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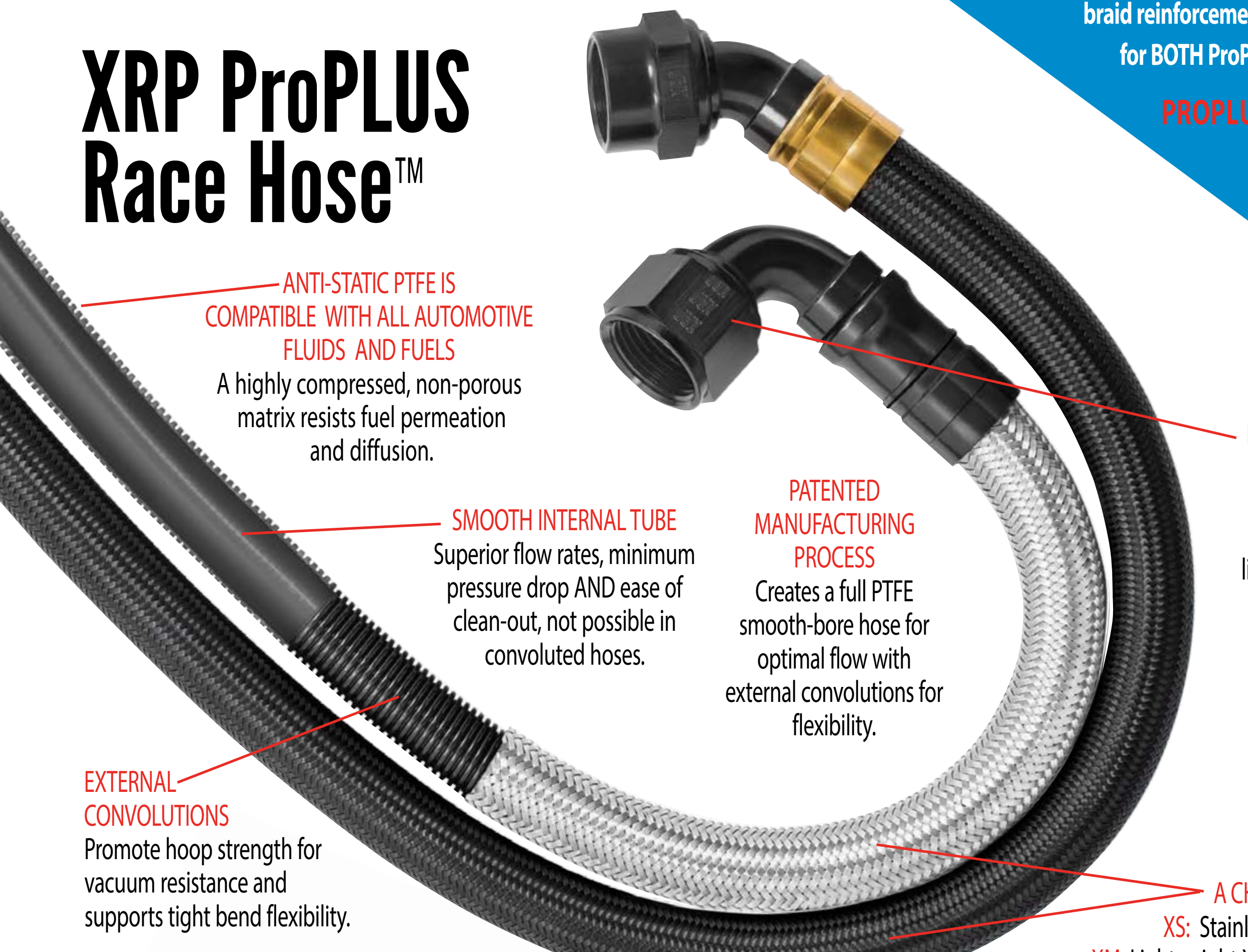

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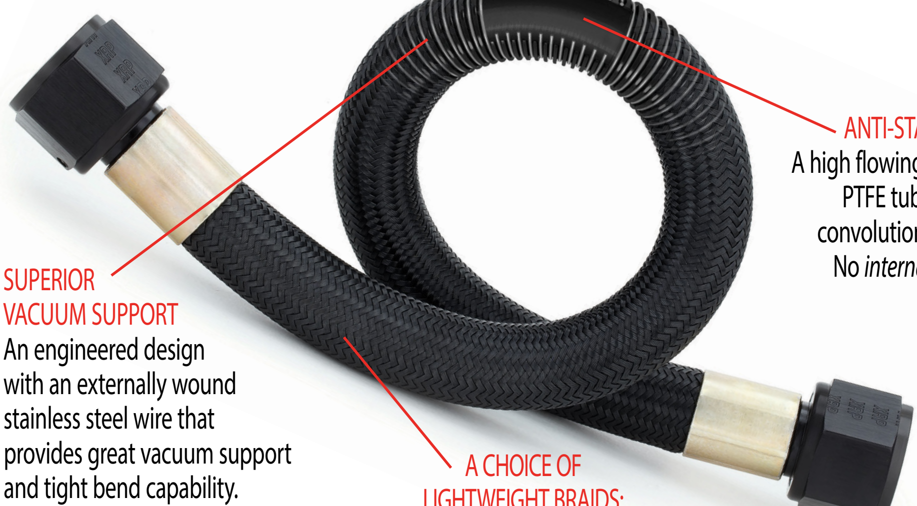

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In many ways the Le Mans GTE battle started at Sebring, while next year the WEC will visit the Florida track. Read the editor's column on the clash of European and US culture in Bump Stop

Heads and tales

How helmets have evolved from cloth caps to hi-tech life-saving pieces of kit

Nature has protected the brain by having a bony carapace completely enveloping it, the skull. A mere fall from standing up can give peak shocks of translational acceleration of 145 to 500*g*, there being a very thin layer of skin covering the bone, almost nil deformation to reduce the *g*.

But from time immemorial it has been found that we could help nature by adding protection, usually for combat. By 900 BC Assyrian soldiers wore thick leather or bronze helmets to protect the head, while the ancient Corinthian helmet and the Roman galea are still iconic even today.

Yet helmets took a little while to catch on in motor racing. Drivers first wore cloth caps, usually facing backwards for aerodynamic reasons, and then leather hats, the first appearing around 1908. By 1914 the Auto Cycle Union made helmets compulsory for riders and in the US leather football helmets or replicas were used in the '20s and '30s. But the big change in helmet technology finally came in 1935, after the motorbike crash death of soldier and writer TE Lawrence. The accident was analysed by a neurosurgeon named Sir Hugh Cairns, who studied the effects of head trauma during a motorcycle accident. From his testing, the first crash helmets were born. The Cairns helmet was a start, but it really only protected from penetration injuries, shock to the brain not being substantially reduced.

Skid lid

The next big step was when Californian Herman Roth patented a protective helmet with an internal, energy-absorbing liner, thus the modern helmet arrived on the scene, with an inner layer made of a 'substantially non-resilient material', a floating inner suspension system, hard outer shell with a visor, and a chin strap to hold it on.

This became the standard for motorcycle helmet design in the 1950s, and eventually car racing. But crash helmets were not compulsory in F1 racing until 1953, and even then Juan Manuel Fangio used a helmet made of pressed animal skin.

Several other materials were used, like the Floyd Clymer St Christopher fibreglass/leather helmet, as well as some of pressed metal, such as aluminium. There was a racer in South America who preferred the pressed aluminium shelled helmet because, as he said at the time: 'It was easier to bang out the dents, whereas the hard leather ones cracked.' He might have had a point there, because that small a brain does not need so much protection.

In 1956 Pete Snell was killed in a crash, wearing a helmet to the Roth design. His family created the SNELL Memorial Foundation in 1957 to establish methods of testing helmets for effectiveness, and their ratings became industry standards in 1959, the FIA then bringing in its own, similar, standards which now govern F1 helmets and others.

Head case

The shape and form of helmets stayed generally the same for a long time, until Dan Gurney popularised a closed version, debuting it at Indy in 1968, and soon after at the German GP the same year. Gurney had already used a leather mask way back in 1962, and then worked with Bell Helmets to refine it into the now universal full-face type helmet.

XPB

An F1-spec crash helmet weighs just 1.25kg and fits precisely, thanks to the 3D scanning of the driver's head before it's made

The closed helmet type eschewed the goggles, using a plastic visor instead, but as that didn't offer enough protection it evolved into a Lexan 3mm thick visor, now reinforced by a Zylon strip across the top, doubling the impact performance.

Visors are now in light yellow, clear or tinted versions and protected by tear-offs so as to be able to eliminate scratches or the buildup of oil and dirt. But tear-offs can cause their own problems. My chance to have a podium in a WEC race at Bahrain was scuppered when the driver had to come in with an 'engine problem', which turned out to be the tear-off visor stuck in the air intake for the restrictor on the side of the car. Not really his fault, being basically a single seater driver – they are conditioned to throw the tear-off to the side.

These days helmet construction is quite elaborate, as they need to be both resistant and lightweight, because of the *g* forces drivers endure. They are made mostly from a combination of carbon fibre and Kevlar in layers, using T800 carbon fibre, consisting of around 12,000 micro threads many times thinner than hair. The total length of all the threads in one helmet is approximately 16,000km, equivalent to 1.25 times the earth's diameter. The final product ends up weighing 1.25kg and fits precisely, with individual heads being 3D digitally scanned.

Ventilation is important and for open cars the shape itself is developed, CFD or tunnel tested to not provide lift, flutter or any other aero effect on the driver or the intakes, usually sited behind the head.

Skull candy

Modern helmets also need to cater for microphones, wiring to the ear-pieces and drinking tubes. Heated elements can be used to avoid misting up, and one can envisage HUDs (heads up displays) being incorporated in the future, or direct to eyeball projection taking instruments away.

As the single seater evolves and the Halo eventually morphs into a closed cockpit one can see today's helmet further evolve into a cycle type impact attenuator, rather than the fully enclosed item we have now.

But what about the look? The coat of arms was originally designed to distinguish combatants on the battlefield even while covered in armour, so it is not surprising that heraldic elements were incorporated onto the shield and the helmet, these being the most visible parts of a knight's equipment. This tradition has carried on to racing drivers, and it is probable that many drivers can only be identified by their helmet, with their unique distinctive patterns. Or at least they could.

What was previously something drivers used throughout their careers has turned into a messy mishmash of lurid designer themes that was beginning to change every race, to the point the FIA ended up allowing only one design change per season. But they all look the same to me now anyway: lots of colours, not much taste.

Crash helmets were not compulsory in Formula 1 racing until 1953, and even then Juan Manuel Fangio used one that was made of pressed animal skin

Fast and loose

IndyCar has proved that drivers are not always desperate for more downforce

It seems that downforce is culturally different in America than it is in Japan and Europe. Super Formula in Japan has for some time pursued high downforce levels and the drivers love it. In F1, the move to more powerful aerodynamics due to larger wings and diffuser, freed-up bargeboards and wider tyres, has received acclaim from those few privileged to feel its effect. The experience of very significant g-forces with the resultant grip and sheer corner speed really pumps the adrenaline. Anyone who has experienced even a little of the 'great big hand' that pushes the tyres down onto the track will understand this.

So why are the IndyCar drivers in the States enjoying this going the other way? Reducing the overall downforce of the Dallara-built spec cars by around one-third for 2018 has had the likes of Josef Newgarden and Juan-Pablo Montoya raving about the improvement that this has made to their driving enjoyment. Such a contrast in views is, on the face of it, a little puzzling, surely?

Skills set

According to the IndyCar drivers, the reduction in over-body, wing-derived aero has allowed greater finesse back into their driving and a more progressive feel for the limit of grip available. The message coming through is that the importance of steering and throttle sensitivity and balance has returned, so that skill and adaptability and not just big cojones alone is a deciding factor in achieving the lap time. On the superspeedways especially, such as the famed Indianapolis Motor Speedway, it is not hard to comprehend why more forgiving handling goes down well with those in the cockpits. Snap oversteer at 230mph inches from a wall can raise the heartbeat of the calmest driver to stratospheric levels.

But this positive feedback applies to road, street and short oval tracks as well, IndyCar being unique in offering such a diversity of challenges. One can argue, correctly, that it's not only the circuits that are different from those on which F1 generally races. The tyres, too, differ radically, and this will remain so as long as F1 sticks unfathomably to wheel/tyre dimensions that are at odds with just about every other form of modern race – or even street – tyre. It's possible that the lower profile of IndyCar's Firestones results in a much stiffer sidewall, with less compliance/feel on breakaway.

Then there is the key design feature of IndyCar having controlled ground-effect underbodies, rather than knee-jerk conceived and inefficient flat bottoms. Plus, of course, the power-to-weight ratio of these two types of car can be a factor. While the weight of each is comparable now that F1 machines have grossed up to a ridiculous 734kg, they have close to 1000bhp versus the American racecars' 550 to 750bhp (depending on track configuration). Factor in also that US drivers in the main don't have quite the succession through the higher-downforce junior racing formulae that typifies the ladder to Formula 1, be it via Formula Renault 3.5 (as was) Formula 3, GP3 or GP2, and thus maybe don't feel the same need for the out and out thrill of keeping the throttle flat while turning in to very fast corner sequences.

With its new bodykit IndyCar has slashed aerodynamic downforce from its Dallara DW12 spec car, yet the drivers seem to be pleased with the result

Balancing act

Alternatively, it may be quite simply that the previous level of IndyCar grip compared to horsepower was unbalanced in favour of the former, allowing the cars to be planted to such an extent that the final point at which the tyres would let go occurred at high speed, and this was difficult to feel and was therefore sudden and extreme.

Whatever the reasons for this conundrum between the preference for lower or higher aero, the reduction in IndyCar downforce can only improve what is already very good racing by the increased opportunities for keeping up with – and out braking – the car in front. Whereas Formula 1, of course, has gone in the opposite direction, with entirely predictable results.

Bringing back enhanced steering and throttle control are not the only examples of IndyCar showing the way to F1. From having one of the ugliest racing cars ever to offend the eye, the latest iteration of Dallara DW12 bodywork is very pretty as well as effective. In particular, the removal of the airbox has attained a much sleeker overall look. I had hoped, with the re-introduction of turbo power units into Formula 1, negating the requirement to ram air into the engine, that these hump-backs would disappear and we might be treated again to the proportions and lower line of the 1980s turbo cars, such as the Brabham BT52. But I underestimated the cooling demands of the hybrid power units and their ancillaries and the airbox clearly has remained as an efficient solution to meeting this.

However, given the hubris endemic in Formula 1, I see little chance of another series' ideas being followed. Similarly, with F1's Christmas-tree front wings and jumble of bargeboards. Safety being an issue that has spawned the alien Halo, it's strange that no attention has been paid to the dangers imposed by these multiple bits of bodywork being knocked-off and smacking in to the head of the following driver. Halo does not offer good protection in this eventuality, so it might be wise to get rid of them.

Cleaning up

Obviously, it is easier to achieve styled good looks with a one-make formula but heaven forbid that grand prix cars should succumb to this emasculation of design inventiveness. Retaining multi-chassis regulations now leaves Formula 1 virtually unique in this respect – which is a great USP – but the current crop of Formula 1 machines are almost as inelegant as were the redundant IndyCar body kits. They need cleaning up, with better proportions and a reduction in length and weight. It would be so straightforward, really, when the regulations change in 2021, to implement this and at the same time introduce a spec venturi underbody, shape and size mandated for two years, and get rid at a stroke many of the aero issues that have plagued Formula 1 for years.

The message coming through from the IndyCar drivers is that the importance of steering and throttle sensitivity and balance has returned

Bentley **buoyed**

Bentley believes it could have a successful GT3 product on its hands with its new Continental, but is its confidence well placed? *Racecar* took a closer look at its heavily developed GT racer

By ANDREW COTTON

The GT3 looks imposing from any angle. Rear aero includes a new twisted rear wing and aggressive looking diffuser; actually less effective than older version because of position of new transmission

Bentley is confident that it has done enough to make this car better for both the drivers and the teams

Bentley's second-generation Continental GT3 has enjoyed an upgrade in just about every department, from the power steering system to the aero, and from the gearbox to the brakes. It is a major push for a car that competes in a Balance of Performance category, but one that was necessary with the introduction of a new road car with a lighter bodyshell, and also after four years with the first generation car – which won four titles, in British GT, Blancpain Sprint and Endurance, and GT Asia.

That first generation car was something of a trailblazer, re-introducing the marque to endurance racing in 2014 after a layoff of more than a decade since the Bentley Speed 8 programme ended with victory at Le Mans in 2003. It was Bentley's first customer-focused racing programme for almost 100 years, but it was clear that the Continental leaned heavily on the balance of performance system to be competitive against cars such as the Ferrari 458 and Porsche 991. Bentley, like Nissan, always accepted that its car was big, but always refuted the fact that it was heavy. With a 1300kg base weight regulation, the Continental tipped the scales relatively comfortably under this, although there was no denying that it was easy to pick out anywhere on the grid.

The frontal area was big, but so was the engine, and BoP allowed the two to balance out. Where the team had the biggest problem, however, was taking a four-wheel drive super luxury car, modifying it to a race version through a significant update, and still remaining within a competitive sales price bracket. It's an issue that has affected the new car too, but this time there's even more emphasis on the cost.

Sales drive

One key new change to the GT3 regulations came after the introduction of the new model this year, and that concerns the minimum number of cars sold. While Bentley had already worked on the sale price and price per kilometre of the new GT3 car, as well as driveability to make it more attractive to customer teams, it now finds it must sell 20 cars in the first two years. That's no small number, considering just 27 first generation racecars were sold in the four years of production.

'The Bentley has a significant frontal area so for us drag reduction is a big factor'

TECH SPEC

Bentley Continental GT3

Engine:	4-litre direct injection twin-turbo V8; Cosworth engine management system. Power, approx. 550bhp de-restricted. Oil System, dry sump.
Transmission:	Rear-wheel drive; Ricardo 6-speed sequential transaxle gearbox; AP racing clutch: steering wheel mounted paddle-operated pneumatic gearshift.
Drivetrain:	Carbon fibre propshaft, limited slip differential.
Suspension:	Double wishbone suspension front and rear; four-way adjustable racing dampers.
Steering:	Electric power-assisted steering.
Brakes:	Alcon ventilated iron disc brakes front and rear; Alcon 6-piston front calipers, 4-piston rear calipers; driver-adjustable brake bias.
Aerodynamics:	Carbon fibre front splitter, rear wing and body panels. Lightweight, aerodynamically-optimised bumpers, bonnet, sills and fenders.
Safety:	FIA-specification steel roll cage; 6-point FIA safety harness; onboard fire extinguisher; onboard pneumatic jack system.
Fuel System:	FIA-specification racing fuel cell.
Electronics:	Race-specification Bosch ABS and traction control. Lightweight race battery.
Wheels:	BBS Motorsport 18in x 13in rims.
Tyres:	Pirelli 355/705 R18.
Dimensions:	Length, 4860mm. Width, 2045mm. Height, 1355mm.
Weight:	less than 1300kg.

The change means that manufacturers will be forced to make their cars more attractive in an already-saturated market place, and Bentley has worked hard on the reliability and comfort as well as customer service for the new car. Bentley's confident it has done enough to make this car better for the driver, and the teams, while keeping costs down, and it also believes it can meet this new minimum requirement.

Splitter headache

The 2018 Bentley GT3 has addressed many of its predecessor's shortcomings, including a large front splitter that sometimes dragged on the ground through a compression – particularly at Eau Rouge during the 24-hour race at Spa. It also has better front-end grip, while its wet weather capabilities have been improved.

The development of the new car was, says Bentley, a collaboration between the race team, the production car team that gave access to all of its facilities, the customers, and crucially its partner team M-Sport, which provided some rallying philosophy in terms of serviceability – for example, a rally-approved idea of riveting a new panel to the old one if needed, rather than trying to repair a damaged section of bodywork.

Bentley has introduced a new production version of the Continental GT, utilising more aluminium in the chassis than before, a feature that worried the race team, which had feared that it would need a bolted-in roll cage. Thankfully, that was not required and instead the new GT3 racer can rely on an estimated 25kg weight improvement over the old car with the bodyshell from the production line, and weight savings in other areas too.

Pick up line

The new body means that the suspension pick up points are different, and therefore so are the racecar's kinematics. 'We have increased the anti-dive on the front and anti-lift at the rear, and that helps with the driver, too, as if it pops up at the rear that can be unsettling,' says Will Hunt, technical manager – Race Engineering, at Bentley Motorsport. 'The suspension pick up points are different. The concept is similar [to the older car], so it features double wishbone front and rear, but the axle kinematics are different. The roll centre heights have been lifted as well so the car rolls a bit less.'

The transmission has been changed from Xtrac to Ricardo, the latter providing a longitudinal transmission to help the team with weight distribution but that, in turn, has led to a change for the driveshafts, too. 'We wanted more weight on the rear axle, and as a result of that we have ended up near perfect on the weight distribution,' says Hunt. 'That helped

Main picture: There's been much work on the aero at the front. Splitter has been reduced in size; the older car was susceptible to damage in this area **Right:** The suspension concept is similar to the old Continental with four-way adjustable racing dampers and conventional double wishbones front and rear

with traction as well. We had to do the sums to balance losing on the rear diffuser against an overall gain of the car, you increase your yaw moment a bit, but in GT racing, the inertia you can get away with is a bit more than in a rally car, for example, and you want the stability.'

That led to a new clutch design from AP, with the clutch now sitting at the rear of the transmission – where it is also more accessible for customers needing to make a change.

Brake point

One of the other big changes to the car is a switch to Alcon brakes. It provides the discs and calipers all round, as well as the pedal box. 'In GT3 there is a big market and a lot of suppliers have realised this,' says Hunt. 'Price is an interesting point, because unlike a lot of other formulas everything has to be considered with the sale price of the car. It has to be commercially viable, but it was also about performance and stiffness of the system and we have done a lot of work with Alcon on that.'

The team has also switched to BBS wheels, and saved 500g on each of the front wheels, bringing them down to the legal minimum – to the relief of tyre changers around the world.

While other brands within the VW Group had issues with the 2017 Pirelli tyre, forcing the Italian manufacturer to produce a new product for the 2018 season to accommodate the aggressive camber and pressures run by Lamborghini and Audi, Bentley had none of these problems; but then it does have a front-engine, rear-wheel drive configuration, and that could be the crucial difference.

'The number one thing is to make the tyre work, and so we have worked on getting more out of the tyre early on, but always thinking about the stint durability, and now we look after the tyre for the stint,' says Hunt. 'What we are asking the tyres to do at the back is quite different to the mid- and rear-engine cars, so perhaps that's why we haven't seen the same issues as those guys. The sidewall stiffness is key to making that work but Pirelli is fairly prescriptive at what we can do with camber and pressures. We are in the ballpark.'

Racking up

The team has also worked on the power steering system, changing it from a bespoke hydraulic system to a production-based electric system adapted from the production car. That required a lot of work to make the system suitable, but Bentley considers the change to be a significant improvement. 'We tried a couple of different development routes at first, with adaptions of standard racks and so on, and in the end we could make the road car electric steering rack work which was a big win for us,' says Hunt. 'The main reason we have done that is complexity, not that the H-PAS was a bad system, but by its nature it had pumps, lines, fluid, lots of unions and we wanted to reduce complexity. I don't know if it gives us anything in terms of efficiency because what you take off the pump you put on to the alternator so we perhaps don't gain there. Because it is a road car part it is competitively priced for us, and you don't have to make bespoke lines. The racks themselves are not light, but you don't have the pump and so on.'

Inside the cockpit the drive has been to improve safety. The new car, as is now common, features a fixed driver's seat with adjustable pedals and steering column. The driver has been moved further back in the car to the limit of the regulations, but moving the seat closer to the centre of the car was restricted by the transmission tunnel. The car now has a roof hatch to help the driver in the event of an accident and there's a new door and window design that allows for easier driver removal, all part of the general safety drive in GT3 racing.

The team also had access to Bentley's production car crash testing knowledge, and believes that it has built the most advanced crash models ever made for GT3 racing. As part of the crash simulation there is a lot of focus on wheel position, pedal box, seat mounts, harness

One of the big changes to the new Continental GT3 is a switch to Alcon brakes. The company now provides the discs and calipers (6-piston on the front and 4-piston on the rear) and the pedal box

mounts, and deformation after a crash. The FIA is now looking at front bulkhead intrusion to further improve crash safety.

'There is an average deceleration that we must be below for certain front and rear impacts. We didn't want to just meet the regulations, but we wanted to give the race drivers the softest possible landing if the worst should happen,' says Hunt.

V over W

The team carried over the 4-litre V8 engine from the previous generation racecar because of its reliability and fuel efficiency, preferring that to replacing it with the W12 that's used in the new production car. 'It has been really good for us, it's bulletproof, and we target a 20,000km service interval,' says Hunt. 'What is really important for our customers is bringing down the cost per km. We are certainly targeting lower than [we get with] the current car, and want to be similar in sale price. In a BoP category you will go pretty much as fast as anyone else, so then it becomes about reliability and customer service. The driver wants something easy to drive, that won't break down on them. The brand is great, but it will only take us so far.'

The location of the engine is now lower than before, and the team has worked on improving it, too. 'While the base engine is the same, it has been reliable and has been a good engine for

New body means the suspension pick up points are different and this has impacted on the car's kinematics

Bentley has switched to BBS wheels, which are lighter, for this year. Pirelli's tyres have always suited the car

us, but we have [worked on] everything around the engine; so there are new manifolds, the engine sits lower with the dry sump system and the guys at M-Sport worked really hard on that,' Hunt says. 'We have also taken the new road car charge coolers that are more efficient than the current one, a little bigger but with lower pressure drop, which is better for us.'

Smooth flow

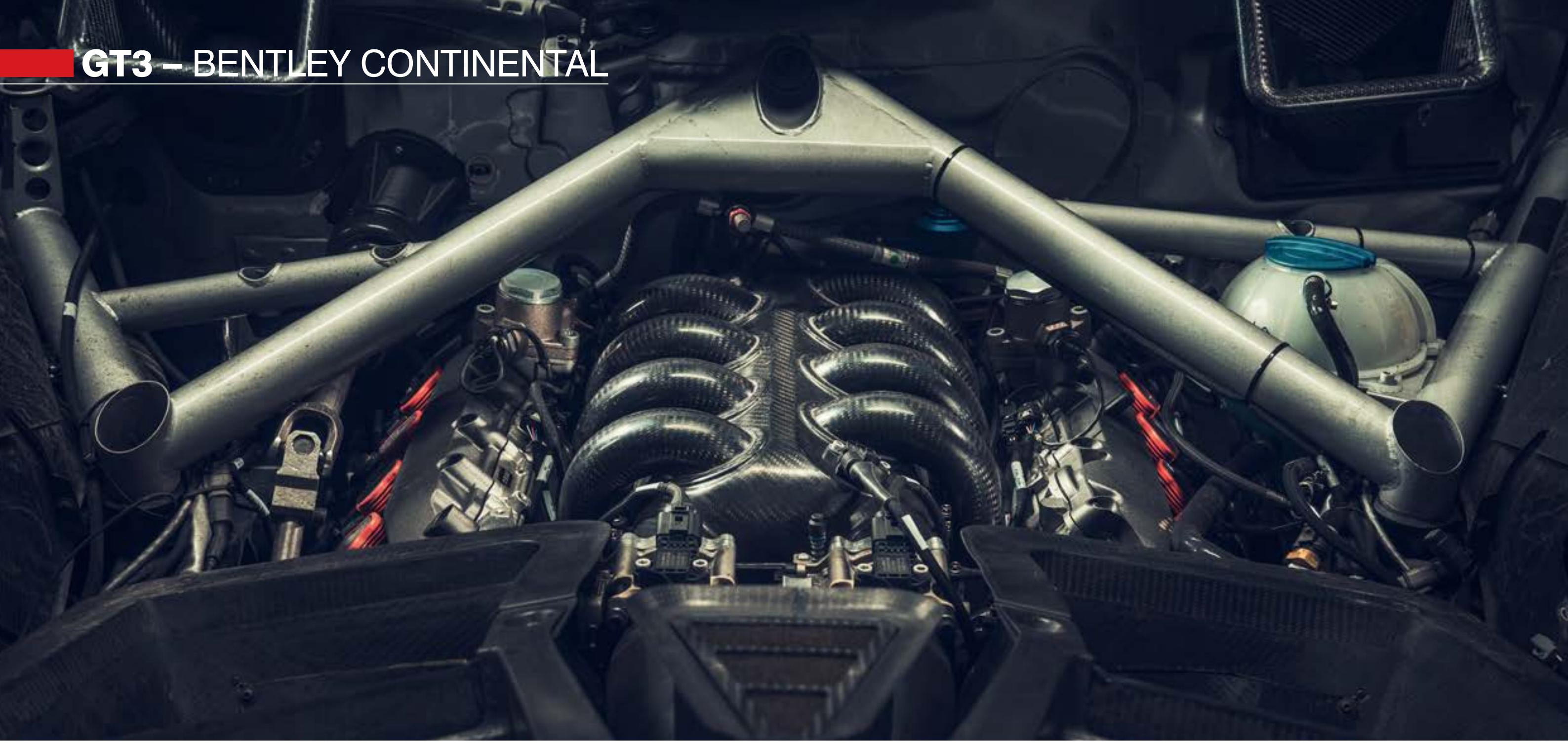
Airflow through the front ducts has also helped to improve efficiency for the engine, and the team believes that it has made a major step forwards. 'The charge coolers sit just behind the main grille where before they were horizontal,' says Hunt. 'The air had to do quite a tight turn so our real focus was to try to promote airflow to those, and this is a function of that. When you compare the two it is a big step forward in every way, but we have tried to make a difference.'

All of this has led to a complete re-working of the aero. The new bodyshell means a slightly different profile, the car is even wider than it was before, and housed within the sills beneath the now sculpted doors are the catalytic converters and exhaust. Those sills have been designed to help with brake cooling as much as increasing the width of the floor, but at the rear there is a big change in design philosophy brought on by that change in transmission.

Diffuser defused

The rear diffuser may look far more aggressive, but the longitudinal transmission now means that the central tunnel starts further back and is therefore less effective. The design team therefore worked on the outer edges of the diffuser to recover some of the lost downforce. 'The big difference is the central tunnel is lower and further back so what we have lost in efficiency there we have tried to regain in the outer channels,' Hunt says. 'The reason that we have done that is because the transmission has gone from being a transverse transaxle with all the gears forward of the rear axle to a longitudinal transaxle box, and so the main

'What's important for our customers is bringing down the cost per km'



Bentley's opted to stick with the 4-litre V8 rather than switch to the W12 that's in the production version of the car; its decision based on the V8's proven reliability and fuel efficiency

There's been much work on the front ducting and on improving airflow around wheel-arch area

New sills increase the floor's width and are also designed to help brake cooling

gear clusters are behind the rear axle and the furthest point forward is the final drive. In terms of aerodynamics and styling, the rear is more aggressive in its appearance than the current car, but in terms of performance it was all about minimising drag and moving the centre of pressure forward a little, but also dialling out some of the understeer tendency.'

Splitter difference

That challenge was made harder by the reduction in the size of the front splitter. So far forward did the splitter sit that the ride-height of the car had to be raised at Spa to give the team a chance of not damaging it through Eau Rouge. 'With the new car, in terms of targets, we wanted to maintain a similar level of downforce to the existing car,' says Hunt. 'That was one of the car's strengths at circuits such as Silverstone with high cornering speeds, and so we didn't want to lose that, but one of the things about the current splitter is that it is vulnerable in the racing pack. We have tried to recover and develop the front end aero so we didn't need that. The front is a lot closer, within 100mm of the road car seen from above. We have lost the radiator shell that we had on the old car and that was a big development around the front.

'The Bentley has a significant frontal area so for us drag reduction is a big factor even though the road car guys made a sizeable step forwards,' Hunt adds. 'We needed to make a similar step on the current racecar. There are a number of features at the front of the car to help that, just to reduce the wake of the car. Obviously this is all in context of the FIA performance window, so you cannot just go and do what you want.'

Louvres at the rear of the front wheel arch help to evacuate air from the splitter, and a lot of work has gone into front wheel arch design to help efficiency. The road car shell dictates to a degree the shape of the overall car, and airflow over the top of the car has been optimised, and fed to a twisted rear wing design rather than the flat plane design of the first generation car.

