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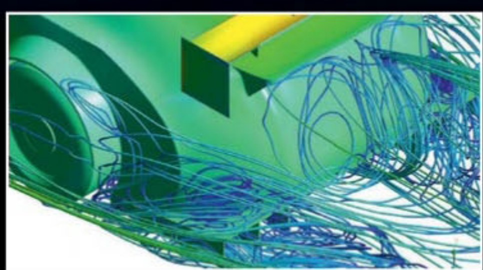

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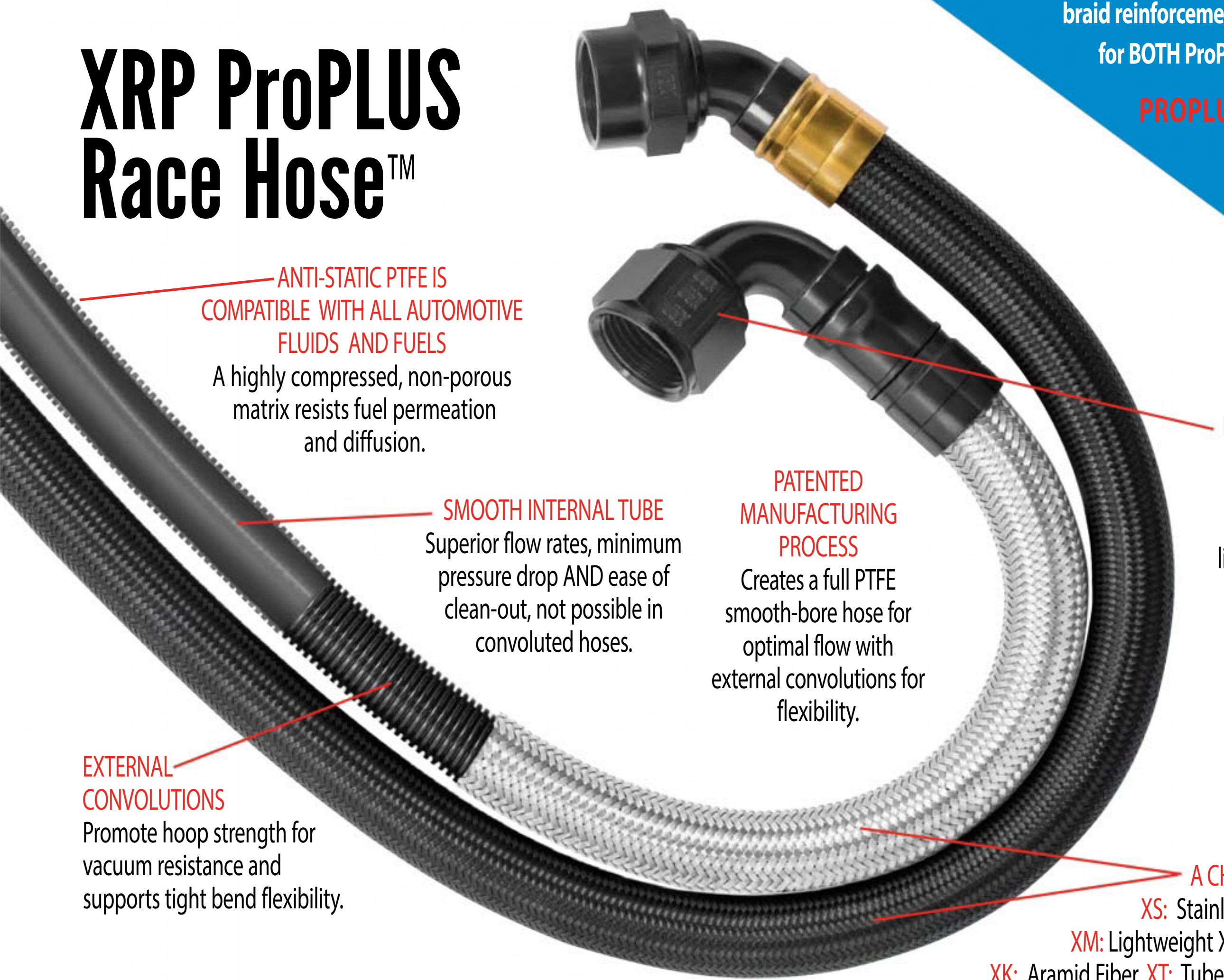

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Joest Racing returns with its Mazda RT24-P DPi at the Daytona 24 hours at the end of January. Can the legendary team do for Mazda what it did for Porsche and Audi?

The fast and the curious

Our columnist recalls the racing legends he's known during 60 years in the sport

With the racing season now at an end, all the championships decided, we are in to the build and testing seasons for 2018. But it's also a time to look back. Because, for me, the end of the 2017 season marked a fairly major milestone in my life, as my first race was the Sao Paulo Grand Prix, on 7 December 1957.

Sixty years in racing has brought a huge cast of characters into my life, of the sort one does not usually meet in a conventional existence, racing being a high risk, high intensity sport, and like a circus – after which it is named – also highly mobile.

Racing does give us larger than life people, then. Here I shall speak about those drivers who have gone. Sadly, there are too many in this list, as the '60s, '70s and '80s were dangerous years (speaking about the years I was present, here).

The maestro

My list starts with Juan Manuel Fangio, nicknamed El Chueco (the bowlegged one), and my first race. He won, and we would meet several times afterwards when he came to Brazil in the late '60s, doing some laps with a two-stroke, front-wheel-drive DKW saloon racer, decently fast and showing his versatility right up to a last meeting at Vallelunga during an F2 race. We would dine at the local trattoria in the evening. Fangio was a gentle, racing-passionate person, with a squeaky voice and the mild demeanour of someone who did not have to prove anything – five world championships with four different manufacturers did all the talking for him.

Then there was Ronnie Peterson; a lovely man, enormously talented with magical car control. We did Formula 2 and Formula 1 together. His main defect was not being a very good test driver, as his natural talent just erased any twitchy handling. The only way to see if a car had improved was taking a note that it was less tail-out than on the previous run. You could spend all day changing things at the track and not find much out as he did the same lap-times. Eventually we settled on a working procedure where his team mate, Emerson Fittipaldi, would set up the car – and then get a bit miffed as Ronnie went a couple of tenths faster.

Graham Hill had already collected several records by the time I met him, but one which is not generally known was his ability to swallow a triple-decker creme caramel in one go, as I once witnessed at a winter test at Paul Ricard, when we were fooling around at the cafeteria as the track was too icy to run the cars. The 'Hill Challenge', as it was known, consisted in piling up three creme caramels on top of each other and proceeding to swallow it in one go, without using hands. The added challenge was that once you had managed the 'double caramel' it was odds on that as you leant to ingest the triple, someone would then mash your face in the plate.

The joker

Several drivers came close to this culinary Holy Grail, but the rules maintained that you had to swallow all of it, just aspirating them and then spraying the spectators while laughing did not count.

XPB

Our man Divila says fellow Brazilian Ayrton Senna (pictured at Monaco in 1987) was the most committed driver, in every sense, he has known

An enormously witty man with a lovely sense of humour, Hill provided one of the high-points in the South American Formula 2 Temporada series at Cordoba by grabbing a microphone and then doing the commentary on a porn film that was being projected on the back of the grandstand by some bored members of one of the teams as we were waiting for the racecars to arrive.

I, and probably most of the racers present, do not remember much of the film or the voice-over as we were rolling on the ground with tears of laughter in our eyes. It must have been awesome, especially delivered in his dry, droll way.

And then there was Ayrton Senna. He was already known by the Brazilian contingent in Europe, as we had heard about his karting prowess from friends back in Brazil, so when he turned up in Europe he was a fixture at the Formula 1 shop, also sharing our pits when doing the Formula Ford 2000 European Championship, an F1 preliminary.

I did not have any racing driver as a hero, but I respected them for their work. Ayrton was really an exception, though. I saw some amazing performances in Formula 1, but the signs were there from the very start. At Hockenheim in FF2000 he set pole in the wet, by eight seconds! That's right, *eight* seconds …Then he stood by the pit wall as the others thrashed around. When they came to within two seconds of his time, he shrugged, got back in the car and opened the gap to three seconds. At Zeltweg, on the old layout, after starting from pole, when he came along alone on to the pit straight we all thought there was a massive pile-up somewhere, only to see the rest come buzzing by when he had disappeared over the brow of the hill. An awesome driver, 110 per cent committed in all senses, and I have worked with some extraordinary drivers, so I know this judgement is correct.

The parrot

James Hunt was a very big personality. During testing at Interlagos before the Formula 1 race one year we ended up doing the Monty Python parrot sketch over the PA, as it was one of our staples, together with the genial scribe Alan Henry, and then egged on by him I ended up training the ice cream sellers at the track to go around the pits, crying 'albatross'. But sadly we never did manage to get them to say 'stormy petrel on a stick'.

Clay Regazzoni had a good run in F1, and after the Longbeach crash that left him paraplegic he still participated in the Paris-Dakar with a specially adapted car. Despite the fatigue he suffered, the suppers at bivouacs gossiping about our mutual friends in Formula 1 were always entertaining.

There were so many others, too, such as Piero Taruffi, Carlos Pace, Jochen Rindt, Francois Cevert, Pedro Rodriguez, Jo Siffert, Bob Wollek, Michele Alboreto, most team-mates or friends, and mostly both, but 60 years is a long time to pack with memories and one page in *Racecar* is sadly not enough space. There is, as always in our sport, far too much to tell.

Fangio did not have to prove anything – five world championships with four different manufacturers did all the talking for him

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Badges of honour

Could the stage be set for more famous marques from the past to return to F1?

Recently a touch of romance has been seen in Formula 1, with the return of the Alfa Romeo name to the sport, and now possibly Maserati, too. There are hard-headed business reasons, of course, for Ferrari CEO Sergio Marchionne's decisions to badge the Scuderia's power units as such and supply the former to the Sauber team and the latter, maybe, to Haas.

Both of these legendary Italian manufacturers have struggled for decades to survive, let alone to do so profitably. Alfa has, especially, never cut it in the American market. With Liberty's US ambitions for F1 this might be a shrewd decision for pepping up the brand, similarly for Maserati. The production volume aims of each make are quite different, so of course is the car pricing and the target buyers. Thus there is no risk of 'cannibalism', the automotive guys' term for losing sales from one make or model to another.

Then there are whispers regarding Porsche taking the big step, too, as well as Aston Martin (though I struggle a bit with this regarding the financing), which has almost committed to joining the 'Piranha Club', if the engine rules for 2021 are more fit-for-purpose.

NATIONAL MOTOR MUSEUM TRUST

If VW was to ever enter F1 might it be under the Bugatti name? The fabled French car maker was dominant in grands prix in the 1920s with its Type 35

Racing spirit

Now, as you read this it is January and it's all New Year resolutions and detox, but as I write it's Christmas. May I, therefore, just for a few minutes adopt the kind of good cheer that accompanies the festive season when drink has been taken and life assumes a slightly hazy and happier, free-thinking atmosphere?

Now visualise a grand prix grid composed, in addition to Ferrari, Mercedes, Honda and Renault, of cars carrying these famous badges. Even if it's just the power units that deserve the identity (maybe the complete cars in due course?), it rather amazingly brings back the same great grand prix names of the more glamorous and heroic era that existed in the late 1940s through the 1960s.

How about (another glass consumed) if VW decided that supercar maker Bugatti, which it owns and is a name perhaps overshadowed only by Ferrari and Mercedes Benz in motor racing heritage, should be the F1 spear-carrier for the Group? Ferrari carried parent company Fiat identification on its racecars for a long time before it was recently spun-off in a public offering. It publicised the connection and enabled some of the racing team glamour and technical excellence to rub off on Fiat's more mundane offerings. A similar case could be made therefore regarding Bugatti and VW.

Should VW-owned Porsche commit to F1 as rumoured, then its powertrain could also be badged as a Bugatti (preferably in a French-blue car, naturally); no real conflict as Porsche has its own identity and, like Alfa and Maserati, sells to a different market. Really, if one can afford a Bugatti Veyron or Chiron, buying a Porsche or two in addition is neither here nor there. Audi, if it continues to maintain that Formula E is where it wants to focus its own motorsport efforts, could compete under its Lamborghini brand. Admittedly Lambo doesn't have such a history in F1, although it did gain some success in a Lola F1 chassis in 1990. Nevertheless, it is a renowned supercar manufacturer and while its GT racing results are commendable, without proper F1 kudos it will always lag a bit behind these other marques.

Binge thinking

BMW needs to be back – it's just too good at what it does to be out of F1. But hang on, before topping up the alcohol again, this could mean 11 powertrain suppliers. At two cars per team, let me see … 22 works engined cars on the grid, without any customer engines for teams less blessed (I have yet to understand whether supplying customer engines, as the top three manufacturers currently have to do, is useful to them as a partial recoupment of development costs or a pain in the backside due to the organisation and logistics required). However, with Ferrari, Red Bull and Renault supporting junior teams, as they currently do, this could work out nicely, with a maximum number of cars on the grid. Assuming, of course, that even with free engines and added financial support, there could be enough outfits with the budgets to cut it in F1. Ah … Oh hell, let's just imbibe some more and keep on dreaming.

Sober light of day

But in the clear light of morning and with hangover receding, reality becomes evident. More likely than the romantic indulgence previously enjoyed and apart from the done deal that is now Sauber-Alfa Romeo, the potential addition of works and customer engines, even complete teams, to F1 might well come from corporations that don't produce cars at all.

Let us assume at least that Formula 1 power units and chassis do return to realistic regulations, therefore significantly reducing budgets. Then it might be that some of the immense high-technology global conglomerates that, while existing mainly in the background, supply very many industries (including, but not exclusively, passenger car manufacturers) with their essential services and products might want to boost their public awareness – and hence their share value. To achieve this means getting coverage in the media beyond solely the financial pages of newspapers and websites. Involvement in F1 via funding the design and development of a branded power unit could be an ideal part of the strategy to accomplish this; the Cosworths and Ilmors of the racing engine world would be experienced and ideal companies to partner with as the facilitators. It would be less expensive than sponsoring a complete team and less likely to create any conflict of interest with major customers of theirs who might also have F1 interests.

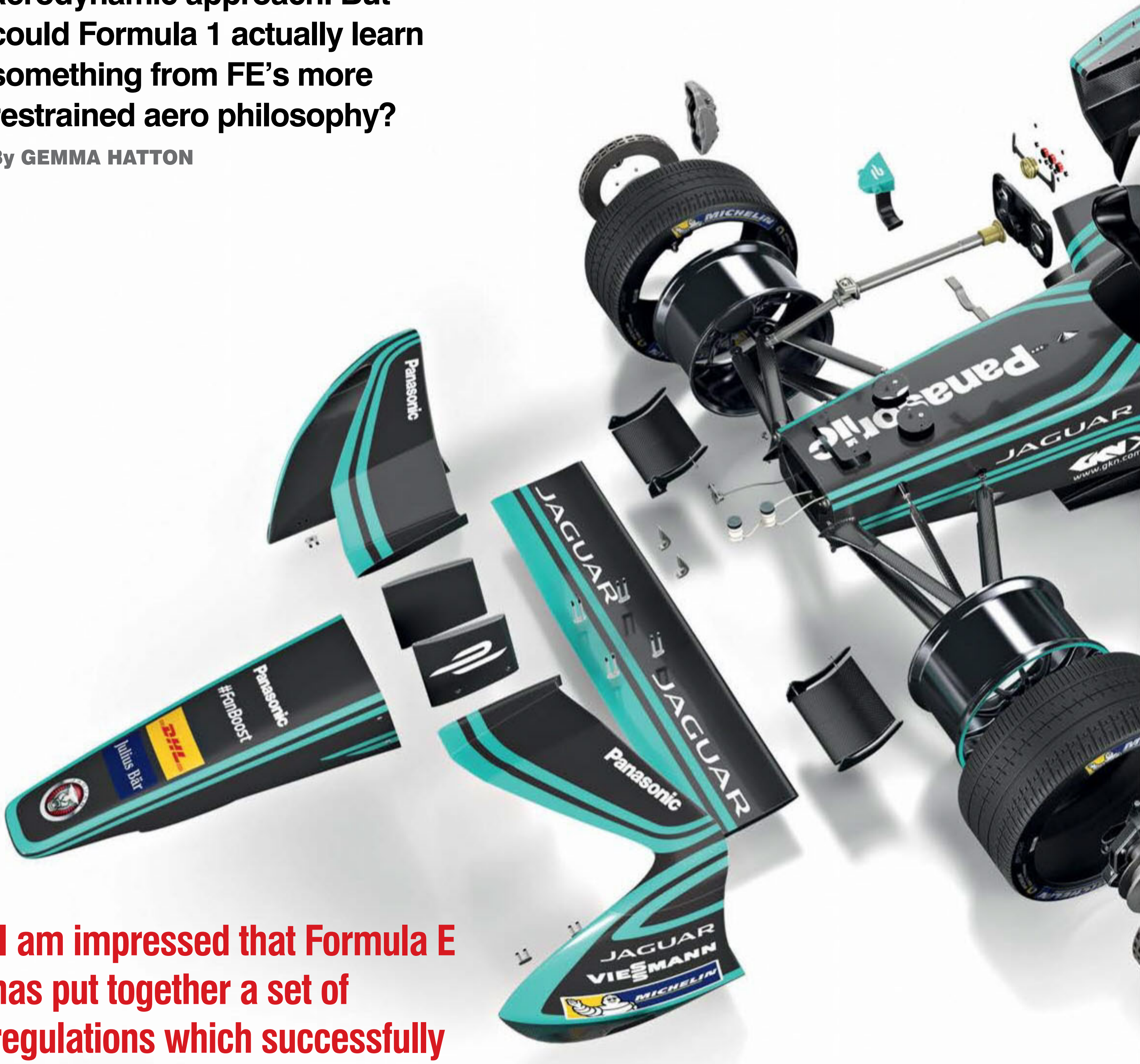
Formula 1 could be where mega-rich IT and social media corporations, which are playing with entering the passenger car market and emulating Tesla, might find a way to promote their automotive credentials too. But please don't call the engine, or racecar, a Google.

It's more likely the addition of works and customer engines, even teams, to F1 might well come from corporations that don't produce cars at all

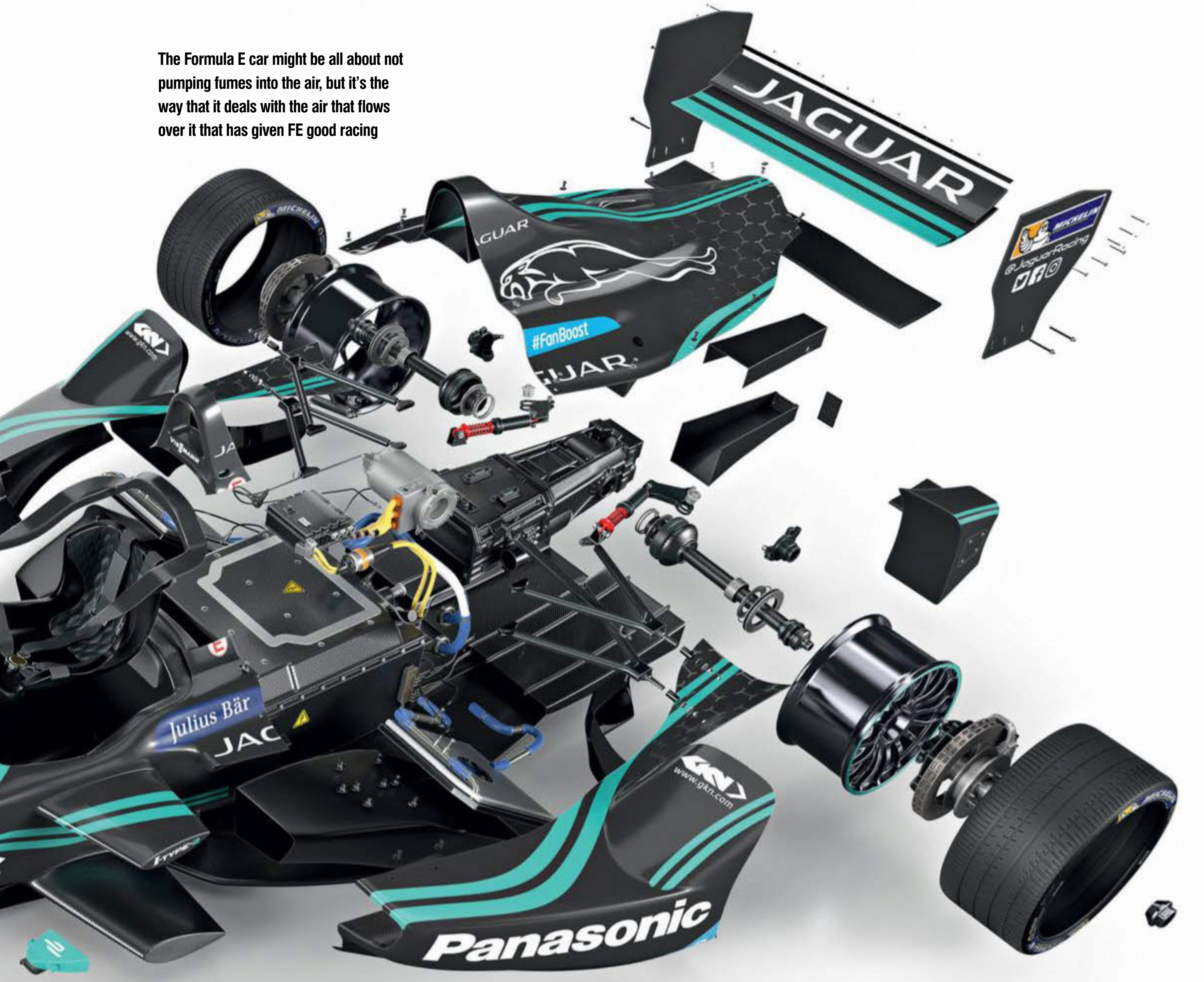
Clean air

It's not just the power source that sets F1 and Formula E apart, for each also has a very different aerodynamic approach. But could Formula 1 actually learn something from FE's more restrained aero philosophy?

By GEMMA HATTON



'I am impressed that Formula E has put together a set of regulations which successfully achieve a lot of things that F1 has been targeting in recent years'



The Formula E car might be all about not pumping fumes into the air, but it's the way that it deals with the air that flows over it that has given FE good racing

Formula 1's new owner is trying to use the 2021 regulations to help generate exciting racing. But could the answer to this problem actually lie with its electric cousin, Formula E? As F1 teams continue to spend millions developing intricate aerodynamic devices for minute performance gains, Formula E is running on approximately nine to 18 per cent of the budget.

By restricting the aero surfaces of the car and limiting top speed, FE teams are focusing their resources on innovating the next generation of powertrain components. This energy-saving electric ethos reduces the championship's dependency on aerodynamics, which means closer racing and more attractive cars. Meanwhile in F1, aero remains the biggest performance differentiator, and although the increased grip in 2017 was aimed at improving the spectacle, the resulting larger wakes actually made close racing almost impossible.

'You may remember playing the game of Top Trumps as a child. If you had the Rolls Royce Phantom card in your half of the deck, you had a very high chance of beating your opponent, as they were unlikely to have a higher engine capacity, power output, number of cylinders or top speed,' says Phil Charles, technical manager of Panasonic Jaguar Formula E Team. 'Now fast-forward to 2017 and imagine your opponent has the card for the aero stats of the 2017 F1 car, and you have the equivalent for the season four Formula E car. Unless he picks the drag coefficient, you have most likely lost this round. However, having spent the last four seasons as a chief race engineer in Formula 1, I am impressed that Formula E has put together a set of regulations which successfully achieve a lot of things that Formula 1 has been targeting in recent years. One of which is the aero package.'

Taking charge

When the FIA decided to introduce the world's first all-electric racing series, it established some very clear targets which underpin the ethos of Formula E. Its aim was to create an affordable, futuristic championship with close and exciting racing, whilst encouraging teams to focus their budgets on developing new technologies. One of the key ways that it has met these criteria is by reducing the car's dependency on aerodynamics for performance, the regulations being written with the aim of restricting top speed and aero development. 'We wanted Formula E to provide the manufacturers with an ideal platform to develop powertrains, so aerodynamics must have no influence,' explains Theophile Gouzin, technical director of SPARK Racing Technology, which developed the STR01 chassis raced by all the teams for the first four seasons. 'If you have a complex car, teams will spend a lot of time and money to try and find the optimum aero set-up to gain an advantage. This is why we have worked with the FIA to define a suitable downforce level so that the aerodynamic advantage on track is much less than in F1. Therefore, it pushes teams and manufacturers to spend their money on areas that are more efficient in gaining performance, such as developing the powertrain.'

Getting the teams to invest in the efficiency of the motors and inverters has driven the

Lower downforce in Formula E compared to Formula 1 results in less drag and therefore a smaller wake, so the racecars can follow each other closely, which can mean better racing

level of innovation, which is why so many manufacturers are moving to Formula E. Season five will be a battle between nine manufacturers, including Mercedes, Porsche, Nissan, BMW, Jaguar and Audi. 'Currently, automotive manufacturers often partner for their battery solution and have specific budgets for developing the motor and inverter for their electric vehicles,' says Charles. 'Well, this is very similar to what we do in Formula E and we all know that racing doubles the intensity of any development testing. Cleverly, the regulations have been written to give manufacturers a platform to develop their road car technology.'

Power play

One of the main approaches the FIA has used to reduce Formula E's dependency on aerodynamics is to restrict the speed because lift is proportional to v^2 in the equation $L = ½ \rho v^2 C_L A$ where v is velocity, ρ is air density, A is the frontal area and C_L is the lift coefficient.

'The main performance differentiator in Formula E is how efficiently teams can use the energy from the battery over a race distance and it therefore requires high thermal and mechanical efficiency from both the motor and inverter,' says Mark Preston, team principal at Techeetah Formula E team. 'Top speed is proportional to peak power and because we are given a peak power limit by the regulations, theoretically there cannot be dramatic differences in top speeds between the different cars. In Formula 1, they are restricted to the 1.6-litre engines and are effectively free to generate as much power as they want.'

Formula E needed to be visually entirely different to traditional formula cars

Head to head

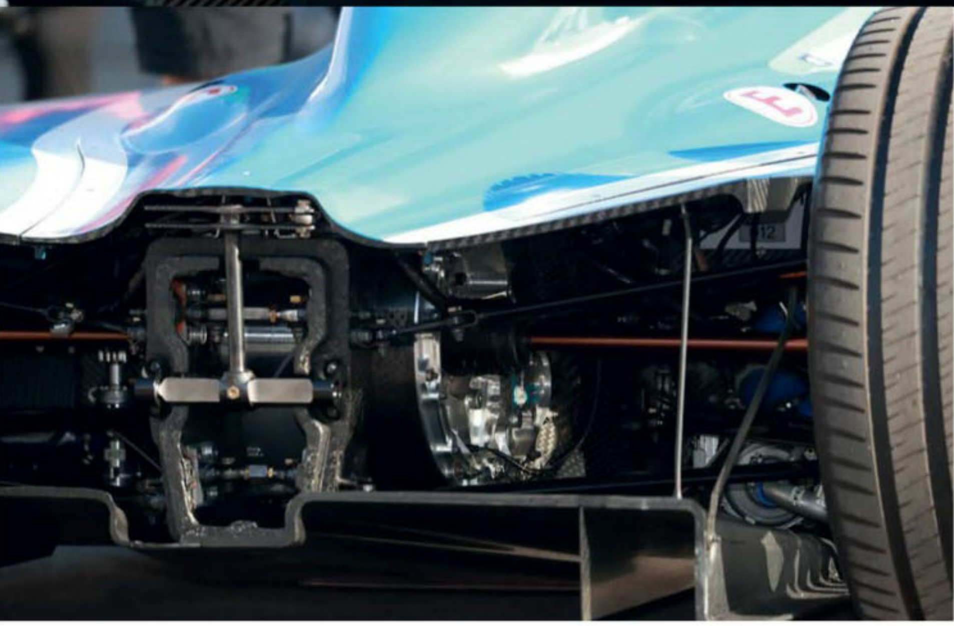
	Formula 1	Formula E
Horsepower	Approx 900bhp	250bhp
0 – 60mph	Approx 2.0s	3.0s
Top speed	355kmh (220mph)	215km/h (134mph)
High speed corners	225kmh (146mph)	120kmh (75mph)
Downforce (CL)	Approx 4.3	Approx 2.0
Weight	728Kg	880Kg
Budget	£165m (average)	£15 to £30m
TV audience	390 million	192 million

Cha1k and chEese

In addition to limiting top speed through peak power regulations, the FIA's strategy to showcase FE within city centres means the tracks are naturally narrower and shorter with more corners; demanding lower speeds. Although top speed has doubled since season one, the cornering speeds remain much lower than those seen in F1. An average high-speed corner in FE is around 120kmh, compared to 225kmh in F1 – that's roughly 53 per cent slower. This is why FE cars are geared for short sprints with lower top speeds; peaking at around 215kmh during qualifying in season three. F1can achieve speeds of 355kmh on long straights in low downforce configurations.

'The lower speeds mean the cars are not dominated by aero which is why the wing profiles on FE cars are much less aggressive,' explains Preston. 'It is still important to achieve minimum drag and ensure the car is in the right window in terms of per cent aero balance, but because we are given a stock vehicle we cannot optimise the aero package like F1, we can only adjust the angles of the wings.'

At this point, you may think the FIA's job is done. By ensuring the cars race at lower speeds, the need for downforce is less. However, downforce can still play a role in increasing performance, regardless of how slow or fast the speeds are, as Guillaume Cattelani, head of aerodynamics at McLaren Racing explains. 'In Formula 1, even in the slow speed, twisty sections of a circuit, downforce can make a big difference to the level of grip and balance. Furthermore, the 2017 Formula 1 regulations have allowed more freedom with regards to the bodywork and the track of the car has increased as well as the tyre sizes. The change in bodywork regulations has led to approximately 30 per cent



Above and left: The futuristic aesthetics of Formula E was a major design consideration and the bodywork has been cleverly sculpted to hide the large batteries that are located at the rear of the FE car

more downforce compared to 2016, increasing the amount of available grip, resulting in much higher cornering speeds. If you have a lot of grip, the grip limited sections tend to reduce and so the engine power becomes dominant and this dictates the sensitivity of the car to drag. Efficiency is at the heart of our development in F1, but the threshold of efficiency between F1 and FE is very different because of the differences in power and weight.'

Therefore, even though a Formula E car has a coefficient of lift approximately half that of an F1 car, downforce is still a tool that engineers can use to enhance performance irrespective of the speed, so aero wins once again.

Sparks will fly

To avoid teams investing in these aerodynamic areas, the FIA homologated a stock chassis, produced by Spark Racing Technology, where all the aero surfaces of the car are fixed and intricate carbon fibre work is forbidden. 'These regulations are very clever, because you simply cannot invest millions in tiny little flicks on the front wing or complex brake ducts,' says Charles. 'Restricting aero development effectively takes away one of the biggest budget-linked performance differentiators that you currently see in F1. These cars are also much easier to work on because we are not spending hours achieving a good fit between intricate carbon parts. Overall, the beauty of FE is the clean and clear regulatory decisions that have helped the FIA achieve what it set out to do, unlike F1 where controlling costs remains an issue.'

This strategy has also led to more freedom when it comes to aesthetics, allowing the designers to create a futuristic racecar. The rear bodywork subtly hides the large batteries and the design is more adventurous, as illustrated by the front and rear bumper pods and the so-called 'eyebrows'. This was one of the main criteria of the FIA from the start; Formula E needed to be visually entirely different to traditional formula cars, with the season five car taking this concept to new levels (see page 17).

We are constantly told in Formula 1 how the regulations are written to try and induce more exciting and closer racing. This was partly the aim of the 2017 regulations; to make the cars harder to drive, increasing the variability. However, due to aerodynamics remaining one of the key performance differentiators, the consequence of these high downforce F1 cars is high drag as well, because for every count of downforce, you gain a count of drag.

Drag racing

Let's assume the lift to drag ratio of an aggressive rear wing on an F1 car is 1:1. The more efficient aero devices such as the diffuser may have a lift to drag ratio of 20:1. So any aggressive winglets used to improve downforce come with a penalty. These wings, along with the uncovered wheels, generate huge amounts of turbulent air flowing off the rear of the car, forming the wake – the dirty air that the drivers constantly complain about. This not only degrades the tyres faster in a following car due to reduced grip, it reduces the available cooling for the engine and brakes, and destroys the downforce because the aero devices cannot work efficiently in such disrupted airflows.

With every Formula E team having to bolt on the same aerodynamic parts to their car, the FIA can dictate the lift coefficient, which they chose to be less than Formula 1. 'The nature of the city tracks being quite tight and twisty means that cornering speeds are less and the drivers are used to cornering with

‘The main performance differentiator in Formula E is how efficiently teams can use the energy from the battery over a race distance’

less downforce in play,’ Charles says. ‘The aero choices made by the FIA also mean there is less induced drag and a smaller downstream wake for the following car. So, the drivers are less reliant on clean free stream flows ahead of them and can follow each other quite closely.’

Fewer variables

‘Put simply, because our cars have lower downforce, they don’t produce large wakes,’ says Preston. ‘My theory is that track performance is always a factor of power, aerodynamics and tyres. We have one type of tyre, so that is controlled, we are restricted with regard to our aero package and are limited in terms of peak power; so we have a lot less variables than in Formula 1, which leads to much closer racing.’

Yet variability is also key to ensuring an engaging race, so with Formula E so heavily constrained, how is this achieved? Actually, it is the result of some of the more aggressive regulations that have increased variability. For example, one of the consequences of banning brake ducts is the imbalance in brake temperatures across the axles and front to rear, making the car harder to drive. ‘The drivers are also purely responsible for controlling tyre temperatures,’ Preston says. ‘In the qualifying sessions leading up to Superpole, they get an out-lap, a warm up lap and then the hot lap. This gives them the opportunity to gradually bring the tyre and brake temperatures into the optimum range, ready for the start of the hot lap. But in Superpole they only get one lap with no cooling allowed, so there is no time for the drivers to balance the temperatures – it’s in the lap of the Gods. This format of Formula E means there is simply no time to get everything perfect, which puts more responsibility on the driver and makes my job harder, but ultimately leads to more exciting racing.’

Same place, different approaches. Formula E and F1 (below) at Monaco. FE package is as much about the styling as aero

F1 aero development has led to complicated wings and flaps, in stark contrast to the cleaner lines of the Formula E racecar

Cooling flow

A large part of aero development in Formula 1 is about using the airflow to improve cooling. ‘In Formula 1, we are relatively free in terms of cooling design. Teams use either conventional air-cooled radiators or heat exchangers with different fluids such as water or oil,’ says Cattelani. ‘But more cooling always removes performance from the car so radiators are a nightmare for aerodynamicists. The problem is that you have two competing airflows; you have the airflow that works the outer surfaces of the car and the internal cooling airflow. The more cooling airflow inside the car removes downforce and adds drag. So the challenge is to maximise aero performance whilst defining the cooling to suit every race track. For instance, circuits such as Mexico where high altitude means the air density and therefore cooling capacity is low, and also Hungary where the ambient temperature is high and there are few long straights to reach top speed.’

This is yet another fundamental difference between FE and F1. In Formula E, the cooling inlet ducts and bodywork exits are fixed, which immediately takes away this trade off.

The heat is on

A further difference is the actual temperatures reached in both series. ‘When running an internal combustion engine you are limited by the capabilities of the water in the cooling circuits which is why teams increase the pressure to try and raise the boiling point up to around 130degC,’ Preston says. ‘Fundamentally, the level of required cooling depends on the difference between the ambient temperature and the component you are trying to cool. Let’s assume the ambient temperature is 32degC and track temperature is 45degC. As specified by regulation, our batteries start at ambient temperature but then can reach up to 60degC, whereas F1 can see maximum temperatures of 130degC. So, you can see that for us, the airflow actually warms the batteries up initially rather than cooling them down, which is a completely opposite challenge to Formula 1.’

Despite the lower temperatures, cooling remains essential in FE as it directly affects the

‘The lower speeds mean the cars are not dominated by aerodynamics, which is why the wing profiles on FE cars are much less aggressive’

Cooling strategies for motors and inverters are all about improving efficiency, essential for saving energy in electric racing

Brake ducts

In Formula 1 brake ducts are crucial engineering tools. They are complex carbon structures located on the inner wheel and they guide oncoming air into the brake system to cool the brake pads and discs, which can exceed temperatures of 1000degC.

Brake cooling systems can also be designed to influence the tyre temperature, using the hot air coming off the discs. Establishing the optimum working temperature ranges of both the tyres and brakes and adjusting the set-up to get within these windows is one of many trackside headaches for a Formula 1 race engineer. However, get this right and not only does the tyre grip increase, but braking distances reduce; both contributing to saving several tenths of a second per lap.

Of course, maximising these lap time gains from a single part comes with heavy development costs in the millions, which is outside the stringent budget of a Formula E team and explains why such devices are banned. Aside from cost, there is an argument to suggest that brake ducts may not be needed in Formula E anyway, due to the lower speeds and consequent less heat generation.

‘Formula 1 cars are not only heavier compared to last year, at 728kg under the current regulations, but they are also more powerful and carry more aerodynamic load and are therefore much quicker,’ says Guillaume Cattelani, head of aerodynamics at McLaren Racing. ‘So you have to stop the car from higher speeds, which generates a lot of temperature, whereas the weight and power of a Formula E car allows you to standardise the braking system. The effect of banning brake ducts in Formula 1 would be huge. Without brake cooling devices, the brake temperatures would not be easy to manage and that would slow down F1 cars considerably.

