifting captivates young people around the world and its appeal is growing. **Hal Ridge** meets one of its champions

THE constant evolution of technology in chassis dynamics, engine drivability and tyres mean that today it's no longer efficient or cool to be travelling sideways in a competition machine.

Even in off-road disciplines like rallying and rallycross, keeping the car as straight as possible, especially post-apex, is critical. But not in drifting, a sport first established in Japan in the 1970s.

It's not unfair to suggest that many in the motor racing fraternity have historically frowned on a discipline where beating the clock has been largely insignificant and style to impress a panel of judges is key.

Then there's the type of cars that are used. Often they are hugely powerful rear-wheel drive Japanese machines with large exhausts and tyres that shred rubber debris and emit clouds of smoke while the car pendulums its way around a course.

Surely anyone with an ounce of courage can push their right foot to the floor and hold on for grim death while applying opposite lock? But, it really isn't that simple, and since being recognised by the FIA in 2017 with the launch of the inaugural FIA Intercontinental Drifting Cup in the centre of Tokyo, the sport has gained new credence.

On top of which, one of the leading lights of the discipline, New Zealander 'Mad Mike' Whiddett, is championing a move away from results being solely decided by the opinion of judges.

"Drifting is perceived in many countries as still being a boy racer sport. But as the sport grows, with big partners supporting us at events like the Goodwood Festival of Speed, straight away that is giving credibility," he explains. "For me the hardest thing has always been finding the balance between impressing the three judges enough to win, and also impressing the 30,000 people in the grandstand and giving them their 20 bucks' worth.

"What I've come up with is Red Bull Drift Shifters, which uses a fully automated scoring system which calculates all of the same stuff that we're judged on: line, speed and angle. That's calculated by proximity sensors, radar guns with GPS sensors, all in real time. You have a time limit. It's like a giant pinball machine and in real time: as soon as you hit the sensor [that comes complete with sound effects], the score comes up on the screen. For me it's about bringing drifting to the people and making it easier. And if you lose, now you've only got yourself to blame. You missed the sensor or you weren't going fast enough."

SOPHISTICATED CARS

The first event of its kind in the UK was held in Liverpool in August.

Gaining status from the FIA is hugely significant for the discipline, but what are the machines like from a technical perspective? Varied would be a suitable adjective, but so would sophisticated. Several of these efforts have factory backing, including Whiddett's fleet of Mazdas.

Two of his most significant machines are named MADBUL and BADBUL. While many in the drift scene use thundering V6 and V8 engines, what links all of Whiddett's creations ▶

Red Bull

RIGHT F1 star Daniel Ricciardo strapped in to New Zealand drift ace 'Mad Mike' Whiddett's 1,200 bhp Mazda MX-5 to take a drift lap of Albert Park prior to this year's Australian GP

JEP

LEFT Even purists can ignore drifting no longer when it becomes a fixture on the Goodwood Festival of Speed roster

Hal Ridge

ABOVE Where many rivals harness huge V6 or V8 units, Whiddett's creations are notable for the use of rotary engines. This is the turbocharged RX8, affectionately dubbed BADBUL

is the use of rotary engines.

MADBUL is a Mazda RX7 (that is now clad in bodywork from an RX3, instigated for the Goodwood FOS 25-year celebration) and BADBUL is an RX8. "As much as drifting looks like we're trying to be out of control and slide sideways, where you'd think the cars would have as less grip as possible, which is kind of how you start as a driver, as you progress, you want to hit the same corner faster so you need more and more grip and then you need more horsepower. Different configurations will produce more power or torque, or different sounds. For me it's a balance as to whether it's going to be a demonstration car, where it's not about having the fastest car with the most grip, or a competition car," explains Whiddett.

While cars for competition have to be built within the parameters of a substantial rule book, engines are fundamentally free. "Fuel is the only real restriction," he says. "You can run ethanol, or E85; we run race gas with a two-stroke pre-mix [housed in Fuel Safe fuel cells and fed to MoTeC fuel rails by Bosch pumps though Proflow braided hoses and a Turbosmart pressure regulator], but methanol and nitro are the only restrictions. You can do nitrous injection, whatever you need to make as much power as you need," he grins.

> *"A balance between impressing the judges enough to win, and also impressing the 30,000 people in the grandstand"*

With rotary motors not renowned for their reliability, some may consider Whiddett's choice of engine odd. MADBUL runs a 26B naturally aspirated quad-rotor engine while RADBUL is fitted with a turbocharged 20B three-rotor unit.

"When you're young and you don't have a big budget, you try and learn yourself by pulling motors apart. That's what we did anyway and over all these years we've developed it," he says. "The one in MADBUL is five years old now, and we're pretty hard on it."

The New Zealander's engines are built by ▶

Red Bull

ABOVE A lot of technique comes into play when drifting in tandem

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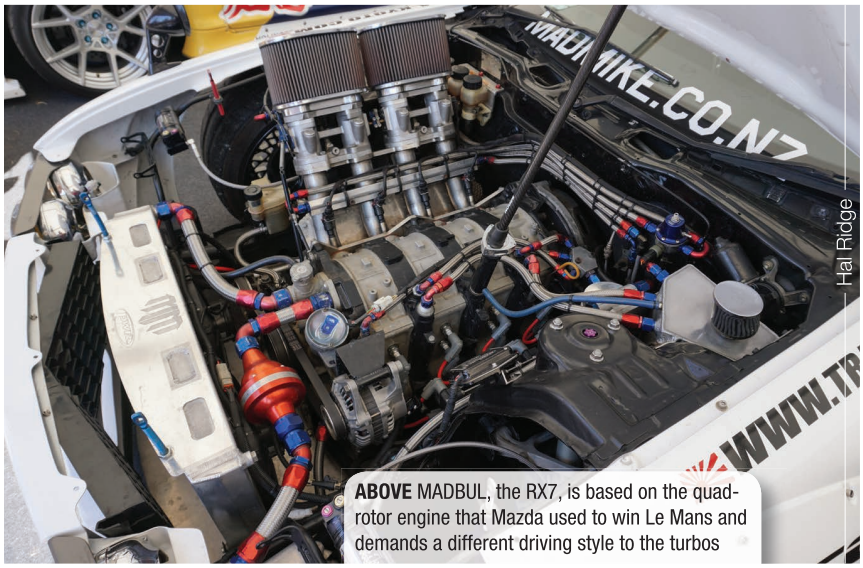
ABOVE Suspension set up, like the steering, is crucial

Pulse Performance Race Engineering, the firm also designing and producing many of the internals, including crankshaft and rotors. BADBUL (the RX8) uses a Garrett GTX-45 turbocharger with a Turbosmart external wastegate, custom made exhaust manifold and Redline Performance intercooler to produce 812 horsepower. Injection Perfection supplies the throttle bodies, while K&N provides the air filters. Oil is cooled by a pair of Setrab coolers, while the water radiator core is provided by PWR. Engine management is courtesy of HalTech, while Whiddett's machines use HalTech and RacePak digital dashes and displays.

Without the benefit of a huge turbo, by comparison MADBUL produces a mere 537 horsepower and is based on the 26B quad-rotor engine that Mazda used in the 787B to win Le Mans in 1991. "Everything's had to be custom-made from the crank to the intake and headers," says Whiddett, before grinning: "We use secondary injectors and they're on such an angle that they don't even touch the manifolds, they just spray straight in. It runs EFI hardware [55 mm], an individual throttle body setup and has no torque compared to the turbo cars but it's got all the RPM, it's just a way different driving style, and my favourite."


Hal Ridge

ABOVE MADBUL, the RX7, is based on the quad-rotor engine that Mazda used to win Le Mans and demands a different driving style to the turbos

NEW ENGINES EVERY ROUND

Whiddett finished third in the World Drifting Championship last year in a Mazda MX5 [RADBUL], fitted with the same 26B quad-rotor engine that is in the BADBUL, but with the addition of a pair of Garrett turbochargers to achieve 1,200 horsepower. "That has proven the reliability," confirms Whiddett. "Some of the US teams we're up against are having brand new motors every round. For me it's also about being different; this is also about the show aspect with the different characters and I feel like my vison of building a car is that I can show my personality just by looking at it. If I was a car, that's what I would look like and sound like."