The team believes it's built the most advanced crash models ever made for GT3 racing

However, it is at the rear of the car that the work with the production car team is most visible. 'We say that Bentley is the perfect mix of luxury and performance, and this is the ultimate in performance for Bentley, so we wanted styling to be involved in this programme,' says Hunt. 'Some of the guys were really particular about when a surface goes from concave to convex and so on, and the approach that we took was we told them to let us know what they would really like, and then we would try to get it approved and make it work. We didn't win on everything but we believe that we have a well-balanced end-product.'

Gushing praise

For Bentley's director of motorsport, Brian Gush, the new car is a big step. 'After four years of success with our Continental GT3, we are excited to reveal our second-generation car,' he says. 'The new car leaves no area or system untouched in the search for even better performance … The new Continental GT road car has proven to be a great starting point for the development of a new racer, and the engineering development work is true to Bentley's impeccable standards.'

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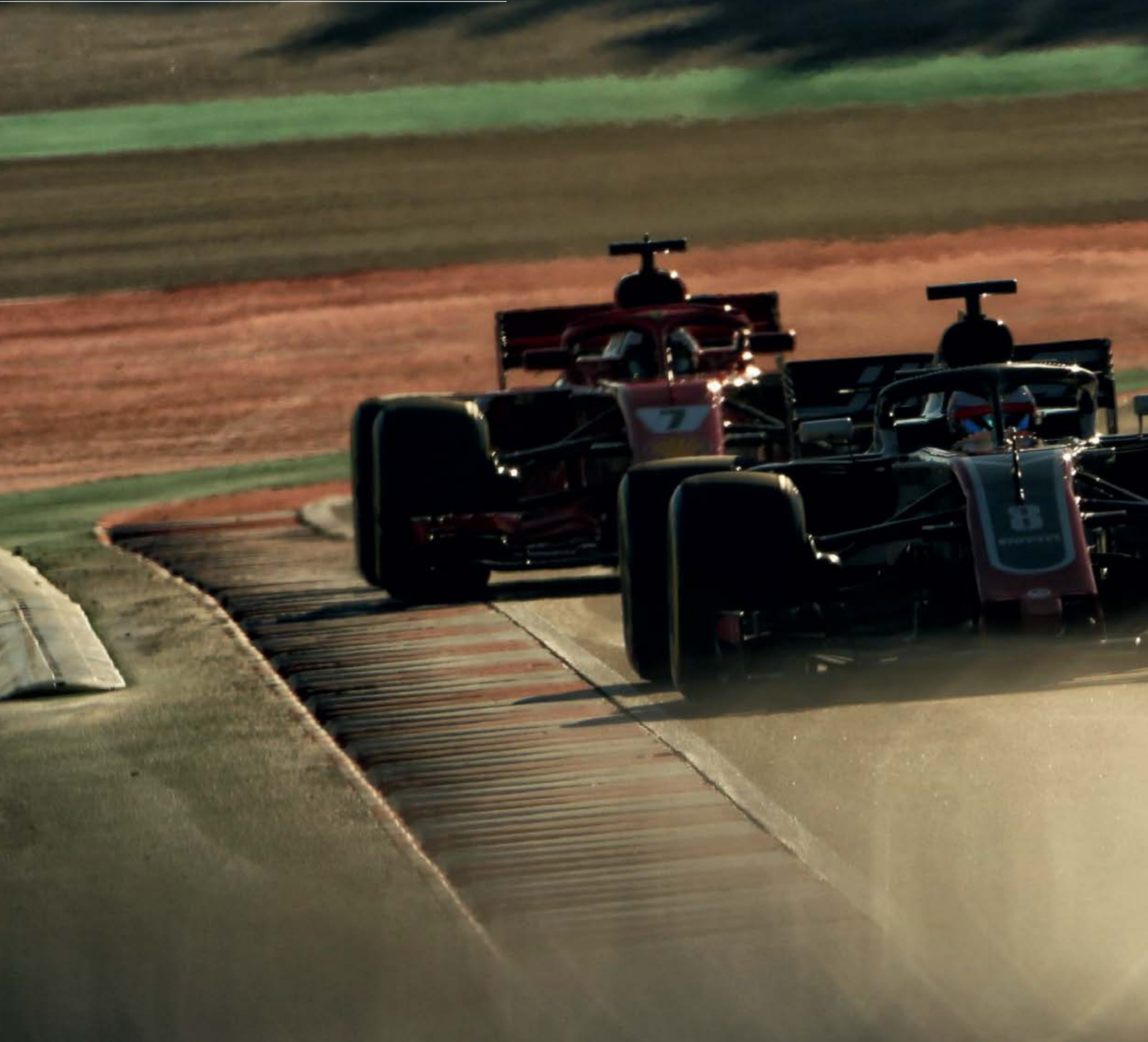


Let battle commence

As Formula 1 winter testing came to a close *Racecar* spoke to those in the know to find out which technical developments and regulatory issues will be the talk of the paddock this season

By SAM COLLINS

As the sun went down on pre-season testing we began to get an idea where each team stood in relation to the rest. The usual suspects came out on top but Haas (in foreground) also impressed

By the time you read this the 2018 Formula 1 season will have kicked off in Melbourne, Australia. From pre-season testing we have a good idea that Mercedes should be pretty quick again, and clues as to where the other teams stand in relation to it. But what the Barcelona tests have also shown us is the state of play in the Formula 1 development war. And that might be a much more interesting story this season.

Take cooling, for instance. Here, there is a distinct divergence of opinion in terms of the design of the cooling systems on the current generation of car. 'I think that the teams have approached it knowing which areas of bodywork are most sensitive and that tends to drive you on how you want to lay the cooling systems out,' Renault F1 chassis technical director Nick Chester says. 'Obviously, with the new set of regulations we have learned more about what the cooling level is over the last year. You learn more about how your coolers are working and you think about how you can repackage them to get the best aerodynamic performance. There are some different approaches out there; where some teams have all of their cooling in the sidepods, some have cooling in the sidepods and a lot of cooling fed from the top of the engine cover, and I think the difference is driven by what teams view as their most important sensitivities.'

Cold war

The first of the concepts Chester mentions is centreline cooling. This was first introduced by Toro Rosso in 2012 and then taken to an extreme in 2014. It sees a number of coolers relocated from the sidepods of the car to the centre, either directly behind the driver's head, or above the bellhousing at the rear of the engine. The second of the concepts is the short sidepod solution introduced by Ferrari last season, where the main duct sits further rearward than on a conventional layout, requiring the relocation of the upper side impact structure. Every car on the grid features one, or both, of these concepts – with the exception of the McLaren which has neither.

Relocating coolers to the centre of the racecar seems to be the more widely accepted solution, with most cars having some degree of cooling on the centreline fed by ducts around the roll hoop, Renault and Sauber having perhaps the most extreme examples.

'Some teams may want to pull the sides of the bodywork in as tight as they can so they are pushing cooling high, and others may be of the view that they want to keep the engine cover very thin and keep weight low, so push it into the sidepods,' Chester says. 'All have numbers on the various sensitivities and it's interesting that the designs have not converged yet.'

Cool for CADs

More uncertain, and something of a bigger challenge to adopt, is the short sidepod concept used by Ferrari, with teams such as Mercedes and Force India going as far as claiming that following that concept would not be beneficial to overall car performance. While it is claimed to give an aerodynamic benefit, getting the most from it appears to be a substantial challenge and not just in aerodynamic terms, as taking this approach requires relocating the side impact structure, which means that the monocoque itself has to be extensively reworked.

'It would mean a very big structural change to the car to do something like Ferrari has done,' Force India technical director Andy Green says. 'The disadvantages of it are that it is potentially quite a bit heavier with the way the impact structures sit on the chassis, they don't sit in an optimal place from a structural perspective. While they do move to an optimum place from an aerodynamic perspective, you have to add a huge amount of structure to the chassis to retain the impact structures.

'If you put the structure in the middle of the panel with no structure to support it then it won't work. It flexes and moves around, then you have to put a lot of structure in to stiffen it up as it has to pass an FIA test,' Green adds. 'If you put it at a point on the chassis where the structure already is, then you don't have to add anything, and that is where we put them at the moment. So the shorter sidepods are weight inefficient. That was one of the reasons why we couldn't develop the system this year, because we had the Halo structure to contend with, and we couldn't really do both at the same time, one step at a time. It's a weight thing, it really does cost you weight, and if you don't have any head room on ballast then you are going to struggle.'

Both Renault and Honda have freely admitted that they are looking into deliberately taking penalties

Cool heads

But while it appears to be a difficult solution to implement it is one some teams, including Force India, are still evaluating. 'It is something we have been actively looking at for quite some time, but we still couldn't do it in time,' Green says. 'We are looking at it, it is something that will take a long time to understand whether it would potentially give a benefit. Certainly, if we put something like that on our car now it would be a loss. It just depends on how much resource we are prepared to put into it at the

Sauber is claiming that it has achieved as much as a 10 per cent increase in overall cooling system efficiency over its 2017 design

Toro Rosso introduced the centreline layout. It's clear from this image that the Halo could have an impact on a car's cooling

Williams uses centreline cooling. The 'A' of the roll-over structure is clear to see here. The outer segments of the intake feed air to coolers over the bellhousing, while the centre portion is for the air to the internal combustion element of the power unit

Force India uses a conventional sidepod set-up as it judged that, for now at least, the short sidepod might prove too heavy

beginning, to see if it could overtake the current philosophy, we [need it] to give us a net gain in a reasonable time-frame. I know it sounds a long way away, but in 2021 we are going to have new cars again, so there is no point us developing a car that might be ready for 2020.'

Core values

Cooling system development is going on under the skin, too, with one team, Sauber, claiming as much as a 10 per cent increase in overall cooling system efficiency over its 2017 design. One of the reasons for this 'war of the cores' is that aerodynamic testing on cooling cores and ducting is unrestricted and is not counted as part of the wind tunnel and CFD restrictions applied to other parts of the car. As a result investigating the scrap bins of most F1 teams would reveal piles of prototype heat exchangers.

'Everybody is still trying to get the best cores,' says Chester. 'As soon as you change the layout you end up needing to change the core or the cores that you are using so you do complete a lot of testing. You might end up playing around with a lot of different samples, so you do the same every time with a new car.'

Mirror image

It is not just the cooling systems where the teams are trying to find small gains, but in every area of the car; even the wing mirrors look set to become part of the ongoing development war. Ferrari launched its SF71-H design with ducts in the mirror housings, leading to speculation that they somehow fed air into other parts of the car via the stalks, but the reality seems to be that the Italian team has discovered a novel way to reduce the drag the mirrors cause.

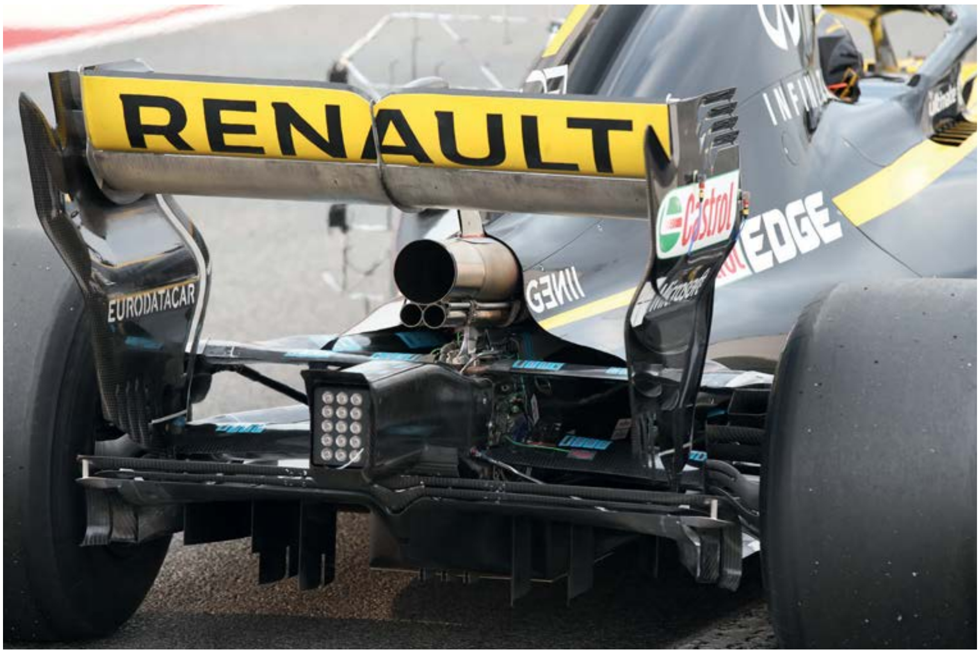
In 2014 Greg Woyczynski, a University of Miami science masters student, wrote a thesis with the title *Low Drag Automotive Mirror Using Passive Flow Jet Control*. In this he suggests using a duct on the leading edge of the wing mirror housing feeding slots above and below the mirror glass in an attempt to reduce drag.

'By splitting the mirror into two parts, an inner shell component [centre body with the mirror attached to it] and an outer shell [case] the concept of jet flow control can be applied,' Woyczynski writes. 'This method potentially reduces the drag compared to conventional mirrors by using flow control techniques similar to those used for slotted airfoils. The front of the mirror will have an opening inlet with a conical centre body that introduces airflow, which is accelerated by a converging duct surrounding the centre body. This airflow is ejected through a slot surrounding the mirror and located between the centre body and the casing. The

Aerodynamic testing on cooling cores and ducting is unrestricted, it is not counted as part of the wind tunnel and CFD restrictions

Red Bull has adopted Ferrari-style short sidepod with its side impact structure now lowered; a major engineering challenge

The McLaren MCL33 is the only current Formula 1 car not to use either the centreline cooling or the short sidepods solution



Renault is using its exhaust position to direct the plume so that it interacts with the underside of the rear wing main-plane

area of the inlet determines the capture area and the amount of air mass flow the inlet can introduce. The slot will produce a jet of air moving at a faster speed than the air that enters the inlet area and the air that moves around the outside of the casing. This jet should be angled to form a stable vortex zone behind the mirror. The jet forms a boat-tail effect that entrains high energy flow from the free stream to the base area, increasing the base pressure, and reducing the base drag.'

This appears to be the concept that Ferrari is pursuing with its mirrors, and it will be interesting to see if any other team opts to employ the technique later this season.

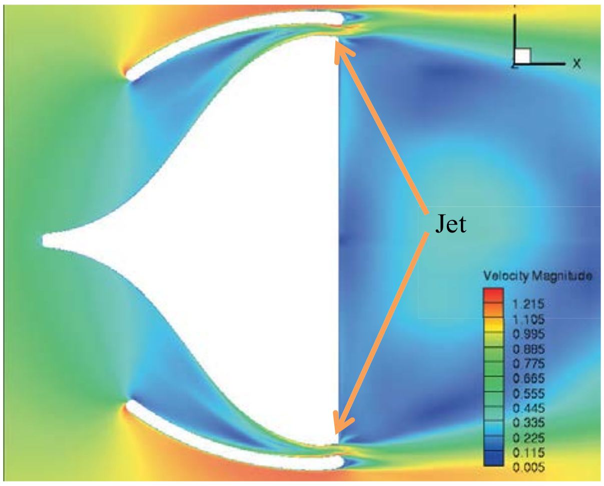
Hot air

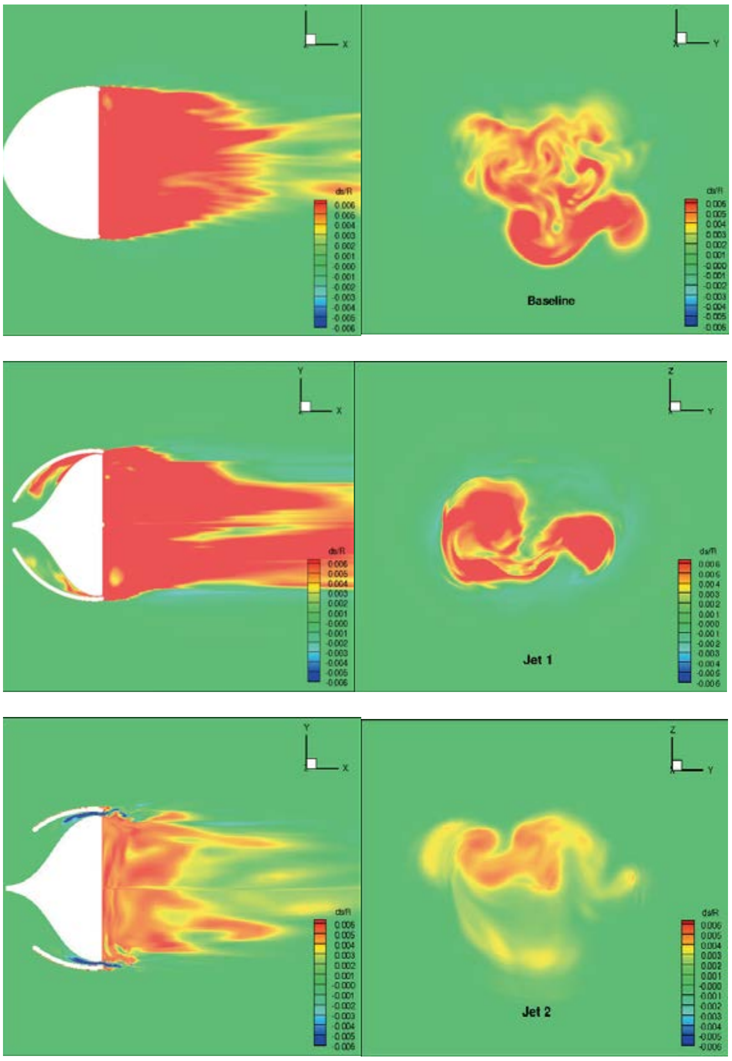
Ferrari is not the only team on the grid with a novel aerodynamic solution on display. Renault has angled its exhaust tailpipe upwards at the underside of the main plane of the rear wing, which is covered with a ceramic thermal barrier coating, seemingly confirming that the exhaust plume does have some influence on the underside of the wing. 'Everybody has to have an exhaust and all exhausts are going to blow the rear wing to a degree,' Chester says. 'You are quite limited for what you can do, but it's like everything else. If there's a small gain there, we'll have a small gain because it's available.'

With some of Renault's rivals concerned that the French manufacturer will utilise off-throttle blowing the FIA has made it clear that it will look closely at the modes and maps it uses. 'I think it is absolutely minimal what they will get from it, but I don't see any problem with it provided we are sure they are not operating their engine in a false mode – a mode that wouldn't be normal,' the FIA's Charlie Whiting has said. 'We have to accept that there is and always has been some exhaust effect, but obviously in 2012/2013 it was massive. We've chipped away at that and one of the things for the 2014 rules was to make sure there was no effect from the exhaust – but there must be a little one.'

Burning issue

One area where the FIA has clamped down heavily in 2018 is on using lubricants as fuel to get an additional performance boost. In a fuel flow limited formula an advantage could be gained by venting lubricants into the combustion chamber and taking advantage of their calorific value. It was believed at least two manufacturers were doing this in 2017, but in 2018 new rules have been created which define the make-up and function of engine oil – previously this had not been defined. 'Engine oils should not enhance the properties





Above: Greg Woyczynski has suggested in an academic paper that the use of a duct on the leading edge of the wing mirror housing might be a good way to cut drag **Right:** These CFD images show the difference the internal shapes within the mirror's housing can make on the airflow

Is Ferrari using the technology shown in the CFD images (top and right) in its mirrors?

of the fuel nor energise the combustion,' the new regulation states. 'The presence of any component that cannot be rationally associated with the defined functions of the engine oil will be deemed unacceptable. Any engine oil, which appears to have been formulated in order to subvert the purpose of this regulation, will be deemed to be outside it.'

Smoke signals

The new rules do seem to be taking effect. In testing all three of the Ferrari-powered cars (Haas, Sauber and the works machine) constantly had a small plume of smoke issuing from the rear impact structure when running. This is due to another new rule aimed at preventing illicit oil burning, as all breather fluids must now vent externally via the rear of the car. Interestingly, no such smoke was visible on Mercedes, Renault and Honda powered cars. However, not everyone is entirely confident that the loop hole has been entirely closed.

Even the wing mirrors look set to become part of the ongoing development war

'I believe that lots has been done to close this loop hole in the regulations. I think we now have clear regulations, and we are working with the FIA to make sure that there is equipment to monitor the situation on a permanent basis,' Renault team boss Cyril Abiteboul says. 'We need to ensure that the oil that is consumed by the engine is in quantities that is relative to the true purpose of the oil; lubrication. It is not just about having the regulation, but also the capacity to enforce it and I am not fully confident that the FIA has the capacity yet to fully enforce the regulation, so that's why we are working in partnership with them.'

Power games

Fuels and lubricants are not only a matter of contention when one is used as the other, but also when the subject is the equal performance of power units. During the opening test the FIA issued a technical directive stating that manufacturers must supply all teams with the same specification of power unit. This was thought to be in response to the very public suggestions made by the Toro Rosso team in late 2017 that Renault was not giving the customer teams the same engines as the works effort. Renault strongly denied this. For 2018 Toro Rosso has switched to Honda power.

'I know it is a constant concern from customer teams that they should be treated equally in terms of power-unit performance,' Abiteboul says. 'It's the way we have always acted with our customers in our 40 years of history of being an engine supplier in F1. That was always our intent and now it is in the regulations, now there has been a clear directive in relation to that. You also have to accept that there will also be some small differences between units. To give one example, Red Bull is using a different fuel partner so they will have different fuel and lube and that will create small discrepancies. That is something for them to decide, we did not force them to adopt a different partner, in fact our partners products were available for them to use, but they chose not to. That starts to create discrepancies, and maybe more in the future.'

It was not just the performance that irritated Toro Rosso in late 2017, it was perhaps more that the Renault power unit proved to be very unreliable. And reliability is likely to also be in the spotlight in 2018. The life of the power unit has been extended significantly with three combustion engines allowed per driver per team (including turbocharger and MGU-H), two MGU-Ks and two control electronic systems. In 2017 car were allowed four PUs each but only texense sensors by TEXYS

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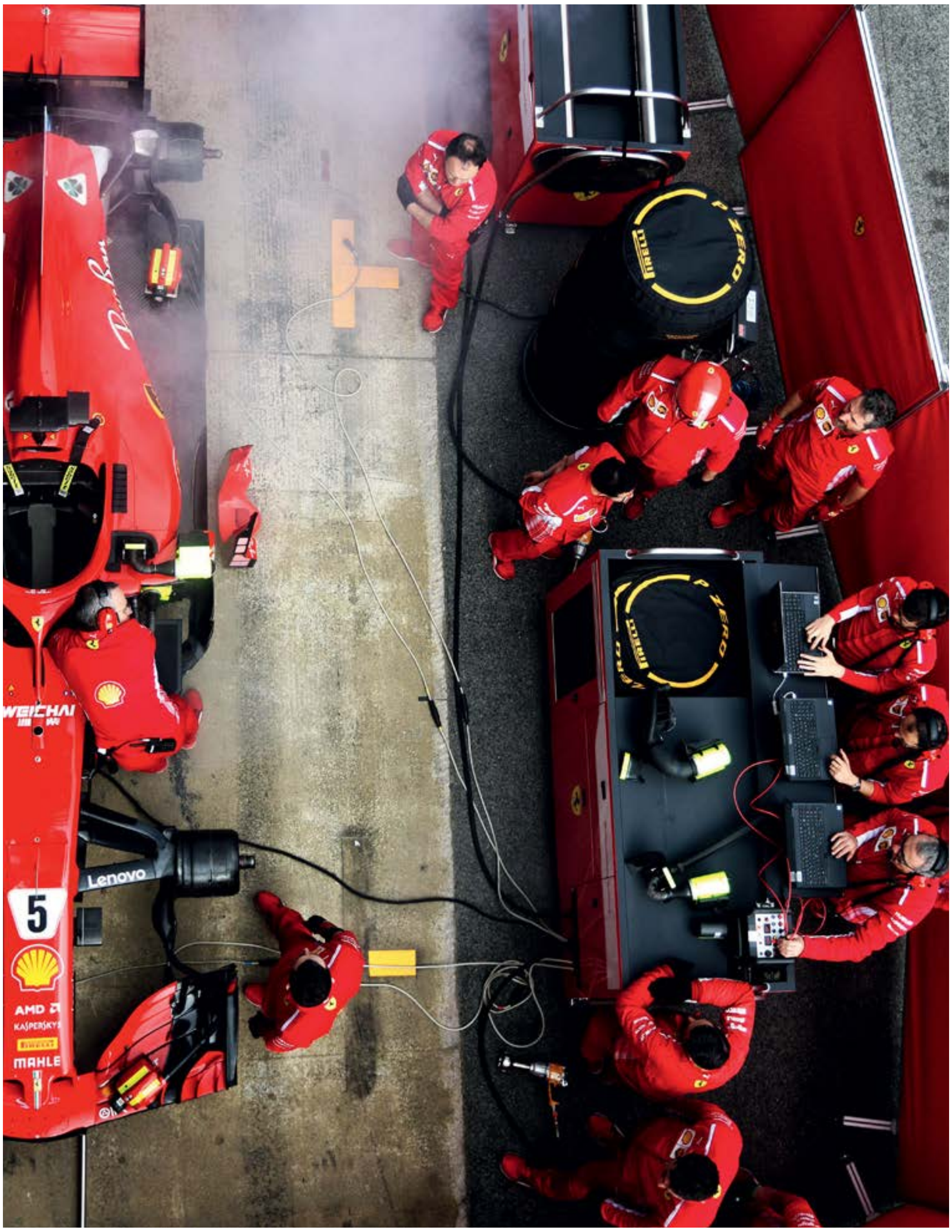
One area in which the FIA has clamped down heavily for 2018 is on the use of lubricants as fuel to get an additional performance boost

Power unit manufacturers now have to ensure they supply each of their teams with the same spec PU as the works outfit


Smoking Ferrari-powered cars could be a common sight in Formula 1 this season, thanks to the new oil-burning regulations

the Mercedes runners managed to get through the season without any penalties. Meanwhile, this year both Renault and Honda have freely admitted that they are looking into deliberately taking penalties (and starting the race from the back of the grid) to increase their supply of power units, an approach which could bring a notable performance gain at certain tracks (Spa, Monza and Baku for example).

Maximum talk

As Formula 1 teams struggle to get the best out of the current regulations thoughts are increasingly turning to the 2021 season, which is likely to see the biggest shake up the sport has ever seen as a brand new power unit is due to be introduced along with new chassis and aerodynamic regulations. However, the rules for both are still very much in the debating phase, despite being overdue for release.

'I think what's good is that FOM and the FIA are both consulting the teams and the PU manufacturers about the new rules,' McLaren technical director Tim Goss says. 'Ross Brawn and his team of engineers have visited all the different teams, plus we've got other dialogue going on at the Technical Working Group meetings. Then Pat Symonds at FOM will give us a report and an update on what they're considering; so there's a lot of engagement and involvement. We fully support the approach they're taking which is a properly well-researched approach to where we're going, with not just the regulations but the sport in general. So thinking about what we want the cars to look like, what we want as differentiators in terms of aerodynamics, vehicle dynamics, engine, how much differentiation there's going to be, the commercial side of it, all of those things. So they're fully engaged and being as open as they can at the moment without wanting to allow too much into the media until they've actually decided what they want to do.'

Brawn and brains

Brawn's engineering group is believed to have acquired the 2017 Manor chassis and wind tunnel model and is already using those as development tools for the 2021 rules. It remains to be seen if a Manor chassis will be converted into a NASCAR R&D style test car.

'They've got a model that they're running in a wind tunnel, they're doing lots of CFD work, looking at one car following another car to try and work out actually what's important,' Goss says. 'There was a lot of discussion around it when we changed the cars for 2017: "We won't be able to follow", "Oh this will hurt overtaking", "They're wider so you won't be able to get past",

The 2017 Manor design is being used by Ross Brawn and his team of engineers to evaluate ideas for the 2021 regulations

etc. To be honest it's very difficult for us – even people that are very close to the sport – to be able to pin down whether it really does matter or not. They're going away and trying to put a bit more science and some numbers on it. If they need to run simulators then simulators are open for them to run. So what we fully support is the fact that they're researching it properly, they're engaging with the right people and everyone's looking for a bright future for the sport, and a sustainable sport as well.'

Standard bearer

The new regulations are thought likely to include a number of standardised parts with a control fuel, single specification brakes, battery and MGU-K all on the agenda. But not everyone is entirely happy with this, especially when it comes to the new power units. 'In the debate about standardising some parts we need to think about what Formula 1 stands for,' Abiteboul says. 'It stands for great drivers, great cars, great engines. In terms of cars in particular that means aerodynamics, but when you look at differentiation in the engine world you have to define where that comes from.

'As far as I can see it, looking at the world around us, I don't believe that electrification is going to go away so I find it counter-intuitive to standardise any part which will matter a lot to an existing or new manufacturer coming in,' Abiteboul adds. 'One area which I don't see is bringing a lot to the sport is the energy store; we are spending a fortune on development of the battery. Who cares about the battery frankly, that is a perfect candidate for standardisation.'

Looking toward the new power units some, including Abiteboul, think that the whole thing is something of a waste of time and effort, preferring to stick with a version of what is in use now. 'I think we should be a bit careful not to over-regulate Formula 1. There are lots of regulations already,' Abiteboul says. 'We have made it clear that our preference is that given all of the investment that has been made in the existing regulations, we should keep on using these units and leveraging that investment as long as possible. I hope the engine is becoming less of a perceived problem in Formula 1, and instead an opportunity to talk about the most advanced powertrain in the world.

'We may not like it, or we may like it, but it is the most advanced thing from a technological perspective,' Abiteboul adds. 'It would be sad to go backwards and start over from scratch because starting with a new engine would just restart the problems we had in 2014 and I don't think anyone wants to experience all that again. Right now we have something that is starting to work, it's quick enough and performance convergence is happening, not quickly enough, but it is happening. In my opinion Formula 1 has bigger problems than the engine. If something different has to be done for 2021 then this summer is the deadline.'

As ever in Formula 1, it is just getting used to the current regulations in only their second year and the sport is already thinking about what comes next, and also as ever, not everybody agrees with the direction being taken. Which could lead to some rather frosty relations in the paddock as this season progresses.

'Red Bull is using a different fuel partner so they will have different fuel and lube, and that will create small discrepancies'

‘We are committed to e-TCR because we are convinced that the future of competition is with electric engines’

SEAT’s Cupra e-Racer could be the first of many e-TCR cars

Circuit Racer

TCR has now jumped on the electric bandwagon with a series planned for 2019, and category stalwart SEAT has already built a car to the new regulations. *Racecar* went to the Geneva Show to check out the all-new Cupra e-Racer

By ANDREW COTTON

The details remain sketchy, but there is no doubt that plans for an electric TCR series are well established, and at the Geneva Motor Show in March SEAT launched the Cupra e-Racer which the company hopes will form the basis of an all-new series, e-TCR, set to start as soon as the 2019 season.

TCR creator Marcello Lotti was on the stand with Jean Todt, president of the FIA, as the first car was launched, and it seems clear that the two will work together to promote the concept.

The outline regulations that were announced at the Geneva launch included the stipulation that the electric racecars will be standard TCR cars of four- or five-doors, fitted with an electric motor capable of delivering 300kW of continuous power and 500kW of maximum power at 12,000rpm. Battery capacity is 65kWh and the system will run at 800V.