‘The quicker you arrive in a corner and the later you brake, the faster you need to transform the car’s kinetic energy into heat which cannot be achieved easily without brake cooling ducts,’ Cattelani adds. ‘Some of that is taken out by the MGU-K, but the majority would still have to be dealt with by the hydraulic brake, so you would need large and heavy brake discs, which would increase sprung mass which is detrimental to performance. You might be able to vent the disc differently to reduce the size of the brakes, but overall it would be a huge performance setback. However, like everything else in motorsport, the regulations are what they are and the aim of the game is to be quicker than our competitor, whether we have carbon, steel or wooden brakes.’

‘The effect of banning brake ducts in F1 would be huge’

The design of Formula E brake discs differ greatly from Formula 1. They are designed to retain the heat, rather than dissipate it and the discs are not fully ventilated. Although there are holes in both the front and rear discs, these do not go through the entire cross section and are primarily used to save weight. However, with the increased power expected from these cars in the near future, it is likely that fully ventilated discs will be used.

efficiency of the batteries, motor-generator unit, gearbox and inverters. It’s this efficiency which is the main performance differentiator in FE, and developing a cooling strategy which ensures that these powertrain components operate in the optimal thermal window is the secret to a team’s success. Unlike in F1, however, designs are all homologated, so even if a team was to spot a novel cooling system on a competitor’s racecar, they cannot then copy it until the next season. Again, this helps to focus attention and budgets on next year’s technology, rather than initiating a spending war.

The efficiency at which a team uses the power from the batteries over a race distance is ultimately what can win or lose the race. ‘We are all limited to the same power coming out of the batteries,’ Preston says. ‘If a competitor has a more efficient powertrain, then they can use more peak power whilst exiting a slow speed corner. Also, they may not need to save as much energy at the end of the straight. Ultimately, the team with the better efficiency can use the trade off across a lap better in a race situation.’

Future challenges

This energy conservation philosophy also points towards low downforce cars to minimise the drag penalties, which drains that all important battery power. ‘Electric cars gain their performance through efficiency, which is why teams focus on minimising drag as it uses less energy,’ Preston says. ‘Logically, you want to use the most efficient aero devices, whilst covering the least efficient. Therefore, covering the wheels and utilising larger diffusers and more effective floors is the obvious direction to go in because it reduces the wake hugely.’

This philosophy is highlighted by the first conceptual images of the new season five Formula E car. Developed by Spark Racing Technology once again, the bodywork appears to cover the front and rear wheels even more, to help clean up the tyre wake (see page 20).

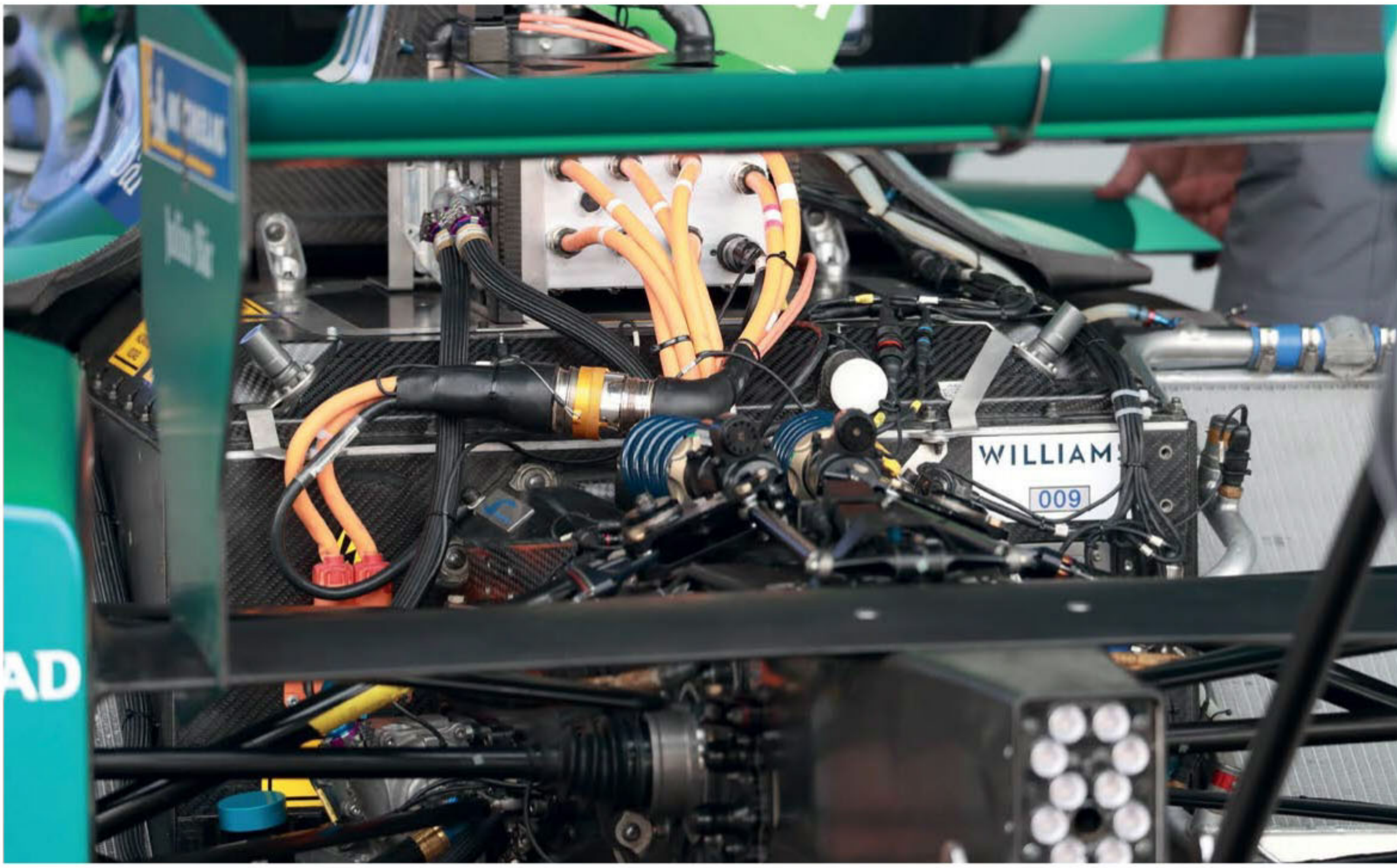
Overall, Formula E does not need to achieve the level of downforce of a Formula 1 car, but it does need to achieve higher efficiencies. Therefore, although the aerodynamic challenges of both categories are very different, they remain complex engineering problems. This complexity is bound to escalate as the focused regulations continues to drive innovation of the powertrain components. But will these electric racecars ever match the speeds of their Formula 1 cousins? Or, should Formula 1 take note from the less aero dependent Formula E, reduce the reliance on downforce and cooling to improve the racing, decrease budgets, and achieve all the goals F1 has set itself for 2021?


Cranfield
Transport
Systems

Out of this world

Formula E's 'otherworldly' season five car has been undergoing top secret testing before its public unveiling in March. *Racecar* talked to those in the know about what to expect from the SRT05e

By SAM SMITH



For a series that sees itself as hi-tech FE's hardware is beginning to look a little long in the tooth. This includes the same chassis as used in season one, but a new car is on its way

The momentum achieved by the Formula E series in just three seasons has surprised even those that have spearheaded racing's great electric revolution. While the fourth season kicked off with what is now some very elderly hardware in Hong Kong in December, the prototype of the second-generation Formula E car had already conducted its first endurance tests.

The car, known as the SRT05e, had already clocked more than 2000km of initial running by the end of October, amid great secrecy in Spain. It's an important step forward for Formula E as with the introduction of the SRT05e it's planned that the mid-race car swaps that have been a feature of Formula E since the beginning will no longer be a part of the show. The new car will run with 54kW/h of usable energy.

One source has described the design as 'otherworldly', which is just what Formula E is after, a futuristic car. The design incorporates a large venturi at the rear rather than a conventional rear wing and an expansive one-piece frontal bodywork section. The same source told us that the late autumn tests were 'the most significant to date and ticked many of the boxes identified by the FIA and Spark.' The latter is the racecar's maker.

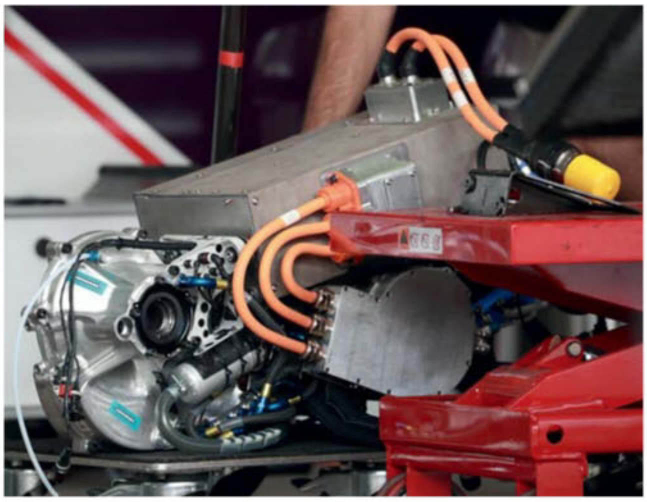
Spark and ride

The exhaustive runs came after the initial validations of the racecar were carried out by GP3 driver Anthoine Hubert and former Audi Le Mans winner Benoit Treluyer. This was conducted in early September, mainly to evaluate the more powerful season five battery,

The SRT05e is known to have been constructed using new materials that are aimed at reducing the overall weight

‘We can’t have production cars being more advanced than Formula E’

FE supplier Michelin has developed new lightweight tyres for the SRT05e and has tested them extensively on the new car



Above: The Williams Advanced Engineering battery will be replaced by a far more powerful unit from McLaren Applied Technologies
Right: While the chassis and battery will be controlled there will still be some scope for development in other areas, such as the transmission

which is being managed and overseen by McLaren Applied Technologies.

Porsche factory driver Frederic Makowiecki also tested the car, working on development of the next Michelin product. The new rubber will see ‘a big challenge for the tyres’, according to Michelin Motorsport director Pascal Couasnon. ‘This is because if you go with [a] lighter tyre you’re going to have more load to carry. So that is something that’s going to be very difficult but it is very interesting for us.’

Circuit testing

The more involved tests that took place at Monteblanco and Guadix in October and November were the first time that the SRT05e had run with its full bodywork. Four full-race simulations are understood to have been carried out over the course of October while the car’s builder, Spark Technologies, also ran several more tests before the end of 2017.

The SRT05e must be able to go twice the distance of the current cars and it is known to have been constructed using new materials that are aimed at reducing the overall weight.

But the new car now faces a delay of approximately six weeks due to re-tooling and design work which is centred around the implementation of the Halo safety device.

This means that registered manufacturers will not get their cars until late February at the earliest. Testing is scheduled for early March, while the car will publicly be unveiled at the Geneva Motor Show in mid-March.

Weighty issues

For the FIA, an immense amount of work has gone in to weight saving and implementation of the Halo device. ‘Weight is a key factor and we can compensate something with the chassis but again the Halo situation is working a little bit against us,’ says Professor Burkhard Goschel, the head of the FIA’s Electric and New Energy Championship Commission (ENECC).

Goschel believes that a more aesthetically pleasing Halo safety device for Formula E could be worked into the future car’s design from season eight onwards. ‘It is much easier if you can integrate the Halo in the new design of the body and make it an integral part of the structure, so it is not added on,’ he says. ‘We are getting much more experience in what we can do to get better aesthetics.’

This opinion tallies with that of reigning Formula E champion Lucas di Grassi’s on the cockpit protection device. ‘The Halo was not designed or tested for our speed, so our Halo could be developed and tested for a Formula E scenario,’ he says. ‘It is a totally different energy, totally different car weight, and it has to withstand the required loads.’

MGU from an Audi LMP1 car. Audi has now moved from the WEC to FE, but it will be unable to bring to bear the full weight of its development potential

Conceptual rendition of season five car. While it may not look quite like this, it will have a large venturi at the rear rather than a conventional rear wing, plus a one-piece frontal bodywork section

Formula E cars don't need an air-intake and it is understood that this area of the racecar could, in theory, support an alternative solution in order to fit in with the more futuristic styling.

'It could be a kind of half canopy. We don't have fuel, so there is no reason to not have a canopy style,' di Grassi says.

The Audi Sport ABT Schaeffler driver also made it clear that he thought protection for the drivers was only a positive addition to safety in single seater cars. That said, he also strongly believes that Formula E cars should go through separate tests and the series should have an alternative solution for future racecars.

'In my opinion the Halo is a good thing, but in Formula E it should be designed with the mentality that this is inherently a different car to Formula 1,' says di Grassi. 'An electric car generally can have a completely different way of designing and engineering, which does not have to emulate what motorsport has been [in the past]. So they have to follow a direction. I agree that let's do the Halo in F1 and across the board in motorsport, but then after that let's do a study and get a solution which fits Formula E.'

Meanwhile, while the season five car is now almost ready, talks about season eight and the third generation car have now started with the first serious meeting between the FIA and manufacturers taking place in Geneva last November. It is understood discussions centred around a possible inclusion of front-axle MGU and four-wheel drive technologies.

Current affairs

The meeting group is an extension of the regular Technical Working Group, led by FIA Electronic technical delegate Sylvain Riviere. One attendee at the meeting told *Racecar* that 'the leap we need to make in 2021 will be significant because we can't have road production cars being way more advanced than Formula E. There has to be good transfer of technology because this fits in to the whole marketing landscape'.

While nothing has been finalised, and is not expected to be for at least another nine months, representatives at the meeting stated they want to filter down ideas at the next summit, which is likely to take place in February. The FIA is aiming to have a definitive plan on the direction of the car by September 2018 at the latest.

Head of Audi Motorsport Dieter Gass believes that a compromise of new advanced technologies with a close eye on development budgets are key. 'For sure there should be some freedoms and possibilities in development, but we still need to keep costs in-line, shall we say, because as we know the costs can go up when a few manufacturers come in to a series,' he says.

'I would say that the teams and manufacturers that are currently participating have a good understanding of [the cost control]. But it is difficult to judge at the moment the feelings of those that are yet to come in to the Formula E championship,' Gass adds.

Gass described Audi's slight frustration in not being able to use its resources to create its own 100 per cent bespoke Formula E package, but said he understood the reasons why. 'We are obviously geared up as a manufacturer to develop a full car, with aero, monocoque, everything,' he said. 'We would like to use that capability which currently is just not possible. On the one hand it is a shame but on the other we have common parts which makes sense for the cost control as things stand.'

Free battery technology is believed to be off the table until at least 2025. However, a possible compromise situation of having up to three different battery suppliers could come into the equation, but for now the strictly controlled three-headed technical hydra of chassis, battery and aerodynamics looks set to be fixed for the next seven years.

Budget escalation

The championship's rigid roadmap currently runs to a three-year cycle up to and including season seven in 2021. Beyond that there is scope for more openness in technical systems, which could escalate budgets above and beyond those which attracted several manufacturers to the series.

DS Performance director Xavier Mestelan-Pinon has called for Formula E to further manage competitors' financial outlay as manufacturers continue to flock to it.

'For us, road car relevance is the key, but we have to do this with a closed budget and a good return on investment,' Mestelan-Pinon says. 'Today, I am a little bit afraid of some of the other manufacturers, and of how tricky they could make it for the series.

'Formula E is still fragile and brand-new,' he adds. 'We have to work and to spend our money step-by-step. For me it is very important to avoid a dramatic increase in the budgets.'

With the introduction of the SRT05e the car swaps that have been a feature of FE since the beginning will no longer be a part of the show

W08 was the eighth Mercedes Formula 1 car since it returned to F1 in 2010. It won both drivers' and constructors' crowns for the fourth time in four years

Eighth wonder

Mercedes once again claimed both Formula 1 world championships in 2017, but it faced a stiffer challenge on track and it had to tame a 'diva' of a car to do so. Here's the inside story on how it developed its W08 EQ Power+ into a title winner

By SAM COLLINS

With Ferrari pushing Mercedes hard all year it forced the team to be fairly aggressive with development

A storm called Doris was blowing across the Silverstone circuit when Mercedes rolled out its 2017 Formula 1 car for the first time. The car's official name was not quite as snappy as the storm's, but the Mercedes-AMG F1 W08 EQ Power+ (the 08 testifying this is the eighth in a remarkably successful line since the manufacturer returned to Formula 1 in 2010) had the power of a mighty storm, alright, and its rivals would have possibly anticipated its arrival with as much trepidation, too.

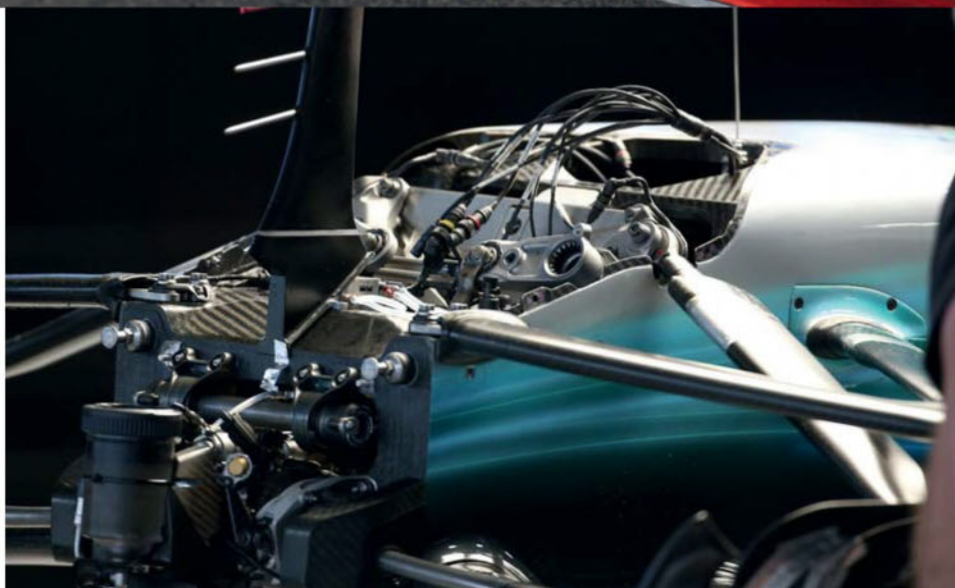
Penned by the design team at Brackley, England, the W08 had to be a completely clean sheet of paper design, due to the new aerodynamic regulations introduced at the start of 2017designed to increase the speed of the cars, along with much wider and theoretically grippier Pirelli tyres. Thus only 17 per cent of components had carried over from the W07.

'The project started to take shape at the beginning of March [2016], doing some wind tunnel studies and car layout configuration work,' explains engineering Director Aldo Costa says. 'Our first target was to have a sound layout that allowed us room for further development, a very high-potential layout, so the aerodynamic development find performance during the whole season. Then, during the summer, we defined the layout and went into the detailed development, and it was like an aerodynamic festival, I would say. Aero had plenty of opportunity to find performance. We were super happy about the new rules from the engineering point of view and this generated quite a lot of performance. The car is more complex than before. The aerodynamic development of the massive new surfaces obliged us to review everything.'

Severe test

The new regulations and the work in the Mercedes 60 per cent scale wind tunnel in Brackley resulted in a significant increase in the downforce, which had an impact on almost all of the mechanical and structural parts of the racecar. 'Most of the components of the car had to withstand much more severe

Above: W08 could be tricky to drive, something Mercedes sorted as it learnt to understand how the new tyres worked in terms of thermal management and generating and maintaining grip
Right: Front suspension is a double wishbone layout with pushrod actuated torsion bars mounted at the front of the monocoque

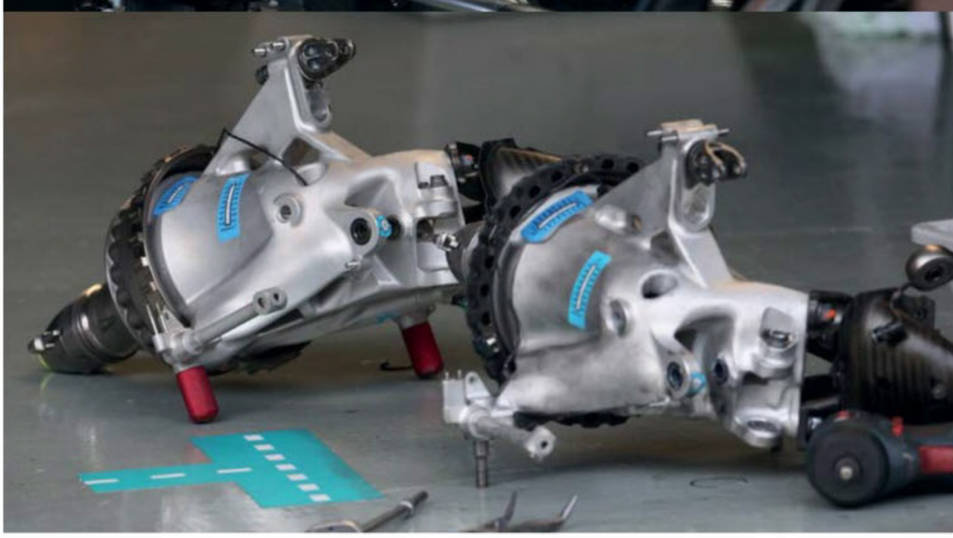


'The aerodynamic development of the massive new surfaces obliged us to review everything'

duty cycles or simply had to be subjected to much higher loads and this created a huge challenge for the whole design group,' Costa says. 'Obviously, we wanted to take the maximum possible advantage from the development of aerodynamic shapes and chase all the opportunities that the rules allowed. From the vehicle dynamic point of view, it was the same thing, trying to predict tyres and car behaviour from the little amount of information we had, was key.'

Wishbone details

The overall design of the car, especially at the front end, followed a rather different concept to most of the field. While the front suspension featured a double wishbone layout with pushrod actuated torsion bars mounted at



Rear uprights. Suspension parts were beefed up to cope with the higher loads from extra aero and wider tyres

Above: The striking front upper wishbone treatment sees the pickup some way rearwards and inboard of the more usual location. Mercedes tells us this was not an aero development **Left:** New for 2018 is the Halo cockpit protection device. Mercedes and other teams tested with it in 2017 and the new W09 for the coming season has had to be designed with this in mind

the front of the monocoque, a lot of attention was placed on the outboard upper wishbone mounting from the moment the car was shown off to the press. An extension on the upper part of the upright allowed the wishbone to pick up some way inboard and rearward of where it might have done otherwise.

This is an extremely similar concept to that used on the Toro Rosso, something the Italian team claims brings aerodynamic gains, but Costa disagrees. 'These days, F1 cars are extremely complex and what could appear, from the look of it, simply obvious, in reality is not,' he says. 'Yes, the front suspension is pretty extreme and you could think this was done for aerodynamic benefits, but in reality there is much more to it than that. As the car corners you need to have the best aero, but as well as that you also need to hit car compliance targets and develop it [with the aim of] helping tyre management. Talking about that particular element, if anything it is slightly worse, purely from the aero numbers point of view.'

Title fight

From the moment the season started it was clear Mercedes would have a harder time than it had had in 2014, '15 and '16. Ferrari had made a major step forward and at the opening race in Melbourne, Australia, good pit strategy saw the Italian team take victory in a straight fight with the Silver Arrows. This was the beginning of what Mercedes technical director James Allison refers to as a 'season long slugging match'.

'The season was divided into three types of experience,' Allison says. 'There have been a

TECH SPEC

Mercedes-AMG F1 W08 EQ Power+

Monocoque: Moulded carbon fibre and honeycomb composite structure.

Bodywork: Carbon fibre composite including engine cover, sidepods, floor, nose, front wing and rear wing.

Safety Structures: Cockpit survival cell incorporating impact-resistant construction and penetration panels, front impact structure, prescribed side impact structures, integrated rear impact structure, front and rear roll structures.

Cockpit: Removable driver's seat made of anatomically formed carbon composite, OMP 6-point driver safety harness.

Front Suspension: Carbon fibre wishbone and pushrod-activated torsion springs and rockers.

Rear Suspension: Carbon fibre wishbone and pullrod-activated torsion springs and rockers.

Wheels: OZ forged magnesium.

Tyres: Pirelli.

Brake System: Carbone Industrie carbon/carbon discs and pads with brake-by-wire. Calipers by Brembo.

Steering: Power-assisted rack and pinion; carbon fibre steering wheel.

Electronics: FIA standard ECU and FIA homologated electronic and electrical system.

Instrumentation: McLaren Electronic Systems (MES).

Fuel System: ATL Kevlar-reinforced rubber bladder.

Gearbox: 8-speed forward, one reverse, unit with carbon fibre maincase. Sequential, semi-automatic, hydraulic activation selection.

Clutch: Carbon plate.

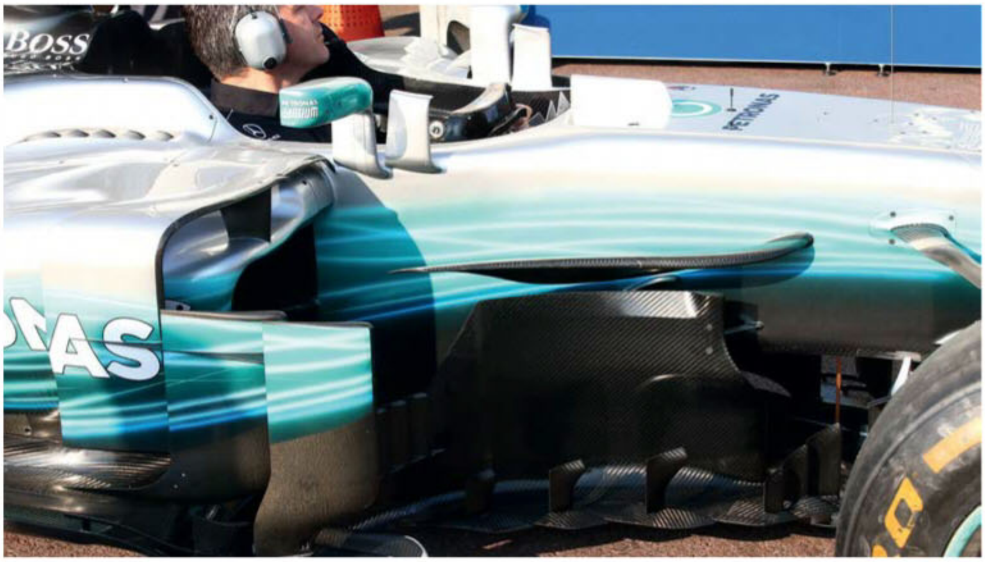
Fuel and Lubricants: Petronas Primax (fuel); Petronas Syntium (oil).

Dimensions: Overall Length, over 5000mm; overall width: 2000mm; overall height, 950mm.

Weight: 728kg

Only 17 per cent of components had been carried over from the W07

Mercedes was the first team to run the controversial T-wing. With the new aero rules there was scope for design creativity



Development of bargeboard area was freed up in 2017. On the W08 this was complex and it changed throughout the season

The roll hoop showing the segmented ducts. The outer ducts feed air to the ERS cooling, while the central duct is for the ICE

few races where we have come out and crushed everything in front of us. There have been a few where we've had the other end of that deal, where we have definitely come off second best. And then a whole lot in the middle where it has been pretty much a 50/50 slugging match.'

One of the advantages Mercedes had in that slugging match was a very high rate of development. Even during the launch of the W08 at Silverstone new developments were introduced, including the controversial T-wing. At the first proper test more updates appeared on the car and it then seemed that the British-based German team was winning the development war. 'It was simply due to the very new aerodynamic rules, allowing for big potential developments,' Costa says. 'So we were not at all exhausted with the first race configuration. The activity was really frantic and we had to fully count on the strength and the determination of our people.'

Narrow window

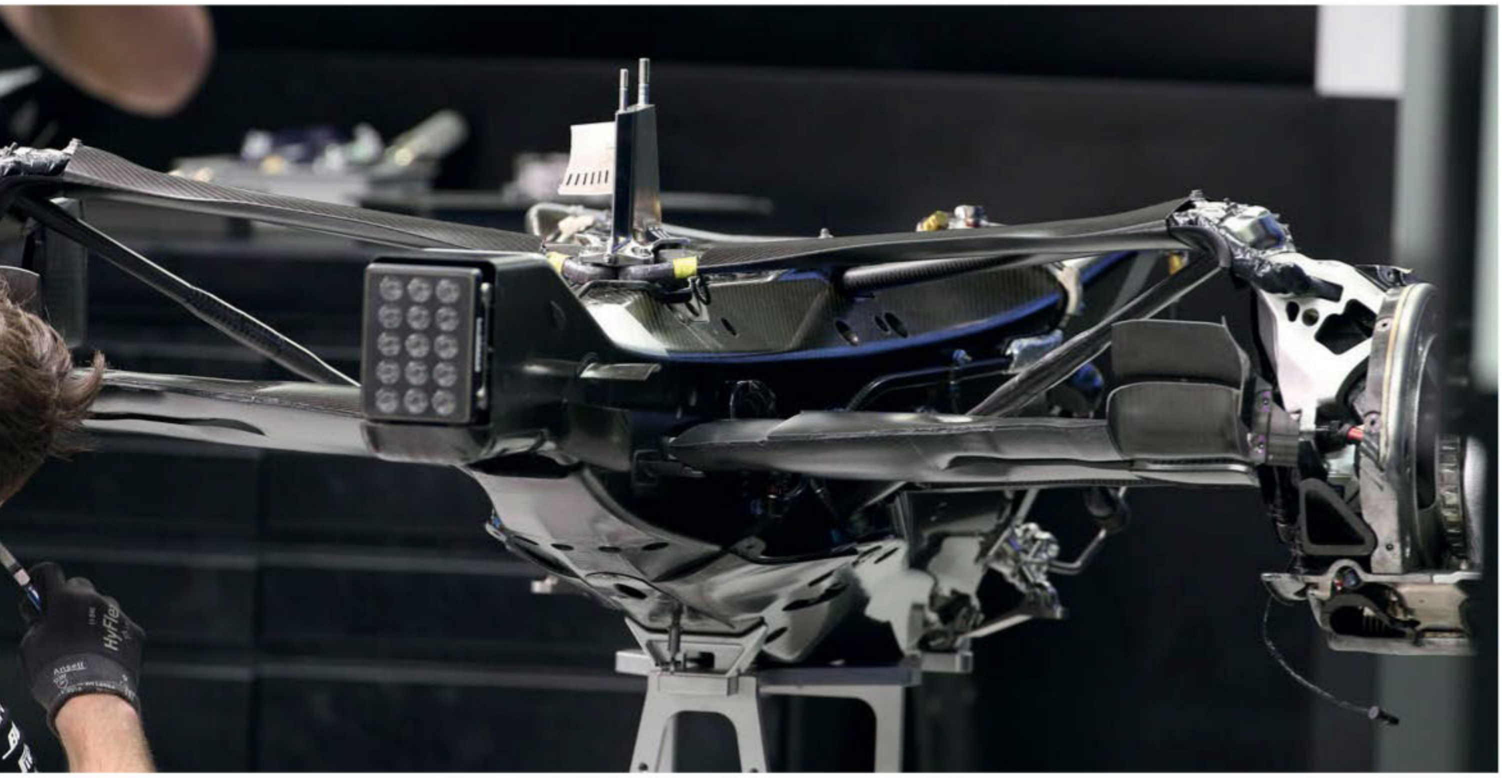
As the season went on it became apparent that the W08 had a fairly small window of operation which led to team boss Toto Wolff and driver Lewis Hamilton referring to it as 'a bit of a diva'. Many suspected that this was an aerodynamic issue, but it seems that this was not the case. 'Mainly it was due to the tyre behaviour.' Costa says. 'How to manage them was a clearly defined problem for the organisation to solve. I'm sure this issue was happening in other teams, too, but we simply admitted it, and in a nice way. The thermal management of the tyres in general and how in particular to generate and maintain the grip front and rear, in the sweet spot, was the key point to solve race by race.

'Understanding tyre behaviour and finding set-up solutions to nail down the issue was the main and constant activity of the year,' Costa adds. 'The team made remarkable progress on this, arriving in the last part of the season more prepared. From a *reactive* approach – always difficult to manage during a race weekend – using our improved understanding we moved toward a successful *predictive* approach, which is normally the best way to go.'

Challenging year

Allison says: 'It is a difficult car, but it doesn't disobey the laws of physics. It is clearly understandable but that doesn't mean it's always easy to get the best from it. It's been a challenge this year [2017] to achieve the results we have with it, but nevertheless we have achieved some pretty decent outcomes, so it's not been a bad machine for us. However, we would like a car that is easier to throw at the race track and easier to guarantee that every time we come racing we get every last little bit from it. Such changes as we have been

It became apparent that the W08 had a small window of operation



Mercedes gearbox is made up of a composite outer skin to carry chassis loads with a metal cassette inside it to house gears. Aggressive development led to gearbox issues in 2017

able to make this year we have, and we hope that next year we make something with a slightly sweeter temperament.'

With Ferrari pushing Mercedes hard all year it forced the team to be fairly aggressive with development of the car, and at one point it pushed a bit too far with the transmission. Its cars incurred grid penalties mid-season due to unscheduled gearbox changes as a result.

'We did all of our normal processes to prove-off a layer of greater aggression with the shift settings than we had used previously,' Allison says. 'But, despite the fact that everything looked fine in our sign-off process, sadly that particular plan did not survive contact with the enemy on the race track, where things were a little different, where the *g*-loads moved the oil around the box differently than you can simulate in a dynamometer. So we just overstepped the mark by the tiniest of margins, and paid a price.'

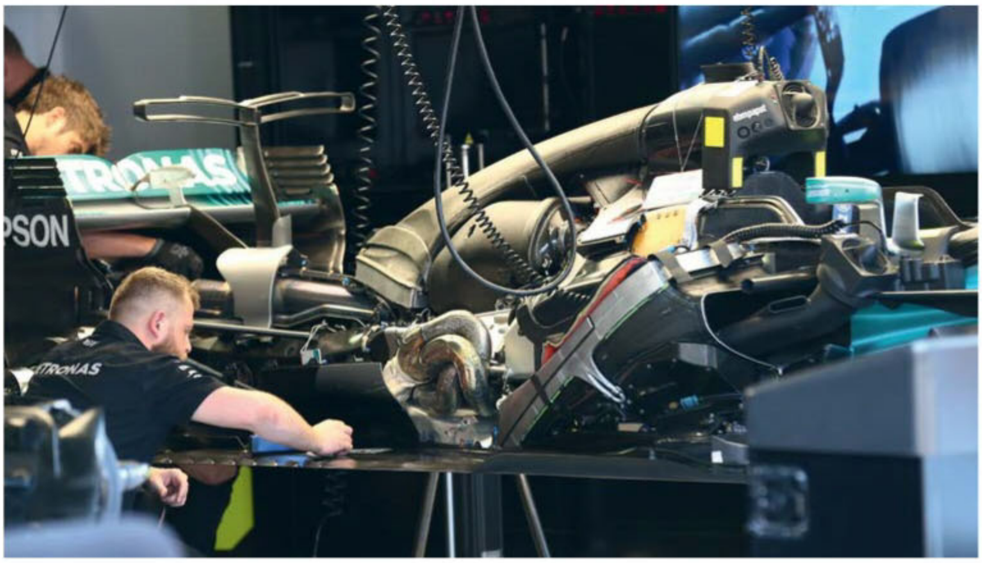
Box of tricks

The W08, like all recent designs from Brackley, uses an interesting gearbox design with a composite outer skin to carry the chassis loads, and a metal cassette inside that to house the gears themselves. It was not the general design that failed mid-season, just how the team had chosen to utilise it. 'Due to the increased vehicle performance, duty cycles increased and this applied to the transmission too,' Costa says. 'A couple of components on both drivers' gearboxes started to wear out and we carried on for a few races monitoring them. We evaluated the possible consequences of a five grid position penalty race by race against a possible DNF and we decided to change the gearboxes at the most convenient moment, losing in the end only three points. The problem was fixed for the last races of the season.'

The year ahead

Looking back over the 2017 season the team is now able to consider the lessons it learned during the year and how those can be fed into the car for 2018. 'The 2017 season was more a blank sheet of paper and therefore you had more design choices to make, that was true for everybody,' Allison says. 'Next year we go with a lot more information about how these cars behave and therefore with clearer ideas of what we would like to do for the next season. But that's true for everybody, too, and therefore everyone will be better guided and the overall level of difficulty in making sure that you are the quickest will remain the same. The new challenge of refining your current weapon will be the same for everyone.'

By the end of the 2017 season the W08 had taken 12 victories and both world titles, it also scored points every single time it finished (with only one failure to finish a race all year). It seems likely that in 2018 Mercedes will once again be the car to beat in Formula 1.