While engines are fundamentally free, chassis design is more restrictive, with all of the standard pick-up points for subframe, ▶

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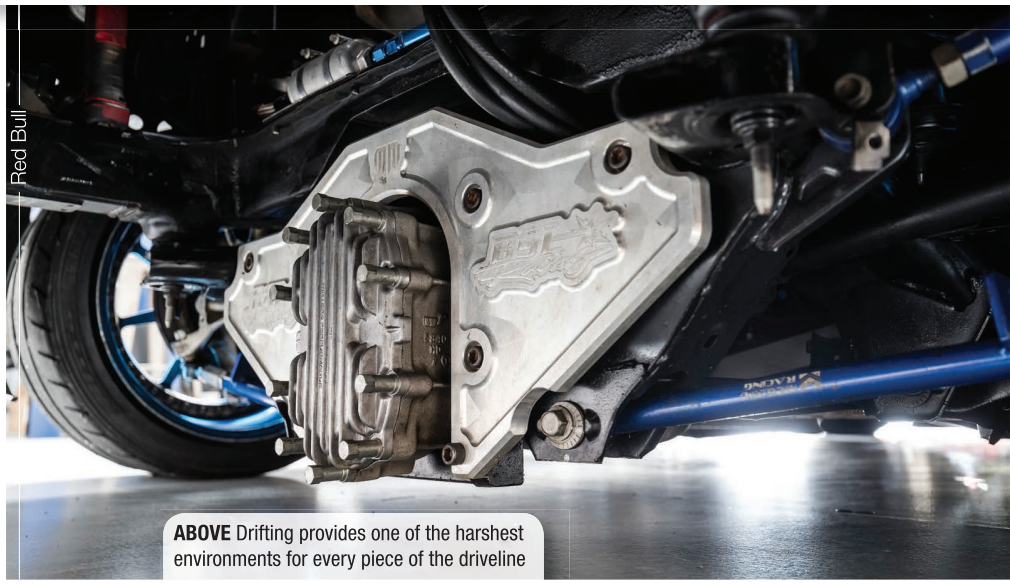
Red Bull

ABOVE Drifting provides one of the harshest environments for every piece of the driveline

steering and suspension needing to be retained. A larger tunnel can be used to house the required transmission. "It means you have to be creative when it comes to all your control arms and all that," says Whiddett.

Drift machines personify the ultimate compromise. Large power is naturally needed to break traction and travel more sideways than forwards, but significant grip is also a requirement to maintain control and forward momentum. Whiddett's cars use KW shock absorbers while Megan Racing provides steering arms capable of achieving somewhat ludicrous steering angles. Almost all the components, from uprights, joints and arms to steering knuckles, are made to spec, to modify the standard kingpin axis and Ackermann angle, and the amount of bump steer and caster angle, among other things. Steering racks are moved close to the centre line of the wheel. The target is to maximise front grip while avoiding binding and over-centring as the wheel turns through far greater angles that would normally be required, in many cases over 70 degrees.

"All the cars are set up different depending on their power, suspension and the tyre compound. We have a lot of adjustability to pretty much be able to get stuck in a puddle," he says, before admitting to slight exaggeration. "We can take grip away or give us more grip than we need. For pro competition, the more grip the better. You can have 1,200 horsepower but if you haven't got the grip you're going to be too slow because you'll get too much wheelspin. It's a balance of getting the drive and the speed and enough power to be able to overcome it. BADBUL is the easiest to drive because of the wheelbase and the way the [turbocharged] power is delivered."

As with any competition car, suspension is adjusted from venue to venue to compensate for grip levels, body roll and how much you want to rely on the sidewall of the tyres for lateral grip. "On a pro car you have a lot more tyre, so you're able to use the edge to bag backwards entries," he says. "At 90 degrees you're getting a lot of side roll compared to a demonstration car. That puts a lot of stress on the transmission."▶

Red Bull

ABOVE 'Mad Mike' Whiddett is a leading figure in the burgeoning drift movement. Crucially, he champions a move away from results being solely decided by the opinion of judges

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ABOVE & INSET Controls need to be well laid out and close to hand

While rallycross is renowned for being one of the hardest disciplines on transmissions as cars transition from one surface to another, over large jumps and kerbs, Whiddett believes drifting is the harshest environment for any part of the drivetrain. His cars run a longitudinally-mounted Hollinger six-speed sequential gearbox, connected to the engine by an HKS clutch and flywheel with carbon fibre driveshafts and propshaft produced by The Driveshaft Shop, the same firm that provides the axles, fitted with Autosport Dynamics Limited Slip Differentials.

CRAZY HEAT CYCLES

"In competition format the whole car goes through such crazy heat cycles because it's cold then you go out for practice and it's on the rev limiter and everything's just maxed out. Then it cools down, then you're back into qualifying. To the best of what we know, we have the strongest stuff on all the cars. Things still break, but it's just a very harsh environment for any piece of the driveline."

The tyres, supplied by Nitto [a brand of Toyo Tires], are used in a wide range of compounds to suit the variety of environments that cars are used in. The rubber tends to be far softer than the general notion of breaking traction to go sideways would suggest, with sidewalls as low as 30 mm.

Those tyres are fitted to wheels made by California firm Rotiform, and have various offsets and appearances, depending on the purpose. Front wheels are 17" x 10", while the rears are 18" x 11.5". As with everything in drifting, styling here plays a critical role alongside functionality. "It's a balance of working out what looks cool and what works. I sketch in pencil, then they put my vision into concept for what tyre we need to run and what size bodykit," Whiddett notes. While the New Zealander runs 'bead looks' on BADBUL, instigated by his 10-year-old son, bead lock rims, which are designed to hold the tyre on the wheel when lateral loads are applied, are banned.

Housed inside the wheels are Wilwood brake callipers and EBC pads with Zinolli bells and large drilled discs to increase rotating mass. On Whiddett's cars, a twin calliper system is used at the rear. With the footbrake bias wound 100% to the front axle, the rear is only braked by the Wilwood vertical hydraulic handbrake, to help drift initiation.

"It's like this because I came from motocross, so I can position the car and manoeuvre it with either the back wheels or the fronts. There's a lot of technique to initiate a drift: it could be a clutch kick or a handbrake or even just to modulate when you're chasing someone in tandem format," he explains. "Instead of being choppy on the throttle and clutch, I can just ride the left foot on the brake to keep the same rolling speed as the car in front, to make sure I'm on his door, but

BELOW The Red Bull Drift Shifters circus brought a selection of the world's top drifters to compete in the shadow of Liverpool's famous Royal Liver building in August
Red Bull

Red Bull

ABOVE Tyre choice is one of the most important factors in drifting

ABOVE The regulatory net has closed recently on extreme aerodynamic devices

give him a bit of room to make his switch. In tandem format it's about getting as close as you can – the crowd love it."

One area where regulations have been tightened in recent years surrounds aerodynamic devices. While there is clearly an element of making the cars look as 'cool' as possible, the wings have purpose too. Endplates are now restricted in size. Prior to the change in ruling, they could reach from the rear wing down to the boot panel.

"Guys were using huge big boards as like an airbrake so when you flick the car in, you can be so much more aggressive and so much faster because it would act as an air brake," he says. "Even if I take one of mine off, the difference is crazy. People talk about drifters not being able to go fast enough to get downforce, but some of the road hill climbs are 242 kph. You need the grip from the aero and I'm telling you it works really, really good!"

The bodywork on his team's Mazdas is designed by Whiddett himself, in collaboration with Rocket Bunny in Japan. Having works support from Mazda means access to CAD (computer-aided design) models of the cars to begin the process and recent inspiration for BADBUL's latest look has been taken from Whiddett's foray into GT3 racing.

For those competing at the highest level in any motorsport, finding gains becomes an ever-increasing challenge. But Whiddett is a man who doesn't sit still, and is always trying to think of ways to improve his steeds.

"Even with suspension or steering, you can always figure out ways to find more steering lock; all of a sudden you find out a different Ackermann works," he says, while noting that despite the level he is at, drifting is one of the easier four-wheel sports to start in as a novice.

"You can have a 100$ Toyota Corolla or Mazda 323 and as long as it's rear-wheel drive, it will drift," he suggests. "It's got to be the most accessible form of four-wheel motorsport."

FIA president Jean Todt acknowledges the discipline's draw. "As we continue to develop motorsport around the world, drifting has a great appeal to young people and has a passionate core following which is only going to get bigger," he says.

Thanks to FIA recognition and people like Whiddett pushing for the discipline to fall more in line with traditional motorsport scoring systems, while still maintaining its wilder side that's so appealing to millennial fans, drifting may not be such a taboo subject for much longer. RT

AVOIDING DEATH BY DATA

How can algorithms designed to predict changes on the stock market possibly help develop a machine conceived to reach 1,000 mph? **Chris Pickering** explains

IF you're reading Race Tech, the chances are that you're already familiar with Bloodhound SSC. After a lengthy gestation period, the mammoth 135,000 bhp Land Speed Record contender is finally poised to begin high-speed runs in the spring of 2019. What you might *not* know, is that there are two of them.