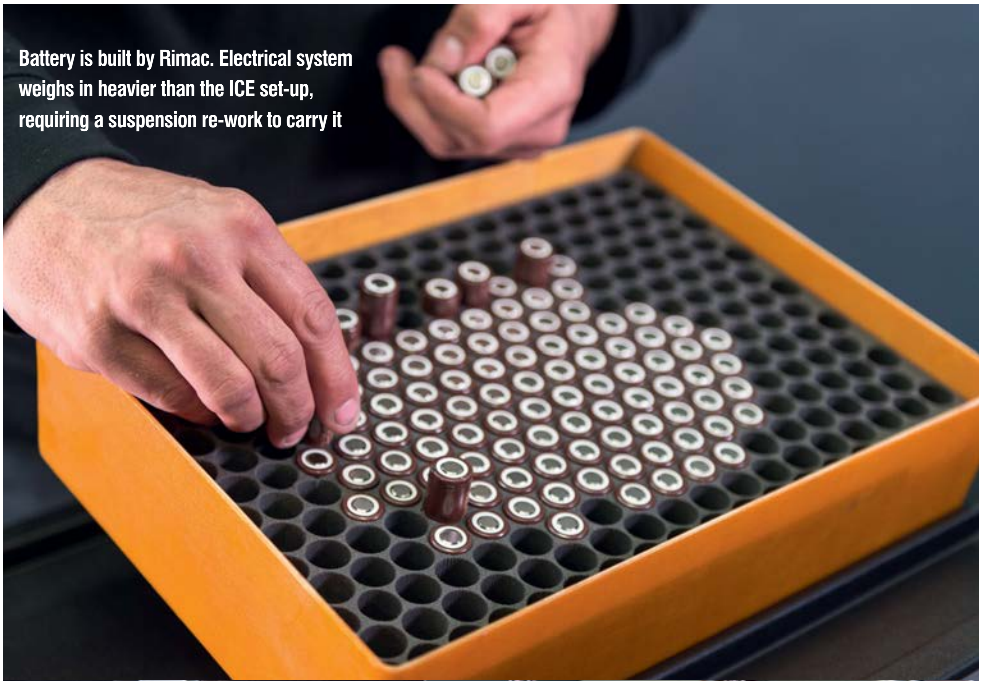
The car will be rear-wheel drive, with just a single gear, while the suspension at the rear has had to change to accommodate the heavy battery and is now a double wishbone layout.

Watt's happening?

There is no schedule for the series yet available, and the only thing that seems to be written in stone is that it will not travel to traditional circuits. That takes it away from the Formula 1 support series that the International TCR started out as. The standard power units across all the cars are not best suited to Grade 1 circuits, and with traditional racing struggling to fill the grandstands it seems also unlikely that electric TCR cars will be able to do so. One possibility is that the series could join the Formula E bill, as its circuits particularly suit the regeneration needed to keep the cars going for 20 minute races – although it has its own production-based one-make Jaguar I-Pace eTrophy support series in the pipeline. But there are alternatives, such as running on a track like Oschersleben in Germany or Adria in Italy, traditional circuits with low top speeds and hard braking.

While SEAT was the first to announce a programme, this is a concept that can be adapted to the already burgeoning TCR category. The Cupra is based on the TCR chassis and has only been modified in moving all the electric components forward to maintain a 40-60 weight balance of the rear of the car, and

‘It features a rear-wheel driven 500kW engine, which equates to 680bhp’



Battery is built by Rimac. Electrical system weighs in heavier than the ICE set-up, requiring a suspension re-work to carry it

Motors sit in a hole sunk into the floor of the chassis. They are capable of delivering more than 600bhp, but only for 10 seconds

In a heavy racecar there seems little point in mirrors when a camera can do a better job

that change to the rear suspension that's been made in order to hold the weight of the batteries that we mentioned earlier; around 400kg over the internal combustion version of the car.

The plan is to start the concept of electric TCR in controlled conditions ahead of a full race programme in 2019. The common drivetrain for every racecar on the grid is a way to limit costs and bring in manufacturers, and in the second year open that up to manufacturer development. Already the likes of Cyan Racing, Volvo's racing team, is now considering this as a possible racing programme in the future. What happens after that has yet to be decided, but it's clear that a manufacturer's involvement will require it to be able to develop the technology – they will need to be able to do so in order to maintain their interest in racing, because a spec system is not interesting for a manufacturer, as they can learn little from it.

Pole volter

As far as the Cupra e-Racer is concerned, this the first touring car that complies with the requirements for competing in the new e-TCR. The motors are located over the rear axle and deliver up to 500kW (680bhp), which is 242kW (330bhp) more than the ICE, petrol fuelled Cupra TCR version, while it is also equipped with an energy recovery system. Compared to the conventionally powered Cupra TCR, despite weighing 400 kilos more, it has impressive performance, with 0-100kmh acceleration in 3.2s, and 0-200kmh in 8.2s.

'The base is the TCR internal combustion engines and we have escaped [skipped] the hybrid phase,' says Xavi Serra, head of technical development at SEAT Sport. 'We thought that we had to be there with new technologies that could be exciting and match the expectations of a racing car. It features a rear-wheel driven 500kW engine, which equates to 680bhp, and we can sustain that for 10 seconds before the system needs to cool down. We can regen 12 per cent of the power, but the limitations of the peak power are due to overheating rather than battery power. Regen is only directly to the motor, so we operate the motors in reverse. You have limitations because of the cells recharging power at high speed, and you have other limitations in the lower speed range because there is a point that the grip does not allow you to regen due to lock ups of the rear wheels, which would prevent you being able to do so.'

Saloon-e tunes

The car was launched with Yokohama branded tyres, but it is not clear that this rubber will be on the cars when the new series starts. The battery is developed by Croatian company Rimac, while the motors are the product of Magelec, in China.

‘The weight of the car is approximately 400kg heavier than a standard TCR car, and most of that is the weight of the battery’

‘We have kept the MacPherson strut, and at the rear a double wishbone to cope with the power and suspension requirements,’ says Serra. ‘The weight of the car is approximately 400kg heavier than a standard TCR car, and most of that is the weight of the battery.

‘We kept the same roll cage, but made a hole in the floor for the battery, and a slight modification to the rear to accommodate the motors and the double wishbone layout, and the front is untouched,’ Serra adds. ‘Weight is the first challenge, and weight distribution is the next one after that. We think that the distribution will be about 60 per cent to the rear, maybe a little more, and at the front we have the radiator, the three pumps for the cooling circuits, the DC-DC, ECU, and all the electronic devices that could be transported to the front. The brakes are standard TCR at the front, and at the rear it is basically a GT3 brake size from AP.’

Lotti, who will develop and promote e-TCR, said; ‘Our group has a sense of responsibility towards the whole touring car racing scene and so consequently could not ignore the trends of developing new technologies. We will be working on the same technical principles that made TCR so successful with the aim of creating a platform for this new configuration.’

The car was presented on Yokohama rubber although no tyre deal has been signed for the new series, set to start in 2019

Batteries included

The car has yet to be crash tested, but it will be before the series starts next season. SEAT says that the battery components do meet all of the safety requirements from the FIA, and it is confident that the car will pass the tests.

SEAT Vice-president for R&D, Dr Matthias Rabe, said of the new series: ‘We are committed to the e-TCR because we are convinced that the future of competition is in electric engines. Just as the SEAT Leon Cup Racer laid the technical foundations of the TCR championship, once again we are blazing trails in this new experience.’ Rabe then went on to encourage ‘the rest of the car manufacturers to join us in this amazing adventure’.

SEEN: Gen 2 Formula E

Formula E has unveiled its second generation racecar, which is to be raced from the start of its fifth season (2018/2019) onwards.

The Gen 2 car has a battery capable of storing energy for twice the range of its predecessor to eliminate the need for mid-race car swaps.

Its technical specifications have also been released. Alongside the improved longevity, the maximum power output of the car has increased by 50kW to 250kW, which will see the potential top speed of Formula E reach 280kmh (174mph).

Including the driver and the 385kg battery the new car will weigh in at some 20kg more than the current STR-01E FE racer, at 900kg, while it is 1.77m wide and 5.16m in length. It also features the new Michelin Pilot Sport all-weather tyre, which is specifically designed for the unique demands of electric street racing and boasts significantly lower rolling resistance, we’re told.

The car also sports a Formula 1-style Halo cockpit protection device, although in this case it carries an LED strip that will give fans information on a particular racecar, such as its position in the race and what power mode it’s running.

The black art

Dunlop is the most successful tyre brand at Le Mans in terms of outright wins, so when it invited *Racecar* to the Aragon tyre test for an insight into the secrets of developing high-end endurance racing rubber we jumped at the chance

By GEMMA HATTON

Tyre manufacturers involved in sprint racing often have to design their tyres to degrade, the polar opposite to what's required for endurance racing

Dunlop's tyres endured 525,000km during race week at last year's 24 hours of Le Mans, equivalent to 13 times round the world. A staggering 9632 laps were completed on its rubber throughout the race – that's 245 million tyre revolutions. Its tyres led a total of 769 laps in various classes, including every lap in LMP2. In addition, 17 LMP2 teams were able to quadruple stint, with five teams completing five stints – that's the same distance as two and a half Formula 1 races on one set of tyres.

Of course, endurance racing is an entirely different beast to F1 and therefore requires entirely different strategies, driving styles and tyres. The majority of today's sprint race categories, including F1, no longer require pit stops for refuelling and drivers only pit when they need a fresh set of tyres. Therefore, the FIA has collaborated with Pirelli over the years to try and develop tyre compounds that offer high grip to keep the drivers happy, whilst sufficient degradation and wear to force them to pit, increasing the number of pit stops and consequent strategies to keep the fans happy.

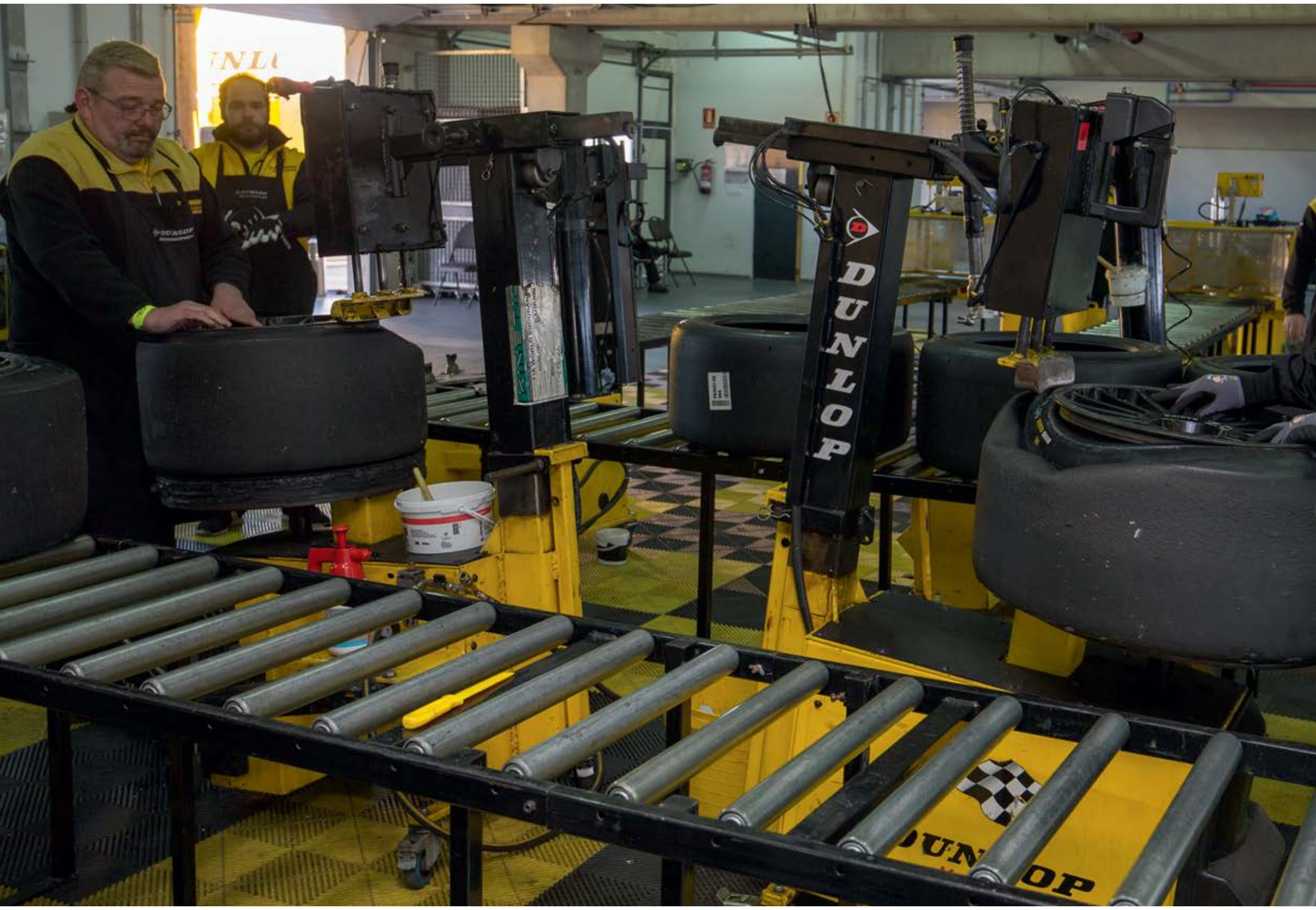
The 'cliff' that Pirelli developed a few years ago is a prime example of this. In 2016 it tried to engineer a sudden drop in grip into its compounds, at a certain level of wear. This secondary phase of tyre degradation occurred at a much higher rate, so drivers lost so much time per lap that the only feasible option was to pit immediately and change tyres. This is a good example of how tyre manufacturers involved in sprint racing often have to design their tyres to degrade, the polar opposite to endurance racing.

Consistent performance

During a long distance race, the main cause for pit stops is refuelling. To minimise the overall time spent in the pit lane, ideally teams want to reduce the number of tyre changes, and when new tyres are needed, they are changed at the same time as refuelling. This strategy is one that the teams will try to do at every opportunity, demanding the tyres to not only last, but maintain performance for as long as possible. 'The goal every year for us is to improve the durability and consistency of all our compounds,' highlights Vincent van Goor, computational mechanics engineer at Dunlop. 'This is endurance racing where our tyres have to last and maintain consistent performance, not sprint racing where you have one lap at peak temperature before the tyre drops off and start to degrade.'

Sebastien Montet, director of tyre technology at Dunlop, adds: 'In endurance racing, the biggest opportunity to improve tyre durability is to have a wide operating temperature window and

Main picture: Dunlop's tyres not only cope with the demands of endurance racing, but also achieve high performance. Five LMP2 teams at last year's Le Mans completed five stints on the same set of tyres – the same distance as two and a half F1 races
Right: Dunlop provides track-side engineers, integrated into each team, who work to help optimise the set-up in order to maximise the tyre performance



Race tyre manufacturers will fit the rubber to the race teams' rims. After they have been used the tyres are then removed by a machine, once the air has been bled out of them

this is something that we aim to improve each year. When you race from one track to another, sometimes on the other side of the world, the different climates really demand a wide temperature range that the tyres can work in. Le Mans is quite specific because of the track length and the weather can vary on the straight compared to the rest of the track, but at tracks like the Nurburgring for the VLN 24 hours, the conditions are 10 times worse. Two years ago it was sunny in pit lane and hailing on track, you can get four seasons in one day there, so we have to develop tyres that can cope with that.'

This wider operating window is aimed to have a typical range of 30degC, with a 10 to 15degC overlap between the compounds. Of course, these numbers vary according to how each compound behaves with the specific

'The goal every year for us is to improve the durability and consistency of all our compounds'

weather and track conditions, which may narrow the working range as well as reduce the overlap. 'By formulating the compounds to widen the working range, we can use compounds in situations that we couldn't previously,' Montet says. 'For example, this morning [at the Aragon tyre test] we could run the B compound [medium] in these cold conditions. In theory, the medium would have been out of the window and not the choice we would recommend and we expected some level of [cold] graining. Actually, it worked pretty well because graining was minimal, so that's one more box ticked with these new specifications.'

Increasing the suitability of each compound to a broader range of conditions also opens up the options for tyre strategies as teams can then run different compounds in similar temperatures and conditions.

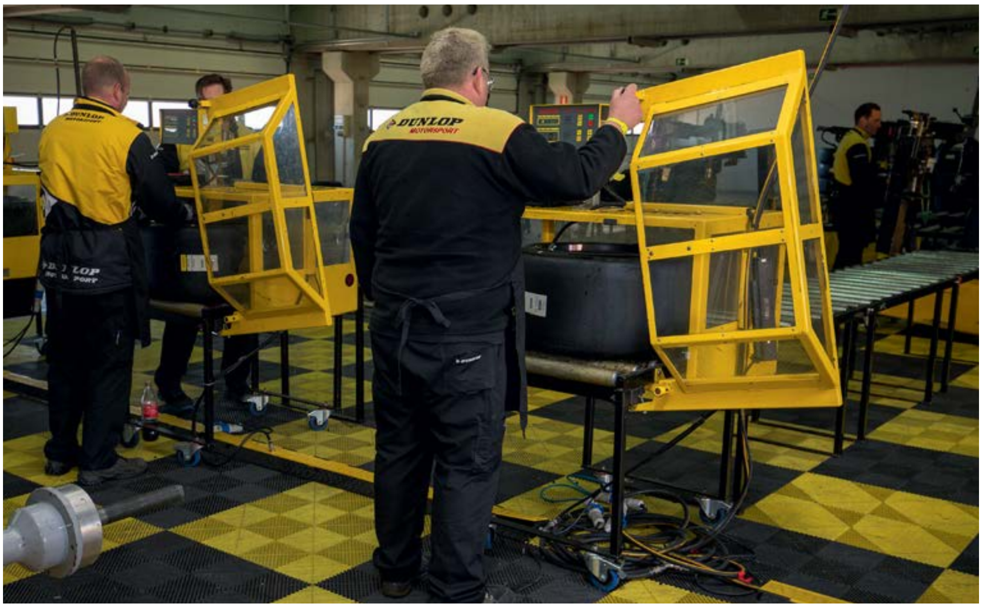
The heat is on

Of course, this wider operating range is pointless if the tyres can't get up to temperature in the first place or can't maintain this peak temperature once it's reached. These are the other areas that Dunlop has been focusing its development on. 'The key to maintaining peak tyre carcass temperature is to effectively manage and control the rate of wear. High wear means less rubber which reduces temperature because there is less material to generate and preserve the heat,' explains Montet. 'The more we can manage the wear, the more grip we can maintain. We can control this through the formulation of the compounds as well as the mixing process. Also, some of the materials we use are more thermally stable, so their stiffness characteristics don't vary with temperature as much as other materials. We can simulate and test these materials across a range of temperatures to quantify these properties.'

Warming up

Warm up is another characteristic that needs to be carefully managed. This is defined as the time taken for the bulk of the tyre to reach peak temperature within the working window. Improving the warm up means the tyres can be switched on faster, particularly in cooler conditions: essential to survive 24-hour races.

'Where this has the biggest impact is after safety car periods and double yellow zones because the tyres cool down completely,' says Montet. 'It all depends on the track length, but



Once the new tyres have been fitted to the wheel rim they are then pumped up to pressure in these special safety cages

Dunlop supplies five different tyre specifications to its LMP2 teams: three types of slick, an intermediate and a wet. All five specs are new for 2018 and each of them features modified constructions and compounds as well as a wider working range

I would say this is most difficult to manage at Le Mans because of the long straight, which cools the tyres more. You can lose between 30 to 40degC bulk temperature if you enter a double yellow down the Mulsanne straight, and the pressure can drop easily by 0.3-0.4bar. If this happens we aim for our tyres to be fully up to temperature by the Porsche curves, but this depends on the weather conditions. Naturally, if it's cold then the warm up will take much longer. It's not just from a performance point of view that we want to minimise warm up time, but also from a durability point of view. The lower pressures of cold tyres can lead to structural problems, particularly when hitting kerbs.'

Surface tension

As well as coping with the differing lateral and longitudinal demands of each circuit, the tyres also have to cope with the different surfaces. The majority of the Mulsanne straight at Le Mans is public road. Therefore, this section of the track will have a different macro and micro roughness which will ultimately affect the rate at which the tyre generates temperature and therefore grip. Furthermore, the continual use of the public roads results in an extremely dirty section of the track, which sounds rather petty, but with the LMP2s reaching 340kph down this straight, any debris, dirt or grease can have a huge effect on tyre performance.

Compound interest

'For the high abrasive tracks you need the stronger compound because it lasts longer and is more stable,' says van Goor. 'But for the low abrasive tracks you want the softer compound because this gives you more chemical grip through adhesion.

'However, if the temperature is low, the harder compound works better, but at low *mu* [coefficient of friction] tracks, the softer compound has better adhesion,' van Goor adds. 'You have to make a trade off and quite often the medium is used as it suits both conditions.'

This is why Dunlop conducts tyre tests at a variety of circuits, so that it can subject its tyres to a wide range of different surfaces. 'We spend a lot of time doing circuit characterisation, which is where we analyse all the car data and try to group the circuits into categories and understand how to optimise the tyres for each track,' says Mike McGregor, track-side support and engineering manager at Dunlop. 'As part of the new 'Super Season' we will be racing at Sebring, which is half concrete and half tarmac. We last scanned Sebring in 2015 and found there were 37 different surfaces around the circuit. Trying to design a tyre optimal for that track, whilst coping with the public road surface at Le Mans as well as the high load and high energy characteristics experienced at Silverstone, is a challenge.

'This is why we come to Aragon for tyre testing because it has very high loads and the tyres don't get much relief,' McGregor adds. 'Here, we hit top speeds that are similar to Le Mans down the back straight, so in terms of gearing we can run in full Le Mans set-up and simulate these loads. However here, immediately after the cars reach top speed there is also a fast left hander, so the tyres have no time to recover. This gives us the worst case

'We found there were 37 different surfaces around the Sebring circuit'

The new Honda NSX was running at the test at Aragon. The track's ideal for testing Dunlop's endurance rubber as there are very high loads and the tyres don't get much relief, while the cars hit top speeds similar to Le Mans down the back straight

The optimum strategy to win an endurance race is to spend as little time in the pit lane as possible. Teams want tyres to last as long as possible and by regulation have only a certain number of tyres for use during a race weekend, forcing longevity

To measure tyre wear first the pick-up on the surface of the tyre needs to be heated up and then scraped off. Only then can a wear gauge be used to measure the depth of the wear holes and therefore the amount of rubber that has been worn away

scenario, rather than the best case scenario, in which to develop our new tyres.'

Open competition

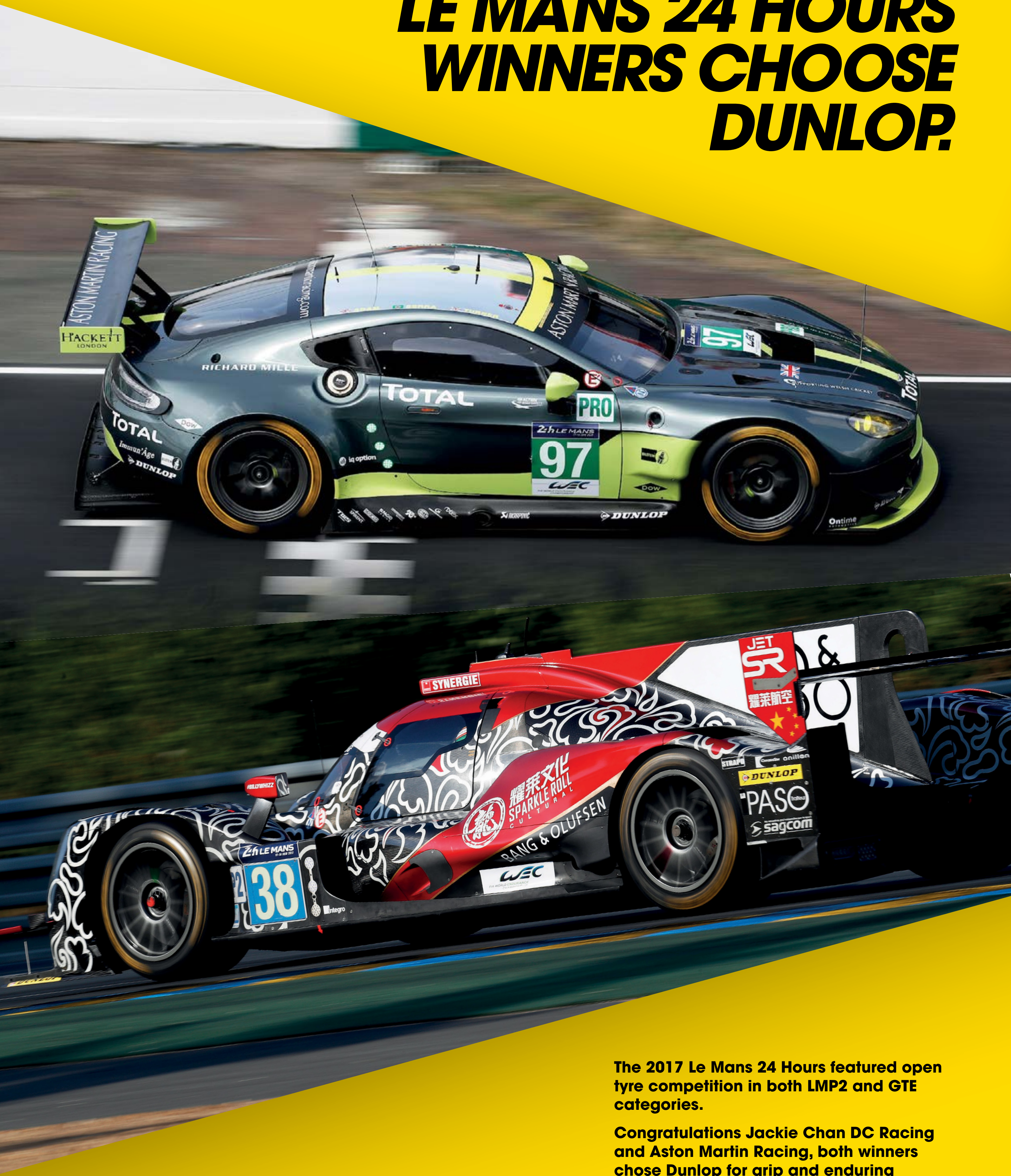
Open tyre competition means that suppliers can optimise their product to suit their teams, to beat the competition. For example, in VLN and WEC GT, although Dunlop has to homologate three compound specifications, it is allowed to modify the construction and supply a unique specification to each chassis. Therefore, last year when Dunlop also supplied Porsche alongside the Aston Martins, it could develop a much stronger rear construction to cope with the higher loads from the rear-engined racecar. LMP2, however, is much more restrictive. By regulation, Dunlop can only supply three slick specifications, so all teams have to use the same specifications, regardless of the chassis they are running. The only tool to optimise tyre performance is the car's set-up.

'Every year it is a big challenge to design one tyre package that suits every team, whilst coping with the different chassis,' says van Goor. 'If the specification doesn't work for one chassis, then we can't release it. In LMP2 last year, the cars gained 100bhp and 40 per cent more downforce compared to 2016 which is why we introduced a totally new tyre package that better suited the aero balance of all the chassis, but it meant that the teams had to adjust their set-up. Last year we made the rear tyres stronger, whereas this year we have made the front tyres stronger whilst keeping the rear tyres at a similar level. We are constantly testing various constructions to learn about the different vertical and cornering stiffnesses which is very important for the aero platform. Stiffer front tyres help to stabilise the ride height and aero platform, so the balance is more consistent which helps the drivers during braking and turn-in and that's what we have improved this year.'

Varying set-ups

The main tactic for optimising the behaviour of the tyres to suit each racecar is through adjusting the set-up. For example, out of the nine LMP2 ORECAs running on Dunlops last year, none had the same set-up. That said, set-up is largely dependent on driving style as well, which is yet another factor that Dunlop has to consider when developing tyres. Unlike F1 where the set-up of each car evolves around the particular preferences of each individual driver, endurance racing teams have three drivers to consider. Not only does this mean the engineers have to deal with three different driving styles, but the combination of Pro and Am driver line-ups also exaggerate these differences. 'From a design point of view we need to ensure the tyres are not too sharp for the Am drivers to

LE MANS 24 HOURS WINNERS CHOOSE DUNLOP.



The 2017 Le Mans 24 Hours featured open tyre competition in both LMP2 and GTE categories.

Congratulations Jackie Chan DC Racing and Aston Martin Racing, both winners chose Dunlop for grip and enduring performance.

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DUNLOP
FOREVER FORWARD

Dunlop brought around 3500 tyres to the Aragon test. At Le Mans this year, just for LMP2, it will need to supply 180 tyres per car for race week, which adds up to 2880 tyres in total

handle,' Montet says. 'By definition, Am drivers are not spending the same amount of hours on track as the Pros, so we have to give them tyres that are still fast, but easy to manage. We could make a faster tyre for the Pro, but there's no point because the Am driver would not be able to cope and endurance racing is a team effort. That's why during testing we actually give a lot of consideration to the Am driver comments as well as the Pro, so we can check that the direction we're going in is not too extreme. The Am driver should be the happiest with the tyres, because the Pro driver has the skills to manage.'

LMP2 changes

The change in LMP2 regultions opened the door to new set ups for the teams which led to some problems, initially, but these are now solved and teams have experience with the cars. 'Although the car regulations are the same for 2018, the problem is that now teams know how to utilise these more powerful cars and extract every tenth from them,' Montet says. 'Of course, the tyres will be punished the most. Therefore for 2018 we have completely revamped everything. The construction has changed for the slicks, intermediates and wets, to maintain the same level of consistency and durability as last year, but with improved performance.

'Obviously, if you change the construction, you change the footprint and so the compound needs to change as well, which is where we widened the operating range,' Montet adds. 'You need to optimise the cavity shape, the construction and the compound and then how all three work together. Another aim for these revamped tyres was to improve the stiffness balance between the front and rear to maximise the potential of the aero platform. We have brought more stiffness to the front, but whether that is done by adding stiffness to the front tyres or reducing the stiffness of the rear tyres is the question. We supply five specifications to LMP2, and all five are new for this year.'

Rule mule

Having to redesign the tyres in the second year of a new phase of regulations is relatively unsurprising. New regulations bring new unknowns and with safety always at the top of the agenda for every tyre manufacturer, often they go conservative. This was seen in Formula 1, where the mule cars that Pirelli used to develop its 2017 tyres were largely unrepresentative in terms of aero loads. This forced an increase in safety margins, producing a range of tyres that were much harder than required, resulting in minimal degradation and less overtaking. With the data and knowledge gained from last year, its 2018 tyres have now all moved a step softer, resulting in the introduction of the new pink-walled Hypersoft to provide more grip at street circuits.

The open tyre competition of LMP2 and the close relationship Dunlop has with its teams meant that its mule car was a lot more representative. 'We used an old LMP2 car and added a mock aero kit to give us the rough level of aero that the new cars would have,' Montet says. 'As the cars would be coming relatively late we decided to supply a preliminary specification for 2017, that we thought was 90 per cent there, based on this data. This was then frozen for 2017 but we have used all the data gathered from the season to make the changes to meet our target, which we knew was reliable.'

On the GT side of things, the rule changes have been much less dramatic, although VLN has made a controversial change to its open tyre competition championship. Previously, the teams had full use of confidential tyres, so Dunlop could bring any specification that it wanted. Now there are new restrictions.

'Three years ago we could run any development tyre, but this changed last year and we now have a "Sample Tyre Procedure"', explains Bernd Seehafer, motorsport technical project leader at Dunlop. 'Effectively all the slick tyre specifications that you run have to go into a so called "impound" where the other tyre manufacturers can access them. Logically that means we have to develop tyres with the same level of performance, without showing all our cards.' The number of specifications are also limited to nine per car, although three of these can be introduced later on in the season.

Ongoing development

Last year, Dunlop won the WEC in LMP2 with Vaillante Rebellion at Bahrain and celebrated with a tyre test the very next day. That approach never changes. 'Here at Aragon, we are already thinking of 2019,' Montet says. 'We are testing designs that have some potential but the season [begins in May, 2018], so we don't have time to industrialise or test these designs, but we will continue to pursue them at other tyre tests, ready for 2019 or 2020. The biggest problem is actually saying when to stop development, and for that we work back from the dates of the Prologue.

'The teams out on track are our customers, but we see them as partners,' Montet adds. 'They have come here to go racing and win and it's our role to bring a product that allows them to. Open tyre competition is fierce so you have to push through the season as well as the winter. We need to keep this leading edge in ELMS and LMP2 and from what we've seen so far, we are on the right track to be successful again.'

Of the nine LMP2 ORECAs running Dunlops last year, none of them had the same set-up

Logistical challenges

In addition to all the on-track challenges of being a tyre supplier, there are plenty off-track challenges for Dunlop to face, too. Tyres not only have to be engineered and developed, but manufactured and shipped as well, and this has become even more of a headache as the WEC embarks on its new 13-month, eight race season.