Rear end of the W08 with bodywork removed; note the cooling ducts feeding down from the roll hoop and snug fit of the PU

TECH SPEC

Mercedes-AMG F1 M08 EQ Power+

Internal Combustion Engine (ICE)

Capacity: 1.6-litre

Cylinders: Six

Bank angle: 90-degree

Number of valves: 24

Max rpm ICE: 15,000rpm

Max fuel flow rate:100kg/hour (above 10,500rpm)

Fuel injection: High-pressure direct injection (max 500bar, one injector/cylinder)

Pressure charging: Single-stage compressor and exhaust turbine on a common shaft

Max rpm exhaust turbine: 125,000rpm

Energy Recovery System (ERS)

Architecture: Integrated hybrid energy recovery via electrical Motor Generator Units (MGUs)

Energy Store: Lithium-Ion battery solution of minimum 20kg regulation weight

Max energy storage/lap: 4MJ

Max rpm MGU-K: 50,000rpm

Max power MGU-K: 120kW (161bhp)

Max energy recovery/lap MGU-K: 2MJ

Max energy deployment/lap MGU-K: 4 MJ (33.3s at full power)

Max rpm MGU-H: 125,000rpm

Max power MGU-H: Unlimited

Max energy recovery/lap MGU-H: Unlimited

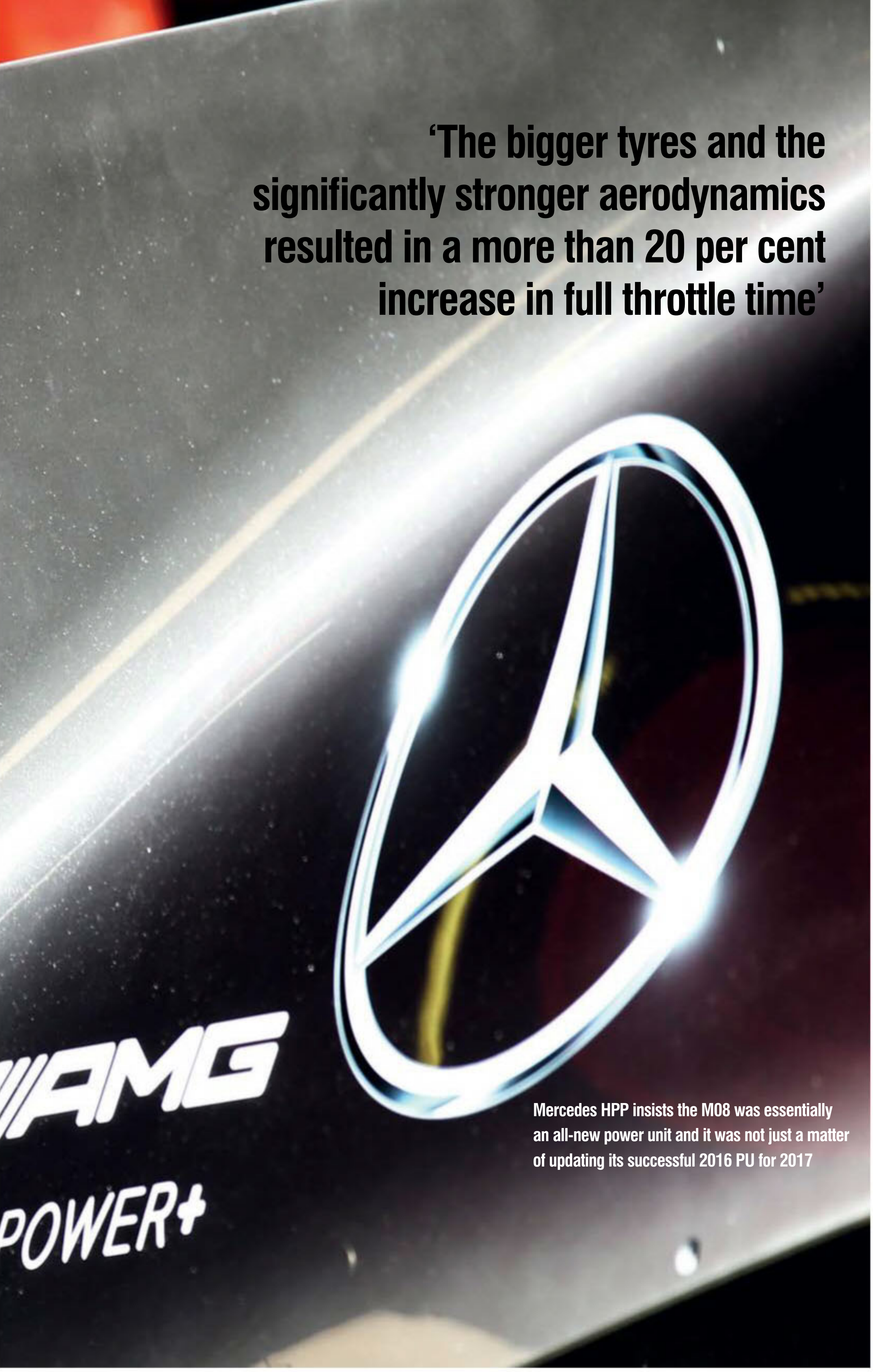
Max energy deployment/lap MGU-H: Unlimited

The heart of a champion

Mercedes has achieved 50 per cent thermal efficiency with its M08 EQ Power+, while the power unit has also propelled it to a fourth consecutive title. *Racecar* talked to HPP boss Andy Cowell to uncover the secrets to its success

By SAM COLLINS

‘The bigger tyres and the significantly stronger aerodynamics resulted in a more than 20 per cent increase in full throttle time’



Mercedes HPP insists the M08 was essentially an all-new power unit and it was not just a matter of updating its successful 2016 PU for 2017

The 2017 season witnessed great change in Formula 1; the ownership of the championship changed, even the series logo was replaced. But most importantly of all there was a huge set of changes to the technical regulations. But some things remained the same, including almost the entire set of technical regulations relating to the power unit. Unsurprisingly, then, the power units developed by Mercedes-AMG High Performance Powertrains (HPP) in Brixworth, England, remained dominant.

But the story is not quite so simple. With the stability in the engine regulations Mercedes might have been expected to gently evolve its 1600cc V6 turbo engine and related hybrid system for 2017, yet the M08 EQ Power+ (as the 2017 power unit is officially known) was essentially all new, and this was actually due to those changes in the 2017 chassis regulations.

‘The biggest change for us was the increase in full throttle time,’ says Andy Cowell, managing director of Mercedes-AMG HPP. ‘The bigger tyres with the significantly stronger aerodynamics resulted in a more than 20 per cent increase in full throttle time. We had to manage the cooling in the power unit a lot better, making sure that things do not overheat. Being on the throttle for longer means that the cool down time reduces significantly. We had to do a lot of work to manage that cooling side, and that had an impact on the chassis too.’

As well as the increase in on-throttle time there was also a decrease in the number of power units allowed per driver from five in 2016 to four in 2017. This placed a particular focus on reliability for PU manufacturers. ‘With four power units per driver, the number of revolutions at full power per unit is substantially higher, so a key objective is that we made sure we were reliable, but at the same time not giving up any performance in order to be reliable. You can always make any machine reliable by taking performance away,’ Cowell says.

Fully loaded

Complicating those reliability demands was the higher stress on the structural parts of the power unit coming as a result of the cars having a higher cornering speed, this was especially the case with the crankcase and cylinder heads, both of which are fully stressed members.

‘The step in loads from 2016 to 2017 was the biggest we have seen in a long time, and it was a concern,’ Cowell says. ‘A lot of the structural side is actually looking at kerb loads, single overload cases, as well as the high cycle fatigue because the engines are doing 4-5000km in the car and the mounts in particular are in that high cycle fatigue arena. You can’t [just make things heavier], you have to be so careful that you don’t throw performance away. Like all competitive sports it’s about increasing your performance. There were some surprising areas of improvement, some of the changes we have made about the ways we are working to ensure reliability have actually helped save costs in the factory too.’

Reliability drive

Reliability was also a key concern for the engineers at Brixworth following a spate of high profile failures in 2016 which ultimately decided the outcome of the drivers’ championship (see *Racecar* February 2017 edition, V27N2). Cowell and the management took action to ensure that there was no repeat of the failures. ‘It was a big team effort to improve the reliability, 2016 was not a year to be proud of in terms of reliability. For 2017 there are about six design changes within the engine to improve the bearing system and probably three or four quality improvements in the way that the power unit is assembled and then looked after through its life,’ Cowell says.

But the changes to improve reliability were not limited to the power unit hardware alone. ‘As a senior technical leadership group, from the Easter of 2016 right through the summer, we did a lot of work to analyse what was going on, and work out what we needed to do to prevent that happening again,’ Cowell says. ‘We came up with a list of actions which did not focus on any

It hurts like hell when you are beaten by Ferrari, but it makes it even sweeter when you beat them. It also make us more and more hungry'

Exhaust exit from turbine with its red bung; clutch basket below it

one department, there were actions for every single part of the company. There were actions with regards to the culture of the company too. I'm exceptionally proud that we went on and did that, nobody argued, nobody shirked any responsibility. Progressively we have seen the benefits in the factory, long runs on the dyno and thankfully on the track. It was a real holistic look at our weaknesses and vulnerability and not just papering over the cracks. It goes right from the way we do our research, the way we approve steps forward, the way we do our concept reviews, the way we confirm that development is appropriate, the way we work with our suppliers, the way we manufacture the bits ourselves, and the way we assemble parts. So, the quality throughout the whole value chain has been lifted.'

Going the distance

At the end of the 2017 season it was very clear that this process had worked, Mercedes only suffered a single power unit failure during a grand prix in 2017 (Valtteri Bottas at the Spanish Grand Prix). This was not just the case for the works team but also both Mercedes customer teams, Force India and Williams, though the latter did retire one car from the Hungarian Grand Prix with a concern that there was an oil leak, but even including this it was a significantly better record in terms of reliability.

With the higher on-throttle time and an increased frontal area as a result of the new aerodynamic regulations and wider tyres it was expected that fuel consumption would increase for all the Formula 1 cars. As a result the FIA increased the total race fuel allowance to 105kg (from 100kg). Despite this, Mercedes stated openly that it would try to complete all races in 2017 with 100kg, regardless of the higher maximum allocation.

'That went pretty well, but I'm not going to give you a number of what we achieved!' Cowell says. 'I think the aerodynamic team did a really good job at coming up with a really efficient package, as well as that the power unit took a step up in efficiency. So the 105kg allocation was not a problem in any of the races.'

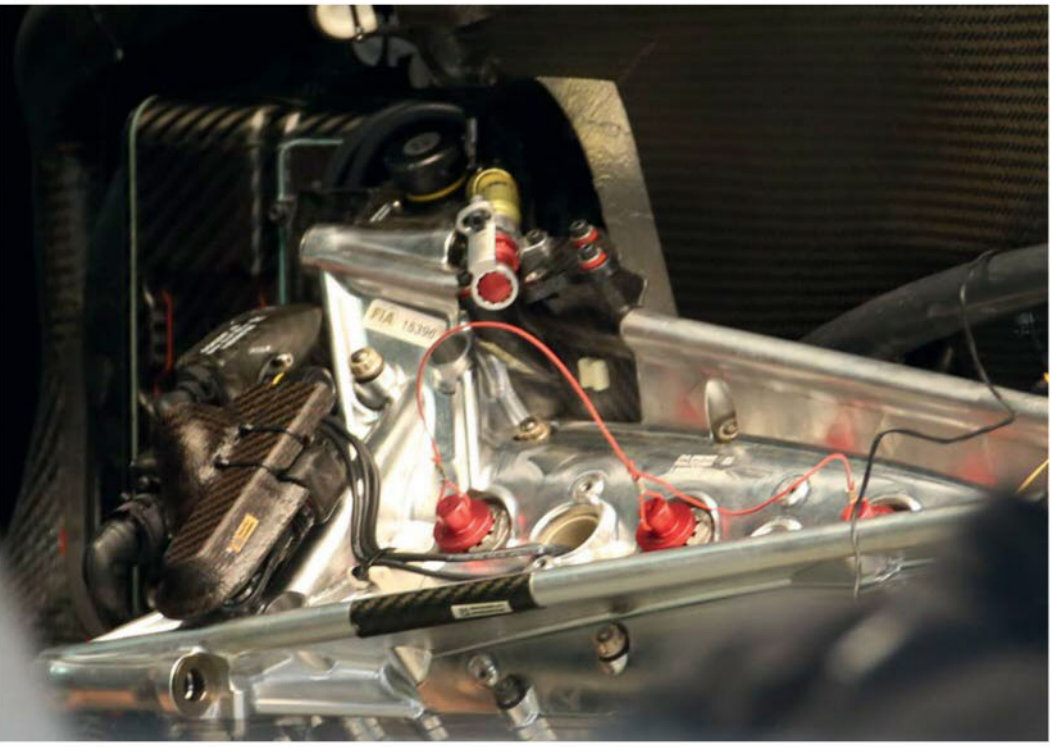
Efficiency milestone

In the second half of the 2017 season Mercedes announced that one of its 2017 power units (serial number GH50) had achieved 50 per cent thermal efficiency on the dyno, and a performance improvement of 109bhp over the 2014 power unit, which achieved 44 per cent thermal efficiency. It was hinted in a video posted on social media by the team that the dyno run where 50 per cent efficiency was achieved was done with slightly cooled intake air, but it's still a very noteworthy feat.

'That's the really good thing about the regulations as they are, they make sure you come up with a very efficient car,' Cowell says. 'Actually, going back some years everyone used to work hard on fuel consumption. The start weight of the car is important because that opening lap and the run down to the first corner is super critical. Reducing fuel weight meant that you asked how many metres could you gain in the run to the first corner, how much more agile would the car be? It can give the edge over your opponents in the opening laps when you are racing wheel to wheel. So, yes, we have always looked after the amount of fuel we use in the race, especially so since 2014.'

MGU improvements

Some of the efficiency gain came via redesigned components in the hybrid system. Both MGUs on the power unit were new designs for 2017 and again came as a result of the increased on-throttle time. 'The MGU-K duty cycle went up considerably, and the MGU-H duty cycle of course goes up with the increase in full throttle time,' Cowell says. 'There was an adjustment on the power level of the MGU-H, based on where we felt we were with the overall balance of efficiencies. With the MGU-K we wanted the on-time to be as close to the full throttle time for the driver, so with that increasing the duty increased too. That increased the cooling



Cylinder heads are fully stressed parts; it's believed they were reworked mid-season when the loads were better understood


188.0
89.1
109.1
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4
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1:49.400
-0.002

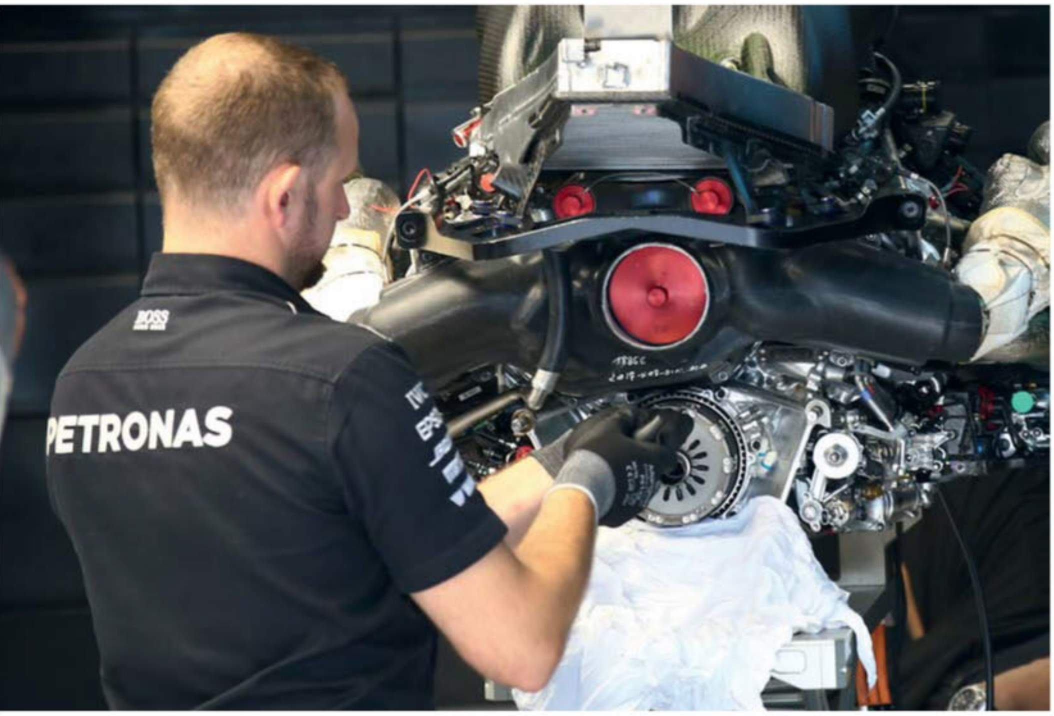
‘We are always thinking about the next challenge, how to make it better’

demand so we made some improvements to the efficiency of the electric machines, just through better design, but the increase in full throttle time outweighed that. We ended up increasing the flow rates of the cooling fluids, for example, to ensure the transfer of heat away from the areas where there is loss.’

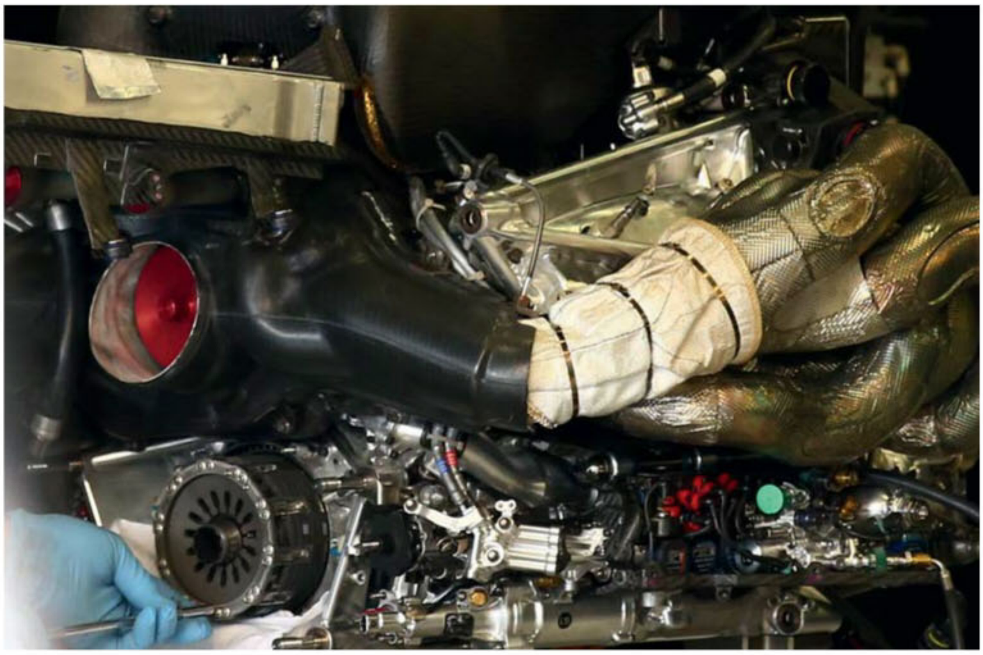
Reliability was also a key concern for the hybrid system, as there had been some issues in 2016, and even at the launch of the 2017 Mercedes F1 car Cowell was willing to admit this, telling the press that: ‘The base architecture of our ERS system is similar to what we started with in 2014. We started with a module that houses the two inverters and DC-DC converters and lithium-ion cells underneath the fuel cell. Is it the same for this year? No, it’s not. There’s improvements in the high-power switches, so the high-power switches are more efficient. There are several improvements on reliability within the box, which means we can run it harder for longer. We are not as vulnerable to having to de-rate the system for cooling reasons because of heating effects within the module.’

During 2017 there were suggestions from a number of people in the sport that development of hybrid systems had perhaps plateaued somewhat, due to the regulatory restrictions on the MGUs, for example, but Cowell argues that even with these restrictions in place there is still significant scope for development. ‘Neither one of the MGUs is at 100 per cent efficiency, so of course there is still room for improvement, though as time goes on the amount of the room for improvement reduces,’ he says. ‘Every single ancillary within the entire power unit has losses and those losses are missed opportunities to propel the car along. It’s a nice double gain with some components like the MGUs as improving the efficiency also reduces the cooling demand. You might think that an efficiency improvement inside one of those elements might only bring a 250 watt improvement and that is only a five milliseconds lap time improvement, but then you also consider that it is a 250 watt reduction in heat rejection and there is a whole car benefit from that in terms of aerodynamics. It’s a virtuous cycle of improvement.

‘Every machine has room for improvement, there is no such thing as perfection or optimum,’ Cowell continues. ‘It is like nature. Everything is always evolving, things become more adaptable to the surroundings, engineering is the same as that. Our battery, for example. Our battery technology is continuing to improve. If you put 100 joules of energy into the battery and then ask for it back out, some of it has been lost through the conversion, so we are constantly striving to improve the conversion efficiency. We are constantly striving to improve the energy density and safety.’



This shows the level of complexity needed to hit efficiency of 50 per cent – which one M08 unit achieved on the dyno in 2017



Right side of M08. HPP improved the reliability after a slightly disappointing 2016, with just one power unit failure in 2017

Wider benefits

Mercedes is unique in Formula 1 in that it conducts all of its Formula 1 hybrid system development in house, while the other three manufacturers outsource to some degree, and this is something that Cowell believes gives not only a performance advantage, but also a competitive advantage to the wider Mercedes organisation. ‘I think we have had some good gains because of the integration we get not just across the power unit but the whole car,’ Cowell says. ‘The technology we have developed is now cascading into Project 1 [the new Mercedes hypercar project], and Formula E with regards to how to manufacture the motors. The individual parts, the assembly, the testing, the prove out, as well as the engineering at the start of development, that whole value stream is going into other areas now. It is where Formula 1 drives that relentless development.’

As the Formula 1 power unit regulations have been largely stable since they were introduced in 2014 (aside from the notable introduction of variable inlet systems in 2015) there have been many who expected the gap between Mercedes and the other three power unit manufacturers to close up as a result of

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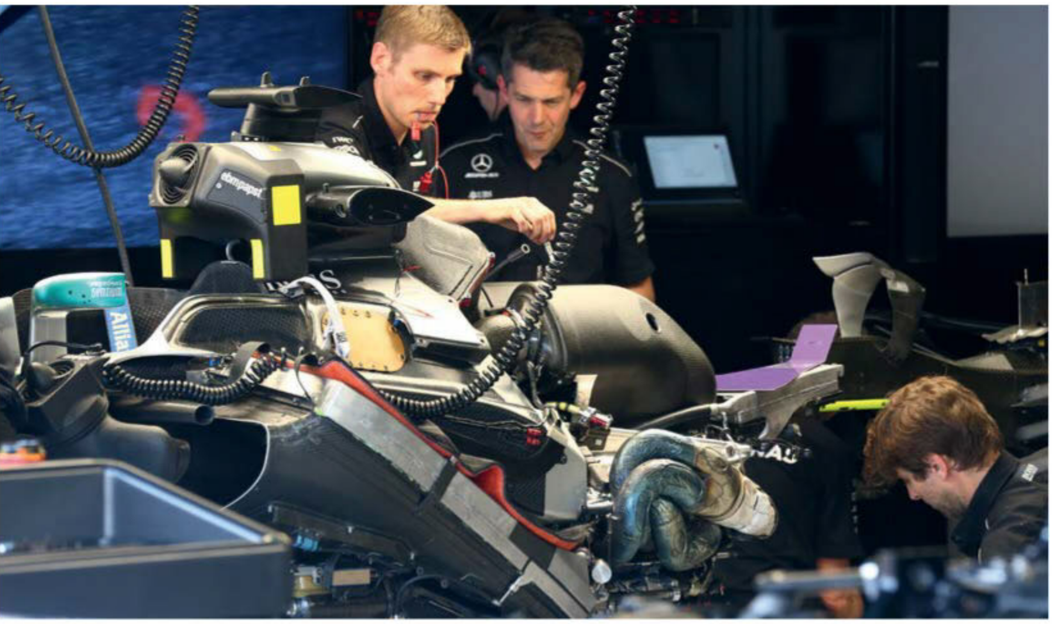
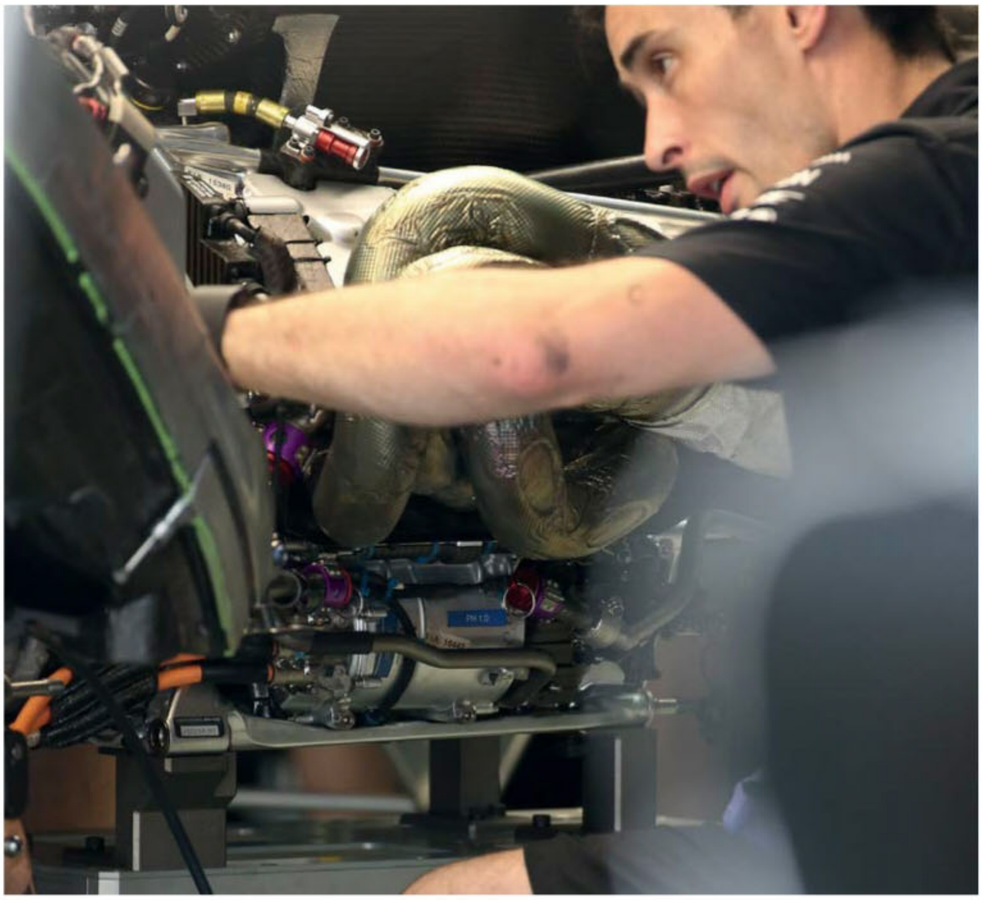
'You can make any machine reliable by taking performance away'

the law of diminishing returns, and in 2017 this seemed to be the case with Ferrari's performance improving significantly. 'I hate that phrase "diminishing returns", it makes people assume that there are no more gains to be had, and I fundamentally disagree with the statement that there are no more gains to be had' Cowell says. 'There are always gains to be had, some of them may be tiny marginal gains, some you get through hard graft, but some are still eureka moments from being open minded enough to explore new things, and sometimes from re-exploring things you have already explored before.

'Huge congratulations to Ferrari, they absolutely reacted the right way to strengthen the organisation and dig deep, recruit and invest and it has really paid off for them this year,' Cowell adds. 'Their adapting to the aerodynamic regulations was superb and the power unit took a step. It's been great fun. Every single competitive person wants a strong opponent and this year that has improved the focus and drive at Brixworth. It hurts like hell when you are beaten by Ferrari, but it makes it even sweeter when you beat them. It make us more and more hungry.'



M08 installed in the W08. It was the new chassis regulations that were the main driver for many of HPP's PU developments



MGU-K is seen here mounted low on the left hand side of the M08 block. Both MGUs were new designs for the 2017 season

Developing in-season

Perhaps then it was this hunger that led the engineers at Brixworth to embark on a rapid development programme for the M08? No longer constrained by the so called token system they were free to develop four different specifications of power unit through the season without penalty. The first version of the power unit ran on track at Silverstone in February 2017 for a short shakedown and by the time the season had come to an end, over nine months later in late November at Abu Dhabi, the M08 had changed quite substantially.

'During that time over 50 per cent of the unit changed and there were big bits changing,' Cowell tells us. Some of those 'big bits' are thought to include the crankcase and cylinder heads as major load bearing parts. With the loads that the power unit would have to withstand uncertain during its development due to a lack of accurate tyre data the engineers found ways to make gains during the season as better data became available.

'We did manage to get a bit of weight off in-season,' Cowell says. 'The simulation work on chassis and power unit structural requirements, that worked very well and that is a continuing evolution now, the guys in the wind tunnel are continuing to improve the downforce that the surfaces are capable of generating and Pirelli are improving the tyre characteristics so that there is more grip from the tyres, while the vehicle dynamics people are improving too, creating a car that goes round the corners like it is on rails. That all sees the structural loads continue to go up again!'

Oil burner

One change that Mercedes had to consider during the season was a limit on oil consumption. During the pre-season period in early 2017 speculation was rife that at least two of the power unit manufacturers were using oil to supplement their fuel. With a fuel flow limitation in place it would be theoretically possible to get a performance boost by dumping additional engine oil into the combustion chamber. However, a technical directive that was sent out by the FIA during winter testing stated, quite unequivocally, that using oil as fuel was forbidden.

'The regulations at the start of 2017 did not have a definition of what an oil is, there was also no restriction on oil consumption,' Cowell says.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'Every single engine, including the one in your road car, will consume some oil, and that consumption happens in the combustion chamber'

'When Charlie [Whiting, head of F1 Technical Department] sent out the directive at the start of the year it said you cannot use oil as fuel, but we sat down with the FIA and pointed out that the technical directive was unenforceable as every single engine burns some oil in the combustion chamber, so it is therefore a fuel. Every single engine, including the one in your road car, will consume some oil and that consumption happens in the combustion chamber. Modern road cars don't leak oil any more, there is no longer that black spot on your driveway. The oil that is being consumed is through the combustion chamber and out through the tailpipe and there is some heat release and therefore it is a fuel.

'Racing engines have always consumed more oil, as you are reducing the friction on the piston rings at the expense of oil consumption,' Cowell adds. 'You can always top your oil tank up, it only has to last a race, it's not a 10,000 mile service. With the type of engine we have got the performance penalty of oil being burnt in the combustion chamber is not as high. It was suggested that the manufacturers work together with the FIA to come up with a limit on oil consumption. They measured consumption at Barcelona and came up with a limit for 2017, and there is now a limit in the 2018 regulations and we completely support that. There is also a definition of what an oil is.'

Catch tanks

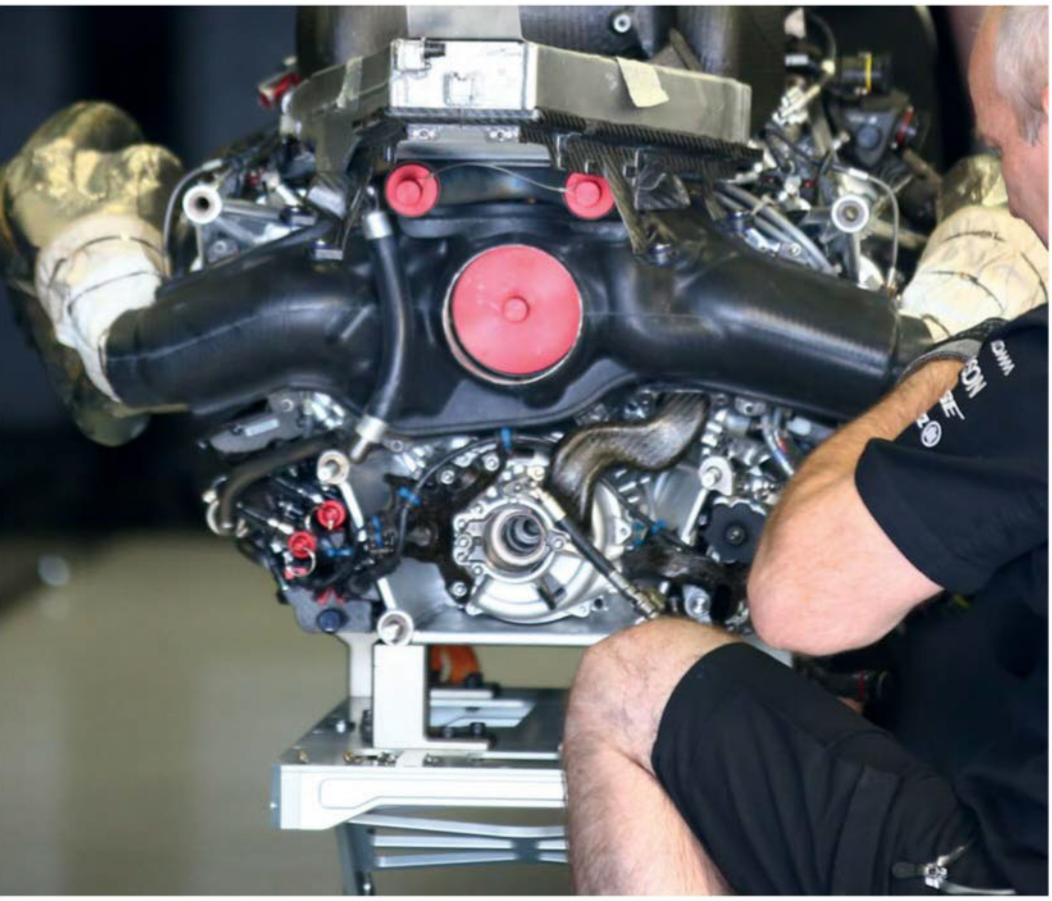
An oil consumption limit of 1.2 litres per 100km was introduced, and then further restricted to 0.9 litres per 100km from the Italian Grand Prix onwards. One alternative suggestion to avoid this debate was for Formula 1 cars to use catch tanks, as they used to in the past.

'It used be the case that blow-by would go overboard but it would be via a 1-litre catch tank. But then there was no incentive that the catch tank would not dump out at race starts, so you had this ugly sight of cars puking oil onto their fellow competitors in the opening lap of the race. The regulation was then changed to have blow-by gasses fed into the intake, which matches road cars,' Cowell says.

Forward thinking

Despite winning both world championships and powering Force India to fourth in the table and Williams to fifth, the M08 EQ Power+ was not the most successful Mercedes power unit of recent years, but it was the most powerful and the most reliable. However, it has now been retired and the engineers at Brixworth have moved on to the next challenge. 'Going into 2018 year on year, the carry over is close to zero again,' Cowell says. 'With the allocation dropping to three units per driver for the season, the continual combustion development, the friction reduction, learning about how to remove the heat, there is not much to carry over. As engineers we are always thinking about the next challenge, how to make it better. That is the great thing about the human race. The human race is very good at thinking about how to improve and how to do things better, it's that way in business, in life, it's the same for an eight-year-old doing a spelling test.

'The mission is to do better the next time and our brains are always creating ways to do better next time, and that is the case in the whole industry, isn't it?' Cowell adds. 'The 2017 power unit is 25,500 individual parts coming together to deliver impressive levels of power to the rear wheels consistently and reliably. But there is a list of things we want to improve for next year, and that is everything in the power unit. The job is not done.'



The rear of the M08 showing the exhaust layout and the turbine location. The turbine can rotate at a staggering 125,000rpm

Batteries included

Formula 1 is exploring options for its future, especially regarding power units. Proposals for the 2021 power unit regulations suggest that, similar to Formula E, all cars will utilise identical batteries and control electronics. This has not proven to be universally popular.

Here's Andy Cowell's take on it. 'I think Formula 1 should be a technology development platform for key technologies in the automotive world. There is not a single motor manufacturer out there that is saying that battery development is unimportant, there is not a single government in the world that is saying that battery development is unimportant.

'I personally feel that it makes sense to use the competitive ingenuity platform that is F1 to drive better development,' Cowell adds. 'This would see the energy density going up, the mass of EVs and PHEVs going down. It is a key technology for the next 20 years for the automotive and transport industry and that is not the limit. Even our homes would benefit from battery technology improvements which could come from Formula 1, having cells installed that can be charged up overnight, and so it would be the battery which would power the kettle in the morning rather than putting the demand on the grid.'

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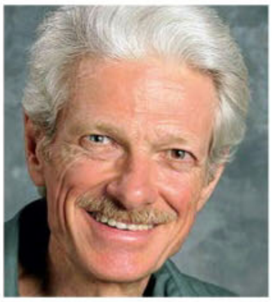

Locating roll centres on a Model T Ford

The suspension quirks of that most famous of old Fords

QUESTION

Could you tell me how to determine the front and rear roll centre for a Model T Ford? Most modern books only talk about the SLA suspensions. The Model T has a buggy spring at both front and rear locations. The ends of each spring has one end of the spring shackle attached to it, and the other end of the spring shackle is attached to a perch that is attached to the axle. I do not know where to determine the roll centre from; the line through the spring shackle where it attaches to the spring or the line through where the spring shackle attaches to the spring perch? Or is there another factor used to determine this?

I think the buggy spring suspension (side to side single spring) was used on many early vehicles. Many books discuss solid rear axles with orientation of the leaf springs mounting points ahead and behind on each side of the rear axle, but do not discuss a single spring attached to the left and right ends of the axle.

What about the advantage or disadvantage of installing an anti-roll bar to the front axle? I know from a historic point of view it would be out of place; this car is otherwise stock, not a hot rod. But would it work?

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The Ford transverse leaf spring suspension provides a roll centre a bit below the upper portion of the spring. It is hard to pin down the location exactly, because the system doesn't really locate the axle very precisely in the lateral direction. The spring has shackles at both ends. To provide really positive lateral location, it would have to have a shackle at just one end.

As it is, theoretically the axle can roll a little about a front view centre of rotation defined by the intersection of the front view shackle centrelines, without deflecting the spring at all. It will tend to do this when acted upon by a lateral force. The axle can also roll a lot more, deflecting the spring, about a centre of rotation defined by the spring. The actual roll when cornering is a combination of these two types of motion.

On the right there is a picture of a Model T in a condition of extreme warp displacement. It appears that the axles are rotating about points pretty close to the spring mount on the frame.

However, there is no cornering force present in that picture. The car is sitting still, on a very irregular surface.

Lateral axle location with this system depends heavily on the converging radius rods that locate the axle longitudinally, and on the rigidity and wear condition of the shackles. In stock form, the radius rods converge to a single pivot ball on the car centreline. For the axle to move laterally with respect to the frame, it has to pivot about that point. One end of the axle has to move forward and the other end rearward for that to happen.

The shackles and the spring have the job of resisting this. That depends on the shackles being rigid in the *XZ* (longitudinal-vertical) plane despite their having to be able to rotate in the *YZ* (transverse-vertical) plane to let the suspension move. If we replaced the shackles with drop links, the whole system would become very wiggly. When the shackles get worn, the system starts to act like that.