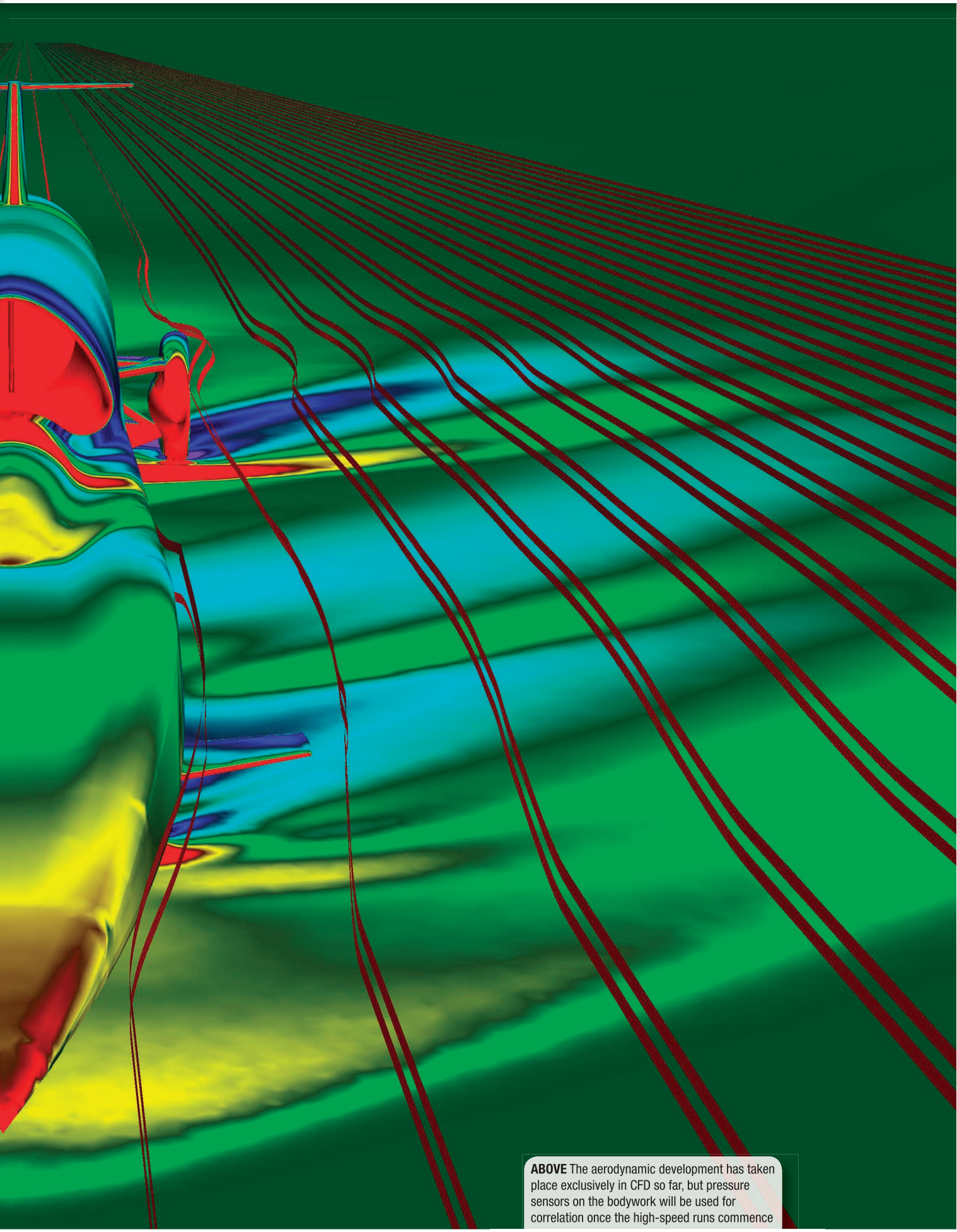
While current Land Speed Record holder Andy Green is at the controls of one Bloodhound on the baked desert surface of the Hakskeen Pan in South Africa, there will be a virtual car replicating the exact same run in cyberspace. The two runs will take place in real-time, with a sophisticated suite of software analysing the results for both the real and virtual cars to flag up any significant disparities between the two. For a project almost entirely based on computer modelling, this correlation will be the key to ensuring that the team's goals are realised safely.

Of course, safe is a relative term when you're strapping yourself into a car with eight times the power of an *entire Formula 1 grid* and aiming to reach 1,000 mph while driving across a desert. Nonetheless, the mind-set of the group is far closer to that found in F1 or aerospace than the hot-rodders of old.

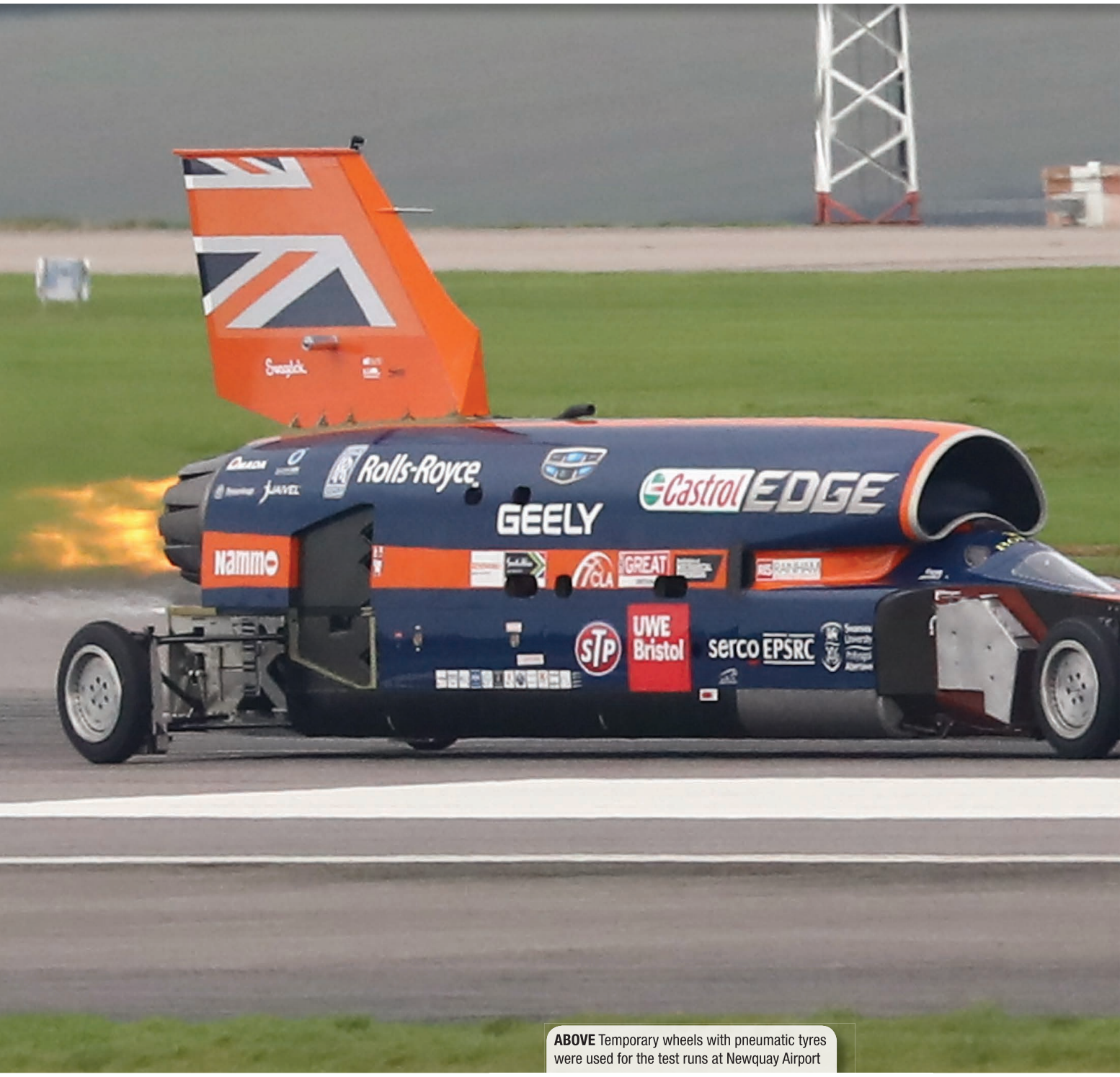
Ron Ayers, chief aerodynamicist for the project, notes with a slight hint of irony that Bloodhound SSC was recently highlighted as 'a perfect example of the way that risks should be taken' by the [UK government] Health and Safety Executive.

Like everyone in the Bloodhound team there's something a little larger than life about Ayers. Born in 1932, he's currently in his 68th year as a professional engineer and he remains the only person in the world to have successfully designed the aerodynamics of a supersonic car.