'It's essentially one and a half seasons, where we race at Le Mans twice and also go to Sebring, which adds about 1500 miles to the season for LMP2,' explains Paul Bryant, key account manager at Dunlop. 'For example, this season at Le Mans we will be supplying 16 LMP2 cars, which equates to around 2800 to 3000 tyres in total, just for LMP2. To get those to Le Mans we will need six transporters and around 30 fitting staff at the track to fit them.'

That said, the logistics team actually has more of a challenge supplying tyres for testing rather than the races, despite the fact that fewer teams take part in a test. 'You might think we would have fewer tyres here than at Le Mans, but when you are testing not only do you have so many variants, but also tyre sets might be disregarded after only four or five laps. So here, we have about 3500, and that's just how tyre testing works.'

Hart' and soul

While Brendon Hartley's been competing in Formula 1 his brother Nelson has been doing something that's perhaps equally impressive – building a bespoke, high specification, big power V12 powerplant from scratch

By DR CHARLES CLARKE

‘This engine is not just about the cost or the performance, it is also about art and emotion’

For those in the know, it’s no surprise that Toro Rosso has given Brendon Hartley a contract for 2018 while it develops the Honda engine. There are unlikely to be many other race drivers in Formula 1, or indeed any top-line formula, with his unique technical background.

Hartley’s father, Bryan Hartley, founded Hartley Engines in New Zealand over 30 years ago and his older brother Nelson, who recently took on part ownership of the company, is forging a reputation as a very capable engine designer and builder, modernising the company, and going up against some of the biggest names in the industry – and producing some amazing engines as he does so.

His latest V12 masterpiece is a case in point. Hartley has always yearned to do a V12 and he has had several project starts, but has never quite got past the doodling stage. ‘I’ve been wanting to do a V12 or something a bit more exotic for quite some time, but I haven’t really had an application for it,’ he says. ‘I’d even started drawing up my own block and heads. I wanted to make something that reflected the V12 grand prix cars I heard growing up. I liked the sound, and they’re relatively simple and reasonably easy to replicate. But like all projects you’re not being paid to do, you don’t finish it unless someone’s waiting. Plus, it’s a major undertaking building an engine from scratch, producing the castings and billet parts.’

Silvia lining

But when Jaron Olivecrona came along wanting to do something a bit different for his Nissan Silvia S14 drift car, the V12 idea resurfaced. ‘I was interested straight away, and had plenty of ideas already on file,’ says Hartley. ‘Jaron and his father Kester import a lot of cars and had had a Toyota 1GZ V12 sitting around for a while that they picked up at an auction somewhere in Japan. To be honest it’s a terrible motorsport engine in standard trim, which is why not many people have used it before. But what is good about it is that I can buy 10 to 20 blocks and heads tomorrow, so if someone wanted 10, I could supply them using the Toyota castings. Whereas, if we used a Ferrari, Aston Martin or Lamborghini V12 as the core I’d only ever be able to do maybe one or two.’

Main picture: The Hartley V12 has been built to power a Nissan Silvia S14 drift car. It will make up to 900bhp but in a future twin-turbo form it could produce anywhere between 1000 and 1300bhp

QUICK SPEC

Hartley V12	
Base engine:	Toyota 1GZ-FE V12
V angle:	60-degree
Internals and components:	All Hartley Engines, except for the castings and the crank
Displacement:	5-litre
Power:	850 to 900bhp in NA form

Big in Japan

For Hartley to make its own block and heads is a significant investment and few customers would want to contribute to the development. ‘There’s a lot of work in making a block and cylinder heads,’ says Hartley. ‘I can definitely do it and if a client wants me to make them from scratch I will, but we’d have to have a considerable order of units to justify it – it’s doable, but there are probably better ways of spending that kind of money.’

Which is why the base engine is a 5-litre Toyota 1GZ-FE V12, Japan’s only V12, which was used to power the Toyota Century limousine exclusively for the Japanese market from 1997 to 2016. In standard trim it produces about 308bhp at a stately 4000rpm.

‘It’s not uncommon for people to use the Toyota 1GZ-FE engine as a base engine,’ says Hartley. ‘But not a lot of people in this industry have the equipment or skills to go too much further than buying and fitting aftermarket parts out of a catalogue. There isn’t a whole lot available, or at least, there isn’t a whole lot available that is worth using for a racecar. So that left the 1GZ-FE as a pretty underdeveloped engine. Perfect for us, as we can make virtually anything given enough motivation.’

Crank call

What appealed about the Toyota V12 was that it’s a readily available donor motor, and also a fairly simple engine that could be modified to suit the new application. ‘We used very few standard parts, just the block and head casting, and at the moment it has the standard crankshaft,’ says Hartley. ‘But I don’t think it’s going to last very long. We are going to have to make a crank very soon – we used the standard part just to get the prototype going.’

That standard crank is steel. ‘It’s actually made from decent material, but once we get to about 1000bhp, I wouldn’t feel comfortable dumping the clutch and doing skids in a drift car with this crank,’ Hartley says.

Perhaps the main thing that Hartley does really well, and uniquely, is getting prototype

Top: The engine itself is based on a 5-litre Toyota 1GZ-FE. This powered the Toyota Century limousine from 1997 to 2016 **Above:** CAD rendering showing the top view of the inlet tracts relative to the cylinder positions. Hartley uses Solidworks CAD

projects going cost effectively. 'Over the years you develop an instinctive understanding with regard to cam angles and the general parameters of an engine, and we have developed specific geometric programs for developing our ports,' says Hartley. 'I don't do any port work by hand anymore and I can't remember the last time I used the flow bench. Our software is incredibly reliable and with accurate CNC there is no need to do things the old-fashioned way.'

Pass the port

Because Hartley could design the intake manifolds and the ports in one go, he could work around the fact that the original ports simply weren't very good. 'I kept the same port locations and didn't add any weld,' he says. 'The heads are too long and they would distort too much if we added any material.

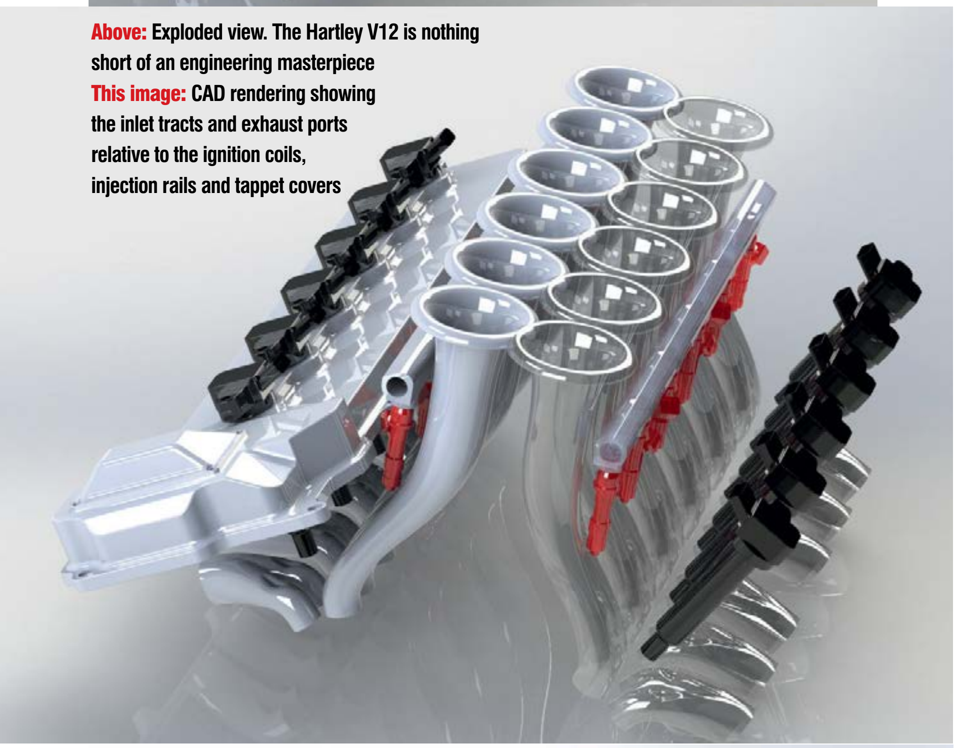
'It was a massive port job. We had to make 48 inserts and 48 valves and had to find a retainer we could use and a spring we could use,' Hartley adds. 'You can't just buy performance parts like these to a custom specification. I don't even refer to it as a Toyota any more, just a Hartley V12. I'm not sure Toyota should get any credit for the final engine, other than the fact that their foundry poured the castings and made the crankshaft.'

Hart' surgery

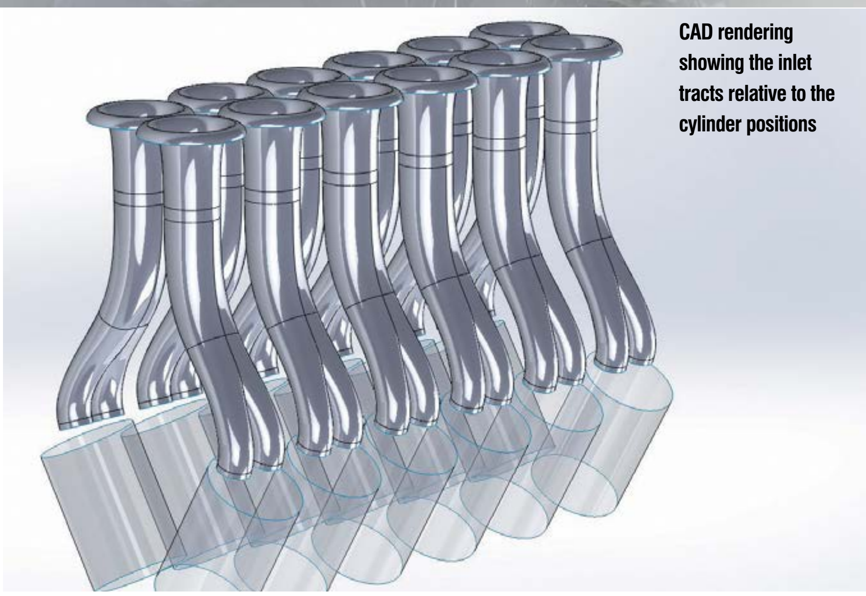
The cam followers were sourced from another engine and Hartley then machined them and the heads to suit. The same process was repeated with the retainers. 'We found a retainer that matched the measurements that we needed and fitted it to the engine,' says Hartley. 'We also found some off-the-shelf forged conrods that matched the overall dimensions we needed and we modified them to suit. It was the same story with the pistons. It's not cost effective to forge our own, so we often just buy blanks with the pin height and the rings in the right spot, then we machine the tops to suit our compression ratio, chamber shape, and valve sizes.'

This is the normal Hartley process. 'This way we can control the design and keep the IP in house,' Hartley says. 'We get what we want and no one else can copy it that way. Most of the piston and conrod suppliers are US based

Piston valves. Hartley had to make 48 valves for the V12 engine. The vast majority of the components were made, or machined to fit, by the company



Above: Exploded view. The Hartley V12 is nothing short of an engineering masterpiece **This image:** CAD rendering showing the inlet tracts and exhaust ports relative to the ignition coils, injection rails and tappet covers



CAD rendering showing the inlet tracts relative to the cylinder positions

– they do forgings really well. For a prototype it's actually cheaper to get something close and then modify it to suit, than to get specialised components made from scratch.'

Flow pointers

The CAD system that Hartley uses is not known for its pure free-form surfacing. 'Solidworks is getting better at free-form surfacing with every update, but when it comes to port shapes, I actually find its more strict requirements for surface manipulation suits my maths. I find that some of the surfacing tools are quite lazy, or unadaptable, but I think that actually works quite well. If the surface won't wrap around a set of curves, the air probably isn't going to want to flow through it very well either. Obviously there is quite a bit more to it than that, but sometimes the simplest approaches can get the most desirable results.

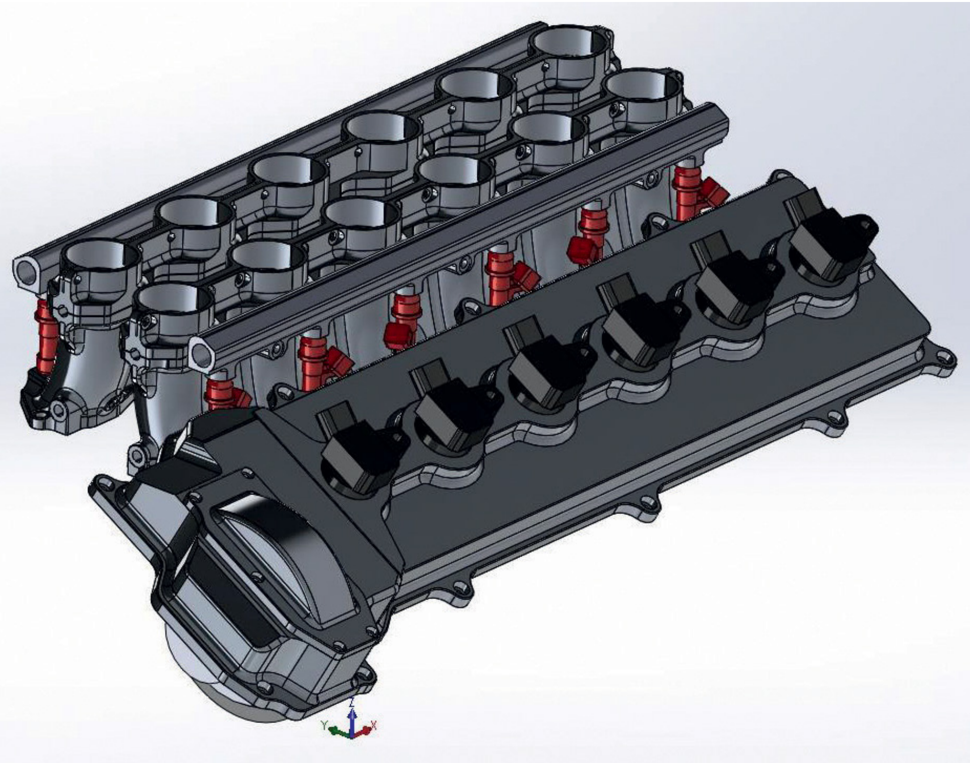
'With the V12, because I went to a lot of trouble to get the port shapes right, it flows very well, and it makes good power,' Hartley adds. 'It's making somewhere between 700 and 800bhp at the flywheel at about 9500rpm.' But like all good engine developers, he's keeping certain information on a need-to-know basis.

Smooth operator

One interesting lesson from the V12 is how much the harmonics impacts the performance. 'We often think that we'll know when an engine is going to hit its rev ceiling,' says Hartley. 'We can normally predict it pretty well based on the weights and measures of the components, in particular the valve train, and the shapes of our cam profiles. Normally we are dealing with eight cylinders and 32 valves going up and down, and we know when we normally expect the power curves to start flattening out; yes, some of our V8s are going well over 10,000rpm, but it's normally overrun at that point. With the V12 at 9500rpm the line is still dead straight and

The thing that Hartley does really well, even uniquely, is getting prototype projects going cost effectively

CAD rendering showing the throttle bodies in relation to the left-hand tappet cover. Every single bit of the engine has a CAD model



Hartley doubts the standard crank will be able to cope with big power drifts so that will need to be changed some time soon

still climbing. With this bore x stroke we never expected it to be quite like it is.'

This means the V12 is very smooth. 'We have yet to get anywhere near its maximum rev range, at this stage we only have the one prototype, so we are keeping the revs limited, but in time we will start to push a bit harder,' Hartley says, adding that that 12-cylinder smoothness has had an incredible effect on the power curve. 'I'm honestly blown away that the power curve is still climbing at the rate it is, because of our cam profile or our port shape. I didn't expect it to be that smooth and keep pulling that many revs. It wouldn't surprise me if we end up taking it to 11,000 or 12,000rpm.'

Hartley funded most of the development work himself, with the intention of eventually selling more units. 'For me this was a passion project,' he says. 'Jaron and Kester were super patient with how long it took, I don't think they realised quite how far I was planning to go, I don't think even I quite realised! They run on a pretty tight budget, but we all got really excited as the project progressed. The car they have built is world class for drifting and the exposure we have been getting has been phenomenal.'

Business plan

When asked about the cost, Hartley said: 'Obviously the engine cost them something, but for me I tried my hardest not to charge them for development, just for an end product. The great thing about it was that they were patient, and they were prepared to wait.

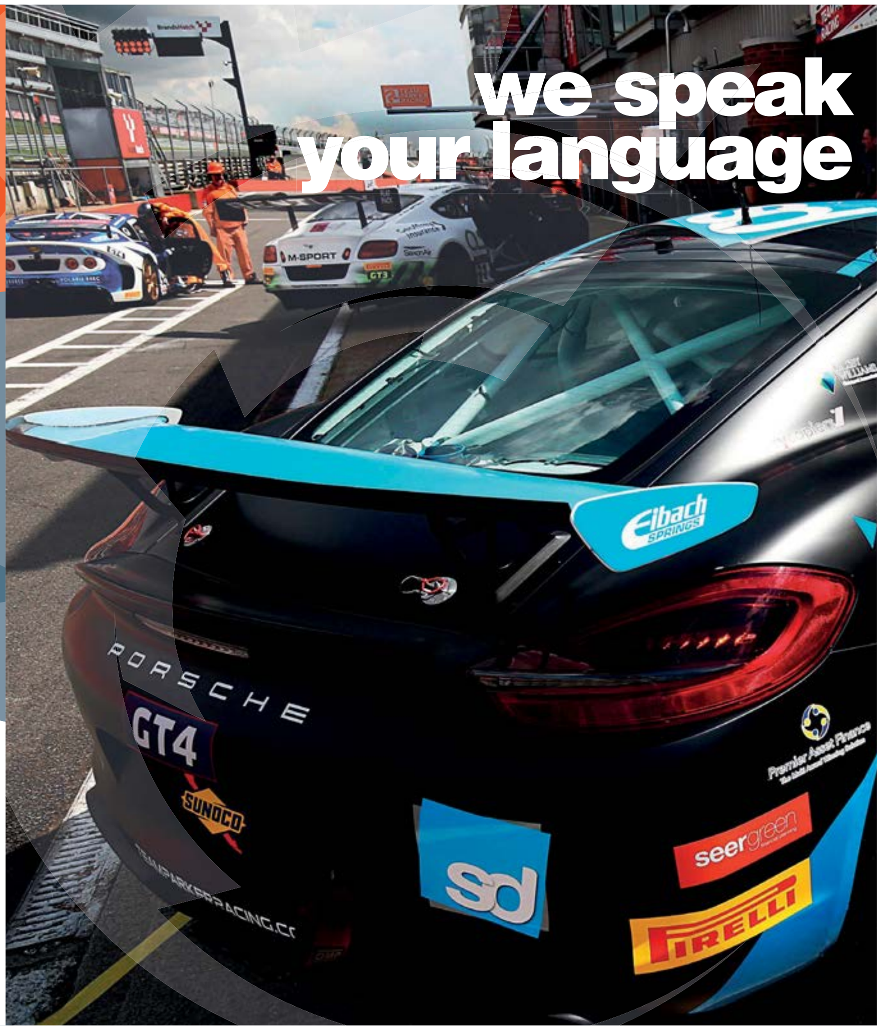
'When I took it on I thought we could sell heaps of parts to people wanting to modify this V12, but part way through the project I started to re-evaluate,' continues Hartley. 'At this stage I've actually stopped wanting to sell the parts, because it's actually too good to sell someone parts and for them to essentially just hot up their road car. No doubt we could sell a lot of parts for them, but for now I am trying to look at the bigger picture. I first need to evaluate the market for a product like this. The moment I sell even a few components, especially the cosmetic ones, I have instantly devalued the complete engine as an exclusive Hartley product.

'What I really want to do is a small production run for a small exotic car company – offer them a bespoke engine that no one else has, with the Hartley name. Yes, there is still the Toyota block and heads in there somewhere, but it's definitely not an off the shelf crate motor from America, and nobody has had to partner with BMW or Mercedes to get it. As far as marketing is concerned, it's a Hartley V12. It's still got a Toyota connection, albeit a small one.'

Niche product

More and more exotic sportscar makers are bringing their limited production run cars to market. While the more established companies can afford to develop their own motors, a lot of the newer, or younger, companies must partner with somebody else. 'I love seeing some of the new sportscars and hypercars coming out,' Hartley says. 'But there is nothing more disappointing than finding out they have an LS7 crate motor in the back of them. They go to the trouble to design an exotic carbon fibre *designer* vehicle and put an off-the-shelf motor in it. But I can offer an exotic V12 with 800bhp in NA form, or 1200bhp with turbos. Plus I can offer exclusivity. And, of course, there's the Hartley connection, it would be a shame not to try and cash in on my brother's success,' he jokes.

'I've had some interest already, [even though] we definitely haven't advertised yet,' Hartley adds. 'I am in no hurry to go into production, but when the right partnership comes along I will be right into it. I'm looking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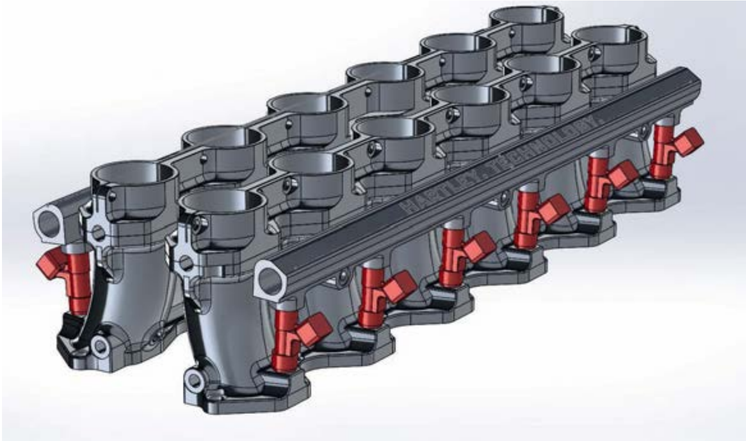
Right: CAD rendering of the throttle bodies and injector rails. The intake manifolds and throttle bodies have all been made from billet and Hartley also produced all the butterflies, spindles and linkages **Below:** Finished throttle body base showing location pegs and butterfly spindle channel



Exposed trumpets look great but they have now been covered up with the addition of an airbox containing two panel filters

for someone that wants to build a unique car for footballers or oil barons and doesn’t want to use a Ford Coyote crate motor or they don’t want to use the same engine as their competitors. They would rather have something raw and exotic. It’s a bit of a risk for me taking on a project like that, as it’s focusing a lot effort in one direction, but it’s potentially interesting. No doubt someone will tell me it’s a terrible business model, but sometimes you have to follow the jobs that are exciting to keep yourself able to do the jobs that are repetitive.’

There’s a CAD model of every part and Hartley has no problem re-engineering any of it to suit a potential client. ‘It would need to be slightly different for a road car. We’d have to have e-throttle and catalytic converters, various performance modes – there are companies in New Zealand that deal with emission controls and I’m keen to keep most of the development here. We punch well above our weight in this country, and I am all for using local engineering.’

Maths and nous

Hartley adds that while there’s plenty of science involved with this project, experience has been key, too. ‘There’s quite a bit of maths involved in developing a new engine, but inevitably we have to use rule of thumb and experience as well,’ he says. ‘Nothing was made by hand, every part has a CAD model and drawing associated with it. And I went to considerable lengths to model everything first before we started making anything, so there would be no surprises. There were a few things, like the airbox that I only just made the other day, that were a bit of an afterthought and dependent on the car installation. It’s basically a box with two panel filters in. The exposed trumpets looked way cooler, but we had to be sensible.’

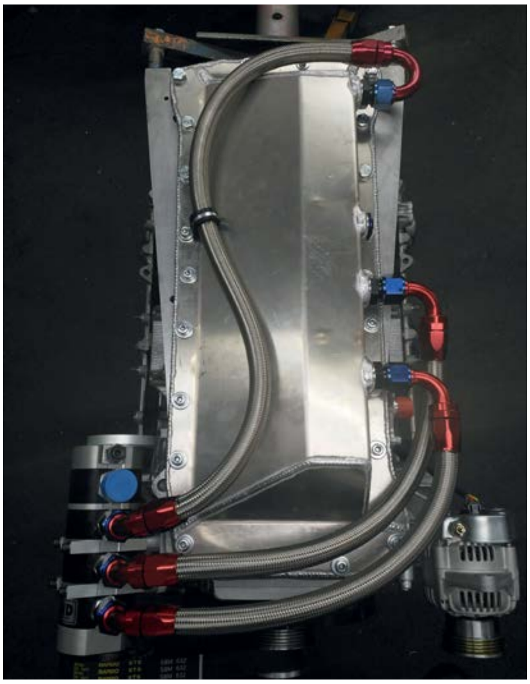
The billet tappet covers started out as 50kg blocks of aluminium and they weigh about 2kgs finished. ‘A seriously large amount of waste material per side, so there’s 96kg of swarf,’ says Hartley. ‘The intake manifolds and throttle bodies are all made from billet and we made all the butterflies, spindles and linkages as well.’

Bespoke parts

The standard watering system was not good, Hartley says, ‘so we threw that away and replaced it with an electric water pump which we modified to suit and changed the routing of the system round the motor. The same with the oil and adjustable cam gears, the list goes on – we actually made or modified everything. The only thing we didn’t touch was the crankshaft.

‘You can’t buy bits like these and even if you could there would probably be a good reason for not using them,’ continues Hartley. ‘When you make everything, you have proper quality control. If you buy stuff in, even from a reputable supplier, you don’t really know what

Underside of left-hand billet tappet cover during machining. Hartley sees the V12 as a great advert for the New Zealand-based company's powerplant design and CNC capabilities



The underside of the engine showing the fabricated dry sump and the oil pump feed and return. All the work is high-end specification

'I'm looking for a company that wants to build a unique car, suitable for footballers or oil barons, but doesn't want to make use of a crate engine'

you are getting in any real detail. There was also ego involved in this as well. We wanted to hold our heads up and say we made everything, so it's a Hartley engine, Toyota just poured the castings. This engine demonstrates what Hartley Engines can do – so even if it's just a portfolio piece it's well worth it.

'We get calls all the time from people wanting special bits made for various cars and engines, and for the most part we just don't have the time to make a lot of these things,' Hartley adds. 'What's more interesting to us for the future of our business is the customer who wants to commission us to make 30 units for a particular race series, or for an exotic sportscar, or something that we know is going to get used over a longer production run. I think our biggest strength is our development efficiency, I truly believe we can be significantly more cost effective at developing and producing engines either from scratch or modifying them. And the V12 helps get that message out there.'

Work of art

With the numbers involved the Hartley V12 should certainly do a good job with getting that message out there. 'I'm hoping we get at least 11,000rpm out of the V12 – we may even get to 12,000,' Hartley says. 'To me, this engine is not just about cost or performance, it is definitely those things, but it was also about art and emotion, which is something I miss out on a lot with our pure racecar engines.

'I'm not going to deny that for a GT car, or even a modern single seater, a V6 turbo – think Formula 1 – is light, efficient, capable of making fantastic horsepower,' Hartley continues. 'But what it doesn't do is make the hairs on the back of your neck stand up when you crack the throttle, or cause every member of the public to pull out their cameras the moment they see it, like this V12 does. And that's what this project has really been all about.'

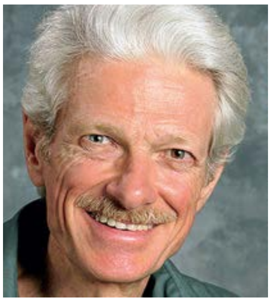
Hartley is also keen to do a twin-turbo version and try and compete with the W16 of the Bugatti Veyron. 'I'm pretty confident we can make as much horsepower as the W16, probably consume as much fuel too,' he says. 'Plus, we can provide customers with a twin-turbo V12 sticker and not many people can do that these days. This engine is so smooth, once we boost it, getting into the 1000 to 1300bhp range should be fairly easy, whilst still being able to flick a switch and make it drive to the shops. With the modern electronics and cam controls you can have very tractable performance engines – and it's easier to do with turbos than with NA motors.'

Competitive edge

As mentioned, Hartley would ideally like to put the V12 into something exotic. 'But just for one or two partners, not for just anyone who walks through the door,' he says. 'At the moment the future of the engine design is a little uncertain, so we don't want to contaminate the future market by selling it to anyone who asks for it. It's too unique to do that and once we do that it will never be an exclusive engine.

'It's a nice engine, I wish I could take all the credit for it, but I haven't reinvented the wheel with this motor. We have just done what we normally do – I've just done a bit more of it on this job,' Hartley says. 'What I've realised doing this engine is that what we can do normally and we take for granted, lots of our competitors can't do, which gives us a useful edge. There are very few engine companies around the world doing what we are doing here. There are not really many companies that can take on a small bespoke engine production job. A lot of our competition build engines from essentially kit-sets of parts, whereas we make or modify everything in house.

'Building a high-performance engine is a fairly straightforward job, but doing it reliably, efficiently, cost effectively and with repeatability is not easy,' Hartley adds. 'But that's what we are quite good at. I would like to do more jobs like this, and I am really interested to see what the future holds.' And his final word on this project? 'It's freakin' cool.'



Snap chat: oversteer in a 1946 Lagonda

A rare old car has a common handling problem; but what's its cause?

QUESTION

I have being reading your articles in *Racecar Engineering* over several years and have kept a good number for reference. The article on camber compensators prompted this question. I do not know how much you know about the 2.6 Lagonda, so I thought I would start by providing some background information.

The car was designed by a small team under WO Bentley at Lagonda, starting in 1944. They had the first experimental car on the road about the time the war ended, and two further experimental cars and three preproduction cars finished by 1946. The company ran into trouble resulting in it being bought by David Brown in the autumn of 1947; he had already bought Aston Martin in the Spring. The Lagonda engine was then fitted in the Aston Martin DB1 to become the Aston Martin DB2, and the rest, as they say, is history.

The 2.6 Lagonda had independent suspension all-round with wishbones and coil springs (pictured is a 1950s example)

Ahead of its time

As to the 2.6 Lagonda, I find myself with two on the road and several cars needing restoration, one of which I intended to improve to use for a bit of fun on track days and also the odd hillclimb. Also, it should make an excellent classic touring car for modern conditions.

I think the Lagonda is an advanced design for 1944. It has independent suspension all-round with wishbones and coil springs at the front and semi-trailing arms and torsion bars at the back with chassis mounted diff. It also has rack and pinion steering. The ride is excellent and the handling okay – as long as you avoid roll-oversteer, I gather these cars have been known to go through the hedge backwards.

We are very fortunate that Donald Bastow, who worked under WO Bentley and did much of the chassis design, has written a book, *WO Bentley, Engineer*, in which he goes into great detail about most technical aspects of the car's design, and other WO designs. This includes: design objectives; constraints and compromises; reasons for the design being the way it is; experiments; data; drawings; many calculations; road tests; design changes between the experimental and the pre-production cars, and much, much more.

With reference to camber compensation, the chassis is an *X* shape, and the torsion bars run up the chassis rails ending just short of where the rear arms meet. They are located in a common sub-assembly which is rubber mounted to the chassis. From my reading of Bastow the intention of the flexible mounting is to *reduce* the rear roll rate, so, if I have understood it correctly, in that sense it is acting the opposite to an anti-roll bar?

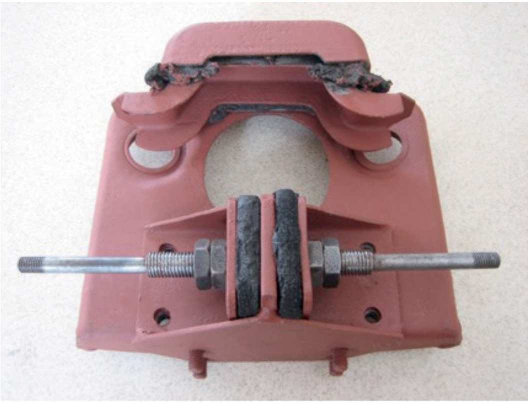
Camber compensator

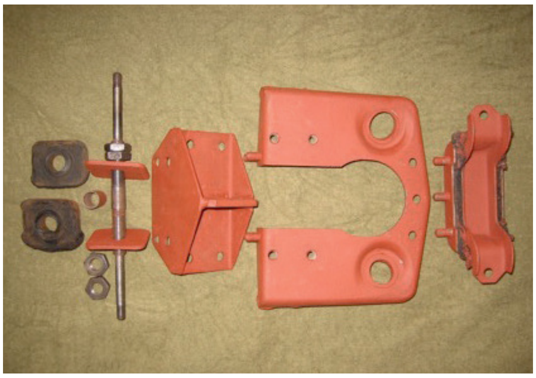
However, as far as I can deduce this design has no effect on ride/heave, which is one of the characteristics you attribute to the camber compensator. But perhaps it does have similarities to the 1930s Mercedes, which you say incorporated a spring?