Model T mods

The Model T spawned a brisk trade in all manner of aftermarket accessories and mods, including some intended to improve the suspension. These included various types of additional springs. Some of these added stiffness and some made the springing softer. I don't know of any torsional anti-roll bars being tried, or any other springs that would do the same thing. Would anti-roll bars work? Sure. You could add them in front, in back, or both. They'd do the same thing on that car as on any other: stiffen the springing in roll and warp; add lateral load transfer when cornering on the end you stiffen and reduce it at the other end.

To add roll resistance yet retain the warp softness of the original configuration, it would also be possible to use longitudinal anti-roll/anti-heave Z bars as are used on Packards, front and rear anti-roll U bars with hydraulically connected telescoping drop links, or diagonal anti-roll/anti-pitch U bars.

What the Model T really needs most urgently is some form of damping. It's got no shocks. So the only damping is the friction between the spring leaves.

If I were designing a transverse leaf spring and I wanted to use it to locate an axle, I think I would give it little enough arch so it was close to flat at design ride height, have no shackle at one end, and use a shackle or a drop link at the other end.

Roll resistance

To add roll resistance without adding a separate anti-roll bar, the spring could be attached to the frame at two points rather than one. One of these attachment points has a locating pin and anchors the spring in three axes. The other attachment point has rolling or sliding contact with the spring and constrains it only in the *X* and *Z* axes. In synchronous wheel movement, the spring deforms in a U shape; when the ends go up, the middle goes down. In oppositional wheel movement, one end goes up, the other end goes down, the middle stays in the same place, and the spring deforms in an S shape. The spring thus has a higher rate in oppositional displacement than in synchronous displacement, similar to a conventional spring and anti-roll bar.

When using such a spring to laterally locate the axle, the end nearest the pinned mount would get a shackle or drop link, while the end nearest the unpinned mount would just have an eye.

A Model T Ford in a condition of extreme warp displacement. Front roll centre is a little bit below the top of the leaf spring

What the Model T really needs most urgently is some form of damping

Four-link rear suspension

The possibility of binding when the racecar's in roll or single wheel bump

QUESTION

I read your article in the November 2017 issue of *Racecar Engineering* [V27N11] with interest. It concerned four-link rear suspension as used on an Australian V8 Supercar. To my mind this arrangement must bind in roll or single wheel bump. Consider the car in rear view rolling to the right with a roll centre below the axle lateral centreline, the upper and lower link pick up points on the axle will move inwards relative to the car body but by different amounts, the upper to a greater extent than the lower.

Therefore, in right side elevation the top link shortens to a greater extent than the lower link, which forces the axle to rotate clockwise. The inverse applies to the left side links which attempt to produce an anti-clockwise rotation.

I would argue that a four-link suspension must rely on compliance in the system to allow any roll at all (conflicting arcs everywhere). The three-link suspension won't have this problem. Also, three links are statically determinate. How the loads are shared between four links will depend on the relative stiffness of the links and the structure they are attached to; how this is analysed is beyond me.

On an historic note, cars built in the '20s such as the Vauxhall 30/98 used a torque arm offset to the right, whether to counteract torque wedge or just to clear the driveline, I don't know, but it is interesting to note that the foot brake operated on the front wheels and a transmission brake at the back of the gearbox, and the rear brakes were operated by a handbrake.

THE CONSULTANT

As a practical matter, verifiable experimentally, a system with four trailing links and some additional lateral locating device will not bind in roll within the travel limits imposed by the joints and the various other packaging constraints involved, if and only if the links are parallel in both side view and top view.

If the links converge or diverge toward the front of the car in top view, then there will be some bind in roll as described by the questioner, above. With rigid rod ends, it does not really take a very big deviation from parallel to produce a bit of bind.

Sprint car lesson

Some years ago, I had the opportunity to observe this. The shop next to mine was occupied by a sprint car builder. We had a sprint car frame with front suspension up on a table, with no springs, shocks, or wheels installed, so the suspension could easily be moved around by hand.

The suspension had four long leading links and a Panhard bar. The leading links were parallel in side view but not quite parallel in top view. They were a bit further apart at the axle than at the frame. They splayed out at the front by about three inches per side. The suspension had a slight bind in roll. It wasn't enough to prevent you from moving the suspension large amounts in roll with your hand, but you could feel a little resistance.

Then we removed the top left leading link. There was then no resistance at all. After that, all of that particular builder's racecars no longer had an upper link on the left.

It is pretty common to have a long torque arm just to the right of the driveshaft. This was used not only on Vauxhalls in the 1920s but Bugattis as well. More recently, it was used on Chevrolet Camaros, as well.

Such an arm is too long and not sufficiently offset to provide very much cancellation of torque roll, but there is a little. It makes more sense to have the arm on the right than on the left. Shown to the left is a car with a beam axle on three longitudinal links, and also a transverse leaf spring with a shackle on one end and just an eye on the other.

When we removed the top left leading link there was then no resistance at all. After that, all of this builder's racecars had no upper link on the left

This crazy car has a beam axle on three longitudinal links and also a transverse leaf spring with a shackle on one end, then just an eye on the other. The question concerns the pros and cons of four-link and three-link suspension set-ups

CONTACT

Mark Ortiz Automotive is a chassis consultancy service primarily serving oval track and road racers. Here Mark answers your chassis set-up and handling queries. If you have a question for him, please don't hesitate to get in touch:

E: markortizauto@windstream.net
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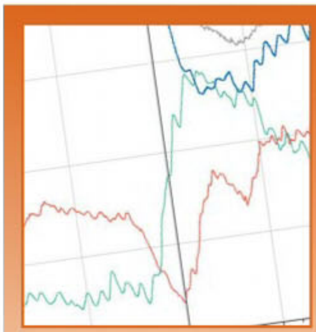


Databytes gives you essential insights to help you to improve your data analysis skills each month, as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems

The direct approach to petrol injection

Gasoline direct injection is now the norm in motorsport, but it takes a little electronics know-how to configure and calibrate these systems

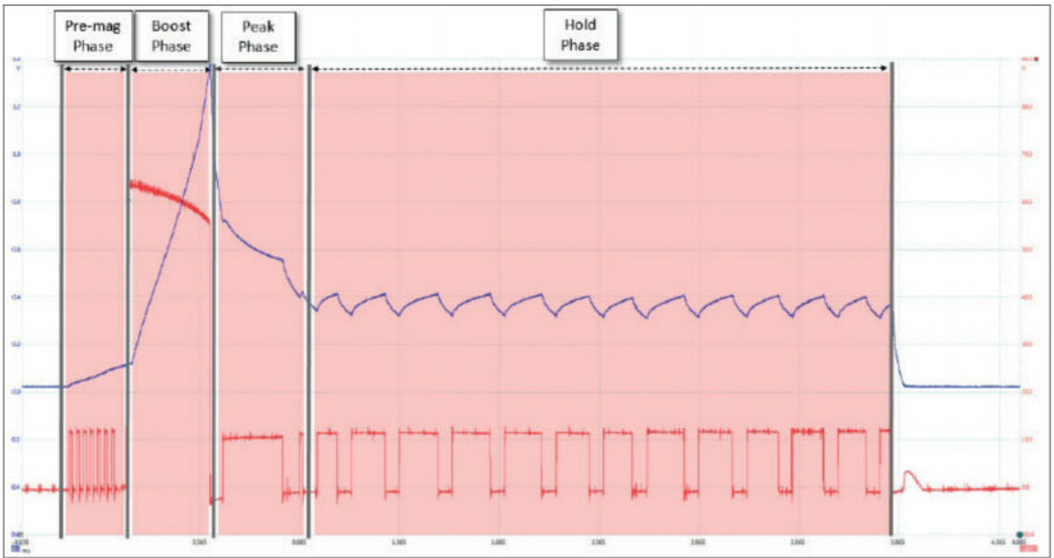


Figure 1: An injector current (blue trace) waveform with the corresponding injector voltage (red trace) applied

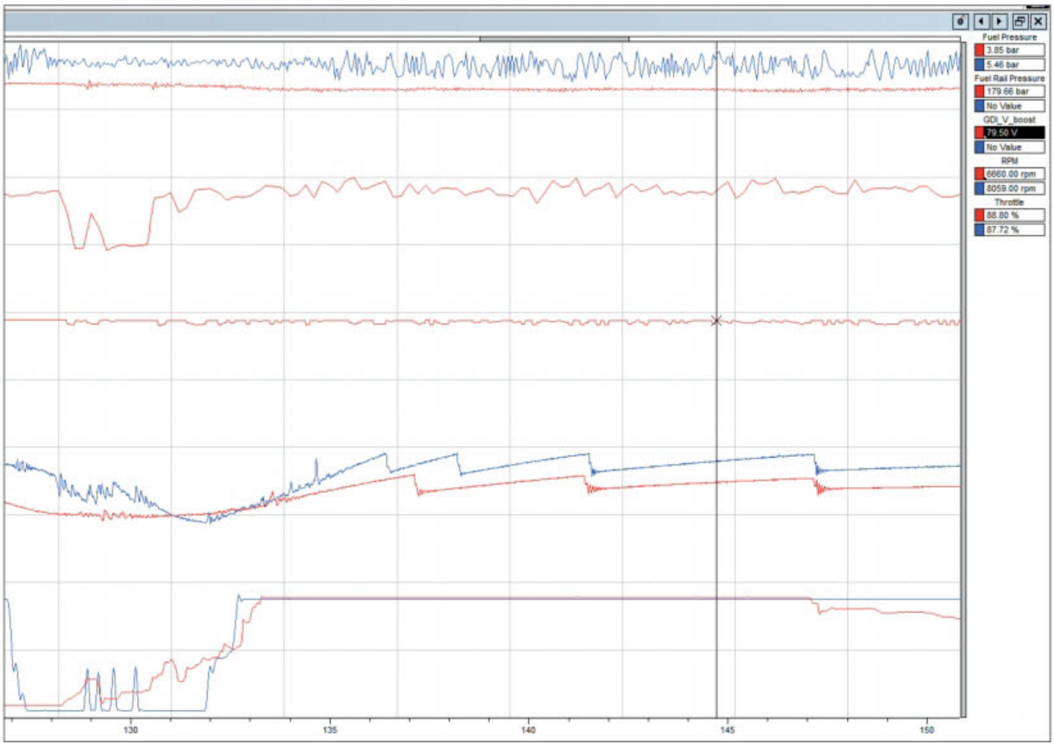


Figure 2: Some GDI injector voltage and rail pressure operating values (in red) and how they compare to PFI (in blue)

Fuel injector technology has progressed greatly in the automotive world in recent times, mainly from an emissions standpoint. And, inevitably, these advancements in technology eventually transition across to the motorsport environment. The main driver of their use in motorsport can vary between utilising base engine platforms that feature these technologies, or exploiting their benefits within motorsport applications.

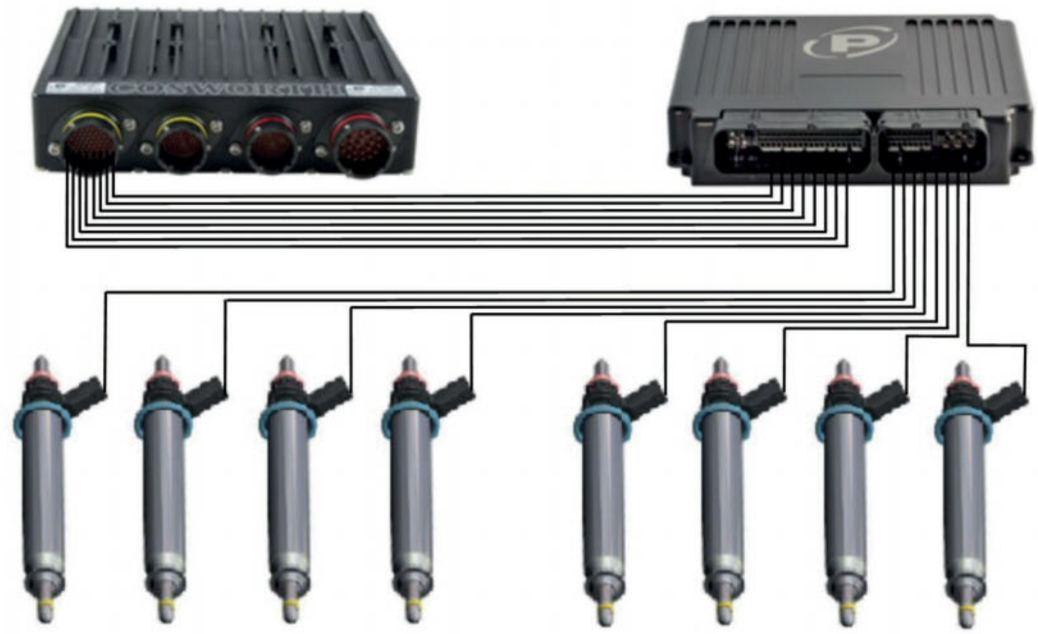
Gasoline Direct Injection (GDI) is now widely used in motorsport across all sorts of applications and it is rare nowadays to find a port fuel injection (PFI) engine, but some engines also combine both port and direct injection technologies together.

Four phases

There are four distinct phases when configuring a GDI injector:

- Pre-magnetisation phase – where the battery voltage is applied to the injector and modulated to wet the injector coil. No fuel is injected during this period.
- Boost phase – where the injector is driven to the boost current threshold with the boost voltage applied.
- Peak phase – where the injector is held at the peak current with the battery voltage applied.
- Hold phase – where the injector is held open at the hold current with the battery voltage applied.

The oscilloscope trace provided in **Figure 1** shows a typical injector current (blue trace) waveform with the corresponding injector voltage



The injection events are scheduled in the ECU and the injector outputs from the ECU are then wired to the IDU-PZ

More and more piezo injectors are likely to be used in motorsport as they filter down from the wider automotive world

Cosworth has put its injector expertise to work as part of the electronics package in the new Aston Martin Vantage GTE

Piezo injectors operate at even higher voltages with faster opening and closing times. Because of this voltage requirement a separate injector driver box is generally required to drive them

(red trace) applied. The four phases of the injection control described above are also highlighted here.

The electrical characteristics for an injector are provided by the injector manufacture in a datasheet. To configure the calibration parameters the operator should have this to hand. Each injector manufacture has their own terminology for the threshold values to be set.

GDI injectors also operate at much higher voltages and fuel rail pressure than port injectors. This is why GDI engines have a low pressure pump and a high pressure GDI pump, whereas PFI engines only have the single low pressure unit.

Figure 2 shows some typical GDI injector voltage and rail pressure operating values and how they compare to PFI engines. PFI are the blue traces whereas GDI are the red traces. Here you can see the GDI data at 180bar and driven at 80V.

Piezoelectric

In recent years we have seen the automotive industry move over to piezoelectric direct injector technology. The functionality is similar to a traditional solenoid based GDI injector, but they operate at even higher voltages with faster opening and closing times. Because of this voltage requirement a separate injector driver box is generally required to drive them such as Cosworth's own IDU1-PZ unit. Here the injection events are scheduled in the ECU, but the injector outputs from the ECU are then wired to the IDU-PZ where the voltage is boosted to the levels required to drive the injectors, the IDU-PZ outputs then drive the piezo injectors.

Whereas solenoid GDI injectors tend to operate up to 100V, the piezo types can operate up to 200V, which most ECUs cannot drive directly from a single box solution. It is likely that the development path of future ECUs will look to incorporate drivers that are piezo capable within a single unit, particularly as more piezo injectors are used as they filter through from the automotive world.

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Tel: +44 (0)1954 253600
Email: ceenquiries@cosworth.com
Website: www.cosworth.com

Honing a Sabre with rear wing revisions

The Aries Bikesports racer gets its final aerodynamic tweaks

The UK's 750MC Bikesports series is numerically dominated by Radicals, but a new car arrived in 2017, the two-seater Honda 1000cc-powered Aries Sabre. With body design input from Enrique Scalabroni, the Sabre has shown good intrinsic pace with a new Class C (up to 1100cc) lap record at Snetterton, in September 2017, where it also pushed for an overall podium place against the larger Hayabusa-engined Class A and B cars, until chain drive problems led to retirement.

With up to 40 per cent less power than its bigger capacity category counterparts the aerodynamic emphasis on the Sabre is different. The car had been running a simple flat splitter, a 'placeholder' wing mounted high and forwards of the tail, and a short rear diffuser. Following pre-session discussions the Sabre came to the wind tunnel in a specification never previously evaluated or raced, with many test parts already in place, it being quicker to remove parts than to attach them. A new low, well-aft positioned full width rear wing was complemented by a longer rear diffuser with extended tail section above, wide front diffusers, and various other parts in place. The baseline run produced fairly low drag, modest downforce, and a 50 per cent front aero balance, slightly too far forwards for a car with a static weight distribution of between 45 and 50 per cent with driver aboard.

Winging the changes

Following wing angle and front diffuser angle mapping, outlined in the last two issues, some alternative wing locations were tried, and the car's original wing was also evaluated. First the team wanted to check that the aft-mounted location wasn't creating too big a lever arm and taking too much downforce off the front tyres. So the new wing was moved 170mm further forwards, where its forward mounting picked up on the rear mounting point of the original wing, but it was only very slightly higher than the baseline position. The angle was kept constant at three degrees. **Table 1** shows results compared to the mid-session re-baselined configuration. The changes or 'delta' values are shown in counts, where one count is a coefficient change of 0.001.

A 37 per cent reduction in rear downforce and a big forwards balance shift were clearly negative responses. Drag also increased by a small amount. The loss of rear downforce and the drag increase may both have been partly due to blockage under the wing, because it was clearly too close at three points across the span. So the new wing was then mounted on the uprights that were used to support the old wing, considerably higher and another 150mm further forward, with the same 3-degree angle. The data are shown in **Table 2**, compared to the new wing in its low, aft location.

Drag net

This was an interesting comparison. The aerodynamic balance (%front) was much the same as the baseline set-up, but drag was 8.3 per cent higher and total downforce was 4.7 per cent lower. Of note was that downforce was lost at the front and the rear, which strongly suggests that the wing in the low, aft baseline location was interacting with the underbody, from where a significant proportion of the extra downforce would have been coming. The low, aft wing was also a much more efficient configuration, the –L/D value being 13.8 per cent higher. Given the limited power of the 1000cc engine, it seems very clear what the preferred location for the wing would be, although more detailed

The response may have been partly due to blockage under the wing

Table 1: The effects of moving the new wing forward

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.459	0.698	0.318	0.381	45.5%	1.523
Wing 170mm fwd	0.465	0.600	0.362	0.239	60.3%	1.290
Δ, counts	+6	-98	+44	-142	+14.8%*	-233

Absolute rather than relative difference in percentage front.

Table 2: The effects of mounting the wing high and further forward

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.459	0.698	0.318	0.381	45.5%	1.523
Wing high and fwd+	0.497	0.665	0.309	0.356	46.5%	1.338
Δ, counts	+38	-33	-9	-25	+1.0%*	-185

Absolute rather than relative difference in percentage front.

Moving wing 170mm forwards had resulted in a 37 per cent reduction in rear downforce

Higher location restored balance but not efficiency, and lost interaction with underbody

Almost all of the rear downforce disappeared when the old wing was fitted to the Sabre

Redundant inlet duct cowl (left) was cut off and taped over (right) with modest gains

Tonneau cover produced a minor surprise, with the small downforce gain all at the front

New end fences (right) shifted balance well forwards with no negative impact on rear

Table 3: The effects of fitting the old wing

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Old wing	0.447	0.425	0.360	0.066	84.6%	0.951

Table 5: The effects of fitting a tonneau cover

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Plus tonneau	-1	+10	+13	-4	+1.2%*	+26

*Absolute rather than relative difference in percentage front.

Table 4: The effects of tidying up a redundant inlet duct cowl

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Minus cowl	-1	+17	+10	+7	+0.4%*	+37

*Absolute rather than relative difference in percentage front.

Table 6: The effects of fitting the larger splitter end fences

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front	Δ-L/D
Plus bigger fences	+24	+79	+78	+1	+6.5%	+125

mapping of the low, aft location would, no doubt, further refine the sweet spot.

Lastly in this sequence, the old wing was mounted in its original high, forwards location, with an angle of four degrees at the ends and eight degrees in the centre, and the results were as shown in **Table 3**.

Almost all the car's rear downforce disappeared by fitting the old wing. However, to put this in perspective the old wing had a smaller chord and narrower span than the new wing as well as a less cambered profile. Also the car had a shorter rear diffuser and had never previously run with the larger splitter end fences fitted for our test, or front diffusers, whereas 6-degree front diffusers were in place for this run. So the car may have had a reasonable balance previously, just at a lower and less efficient downforce level.

To round off our session a few refinements were quickly carried out, and their effects are shown in the tables above. First, a redundant cowl around a previously used engine inlet duct was removed and taped over, with the delta values shown in **Table 4**.The results were modest but beneficial, with a tiny drag reduction and downforce gains at both ends of the car, but mostly at the front.

Next, a simple tonneau cover was fixed over the passenger compartment, with the delta values in **Table 5**. This also gave a tiny improvement to drag and added a modest amount of downforce, but surprisingly this was all at the front, with a small loss at the rear.

Mending fences

Our final test was to replace the larger splitter end fences that had been on the car for the whole session with the smaller ones that were originally fitted to the car. This produced the delta values shown in **Table 6**, given as the effects of fitting the larger fences.

The drag increase from the larger fences was 5.4 per cent but the front downforce increase was 31.6 per cent. The ratio of front downforce counts gained to drag counts was 3.25 to one, so these were reasonably efficient and quite potent devices, accounting for a 6.5 per cent increase in %front. We have found in our studies in the past that making fences any taller than the larger ones used here has tended to reduce rear downforce and ultimately add no more front downforce, so these particular fences look fairly optimal. However, having a range of smaller ones available would enable fine tuning.

Next month, we briefly revisit our project to reduce the drag on a Formula Ford.

Racecar's thanks to all at Aries Motorsport.

CONTACT

Simon McBeath offers aerodynamic advisory services under his own brand of SM Aerotechniques – www.sm-aerotechniques.co.uk.
In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

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Email: enquiries@horiba-mira.com
Website: www.horiba-mira.com

As NASCAR races into its new season its lead R&D engineer talks us through the key technical changes it's made within its three major stock car categories

By ERIC JACUZZI

New year's **revolutions**

One of the major changes is the elimination of ride height rules for the superspeedway events at Daytona and Talladega

This year the Cup cars will run with spec radiator cores and spec bolt patterns for the splitters, as NASCAR moves to reduce development costs

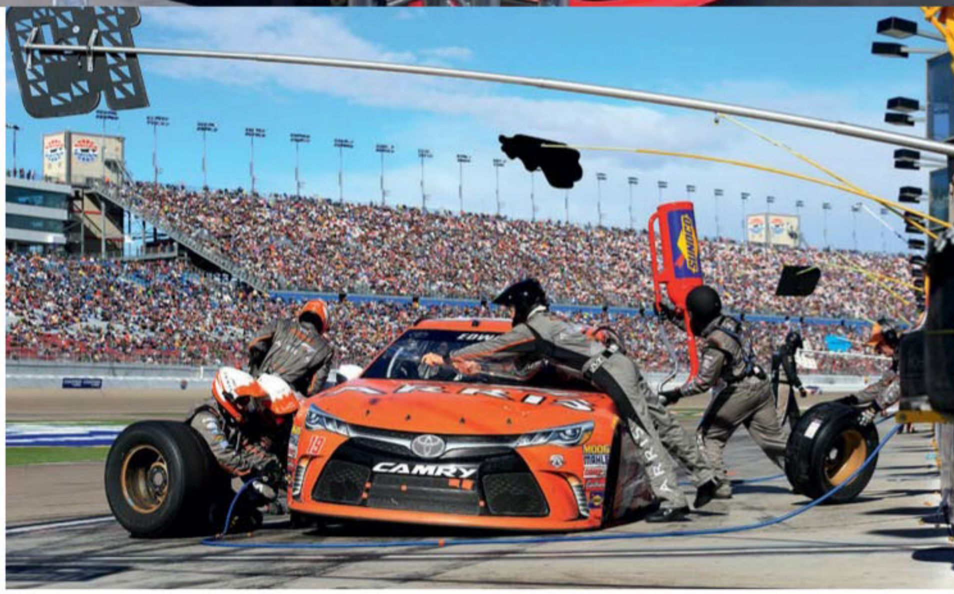
It comes around quick. No sooner have we finished 2017 than NASCAR is starting all over again, in February. And with a new season comes the usual raft of technical changes – NASCAR never sits still.

One of the areas of NASCAR that will take a quantum leap forward this year is officiating of the body and wheel positions at the track. Previously, body inspection was done using mechanical templates to ensure the body was within the allowed tolerances to what is referred to as the 'gold surface'. The gold surface for each manufacturer is the body that was submitted and successfully passed NASCAR's wind tunnel body approval process. The CAD data from this body is then used to create templates in various areas for inspection.

Another critical inspection piece was the Laser Inspection System, or LIS for short. The LIS measured wheelbase and individual toe and camber as well as corner weights. This was done using plates attached to the wheels that were measured by laser.

In an effort to streamline the inspection process, enhance inspection capability and remove subjectivity, NASCAR has developed new inspection technology with Hawkeye Innovations of the UK. Utilising multiple cameras and projectors, the system is capable of scanning the entire body and determining camber and toe within 90 seconds.

Output to teams will show areas of the body that are outside of the tolerances which have been revised for the new scanning technology. The system underwent several trial runs at races in 2017, and will be the main inspection process for both the Cup and Xfinity series in 2018. This will not see the end of body templates, which must still be used for some of the crucial radii and detail that cannot be adequately captured by the scan. Critical areas such as the spoiler and splitter will still be checked by the templates.



Above: NASCAR template inspection. Despite new advances in technology templates will still be used to check critical details
Right: A wheel gun development war has prompted NASCAR to introduce a spec item with monitored line pressure and lug torque

Radiator development had been a hot topic as the teams sought to run higher and higher engine temperatures

Martin Truex's Furniture Row team, with crew chief Cole Pearn, claimed victory in the top-line Monster Energy NASCAR Cup Series (MENCS) after a dominant season in 2017. Looking to 2018, a few changes are in order in the name of cost, competition and safety.

Cooling off

On the component side of things in the Cup, and with costs always at the forefront of many rule changes, NASCAR teams and engine builders agreed to implement a spec radiator and oil cooler package for 2018. Radiator development has been a hot topic as teams sought to run higher and higher engine temperatures, resulting in expensive radiators to handle the extreme water pressures produced and to extract maximum cooling efficiency. Because radiator cooling flow empties under the hood of the cars, this then has a detrimental impact on front downforce, driving teams to run the engines as hot as possible.

Taking these conditions into account and standardising fitting layouts, NASCAR and the industry worked with C&R Radiators to develop the new spec core that will be used in 2018 across all vehicles. Significant savings will be accumulated over the course of the season.

On the aerodynamic side of things, a spec splitter will be introduced for the 2018 season to aid in inspection and reduce costs for teams. With the splitter being one of the most powerful aerodynamic devices on the car, development in this area had escalated to a high degree.

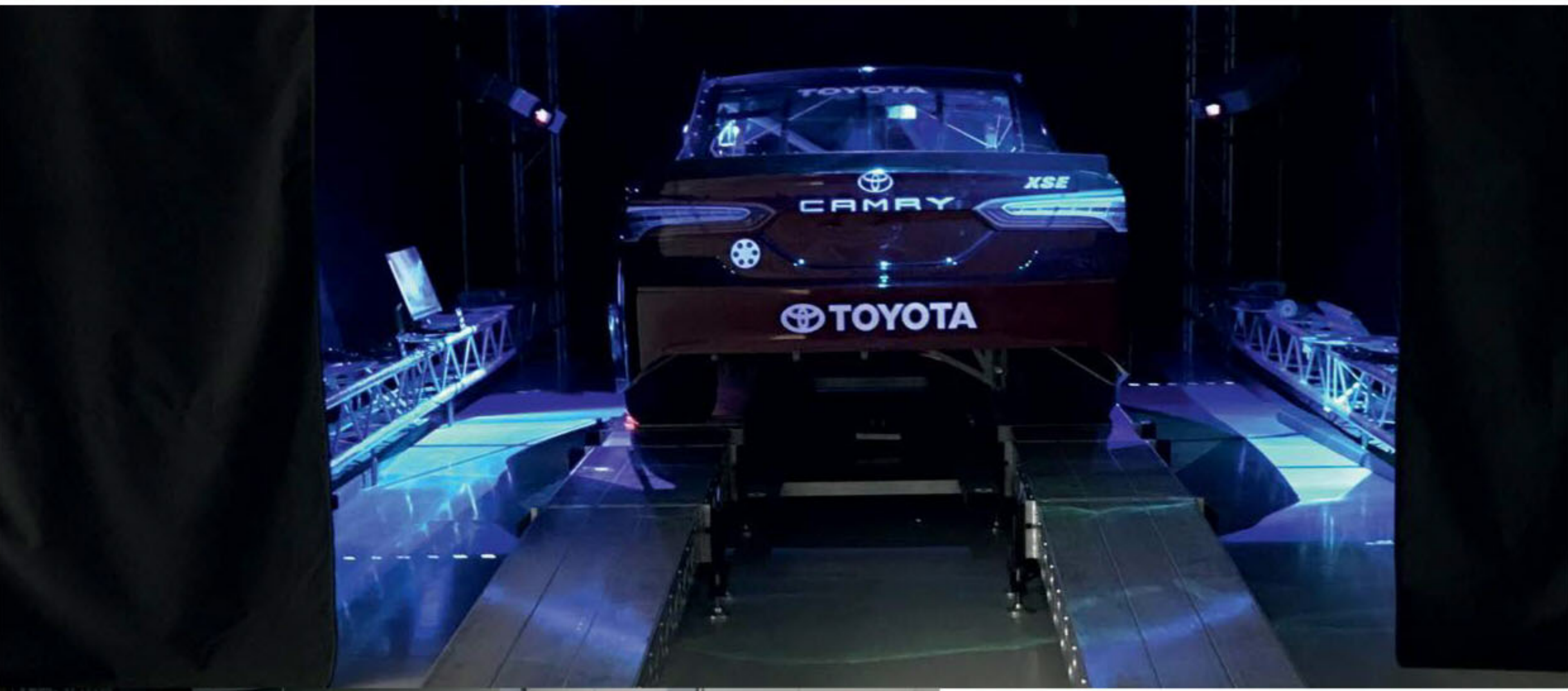
NASCAR splitters are made of a pressed composite material. As development escalated, moulding of the splitter shape became an issue, with extensive effort put in to achieve aero gains and still meet the regs. The end result was a once-simple part becoming a high-dollar item and an officiating headache. NASCAR solicited bids from several suppliers and redesigned the front splitter structure to mandate a common bolt pattern. Savings of more than 80 per cent per piece have been estimated.

On the operational side, it's fair to say the NASCAR pit stop is one of the great pieces of choreography in sport. Instead of waiting for the car to arrive, six pit crew members wait until the racecar is two pit boxes away before leaping into action over the wall. Running to the right side of the car, a front and rear tyre changer drop to their knees and hit five lug nuts at a dizzying pace, while two tyre carriers install fresh rubber and the jack man lifts the car. They then sprint to the other side of the car to repeat the procedure and send the car on its way.

Gun running

A key piece of this process has been the pit gun. As with many things in NASCAR, what was once a humble air gun found in shops has evolved into a specialised instrument. Millions of dollars in R&D have been spent to create ever faster guns and tyre changes, since making up positions on pit road is much easier than on track. In situations near the end of a race the pit crew can ultimately be the deciding factor.

However, this development of faster pit guns has been expensive and does not offer our most



Above: The new inspection system is capable of scanning the entire body and determining camber and toe within 90 seconds
Left: The ongoing switch to composite bodies in the Xfinity Series is a major change. Two of the 11 flange panels are shown here

important contingent, the fans, much tangible entertainment value. The drive for faster pit stops also led to a spate of loose wheels due to incorrectly secured lug nuts.

Working with Paoli, a new spec pit gun featuring monitored line pressure and lug torque will be implemented in the Cup and Xfinity Series next season. The guns will be distributed to each team at the start of the race day and returned to Paoli at the end of the event. The hope is that the new pit guns will reduce costs to teams and level the playing field, and eventually allow NASCAR to use the guns to monitor lug nut tightness in the interest of competition and safety.

The flip side

One of the more major changes that has been introduced is the elimination of ride height rules for the superspeedway events at Daytona and Talladega. After a contact related flip at Talladega in 2016, NASCAR R&D developed several options in CFD to improve the lift-off speed of the MENCS cars, including underbody lift-off panels and eliminating the ride height rules. At superspeedways, teams must meet a 4in ride height at the front and rear of the car before and after races. This means that on the straights, the rear of the car may travel only 1in from the 4in inspection height, compared to when the car is in the banking where it could travel nearly 4in. This created some transient instabilities on corner entry, and from a safety perspective meant that the car would return to a 4in rear ride height when entering a spin.

Low riders

To circumvent development, NASCAR would distribute rear springs and shocks to teams at the event. Since handling is a secondary concern to achieving low drag, the lower the rear of the racecar is at a superspeedway, the faster the car will go. There is of course a limit – the Panhard bar support will impact

One area that will take a quantum leap forward this year is officiating of the body and wheel positions at the track

the track surface if the racecar is too low. This location is tightly constrained.

The proposed improvements were evaluated at the Chrysler Technical Center in Auburn Hills, Michigan. The wind tunnel test validated the CFD results showing a substantial improvement in lift-off speed for both reducing rear ride height and the underbody panelling. NASCAR organised a track test at Daytona International Speedway in April to evaluate the changes on track, with five teams attending. Ultimately, all of the proposed changes had a marginal impact on car behaviour. The elimination of ride height rules was put into the 2018 rules as a cost-effective means to improve the lift-off speed of the cars without necessitating any new parts.

Xfinity and beyond

The NASCAR Xfinity Series (NXS) had another outstanding season of exciting racing in 2017, crowning a new champion in 19-year-old William Byron, who now moves on to drive the iconic Hendrick Motorsports number 24 car in the top-tier Cup Series. The Xfinity series will see several interesting technical changes for 2018, some of which began in the 2017 season.

Xfinity composite cars made their debut alongside traditional steel-bodied racecars at the Richmond Raceway round of the series in September. These will be mandatory from 2019

The current cars in both the Xfinity and MENCS consist of a mix of steel and composite components. The front fascia, hood and rear fascia are produced from composite materials due to the complexity of the shape. The body panels themselves are stamped steel, produced by the car manufacturer. While economical parts, the process to getting them onto the body is arduous in order to meet the tolerances permitted and accuracy desired by the teams.

NASCAR features a very gruelling 38 race schedule, with a mix of low drag superspeedways, high downforce intermediate tracks, and short track/road courses. Chassis and body requirements, while the same in the rule book, have moved toward specialised cars for each of these track varieties to extract maximum performance. The bulk of the schedule consists of intermediate tracks, typically 1.5 miles or greater. The current build process with the steel bodies necessitates a large number of chassis for each team in order to meet the demands of the schedule, in no small part due to the labour-intensive build process.

Build process

For an intermediate track car, a typical turnaround from one race to another would be something in the order of two to four weeks once it returns from a race. The process typically begins with the car being stripped of suspension, engine, cooling and electronic components. The body is typically removed, as race damage is easy to acquire with NASCAR's close-quarter racing. This typically means the front and rear fascia are removed (typically damaged from pushing on restarts), the sides of the body (damaged from contact or pit stops) and even the greenhouse if enough of the car needs to be redone. The chassis is then cleaned and sent to the body hanging area.

The body hangers then begin the process of constructing a new body from the sheet metal stampings after ensuring the components of the chassis are still in the correct location. Components are braced to be held into position on the chassis and then welded together, with the bracing used to meet the regulations and maintain body shape (where desired).

The bodies are then usually scanned to ensure accuracy, then finished to smooth weld seams and correct shaping issues in the steel body. The car is then sent to be painted prior to re-installation of the vital systems. For most higher budget teams, the final stop is a trip back to the wind tunnel to ensure the new build is up to snuff. Because the body of the car is tied to the chassis in a permanent fashion, this process necessitates a large number of chassis, since both need to be prepared and ready to race. The entire process requires significant skilled manpower and inventory. Additionally, the cars are very damage-prone. A slight brush of the wall in practice can result in switching to a backup car, as the damage cannot be repaired adequately at the track to ensure it will pass inspection – and more importantly to teams, perform aerodynamically.

Composite body

With all of the above in mind, composite bodies might be the answer. NASCAR's lower tier K&N series has been using a composite body since 2015, produced by Five Star Racecar Bodies of Twin Lakes, Wisconsin. The K&N series attracts very healthy fields by keeping the costs low, and the composite body had helped achieve this by reducing the costs to the teams. In mid-2016, a small team at NASCAR R&D began investigating whether a composite body could be designed and integrated with the current NXS chassis.

The premise was very simple: save the teams money, increase competition, and reduce tampering. The economics of the composite body were simple, too. The cost of replacing a steel body can range from $25,000 to $50,000, with most of that in skilled labour costs. An early goal of the project was to sell a complete body in the range of $8000, which is similar to the price point of the K&N body.

In order to make installation and repairs easier, the body was segmented into 11 panels that mate up at flanges in what is known as a

With the splitter being one of the most powerful aerodynamic devices on the car, development in this area had escalated to a high degree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The NASCAR R&D department has been working hard on increasing the speed at which the race trucks in its popular third-tier series might take to the air after they go into a spin

Flange Fit Composite Body, or FFCB for short. These flanges were designed with alignment features that allow limited movement of the panels relative to one another, easing installation. Tamper resistant 3D patterns were added to sensitive areas on the racecar to prevent the addition of material to the surface of the parts. Skirt thickness was also reduced in an effort to prevent body panel damage from striking the track.