That vehicle, of course, was Thrust SSC, which set the current Land Speed Record at 763 mph (Mach 1.02) in 1997. It was a ▶



ABOVE The aerodynamic development has taken place exclusively in CFD so far, but pressure sensors on the bodywork will be used for correlation once the high-speed runs commence



ABOVE Temporary wheels with pneumatic tyres were used for the test runs at Newquay Airport

true step into the unknown, with the sound barrier marking not just some arbitrary milestone but a very real shift in the aerodynamics governing the car's stability. A decade and a half earlier the team behind its predecessor, Thrust 2, had discovered that the car peaked at just 7 mph below take-off speed during its own record run.

"The biggest watershed moment with Thrust SSC was undoubtedly the speed of sound," Ayers recalls. "We approached it at Mach 0.01 intervals as we were half expecting the flow to become unstable, causing the car to leap up. This time we're not too worried about the transonic region. That's partly due to the experience we gained in that project, but the biggest change since those days has been the digital aspect. We can now analyse the design at each stage."

STEP BY STEP

When astronaut Neil Armstrong visited the Bloodhound HQ back in 2010 he gave the team one piece of advice: "Data is key to pushing the boundaries – work out what you need and build it in from the start."

To a certain extent, this approach had already been employed on Thrust SSC, but Bloodhound has taken it to a whole new level, not just with the virtual testing, but with nearly 1,000 sensors logging inputs at up to 10 kHz. For comparison, Thrust SSC had around 100 sensors, the fastest of which operated at 80 Hz.

Bloodhound first roared into life last year for a series of shakedown runs at Newquay Airport. Although easy to dismiss as a publicity stunt, the data collected from these runs was vital to correlate the car's standing start performance. In particular,


Tom McCarthy Photography

Stefan Marjoram

BELOW Chief aerodynamicist Ron Ayers says the digital aspect is the biggest change between Bloodhound SSC and its predecessors

> *"A risk of death by data when trying to pinpoint the important factors in a short space of time"*

the team wanted to confirm whether the intake design for the jet engine – optimised for an 800 mph air flow – would still allow it to achieve full power at lower speeds. This is critical, because the limiting factor on the top speed is likely to be the space required to speed up and slow down. Fortunately, it passed with flying colours.

Next spring should see the start of the record runs in South Africa, but don't expect anything to happen overnight. The team plans to work its way up the 1,000 mph barrier over the course of 60 different runs, split into three phases of testing. Initially, the car will only use its EJ200 jet engine (taken from a Eurofighter Typhoon). This produces 20,000 lb of thrust (equivalent to around 54,000 bhp) and should be enough to power the car to over 600 mph on its own.

Hopefully, these subsonic runs should be fairly routine, but they will also cover the first major test of the car's dynamics. Up to around 400 mph, the car will rely on its solid aluminium wheels deflecting the surface of the desert to provide steering. Above that speed they begin to steer the car aerodynamically, acting like aircraft rudders, so this point marks a fundamental shift in the dynamics.

LATERAL STABILITY

"We think we can start off with 100 mph increments up to 500 mph – simply because everyone who has attempted that sort of speed in a car has achieved it safely," comments Ayers. "Up to about 400 mph the main focus will be on the car's dynamics, and in particular, its lateral stability: how sensitive is it to crosswinds? Will it respond immediately to steering inputs or will the wheels slide a bit first? Beyond that, the trim will be changing, so we will need to keep an eye on the results and ensure that the car is behaving as we expect."

One of the challenges facing the team is that the car will require a certain amount of inherent instability. If it's set up to be too stable, the danger is that Green won't be able to correct against any unintended changes of direction, brought about by surface imperfections or crosswinds. To investigate this behaviour, the engineers plan to task Green with a series of lane-change manoeuvres, following a steered course at speeds of 450, 500 and 550 mph. An array of measurement devices will be used to record the vehicle's dynamic behaviour throughout these tests, including 196 external air pressure sensors, multiple GPS receivers and an assortment of accelerometers.

The programme should move into its second phase in the autumn of 2019, when ▶

Satellite data to the rescue

ONE of the greatest challenges facing a supersonic car is simply where to run it. Again, data came to the rescue. Researchers at Swansea University wrote a computer program to scour satellite imagery in search of suitable regions.

This split the surface of the planet into a series of 20 km discs and selected those with an altitude change of less than three metres. It then analysed the colour to determine whether the surface was ocean, desert or tundra. A total of 22 possible locations were flagged up for further analysis, before the team eventually settled on the Hakskeen Pan. RT

Photos: Stefan Marjoram

ABOVE & BELOW One of the crucial findings from the Newquay test was that the jet engine could reach full power from standstill

it will be fitted with a monopropellant rocket. If all goes to plan, this should see the car break the Land Speed Record, with a speed of more than 800 mph, but this will bring a whole new set challenges.

By 600 mph the car will be going transonic, with the air flow around the body reaching supersonic speeds in some regions but remaining subsonic in others. By that point the vast majority of the forces opposing the car will come from the 'base drag' generated by the partial vacuum in its wake. One of the key questions will be whether this correlates with the CFD simulations. Another important indicator will be whether the shockwaves generated by the real car match those in the CFD. The aerodynamics of supersonic land vehicles are now much better understood than they were when Thrust SSC became the first car to break the sound barrier back in 1997 – not least due to the advances in simulation since that time. Nonetheless, it will still represent a major landmark in the project.

After the first supersonic runs the plan is for the team to return to the UK, crunch the numbers and revise the car for the final push, due in 2020 or 2021. Notably, this will see the monopropellant rocket swapped for a hybrid design from Norwegian company Nammo Raufoss, originally developed for satellite launch vehicles. This uses a solid block of synthetic rubber as its fuel source with liquid high test hydrogen peroxide (HTP) as an oxidising agent. One of the advantages of this approach is that it means the rocket can be throttled by adjusting the supply of HTP. Currently a supercharged Jaguar V8 is used to drive the fuel pump, although the team is looking into an electric motor for the record runs: the theory is that a battery electric system would work well for a short, high-energy duty cycle. You might argue this would also make Bloodhound the ▶

ABOVE A mock up of the control system for the EJ200 and the AMAD gearbox which starts the jet and also generates AC and DC current from it

world's fastest hybrid.

As any aerodynamicist will tell you, the power required to overcome a given level of aerodynamic drag goes up with the cube of the speed. That means the hybrid rocket (working in conjunction with the EJ200) will need to deliver almost three times the power of the monopropellant unit to cover the last 200 mph. It also means that the engineers will be looking to redesign the rear end of the bodywork.

"We know we will have to redesign the back end for the larger rocket, but that also gives us the opportunity to look at things like wheel fairings and air intakes," comments Bloodhound SSC's chief engineer Mark Chapman. "We think we can reduce the drag using a base bleed technique to take the high pressure air from the front of the car and use that to fill the vacuum at the back. But does that actually work? Do we want to add more features like that for the 1,000 mph run?"

Parts of this redesign will be underway as the car goes off to South Africa for the first time, but other elements will rely on data collected from the transonic runs. Chapman estimates there will probably be 10 to 12 months' worth of work required before the team can return. That, of course, is subject to the weather window.

BIG DATA

Initially, the team plans to work on a three-day test cycle. The car will complete one run in each direction on the first day (largely so it returns back to camp under its own power) and the engineers will set about analysing the data; day two in the cycle will see the car prepped for the next test; and on the third day the car will go back out to complete another batch of runs.

The data from each run will help the team to decide whether or not it is safe to progress to the next stage, explains Chapman: "We're going to be collecting around a gigabyte of data on each run. ▶

ABOVE Chief engineer Mark Chapman knows data must be analysed quickly in order to prepare the car for its return run

Stefan Marjoram

> *Bloodhound SSC has nearly 1,000 sensors; Thrust SSC had around 100”*

That’s not a vast quantity in outright terms, but it will be spread across 1,000 channels and it will need to be analysed very quickly in order to prepare the car for its return run. Once we’re into the record runs the car will need to make its return run within an hour. There is a risk of death by data when we’re trying to pinpoint the important factors in such a short space of time.”