The transverse arm is located in the middle of the crossmember behind the diff. The forward arm is located on top of the X-frame: on the offside it is just behind the silencer, on the nearside it is above the tyre to the left of the lever-arm damper. This is how Bastow describes it: '*The Lagonda independent rear suspension amounts to a single triangular member for each wheel, the two arms comprising this sprouting from the housing for the hub bearings [*an early example of what is now known as a semi-trailing arm*]. The pivoting point at the inner end of each arm consists of a steel ball enclosed in a spherical housing with a skin of rubber about 0.25in thick trapped and compressed between the two. The proportions and general design are very much those of the rearward part of the lower lever of the pre-war Packard front suspension, and, therefore, of the Mark V and Mark VI Bentley suspension which was based on this. The spherical joint housing is split along the horizontal centreline, and the pips moulded onto the rubber engage with holes drilled in the housing to provide a location for the rubber. The joint housing for the two rearward arms sits on a crossmember between the rear frame extensions as close behind the final dive unit as possible. Each front housing sits on the arms of the X, the axes of pivoting diverging at some 34 degrees to the centreline …*'

In the original design the line between the two location points declined towards the front,

The ride is excellent and the handling okay, as long as you avoid roll-oversteer; these cars have been known to go through the hedge backwards





Top: The sub assembly and how it relates to the torsion bars **Middle:** The same shown from the other side **Bottom:** Its parts

The snap oversteer results from the large increase in net jacking force as the rear tyre loads become unequal, combined with the severe camber change that occurs as the suspension extends

but this was changed, as Bastow explains. *'The final position, with the axis sloping down towards the rear at a true angle of 4.5-degree, gives some toe-out on bump, but no more than 0-degree 23 minutes at 2.9in bump. This axis position gives a roll centre height of 13.6in, and the sideways movement of the contact point with wheel rise and fall gives sideways pushes, but because one wheel only is pushing and the push is resisted by the other wheel, this effect is a good deal less, and less noticeable, than the corresponding effect with a rear axle. One was very conscious of this difference between the pre-war V12 [Lagonda] and the post war 2.6-litre Lagonda.'*

The length of the forward arm is adjustable so the rear wheels can be set parallel to the car centreline at the normal ride height.

Sub assembly

Returning to the mysterious 'sub assembly', Bastow refers to it (i.e. reducing rear roll rate) but does not explain it. I have now found an old photo that should give you a better idea of how it relates to the torsion bars. Note screw adjusters act on the chassis frame (see picture top left; the next picture down shows what this looks like from the other side while the final picture shows the parts). Note also that the ends of the torsion bars simply sit in the holes in the sub assembly. The double ended shaft is held in the X-frame on both sides.

My conclusion is that as the sub assembly is rubber mounted to the chassis it is free to twist, resisted by the rubber. If the torque from the two torsion bars is the same, as in ride, then there is no effect. If the torque is higher on one side then the sub assembly itself twists and in so doing reduces the torque on the other side. And the effect is to reduce the roll rate.

If this is correct, and the objective for doing so is sound, then this seems to me a rather elegant, if a somewhat complicated, means of achieving the desired intention of improving the handling of the Lagonda.

THE CONSULTANT

From pictures you have sent me, and other sources on the internet, I see how this works. But it is analogous to the Triumph swing spring, rather than the camber compensator or the Mercedes third spring. All of these are ways of making the wheel rates softer in roll than in ride or two-wheel heave, but the Triumph and Lagonda do this by putting a rubber spring in series with the main springing.

That extra spring acts only in roll, thereby softening the roll mode, whereas the camber compensator and Mercedes arrangement put a spring in parallel with the main springing that acts only in ride and stiffens that mode. A similar net effect can be had either way.

At first I didn't even see the torsion bars (when looking at a picture on the web) or the forward portions of the control arms. I was thinking the tubular frame members housed torsion bars. I also missed the outboard U-joints at first sight of this set-up.

So the system does have all the parts of a semi trailing arm layout. However, because of the arm geometry it acts like a swing axle. The pivot axis very nearly passes through the inboard U-joint. It looks to me like the 34-degree angle Bastow mentions would be from transverse rather than longitudinal.

Rear pivots

It also looks to me like the rear pivots would be at about 13.5in height. If the tyres are 175SR16, theoretically the loaded section height would be something like six or six and a half inches and then hub height would be somewhere in the 14in to 14.5in range. The rear pivots look like they might be about an inch below the ring gear centerline, although it's hard to really tell. So that would give you about a 13.5in roll centre height if those were the front view projected instant centres – but they're not. The front view instant centres are where the pivot axes cross the *YZ* axle plane. That would put the actual roll centre somewhere around the top of the differential, or more like 16in. Either way, it's way too high, and the front view swing arm length is way too short.

Curing oversteer

With the above in mind it's not surprising that the car exhibits snap oversteer at the limit, just like most swing axle cars. This is not due to roll oversteer. It results from the large increase in net jacking force as the rear tyre loads become unequal, combined with the severe camber change that occurs as the suspension extends. Reducing rear elastic roll resistance helps a little, but the only way to really make the car controllable at the limit is to drastically increase stiffness in ride but not roll at the rear, increase stiffness in both ride and roll at the front, and also lower the car to get some static negative camber at the rear. If you do this enough, you can keep the rear wheels from tucking under sufficiently to be a problem.

You should not expect a soft ride. This is a case of 'any suspension will work if you don't let it', as Colin Chapman put it. It can be controllable at the limit on a smooth road, or it can ride bumps well, but not both.

CONTACT

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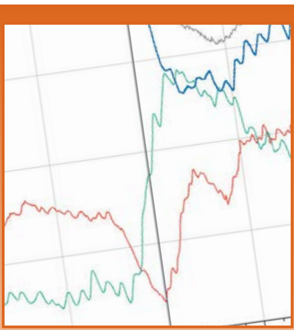

Databytes gives you essential insights to help you to improve your data analysis skills each month, as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems

Hunting down those maddening misfires

It might seem an old-school problem but even in this electronic age finding the cause of an engine misfire can be a tricky task indeed

A misfire can be one of the most difficult engine faults to track down, despite its seemingly simplistic cause. Either an engine does not have enough fuel or a spark at the right time. It is the underlying causes of these two conditions that can cause powertrain engineers to pull their hair out.

Fortunately, modern ECUs in motorsport have extensive logging capabilities, and are often coupled with chassis systems that are also capable of logging everything you could possibly need to help with diagnosis. Misfires can range from being a mild irritation if they only occur under very specific circumstances, to extremely destructive if they are consistent on a highly-strung engine. What's more, a driver will be relying on having power available at all times to control the car at the limit, and a misfire can make a car unpredictable and undriveable.

When it comes to misfires, it is often thought that the lambda data trace will be most useful in fault-finding. It's true that lambda can provide some insight into the issue, although it is often far too inconclusive and subjective to be of any practical use. Seeing that lambda has gone lean does not tell you if the engine is under-fuelled or failed to spark and, unless you have a lambda sensor on each exhaust port, it does not allow you to isolate which cylinder is at fault. You may be able to narrow the issue down to a bank of cylinders on most V configuration race engines, as they will run dual lambda, but you are still completely in the dark as to what your issue actually is. The problem with lambda is further compounded by the fact that a fuel soaked lambda sensor will read spuriously and cannot be trusted.

A fuel soaked lambda sensor will read spuriously and cannot be trusted

Director's cut

There are occurrences where a misfire is reported, and is present, but it is in fact a scheduled cut by the ECU. A properly set up logging configuration will allow very fast diagnosis of this condition, and it is usually a self-reported and easily rectifiable fault.

In **Figure 1** a shift check is being performed while the car is on stands in the garage. At the point of interest, the rear wheel-speeds are around 50kmh and the front wheels are stationary. Usually, the traction control strategy is switched off for the shift check (or in some way calibrated out), however, that has not happened

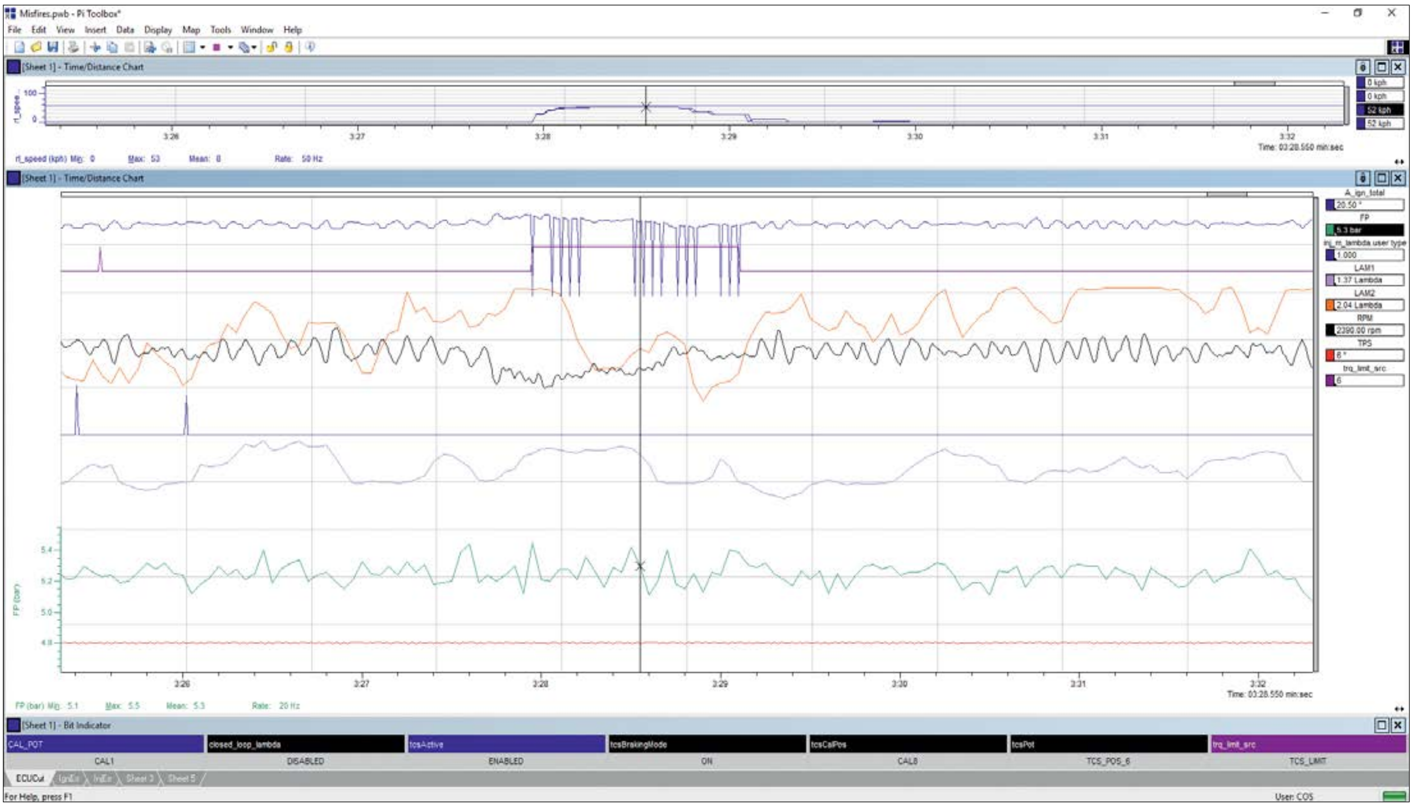

Figure 1: The fields along the bottom of the screen allow for a very quick diagnosis as to why the ignition cuts are being scheduled, so this is easily resolved

As ECUs evolve it is more likely that issues will self-diagnose, while more and more useful channels will be made available

in this instance. The result is ignition cuts are seen as scheduled by the ECU (note that '-90-degree' is this ECU's way of describing an ignition cut out and not that ignition is actually scheduled for '-90-degree').

Quick diagnosis

The fields along the bottom of the screen allow for very quick diagnosis as to why the ignition cuts are being scheduled (Torque Limit Source is Traction Control Limit) and therefore they are easily resolved. Notice that lambda is seen to go lean during that cuts but does not give a discernible pattern. *Fresh air* and *fresh air with fuel* are almost identical when viewed in logged data of this quality.

If your misfire is not a clear-cut case of ECU strategy, you need to look closer at the fuelling and ignition processes. On modern direct injection engines, you may be lucky enough to see spikes on the fuel rail pressure (FRP) that would indicate an injector (or injectors) failing to fully open, or even open at all. In **Figure 2** you can see how the peaks in RPM coincide with the troughs in FRP, and vice versa. This might not always be a smoking gun as spikes in FRP will also occur as a result of RPM changes, but does indicate a fuelling issue.

To help distinguish between cause and effect, engine speed and FRP must be logged at the same rate and preferably 100Hz or higher.

Fortunately, in this example, the ECU also helpfully reports that there is an injector error present as well that is likely to be the cause of the overall issue. The self-diagnosing capabilities of modern ECUs are becoming more common, more complex, and more intelligent as technology and strategies progress.

Issues with the ignition system on a modern engine are often the hardest to diagnose. Unless a logging configuration specific for tracing misfire issues has been defined, the standard set of logged data is unlikely to include the channels needed. Channels such as ignition coil voltages are available in most modern ECUs, but their usefulness is limited outside of misfire diagnosis. For this reason, they are generally not included in a logging table.

Ignition issues are usually found in the old school way of viewing sparkplugs whilst cranking the engine, or disconnecting coils and listening for an engine response (or lack thereof). Data in this instance will often be used to rule out other causes, rather than positively identify an ignition issue. In **Figure 3**, significant engine speed oscillations are seen whilst at full throttle (upwards of 2000rpm), and lambda reacts accordingly as fresh air is pumped down the exhaust pipe. There is no discernible drop in the FRP (certainly nothing that would not be expected with the large swings in engine speed) despite it being logged at 500Hz, and there are no scheduled cuts from the ECU.

From the data available, you would have to conclude that you are not sparking correctly, and this is therefore the cause of the issue.

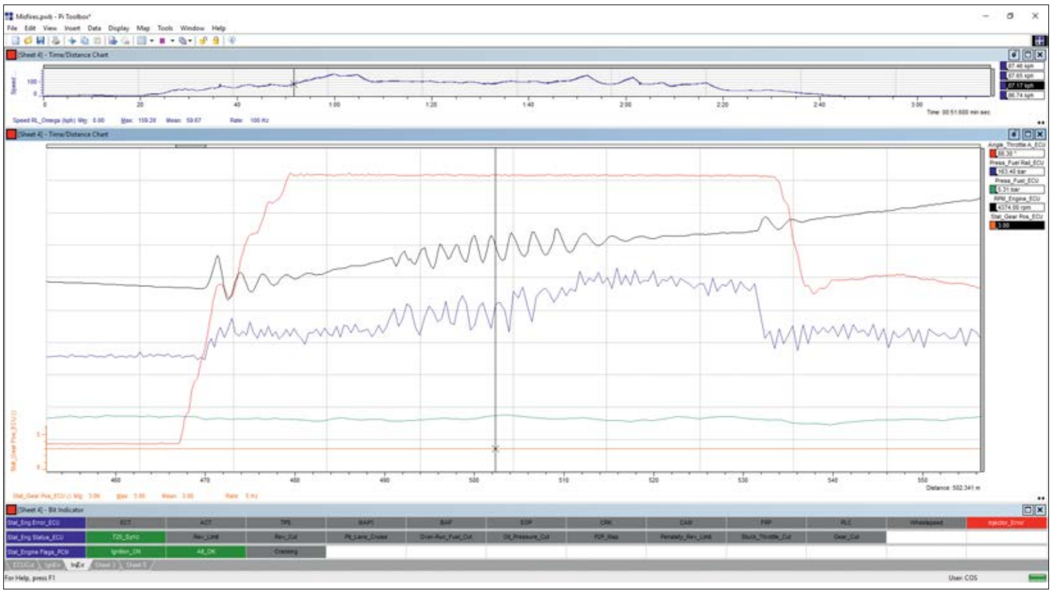

Figure 2: Note how peaks in RPM coincide with the troughs in FRP and vice versa. This indicates there's a fuelling issue

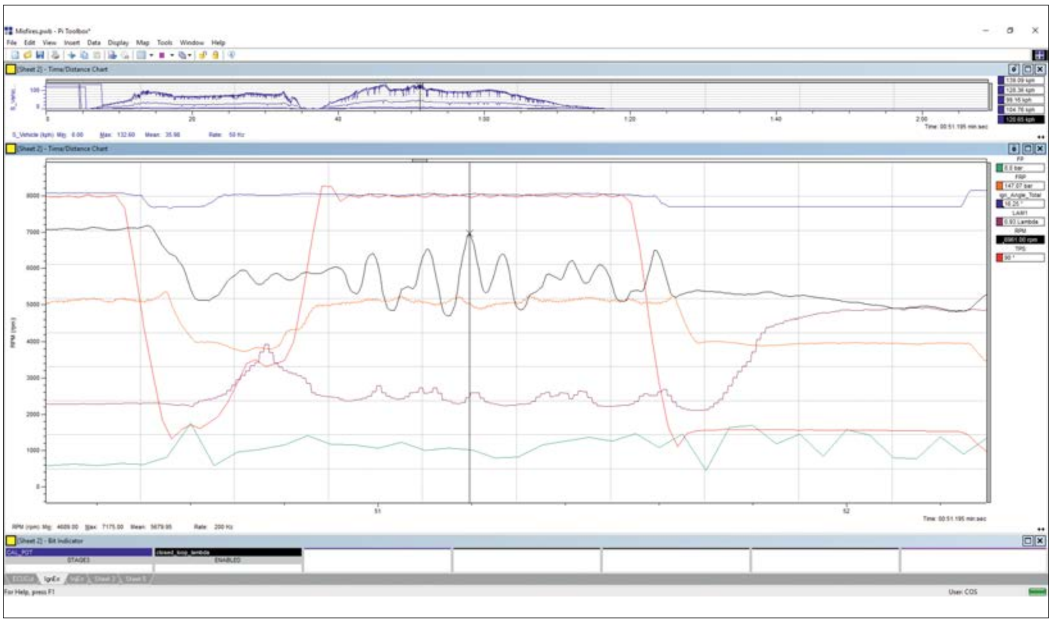

Figure 3: From this you would have to conclude that it's not sparking correctly and that this is the cause of the misfire

Human input

Fixing a misfire can be as simple as changing the spark plugs, or as complex as changing an entire wiring loom or recalibrating your injector configuration. Tracing misfires is significantly helped by having the correct data available to you, and having your logging configuration set up specifically for diagnosing them.

As ECUs evolve, it is more likely that issues will self-diagnose and more and more channels that are useful will be made available, but it still relies on an engineer's interpretation of the information and data available to make an informed decision and plan a fix.

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Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

OptimumG engineer Claude Rouelle's 101 top tips for Formula Student teams continues with some thoughts on budgets, aerodynamics and racecar set-up

Claude Rouelle plays a lead role at renowned vehicle dynamics consultancy OptimumG. On occasion he also offers his services as a design judge in Formula Student competitions, which means he's in an ideal position to offer advice to those looking to take part in these events.

51. Let's begin where we left off with point 50 last month, discussing sponsorship. Sponsors do not buy your project; they buy into what you believe in. So it's all about selling your emotions.

52. There are only two kinds of sponsorship: with and without television. If you can have your racecar shown on local or even national TV, it will also be easier to get sponsors. Invite a professional racing driver to drive your car. Not only will he or she share with you many observations about your racecar ergonomics and its on-track behaviour, but they might also attract the TV reporters.

53. Be realistic: you will not make a competitive Formula Student car with a budget of $10,000.

54. The best sponsors are not necessarily the ones giving you money. You will get more benefit from technical partners who give you material or parts free of charge; you might also be able to engage in fruitful engineering conversation with them, too.

55. Never say to a judge that you 'did not have the money'. The money is there. If you do not get it, it is because you do not know how to find it. Similarly, never say to a judge 'we did not have the time'. If you do, you are presenting yourself as a victim. Instead, say 'we did not take the time'. *You* are the one overseeing your project, deciding your goals and priorities within your means.

56. It's worth including in your upright and chassis design some adjustability in suspension pick up points. A difference of just a few millimetres of suspension pick up points coordinates can sometimes give you major performance increase. Of course, you won't have the possibility to test different suspension kinematics if your racecar is finished just a few weeks, let alone a few days, before the competition starts.

57. On any circuit, even street courses with a lot of braking and acceleration, a five per cent increase in

A five per cent lateral grip increase will give you three to five times the lap time gain of a five per cent increase in longitudinal grip

While sponsorship of any type is always welcome it's often the companies that supply parts and advice rather than cash that prove the most useful of backers

Of all the car set-up parameters the rear toe adjustment has by far the biggest influence on the racecar's control and stability

lateral grip will always give you three to five times the lap time gain given by a five per cent increase in longitudinal grip. That is why camber control in roll is more important than camber control in heave.

58. I have seen slow motion videos of in-lab tests of Formula Student cars (four- or seven-post rigs) where, at some frequencies, the wheel moves versus the chassis but the damper-spring unit doesn't! Indeed, in one case, I saw the edge of the rocker axis moving on a circle of about 12mm of diameter. Sometimes your compliance *is* the suspension. It's worth performing some FEA with frequency, as all good aircraft engineers will do.

59. I would expect a good team to show design judges each wheel toe and camber compliance (in deg/KN or deg/KNm) graph versus separate or combined inputs of tyre *Fx*, *Fy*, *Mx*, *My* and *Mz* in simulation and from workshop measurements. That implies building a simplified K&C test rig. Of course, such workshop measurements are not worth anything unless you explain how they helped you to validate (or not) your FEA simulation, to design this year's car (or will help you to design a better next year car), and how you included these numbers in your vehicle dynamics simulation.

60. Good drivers can feel the difference of a 0.1-degree of rear toe adjustment. That gives you an idea of the importance of the accuracy and the repeatability of the rear toe adjustment. In fact, within all the car set-up parameters, the rear toe adjustment (and compliance) has by far the biggest influence on the car's control and stability.

61. If a design judge with his hands on the front and rear part of your wheel simulates a self-alignment *Mz* torque and he can see or feel a toe angle variation your suspension has unacceptable toe compliance. Back to the drawing board. The *Mz* that even a strong human being will be able to produce is smaller than the *Mz* created by your tyre.

62. The two best ways to avoid toe compliance is to make sure you design your upright with a large distance between the toe link pick up points and the wheel centre while also having the toe link (or the steering arm) as perpendicular as possible to the chassis longitudinal axis.

63. The fishing string is simply not an accurate enough tool for measuring toe.

64. If you want to play aero, play aero. A good aero design judge will want to see your downforce, drag, side force, aero-balance, aerodynamic roll, pitch, and yaw moments numbers in 5D; front and rear ride height, yaw angle (with as much as

It's worth including some adjustability in suspension pick up points in both your upright and your chassis design. A difference of just a few millimetres can sometimes reward you with a major performance gain

Extreme aerodynamic packages are part and parcel of Formula Student competition. But you will need to ensure you have all the relevant figures at your fingertips if you want to impress a good aero design judge

CFD numbers are usually 20 per cent too good compared to reality

180-degree yaw angle when your racecar spins and goes backwards), steering angle, and roll angle. Of course, they will also want to see how you use an aeromap in your vehicle dynamics simulations.

65. Bear in mind that CFD numbers are usually 20 per cent too good compared to reality.

66. Do not even consider playing with CFD unless you simulate a moving floor and rotating wheels.

67. A few years ago, we were asked by a journalist to predict the lap time of a Formula 1 car on the Austin circuit before the first visit of F1 to the COTA (Circuit of the Americas) race track.

We were wrong by six tenths of a second, which in Formula 1 is a pretty big gap. But the reality was that two weeks before that first grand prix took place we did not know what the tarmac temperature was going to be and in which direction the wind would be blowing, and that's to name just two of the parameters that influence the lap time. There are too many parameters (the racecar, the driver, track, environmental conditions, etc.) to be spot on in your predictions. What is important is to evaluate the lap time *variation* (much more than the absolute value) versus the amount of fuel, or the front wing angle or the static rear ride height. We really need to work in delta, trends and sensitivities more than in absolute value.

68. If two numbers (for example, performance prediction from simulation and recorded test data) are not the same, at least one of them is wrong. It could be your simulation input or algorithm is wrong, or it could be your sensor is not properly calibrated, or it might be both. However, if two simulations give you the same results it doesn't necessarily mean they are correct. In any case, all simulations are wrong, but some are useful.

69. There is no useful measurement without another kind of number: the degree of uncertainty.

70. You cannot get realistic and useful anti-dive, anti-lift and anti-squat numbers unless you have a relevant tyre model, a good knowledge of your brake balance distribution and, in the case of combined lateral and longitudinal accelerations, a relevant differential model.

71. Any bodywork part (sidepods, engine cover, nose, panel to access the pedal box, etc.) should be able to be removed and then attached back on to the car in less than 30 seconds. If not, you need to go back to the drawing board. Similarly, any toe or camber or ride height adjustment should not take more than two minutes. If it takes longer, again, back to the drawing board.

72. Do not start to manufacture any car part or jig unless *all* drawings are complete. If you do so, you should be able to manufacture and assemble your car in six weeks with no surprises, and you will know the complete list of materials and parts to purchase.

73. Brake fluid is hygroscopic. The boiling temperature point goes down significantly with the humidity percentage. Flush and replace the brake fluid after a test or a race in the rain.

74. Brake fluid is incompressible, right? Then why is there a brake pedal stroke? Put a dial gauge right where the brake master cylinders are mounted on the chassis, or on the brake caliper. Push on your brake pedal and look at your dial gauge. You will get a good example of what compliance is here.

75. Performance is like a volume. That is, *Volume = Surface x Height*. But the surface here is your starting conditions: the size and experience of your Formula Student team, the strengths of your teacher, the software you have access to, etc. You cannot blame yourself for the things you have no influence on, such as the team state at the time you joined it. However, you can influence the height of the volume – and that is your input.

Next month: *Don't miss points 76 to 101.*

Competing in the wet is about more than simply considering the reduced grip – for instance, brake fluid is hygroscopic and so this needs to be flushed out and replaced after the racecar is taken out in the rain

Bodywork pieces such as sidepods and engine covers need to be removed and then replaced within 30 seconds. Similarly, any toe, camber or ride height adjustment should not take more than two minutes

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RLR Ligier gets the drag treatment

Our aero study of the Ligier JS P3 continues with wing tweaks

When RLR Motorsport team principal Nick Reynolds spelled out his main objective for our session with one of the team's Ligier LMP3s in the MIRA full-scale wind tunnel it was a surprise. We would not be chasing downforce and balance, as is often the case with these projects, but instead we would be looking for drag reductions and efficiency gains. The reasoning was straightforward, Reynolds explaining that track data showed that the Ligier had intrinsically greater drag than its Norma and Ginetta opposition. So the quest for our session was to find drag reductions while preserving or improving aerodynamic balance and efficiency.

Drag racer

The aerodynamic package allowed in LMP3 provides a few options for fine tuning. In last month's *Racecar* we looked at the effects of removing the rear body Gurney and then the rear wing Gurney (the latter change is only permitted at Le Mans), and also taping over some cooling inlets. The Gurney removals saw drag cumulatively reduced by over 13 per cent, with fairly significant forwards shifts in downforce balance, which were to be addressed in due course. Partly taping over the driver, brake and radiator cooling inlets had practically no effect on drag but did create a little more front-biased downforce. This month we will examine the effects of wing angle changes and also look at the impact the removal of the large front dive planes has on the racecar's drag and balance.

LMP3 mandates a 1600mm span, 300mm chord single element wing, fitted with a mandatory 25mm Gurney. Wing profile is free within the regulation bounding box, and the Ligier's wing was modestly cambered. Thus, if the car is to be aerodynamically balanced, the wing restrictions effectively limit an LMP3 car's total downforce. Nevertheless, we saw last month that removing the wing's Gurney reduced drag by just over five per cent and also moved the aerodynamic balance, expressed as %front, forwards by almost 3.5 per cent in absolute terms. So, what would be the effects of wing angle adjustments? The car arrived at the wind tunnel with the wing set at 10.5-degree, and its angle was adjusted by changing to different mounting plates, which permitted 12.5-degree, 13.5-degree and 14.5-degree angles to be set.

We have only been permitted to publish the percentage changes on the Ligier, so **Table 1** shows the incremental percentage changes to each parameter at each wing angle tested, relative to the adjacent angle.

Table 1: The effects of the wing angle adjustments

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
12.5deg	+1.6%	+0.9%	-1.9%	+2.6%	-1.0%	-0.6%
13.5deg	+1.3%	+1.0%	-0.2%	+1.8%	-0.5%	-0.3%
14.5deg	-0.2%	-0.5%	-0.2%	-0.5%	+0.1%	-0.4%
Max change	+2.9%	+2.0%	-2.3%	+4.5%	-1.5%	-1.2%

*Absolute rather than relative difference in percentage front.

The aim of the exercise is to reduce drag on the RLR Ligier LMP3 without impacting on the aero balance and performance

Wing angle is adjusted by fitting different brackets between swan neck plates and wing

Steeper wing angle. It was possible to shave drag from the car with wing adjustments


The racecar has dive planes to help front end downforce, but these often produce drag


Removing the dive planes reduced drag by over four per cent, with a nice balance shift

Table 2: The effects of removing the front dive planes

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
No DPs	-4.3%	-5.2%	-13.9%	+1.1%	-3.8%	-0.9%

*Absolute rather than relative difference in percentage front.

Table 3: The effects of rebalancing with the wing Gurney fitted

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
8.5deg+G	+0.4%	+0.8%	-1.4%	+1.9%	-0.7%	+0.3%
10.5deg+G	+2.2%	+1.6%	-1.2%	+3.3%	-1.0%	-0.5%
Total change	+2.7%	+2.4%	-2.5%	+5.2%	-1.8%	-0.2%

*Absolute rather than relative difference in percentage front.

Thus the 12.5-degree data are relative to the 10.5-degree data, and so on. The 'max change' row shows the overall maximum difference achieved to each parameter over the angle range from 10.5 to whichever angle yielded the peak parameter value.

Not surprisingly, modest angle changes to a relatively modest wing made commensurately modest changes to the aerodynamic parameters. Interestingly, the wing's maximum downforce angle appeared to be 13.5-degree with the Gurney fitted, so it's slightly mysterious that Ligier should have provided a steeper setting than this. But, the change to drag from the peak downforce wing angle to 10.5-degree was almost three per cent, while the change in aerodynamic balance over that range was a relatively minor 1.5 per cent shift in absolute %front terms. In short, adjusting the wing with its Gurney did not create any major shift in balance but it was possible to shave another three per cent off the drag.

Dive planes

Taking into account the rear deck Gurney removal and wing angle reductions, the car's %front value would have been heading north of 40 per cent, and in race trim the team was more used to running an aerodynamic set up that gave less than 35 per cent front because rear tyre degradation is apparently greater than front, so this helped prevent oversteer later in tyre stints. For qualifying, a more forwards balance would seemingly be considered, the drivers preferring a sharper front end in that scenario. So, what would the removal of the dive planes do to downforce balance and to drag? **Table 2** illustrates the percentage changes.

We have seen before that dive planes can be quite significant drag contributors as well as potent balance adjusters

As we have often seen in our wind tunnel sessions, dive planes can be quite significant drag contributors as well as potent balance adjusters. In this case removing the dive planes reduced drag by over four per cent. The significant loss of front downforce contributed to a fairly significant shift in downforce balance, actually producing a value in this particular configuration, which also featured no wing Gurney, of just under 37 per cent front. In fact this particular configuration produced the lowest drag value of the session, nearly 13 per cent lower than the starting configuration in fact, with arguably better balance, at least for qualifying. And efficiency, as determined by the –L/D figure, was some 3.5 per cent better than the starting value too.