Working with Five Star, the team began producing test parts in early 2016 and building a prototype vehicle at NASCAR R&D. Team input throughout the process was used to revise designs and zero in on the most efficient alignment features and build methodology. As a final validation step, the racecar was taken to the wind tunnel to validate panel stiffness and reinforcement location.

Richmond debut

The race debut of the composite body came at Richmond in September. For the 2017 season, three races were selected for the composite body to be optional: Richmond, Dover and Phoenix. As mentioned earlier, the similarity of the chassis and bodies for these three tracks drove the introduction to these events rather than simply picking a date on the calendar. For the 2018 season, the bodies are optional at all events other than superspeedways. In 2019 all bodies will be mandated to be composite.

With the industry headed toward the composite body, teams and NASCAR agreed that it was best to promote early adaptation rather than continuing development of the soon to be extinct steel bodied cars. Working with teams, NASCAR assessed NXS car sensitivity to weight and aerodynamic properties.

One concern was that the dynamic movement of the body achievable with the steel car would be impossible with the composite body, putting it at a downforce and sideforce disadvantage on track. Early numbers put this deficit somewhere in the range of 60 to 100lbf of downforce at 200mph. To overcome this deficit, NASCAR used a combination of weight change (weight reduction for the composite racecar and weight increase for the steel racecar) as well as mandating that steel cars do not run a radiator pan. The radiator pan is attached to the front splitter and acts as a diffuser; removing it reduces front downforce significantly. With these changes, teams were assured that they would not be at a performance deficit by adopting the composite body early on while it races against steel cars.

Promising start

The event at Richmond was a promising start for the body, with only minor installation issues. One car struck another vehicle in practice and was able to change a front fender at the track and race the car. Damage that on a steel car would have meant either difficult at-track repairs or going to a backup car.

The 2018 season will see widespread use of the composite body for most of the Xfinity schedule with only minor updates. The hope is that the team owners will be able to save on repair costs and truly determine whether the composite body saves money as anticipated. Estimates from some team owners have projected savings of nearly a half million US dollars over the course of next season.

The Xfinity Series will also expand the use of the successful Indianapolis drafting package to Michigan International Speedway and Pocono Raceway in the summer. The package features lower power engine restrictor plates, higher downforce and the use of the innovative aero ducts in the fascia to promote drafting. The Indianapolis event broke all previous race metric records at the Brickyard, including margin of victory and unique leaders, and it is hoped it will deliver the same excitement for fans at Michigan and Pocono.

Flying trucks

Ever a fan favourite, the third-tier Camping World Truck Series capped off an exciting season crowning Christopher Bell as the 2017 champion. After several near misses at Daytona in February of 2017, NASCAR embarked on a significant effort to increase the lift-off speed of these race trucks.

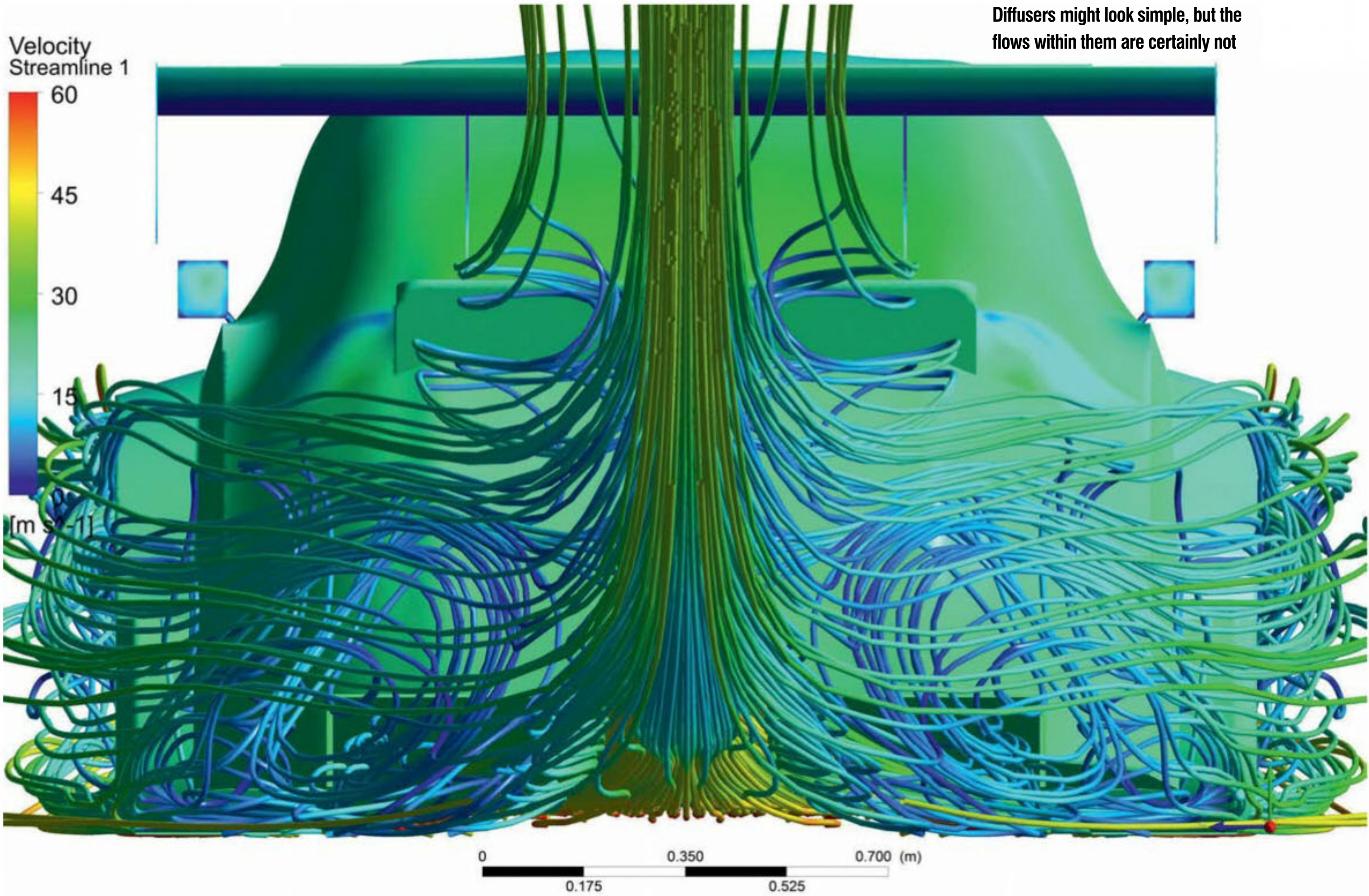
The results of all this were put to the test at Talladega Superspeedway in October, with a truck returning to the track after striking the wall, then finishing up on top of another truck. But the vent flaps had deployed to keep the car from flying, so that worked well.

The package features lower power restrictor plates, higher downforce and the use of innovative aero ducts in the fascia to promote drafting

Diffusing situations

Racecar fires up the CFD to gain an insight into the highly complex flows generated by diffusers on GT cars

By SIMON McBEATH



Diffusers might look simple, but the flows within them are certainly not

The benefits of even a simple rear diffuser on a racecar are widely appreciated; the details of some of the flow complexities that occur perhaps less so. With this in mind we have put our generic GT CAD model through its paces once more in ANSYS CFD to examine some of the intricacies of diffuser aerodynamics. Our findings will likely be applicable to other closed-wheel racecars, too.

It's all too tempting to think of a rear diffuser merely as a two-dimensional device. Indeed, the many graphical representations that describe what a diffuser is and what it does show a simple cross section of a gently expanding region that is the third and final stage of a venturi system. The upstream components are the inlet and the throat, and the design of a venturi system encourages air velocity to increase through the throat and hence increase the dynamic pressure and thus, in accordance with Bernoulli's equation, to decrease the static pressure there. So the diffuser's general role is to then slow the velocity down again so that the static pressure in the flow returns to ambient.

In the context of racecars, the venturi throat is bounded on one side by the flat or gently sloping part of the car's floor, generally delineated between the front and rear axle lines or within other similar regulated limits, and on the other by the road surface, and this is where the reduction in static pressure creates most of the underbody's downforce (the sides of our venturis are generally open, which can bring its own complications). The diffuser then slows the flow velocity down, but on road vehicles the rear diffuser's function is modified by the fact that it exits into the wake, which of course is another region of low static pressure (albeit one where the loss of energy, or total pressure, has led to the decrease in static pressure). Thus, in a sense, the diffuser has a dual role to play in that it connects the underbody region to the wake. And, as we saw in our June 2017 (V27N12)

It's tempting to think of a rear diffuser as a two-dimensional device

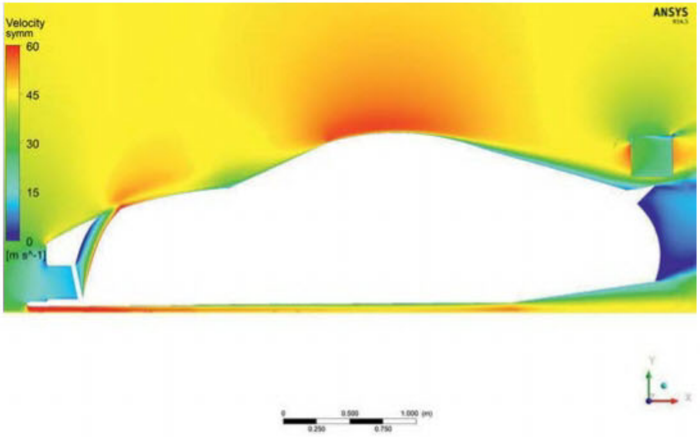


Figure 1: This shows velocities on the symmetry plane on our car, showing acceleration into the inlet, the high velocity flow through the throat, and deceleration in the diffuser

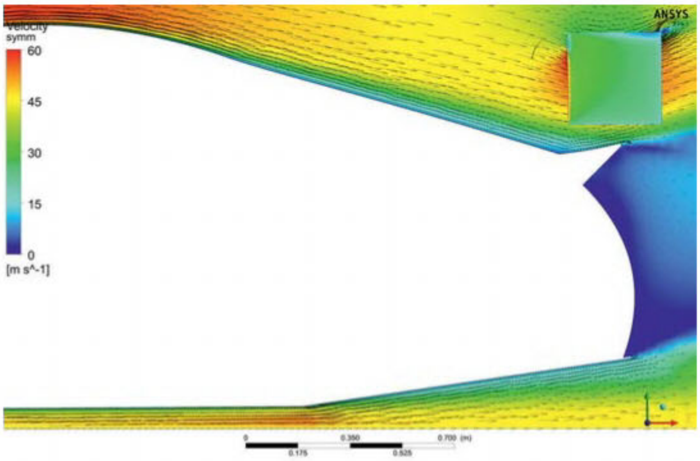


Figure 2: The velocity profiles in the diffuser shown here in close-up. This shows that the flow is attached to the diffuser roof, despite the velocity reductions adjacent to it

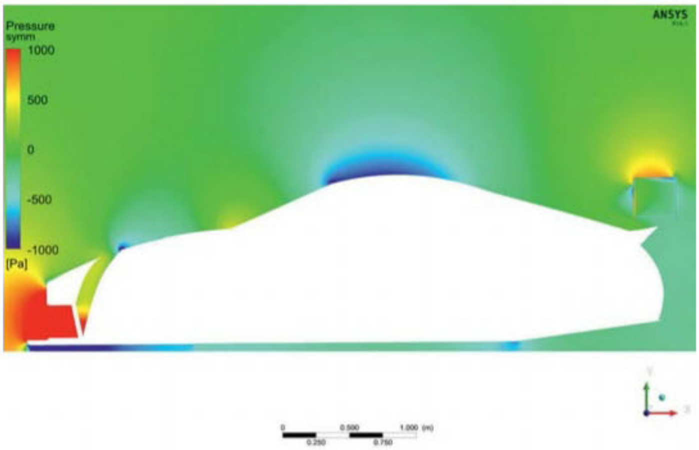


Figure 3: Static pressure image through underbody reflects Bernoulli velocity profile

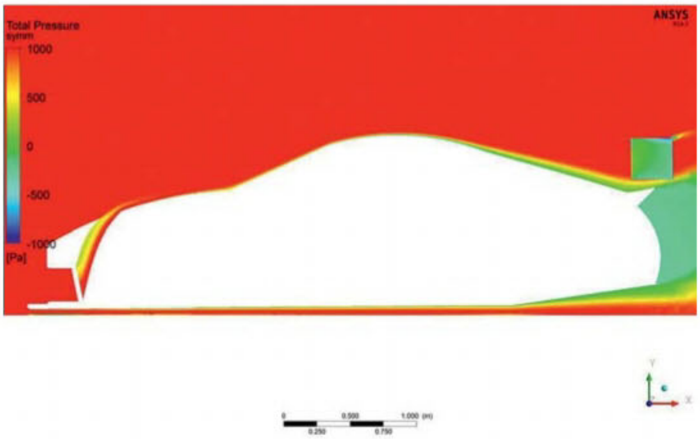


Figure 4: Losses of energy show how the diffuser connects to the GT racecar's wake

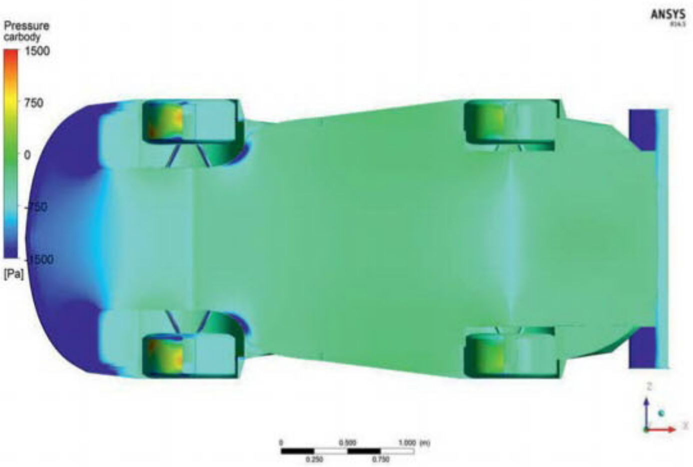


Figure 5: The static pressures on the car's underside begin to show the 3D picture

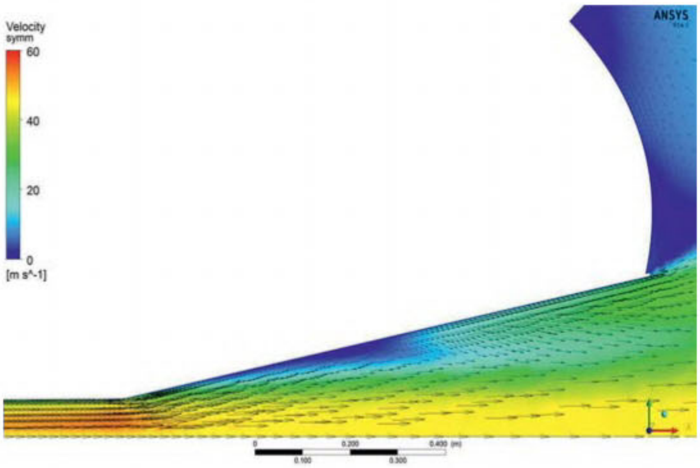


Figure 6: Diffuser stalled in the centre in an earlier run with a steeper diffuser roof angle

feature, among others, by modifying the diffuser exit or the low pressure in the wake (for example by using a rear wing) we can alter the performance of the diffuser and the entire underbody, the wake's low pressure helping to draw air through our underbody venturi system.

We can illustrate the basic principle of how a racecar diffuser functions in two dimensions by looking at the simulated pressures and velocities on our generic GT car's longitudinal symmetry plane. **Figure 1** shows the velocities in the flow field around our car on the symmetry plane. Looking purely at the underbody as the venturi system, the airflow accelerates into the inlet under the splitter's leading edge and maintains fairly high velocity thereafter, slowing slightly through viscous interaction with the car's underside and, to an extent, with the ground where the velocity is higher than ground speed under the splitter.

There is then a further acceleration as the flow makes the direction change around the transition into the diffuser before velocity reduces in the diffuser itself. Clearly there is a vertical velocity gradient in the diffuser, too, as the air adjacent to the diffuser roof slows more because of viscous effects. **Figure 2**, with velocity vectors imposed on the symmetry plane, illustrates this in close up, and shows that the flow is attached to the diffuser roof despite the velocity reductions that are adjacent to it.

In **Figure 3** we see where the static pressure reductions occur in the underbody in response to the velocity changes; 'suction peaks' are visible (in blue) under the splitter and at the diffuser transition. But the pressure remains low throughout the length of the underbody, and the pressure rise in the diffuser is relatively minor as that area merges with the wake.

It was stated above that the wake is at low pressure because of losses of

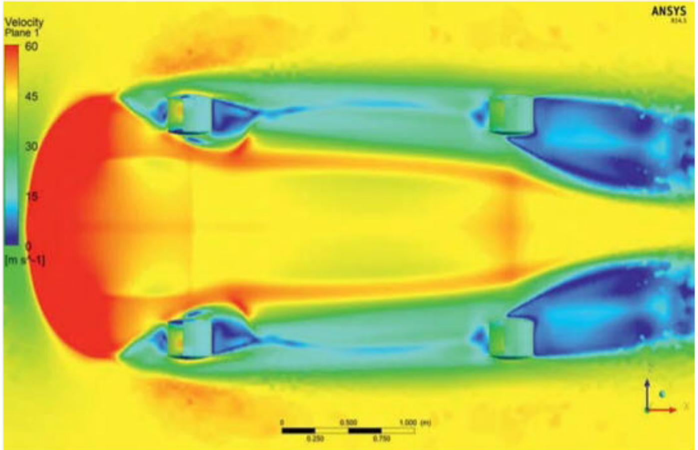


Figure 7: The velocities on a plane just under the car's floor show front and rear wheel wakes entering the diffuser – if only racecars didn't need to have wheels!

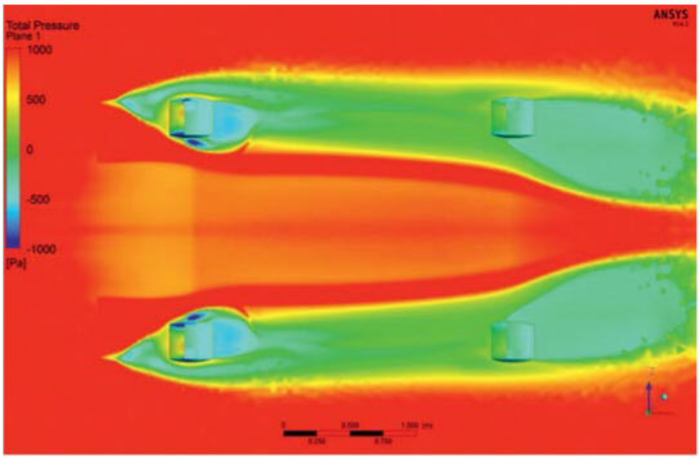


Figure 8: The total pressure plotted on the same plane 40mm above ground. It can be seen here that air entering the outer sections of the diffuser is at reduced total pressure

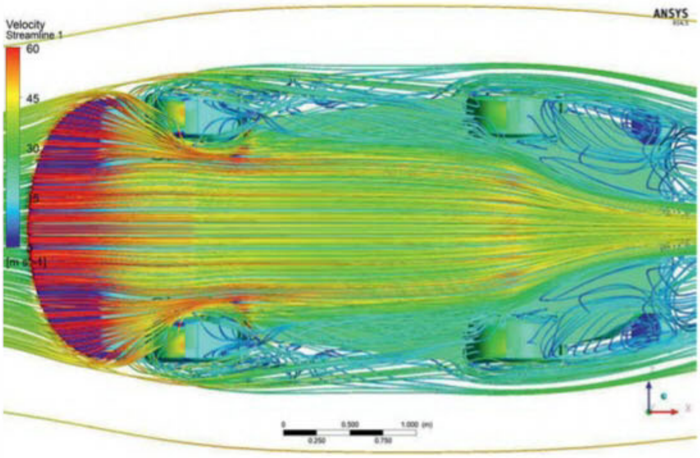


Figure 9: 3D streamlines show reverse flow entering outer diffuser sections from rear

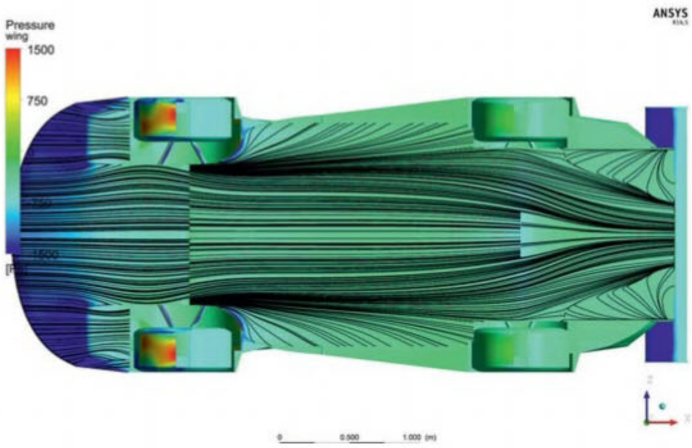


Figure 10: Surface streamlines show that the outer diffuser sections were stalled

energy, or total pressure. This is shown in **Figure 4**, where areas of total pressure loss (or energy loss) appear as anything other than red. In **Figure 1** the car's wake was apparent from the very low velocities, but **Figure 4** shows the losses of total pressure that have occurred. This is why the static pressure is low where the velocity is low, in apparent contradiction of the common understanding of Bernoulli's principle. however, in fact Bernoulli did take losses of total pressure into account, but that part of the equation is very often left out to simplify explanations of the trade-off between dynamic and static pressures.

Another dimension

The function of the diffuser looks quite simple in two-dimensions then. But a glance at **Figure 5**, showing the static pressure distribution on our GT car's underside, starts to hint at a more complex picture. Here we see the pronounced suction created by the splitter and front diffusers (a topic covered in December 2017's issue, V27N12). Static pressure then remains generally just below ambient through the majority of the flat underbody. Then at the floor-to-diffuser transition there is the suction peak that we saw in side elevation and we can just make out that it is more pronounced in the centre of the car than at the outsides. Less obvious is the rise in pressure in the diffuser which, although hard to see in the image, is slightly greater in the centre of the diffuser than towards the outsides, giving rise to a steeper 'pressure gradient' here; that is, the pressure goes from lower to higher in the direction of the flow, which of course it can be reluctant to do. This last point has ramifications with respect to the potential for the diffuser to stall, and **Figure 6** shows what happened in an earlier configuration with a steeper diffuser. The velocity can be seen to have dropped very low part way along the diffuser roof, and the vectors actually show reversed flow here. Elsewhere, the vectors are obviously not following the angle of the diffuser roof. The diffuser had stalled in the centre.

Aero force

The static pressure distribution across the car's floor and diffuser was generally reduced by a modest amount then, but because of the large plan area involved it generated over 1500N (155kg or 345lb) of downforce, making it the second biggest downforce contributor on our model after the splitter. Of course, our floor is perfectly smooth and devoid of interfering components like exhausts, transmission components, and the lumps, bumps and cavities from which many production-based racecars suffer. But this demonstrates the benefit of having a nicely panelled floor, where technical regulations permit and where it's practical.

If the static pressure distribution in **Figure 5** looks slightly more complicated than the 2D side view of earlier, then now take a look at **Figure 7**, which shows the velocities on a plane just below the car's floor level, at 40mm above ground. If only racecars didn't have to have wheels! But until levitation becomes technically feasible, we're stuck with wheels and tyres as well as wheel arches and suspension and, to a large extent, the aerodynamic problems they create. In **Figure 7** it seems that although the front wheel and wheel arch wakes were to some extent deflected outboard by the shaping behind the front wheels (see V27N6), the inner part of their wakes were entering the outer sections of the diffuser and appeared to be drawn further inboard with the wake of the rear wheels, with just a narrow region of fast, tidy airflow to the centre of the diffuser. **Figure 8** shows the total pressure plotted on the same plane

This diffuser configuration generated over 1500N of downforce, making it the second biggest downforce contributor on our GT model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The smoke plume shows organised energetic flow from the centre of this diffuser …

… and then a disorganised and even a reverse flow of smoke behind the outer diffuser

Table 1: The effects of fitting tyre and diffuser skirts, shown as Δ or delta values, relative to the baseline

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Tyre skirt	-3.7%	+3.5%	+2.6%	+3.9%	-0.4%	+7.4%
Diffuser skirt	-2.5%	+4.8%	+3.8%	+5.7%	-0.5%	+7.6%

*Absolute rather than relative difference in percentage front.

Table 2: The effect of fitting long, ground-contact skirts, relative to the baseline model

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Long skirt	-3.0%	+7.8%	+9.4%	+6.4%	+0.71%	+11.2%

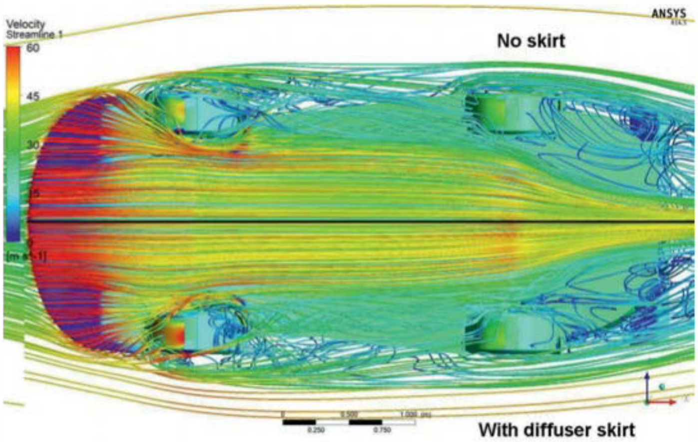

Figure 11: Diffuser skirts prevented air from rear wheels entering the diffuser, but the outer sections were still stalled, while air from front tyre wake was still entering here

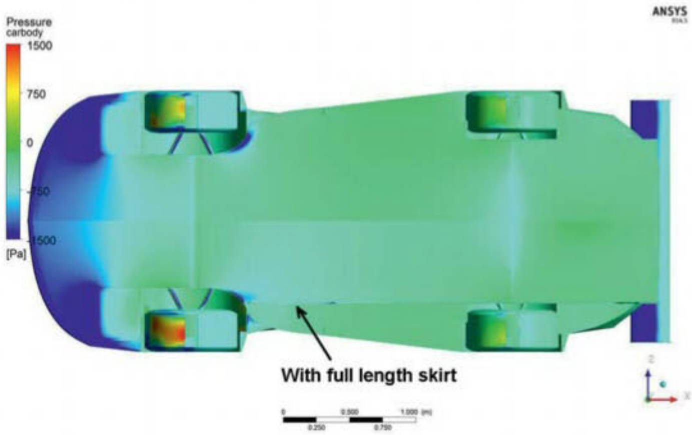

Figure 12: A full length skirt, this time making contact with the ground, did increase the suction in the forward floor but actually did not benefit the racecar's rear diffuser

40mm above ground and it can be seen that the air entering the outer sections of the diffuser is at reduced total pressure (energy), and the air apparently coming off the inside of the rear wheels is at lower total pressure still, suggesting a compound effect of front and rear wheel wakes.

Figures 9 and **10** illustrate how the flows are affected. **Figure 9** shows 3D streamlines initiated on a plane 50mm above the ground, and **Figure 10** shows surface streamlines, akin to an 'oilflow' or flow visualisation fluid plot. It would seem that the combined wheel wakes were not only converging into the diffuser, but air that passed around the outside of the rear wheel was also then flowing backwards into the outer sections of the diffuser. In effect, these outer diffuser regions had stalled. We have seen in Aerobytes that the wind tunnel smoke plume invariably shows this to be a very disturbed region and that reverse flow does indeed occur, albeit very unsteadily (see pictures top of this page). Here we are looking at time-averaged simulations that are telling us this reverse flow was a 'steady' feature, but in essence the two tools qualitatively correlate.

The obvious question is: what can we do about it? Can we improve the flow in the outer sections of the diffuser to try and improve its performance? And the supplementary question is; how? If we could steer more energetic air to the diffuser, could the stall in the outer sections be prevented or at least reduced in extent? The first ideas to be tried involved skirts that extended down under the car to ground clearances that would be lower than the permitted minimum in most categories. Nevertheless, they were tried so as to eliminate various potential causal mechanisms.

Skirting the issue

The first modification involved the attachment of skirts to the floor just inside the rear tyre to see if preventing (most of) the rear tyre wake from interacting with the flow into the diffuser entrance had any effect. Two trials were done, first with a skirt roughly 700mm long inside the rear tyre only, and second with a skirt that started at the same point in line with the front of the tyre and ran along the length of the outer wall of the diffuser to its trailing edge. These extended vertically down to be within about 10mm of the ground, so they did not totally close the gap to the ground.

The data in **Table 1** show that the skirts both appeared to have beneficial effects on the coefficients, bringing about modest increases in downforce and reductions in drag compared to our baseline model, along with a slight rearward shift in downforce balance. And the pressure distributions on the underside showed increases in the suction peaks at the diffuser transition, more so with the longer diffuser skirt. So it looks like floor and diffuser performance was enhanced, and the component group forces calculated by the CFD did indeed show increases in the downforce contribution of the floor and diffuser, 8.1 per cent and 10.1 per cent up respectively with

Can we improve the air flow to the outer sections of the diffuser?

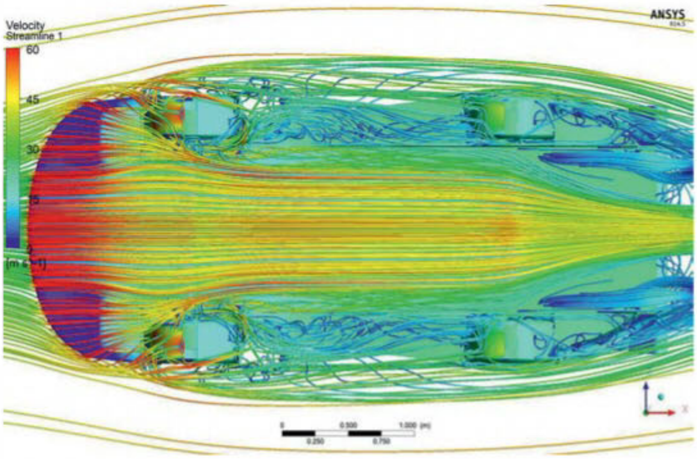

Figure 13: Even with the long ground-contact skirts the flow pattern was not altered and stall was still present in the outer diffuser, despite the rear tyres now being isolated

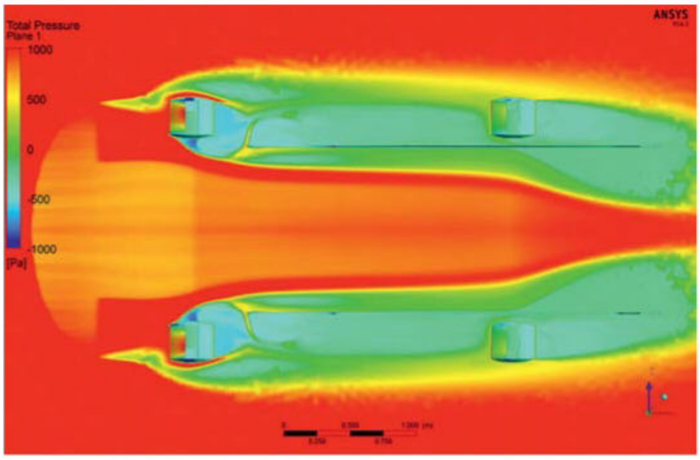

Figure 14: Total pressure just under the racecar showed that the front wheel wakes were once again pulled into the central region to affect the diffuser further downstream

Table 3: The effect of one pair of strakes, relative to the baseline model

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Straight	-0.9%	+1.0%	+3.5%	-1.2%	+1.1%	+1.8%
Curved	+0.4%	-1.1%	+1.7%	-3.3%	+1.2%	-1.4%

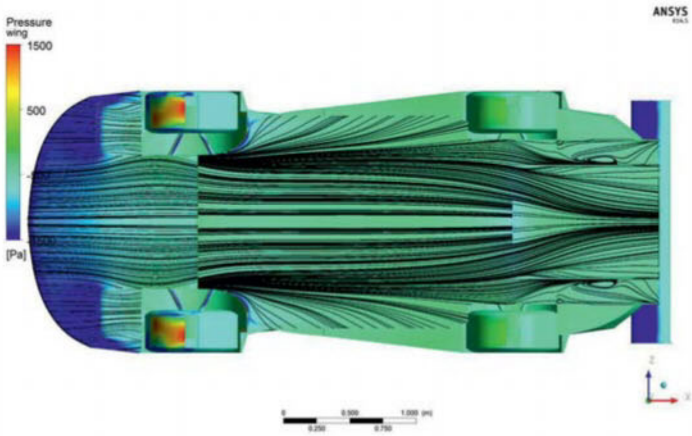

Figure 15: Pair of straight strakes reduced the area of stall to the outer diffuser channel

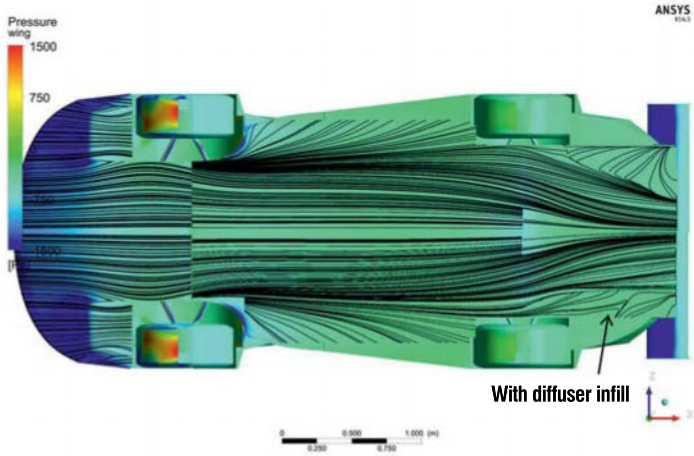

Figure 16: Diffuser infill eradicated the stalled region, as compared to the baseline (top)

the shorter and the longer skirt. However, looking at **Figure 11** we can see that there was no wholesale change in the general flow regime in the diffuser despite the presence of the full diffuser skirt. The skirt did actually constrain the flows coming off the inside front shoulder of the rear tyre, but the diffuser still showed the same stall in the outer sections. Perhaps crucially, air from the front tyre wake was still entering the rear diffuser's outer sections.

Longer skirts

Diffuser skirts, then, seemed to bring modest benefit to the diffuser's performance, but did not significantly modify the flows within the diffuser.

So a more extreme approach was tried using much longer skirts extending forwards to the front wheel arches, this time making contact with the ground. Thus, the diffuser was totally isolated from the rear wheels and rear wheel arches, and would hopefully see a wider area of energetic air from the front. **Table 2** shows that better gains were achieved than with the shorter rear wheel and diffuser-only skirts, but the static pressure plot in **Figure 12** illustrates that the gains were mainly from the forward half of the flat floor within the skirt (arrowed). Fascinatingly, **Figure 13** showed that the diffuser flow patterns were basically unaltered, proving that the cause of the outer diffuser stall was not the flow coming off the front of the rear tyre. However, **Figure 14** shows that the outer part of the floor inside the skirts had once again entrained airflow with reduced total pressure, and it seems likely that the reduced static pressure in the forward region of the flat floor pulled this in from the front wheel wakes.

Strake talking

Ideally then it would appear that improving things well upstream of the diffuser would be the preferred route. However, keeping focus on ideas to aid the rear diffuser for now, what remedial measures might help? Vertical or near vertical strakes are often seen terminating at the rear of diffusers, and our feature in October 2014 (V24N10) examined the effects of simple fore/aft vertical strakes on a generic test body, concluding that one pair of strakes in the outer diffuser was good, and two and three pairs further inboard were better but with diminishing returns. The effect in the visualisations in that article was, as expected, to straighten out the flow in the diffuser. However, of more obvious benefit to downforce was the formation of vortices arising from the convergent flow crossing the strakes, which locally reduced the static pressure and boosted the suction at the diffuser transition. What, then, would strakes achieve in our basic diffuser? A pair of straight fore/aft strakes located 190mm inboard of the diffuser side wall was tried first, followed by curved strakes shaped to align with the converging streamlines.