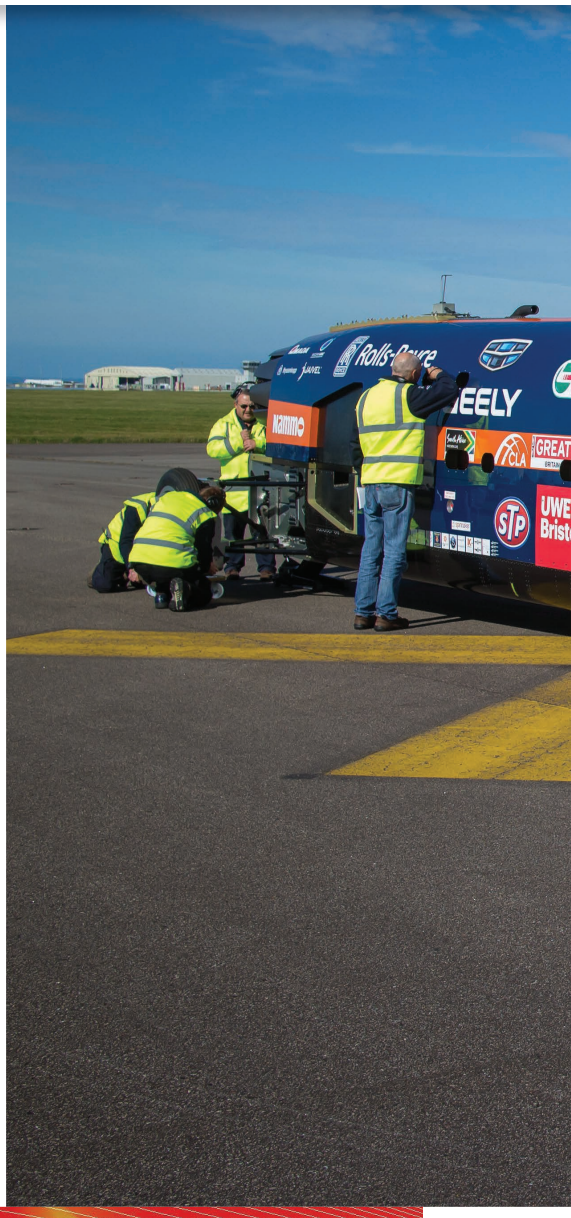
STOCK MARKET INSPIRATION

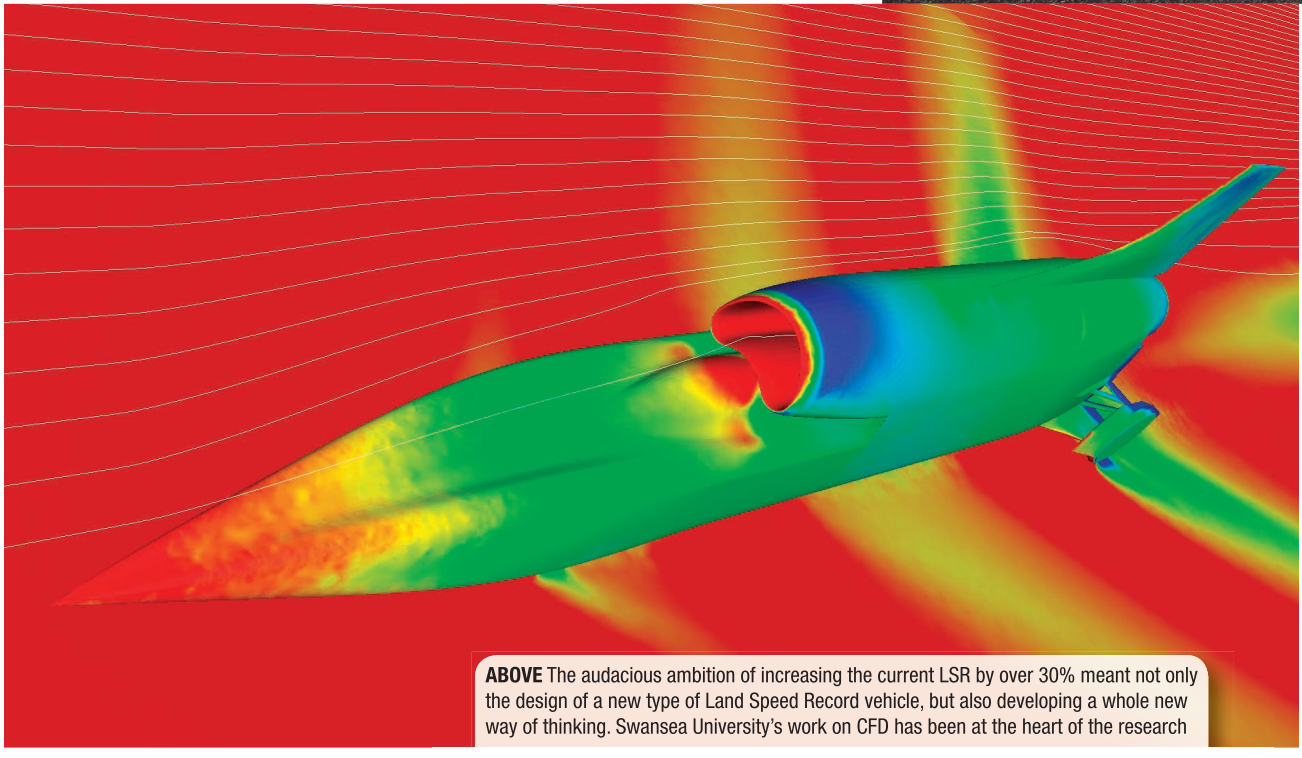
The Bloodhound engineers are working with cloud computing specialist Oracle to overcome this challenge. They have developed a machine-learning system to pick out the beginnings of complex trends. This is based on the algorithms that are used to predict changes on the stock market by identifying small correlations between seemingly unrelated factors.

“This technique is designed to spot relationships between parameters that we would never think to compare. For example, a temperature rise in a bearing that leads to a vibration at the other end of the car or a change in downforce with steering angle. It helps us to spot those trends before it’s too late,” comments Chapman.

The bulk of the data for the engineers will be downloaded at the end of the run, but the plan is to stream some of the channels live over 5G. Preliminary tests have used a set of 4G sims and a router at the base station. Once transmitted to Oracle’s cloud platform there is a service bus that streams the information to a central data store, which means that it will be accessible anywhere in the world, both to the engineers and the fans. The team is also planning to use a series of GPS ‘gates’ along the course to filter different data channels as the run progresses (for instance, switching to different parameters once the braking phase begins).

By intelligently processing these vast quantities of data the Bloodhound engineers hope to gain a better understanding of what is lying in store for the later runs. Part of the feedback, of course, will be subjective, with Green uniquely qualified to take on his role as a supersonic test driver. But fundamentally it is the data coming off the car that will determine whether it is safe to proceed, particularly in the higher speed runs – above 800 mph – where Bloodhound SSC will be truly venturing into the unknown. RT





ABOVE The audacious ambition of increasing the current LSR by over 30% meant not only the design of a new type of Land Speed Record vehicle, but also developing a whole new way of thinking. Swansea University’s work on CFD has been at the heart of the research

Stefan Marjoram

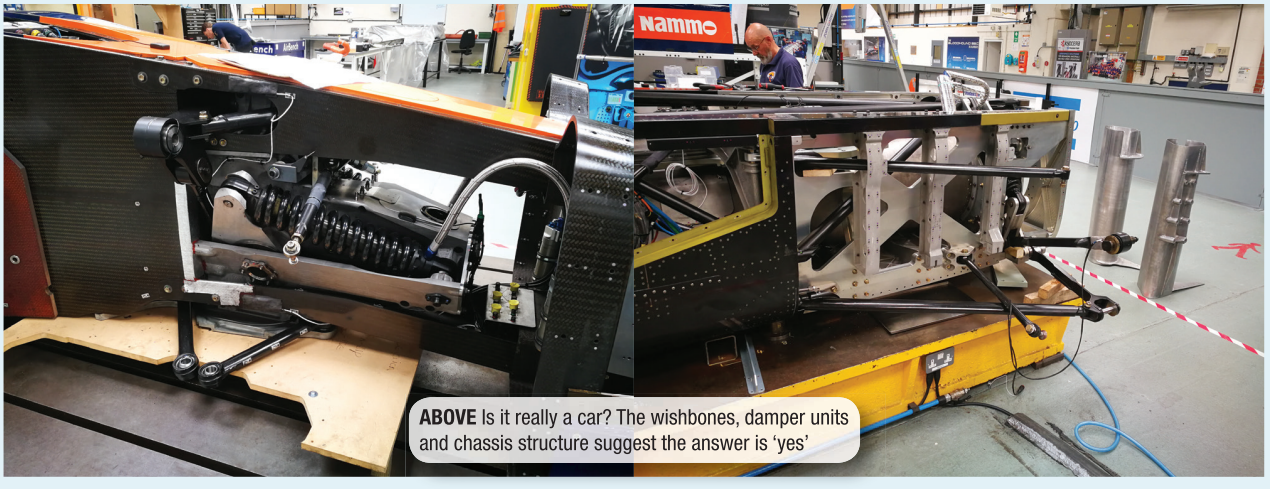
ABOVE Driver Andy Green surveys his machine

The world's fastest *car*?