Race trim balance

The above mentioned configuration featured no wing Gurney and as such could only be used at Le Mans, so it was important to try to attain a good race trim balance that could be used at race circuits other than Le Mans. Thus, the wing Gurney was refitted and wing angle was reduced to find, first, a roughly equivalent 'qualifying' balance and then a balance better suited to racing trim. Wing angles of 8.5-degree and 10.5-degree were successively tried, and the percentage changes relative to the racecar with the wing at 13.5-degree with no Gurney are shown in **Table 3**.

Refitting the wing Gurney to the wing with the overall angle at 8.5-degree produced figures quite close to those obtained with the wing at 13.5-degree with no Gurney, while increasing the wing angle to 10.5-degree saw slightly greater changes but still retained a low total drag level, and put the aerodynamic balance value to around 35 per cent front. This was still slightly heavier on the nose than our starting configuration but if the %front value needed to be reduced slightly further at least the response to wing angle adjustments was now known.

Next month we'll look at other ways in which aero set-up might be influenced.

Racecar's thanks to RLR Motorsport.

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In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

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Pressure relief

Thanks to a tiny new device, measuring aerodynamic pressures on and around cars may have just become a whole lot easier, and in some areas actually possible for the first time. *Racecar* investigates

By SIMON McBEATH

Photographs of pre-season and pre-race testing often show top race teams, especially in F1, measuring aerodynamic pressures around their cars. The most obvious manifestation of this is the pressure sensor array, like a two-dimensional rake with pressure sensors arranged over the area of the rake, positioned on the raceccar in key areas where what might be described as partial plane pressure plots can be logged and recorded.

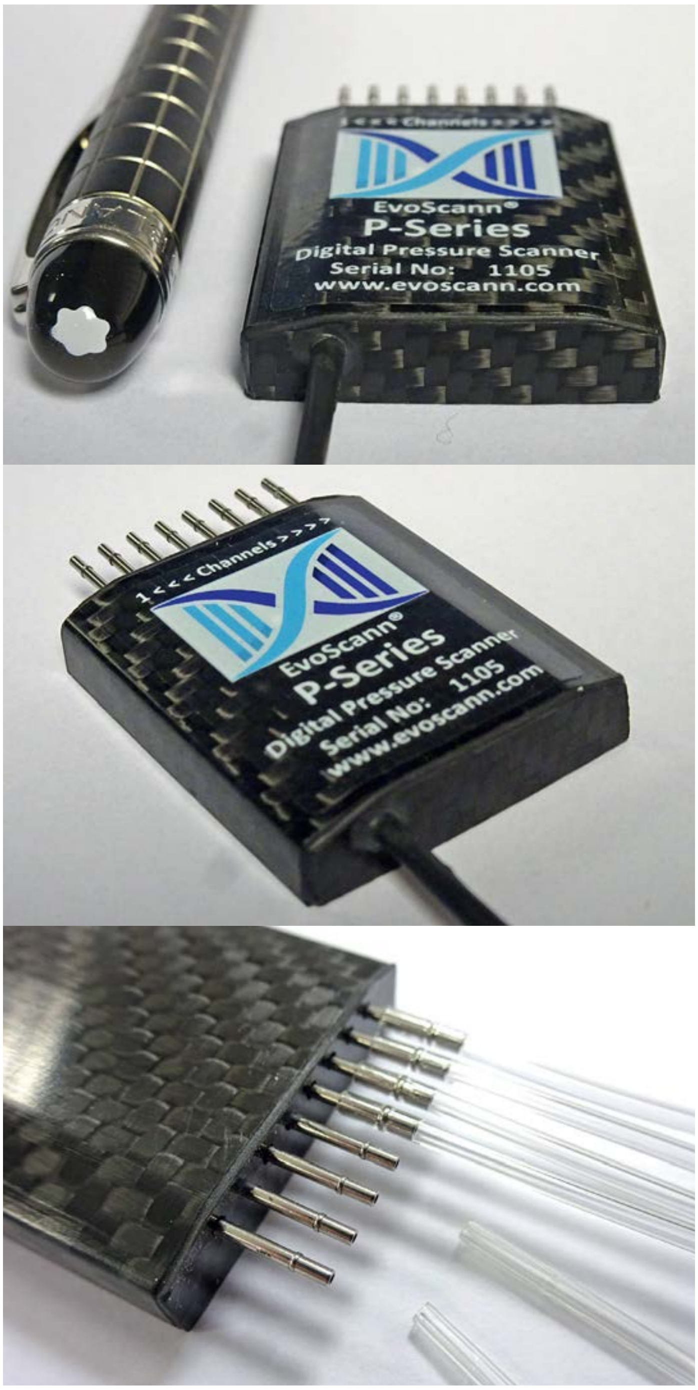
Less apparent and no less important is the measurement of surface pressures on the cars themselves, via tiny pressure port tappings over and under the major downforce-generating surfaces. Using these techniques enables aerodynamicists to gather pressure data around and on the car's surfaces that can be used to correlate with CFD and wind tunnel data, as well as to calculate the real forces acting on individual components.

Pressure measurement is an everyday critical part of wind tunnel testing too, with the wind tunnel models equipped with surface pressure ports, and measurements also being made around the wind tunnel as well, to accurately monitor and control flow conditions.

But how are these measurements made? And what are the practicalities? We visited Evolution Measurement Ltd (see sidebar, p77), based in Andover in southern England, to learn more about the challenges involved, and to see an ultra-compact new pressure sensor the company has come up with, that will open up exciting new possibilities.

Although Evolution Measurement is itself a new company, managing director Paul Crowhurst and export sales manager Iain Gordon have been involved in the distribution and calibration of pressure sensors for many years, and have worked closely with a concern that might accurately be described as the sector founder, Scanivalve (see sidebar p76) since 2001. With an intimate knowledge of the available products and, importantly, a firm grasp of the customers' needs, Evolution Measurement has come up with the EvoScann P Series pressure scanner which, they confidently assert, is the smallest, lightest such pressure sensor currently available – no surprise then that it has been generating interest among F1, DTM, LMP and

Renault RS18 with pressure sensor array. This is highly visible but there might also be small sensors measuring air pressures that are fitted to the car itself



The EvoScann P Series miniature pressure scanner is so small (36mm x 33m x 8mm) it can be located in areas of a racecar that have previously been impossible to access

MotoGP teams. This compactness – the 8-channel launch version is just 36mm (1.42in) x 33mm (1.30in) x 8mm (0.31in) and weighs only 16g (0.56oz) – will enable the sensors to be located in areas previously difficult or impossible to access, such as within front wing elements or other important small aerodynamic parts.

Pressure change

To see where and how this new compact pressure scanner fits into the overall scheme of things, let's first take a brief look at some of the complimentary products and their applications. Traditionally pressure sensor array and surface pressure measurement has often been done with one of the Scanivalve multi-port scanners such as the ZOC (Zero, Operate Calibrate) range of analogue devices in 32- or 64-channel form, and these measure 105mm (4.1in) x 36mm 1.4in) x 14mm (0.55in), finding use in wind tunnel models and other space-limited applications.

Another oft-used device is the popular DSA range, described by Crowhurst as 'a good workhorse' and by Scanivalve themselves as 'intended for most laboratory, educational or other controlled environments'. It is a 16-channel device typically used in wind tunnels where installation space is not an issue, overall length being around 200mm (8in).

The newest and most advanced Scanivalve product is the MPS (miniature pressure scanner) range, a 64-channel high-end device measuring roughly 89mm (3.52in) x 40mm (1.56in) x 22mm (0.87in), several of which might typically be seen on a wind tunnel model, and which is also used in on-car applications, too. 'It's a fantastic product,' says Crowhurst, 'and the

These enable aerodynamicists to gather pressure data around and on the car's surfaces

Scanivalve MPS 4264 pressure scanner, with pen for scale

Scanivalve DSA3217 pressure scanner

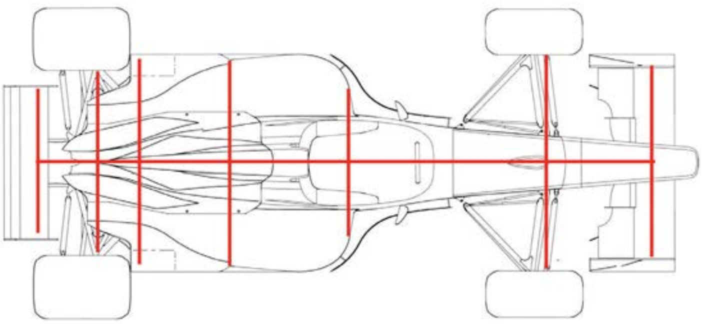
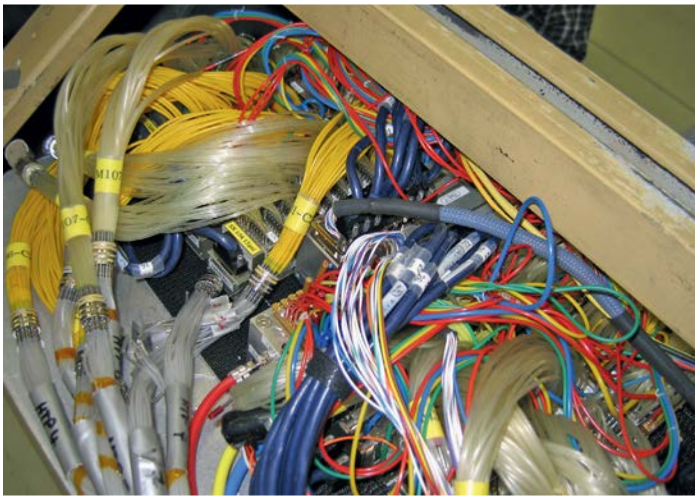


Figure 1: Schematic layout of tube runs in a conventional pressure scanning system



The schematic in Figure 1 might not look so complicated but in reality on a wind tunnel model (or a racecar) a conventional pressure scanning set-up can look more like this

Tubing lengths should be as short as possible to avoid frequency response issues

latest version is a big technical advance over its predecessor as well as being the most technically advanced, fully digital instrument available.'

Tube lengths

Among the criteria for obtaining accurate and repeatable pressure measurements is that tubing lengths should be as short as possible to avoid frequency response issues, and should ideally all be of equal length to maintain consistency between channels. The diagram in **Figure 1** generically illustrates this challenge. With tightly packaged racecars, available space for pressure scanners, associated hardware including power supplies and signal conditioners, not to mention bundles of tubing, is clearly at a premium, and options are severely limited within the chassis of a racecar and perhaps other areas within the body of a scale wind tunnel model. So getting reliable data from 'outposts' such as front wings, endplates and so forth has therefore inevitably been highly compromised by the long tubing runs that have been intrinsically required.

However, on the strength of feedback from customers, Evolution Measurements' concept for the EvoScann P Series was to reduce the size (and channel count) of the scanner so that they could be located much closer to where the pressure measurements needed to be taken. The concept of a 'distributed system', shown in **Figure 2**, was to switch from a small number of centrally located multi-channel scanners with complex tubing runs to more scanners with lower channel counts, and to locate the scanners around the car close to areas of interest.

This vastly reduces the length and complexity of the tubing runs and associated installation, with just a single cable emerging from each scanner to connect with data acquisition systems using the usual on-vehicle communication protocols (CANBus). The scanners pick up their power supply from the communication cable, and feature integral signal conditioning.

Small and light

Gordon says: 'Our Evoscann P series is certainly the smallest and lightest pressure scanner available and it can be fitted [to measure pressures] in places that were previously not measurable. It's been interesting that the door has been held open wherever we have introduced it, so it's clearly meeting an un-met need. We have presented it to the F1 teams and a few others outside F1 and many have either bought it or asked for customisations, or want to have it when we reach the next stages in our roadmap development.'

Gordon also revealed that EvoScann sensors were run on three cars in free practice at the last F1 race of 2017, and reported that 'feedback on accuracy, performance, sensitivity and noise insensitivity was great.'

The P8 launch model offers a choice of pressure ranges; at the low end of the scale +/-20kPa range is offered with an accuracy of 0.1per cent full scale claimed, providing +/-20Pa resolution. However, a number of developments are underway, Crowhurst says: 'The launch version was primarily aimed at absolute surface pressure measurements. But we will shortly be releasing a differential pressure version which will measure the difference between atmospheric pressure and the [local] surface pressures creating lift or downforce. This will have a choice of ranges from +/-7kPa upwards.'

With a similar accuracy to the launch model this would enable +/-7Pa resolution, which would be well able to resolve the small variations in surface pressures seen on many areas of racecars. However, Crowhurst added that 'sensitivity and resolution

Introducing the PR8, motorsports smallest 8 channel pressure scanner

FS-PR8 is the smallest 8 channel absolute pressure scanner available for motorsport

Its super light weight compact rugged design allows it to be mounted and used in harsh motorsport environments.

It has been designed to be used in wind tunnel model applications and has been temperature compensated so it can be used on a full size car.

This allows the same measurement technology to be used in concept and final design and enables the comparison of results without errors.

The PR8 has five user selectable sample rates up to 500 Hz and has a user configurable CAN ID system.

The user configurations can be changed using the PR8 app or it can be programmed over a CAN bus.

The PR8 also supplies a temperature output to monitor the environment it is in.

Pressure range is in engineering units from 200 to 1200 mbar via a 1 mb CAN output.

Many hours have been invested in the development of the PR8 super accurate temperature compensation in order achieve the best available accuracy over a wide temperature range giving 0.1% full scale over a 1200 mbar range up to 115C.

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www.firstsensors.co.uk karen.barnett@firstltd.co.uk will also improve, we will likely increase resolution by a factor of 10.' Further variants with more channels will also be available; a 16-channel version that fits the same dimensional envelope will come, and a 32-channel version that will only be slightly longer will follow that.

Embedded device

One of the advantages of this slim pressure scanner is that in some instances it can be inset into the surface of the device it is intended to measure. For example, one F1 client wanted to attach one to a bargeboard. The slender dimensions of the EvoScann would enable it to be embedded in the surface of the bargeboard itself and cause negligible interference with the flows and pressures it was there to measure.

Clearly, the small size of the device will enable it to be mounted inside many aerodynamic components to allow the collection and local conversion of pressure data into electronic signals to be communicated to the data acquisition system through just a single cable, rather than through many metres of delicate and vulnerable small bore plastic tubing. It is even feasible to fit the P Series scanner inside the small chord front wing flap elements on an F1 car. And in some instances wind tunnel teams have used additive manufacturing methods (3D printing) to provide not only a snug location for the pressure scanner within the test part but also to print the tubing runs that connect to the surface pressure tapping ports.

'We can even supply the EvoScann without its carbon composite casing, which reduces the thickness to just 4.5mm (0.18in) if the customer wanted an even more compact installation,' Gordon says. 'But if there really is an inaccessible location that is too tight even for the EvoScann P8 then it is possible to run the tubing through it and mount the sensor nearby where it can be accommodated.'

One F1 insider who is familiar with these new sensors says: 'The test teams are interested in mapping ever more areas of the car with these small sensors. Getting a feel for downforce, especially at low speed, is better done with pressure mapping than with the four [suspension] pushrod load cells. The pushrods have to measure car weight and take impacts, whereas pressure sensors can be scaled for the pressures they have to measure.'

A further interesting feature is that because the EvoScann P Series

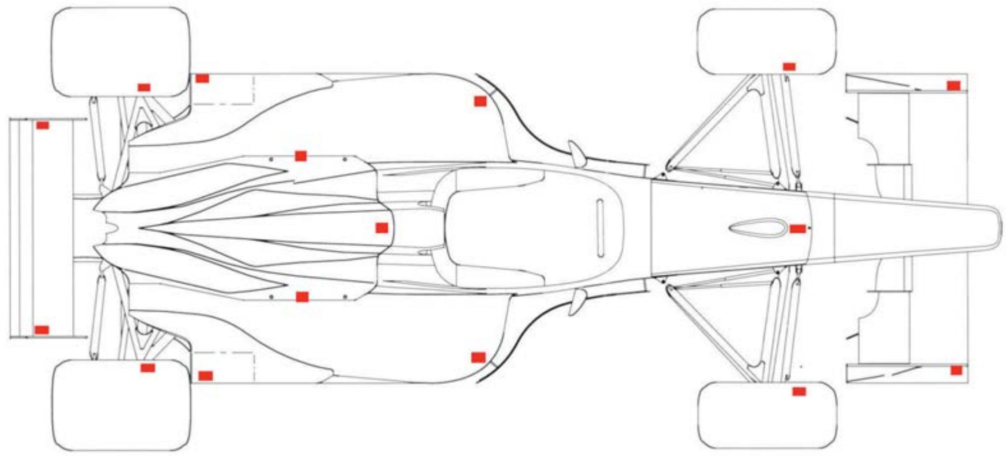


Figure 2: A distributed pressure sensor system vastly reduces the length and complexity of the tubing and installation. It puts local scanners at the point of measurement, with the tubing installation then connecting via a single CANBus cable to the nearest node

Its slender dimensions would enable it to be embedded in the surface of the bargeboard itself

Pressure scanners

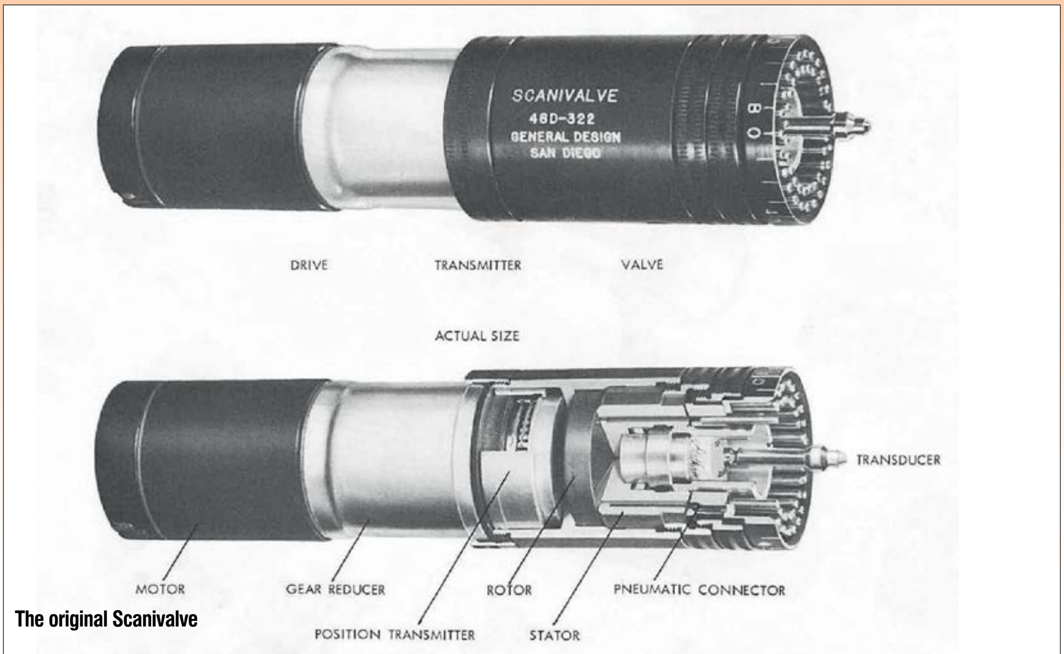
Simply put, a pressure scanner is a device that converts data from pressure tappings, for example over a car's surfaces or from a sensor array, into electrical signals that can be logged by a data acquisition system.

The concept was devised by one JC Pemberton, who worked at Boeing In Seattle, Washington, in the 1950s and was endeavouring to measure pressures over aircraft surfaces using lots of liquid-filled U-tube manometers.

Scanning valve

Not surprisingly it was incredibly difficult to zero and stabilise all these devices and to obtain synchronous data. So Pemberton invented and developed a motorised, mechanical scanning valve that multiplexed many pressure signals into one transducer. The device was called a scanning valve because, in essence, the motor drove the transducer to sequentially scan the 48 ports connected to the valve. It did this in about 90 seconds, which vastly improved the rate at which pressure data points could be obtained. Nobody else was doing this at the time and it became a huge advantage.

Pemberton subsequently left Boeing and founded Scanivalve Corporation in 1955, and the products were quickly adopted by the wind tunnel industry. The company developed a large line of products to support the use of the scanners, including connections, small bore tubing, steel tubulations and so forth. Subsequently the company had to adapt to – and exploit – some world-changing technological



The original Scanivalve

Figure 3: Screenshot of EvoScann GUI. Device has an onboard integral microprocessor so the output is in engineering units of pressure

devices have an onboard integral microprocessor, the output is directly in engineering units of pressure, as **Figure 3** illustrates. Here the pressure scale is in mbar but this is configurable via the GUI to the units of choice.

The design of the EvoScann incorporates temperature correction for each pressure channel. It can be configured to measure differential pressures by setting one channel to measure static pressure. And it corrects for ambient pressure too. 'It fits most known requirements' Gordon says. 'Our aim is to not only fit the niche applications where the standard device is most suited but also, where required, to customise for bespoke requirements. And, for example, the price per channel is comparable to the Scanivalve MPS scanner [mentioned earlier] so it's a good fit in terms of the applications it can satisfy.'

The carbon fibre outer casing, combined with the resin potting process enable a wide range of environmental conditions to be handled, although for applications that don't need it the outer casing can be omitted. The size of the internal printed circuit board is a key factor in the dimensions of the sensor; however there is the capability to reduce the size and thickness still further. The in-plane alignment of the output tubulations helps to maintain a compact installation. Scanning rates up to 1kHz per channel are possible, which Crowhurst says 'is typically faster than most people need'. Pressure ranges from +/-20kPa to +/-120kPa (200-1200mbar or 2.9-17.4psig) are currently available, with lower ranges set to become available.

Homologation

As this article was being written Evolution Measurement was notified that EvoScann had been homologated for use with the FIA standard ECU. This process included, among other things, being able to demonstrate that, as a microprocessor-equipped sensor, it was not possible to re-programme the device for 'alternative purposes', something it is demonstrably not possible to do with the single CANbus communication cable that provides the power to and data from the sensor. So prospective customers now have the added confidence that this compact, innovative new pressure sensor has FIA homologation for use on their racecars.

This also means that it will be permissible in FIA-sanctioned events to run the sensors during qualifying and in the races, and not just in test sessions or free practice. Before such a compact sensor was available, though, this probably wasn't even considered by the race teams.

advances. During the 1970s Scanivalve developed a combination of valving and calibration that was applied to miniature silicon sensors and used computer correction of temperature errors. And measurement of individual sensors was now multiplexed electronically, enabling much faster sampling rates.

An advert for the first Scanivalve device

In 1982 Pemberton sold the company to his sons Addison and Jim, and around this time PCs started landing on all our desks, so the company developed PC-based data acquisition systems which allowed ever faster data sampling rates.

Digital age

In the 1990s Ethernet-based communications boosted things, and in the early 2000s UBS connectivity speeded everything up further, and all the while miniaturisation was continuing. Originally signal outputs were analogue so the voltage signals required conditioning, but now everything is digital and processed to output in pressure units, and it is possible to take thousands of readings per second per channel from increasingly compact devices.

Such has been the impact of Scanivalve Corporation that it has become the Hoover of the pressure scanning industry, the generic name most folk reach for when a need arises.

Evolution Measurement

Evolution Measurement was founded in July 2016 and is located in Andover, Hampshire, UK. It is staffed by a team of engineers highly experienced in measurement, instrumentation and calibration. The team has actually been in its current premises, in a previous guise, since 2006 and is now fully focussed on the high-end fluid temperature and pressure measurement market. The relationship with Scanivalve in fact goes back to 2001, via the companies that the current staff used to work at.

Highly evolved

Evolution Measurement now handles northern Europe-wide factory-level calibration, repair and service support for Scanivalve while special relationships also exist with Guildline (as its exclusive UK distributor for precision measurement solutions) as well as with Meggitt (as its UK application-specific distributors for dynamic pressure sensors).

The company offers sales of the devices including spares supply, consultancy, support, installation, service, calibration, repair and bespoke solutions, as well as now designing and manufacturing its own new products.

Managing director Crowhurst says: 'we work in various sectors, niche areas especially where, as a small, responsive company we can provide turn-key solutions for multiple applications in building design, wind engineering, aircraft design, automotive, wind tunnel assessment and models, and of course in motorsport.' The latter includes MotoGP, from where interest is emerging in what is an increasingly aerodynamics savvy sport.

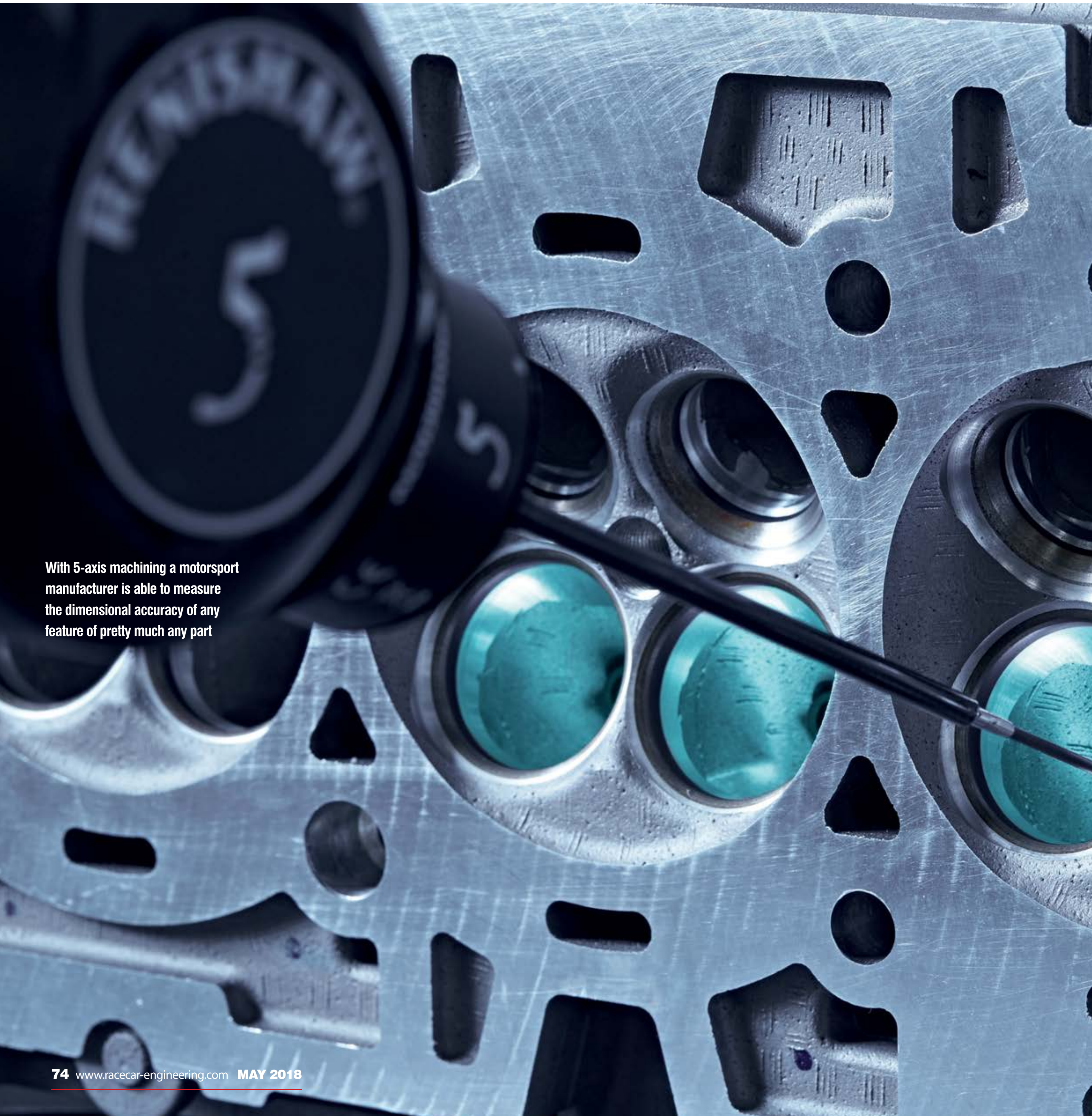
There are applications in cycling, too. And the company is also working on a package for Formula Student. Please form an orderly queue …

Contact: Evolution Measurement Ltd Tel +44 (0)1264 316470, web: www.evolutionmeasurement.com

For good measure

Micron-perfect dimensions are vital in motorsport and with recent developments the metrology industry is now achieving phenomenal levels of accuracy. *Racecar* spoke to those active in the sector to get the measure of this exciting technology

By GEMMA HATTON



With 5-axis machining a motorsport manufacturer is able to measure the dimensional accuracy of any feature of pretty much any part

In last month's issue we looked at the world of machining and discovered the growing importance of automation over human intervention. Fully autonomous manufacturing has now not only become a viable option but is possibly the best option for companies, and this is mainly due to the advances in coordinate measuring technology.

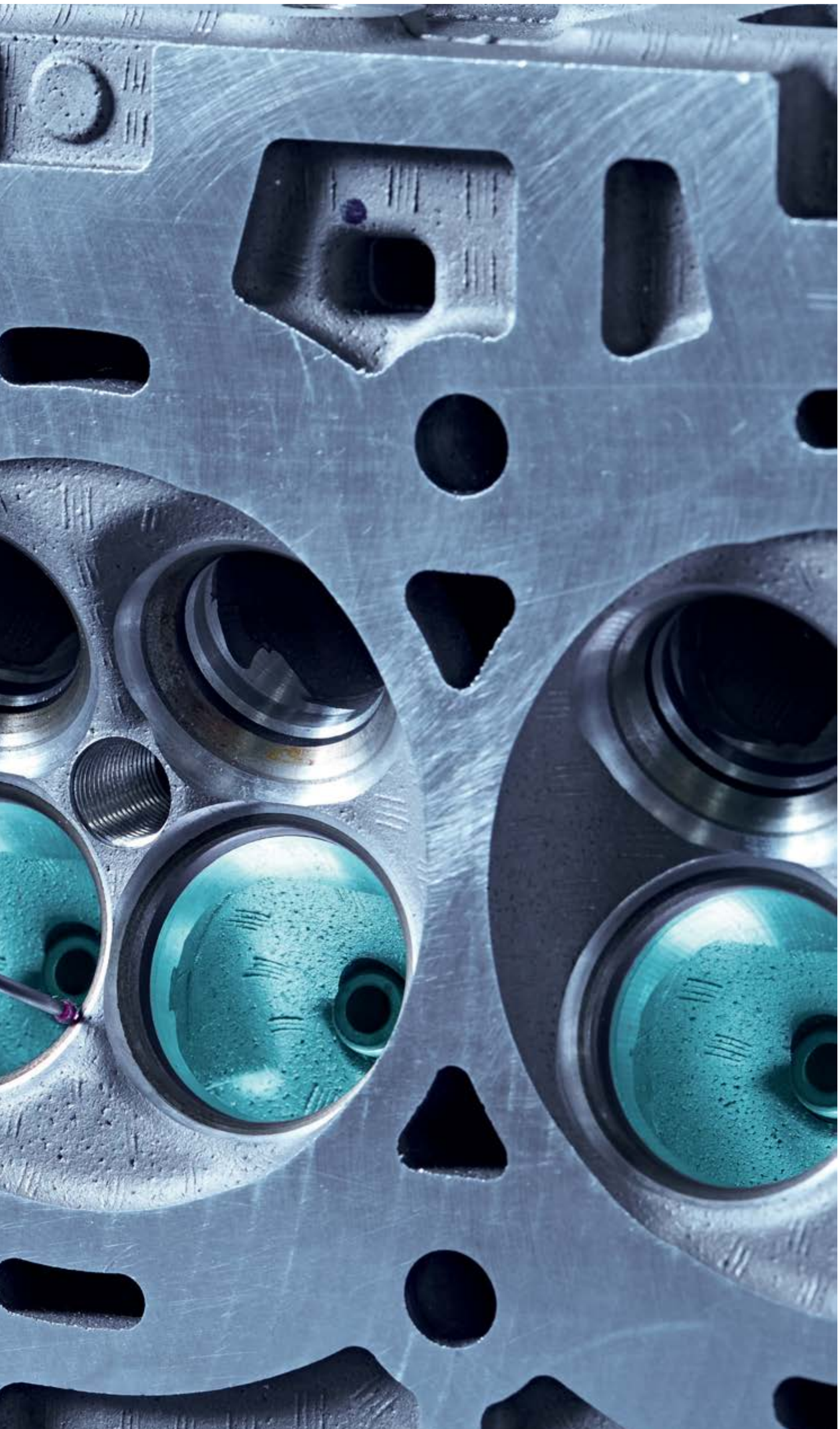
Coordinate measurement machines (CMM) inspect and measure the dimensional accuracy of parts. They become an integral stage in the manufacturing process. Capable of capturing 4000 data points per second, every feature, surface or shape can be measured to within microns to ensure a part is within tolerance.