The results (see **Table 3**) showed that the straight strakes brought small downforce benefits although interestingly this seemed to be more at the front of the car than at the rear, the splitter's downforce increasing slightly as well as the floor and diffuser's. This may have been the result of increased mass flow through the underbody, and produced a

Skirts seemed to bring a modest benefit to the diffuser's performance, but did not significantly modify the flows within the racecar's diffuser


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Table 4: The effects of widening the diffuser behind the rear wheels, relative to the straight strake case

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
With wider diffuser	+0.5%	-2.3%	+3.0%	-7.1%	-2.6%	-2.6%

**Absolute rather than relative difference in percentage front.*

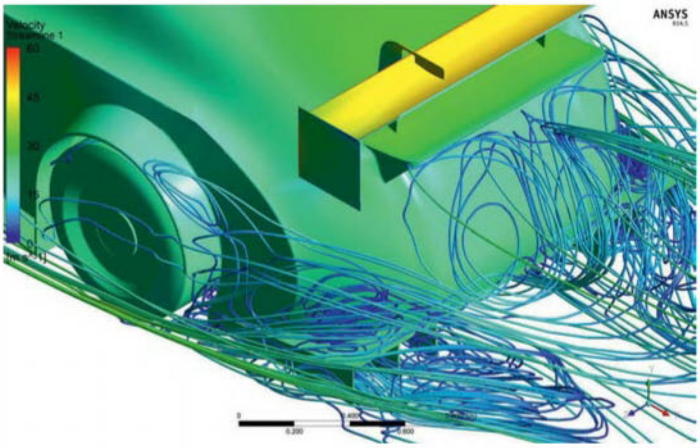

Figure 17: The diffuser extensions behind the rear wheels reduced rear downforce

Table 5: The effects of diffuser footplates behind the rear wheels

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
With foot-plate	-	-6.5%	-3.5%	-9.0%	+1.5%	-6.2%

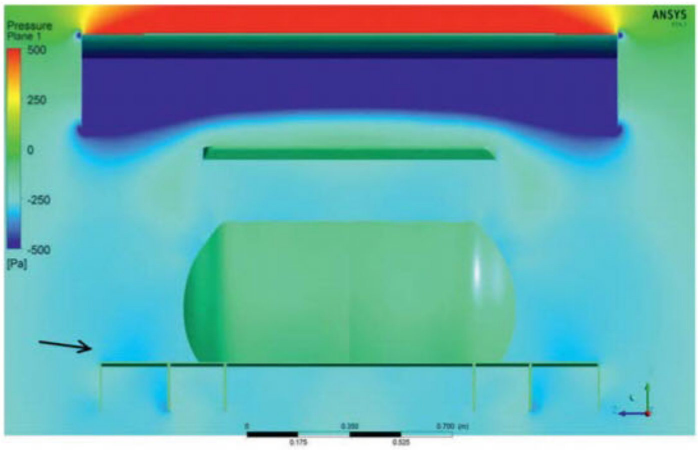

Figure 18: Static pressure, as seen on a transverse plane at the rear of the racecar model, was lower above the diffuser extension (arrowed here) than it was below it

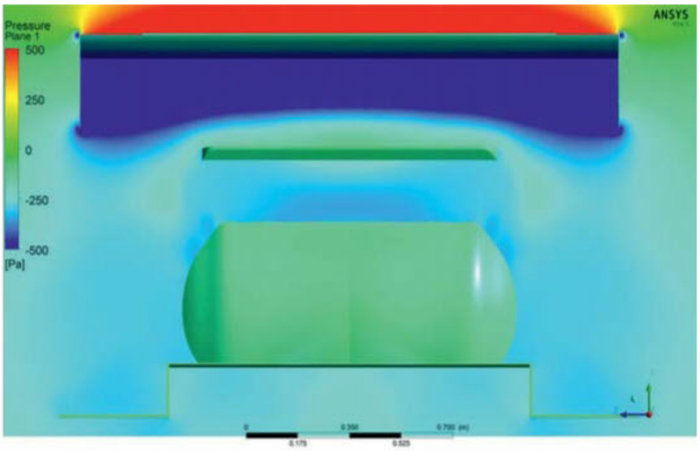

Figure 19: The diffuser footplate also saw lower static pressure above it than below it

small net forward shift in downforce balance of around one per cent front.

The static pressure distribution in the diffuser was subtly altered though, the suction peak being concentrated between the strakes in the central channel, and the surface streamlines showed that the region of stalled flow was narrowed **(Figure 15)**.

A second pair of straight strakes a similar distance inboard improved the flow organisation somewhat but brought no significant benefit. The curved strakes brought smaller benefits and less change to the pressure distribution, and the surface streamlines showed that the straight strakes had more effect.

So if straight strakes had modest benefits and curved strakes had minimal effects, and the areas of apparent stall were still present in the outer sections of the diffuser, what about filling in those seemingly redundant sections of diffuser altogether with infill blocks the same plan-view shape as the strakes?

Straight infill blocks, which essentially filled in the outer sections of the diffuser between the strakes and the outer walls of the diffuser, and curved infill blocks, which similarly followed the shape of the curved strakes and filled the outer sections between the strakes and the outer walls were both tried. In both cases the flows in the narrower diffuser appeared better organised, and tidier flow seemed to have been encouraged further outboard at diffuser roof level, as shown by the surface streamlines in the curved infill case in **Figure 16**, compared with the baseline configuration. Somewhat counter-intuitively, although the area and volume of the diffusers was now smaller and plan area was reducing aft in the case of the curved infill, the data were very similar to the baseline numbers; no better but no worse, implying improved effectiveness and suggesting the outer sections might best be sacrificed if all they do is create stalled regions. This assertion might well be modified with further development of upstream and other components, of course, but in a situation where nothing else could be done, it might be applicable.

Going wide

Two more frequently seen devices were also evaluated, the purpose of both is presumably to try to prevent or reduce inflow into the diffuser from behind the rear wheels. The first of these was simply a widening of the diffuser roof and the attachment of a side fence to the new outboard extremity of the diffuser. The straight strake was retained in this trial, so the results in **Table 4** are comparisons with that configuration. As can be seen, there was an overall small reduction in downforce but this was made up of a small gain at the front and a more significant loss at the rear, with a commensurate forward shift in overall downforce balance.

Although it was not expected that an extension of the diffuser into the turbulent region behind the rear wheels (see **Figure 17**) would bring significant benefit, a reduction in rear downforce was not expected. However, **Figure 18** shows there was a small lift-inducing pressure differential vertically across the diffuser extension.

Footloose

A further modification was a 'footplate' attached to the outer wall of the diffuser side fence behind the rear wheels. This modification was made to the no-strake diffuser, and again its effects were surprisingly negative, as the data in **Table 5** demonstrates. This time there were downforce losses at both ends of the car, more so at the rear than in the previous case. Once again there was a small lift-inducing vertical pressure differential across the footplate, as shown in **Figure 18.** These two modifications suggest there may be little to be gained from devices located entirely behind the rear wheels, where the airflow is turbulent and lacking in energy.

Simple diffusers, along with flat floors, can provide highly efficient downforce but the flows within the diffusers are far from simple. It would seem that the disorganised flow emerging from the outer sections of simple diffusers, as seen in the wind tunnel and in these CFD trials, is the result of stall and is not due simply to disruption from the rear wheels, although the latter undoubtedly complicate matters.

Straight strakes had modest benefits and curved strakes minimal effects


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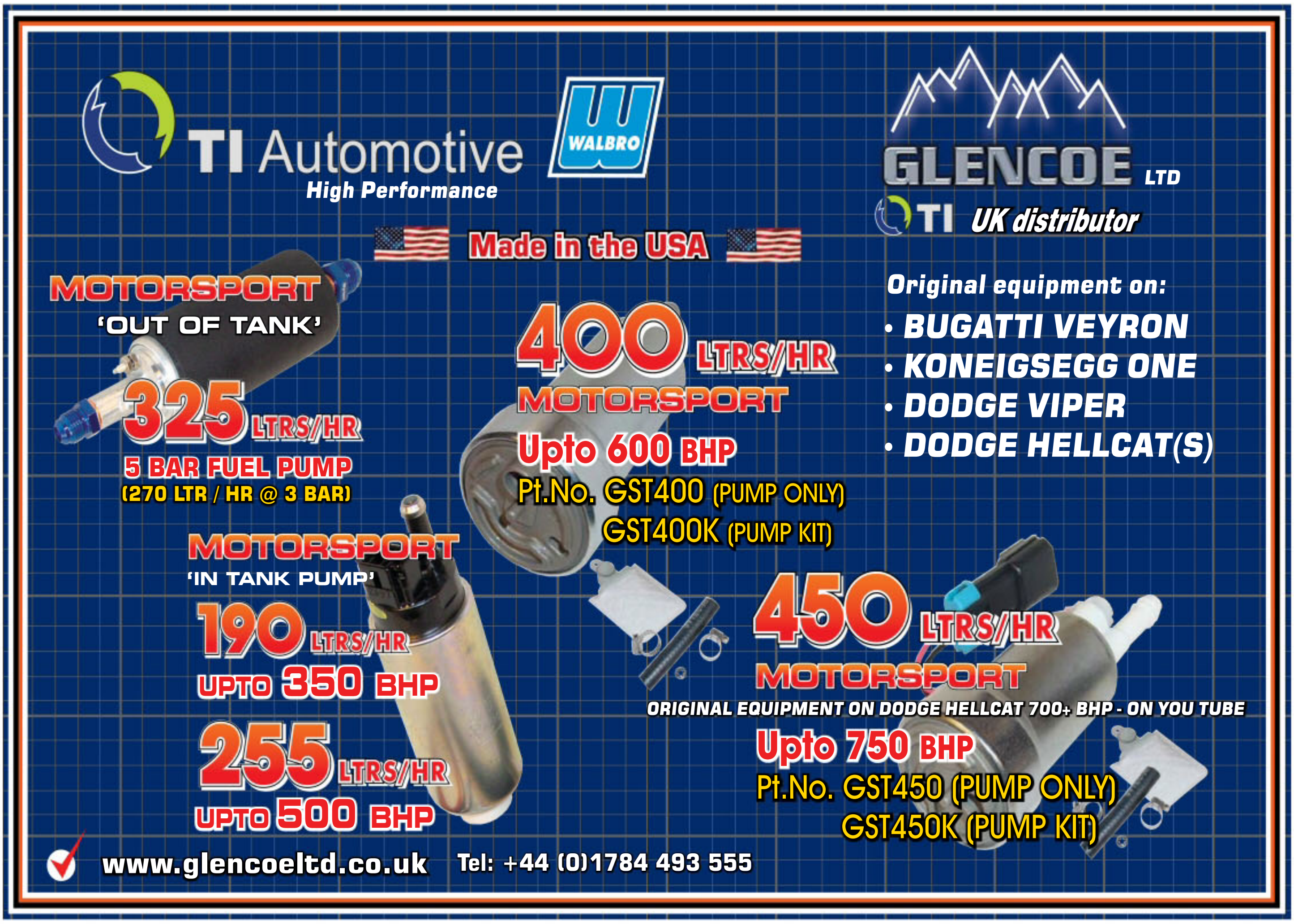
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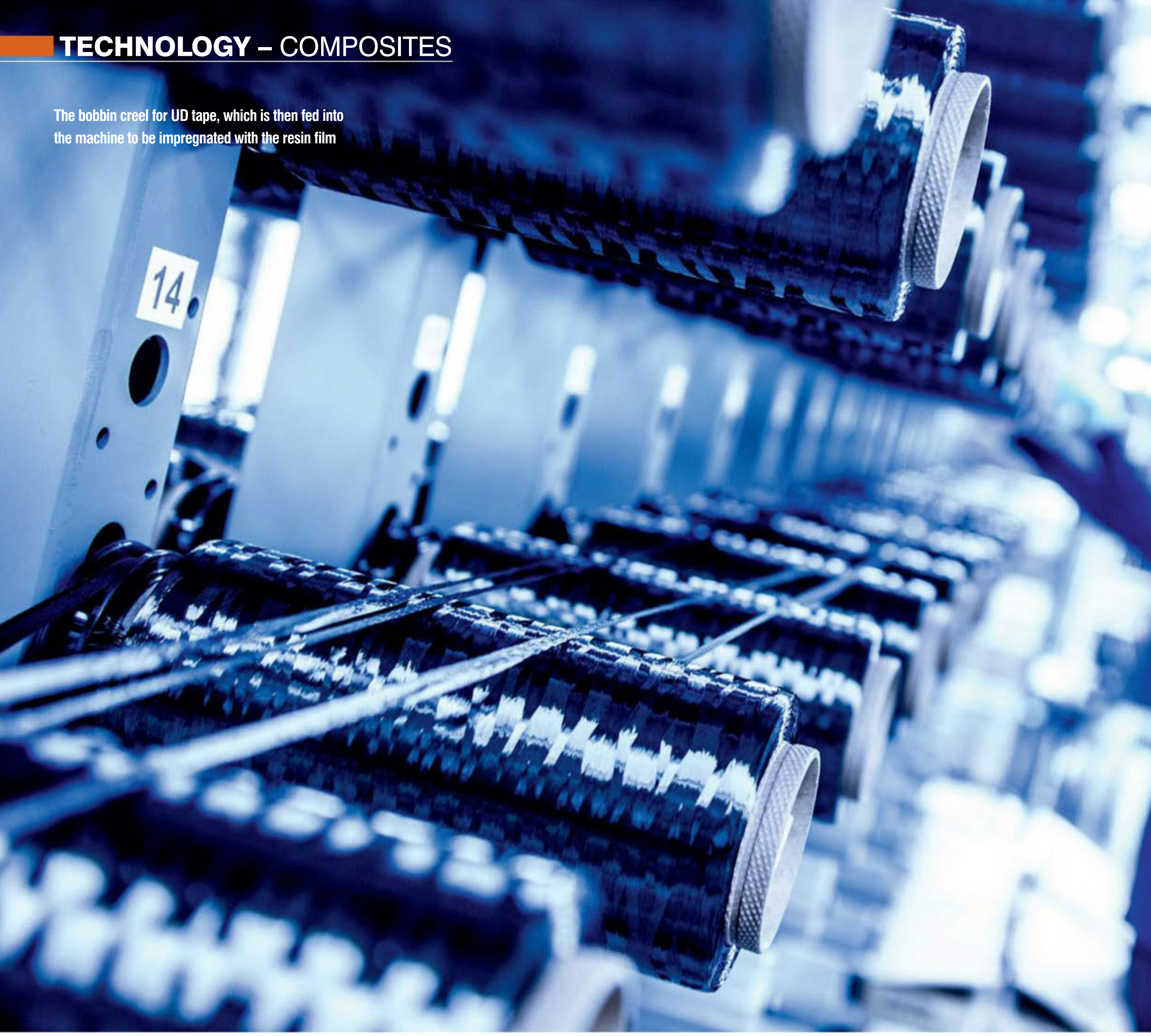


The bobbin creel for UD tape, which is then fed into the machine to be impregnated with the resin film

Material benefits

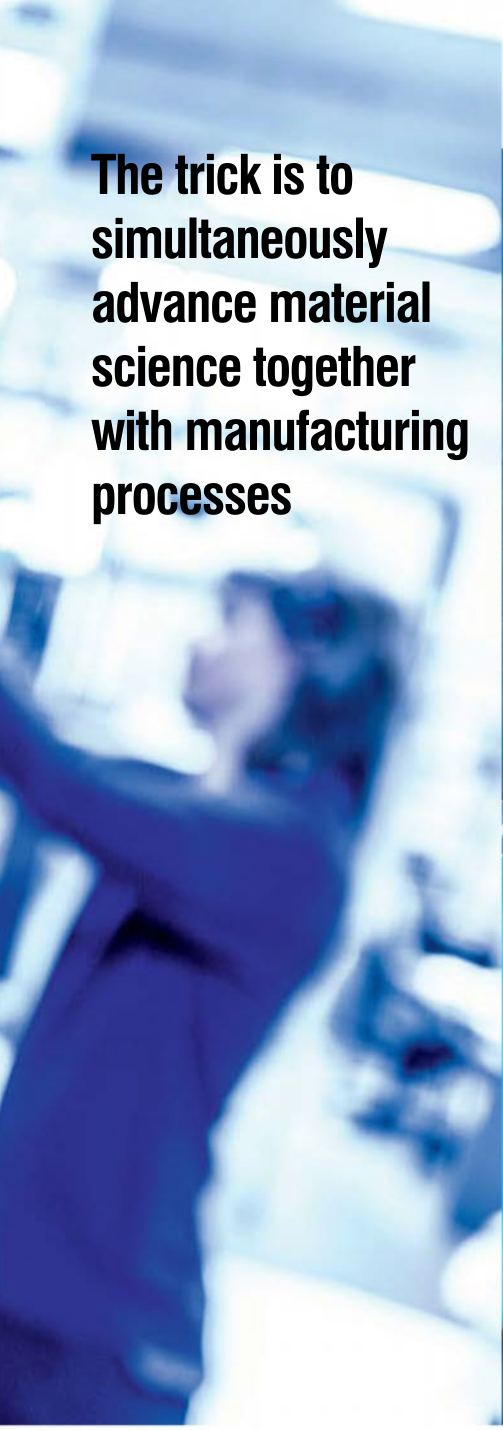
The processes involved in manufacturing motorsport composites are as impressive as the wonder materials that are the result, as *Racecar* discovered when we delved into the trade secrets of the industry

By GEMMA HATTON

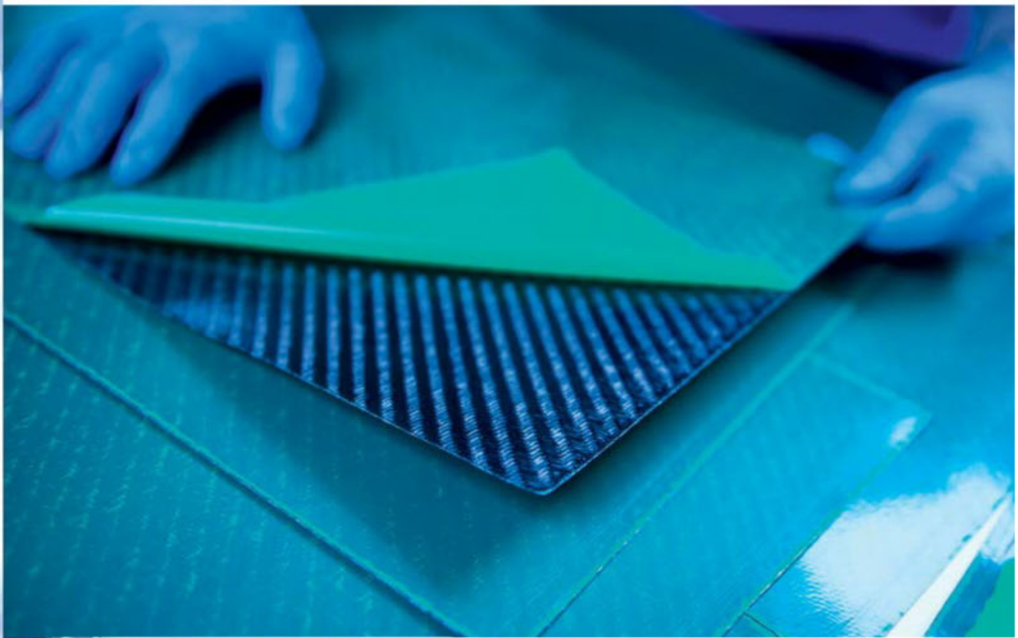
Composite components now account for up to 85 per cent of today's Formula 1 cars, but only roughly 20 per cent of the weight. It's an achievement only made possible by continuously exploiting and developing the capabilities of carbon fibre.

The white heat of competition has driven teams to not only optimise this material's mechanical properties, but refine the manufacturing process as well; all with the aim of pushing the boundaries of carbon fibre's strength-to-weight ratio.

Furthermore, the adaptability of carbon fibre, especially in collaboration with modern additive manufacturing technologies, is increasing the material's potential across all areas of the car. The result is some seriously intricate and complex parts that are built by laying up plies of carbon fibre prepreg on top of one another at different angles to ensure mechanical performance in all directions. This



The trick is to simultaneously advance material science together with manufacturing processes



Prepreg is a material format using carbon, glass or aramid fibres and fabrics that have been impregnated with a polymer matrix Above: Woven carbon fibre prepreg Left: Uni-directional prepreg

process is often discussed. However, what is frequently forgotten is the manufacturing process required to make these carbon fibre prepregs in the first place, before they even enter the doors of a motorsport operation.

Prepregs

Advanced composite materials, such as prepregs, have been used by the Formula 1 and motorsport markets for almost 40 years. Prepreg is essentially a material format using carbon, glass or aramid fibres and fabrics that have been impregnated with a polymer matrix. Functionally, fibres give the composite strength and stiffness along their fibre direction.

Careful selection of fabric prepregs allow component stresses to be considered, and directed along critical load paths. The combination of woven fabrics usually oriented at 0-degree and 90-degree and unidirectional formats allow optimal performance to be designed whether quasi-isotropic or anisotropic properties are needed. Typical applications of unidirectional materials include suspension components, whereas woven reinforcements are used mostly for bodywork.

The primary role of the thermoset resin matrix is to act as an adhesive, bonding and fixing the fibre mass together. However, resins can also be optimised with fillers and particles to increase their functionality, improving toughness, plus impact and fire resistance.

Fundamentally, each fibre is immersed in resin. Not only does this allow them to absorb higher compressive loads, but the loads are transferred between the fibres resulting in an overall better distribution of external loads. The most commonly used resin in motorsport is epoxy, which is essentially made from an epoxy molecule and an amine. Mixing these two together initiates a chemical reaction that results in these molecules forming a closed chain that is more regular in structure than other polymers such as vinylesters.

'In the simplest terms, manufacturing prepreg is effectively combining a resin matrix and an appropriate reinforcement in a strictly controlled process,' says Jed Illsley, product manager at TenCate, which manufactures prepregs for Formula 1. 'In general, resin components are blended to initiate the reaction of polymerisation. Working with prepreg is a sensitive operation so great care is taken throughout our processes. Once that chemical reaction starts, you have a finite time to complete the manufacturing operation, guaranteeing the customer quality and performance. Some of the resins we produce have an outlife [maximum accumulated time allowed at room temperature] of only 50 hours, so time management is critical.'

The process

Stepping through the manufacturing operations, the resin constituent raw materials are blended together in large mixers. 'The mixing process can be quite complicated. Every resin system in our portfolio has a documented and controlled mixing process using sophisticated dispensing methods,' Illsley says.

Once the resin is mixed there are two principle conversion processes. Firstly, direct coating. This process evenly distributes the resin immediately onto the fibre reinforcement and is favoured for heavyweight fabrics such as those used in wind energy. The second option is film coating, this method coats a thin film of resin onto release paper and is favoured in lightweight fabric/fibre constructions, such as those used in motorsport. 'This allows you to test and calibrate resin prior to impregnating the fibre,' says Illsley. 'It is all about process control, we know exactly the weight of resin before committing to fibre impregnation.'

Manufacturing prepreg is effectively combining a resin matrix and an appropriate reinforcement in a strictly controlled process

Fibre selection starts as a price versus performance consideration. Each fibre format, glass, aramid and carbon have a distinct value proposition when looking at the end use application. In racing applications where weight optimisation is critical, carbon fibre provides the best solution, but not all carbons are equal. Each type of carbon fibre exhibits different strength and stiffness per unit weight. A 3K fibre, for example, means there are 3000 filaments in every tow – a tow is a bundle of filaments.

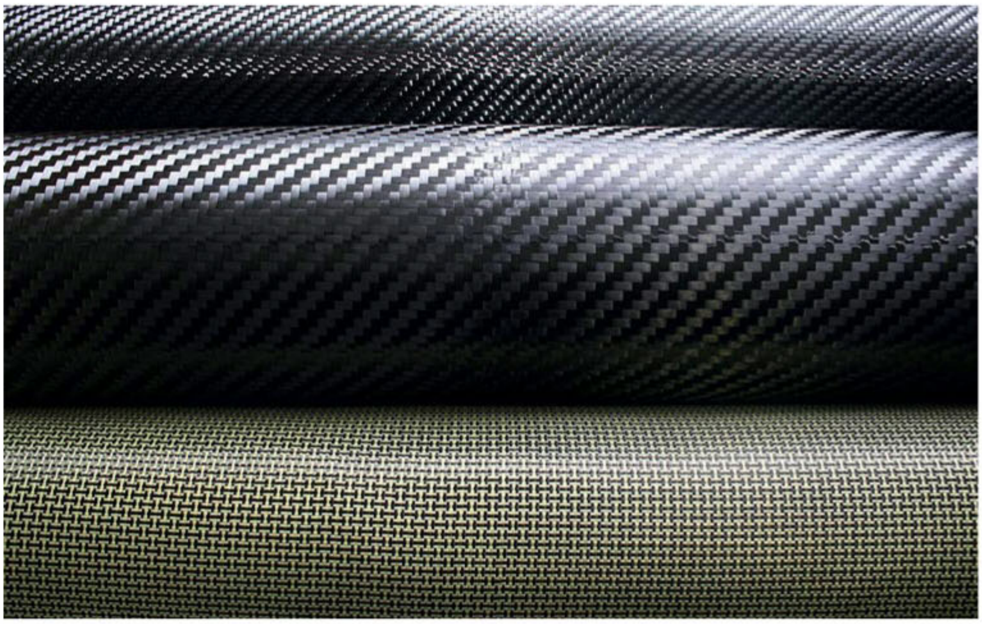
Carbon fibre reinforcement for F1 generally comes in two formats; woven or uni-directional (UD). Woven carbon fibres often use a twill weave that visually has a diagonal pattern. This format achieves an open, looser weave pattern, allowing it to drape more easily and is particularly useful when laminating mould surfaces with complex curves and contours. For this reason, these are widely used in motorsport.

Uni-directional

However, in applications where strength is only required in a load direction, UD can be used, surrounded by woven fabric to hold it together. The principle for uni-directional material is to get all the fibres aligned in the same direction, thereby maximising the benefit of the high strength achieved in that direction.

To manufacture UD prepregs, multiple bobbins of fibre are aligned on a creel, each supplying one tow of carbon fibre with filaments that are spread out and lined up. The resin film is then applied to the fibre through the manufacturing process. The amount of resin applied is carefully controlled to match the tolerances demanded by F1 teams. 'Formula 1 teams demand an optimised balance of reinforcement and matrix resin. For example, some of our prepregs that have been homologated for the chassis now utilise lower resin contents combined with very lightweight fabrics,' says Graham Roberts, business development manager at TenCate. 'This ability to customise elements of our materials, whilst maintaining high tolerances, at this stage of the process, allows teams to benefit from incremental gains which they can use to their competitive advantage.'

Producing woven prepreg follows a similar method, with the reinforcement being delivered to the manufacturing line as woven fabric, typically in widths of 1.25m. Once laminated together with the resin, the process then controls the level of impregnation.



There are many different types of woven fabrics. These are useful when laminating mould surfaces with complicated curves

A uni-directional prepreg machine. This material is ideal in applications where strength is only required in the load direction

Frozen goods

Prepreg is typically stored in a freezer to maximise outlife, and shipped to the customer under controlled conditions. Quality control is also an important step in the process for companies such as TenCate and replicate samples of the application construction are generated, and rigorous tests are then performed to obtain the performance data for FEA engineers to use in their simulations.

The vast array of directional properties that can be achieved with carbon fibre lead to endless end-use possibilities. It is easy, therefore, to see why composites are used so extensively. 'Not only can we change the type of fibre and therefore the strength, modulus and number of filaments, but we can also change the type of resin, the way we apply, as well as the ratio of resin to fibre,' Illsley says. 'This is why manufacturing composites to achieve optimum performance is so complicated, because there are so many parameters that you can modify.'

The heat is on

The resin matrices used in prepreg manufacture are thermosets which do not melt under heat, they instead disintegrate. Uncured, the short molecular chains that make up this group of polymers have low viscosity, which is ideal for the impregnation of fibres. The chemical reaction induced by the hardeners mixed into the resin blends form bonds between these short chains, creating a 3D 'cross-linked' network which is incredibly strong. However, these type of plastics are difficult to use in processes such as additive manufacturing because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Typical applications of uni-directional materials include suspension parts, whereas woven reinforcements are used mostly for bodywork

once melted, they are destroyed. So instead, thermoplastics are required.

The long entangled molecular chains of these polymers are free to move once heated, allowing thermoplastics to melt and become formable. Once cooled, they solidify which makes them perfect for 3D printing applications, where the plastic needs to be initially formable to create the complex geometries, before solidifying. 'The very nature of thermoplastics means that if you put them in environments that exceed their original glass transition temperature (Tg), they are going to melt, become soft and unable to transfer mechanical load,' says Kieron Salter, managing director of KW Special Projects. 'This is why there are currently limited opportunities in motorsport for 3D printed parts in high temperature areas such as in the engine bay or as brake ducts. Instead, thermoset epoxies, similar to the ones used in carbon fibre prepregs, have to be used.

'We need to start looking into complex epoxy based materials that can be photo cured and also develop materials with high temperature tolerance such as PEEK [Polyether ether ketone],' Salter adds. 'Then maybe we could start to print additive manufacturing parts that can go directly into these higher temperature areas, with mechanical properties that are similar, if not better, than thermosets. I think the opportunities for thermoplastics will increase with electric vehicles, though, because these powertrains completely change how the thermal management system operates.'

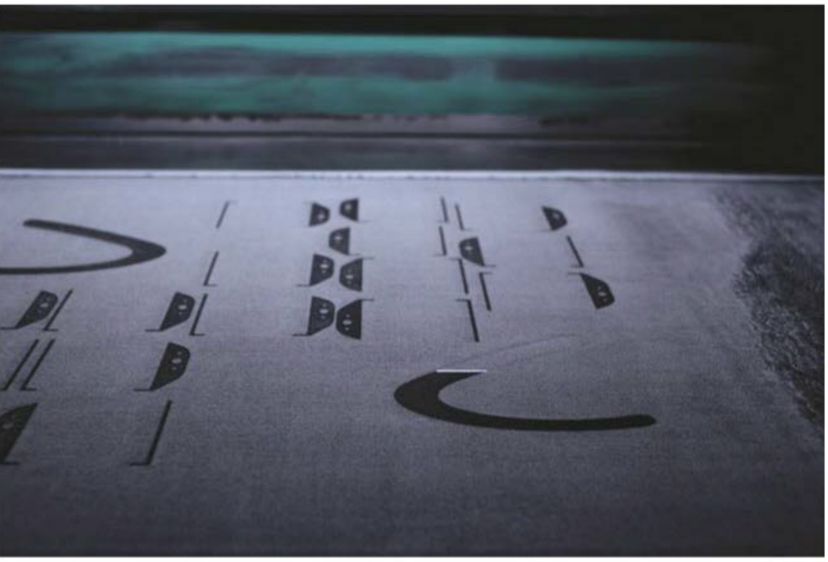
To protect thermoplastics from these high temps it is possible to coat 3D printed parts with materials such as ceramic in order to improve their heat resistance, as Amos Breyfogle, senior application engineer at Stratasys, explains: 'The problem is when the car stops, and the heat soak from the brakes and engine results in increasing these already high temperatures even further. Whether it is the floor or brake ducts, material development for polymers needs to advance a little more before printed parts can survive these higher temperatures.'

Sterolithography, or SLA, uses a UV laser beam to bond liquid resin. Unlike SLS, supports need to be created, and these are snipped off during post processing. Its high accuracy could be why some teams are shifting from FDM 3D printing to SLA

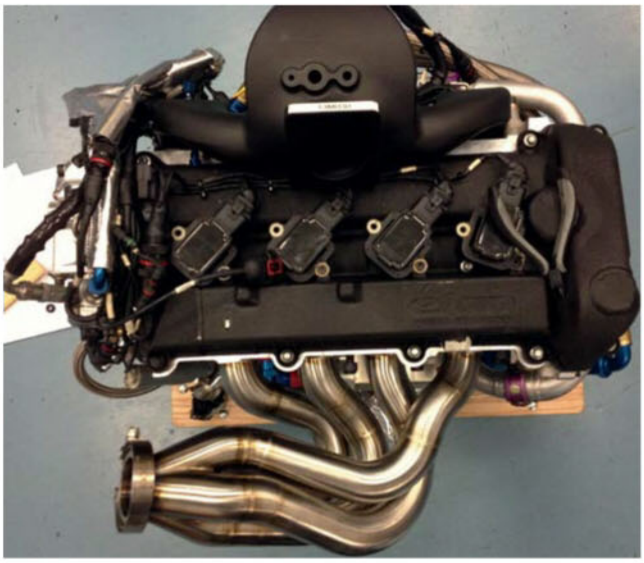
Rapid turnaround

A further issue with thermoplastics is processing in the rapid turnaround environment of motorsport. Although autoclaves can be used, only low performance thermoplastics tend to be processed in this way – these include materials for bumpers or wheel arch liners. 'To manufacture high performance thermoplastics [with higher Tg], you need to process them under high temperatures and pressures,' says Mike Dewhirst, CTO at Lentus Composites. 'Traditional composite processes are not suitable for these temperatures, higher temperature autoclaves or presses are required. There is a lack of appropriate infrastructure in the motorsport supplier base to enable the rapid turnaround processing of high performance thermoplastic composites that is so vital in the motorsport industry.'

Although thermoplastic part manufacture can have short cycle times and they can be easier to join, weld and post-form, it can be difficult to bond them to adjacent parts without using surface treatments. 'In general, thermoplastics could bring benefits in areas where they are not primary structures and their job is to absorb impacts, because they can spring back, as opposed to thermosets which



Selective Laser Sintering (SLS) uses a laser to fuse grains of powder – usually a combination of nylon and reinforcement materials – together to form layers; shown here as the dark areas



Windform's materials can be used in very high temperature areas, despite them being thermoplastics – as this example of an intake manifold clearly illustrates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The resin matrices used in prepreg manufacture are thermosets which do not melt under heat – instead they disintegrate

crack,' Dewhirst continues. 'Fundamentally, you don't need to cure thermoplastics, you just need to melt them. These processes are making great headway in the automotive industry for secondary structures where the high up-front investment in tooling and equipment can be offset against the short cycle times and high volume output required. It would need a major development in the motorsport industries to support the widespread adoption of thermoplastics in major components.'

Despite this, the use of thermoplastics is increasing in aerospace and automotive as its lower melting point allows it to be recycled, which is becoming increasingly important within these sectors. Whereas currently, carbon fibre prepreg can only be recycled through using 'carbon dust', which is short strand carbon fibre used to reinforce polymers. Although this increases the strength of the part, the original high performance mechanical properties of the carbon fibre will have deteriorated.

Composites are used for a wide range of components. This is a torque test for a thermoset composite transmission shaft

FDM technology can create the tools to help manufacture composite parts within a few days, rather than a few weeks

McLAREN HONDA

The composite layup tool for this year's F1 McLaren rear wing – which was produced on a Stratasys Fortus 900mc machine

However, high performance can still be achieved by reinforcing polymers with short fibres, as the family of Windform materials, developed by CRP Technology proves. 'I wanted to create a real composite material, rather than just adding something to a mixture to increase mechanical performance,' says Franco Cevolini, CEO and CTO of CRP Technology. 'Experts told me that I should forget it, because carbon fibres as well as any other fibres would not work with Selective Laser Sintering (SLS) processes. It was challenging, but in the end I created the first carbon fibre reinforced material for SLS manufacture: Windform XT.'

Wind power

The Windform family of high performance composites includes two polyamide based carbon filled materials; Windform XT 2.0 (the evolution of Windform XT) and Windform SP, most commonly used in motorsport. As well as prototype parts for wind tunnel testing, the higher melting points of 180degC means that Windform XT 2.0 parts can go directly from the printer to the car, and even retain their performance in higher temperature areas, such as intake manifolds. Windform SP has high performing mechanical properties similar to Windform XT 2.0, with the addition of increased resistance to shock, vibrations, and deformation. The material also shows increases in impact strength and elongation at break.

Printed material

SLS is one of the many additive manufacturing or 3D printing methods that can use composites. Here a layer of powder, which is usually a combination of nylon and reinforcement materials, is spread onto the bed of the machine. A laser then traces the pattern of a cross sectional layer of the 3D part onto the powder. As the laser scans the surface, it fuses the grains of powder together; creating a solid layer. The machine bed is then lowered and a new layer of powder is applied and the process is repeated; gradually building up the 3D dimensions of the part. One major benefit of this technology is that no supports are needed because the part sits in the bed of powder.

A similar process is Sterolithography (SLA), which also uses a laser. However, here it is a UV laser beam that selectively hardens a UV sensitive liquid resin. Unlike SLS, supports need to be created, and are snipped off during post processing. The end result, however, is an extremely detailed part due to achieving layers four times finer than a single human hair.

The other 3D printing process commonly used is Fused Deposition Modelling (FDM). This is where fibre reinforced thermoplastic filament


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‘Material development for polymers needs to advance a little more before printed parts can survive these higher temperatures’

is extruded through a heated nozzle, alongside another nozzle which extrudes support material. Once a layer has been fully deposited, the build platform is lowered, and the nozzles begin building the next layer.

‘If you were to take a hot glue gun, draw a circle on a table, and draw another one on top, eventually the layers would build up and that’s essentially what FDM is,’ explains Breyfogle from Stratasys. ‘But instead of glue, we use a stream of plastic and inside this stream of plastic is very short strand, chopped carbon fibres that sit within Nylon 12. It is the carbon fibre that gives the material its stiffness, which is why these parts are used in racing. Our machines can currently achieve layers as fine as 0.127mm, although we are always looking to improve our technology.’

The next development in FDM is designing machines that can produce larger and stronger parts, potentially through the use of robotics to build in more axes; like when you go from a traditional machine to a 5-axis machine. More of these would allow stiffness and strength to be achieved in different axes while minimising the need for support structures.

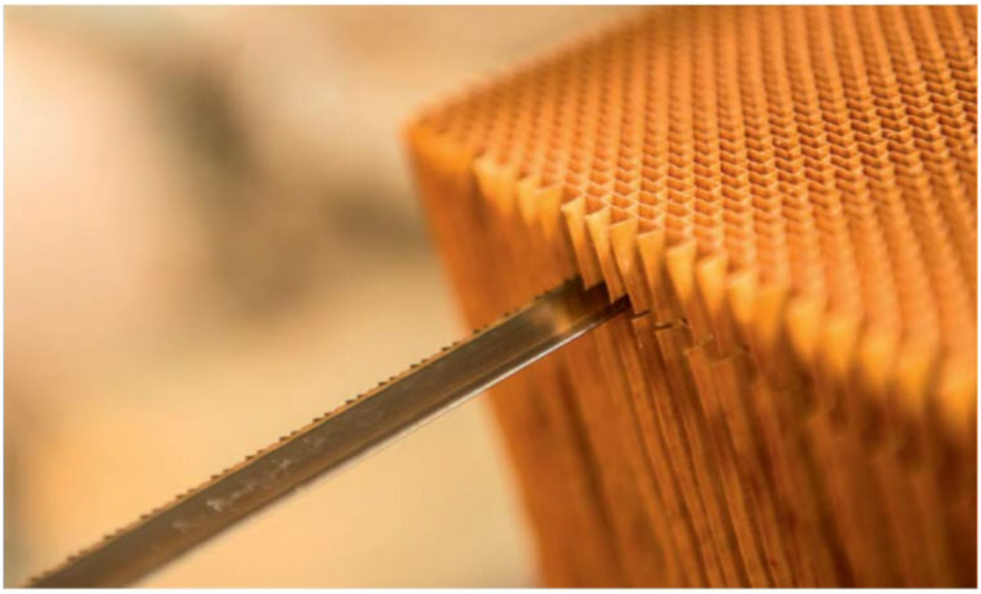
Shift to SLA

Recently, teams have shifted some of their additive manufacturing activities from FDM processes to SLA. Both require support structures, which is not ideal. However parts produced by FDM also need to go through several post processing stages to achieve the desired surface finish. It is also a relatively slow process, with restrictions in terms of build volumes and size of parts. ‘SLA, on the other hand, is a much more technical tool which allows you to build more complicated geometries with a higher quality, better finish,’ says Jonathan Warbick from Graphite.