THE first thing you're struck by when you see Bloodhound SSC in the flesh is its sheer size. At 13.4 metres long and 7,786 kg it has the sort of presence that no conventional car can match. In fact, you might start to question whether something propelled by a rocket engine and steered by a set of rudders (albeit doubling as wheels) really counts as a car at all.

But if the bodywork happens to be off, the next thing that strikes you is just how familiar some of the engineering looks. Granted, they're on a different scale, but the wishbones, the pullrod-operated coil-over damper units and machined aluminium uprights bear a startling resemblance to those of a high end circuit racer. Even the chassis structure, with its carbon fibre safety cell and the steel-skinned aluminium frame behind, looks like an elongated racing car.

Bloodhound's performance will be dominated by its aerodynamics, but the same goes for just about any car designed to reach well into three-figure speeds. The difference, of course, is that the speedometer here reads in four figures. RT



ABOVE Is it really a car? The wishbones, damper units and chassis structure suggest the answer is 'yes'

THE HOLE TRUTH!

Alan Stoddart discovers that when it comes to motorsport, the additive manufacturing journey is just beginning

"A hole is just nothing with something around it," points out Alexander Champion, 3T RPD's automotive account manager. "So, when making a component such as a hydraulic manifold, why would you start with a large block of metal and then spend hours drilling holes in it? You could simply build metal up around the holes instead."

This question is indicative of the way in which additive manufacturing (AM) opens a huge range of possibilities, allowing complex components with unique properties to be manufactured efficiently and repeatably. However, for engineers to maximise their gains from additive manufacturing they must reconsider their designs to play to the technology's strengths. This is such a crucial part of the process that 3T RPD, which specialises in productionising and producing end-use manufactured parts in both plastics and metals, even offers training sessions to engineers from all different disciplines, including those involved in motorsport.

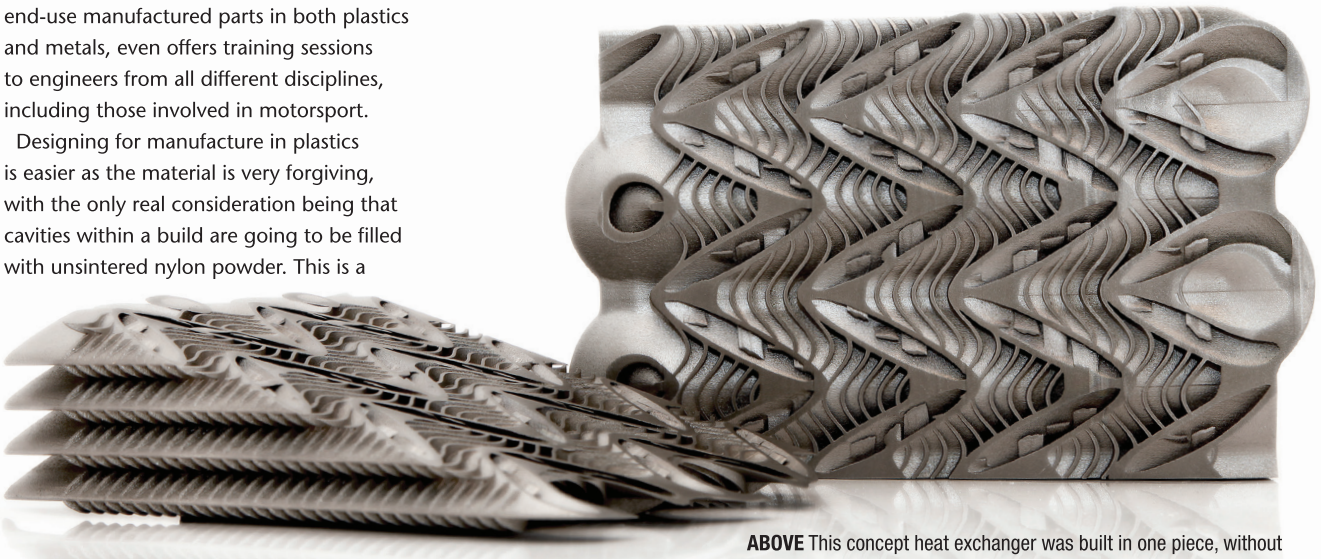
Designing for manufacture in plastics is easier as the material is very forgiving, with the only real consideration being that cavities within a build are going to be filled with unsintered nylon powder. This is a result of the laser sintering process, which sees a layer of powdered nylon spread across the bed of the EOS machines that 3T uses. This layer, which is only some 130 microns thick, is then exposed to a laser which very precisely traces the design into the powder, melting together the particles of nylon which fall under the beam. This effectively creates a very fine horizontal slice of the finished component. The bed of the machine is then lowered by the thickness of one of these slices, so a new layer of nylon can be spread on top.

The sintering process is repeated, with the laser not only fusing together nylon particles on the same level, but also fusing them with lower levels so as to give the finished part strength along its vertical axis. As the process continues, thousands of horizontal layers are built up, one atop another, until the finished part has reached its final height, with the additional powder around the part acting as a support during the manufacturing process.

This powder-based procedure means that the part must be designed with the expectation that excess powder will need to be extricated through a small drill hole or that a small pocket of powder is acceptable in the finished piece. This also means that channels and ducts need to be designed with as wide, flowing radii as possible, rather than sharp angles that would prevent the powder being removed. Other than that though, "if it will fit in the machine, we can pretty much build it," says Champion.

Designing for additive manufacturing in metal however presents another problem: supporting the structure as it is being built up. Unlike with plastic, when dealing with aspects of a design such as overhangs and larger holes, the weight of the material means they cannot support themselves when the material is in a softer state during fusing. One way of tackling this is designing in supports in addition to the component. These are usually of a lower density, so are effectively hollow and can be easily removed after manufacture. This is less than ideal, however, as it means that additional material is being used in the build, the parts require more time to be manufactured, and removing the supports and tidying up where they were means that there are extra processes, all of which adds to the cost and reduces the efficiency of production.

The better solution, explains Champion, is starting a design with the requirements of AM in mind and designing a component to be self-supporting. This is where 3T's



ABOVE This concept heat exchanger was built in one piece, without any support structures, in around a week – a fraction of the time normally expected to produce such a complex part

ABOVE & BELOW Even safety-critical, structurally demanding components like this titanium alloy roll hoop can now be 3D printed

advice and counsel can be very valuable. "Designing parts to have no support structure is where we want to be," he says. "There are ways of making parts that don't need a support structure, which saves a huge amount of machining time. It might add a tiny bit of weight, but it will significantly reduce the cost and make the parts much quicker and easier to build."

In practice, this means that instead of having external supports, things like buttresses and scaffolding structures are designed in so as to support parts of a component that strike away from its main form such as flanges and bosses. Instead of large round openings, which have a tendency to sag at the top, self-supporting structures such as pointed arches and diamonds are used. Similarly in interior channels and ducts, such as in oil galleries, instead of round channels, teardrop shapes, which don't need any extra support, can be used. These amendments often result in designs that look different to components which are manufactured in more traditional ways.

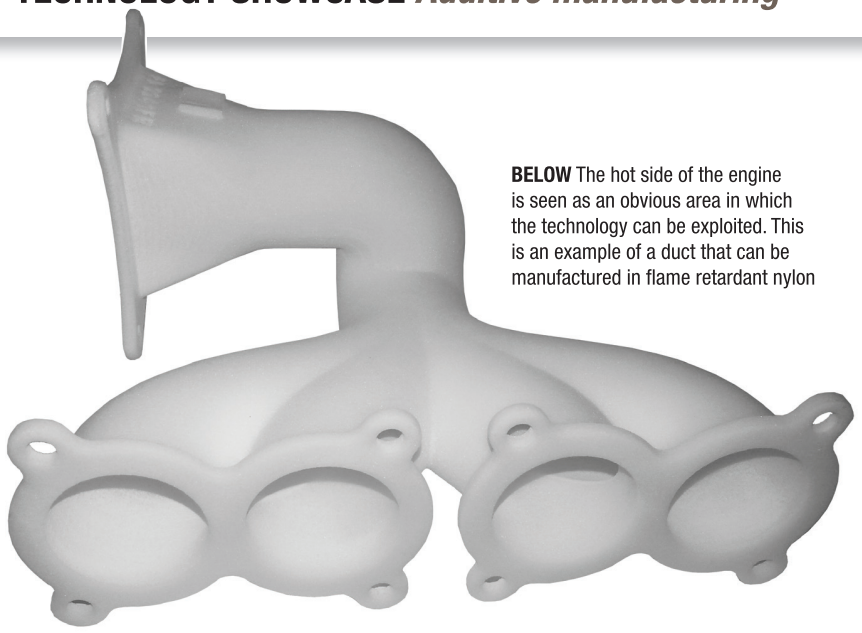
Ian Halliday, 3T RPD's chief executive, suggests that getting into this mindset of designing for additive manufacturing can not only improve the efficiency and cost of producing parts, it also has the potential to bring about performance gains by allowing parts to be made in ways that would otherwise be impossible. "AM offers design opportunities and material opportunities, and those translate into the benefits you are actually after which would be durability, lower mass and higher performance forms," he notes.