CMMs are predominantly used as part of the quality control stage, once the part has been manufactured. Flexible fixturing strategies are used to secure the part to the bed of the CMM machine in a particular orientation. The machine automatically picks up the required probe and hovers a few microns above the bed, using air bearings to smoothly travel along the machine's *x*, *y* and *z* axes towards the part.

Software is used to conduct 'off surface motion planning' which is effectively where the algorithms determine the most efficient machine path from one measurement point to another without colliding with the part being measured, and this is calculated for all the axes. Thereafter, the probe follows this predetermined path and begins measuring.

There are several ways in which probes collect dimensional data with touch trigger and scanning the most commonly used methods. Touch trigger is essentially where discrete points are measured at pre-defined locations and when the stylus of the probe makes contact with the surface a trigger event is generated. Within the body of the probe there are three rods or rollers which each rest on two balls, providing six points of kinematic contact. A spring is used to hold the stylus assembly against these contacts and re-seats the probe after any deflection.

When the tip of the stylus has contacted the surface the consequent contact force is resisted by the reactive force of the spring arrangement in the probe's head. This deflects the stylus, which pivots about the kinematic contacts, resulting in one or two of the contacts moving apart. The deflection of the stylus and the resulting trigger event is then detected and the machine's position is latched electronically and the machine then moves away from the surface, allowing the stylus to reseat back into its original location to within one micron, before beginning the next measurement.

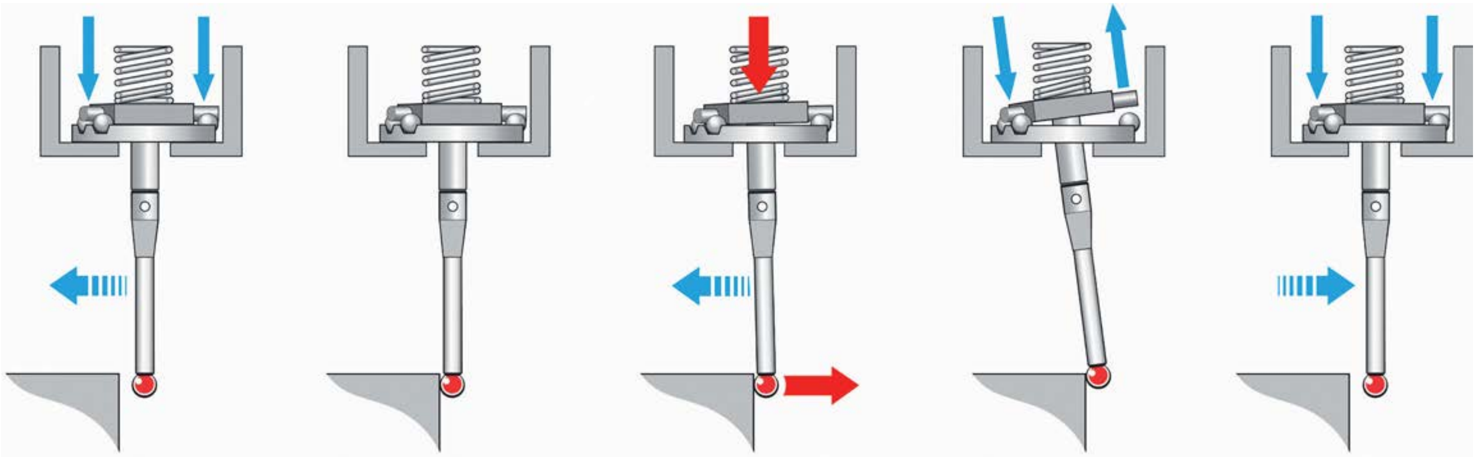


Trigger happy

'To generate a trigger, the trigger force needs to be overcome as the stylus touches the work-piece,' says Andy Holding, who is the marketing manager of CMM products at Renishaw. 'If I were to blow on the stylus, it would move to a certain extent, maybe nanometers, but that isn't a trigger. There can be vibrations and movement within the machine caused by accelerations and you want to minimise this to avoid any false triggering. The machine is a very lightweight structure, so you don't want to introduce any dynamic errors, which is why we use air bearings to ensure a smooth drive as it moves the probe around the part.'

To capture accurate profile and shape data, a large number of points need to be measured which would take too long for a touch trigger probe. This is where scanning probes come into play as they can quickly acquire a constant stream of data points as the stylus continuously

Coordinate measurement machines inspect and measure the dimensional accuracy of a part and have become an integral stage in the manufacturing process



As the stylus contacts the surface the spring, roller and ball mechanism within the head of the probe allows it to pivot, generating a trigger force which is then translated into data

travels over the part's surface. There are several different principles by which these scanning probes function. The REVO RSP2 scanning probe uses a process of 'tip sensing' where a beam of laser light is directed from its source in the probe body, down a hollow stylus holder to a reflector at the tip and transduces the lateral displacement of the tip. Unlike conventional stylus holders that need to be as stiff as possible, the REVO stylus holder is designed to bend. This deflects the return path of the laser beam, which is received by a position sensing detector (PSD) also mounted in the probe body. Movement of the laser spot on the PSD is translated into a measurement output by combining it with the head and probe geometry and each of the CMM axis scale outputs. Thus, the exact stylus tip position in space can be derived. This all takes place while the stylus tip is dynamically scanning the part as the head moves synchronously with the CMM. High speed sampling results in data capture rates of up to 4000 points per second.

Both touch trigger and scanning probes require a vast array of stylus shapes and sizes to allow use on every type of profile

Micron machines

Both touch trigger and scanning probes require a vast array of stylus shapes and sizes to allow use on every type of profile and feature. The stylus is the part of the system that makes contact with the component and consists of the stem and the styli tip. The most frequently used stylus is the straight styli which can have stems made from titanium, ceramic or carbon fibre. These come in a variety of lengths, up to 800mm long for some applications.

The optimum stylus ball can be made from ruby, ceramic or tungsten carbide, although ruby is the industry standard. Synthetic ruby is 99 per cent pure aluminium oxide which is grown into crystals at 2000degC and is one of the hardest known materials. Therefore, it is extremely resistant to wear and so maintains highly accurate measurements.

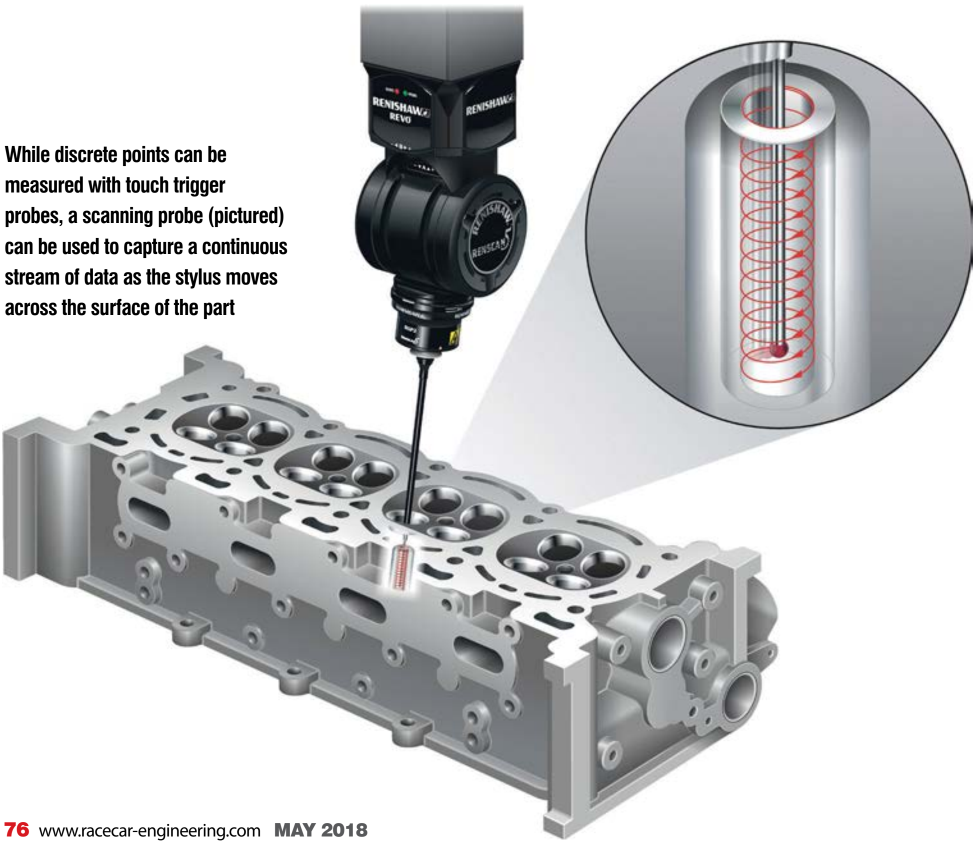
Also commonly used, particularly for indexing heads, is the multi-tip star styli, which allows holes to be measured and has the capability to contact features in many orientations, without the need to change the stylus. However, the most important aspect for the design of the stylus is to try and utilise the smallest styli with the shortest stem and fewest number of joints, to minimise mass and any consequent inertial errors.

Articulated heads

To carry out all the desired measurements of a part, the probe has to be able to move in different axes. Traditionally, CMMs have only had the capability to move in the *x*, *y* and *z* axes with the option of a rotary table. But recent innovations in articulating heads, such as the REVO technology developed by Renishaw, mean that they now also have the ability to move in two rotary axes, whilst measuring. This allows the CMM to conduct 5-axis motion around complex parts with the machine moving smoothly, at constant velocities where possible to minimise dynamic errors.

'In 3-axis CMMs the accelerations associated with moving the machine in discrete directions can cause inertial errors within the machine,' explains Holding. 'In 5-axis CMMs our controllers move the machine as little as possible while the head does as much of the work as possible. The head is lighter, so it can move more dynamically and minimise the machine distortion which can detract value from the data.

'Our REVO system achieves infinite position capability, which also means you can get away with far fewer styli and stylus combinations,' Holding adds. 'Normally, with a fixed head, you have to build many different stylus configurations which then require storage, but then when you change the part, you

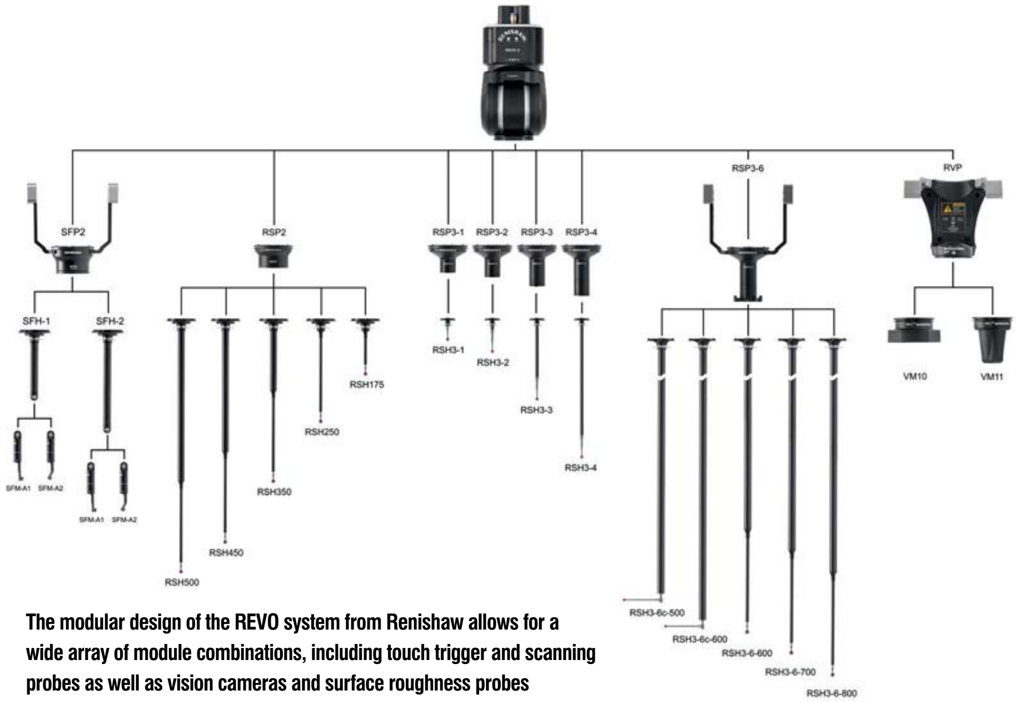


While discrete points can be measured with touch trigger probes, a scanning probe (pictured) can be used to capture a continuous stream of data as the stylus moves across the surface of the part

These 5-axis CMMs are allowing components such as engine blocks and cylinder heads to reach new levels of accuracy and certainty

The SFP2 consists of a two micron radius diamond tip which deflects vertically as it's dragged across the surface of the component, going across the grain of the machining, thereby generating the signal in a similar way to a record player

A 5-axis CMM using REVO. The CMM head automatically selects a stylus from the rack via magnets in the probe's head



The modular design of the REVO system from Renishaw allows for a wide array of module combinations, including touch trigger and scanning probes as well as vision cameras and surface roughness probes

may need even more different combinations, this can all be avoided with REVO.'

The key to REVO's success is the modular design which allows different probes and stylus' to be used all on one head. This is achieved through an arrangement of magnetic joints, which not only allows the machine to automatically pick up the required module (probe and stylus) when required, but also ensures that the module is seated in the correct position immediately, ready to measure.

Rough stuff

As well as its full array of touch trigger and scanning modules, another Renishaw system is the innovative SFP2, which is used for measuring surface roughness.

'We use a two micron radius diamond tip at the end of a stylus which is held in place by a spring loaded joint, isolating it from any machine movements,' says Holding. 'We apply the stylus to the surface at 90 degrees and the spring joint allows the stylus to move up and down as we drag it across the work-piece. Normally we do 10mm strokes, going across the grain or the direction of machining, in a similar way to a record player.'

This vertical motion is then translated into a roughness report via Renishaw's bespoke scale and read head system. Previously, surface roughness measurement was conducted manually with a hand held device that was placed on the surface, and a motor would drive the stylus across the work-piece. However, different operators can get different answers and the tools are extremely fragile. Some machine shops can spend tens of thousands of pounds on their surface roughness measurement capabilities alone.

Surface finish

'People often see surface roughness measurement as a black art, but really that's because it's mostly done in a very uncontrolled way,' Holding says. 'Our SFP2 system offers huge benefits. Take a conventional 3-axis CMM and a separate manual gauging station for surface finish monitoring. A particular part could take an hour and three quarters on the machine and 50 minutes on the gauging station, totalling two hours and 35 minutes. With REVO we reduce that down to one hour and 20 minutes because you can now completely remove the gauging station and use our SFP2 probe instead. This not only reduces the footprint and cost, but also risk, because every time you move a part you risk damaging it, whereas with REVO all the measuring is done in one place.'

5-axis CMMs, along with the advanced capabilities of Renishaw's REVO system, are

Measuring surface roughness has traditionally been seen as a black art but with Renishaw's SFP2 probe the roughness of a surface can now be measured in a controlled way, ensuring the smooth surfaces essential for engine components

There are many different stylus combinations to suit any application or component. The stems are often made from carbon fibre while tips are usually ruby balls, as this is one of the hardest materials. Ceramic or tungsten carbide tips are also used

Probes have now been incorporated into the machining environment so the accuracy of a part can be monitored while it's being made

allowing components such as engine blocks and cylinder heads to reach new levels of accuracy and certainty. The only issue is that CMMs are mostly used once the part has been made, so if there are any errors, production usually has to stop until the problem is solved. So why not integrate the technology from CMMs into other machines and make inspection an integral part of the manufacturing process? Good news – they have. Probes have now been incorporated into the machining environment so the dimensional accuracy of a part can now be monitored while it's being made.

In-process inspection

'From a machine standpoint, we absolutely love probes,' says Mark Terryberry, applications engineer at Haas CNC. 'We use probes for automatically setting up parts and tools and also for in-process inspection. When you use probes with machining, it creates an internal feedback loop throughout the process, rather than just a final inspection that is carried out offline. The machine can then make adjustments based on those in-process measurements.

'I help customers programme their machines and their first question is always about probing,' Terryberry adds. 'If a feature is made too small, they want the probe to quantify it, the tool to adjust automatically and rerun the part. If a feature is oversized, then they want to automatically machine a slave feature to ensure that an inaccurate part is never mistaken for a correct part when coming off the machine. All of this logic is programmed into the Haas control. Ten years ago in-process inspection was not very common, but now it's a necessity.'

Calibration probes

In addition to part set up and monitoring tool wear, probes are also critical for calibration. Last month we touched on how both machine tools and the working space are standardised with various calibration probes such as the Renishaw ballbar, but the probes themselves also need to be calibrated. 'We have developed a Visual Programming System (VPS) where with a few button presses we can not only automatically calibrate the probe, but also use the probe to automatically find the centre of rotation on our rotary devices,' explains Terryberry. 'Machining five sides of a part within one operation is becoming increasingly popular, but to do that you have to be able to find the centre of the part quickly. So we've written probing routines which just require a few answers to some questions, it's never been easier to probe.'

In addition to parts being inspected post manufacture, they can also be measured in-situ, immediately after manufacture has finished. One of the best ways of doing this is to use the Equator Gauge from Renishaw, which measures and compares the dimensions of a manufactured part against another known 'master' part. The Equator Gauge can be used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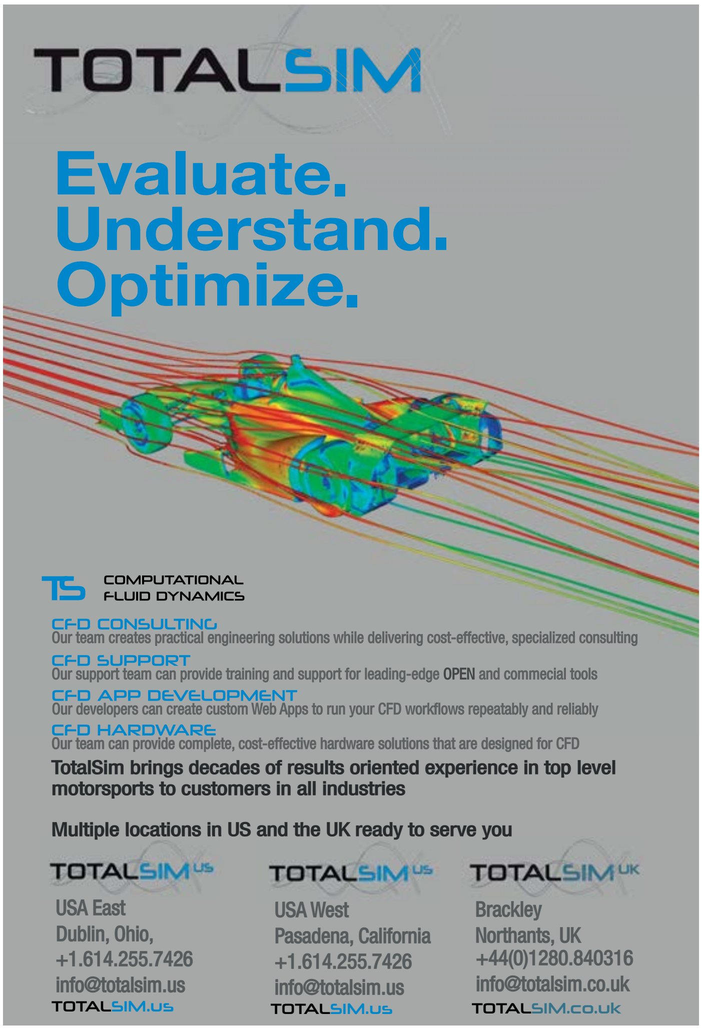
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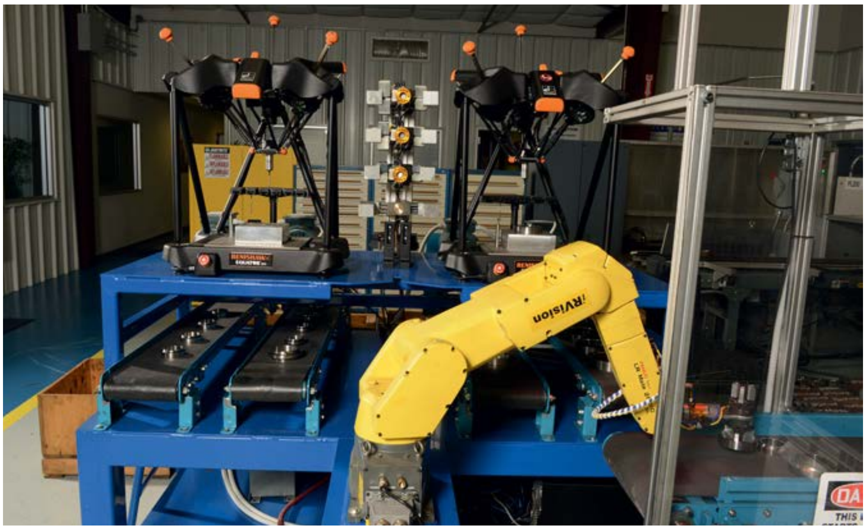
‘With a few button presses we can automatically calibrate the probe’

Vision probes can also be used on 5-axis coordinate measurement machines. These are non-contact, allowing the measurement of 0.5mm diameter holes, for example. A 1.3 mega-pixel global shutter CMOS sensor and digital signal processor are used and then the grey-scales of the images translate into spatial data

Coordinate curing

Manufacturing and motorsport are not the only industries that benefit from the positional accuracy of advanced coordinate measuring systems. The medical world actually utilises such technology to help with illnesses such as epilepsy and Parkinson’s.

Renishaw makes robots used for neuro-surgery which help to deliver probes and drugs to precise locations in the brain. MRI data is used to develop a 3D image of the human body and the software controls a robot which tells the surgeon the exact position in which they need to drill into the skull to get to the required part of the brain. The patient is often awake and told to sing nursery rhymes because the surgeon needs a response. If they stop singing then they know they have gone too far, and so they back out. This process can also be used when patients are undergoing a seizure, so the surgeon can see where the active part of the brain is to precisely deliver the drugs.



The Equator Gauge can be fully integrated into the manufacturing process and used to check parts as soon as they have been made. Robots move parts from the machine and automatically load them on to the Equator

as a standalone quick-check or can be fully integrated into a machining station. In the latter case, a robot picks up the finished part from the machine and secures it onto a platform, ready for the Equator to begin running through its measurement program. Therefore, not only has the part been machined automatically, whilst being inspected, but it is also checked in more detail by the Equator, completely autonomously without any human intervention.

Master parts

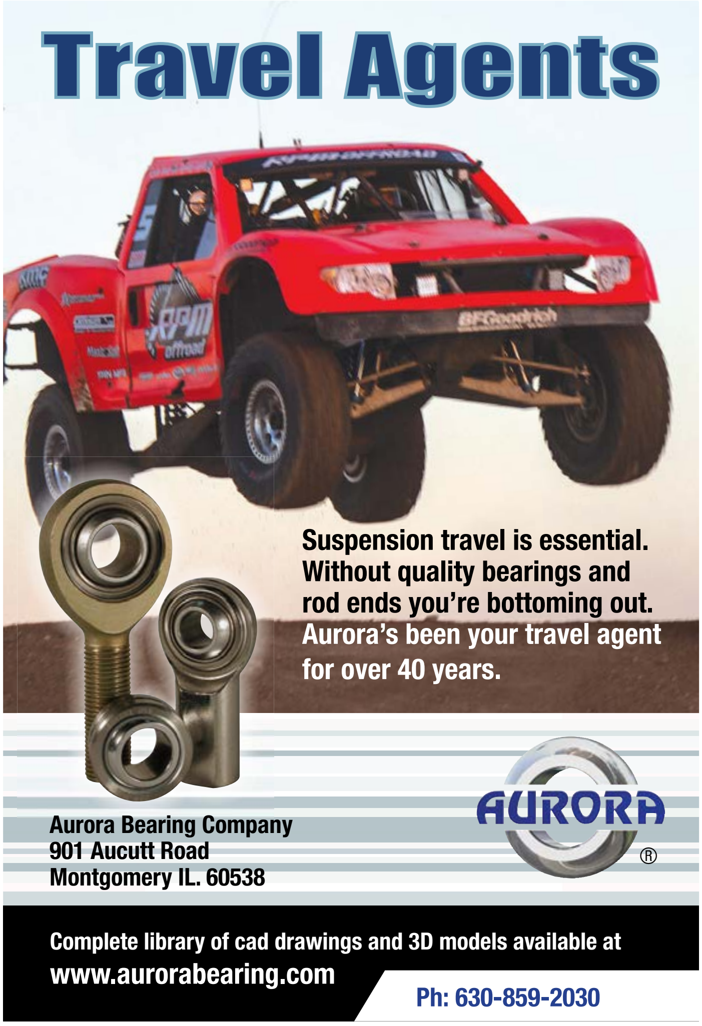
‘We supply machine shops all over the world,’ Holding says. ‘Which means they could be making parts in temperatures between 10 and 50degC. Comparing the produced part to a drawing that was nominally correct at 20degC is unrepresentative, because the dimensions will vary with temperature. Therefore, a master part is produced and inspected on a CMM first, before being situated in the same working environment as the machine tools. Any temperature fluctuations in the environment are removed by re-measuring the master part, which has been subject to the same effects of the environment, but is of known dimensions. This act of re-mastering the gauge re-zeros the system and can be conducted as infrequently as the daily factory temperature profile demands. Moreover, any residual errors in the measurement of the part can indicate tool wear or drift over time. These errors can be corrected through automatically sending tool offset feedback to the machine tool controller, based on an average of part measurements. Rather than measuring every feature, only the key features which relate to a particular cutting tool need to be measured. This ensures parts remain within tolerance and confidence in the process remaining consistent over time can be gained.’

In addition to probes measuring real 3D parts that have just been manufactured, probing technology can also be used to work backwards – reverse engineering parts for further machining. ‘We can use probes for adaptive machining,’ explains Alan Mucklow, managing director of UK Sales at Yamazaki Mazak. ‘Take the example of an aerofoil which requires some detailed machining. Although the aerofoil service will have some tolerance, it may not necessarily be fully defined. Adaptive machining can measure the surface with the probe, generate a solid model, create a bespoke programme and output that to the machine which can then conduct the cutting process. It’s a fully automated closed loop system.’

Measure by measure

The racing industry has fully embraced the capabilities of both autonomous machining and autonomous measurement. Although both have obvious benefits for mass production, the ability of 5-axis CMMs to measure any feature or surface, inside and out, at any angle or orientation, also brings huge advantages to complex motorsport components produced at lower volumes.

Witnessing the latest CMMs in action at Renishaw’s UK base is an incredible sight. These huge CMMs glide across the measurement area, release one probe and carefully select another, effortlessly gliding back to the part, where the head begins its controlled measurement dance, with the successful sound of a beep every time a measurement is taken. Walking from the noisy machine shop to the CMM lab, you could believe that you had gone deaf, because these machines operate in silence due to the low friction design of the machine drives. Add to that the isolation of movement between the overall machine and the probe head and you do feel like you have taken a wrong turn and accidentally ended up in the future. It’s very impressive, by any measure.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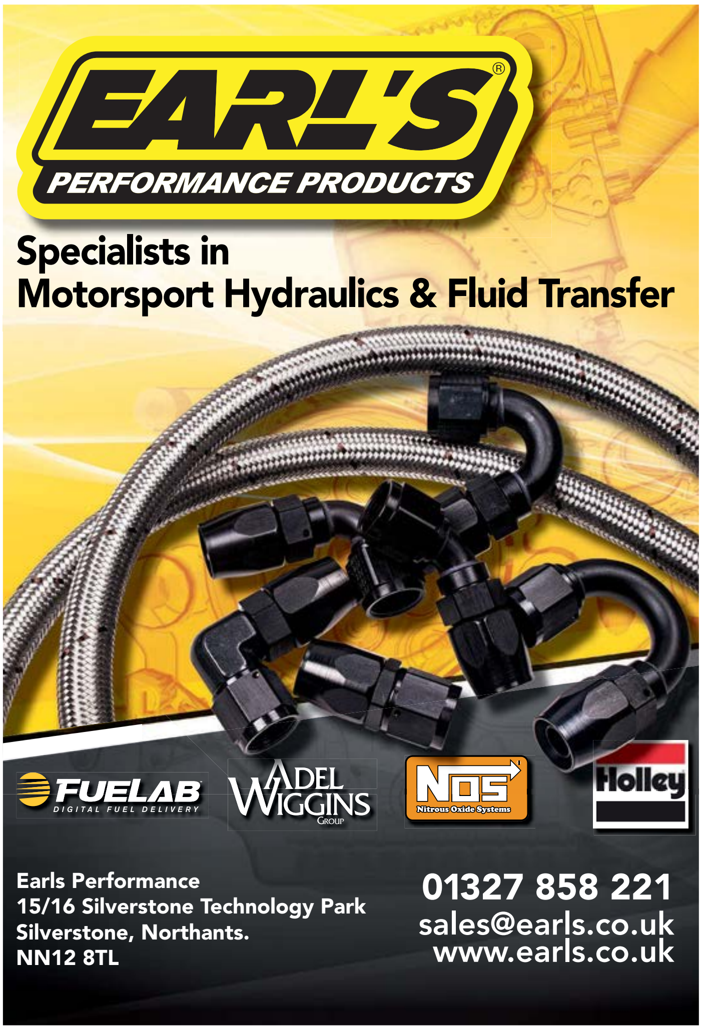
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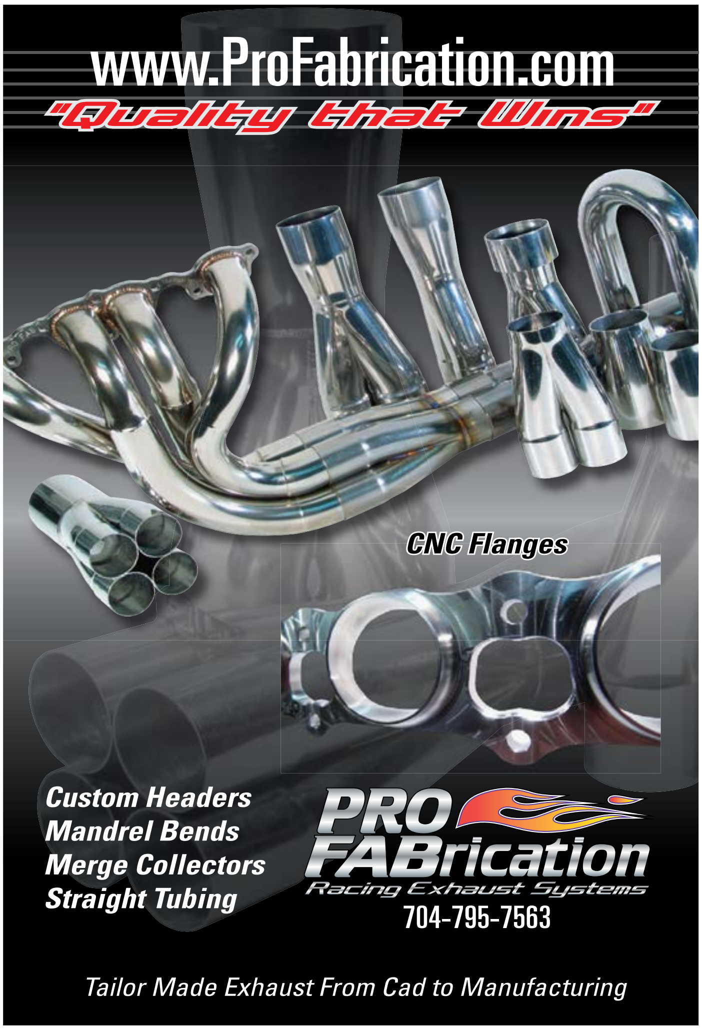
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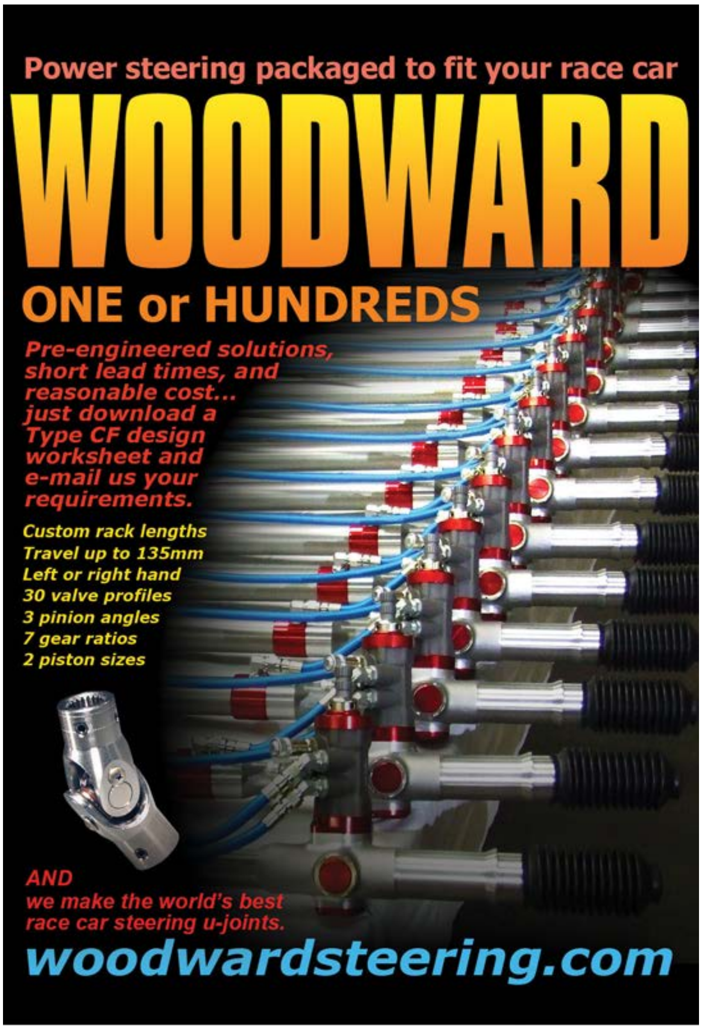
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Charging attack

Racecar's resident simulation expert crunches the numbers to find out if an electric-powered Lotus might make a decent Time Attack car

By DANNY NOWLAN

One of the last remaining bastions of technical innovation in this business is Time Attack. In most categories when an innovative technical solution is presented the first instinct of a regulatory body is to ban it. For all its foibles Time Attack, in particular World Time Attack Challenge, not only encourages technical innovation but embraces it with gusto. In that regard it's a positive breath of fresh air and God help our business if this is ever messed with.