‘The main advantage of SLA materials is the improved accuracy as well as the range of clever mechanical properties,’ Warbick continues. ‘In the right hands, with the right technical knowledge, these parts can perform all sorts of different functions. People are starting to realise that these well known materials can actually be used in many different ways and although this shift is in its infancy, we only see this demand increasing.’

In addition to using carbon fibre to reinforce plastic, 3D printing can also be integrated into the tooling manufacturing process. ‘What we’ve been doing for a long time is making a 3D composite part as the end product, but the process of making the tooling has been delivered by 3D printing capabilities,’ Salter says. ‘We use Stratasys machines and therefore the FDM process to print thermoplastic, but we are also able to print in soluble tooling material. This means we can then create mandrels and other complex shapes which we can then wrap carbon fibre prepreg around. Once cured in an autoclave, the soluble material is dissolved away, leaving the shell of carbon fibre in the net shape of the part. It’s a very complex tooling process which is delivered in a cost effective way because of 3D printing.’

The filament used in FDM is supplied in cassettes, such as the support material cassette S1 that’s shown here. Stratasys machines can now simultaneously print different materials and colours, requiring the use of a number of these cassettes



Nomex honeycomb core is the ‘sandwich filler’ between two skins of carbon fibre prepreg. It is mostly used in bodywork as it is lighter than aluminium honeycomb. Such structures are imperative when it comes to dissipating energy in an accident

The future

Like most things in this modern era, the future is digital. Robotics may be the next step in increasing the complexity of 3D printed parts, both in terms of function and aesthetics. Especially as these innovative digital processes are so well suited to low volumes, such as those that are required in motorsport.

However, there is only so much strength that can be achieved with composites. As manufacturing processes continue to evolve ways of increasing the materials’ performance, the question is; when will we reach the limits of the materials themselves? The answer to that is, we already have in some cases; take the example of thermoplastics in high temperatures, for instance.

Yet there is much performance still to be gained from materials. The trick is to simultaneously advance material science together with manufacturing processes, and in motorsport that is an on-going activity.

Stable environment

Racecar's numbers man examines two key concepts for helping your driver to keep the car on the track – control power and stability index

By DANNY NOWLAN

During my time working in the field of racecar vehicle dynamics, both as a race engineer and vehicle dynamicist, one thing that the motorsport community has made a mess of is defining car control power and stability. I've found that terms like understeer, oversteer and stability are often exchanged like frisbees.

Then, on the other hand, you have Formula Student teams spending hours on moment diagrams that look incredibly impressive but are practically useless. The great news is there are two very simple concepts that can help us greatly, and these are the concept of the control power and the stability index.

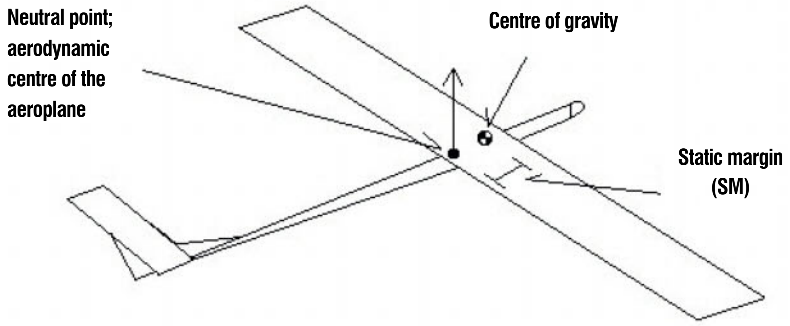
Let me also apologise in advance for bringing up the stability index again. Over the last couple of months I have been on the road talking with customers and prospective customers and delivering lectures/attending lectures. To say that I have been appalled at the misconceptions that are currently out there is an understatement. Consequently, the need to repeat this is more important than ever.

To set the scene for this discussion it would be wise to see how the aerospace industry deals with the question of pitch/longitudinal dynamics. We have much to learn from it, because it has dealt with this question rather elegantly. This is summarised in **Figure 1**.

Mick Schumacher with snap turn-in oversteer under braking in a Formula 3 car at Macau. The two concepts explored in this piece will help to provide race drivers with a stable platform

XPB

Figure 1: An illustration of aircraft longitudinal/pitch dynamics



EQUATION 1

$$C_m = \frac{-S.M}{\bar{c}} C_L + C_{m\delta e}\delta e$$

Where:

C_m pitching moment coefficient

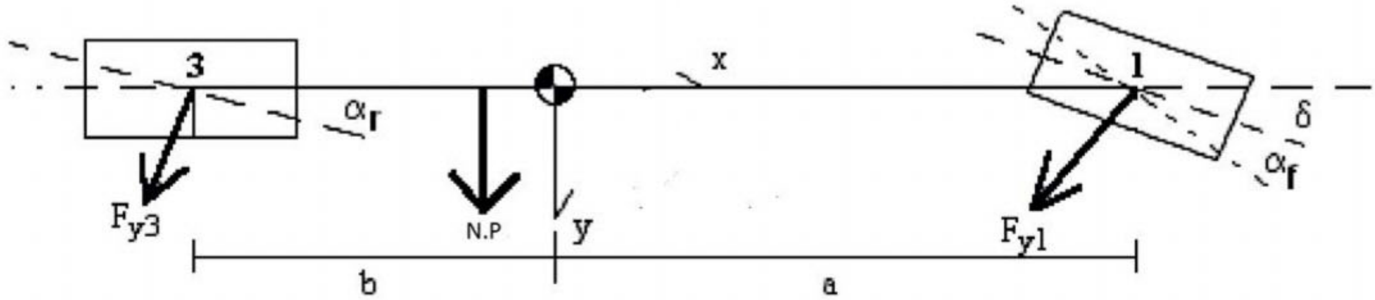
S.M the static margin, the distance between the lift vector and the centre of gravity of the aeroplane.

C_L lift coefficient of the aeroplane.

$C_{m_{\delta e}}\delta$ moment coefficient due to the elevator. $\bar{c}$ is mean chord of wing.

In the above the $\frac{S.M}{\bar{c}}$ term determines the stability of the aeroplane while the $C_{m_{\delta e}}$ term determines the control effectiveness of the elevator.

Figure 2: Bicycle model for the equations of motion of the racecar



EQUATION 2

$$I_Z\dot{r} = a \cdot C_f \cdot \delta_s + \frac{\partial N}{\partial r} \cdot r + \frac{\partial N}{\partial \beta} \cdot \beta$$

EQUATION 3

$$\frac{\partial N}{\partial r} = -\frac{\left(a \cdot C_f + b \cdot C_r'\right)}{V_x}$$

$$\frac{\partial N}{\partial \beta} = b \cdot C_r' - a \cdot C_f$$

The terms are:

N = total lateral moment about the centre of gravity (Nm).

β = side slip angle of the car (radians)

a = Distance of the c.g to the front axle.

b = Distance of the c.g to the rear axle.

C_f = Slope of front tyre force vs slip angle.

C_r = Slope of rear tyre force vs slip angle

δ_s = Steered angle at the tyre.

I_z = Rotational moment of inertia about the z axis

r = Yaw rate

V_x = Forward vehicle speed

Mathematically, an idealisation of the moments acting about the centre of gravity is then given by **Equation 1,** also shown in **Figure 1**.

The beauty of **Equation 1** is that in one fell swoop you have defined both stability and control effectiveness. Anyone who has spent more than five minutes at a race track knows that this knowledge is the life blood of any race engineer. Also, if you ignore this, then you probably think that denial is a river in Egypt.

The great news is that this visualisation is just as applicable for racecars as it is for aircraft.

To define this, let's consider the equations of motion for the bicycle model of the racecar, as is illustrated in **Figure 2**.

The reason we are using the bicycle equations of motion is due to simplicity. However, there's no need to be overly concerned here. The bicycle model is a subset of the four-wheeled car anyway. When we go through this and then derive the equations of motion we get something that looks like **Equation 2** and **Equation 3** (**Figure 2**). For the derivation of this I would refer the reader to my book, *The Dynamics of the Racecar*. However, the essence of it all is that the dynamics of the racecar is directly analogous to that of an aircraft.

The control power is given by $a.C_f$ and the stability index is the $\frac{\partial N}{\partial r} \cdot r + \frac{\partial N}{\partial \beta} \cdot \beta$ term.

All we need to do now is fill in the details.

The control power in simple terms tells you the rate of moment you can generate through the steering, and mathematically we are able to define this as **Equation 4**.

Fleshing this out a bit more, in particular the

$$\frac{\partial F_{YF}}{\partial \delta_S}$$

term using our tyre model, we see **Equation 5**.

For you undergraduate engineering/recent engineering graduates reading this you have all that you need to derive the control power from first principles and a simple tyre model. However, if you have a yaw rate sensor this term can be readily visualised from race data. All you now need to do is plot yaw rate *vs* steer at the tyre. This is shown in **Figure 3**.

Guess what, the slope of this graph is the control power, and you can readily compare this from set-up to set-up. I don't know about you lot, but I actually believe this is a very profound way of looking at data.

Yaw the boss

However, what do we do if we don't have a yaw sensor? The work-around is breathtakingly easy. Yaw rate can be approximated by **Equation 6**.

I admit this is not perfect, because you will miss the transients, however it will get you a significant way down the road.

Our next task is to nail down the stability of the car. In this endeavour the stability index is about to become our best friend and this

The key question here is; what procedure can we use to calculate the stability index so it can be readily incorporated into a set-up sheet?

Equations

EQUATION 4

$$C_{\delta s} = a \cdot \left(\frac{\partial F_{YF}}{\partial \delta_S} + F_{XF} \right)$$

The terms of this equation are:

$C\delta s$ = The slope of lateral moment vs steer angle (Nm/rad)

a = Distance from the front axle to the centre of gravity (m)

$\frac{\partial F_{YF}}{\partial \delta_S}$ = Slope of front lateral force vs steer angle (N/rad)

FXF = Applied longitudinal force at the front tyre (N)

EQUATION 6

$$a_y = V_x \cdot r$$

$$r \approx \frac{a_y}{V_x}$$

Here we have

a_y = Lateral acceleration of the vehicle.

V_x = Forward speed of the vehicle.

r = Yaw rate

EQUATION 5

$$\frac{\partial F_{YF}}{\partial \delta_s} = a \cdot \left(\left.\frac{\partial F_1}{\partial \alpha}\right|_{\alpha=\alpha_1} \cdot Fm(L_1,T_1) + \left.\frac{\partial F_2}{\partial \alpha}\right|_{\alpha=\alpha_2} \cdot Fm(L_2,T_2) \right)$$

To refresh the reader's memory we have:

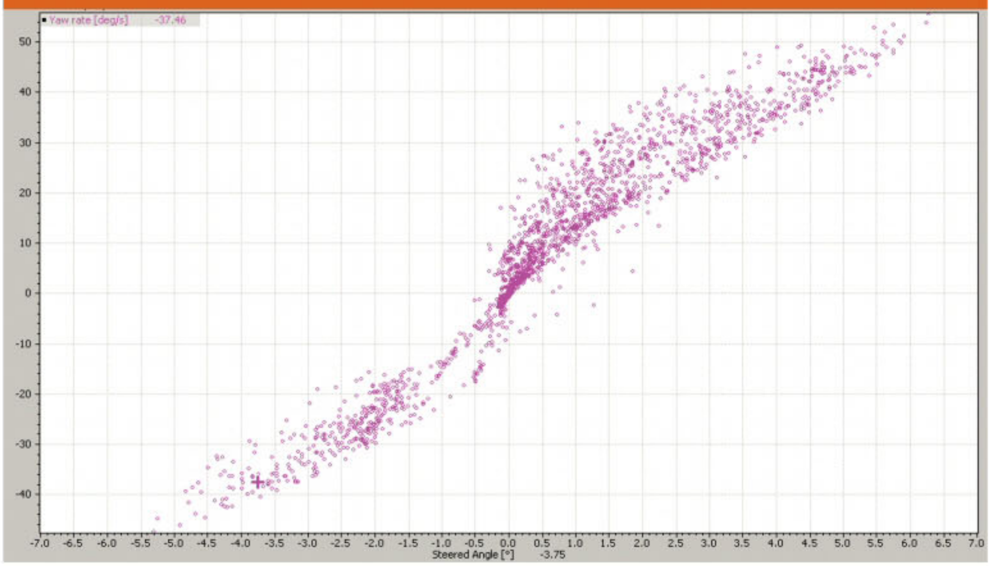
$\left.\frac{\partial F_1}{\partial \alpha}\right|_{\alpha=\alpha_1}$ = Slope of the normalised slip curve as a function of slip angle for tyre 1

$\left.\frac{\partial F_2}{\partial \alpha}\right|_{\alpha=\alpha_2}$ = Slope of the normalised slip curve as a function of slip angle for tyre 2

Fm(L1,T1) = Traction circle radius for tyre 1 (N)

Fm(L2,T2) = Traction circle radius for tyre 2 (N)

Figure 3: A plot of yaw rate *vs* steered angle at the tyre



Our key metrics when engineering a racecar are these: are we giving the race driver the control authority they need, and will they have a car that won't swap ends?

is illustrated in **Equation 7**. If anyone needs a derivation of this I would once again refer you to my book, *The Dynamics of the Racecar.*

The key question is, what procedure can we use to calculate the stability index so it can be readily incorporated into a set-up sheet? Our first goal is to calculate the slope of tyre force *vs* slip angle. In order to do this we need to quantify what the slopes of the normalised tyre force curve are. There are a couple of approaches you can use. However, the normalised ChassisSim slip angle curve has worked very well. This illustrated in **Table 1** on the next page.

The final element in this process is choosing what slip angles to take these calculations from. Looking at **Table 1** it's clear you would be nuts to choose 6-degree or whatever the peak slip angle of the tyre is. The slopes are zero and it makes no sense. In light of this, the procedure will be to set the rear slip angle at 5-degree. Then the front slip angle will be given by **Equation 8**.

Bear in mind here that **Equation 8** isn't something that is set in stone. It is an approximation to help you get an expectation of the relationship between the front and rear slip angles so you can calculate the stability index.

Slide rules

To refresh everyone's memory about calculating the stability index it would be wise to consider a worked example. Let's say the front slip angle is 5-degree and the rear slip angle is 4-degree. Using **Equation 7** and derivatives from **Table 1,** the stability index is **Equation 9**.

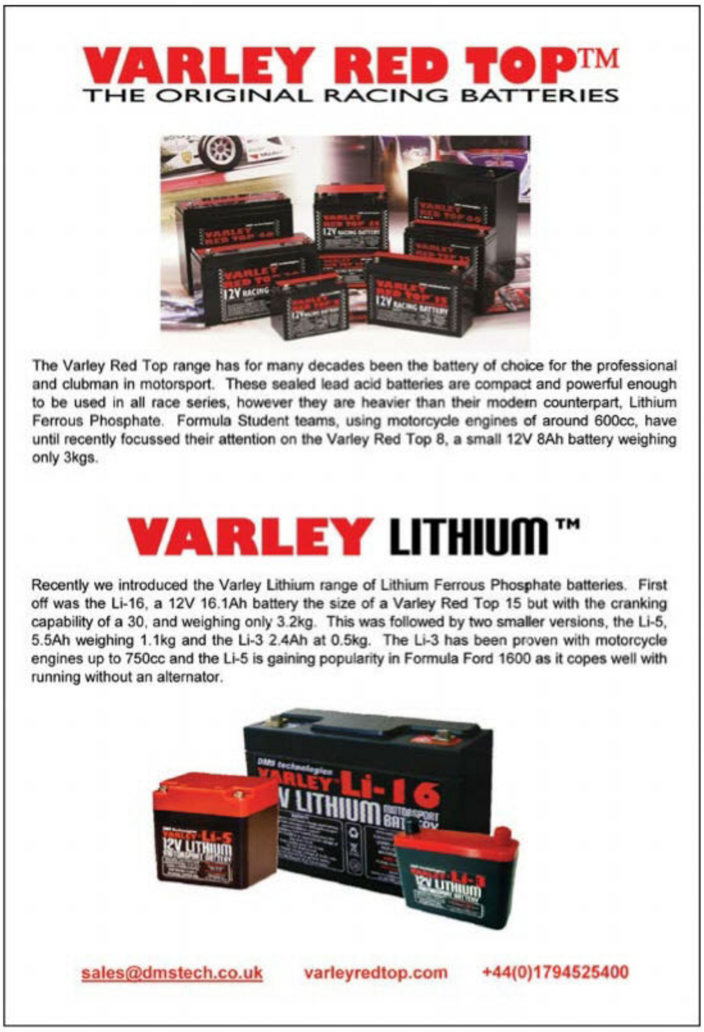
This result tells us that the centre of the lateral forces are 12.5 per cent of the wheelbase behind the centre of gravity.

So to tie this all together how do we go about calculating the stability index so we can incorporate this into a set-up sheet? The procedure is very simple:

- For a given lateral acceleration taken from data using the set-up sheet calculate F_{m1} to F_{m4} incorporating load transfer.
- Fix the rear slip angle at 5-degree or a peak slip angle of -1-degree from the rear peak slip angle.
- Calculate front slip angle using **Equation 8**.
- Then use the normalised slip slopes and **Equation 7** to calculate the stability index.

When you are done with all that you will then find a graph, as shown in **Figure 4**.

The beauty of everything we have just discussed is it cuts to the heart of the matter very quickly. Remember, our key metrics when engineering a racecar are these: are we giving the driver the control authority they need, and will they have a car that won't swap ends?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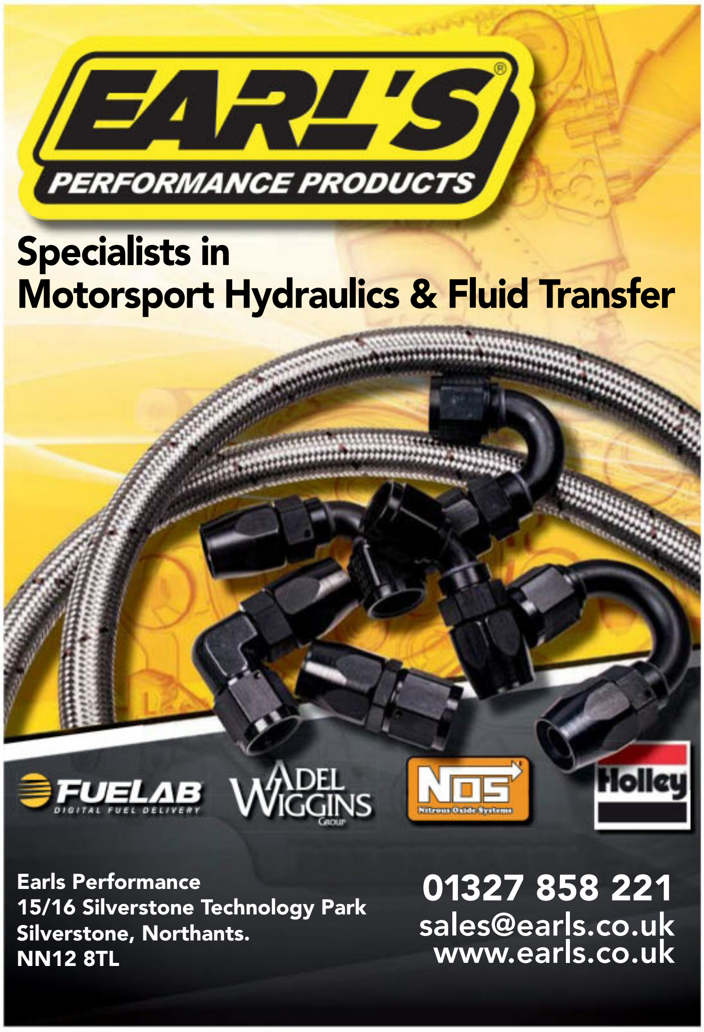
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Equations

EQUATION 7

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\bigg|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2})$$

$$C_r = \frac{\partial C_r}{\partial \alpha_r}\bigg|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4})$$

$$C_T = C_f + C_r$$

$$stbi \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb}$$

Here we have,

$dC_f/da(\alpha_f)$ = Slope of Normalised slip angle function for the front tyre

$dC_R/da(\alpha_r)$ = Slope of Normalised slip angle function for the rear tyre

$Fm(L_1)$ = Traction circle radius for the left front (N)

$Fm(L_2)$ = Traction circle radius for the right front (N)

$Fm(L_3)$ = Traction circle radius for the left rear (N)

$Fm(L_4)$ = Traction circle radius for the right rear (N)

a = Distance of front axle to c.g (m)

b = Distance of rear axle to c.g (m)

wb = Wheelbase (m)

EQUATION 8

$$\alpha_F = \frac{b \cdot (Fm(L_3) + Fm(L_4))}{a \cdot (Fm(L_1) + Fm(L_2))} \cdot \alpha_R$$

Here we have

a = Moment arm of front axle to centre of gravity (m)

b = Moment arm of rear axle to centre of gravity

a_f = Front slip angle

a_r = Rear slip angle

Table 1: Plot of normalised ChassisSim slip angle derivatives

Slip angle (deg)	Slip angle (rad)	δC/dα
0	0	14.323
1	0.0175	13.925
2	0.0349	12.731
3	0.0524	10.742
4	0.0698	7.9567
5	0.0872	4.375
6	0.1047	0

EQUATION 9

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\bigg|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2}) = 4.375 \times 5000 = 21875$$

$$C_r = \frac{\partial C_r}{\partial \alpha_r}\bigg|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4}) = 7.9567 \times 7000 = 55760$$

$$C_T = C_f + C_r = 77634$$

$$stbi = SM / wb \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb}$$

$$= \frac{1.6 \times 21875 - 1.1 \times 55760}{77634 \times 2.7}$$

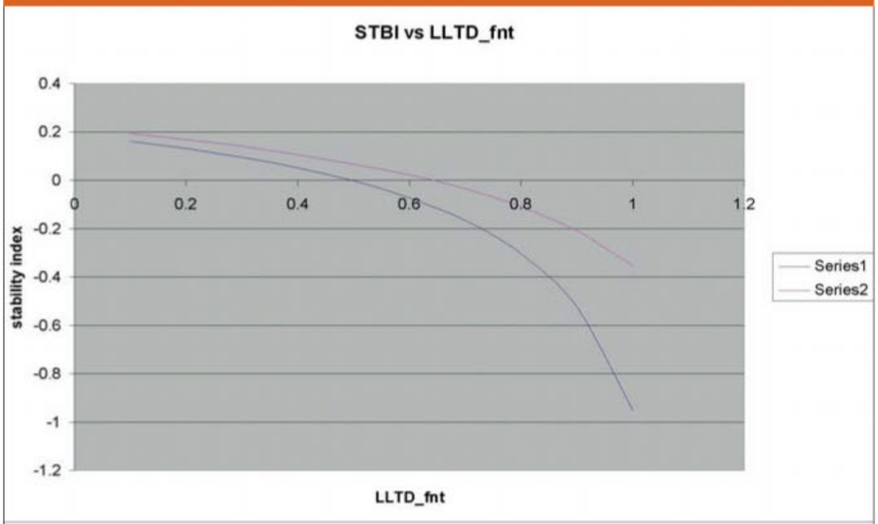
$$= -0.125$$

EQUATION 10

$$I_Z \dot{r} - a \cdot C_f \cdot \delta_s = \frac{\partial N}{\partial r} \cdot r + \frac{\partial N}{\partial \beta} \cdot \beta$$

$$N_{CORR} = fn(a_y)$$

Figure 4: Plot of stability index *vs* front lateral load transfer



Some readers might be appalled that we have bypassed a moment method diagram here

The former question is settled very quickly by **Equation 4** and **Equation 5**, plus **Figure 3**. Also the question of the stability index resolves the question of car stability in a similar expeditious manner. Some Formula Student readers might be appalled by the fact we have bypassed a moment method diagram here. However, in terms of resolving whether we have something drivable we have a procedure that is very easy to implement with this. Consequently this makes it very practical to use.

The critical question is; how do we calculate the stability index from race data? There are a number of approaches we can take for this. However, they all revolve around the identity that is shown in **Equation 10**.

Methodology

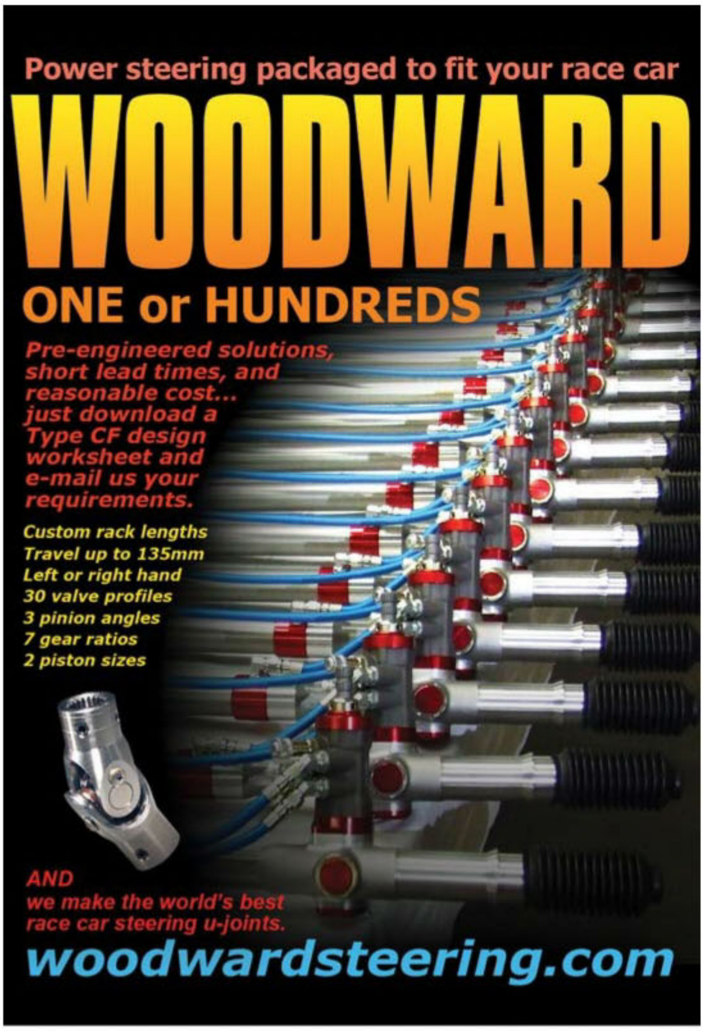
So, in plain English what this means is you're subtracting the total moment by the steering contribution. Then when you plot this against a_y the slope is the stability index. In an article a couple of years ago on using front and rear lateral accelerometers I discussed some useful approximations to get something usable.

However, another approach is that if you are logging steer and tyre loads and yaw rate you can construct something that also works well. What you do here is that you have a look-up table for tyre force *vs* tyre load using a simple 2D tyre model. You then have another look-up table for the normalised control slope as a function of lateral acceleration. Then, if you have yaw rate you take the derivative and you can figure out **Equation 10**. It's not perfect, but it gives you a useful yardstick.

Stable manners

In closing, when it comes to resolving racecar handling we can distil this question down to control power and stability index. The control power tells us how effective the steering is and will start to point us in the right direction if the race driver is complaining about understeer and lack of turn-in.

Meanwhile, the stability index allows us to get to the bottom of what happens if the car wants to swap ends and, more importantly, sending a car out with a set-up that will ensure this will never happen. If you can get your head around these two important concepts you will be well on your way to being able to understand what drives racecar handling.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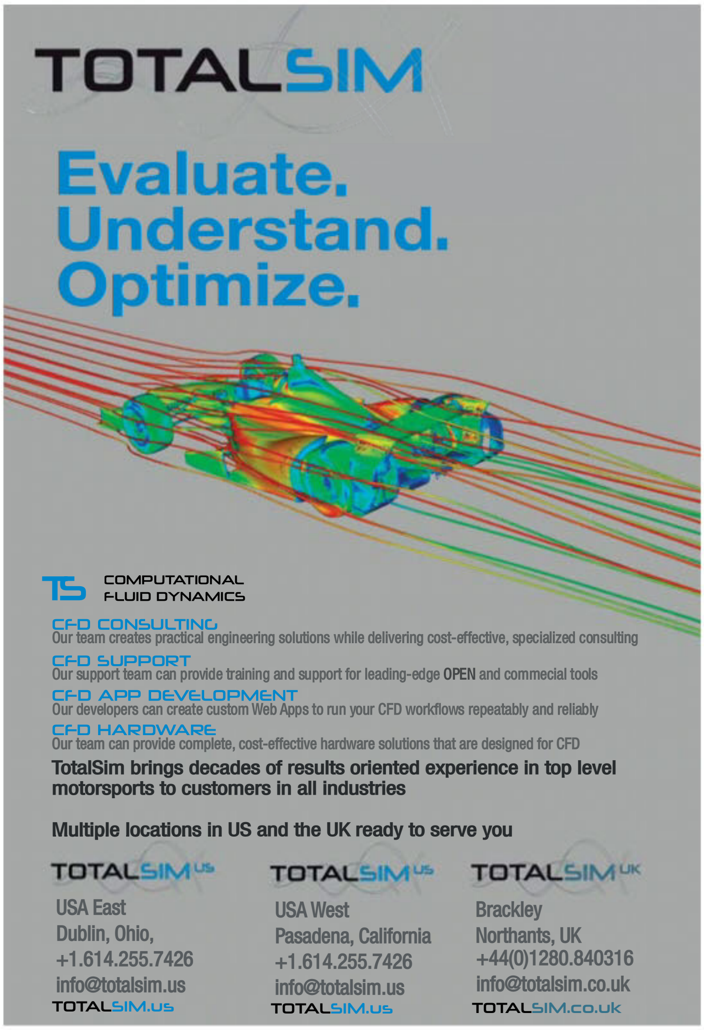
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Restraining order

Could driver head protection in the DTM be improved? A leading doctor involved in the series certainly believes so

By RACECAR STAFF

Mattias Ekstrom at the DTM round in Moscow in 2015, before the accident that was to leave him with temporary short-term memory loss, compelling doctor Vincenzo Tota to take a look at the headrests used in the series

Head protection is key to safety in racing and has been the subject of many studies involving single seaters and touring cars.

Major advances have been made in touring cars, particularly since the accident Danish driver Tom Kristensen had in 2007, when his DTM Audi was T-boned at Hockenheim – an impact that left him with blackouts and, he says, a personality change.

This is not an uncommon phenomenon and in the case of large accidents drivers often complain of headaches and dizziness. While single seaters are introducing the Halo to prevent large objects entering the cockpit, there is still the danger of a head injury following an impact due to the proximity of the headrest, which wraps around the driver.

Mercifully, this is a rare phenomenon compared to other sports, such as the NFL and soccer, which see multiple head impacts and only now is the long-term damage being realised in those sports. In motor racing, major impacts occur rarely, and usually in the case of a crash – although drivers do report impact with the headrest when, for example, running over the kerbs.

Dr Vincenzo Tota, official medical doctor for Audi Sport, conducted a study into Mattias Ekstrom's accident in the DTM in Moscow, 2015, where in the aftermath he demonstrated short-term memory loss symptoms. Incidentally, as mentioned above, it's not just crashes, and Tota says that DTM drivers are also often reporting

Estimates were that Ekstrom's accident was 70*g* around the head area, which is enough to cause concussion

Mattias Ekstrom in his office. Unlike the headrests on F1 cars the DTM device is further away from the driver, allowing more kinetic energy to build up before the head hits it

impacts with the head restraints during normal driving and kerb-hopping, which is even leading to a loss of focus for one to 1.5s.

Memory loss

The accident in question occurred on lap 11 of the Moscow race, with Timo Glock and Ekstrom clashing, sending both cars into the barriers. Ekstrom's accident was a driver side impact, and was severe enough that the car ricocheted off the barrier. Estimates were that the accident was 70*g* around the head area, which is enough to cause concussion.

According to Tota, the driver was able to exit the car by himself, with no physical consequences. All of the protocols were followed and the driver was released from the circuit medical centre. However, after two hours, Tota noticed that Ekstrom was suffering from short-term memory loss. The doctor asked him the same question every minute, and Ekstrom did not realise Tota was repeating this question.

Tota then conducted all the neurological tests, and found them to be negative. He prescribed paracetamol, 500mg every 12 hours, and by the following morning Ekstrom was perfectly functional. MRI scans over the next few days were completely negative, suggesting that he had recovered completely.

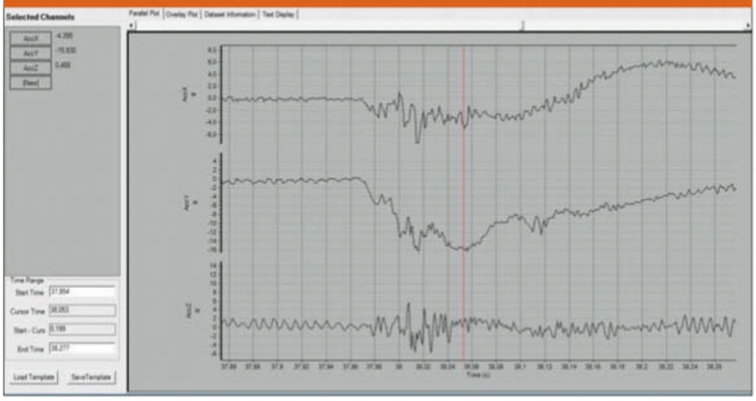
Concussion

However, Tota was still rather concerned and he began an investigation into the incident.

Medically speaking, a concussion may occur even when the head is violently shaken. At the root of the condition there is a functional disturbance of a part of the brain, known as the reticular activating system (RAS), which is a brain cell complex that belongs to the central nervous system.

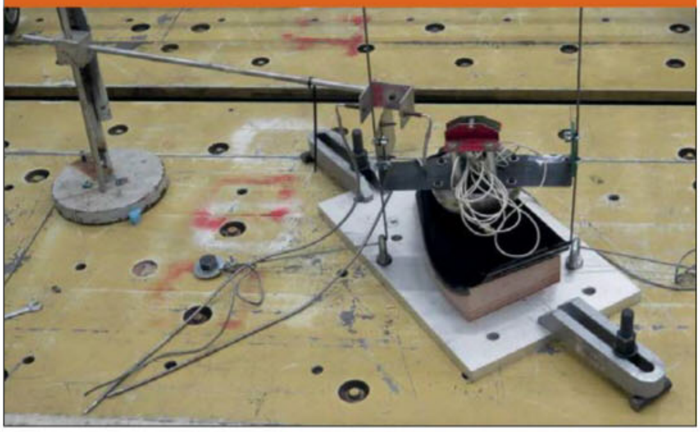
The RAS allows you to ignore relevant information in order to focus on necessary information. In the case of a concussion the brain is displaced from its normal position for

DTM race accident – headrest case study



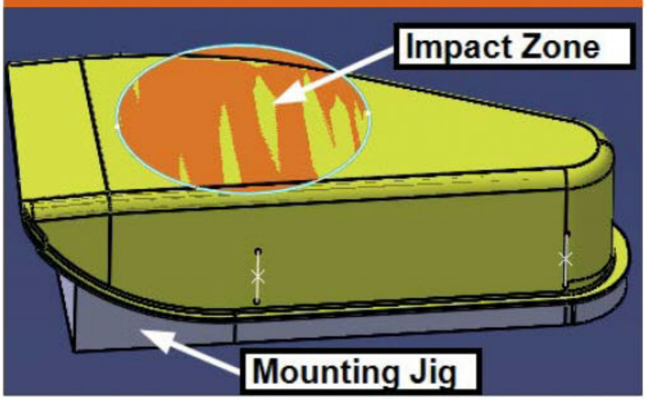
DTM analysis showing the main impact accelerations: longitudinal is at 4.4*g*, Lateral at 16*g*

Headrest materials test set-up



Test comprises hemispherical object (diameter 165mm, mass 8kg) and a vertical axis

Headrest materials test procedure



Procedure for the impact testing of the headrest, as conducted at the Politecnico di Milano laboratory in Italy. A solid hemispherical object with a diameter of 165mm and a mass of 8kg must be projected onto the headrest at a velocity of at least 7m/s along the axis of the main part of the headrest (vertical axis). The centre of the hemisphere must impact the centre of the main part of the headrest

Headrest covers

a short period of time. This rotation then interrupts the electrical activity of neurons that make up the RAS, which in turn triggers the symptoms associated with the trauma, such as memory loss, a short period of unconsciousness and confusion.

While the headrests used in the DTM conform completely to the FIA standards, Tota believes that the regulations need to be changed. He thinks that the headrest is too stiff, conforming to Formula 1 standards where the driver's head has very limited lateral movement. In a DTM car the head restraint sits further away from the driver, allowing more kinetic energy to build before impact with it.

Kevlar skin

The headrest materials specified by the FIA for Formula 1 and sportscars includes a Kevlar skin which increases the stiffness of the overall package slightly, and was primarily introduced for aesthetic purposes. The Kevlar is easy to clean, can be painted and, believes the FIA, adds a margin of safety. However, Tota disagrees.

For Formula 1 and sportscars the head restraint must be removable in one piece and made from two plies of Aramid fibre/epoxy resin composite pre-preg material in plain weave 60gsm fabric with a cured resin content of 50 per cent by weight. The padding must be designed in such a way that, in the event of an accident in which the foam is fully compressed, the helmet would not make contact with a structural part of the car.