A DIFFERENT WAY OF THINKING

"So, you might be able to – to use as an example something that isn't yet done – easily build a structure within an F1 engine's exhaust system to guide the gasses, which could either increase turbulence, or make a smoother flow, depending on what you wanted. So going around a bend, you might even split the curve in such a way as you've got two semi-circular shapes, which guide a central tongue, that guides the gas around the corner."

In order to maximise the benefits its clients get from the technology given the requirements of AM, 3T can get involved early on in the design process, although Halliday acknowledges that its efforts to improve its customers' knowledge means that for some parts this is now less important than it used to be. Still, he reckons, it would be better for many teams and their suppliers to get 3T involved earlier to help them get the most out of 3T's impressive technology because "the fabrication mindset is still dominant". This means that the company has to take on a very consultative role, advising motorsport teams of where improvements can be made and minimising any compromises when the team decides upon the final CAD.

If teams did get 3T involved earlier, Halliday says that lots of improvements could be made. "There is still a long way to go with any of the exhaust side componentry, ▶



BELOW The hot side of the engine is seen as an obvious area in which the technology can be exploited. This is an example of a duct that can be manufactured in flame retardant nylon

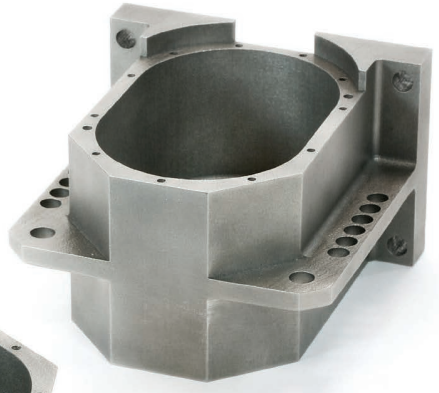
for example, because there are still quite substantial benefits in terms of mass saving and durability to be gained by much more extensively using AM.

"Anything to do with the hot side of the output of the engines, including turbo structures and so on, could all benefit from the mass and lead time savings we could offer. There might even be cost savings through improved durability... we still make parts that look a lot like fabricated exhaust parts. Surely there must be another way of doing it."

There are many other components that could benefit from being produced at 3T, adds Halliday. He sees big gains to be had in some of the reciprocating internals such as valves, pistons and even cylinder heads and crankshafts, something Halliday says has already been talked about with its customer teams. Away from the engine, suspension parts are a possibility, as is "anything to do with hydraulics" because you can make "anything to do with hydraulics more compact than you can by any other method," and "anything that spins" such as pump parts and potentially even gearbox components.

One of the things that enables all this is the materials expertise that 3T has built up through its dedication to research and innovation. This enables the company to offer components that not only match the attributes of fabricated parts, but exceed them. One material that is frequently used for F1 exhaust collectors for example, is Inconel 718, rather than the Inconel 625 that is commonly used for fabricated collectors. As well as offering improved lead times, more design flexibility and better durability, using additive manufacturing means that 3T is able to use a higher performance alloy which is less ductile, has higher tensile properties and offers a performance gain in terms of tensile strength of around 50 MPa at 800 degrees Centigrade.

This process of metallurgic improvement is ongoing, which opens up more possibilities in future. "So if you take what we offer with Inconel 718 over Inconel 625, and if you take that further, there are alloys being developed which would give you another 50 MPa at ▶



ABOVE & LEFT A metal AM gearbox housing optimised for stress and low mass

BELOW 3T RPD's Plastic AM facility

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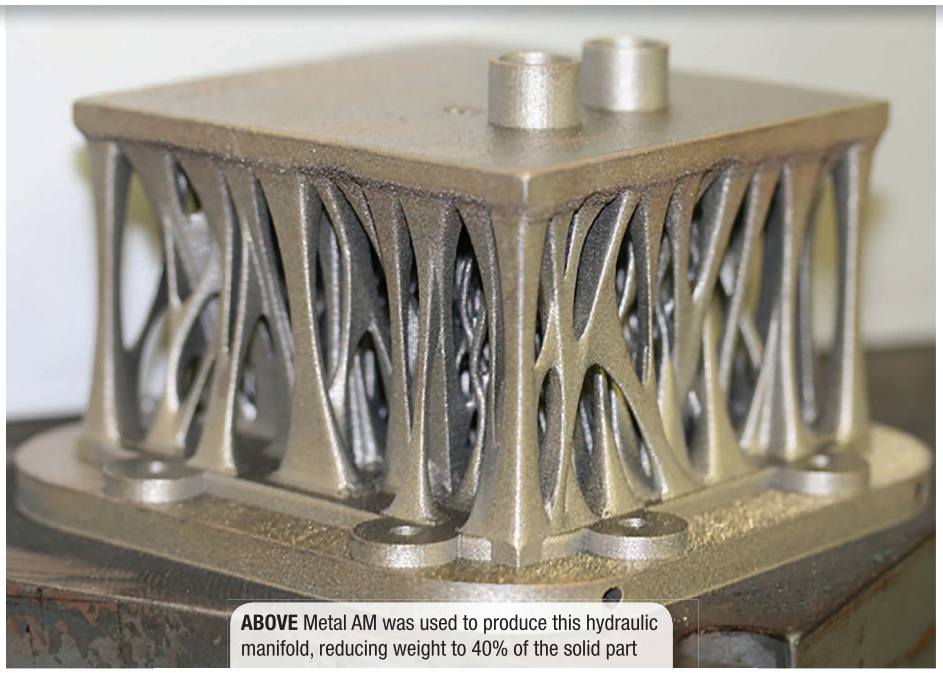

ABOVE Metal AM was used to produce this hydraulic manifold, reducing weight to 40% of the solid part

800 degrees Centigrade," says Halliday.

"What would another 50 MPa give you? I don't know but I'm guessing it's not going to be bad. It may be that you can make parts 0.1 mm thinner, or it might be that you can create structures that would otherwise be unmanageable from a strength point of view."

3T is also working on developing a range of aluminiums it can offer its clients. One of the avenues of development centres around metal matrix composite aluminium alloys, which are high performance aerospace alloys that have a small percentage of ceramic material in them. Currently this ceramic takes the form of titanium diboride. This ceramic material disperses itself throughout the structure and pins down the grain boundaries, which results in a much higher performance material. As long as the level of titanium diboride in the aluminium is less than two percent, regulations allow this material to be used in F1 engines, meaning it has immediate potential. The company therefore expects F1 teams to take up this material fairly quickly thanks to its exceptional performance at high temperatures, and the 50 percent improvement, in terms of mechanical properties, compared to the material currently in use.

Halliday emphasises that this approach is one of the things that sets 3T apart: "The fact we've got comprehensive quality systems right the way through the process trains. That's a big deal, the R&D team, new product introductions, so that kind of rigour of process and that kind of ability to effectively add the science into it all is one of our strengths."

It is also an important approach for engineers to bear in mind when looking to reap the benefits of additive manufacturing, Halliday adds. "Anyone embarking on their journey of learning about and implementing additive manufacturing for their designs should take it one step at a time and choose the components that they will use additive manufacturing for carefully.

"If you can't get the benefits from AM from a particular design, either change the design or you've chosen the wrong part. There are so many parts, particularly in accelerating objects like vehicles that can benefit from AM in terms of performance improvement, complex structures, holes and channels, lightweight structures, whatever they might be that you don't need to try and force it. If you feel like you are forcing the process, you're choosing the wrong part.

"But get advice," Halliday continues. "Learn about the design and be prepared to find a supplier who is prepared to work with you in more of a partnership, and that is one of the many things 3T has to offer.

"We want our customers to succeed and we want them to keep coming back. That is the whole point of becoming the first-choice production supplier of AM components."

BELOW A build platform of titanium swirlers using metal Additive Manufacturing

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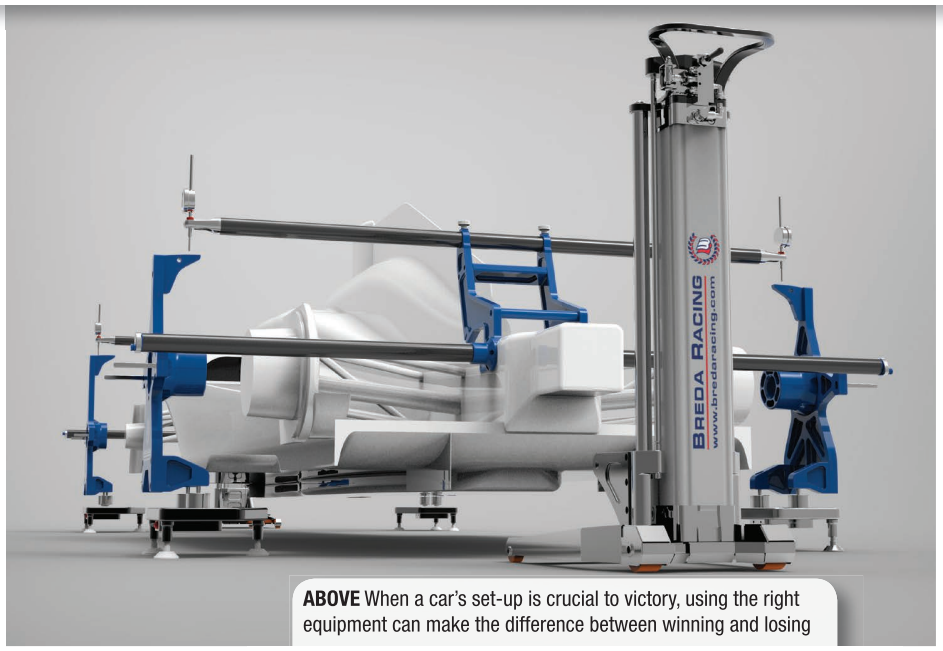

ABOVE When a car's set-up is crucial to victory, using the right equipment can make the difference between winning and losing

WINNING FROM THE PITS

It's not always on-board technology that wins races, says **Alan Stoddart**, sometimes teams are able to gain an edge from the pits

MOTORSPORT fans are keen to revel in the technical one-upmanship a car or team can wield over its rivals. From Brawn F1's double diffuser, to Audi's choice to run diesel for its 2005 R10 TDI, teams are quick to use a particular innovation to gain an edge over other teams. These technical advantages don't necessarily have to be on the cars themselves, however, as the closeness and competitiveness of races often means that everything peripheral to the car often takes on heightened importance, with good pit equipment one of the things that can set a team a part.

This is one of the things that Italian firm Breda Racing specialises in. The company offers a range of high-quality equipment used throughout the very top tiers of motorsport, including set-up wheels and bars with accessories that are tailored specifically for individual cars, and load-cell equipped set-up pads that utilise proprietary software alongside a colour touch screen to check and adjust set-up as necessary.

ABOVE Breda Racing helps teams get the most out of their cars, no matter what the series

In addition to the high accuracy set-up equipment, teams can also opt to use Breda's Ride Height, Toe and Camber Alignment System, which, like most of the company's range can be customised to meet a particular team's requirements.

This is a key part of the design process for Breda. "All our equipment is conceived with this same customisable approach," explains Breda's general manager and R&D leader Giorgio Breda. "Even in championships which feature several teams running the same type of car, we design the product to have a standardised base, but one that allows great amounts of personalisation within it.

"This level of customisation only increases the higher up the series is, and in top tier championships such as F1, for example, it is total."

This focus isn't at the expense of other qualities, however, with Breda Racing ensuring that their pit equipment is both easy to use and made as lightly as possible, in materials such as carbon fibre, aluminium alloy 7075 or other highly specialised materials – an important touch given the transport bills globetrotting teams in top-flight series face.

Important attributes like this derive from the knowledge possessed by Breda Racing. Giorgio Breda highlights that most of the company's technical staff have a background working in teams utilising the equipment's design details and taking advantage of its features, which means they have had to face similar situations to those that will be faced by their clients. This means that Breda Racing can take on a consultative role, listening to their customers' needs and ideas and then developing and modifying the equipment to meet very particular requests and address specific problems the team is having. This approach also informs the design of the company's other products, such as its refuelling systems, which are in use across a huge range of series, including F1, WEC, IMSA, and WTCC among many others.

Fans may get to see only some of Breda's equipment, perhaps only the pit gantries or pit stop equipment in some of the most crucial moments of a race. Similarly, many of its products can only be found inside of garages and seen only during the preparative days before the race, not adorning the cars screaming down straights on race day, but, like that of the race teams which it supplies, Breda's focus on research, quality materials and custom solutions can help to give competitors a different kind of edge.

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BELOW The Iceman's return to Sauber, with Leclerc going in the opposite direction, sees the wheel turn full circle. It was the Hinwil outfit that gave the Finn his F1 break

Tee/LAT

Kimi Räikkönen re-signing for Sauber was a shock, but not for the man who designed the Finn's very first Formula 1 mount

THE ICEMAN COMETH: THE SEQUEL!

THE summer ended with some interesting news.

I have admired Kimi Räikkönen from the moment I first saw him driving the Sauber C20 I designed, at Fiorano in 2001. He was mighty impressive and natural, even driving with a tinted visor on a darkening winter afternoon!

He is not only a very experienced driver today who keeps all his skills intact, but his no-nonsense personality and demeanour is a breath of fresh air in the current days of clinically clean Formula 1.

When I heard the news that he was leaving Ferrari and rejoining Sauber it did not surprise me – he is that kind of guy: he has won a championship and many races and poles but they have never gone to his head. He reminds me of Ronnie Peterson but with more testing and development capabilities. Like Ronnie, Kimi doesn't talk much. When he does, he is direct. He loves driving more than anything else, to the point that he accepts being number two to Vettel as Ronnie did with Mario [Andretti], but he makes a contribution whenever he drives. He too hates understeer (like the highly skilled driver he is) and can drive anything fast, from F1 to Motocross.

It does not surprise me either that Ferrari finally dropped him. In view of the championship they are losing this season, they need to build on a young driver who can win in the near future. Vettel is showing he is no match for Hamilton this year, despite being a four-time World Champion, and Ferrari is not known for being a patient team: remember how they hired Reutemann the day after Nikki Lauda's accident! Kimi is 39 years old and the situation is tricky with Vettel's number one status, so the change makes sense. Sergio Marchionne recognised this earlier in the year and the team has decided to follow on with this legacy.

Signing for Sauber, the team where Kimi started out all those years ago, is typical of the man: enthusiastic, passionate about driving Formula 1 cars and, ultimately, loyal to the operation that gave him the chance when he was just a kid coming from Formula Renault with infinitesimal experience. It is a fitting bow to his brilliant career to help the team go that extra mile, in both the technical and marketing side. Having a World Champion as a number one driver and an Alfa Romeo brand (albeit with Ferrari engines) will allow Sauber to get closer to the top teams, as they did with Kimi himself in 2001.

The first time Kimi drove an F1 car, the Sauber C19 at Mugello, one of the regular drivers went out first to set the car up and establish a reference time. Then Kimi jumps in, does a few laps and comes in (without being called!) to request that the race engineer, Jacky Eeckelaert, give him "two more holes of front wing", as if he was still driving a Formula Renault! Jacky, with his natural calm, tells Kimi that he needs to explain what is wrong with the car for him to decide what to change.

Nevertheless, he puts more wing on after Kimi saying that the car is understeering too much for him. Kimi goes out again and, to the surprise and amusement of the whole team, after a handful of laps he is 20 km/h faster at the apex of Arrabbiata 1 than any of the regular drivers have ever been. The following week he was signed for 2001.

NEW BREED

Kimi has a two-year contract. He will be 41 when that expires in 2020, so it is very unlikely he will drive the new Formula 1 cars announced by Ross Brawn before the Singapore race.

The designs shown look very much like a styling exercise, but say nothing about the performance targets and attributes such a car should have. Last month we spoke about what we would like to see in F1 come 2021 and no doubt Ross wants to see the same, but how to achieve it will take more than the drawings show. We cannot comment on the technical characteristics, which still have front and rear wings and a multitude of winglets. I think that to achieve the targets we spoke about it will take more than that.

It would be interesting to have some figures regarding the level of sensitivity, downforce and power Pat Symonds' team are identifying to achieve the Formula 1 we all want to see. Ross Brawn did not rule out the continuity of a DRS device. If it is used to achieve higher performance and efficiency, it is welcome. If it is used to allow the kind of overtaking we have now, no thank you.

I am sure they will get there eventually but unfortunately Kimi may have retired by then, which is a pity. If there is a driver today in Formula 1 who can handle the kind of cars we need to see, over-powered and under-downforced, it is Kimi Räikkönen. RT

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