Headrest give

Tota asked Audi to evaluate shock absorption efficiency of the headrest with and without the Kevlar cover, and the tests were conducted at the Politecnico di Milano laboratory in Italy. The test was designed to study the influence of the mandatory Kevlar cover on the crash performance of the component. It involved a solid hemisopherical object which had a diameter of 165mm and a mass of 8kg on to the headrest at a velocity of at least 7m/s along the axis of the main part of the headrest.

Two types of headrest were tested, one with the Kevlar support, and the other with a Nomex fabric cover. The test found that the peak acceleration was similar with both types (Nomex slightly higher peak acceleration), but that the Nomex covering offered a more measured path to that peak.

The Kevlar version was steeper by a factor of 2.4, meaning that the first impact is significantly harsher compared to the Nomex version. This, concluded Tota, was the reason for drivers feeding back their discomfort caused by too stiff a headrest, as well as for the concussion suffered by Ekstrom in his crash in Moscow.

The test found that the peak acceleration was similar with both types, but that the Nomex covering offered a more measured path to that peak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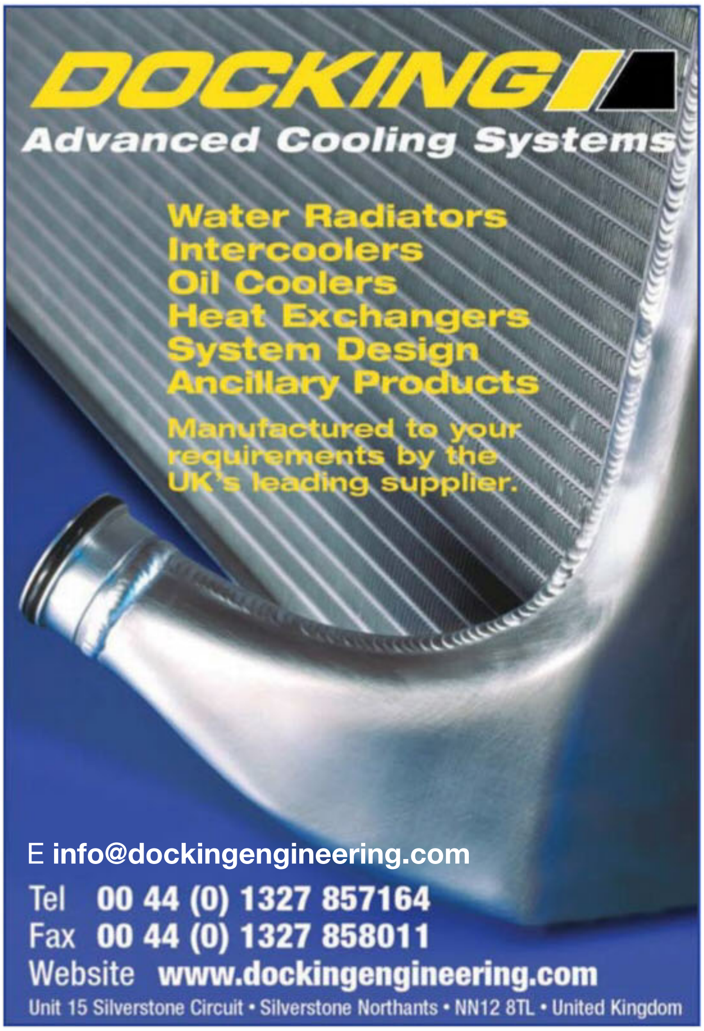
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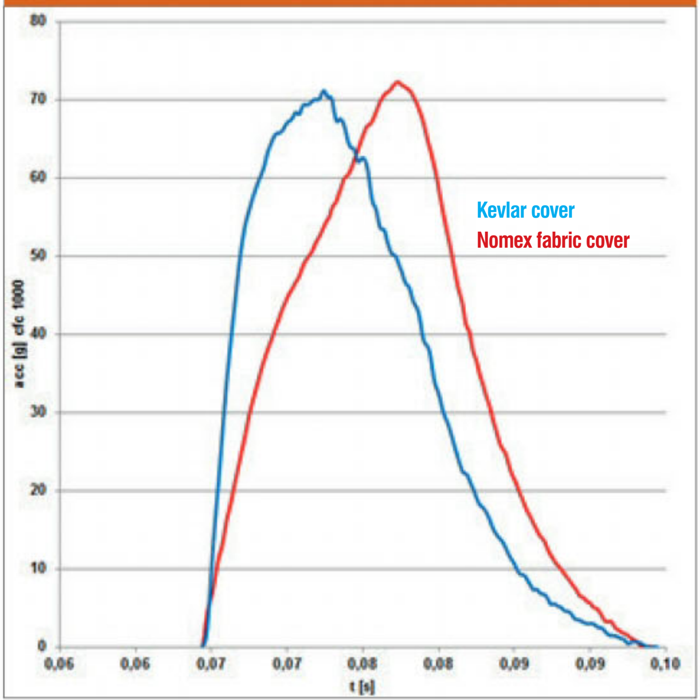
The implication was that the deceleration of the head in the event of an accident was less, and and therefore it could be the safer of the two options

Acceleration *vs* time



Max peak is nearly identical with/without Kevlar cover. One reason for this might be that the foam is compressed to its maximum at the end of the impact, and is therefore rigid

The Kevlar was found to decelerate the body faster than the Nomex, although the deformation was more with the Nomex cover, as could be expected. One could draw from this that the maximum deformation could occur quicker, reducing the impact of the foam and increasing the severity of impact with anything harder than the foam. The peak deformation shows Kevlar at 49.3mm compared to 64.1mm without.

The tests did not prove conclusively that the non-Kevlar option was safer, but the implication was that the deceleration of the head in the event of an accident was less, and therefore it could be the safer of the two options. There are further tests that need to be carried out, including testing different materials including two different types of Confor Foam, although the team was waiting on the advice of the Technical Commission at time of writing.

On track

This solution was tested in a DTM test session, and the drivers found it to be more comfortable. Confor foam CF42 and CF45 is compatible with FIA regulations for open cars, and could be a better solution for DTM, the fastest touring cars in Europe.

Racecar says

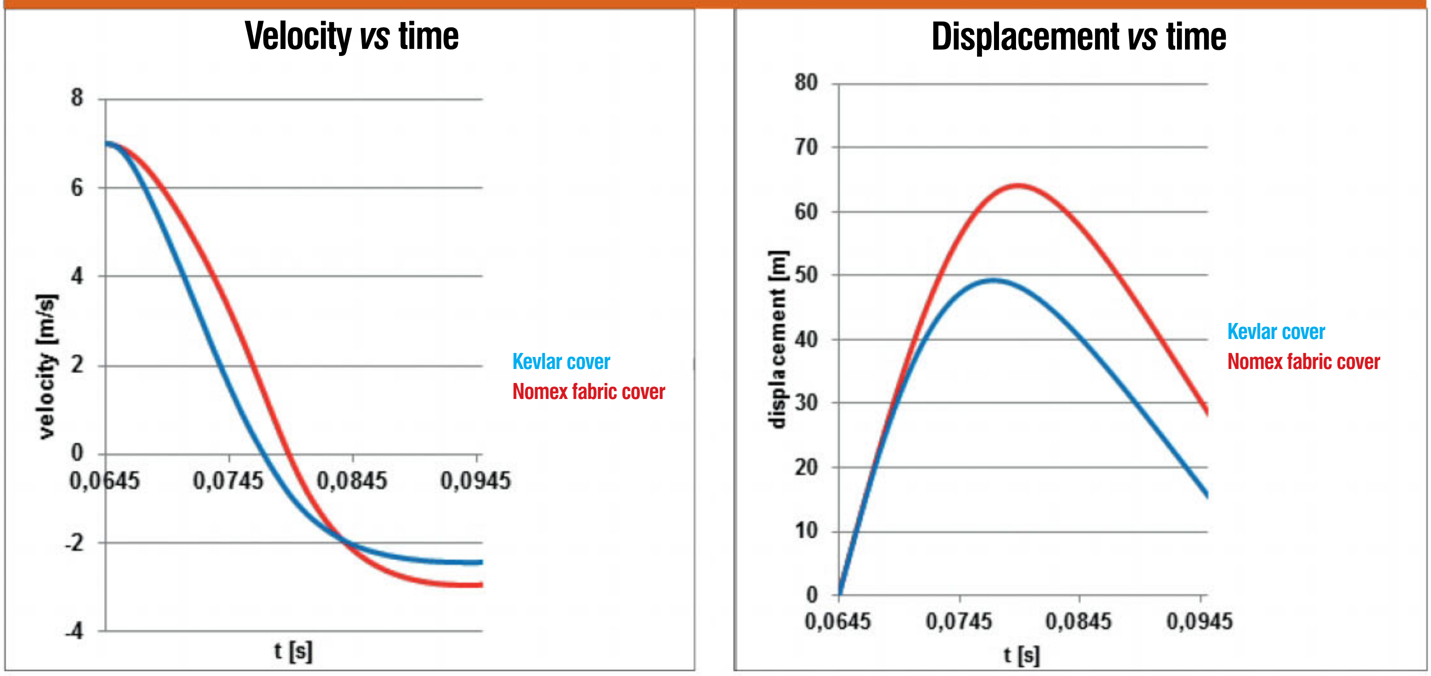
This study throws up an interesting discussion point. While the non-Kevlar head restraint does soften a smaller blow to the head, which are far more common among drivers and according to Tota are regularly reported, it is actually a critical safety factor in the larger impacts that the headrests are designed for.

The headrest is designed so that at full deformation the driver's head does not strike a structural point of the car, but the peak load that the FIA regulation is designed for is 300*g*. Without the Kevlar, the Nomex foam would 'bottom out' faster and would therefore be of less use in a case of high impact, and may actually increase the severity of any injury. The peak load, as shown in this article, is actually higher.

One solution that the DTM could consider would be to add material to the headrest, reducing the distance that a driver's head may travel before initial impact, and preventing the head from ricocheting between the 'ears' of the head restraint.

That may be less comfortable for the drivers and may limit their movement in racing conditions, but is the most cost-effective and safe solution, experts tell us.

Displacement/Velocity *vs* time



Looking at the velocity versus the time analysis you can see the impact speed of 7m/s is reduced a great deal quicker with the Kevlar cover on top of the foam. While looking at the displacement versus time analysis you can see the version without the Kevlar cover is deformed more. The peak deformations are with Kevlar: 49.3mm, without Kevlar: 64.1mm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Interview – Jens Marquardt

Brand awareness

BMW's motorsport chief tells us why DTM, GTE and Formula E currently tick all the right boxes for the firm when it comes to its major racing commitments

By ANDREW COTTON

XPB

'We have always said, we race either a model we want to display, or relevant technology'

Has there ever been such a smorgasbord of categories for manufacturers to choose from as there is right now? On top of the usual fare of Formula 1, sportscars, touring cars and rallying, there is now also Formula E – which ticks the green box – and burgeoning customer sport formulae, which appeases the accountants. So options have to be weighed up and choices made, which means a clear grasp of what the company really wants from its racing programmes is imperative if you're to succeed as a motorsport boss.

While for Jens Marquardt, BMW's motorsport director, the choice also has to be refined. The planned Le Mans Prototype programme was cancelled and shows no signs of returning as the company turns to the cheaper, more accessible and corporate friendly Formula E alongside its GT racing activities. But this is in line with BMW's motorsport philosophy. 'We have always said, it's either a model that we want to display, or relevant technology, like Formula E, with our own in-house developed electric motor and electronics,' Marquardt says. 'That's what we also said in regards to something in the future, hydrogen fuel cell or whatever, and Garage 56, and those options are currently on our radar. Anything else is not.'

This was in response to a question on a rumoured DPi project – which is clearly not on the agenda despite the cheaper cost compared to LMP racing – but it's interesting to hear that BMW is still at least still thinking about a hydrogen fuel cell at Le Mans. 'The technology is still very relevant, I think it is one of the options that we have for the future when it comes to heavier vehicles with long range and electric – obviously – driven. So therefore the relevance of this type of technology for production cars is absolutely there,' Marquardt says. 'So in that respect it is one of the technologies that could feature in racing. It's something that currently we are not pursuing … [but] we have done the study, it could be feasible.'

The future for DTM

For the time being, in the sportscar arena, BMW is focused on its M8 GTE car, with which it will return to Le Mans, while its touring car presence is in DTM. Marquardt actually joined BMW from Toyota Motorsport (where he was F1 team manager) as the Munich marque was gearing up for its 2012 return to DTM. The series remains at the heart of its motorsport effort, but right now, with stalwart Mercedes announcing it's to jump ship, it is at something of a crossroads, as is international touring car racing as a whole. So what's BMW's stance on all this, and on the ongoing efforts to merge DTM with Super GT in Japan?

'For us, with the DTM and the ITR [the DTM promoter], what we have done is really good over the last years. [We have] put a set of regulations together with a lot of common parts, and we are further working on that together with our Japanese colleagues in Super GT. As we have always said, this is the closest link we have so far. The Class 1 [regulations] is what we want to get rubber stamped for 2019.

'We have a clear plan with Super GT together to do the next step on Class 1 regs; we have not gotten together over the last years, because of the engine regulations, which have been postponed twice, by unfortunately the manufacturer that has now said goodbye to DTM [Mercedes],' Marquardt adds. 'So now we have got to fix that, quickly, and then ITR has to sort out together with Super GT what the next step can be. I think the regs are really good, and that's something to build on. At the end of the day [DTM] has survived for quite some time and I think it is a very good foundation to start from.'

This could eventually mean a new World Touring Car Championship for Class 1 cars, but as yet this is not decided, says Marquardt: 'Gerhard [Berger, DTM boss] is discussing with Super GT, FIA, and everybody else, what could happen.'

Differing approaches

The main sticking point when it comes to merging DTM and Super GT into Class 1 is the different technical philosophies the two have, with the Japanese series very open in terms of development. But Marquardt believes a focus on what the fans want should be at the heart of any future decisions. 'I think we have to discuss very, very openly together; what's the benefit? What's the benefit for who,' Marquardt says. 'At the end of the day, we're always talking about the customer, and the customer is the spectator, the fan. What kind of development is really relevant to the fan? What does he actually see? We've discussed this at length this year, on the DTM side. Like in aero; I don't know how many things there are on the car, aero wise, that are completely invisible to the fan. Does he care about them? My

BMW has no intention of letting the sun set on its DTM programme, which it uses to showcase its M4 model opinion is, no, not at all. He wants to see racing. And if the aero accounts for worse racing, because it's too dominant, then it's a double negative for the spectator. He has a worse show, and doesn't even see why. So, if there are things involved that are properly visible to the fans, and for them really something to say, "wow, I'm impressed", then let's discuss. If it doesn't help the show, if it increases the cost, then why go for it?'

But what if the Japanese manufacturers still want to pursue technology? 'If you want to do a technology battle, as Toyota have been, for a while, in LMP1, and they have done so in F1, [then] that's where your technology battles are,' Marquardt says.

Sparking debate

Which brings us to Formula E, another arena in which technical development is a constant talking point, and another category BMW, along with many of its rivals, has now embraced – as a technical partner to Andretti this season (2017-18) and as a full works effort in season five (2018-19). So, is there enough technical development in FE? 'Yes,' Marquardt says without hesitation. 'In relation to what you have to spend. [And that's] exactly the point; learn from mistakes that have been made: fast and free [development] always means money.

'[The future] depends a lot on where Formula E heads from now. At the moment there is a clear plan in place, up until I think season seven – season eight onwards is under discussion. It will depend on [whether or not] battery technology, chemistry, all those kind of things, will become free. Will they keep the spec car? And things like that.

'At the moment the championship is stable, which I think is a good thing,' Marquardt adds. 'Obviously, electronics are an area where you can develop. This is something important to a manufacturer; battery management systems and those kind of things, and the strategy behind them, there is a clear relevance to road car technology there.

'We are developing our motor in house at BMW, so this really [speaks] directly to our production people. This [speaks] directly from a technology point of view, so for us this a programme that fits superbly into BMW. This is not a racing thing where I get 10 suppliers to supply things, I put it together and I go racing, and I put a sticker on the outside of the car and say, "hey, this is my brand and we are racing". This for us is really a kind of technology lab.'

Which, as the man said at the very start of this piece, is one of the reasons why BMW goes racing.

RACE MOVES

Martin Whitmarsh, formerly team principal at the McLaren Formula 1 team, is to be part of a new Formula E Global Advisory Board, which is to be chaired by FE team owner **Alain Prost** alongside former executive secretary of the United Nations Framework Convention on Climate Change, **Christiana Figueres**. Formula E CEO **Alejandro Agag** and other FE stakeholders will also be on the board.

Aston Martin has recruited ex-Ferrari engine chief **Joerg Ross** as it continues to evaluate an F1 engine project from 2021. Ross actually joined Aston in August to work on road car engines but has now moved within the organisation to lend his experience to the Formula 1 evaluation. He will work alongside **Luca Marmorini**, also a former Ferrari engine boss, who was taken on as a consultant (see January's issue, V28N1) but has now been hired on a permanent basis.

NASCAR outfit Richard Childress Racing (RCR) has appointed **Andy Petree** as its new vice president of competition while Dr Eric Warren is now its chief technology officer. Petree joins RCR on a full-time basis after he was brought in in an advisory role in October. Warren, who has served in a competition leadership position at RCR since 2012, will now oversee its engineering department and its new technology strategy.

The No. 18 Joe Gibbs Racing pit crew, which helped **Kyle Busch** to a runner-up finish in the Monster Energy NASCAR Cup Series play-offs, was awarded the Mechanix Wear Most Valuable Pit Crew at the Myers Brothers Awards in Las Vegas at the end of the NASCAR season.

Mike Dunn is now senior consultant at US drag racing body the International Hot Rod Association (IHRA). Dunn, a well-known drag racer in the past, served as IHRA president from February 2016 until moving to this new position. This change allows him to pursue other interests outside of the sport. Dunn has also worked as a mechanic and team owner during his time in drag racing.

Long-time IndyCar race director **Brian Barnhart**, who held the joint position of IndyCar vice president of competition and race director in 2017, is leaving the organisation to become president of new IndyCar team Harding Racing, which made its debut in 2017. Barnhart has worked for the IndyCar governing body since its early incarnation as the Indy Racing League in 1997.

Walter 'Bud' Moore, who won NASCAR championships both as a car owner and a crew chief, has died at the age of 92. A decorated war hero – awarded with two Bronze Stars and five Purple Hearts in Europe in WWII – Moore won the NASCAR premier series title in 1957 as crew chief for **Buck Baker** and car owner titles in 1962 and '63 with **Joe Weatherly**. He had been the oldest living member of the NASCAR Hall of Fame.

Sean Seamer, formerly the CEO of MediaCom, has been appointed as successor to **James Warburton** at the head of Australia's Supercars series. Seamer has spent 15 years with MediaCom, working across the US, Europe, Asia and most recently Australia. Warburton left the post in December, after four and half years in charge.

Jason Ratcliff, the crew chief on the Joe Gibbs Racing No.20 car in the NASCAR Cup Series, was fined $20,000 and suspended from the next race after the Toyota he tends was found to be running with two improperly installed lug nuts during post-race inspection at Homestead-Miami Speedway.

Rick Harris has joined the SCCA national staff to serve as its road racing technical manager. Harris has been a member of the US racing club for 15 years and was the 2008 F Production National Champion. Meanwhile, **John Bauer**, who has served dual roles in the SCCA competition and information technology departments since 2014, will now focus more on IT projects.

Todt elected for third and final term as FIA president

Jean Todt was re-elected as president of the FIA at the body's General Assembly in Paris in December.

The former Ferrari F1 boss, whose career in motorsport started as a rally co-driver, stood unopposed and will now hold the post – which he has filled since taking over from Max Mosley in 2009 – until the end of 2021. FIA rules say only three terms as president are allowed, so this will be Todt's final spell in charge.

Todt was confirmed in the position with a show of hands at the General Assembly, following which he said: 'It is gratifying to have such universal support. I would like to thank all of the member clubs of the FIA for their support.

'I see this as a validation of the direction the FIA has taken under my leadership, and as encouragement to continue the programme we have pursued over the past eight years.'

XPB

Jean Todt will continue as the FIA president until the end of 2021

The FIA has said that during his final term Todt will concentrate on three key areas: 'innovation, advocacy and the development of a strong network of mobility and sport clubs.' Todt said: 'Innovation is essential if the FIA is to continue to improve and take its rightful place in the world as the leader in mobility and motorsport development. To encourage this, we propose to establish an FIA Innovation Fund. Our clubs are the largest consumer organisations in their country and their 80 million road-user members make the FIA one of the largest global consumer bodies.'

As well as a continuing road safety drive the FIA will now also focus on mobility. Todt said: 'This is important because while the future of mobility is exciting, it also holds many challenges, and it is our duty to help shape it.'

Honda management reshuffle sees Hasegawa's departure

Yusuke Hasegawa is no longer the head of Honda's Formula 1 effort, following a management restructure within its F1 business by the Japanese manufacturer.

Hasegawa,endured a trying 2017 season as the Honda power unit failed to deliver on both the performance and the reliability fronts, which ultimately ended in a split with McLaren – its partner for three seasons – and a deal with Toro Rosso for 2018.

XPB

Yusuke Hasegawa no longer holds the reins at Honda's F1 operation

In his post at the head of the F1 project, Hasegawa was responsible for both engine development in Sakura in Japan and the firm's operations at F1 races. This role now no longer exists, and the responsibilities have been split in to two.

Toyoharu Tanabe is now F1 technical director and will concentrate on racing and testing operations, while it's been reported that Yasuaki Asaki has taken the position of operating officer at Sakura, where he will be in charge of F1 engine development.

Tanabe has F1 experience, having been chief engineer for Jenson Button at BAR and then Honda itself, while earlier in his career he was an engineer for Gerhard Berger at McLaren. More recently he held the post of senior manager and race team chief engineer at Honda Performance Development, the company's American motorsport division.

Katsuhide Moriyama, Honda's chief officer for brand and communication operations, said: 'In the past, the head of F1 project assumed responsibility in both technological development and directing the team at the spot of racing. By separating these areas of responsibility, we will evolve our structure so that both the development team and racing/testing team can assume their respective responsibilities more speedily'.

RACE MOVES – continued

XPB

Ex-Formula 1 driver **Mark Webber** is to serve on the Australian Grand Prix Corporation board for the next three years. The nine-time grand prix winner has been named as one of two new additions to the board, with Saltwater Hotels general manager **Kimberly Brown** also joining. Their appointment comes as **Alan Oxley** departs, after 15 years on the board.

The International Motor Sports Association (IMSA) has appointed **Eric Albrecht** as director, Business Development. In his new position he will be responsible for finding sponsors. Albrecht comes to IMSA from the National Kidney Foundation in the US, where he was vice president of Events Development and Sports Marketing for the last seven years.

Australia's Supercars series has promoted TV director **Nathan Prendergast** to general manager of Television and Content. He will now manage its award-winning television production arm.

Tom German is to be race engineer for **Graham Rahal** for his 2018 IndyCar campaign with the Rahal Letterman Lanigan team, while Rahal's former engineer, **Eddie Jones**, will move to oversee the sister car of **Takuma Sato** – who has come to the team as it expands from a single car entry.

Roz Bird, the commercial director at Silverstone Park, has been named as one of 100 business people likely to have a significant impact on the UK economy in the next 12 months. Bird was named as a Face of a Vibrant Economy for 2017 by Grant Thornton UK. She has been in charge of the hi-tech business estate development since commercial property developer MEPC took control of the site in September 2013.

Re-elected FIA president **Jean Todt** (see lead story) has announced a restructured team, with **Brian Gibbons**, formerly deputy president for Mobility, now taking over from **Nick Craw** as president of the FIA Senate. Meanwhile, **Thierry Willemarck** leaves his role as president of Region I of the FIA to replace Gibbons.

Robert 'Bootie' Barker will no longer be the crew chief for **Ty Dillon** at NASCAR Cup outfit Germain Racing. Barker joined the team for the 2010 season. He has chalked up 17 top-10 finishes as a Cup Series crew chief.

Veteran NASCAR crew chief **Matt Borland** has been signed up by Cup Series team Germain Racing to tend the No.13 Chevrolet, driven by **Ty Dillon** in the premier NASCAR series, in what is said to be a multi-year agreement with the team. He replaces **Bootie Baker** in the position (see above).

IMSA outfit BMW Team RLL has signed up former Chip Ganassi Racing IndyCar race engineer **Brandon Fry** as its new technical and racing operations director. Fry's previous sportscar experience includes working with the Nissan LMP1 programme and also as team manager/race engineer with the Muscle Milk Racing championship-winning ALMS LMP1 team.

◆ Moving to a great new job in motorsport and want the world to know about it? Or has your motorsport company recently taken on an exciting new prospect? Then email with your information to **Mike Breslin** at **mike@bresmedia.co.uk**

The silent majority

The changing face of motorsport on the race track and in the grandstands

Much has been made of the UK government initiative to ban the sale of internal combustion engine powered cars in 2040. But if you really read what was said, the majority of cars will have moved to a form of electrification by then, and that is an admission, but clearly they see electrification and electric power as the future.

It does not mean that on that date all internal combustion engine cars will disappear. There is an acceptance that a form of hybridisation may go a further way than we imagine. Using an ICE in a smaller, more efficient form, coupled with faster charging and storage of electricity, is certainly on the roadmap. The target date is 20 years and the speed of change is so fast that we may find compromises along the way, but most governments have to set a proper target. You can criticise it, but by making a clear target as many have across Europe, then you will start moving towards it.

The British government is working with organisations that have their basis in racing. It is always shorter and easier to make the statement than put it into practice, but companies such as RML in Wellingborough is but one of several of these companies. They seized on the opportunity to say that there is going to be a powerful demand for Britain having a powerful and substantial battery production facility close to our OEMS, and there is a tremendous drive for small companies to produce short runs of increasingly better performing energy storage facilities. The two go hand in glove. There will be big OEM development, and this kind of prototyping opportunity for small runs not just of cars, but also of batteries. Battery technology is changing so quickly you don't want to commit to making millions of the things. Companies like RML are being pioneers, and that is being supported by the British government through funding. It is just as exciting for engine tuning companies to become electric power and tuning companies. The two are completely different engineering challenges, but they are powertrain people. This 20-year story is not very long and you don't want to miss the opportunity of earning money from these prototype powertrains, either semi electric or fully electric.

Efficiency drive

Hybridisation in racing is in its early days still, even with Formula 1 and endurance racing embracing the technology. If we talk about consumer demand or government policy you would say that the end goal is this magic 100 per cent electric, which I think is a lot further away than we would ever imagine. Before that, there is going to be this changing role of electrification and energy storage, of using your energy more efficiently. I am pretty confident that motorsport guys will make lighter smaller super efficient ICE powertrains which will keep changing the argument, so or not whether Le Mans decides that it's not quite where they are now, there will be a drive from the top down from the OEMs to say we need something from motorsport to do the rapid development to see what works. It may prove to be the case that touring cars seize the opportunity more than endurance cars. I think that is only a matter of a very short lead-time.

The other interesting thing is that it is as though people forget that if you get a promoter and funding source and to some degree an OEM together as an entity, like they did with Formula E, you will create a series. We are reactive, not proactive, when it comes to going in front of an audience. We are quite proactive in terms of technology, but when it comes to going on stage we react to a demand.

Brand value

The way you reach the audience is going to be different and if you don't have footfall through the gate, that is no longer going to be the sole source of recognising whether the sponsors get brand value. Brands won't be slow to activate their brand value in a myriad of streams. An audience walking through the gates will in the future be just one part of entertaining anybody in sport entertainment. A soccer ground can only hold 50,000 or 80,000 people, for example, but a team such as Manchester United can get millions watching the game. It's the millions that the brands are after.

Ninety five per cent of races take place in front of one man and a dog, and racing provides enormous entertainment to the people who are participating in it, and you only have to look at the track days to see the enjoyment that people get from driving their cars fast, and those who watch from the grandstands to illustrate the point. We forget the joy of racing in this environment can please millions of people who don't care if anybody is watching.

There might only be 100 fans, yet there may be one million spectators

There is a big difference in the audience; there are the fans, and there are the spectators and they are two quite different things.

The fan is a fanatic, and there is an excessive extreme involvement with a particular issue. There may only be 100 fans for something yet there may be one million spectators, and when you think about an audience of 160,000 at a grand prix, they are not fans going to every single grand prix in the pouring rain, but they want to be part of the audience. I spent my life surrounded by fanatics. Perhaps we are getting the wrong impression of what constitutes a successful racing series?

Nothing sums up the fanatic quite as well as the rally fan. But while they are willing to stand out in the rain to watch heroes blast by, perhaps the really important people from a business point of view are casual spectators

Pit equipment
Members of the board

A pit board is a must-have item in almost all forms of motor racing, despite the increasing use of pit-to-car technology.

BG Racing has produced new pit boards that are manufactured from lightweight T6 aluminium and come in four colour options: red, blue or black powder coat or a durable bright silver anodised finish.

The standard BG pit board name plate is the ideal solution for those who struggle to pick out their pit board amongst the crowd. It is produced from foam PVC ready for personalising with a driver's name, number or team logo, to create a professional appearance.
www.bg-racing.co.uk

Turbochargers
Ruling the boost

US-based Precision Turbo and Engine (PTE) is a worldwide supplier of high-performance turbochargers. Over the years, the company has designed, tested and manufactured record-setting and championship-winning turbochargers for many motorsport categories.

As it continues to expand its operations and product offerings, PTE has announced the release of its long-awaited GEN2 PT7275 CEA turbocharger. The new turbo is one of the most technologically and aerodynamically advanced units on the market today, the company tells us, and it offers higher efficiency and faster transient response for maximum power and performance. Purpose-built for improved strength, durability and longevity, every new GEN2 PT7275 CEA turbo will be equipped with an air-cooled, dual ceramic ball bearing centre housing rotating assembly (CHRA) for faster transient response, less turbo lag, and added thrust capacity.
www.precisionturbo.net

Inspection
Heat seeking device

Intercomp, which is celebrating its 40th anniversary in 2018, designs and manufactures measurement and weighting solutions.

It is showcasing its Thermal Imager at the Autosport International Show in the UK in January.

Although primarily aimed at the motorsport and automotive industries, this tool can also be beneficial in any environment where a clear, saveable image of heat signatures given off by a particular item is required. This could be useful in a range of applications including military, aviation, automotive and materials handling, Intercomp says.
www.intercompracing.com

Transmission
Shifting perceptions

Steeda, the world's largest aftermarket manufacturer of Ford performance equipment, now offers a race spec short throw shifter for Mustangs.

Designed to eradicate all slop and deflection in the factory supplied shifter, Steeda claims this offers a 30 per cent reduction in throw between gears.

The kit comes complete with two medium-resistance springs and two high-resistance springs to make it fully adjustable, and adjustable return springs to fit every drivers' preference on shifter feel. Since it's S550 MT-82 short shifter is top-loaded, once the base plate is mounted you can change all of your springs, levers and other options from inside the car.
www.steeda.co.uk

Driving simulators
Sensible Ansible

If teams and manufacturers want to improve the offering of any static or dynamic simulators, they have two options: upgrade the vision system (high cost, for little return) or upgrade the hand wheel loading system.

The latter option will bring vast improvements to the range of testing, set-up and R&D experiments, and while it's pricey it can be used for more things.

Ansible Motion now offers its bespoke handwheel systems that can be used on other simulators. With steering torque feedback, a primary contact cue, it relays information to the driver about the state of the vehicle. Investing in the best wheel is essential for vehicle development. Ansible Motion's peak torque for its HWLS is 20Nm, but higher torque options are available.
www.ansiblemotion.com

The International Journal of Motorsport Technology
Racecar engineering

PIT CREW

Editor
Andrew Cotton
@RacecarEd

Deputy editor
Gemma Hatton
@RacecarEngineer

News editor and chief sub editor
Mike Breslin

Design
Dave Oswald

Technical consultant
Peter Wright

Contributors
Mike Blanchet, Sam Collins (associate editor), Ricardo Divila, Eric Jacuzzi, Simon McBeath, Danny Nowlan, Mark Ortiz, Sam Smith

Photography
James Moy

Deputy managing director
Steve Ross **Tel** +44 (0) 20 7349 3730
Email steve.ross@chelseamagazines.com

Advertisement Manager
Lauren Mills **Tel** +44 (0) 20 7349 3796
Email lauren.mills@chelseamagazines.com

Sales Executive
Stephen Upfold **Tel** +44 (0) 20 7349 3775
Email stephen.upfold@chelseamagazines.com

Circulation Manager Daniel Webb
Tel +44 (0) 20 7349 3710
Email daniel.webb@chelseamagazines.com

Publisher Simon Temlett

Managing director Paul Dobson

Editorial and advertising
Racecar Engineering, Chelsea Magazine Company, Jubilee House, 2 Jubilee Place, London, SW3 3TQ
Tel +44 (0) 20 7349 3700
Fax +44 (0) 20 7349 3701

Subscriptions
Tel: +44 (0)1858 438443
Email: racecarengineering@subscription.co.uk
Online: www.subscription.co.uk/chelsea/help

Post: *Racecar Engineering*, Subscriptions Department, Sovereign Park, Lathkill St, Market Harborough, Leicestershire, United Kingdom, LE16 9EF

Subscription rates
UK (12 issues) £86.00
ROW (12 issues) £98
racecar@servicehelpline.co.uk

Back Issues
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News distribution
Seymour International Ltd, 2 East Poultry Avenue, London EC1A 9PT
Tel +44 (0) 20 7429 4000
Fax +44 (0) 20 7429 4001
Email info@seymour.co.uk

Printed by William Gibbons
Printed in England
ISSN No 0961-1096
USPS No 007-969

THE CHELSEA MAGAZINE COMPANY LTD
independent publishing company of the year 2015

www.racecar-engineering.com

Questions of sport

Over the past few months I have attended races on many different continents. From the final round of the IMSA United Sportscar Championship at Road Atlanta, to the Intercontinental GT race at Laguna Seca, then the Macau Grand Prix, and on to Formula E in Hong Kong.

It has been a smorgasbord of racing, not only different disciplines but also different racing philosophies and powertrain solutions. The conversations in the paddocks have been as illuminating as the racing itself.

There has been fan-focused racing (IMSA), racing pretty much for for a virtual audience (Formula E), manufacturer racing and customer racing. Then there's been the contrast between gasoline and electric powertrains, too.

The long-haul flights have given me time to ponder the sport and how it may develop in the future to meet with our motoring needs. I've realised that the mistake I have made in the past is to mix them up; would hybrid fit in the US; or would Formula E work in Macau? The answer is 'no'. Each series is catering to its own fanbase and market, and that is key.

Has motor racing adapted to this changing vision of motoring?

But was I looking in the wrong direction? As the average age of the motorsport spectator increases, and numbers consequently dwindle no matter what happens on track, are we actually losing sight of what racing is all about?

As humans, we love competition. We love to see one car, one driver, race another. We enjoy the spirit of competition, the no-holds barred competition that was evident in the F3 race at Macau and actually was pretty prevalent in FE in Hong Kong, too. Anyone who has watched WEC racing, or F1 qualifying, has that competitive spirit well catered for. The fan seeks to have their senses assaulted, either through noise, visual speed, smell or even feel as a thundering V8 passes by.

However, we have also got it into our heads that we need to travel, for work or pleasure. We travel from one place to another, often by car, and for many it's becoming simply a functional tool, a high-speed bus. Therefore, we are losing the desire to enjoy motoring and instead we have switched our attention to efficiency, and ease of use. That's why autonomous driving is becoming a possibility. As Peter Wright says; a drive to the airport on a wet morning in heavy traffic is not pleasurable, if he were chauffeur driven, either by a person or a pod, he would be happier and less stressed.

So has racing adapted to this changing vision of motoring? There are perhaps three stages to this question.

The first is that Formula 1 and the WEC have embraced hybrid technology, but both are struggling with it, either due to a lack of the competitive element in racing, or due to development costs. However, it's clear that hybridisation will be part of our short to medium term future and therefore racing has to cater to this. In this issue (page 95) Chris Aylett wonders why touring cars don't embrace hybrid technology. But it is catering to the crash-bang-wallop audience, not the technology driven fans. It's a mix of cultures, even though on a practical level it makes sense. Arguably the only place that a hybrid touring car concept will work is the DTM.

The second part is electrification, and Formula E is attracting a new, digital audience and strong manufacturer support, although I still question the technology. Then there's the Electric GT Championship, that has yet to get off the ground, but when it does will be exciting.

The third part of the conundrum is seeking new alternatives, such as hydrogen, and here racing is falling woefully short. Le Mans has Garage 56, but that's pretty much it, at a time when everyone is crying out for something other than high-pollutant energy sources.

The opinion of one major manufacturer is that there will be a split in the introduction of new powertrain technologies. In Asia, there could be a rapid movement towards all-electric as governments have the strength to make such a change quickly. In Europe, hybrid is a far easier sell for now, while the creation of the infrastructure needed for an all-electric fleet will meet with potentially crippling resistance. Wright has an answer for that, too, which is local power stations, a windmill or solar panels on every roof, for example. For the US, it's gasoline only through middle-America, though, while the two coasts are more willing to embrace change, either electric or hybrid.

This seems to be a sensible split of technologies, and so will that then affect how racing is sold in those respective markets, and how the technology may develop there too? Perhaps now is the time to let go of the traditional racing concepts, stop the globalisation of racing and allow territories to develop on their own. Perhaps we also need to consider a more theoretical approach. What worked in the 20th century will not work in the 21st as our attitude to cars is changing. There will still be traditional racing long enough to see me through my career, and for that I will be forever grateful. But perhaps we are not looking at the changing face of motoring enough, and then rolling with it in competition.

ANDREW COTTON Editor


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