However, there is one technology that has yet to appear on the Time Attack radar, and this is electric powertrains. This is particularly apparent in the World Time Attack Challenge event. A lot of this is due to the street drag racing/tuner origin of Time Attack. Another reason is that the technology has not been mature enough. But with the emergence of Formula E, the latter concern has been dealt with to a degree, so the question needs to asked; is an electric World Time Attack Challenge (WTAC) contender viable, and what might it look like?

Time lord

Firstly, this article will focus its attention on World Time Attack Challenge, which is held at Eastern Creek in Australia in October of each year. In particular, I will be focusing on the Open class category. For the last couple of years I have been engineering one of the front runners in this class and, not meaning to sound self serving, but I now might know a thing or two about these cars and what is required.

Before we begin this discussion we first need to decide whether an electric powertrain is legal. It's a legitimate question. In the Open class regulations, section 5.4 is most enlightening. It reads: 'Engine modifications are free save for the engine must be based on a production engine from a recognised vehicle manufacturer.'

Given that Tesla is a vehicle motor manufacturer and it's highly likely it is using a derivative of the Remy HVH 250 motor, we should be in the clear then. Where things could get a little dicey is with 'Each vehicle must use a commercial fuel, E85 or unleaded racing fuel in accordance with Schedule G of the CAMS Manual'. Technically, this could be used to ban an electric vehicle. However, what is obvious is that the use of an in-production electric motor

A lightweight car such as the Lotus Elise or Exige (pictured) could be an ideal base for an electric-powered World Time Attack Challenge assault

The first thing we will need to do is to run an internal combustion simulation of a Lotus Elise at the Eastern Creek track at 300kW, so we can size the battery pack we will need

is within the spirit of the regulations, so let's continue with the case study.

In order to have a frame of reference let's outline some parameters. Our base car will be a Lotus Elise or Exige. We are choosing this because it's lightweight and it gives us considerable weight margin to exploit. The other parameters are outlined in **Table 1**.

Current thinking

As discussed previously, the Remy HVH 250 motor is being used because of its wide availability. Also, while Tesla remains very tight lipped about this, given the peak power of a Tesla Model S rear-wheel-drive is 285kW you don't need to be a rocket scientist to figure out that it is either using a Remy motor or a close derivative of it. The mass of 870kg for the IC (Internal Combustion) Lotus was used to get us in the ballpark. I realise this is heavier than a stock Elise but I'm simulating a worst case scenario and so we are modelling a mass of 1000kg for the electric version. We'll discuss the significance of this later. Lastly, in order to be competitive in Open class you need to be running a CLA of about three. The CDA has been the appropriate level of drag that goes with this.

The first thing we need to do is to run an internal combustion simulation of a Lotus Elise at Eastern Creek at 300kW, so that we can size the battery pack we need. The lap time simulated was 84.7s. While this is highly optimistic we did this to provide a worst case scenario, to see how long you'll be on the power for. The breakdown of the lap is summarised in **Table 2**.

There is a slight discrepancy due to transient braking. However, this will get us in the ballpark. So our working voltage from Table 1 is 700V. Consequently, for the lap our current draw and Ah consumed will be **Equation 1**.

Note the 58.9s figure came from 48.9s at full throttle, and approximating the part throttle of 20s at 50 per cent. Let's suppose in regen we have a max harvest of 150kW, which brings us to **Equation 2**. Hence the total current used in the lap will be as shown in **Equation 3**.

For a flying lap we'll be using 5.9Ah of battery capacity then. What makes WTAC unique is that you get 15 minute sessions. So typically it's an out lap, a flyer and an in lap. As a rough rule of thumb, if on the in and out lap you are using 50 per cent battery capacity, each run will set you back 12Ah and you have to budget for at least two runs. So all in all you will need 24Ah of capacity. However, we don't want to run this down to zero so we will need a bit in reserve, too, say about 40 per cent. This will also cover us if we need to double stint on a session. So let's set the pack capacity to 38Ah.

On the Rampage

The next question that needs to be asked is what cells shall we use? When it comes to cells the C rating in both discharge and charge is king. Since we want to maximise our effectiveness we'll choose the Thunder Power Rampage cells. The cell specifications are shown in **Table 3**.

The attractiveness of the Rampage cell is its C rating in charge. With electric vehicles it's key to harvest all available brake energy. So in terms of what we need from the pack, let's say we have a working cell voltage of 3.5V and we need a capacity of 38Ah, then the pack configuration is given in **Equation 4**. Bottom line is, we need 200 cells in series, 10 cells in parallel.

To refine our choice of battery pack we then put the electrical vehicle parameters into ChassisSim. The resultant lap time was 85.9s and

Table 1: Parameters for an all electric WTAC vehicle

Parameter	Value/description
Car	Lotus Elise/Exige
Mass	870kg/IC, 1000kg electric
Engine	Remy HVH 250
Power	300kW at 8000rpm
Target Voltage	700V
CLA	3
CDA	1.2

Table 2: Parameters for the Lotus Elise lap at Eastern Creek

Lap Segment	Time
Full throttle	48.9s
Part throttle	20s
Full brakes	14.1s

Table 3: ThunderPower Rampage Cell specifications

Parameter	Value
Capacity	3.8Ah
Charge rating	12 C
Discharge rating	70 C
Cell mass	0.1kg
Cell dimensions	8mm x 22mm x 138mm
Price	USD $30

Equations

EQUATION 1

$$I_D = \frac{P}{V} = \frac{285\times10^3 W}{700V} = 407A$$

$$Ah_{DISC} = 407\cdot\frac{58.9}{3600} = 6.67Ah$$

EQUATION 2

$$I_C = \frac{P}{V} = \frac{150\times10^3 W}{700V} = 214A$$

$$Ah_{DISC} = 214\cdot\frac{14.1}{3600} = 0.84Ah$$

EQUATION 3

$$Ah_{TOT} = Ah_{DISC} - Ah_{TOT} = 5.9Ah$$

EQUATION 4

$$PackConfig = \frac{700V}{3.5V}S\times\frac{38Ah}{3.8Ah}P = 200S\times10P$$

An electric engine offers a completely flat torque curve *vs* RPM, consequently it can take off like the proverbial bat out of hell

Figure 1: Electric vehicle parameters

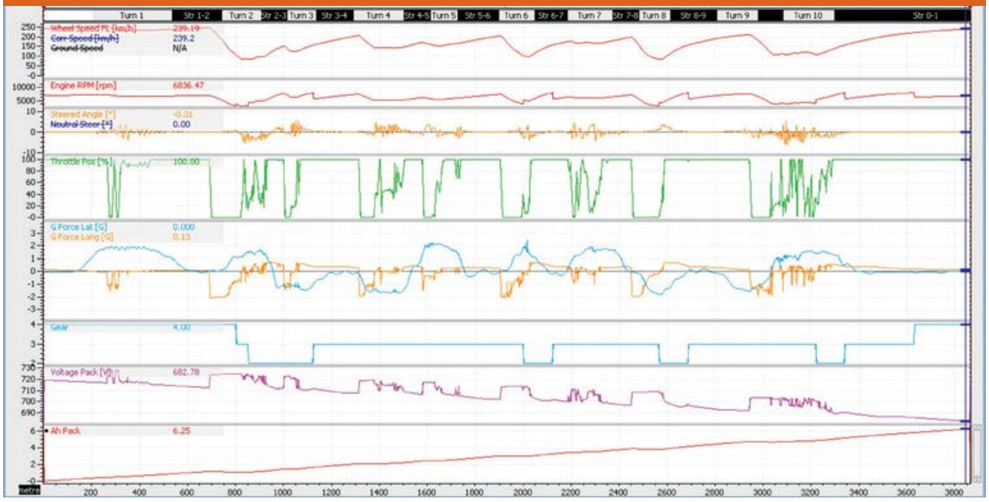


Table 4: Electric powertrain mass budget

Item	Total (kg)
Batteries plus protective casing	170 + 30 = 200
Remy motor	57kg
Electronic speed control	10kg
TOTAL	267kg

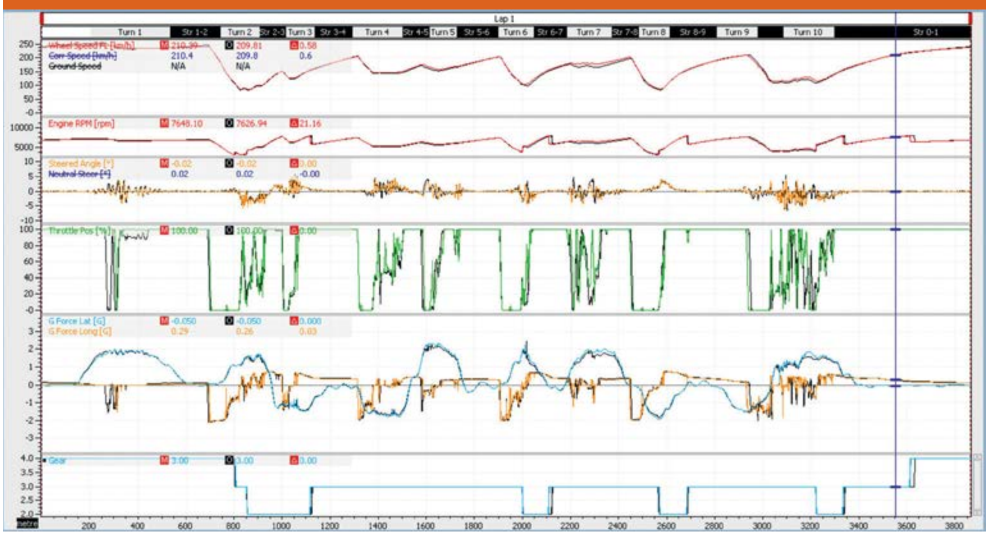
Table 5: Electric powertrain cost budget

Item	Total (US Dollars)
Batteries	1700 x 30 = $51,000
Remy motor	$10,000
Electronic speed control	$5000
Ancillaries	$5000
TOTAL	$71,000

Table 6: Lap time analysis ICE *vs* Electric

Item	Lap time
Internal combustion	84.72s
Electric	85.9s

Figure 2: A comparison of internal combustion car *vs* electric car



the relevant parameters are shown in **Figure 1**. Two interesting things came out of this analysis. Firstly, the discharge estimate of 5.9Ah was confirmed at 6.25Ah. Also, we could get away with a lower cell count in series. Final pack configuration was confirmed at 170S and 10P.

Mass distraction

Armed with all this information we can now do a mass budget for the electric powertrain. Firstly, for the mass budget we require 170 x 10 cells so 1700 cells in total, or 170kg of cells. The mass budget is outlined in **Table 4**.

Before you all baulk at this mass budget just remember, a Toyota 2ZZ-GE for an Elise weighs in at 120kg with liquid. By the time you put on an intercooler and turbo to get 285kW you would be looking at 135kg in total. By the time you fill it with fuel that is another 15kg. So the net weight penalty here is 110kg which, while not ideal, is certainly not a show stopper. Note I didn't take cooling into account because whether you are dealing with an IC engine or an electric engine you will need a radiator system anyway.

However, where you really pay for the electric engine is where it hurts; in money. The cost budget and final price for an electric powertrain is shown in **Table 5**. In contrast, a 4-cylinder internal combustion engine brought up to the 300kW power rating will set the end user back $24,000. Clearly, this is a significant cost deficit. However, this can be managed in both cost and end weight, but we'll discuss this shortly.

Head to head

So the next question that needs to be asked is which is quicker, the internal combustion engine or its electric equivalent? To resolve this question 135kg of weight was taken off the electric vehicle and they were run back to back in ChassisSim. I should also add that we were assuming a very small fuel load here. The results are shown in **Table 6** and the overlay is presented in **Figure 2**. Ultimately, where the electric engine lost to its internal combustion counterpart was in its increased weight, and this analysis is illustrated in **Figure 2**.

The internal combustion car is the coloured trace and the electric racecar is the black trace. As can be seen, the electric racecar very much pays for its weight in cornering speed, and this is all too obvious in the first trace which is speed, where the average difference is 4kmh. However, what is most interesting of all is that despite this handicap, down the straight the electric car is up 1 to 2 kmh. This is due to the flat torque you get from an electric powertrain.

There is no doubt that right now the advantage is with the internal combustion

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At 930kg the cornering disadvantages of the increased weight was offset by the superior traction that the electric powertrain offered

engine, but the electric engine would give a competitive showing – in 2017 the winning Open class time was a 1m27s lap, so the electric powertrain certainly wouldn't disgrace itself. However, as a straight bolt-in option the electric powertrain would struggle against an internal combustion equivalent. Yet there is a big *but* with this, which we will discuss shortly.

Positive points

There are a couple of key areas where an electric engine offers two big advantages. Firstly, an electric engine offers a completely flat torque curve *vs* RPM. Consequently it can take off like the proverbial bat out of hell.

Also, if you run an electric engine within its power and load specifications, and if you run a battery pack within its charge and discharge limits, they will last forever with zero maintenance. Since the World Time Attack Challenge is predominantly the domain of smaller teams this has ongoing cost saving implications, particularly so if the racecar is campaigned over a number of years.

One thing that hasn't been stated is the design optimisation that can be achieved through using an electric vehicle. One huge advantage that an electric engine brings to the party is its lack of vibration. Consequently, the structural safety factors that you need for an internal combustion engine aren't as critical for an electric powertrain.

We have much to learn from the radio controlled aircraft community here. Earlier this year Extreme Flight, a premier manufacturer of high performance aerobatic aircraft, released an all-electric 95in wingspan unlimited aerobatic aircraft. Since it was designed as an electric aircraft significant savings could be made on the empty weight (in the order of 1kg). Consequently, its all up flying weight is equivalent to its IC counterparts.

Also, continuing on this theme in relation with the Elise, there is a lot to be gained using the all-carbon Elise chassis designed by my UK Dealer Pilbeam Racing Designs. I don't just say this because Mike Pilbeam and I go way back. The structural and weight advantages offered by the Pilbeam Elise chassis speak for themselves, while at a cost of £25,000 it is also outstanding value for money. It may be, strictly speaking, against the letter of the law of the World Time Attack Challenge regulations, bit it is within the spirit of them. What the combination of the carbon chassis and electric powertrain would do is it might enable the WTAC competitor to effectively not have to worry about the chassis and powertrain, so they can focus on the aero and suspension elements of the car.

Tipping point

In terms of where the crossover point is between electric and internal combustion, on this analysis it was found the electric weight would need to be 930kg. Simulation analysis was run and at 930kg the cornering disadvantages of the increased weight was then offset by the superior traction the electric engine offered.

However, it's hard not to start playing Devil's advocate here. What this analysis has shown is that the Achilles' heel of an electric powertrain is its cost and energy density. Even though time attack is a sprint event, we still need a battery pack that weighs 200kg. Not to acknowledge this would be foolish. Ditto with the cost of the pack. However, we are using the Rolls Royce of lithium polymer cells, so this really is a worst case scenario. The other unknown is how CAMS (the Confederation of Australian Motorsport), the Australian division of the FIA, will react. This is an important aspect as it could affect the car's ability to get through scrutineering.

Circuit racer

The other thing we need to cover is what an electric powertrain needs. First things first, a true crunch point is the radiator design for the battery pack. The radiator to a battery pack is the IC equivalent of having a good coolant system for the engine. Also, if you want to charge the car battery pack at a 1 C charge so it can be charged in an hour you're going to need a power source that can handle 27kW. This is the equivalent of having 10 power-points in series with one another. That could present a very serious problem when you get to the race track.

Another thing that needs to be discussed is whether electric power is suitable for the Pro-Am and Pro classes. The answer is no. The Pro-Am and Pro classes run downforce levels well in excess of DTM cars. That is CLA numbers well in excess of seven. Consequently, the drag goes up and we are talking peak CDA in the order of at least 1.6. Which means these cars need to produce engine power of at least 500kW plus. In this case the pack capacity doubles (since you need two motors) and you are talking about a battery pack weight of 400kg. There's no way you are going to make up for a weight deficit of 250 to 300kg. Also, due to its wheelbase the Elise platform would be hard-pressed to make those aero numbers anyway, so it's a moot point.

Electric dream?

In closing, not only is an electric powertrain viable for WTAC it can also be competitive in the Open class. This analysis showed that combined with a Lotus Elise chassis, an electric powertrain offers key advantages in maintenance and packaging. In particular, large gains can be made by capitalising on the advantages that can be presented by designing around an exclusive electric powertrain. But there are risks and not to acknowledge these would be foolish. In particular, energy density for an electric powertrain is still marginal. This is the reason it is not suitable for the Pro-Am and Pro classes. Also, charging the battery pack is something that could be a problem and the reaction of event officials is an unknown. But it will be interesting to see what happens when someone tries this. Probably a matter of *when* and not *if*.

Danny Nowlan (right) has had success with conventional WTAC cars; in 2016 he helped to sort this third-place finishing Evo 6


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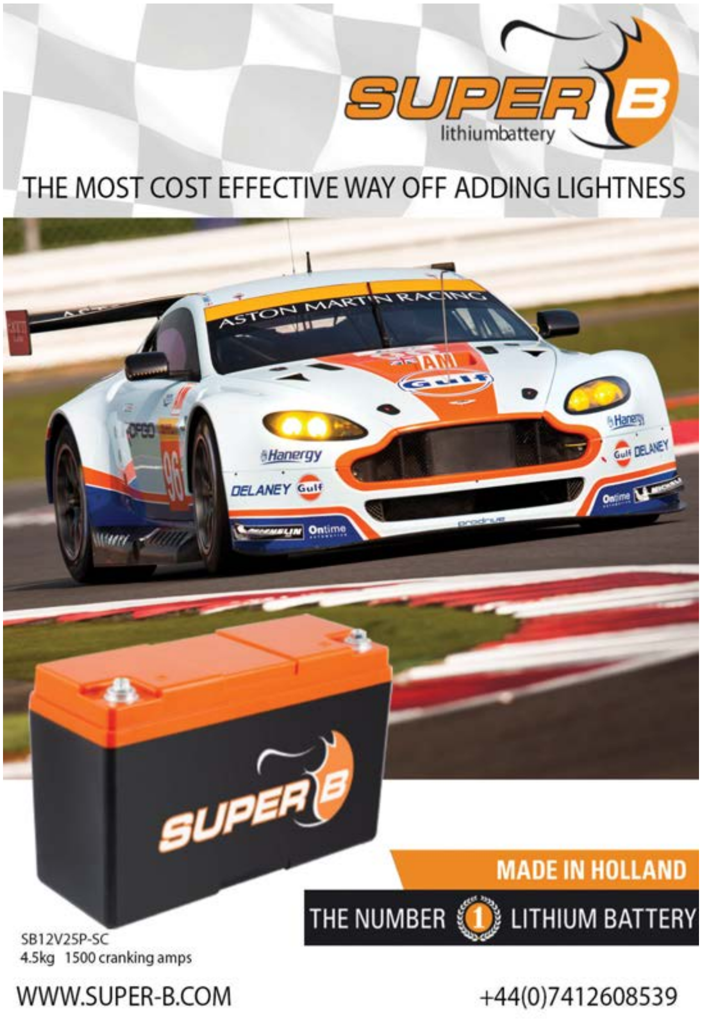
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Interview – John Doonan

Zoom with a view

Mazda's US motorsport boss tells us how grassroots racing helps the company to bankroll its high profile DPi programme

By MIKE BRESLIN

'Whereas in most companies the motorsport money is flowing out the door, we have a solid model that our executives have supported for years'

Go to an SCCA meeting in the US and you will be almost guaranteed to find examples of one make of car: Mazda. The product of the Japanese manufacturer makes up 55 per cent of all SCCA entries, John Doonan, director of Mazda Motorsports in North America, tells us. And that's great news for Mazda, because it's due to this saturation of the grassroots of American road racing that it can afford its pinnacle motorsport campaign in IMSA DPi, as well as its well-known driver development programmes.

'It really all started with the grassroots,' Doonan says. 'We have built a foundation of customer support programmes; allowing them to buy racing parts, and stock parts, directly from us in the motorsports division; being able to offer that, and also being able to offer a technical support hotline, where they can call any time for troubleshooting, and then offering a massive contingency programme for grassroots such that when they have success they earn prize money directly from Mazda. It's those three things, all about the customer, that have allowed us to grow that footprint such that there is a revenue and profit model that sustains the programme.

'Whereas in most companies the motorsport expense is money that's flowing out the door, we have a solid model that our executives have been very supportive of for years,' Doonan adds. 'Because there's profit in that it allows us to do things like the DPi programme in IMSA, our driver development programme with Mazda Road to Indy, and Mazda Road to 24, too. So it's really given us a footprint that we're very proud of.'

Five star

And it's one model in particular that's really driven this upsurge in Mazda's presence in US grassroots motorsport. 'The advent of the Miata [MX-5] definitely changed the concept of an affordable sportscar on the street. Because it was such a well-engineered street car it made the ideal racecar from a balance perspective, horsepower to weight, performance, handling, and braking,' says Doonan, a club motorsport competitor himself when he gets weekends off, racing a Crossle 32F Formula Ford 1600. 'With the Miata we offered a kit to take it from street version to race version, and we've sold about 3000 of those kits. And then, for the first time, we offered the Global MX5 Cup car, and we've sold just over 170 of those, since October 2016. The MX-5 has definitely changed the face of the sport.'

And while it's changed the face of the sport, the face of the MX-5 is also clear on Mazda's DPi offering, the RT24-P, and it was actually this link to its road car styling that sold IMSA's new sports prototype rules to Mazda. 'That's 100 per cent so. We could not be more grateful to IMSA for coming up with this concept. Because in prototype racing it's certainly difficult to make a consumer connection, but when they allowed our designers to come up with what is essentially the same design language – we call ours Kodo – they embraced it; it was almost like asking a little boy or a little girl to design a rocket to go to the moon. I had people saying your car's never going to work, prototype racing is all about these blunt angles and downforce. Candidly, the way our designers worked with Multimatic [the builder of the car], we have a car that's in the aerodynamic window; I'm obviously a little biased but it's taken IMSA's strategy probably the farthest from a standpoint of design.'

For 2018 Mazda has hooked up with sportscar super-squad Joest and expectations are high, and from the off Doonan saw something different in the way the former Audi LMP1-running team went about its business. 'First of all it's the people, they have never shied away from hiring the best in the business. And then it comes down to process; I think that was evident to me from the first test we did together at Hockenheim; it's just an extremely productive use of time when you're at the race track and trying to maximise every aspect of the programme.'

Le Mans return?

At the time of writing the car has yet to win, but Mazda has a good pedigree in sports prototypes and in 1991 it did something no other Japanese manufacturer has managed to do: it won Le Mans. So could there be a chance Mazda might return, at some point? 'Essentially the rules don't allow us to participate there at the moment. I hope the ACO and the FIA come around on that, because I think it [IMSA's approach] is an extremely affordable way to have prototype racing, have fan engagement, have brand engagement. I do hope, but right now our focus is one thousand per cent on the North American programme, but in the back of our minds, yes, Mazda's a global brand, Le Mans is a global stage, so if it comes around, great, but we're focussed on trying to win races here in the US.'

Since October 2016 Mazda has sold 170 of its Global MX-5 racecars. This is just part of a business-driven grassroots racing programme which enables it to justify higher profile projects

Another great race that is now hard-wired into Mazda's DNA is the Indianapolis 500. But not for this company an IndyCar involvement as a manufacturer, like Honda and Chevrolet. Its presence is a bit more subtle than that. The Mazda Road to Indy initiative involves cash scholarships to get worthy drivers racing and progressing, and then there's the three Mazda-backed formulae on the ladder to IndyCar (US F2000, Pro Mazda and Indy Lights).

'Much like the grassroots programme we sell engines to all three series, so there's a business model behind it, with income and revenue, and the scholarships then enable us to give drivers an opportunity that they may never otherwise have,' Doonan says. 'It's the most clear cut path to the top, and outside of just training them to win races we've tried to provide the drivers with PR training, fitness and nutrition training, business of motorsports training, and engineering training.'

Indy final analysis

The thing about ladders, though, is that they reach upwards. So, have there been conversations about an actual involvement in IndyCar? 'I think the costs of entry are pretty tough for us, we're still a small company, so unfortunately I don't see us playing at that level. But someone did ask me, when are we going to participate in the Indy 500? I said, basically we already are; there are 25 drivers that have come through our programme, and we stand there very proud on the Friday of the Indy 500 weekend with the Indy Lights race, the Freedom 100, knowing that on Sunday afternoon when the 500 rolls off, 25 of those guys and girls at some point have been through our programmes. So we're pretty excited about that and we're going to focus on the sportscar programme while we'll keep doing what we can to develop the next generation of champions.'

In the final analysis, that's the thing about Mazda; sportscars. 'We've always been a sportscar company. We said it in our old ad' campaigns, "always the soul of a sportscar", and I think that element is exactly correct. We've been a participatory brand, we want our customers out racing, and then we use the [DPi] programme as the ultimate expression of our brand.'

With the Global MX-5 racecar now being launched into new one-make series all over the world chances are that Mazda will sell a heap of them. Who knows, it might even sell enough to fund another shot at Le Mans, just as it funds DPi in the US on the back of its grassroots racing. Now that would be the ultimate expression of its sportscar brand.

RACE MOVES

XPB

Red Bull has promoted **Pierre Wache** to the newly created position of technical director. Wache joined the team from Sauber in 2013 and previously held the role of chief engineer, performance. The new job title reflects the fact that chief technical officer **Adrian Newey**, while still very much involved in the F1 operation, is also spending time on the Aston Martin Valkyrie project, Red Bull tells us.

Monisha Kaltenborn, the former team principal of the Sauber Formula 1 team, has now set up a Formula 4 outfit which will compete in both the German and the Italian F4 championships. The team is called KDC and it will be based in Granollers in Spain. It is co-owned by Kaltenborn and French-Monegasque businesswoman **Emily di Comberti**.

Former Ferrari F1 chief designer **Nikolas Tombazis**, who was more recently the chief aerodynamicist at Manor, has joined the FIA as its single seater director, with responsibilities for Formula 1, 2 and 3. Tombazis will work with F1 race director **Charlie Whiting** and will report to FIA technical director **Gilles Simon**.

Former McLaren head of aerodynamics and chief engineer **Doug McKiernan** is now to work as chief engineer in a 'project-focused position' at rival Formula 1 operation Williams. He will report to chief technical officer **Paddy Lowe**, who he previously worked with at McLaren. McKiernan joined McLaren in 1999 from BAE Systems, where he had specialised in aircraft wing design. He left the Woking team in 2015.

IMSA has appointed experienced race official **John Maesky** as race director for the 2018 season for both the Porsche GT3 Cup Challenge USA by Yokohama and the Ultra 94 Porsche GT3 Cup Challenge Canada by Yokohama.

Also at IMSA (see above) **Todd Snyder**, who currently serves as race director for the Lamborghini Super Trofeo and the Ferrari Challenge in the US, will add the role of IMSA Prototype Challenge Presented by Mazda race director to his responsibilities for the 2018 season.

Neil Mallard, who played a part in the founding of FOCA TV alongside **Bernie Ecclestone** and was considered a pioneer of modern Formula 1 television coverage, has died at the age of 86. Mallard was known for his ability to solve complex logistical problems.

Legendary Swiss touring car team boss **Rudi Eggenberger** has died at the age of 79. His team, Eggenberger Motorsport, was especially successful in the 1980s, when its BMWs, Volvos and most memorably its Texaco-backed black Ford Sierra Cosworth RS500s, achieved great success in what was then called the European Touring Car Championship.

Former Australian Supercars driver **Cameron McConville** has been appointed race director for the all-new SuperUtes Series, a Supercars supporting act that features pickup trucks. He already has experience in race control, having been the Supercars driving standards adviser in 2013.

The Williams F1 drivers will have two race engineers each for this season. **James Urwin** will continue to work with **Lance Stroll**, but will share duties with **Luca Baldisserri**, who filled in for the final four races of 2017 while Urwin was on paternity leave. Meanwhile, **Andrew Murdoch**, who worked with **Felipe Massa** last season, will team up with **Paul Williams**, who was previously a senior track-side aerodynamicist, to engineer Sergey Sirotkin.

Sean Seamer, the new CEO for the Australian Supercars series, started working for the championship at its season opening Adelaide 500. Seamer joins Supercars from MediaCom. He replaces **James Warburton**, who stepped down at the end of 2017.

Formula 1 has commissioned leading Hollywood composer **Brian Tyler** to write an official theme tune for the championship. Tyler's written scores for a number of blockbusters, including *Rambo* and five of the films from the *Fast and the Furious* franchise.

Hyundai appoints Scott Noh as new head of motorsport

Hyundai Motorsport has announced a change to its senior management with Scott Noh now taking on the role of president.

The Korean replaces Gyoo-Heon Choi, who has headed Hyundai Motorsport since its inception five years ago. Choi has returned to Hyundai Motor in Korea to take up a position within the newly established High Performance Vehicle and Motorsport Division. This new department, which will be headed by Thomas Schemera, will be responsible for 'maximising synergies between headquarters and Hyundai Motorsport, to further develop the high performance vehicle business'.

As president of Hyundai Motorsport Noh will be in charge of all areas including its participation in the WRC, its driver development programme (HMDP), as well as its increasing customer racing activities with R5 in rallying and TCR.

Scott Noh has worked for Hyundai for 25 years and is now its motorsport boss

Noh said: 'It is with great pride that I take on the role of president at Hyundai Motorsport following the strong foundations laid by my predecessor over the past five years. Motorsport plays an important role within Hyundai. It helps to change the public perception of our brand internationally, while also enhancing engineering skills, which is of crucial importance in our mission to create high performance vehicles.'

Noh has worked for Hyundai for 25 years, firstly in Korea, before moving to the USA in 1999, where he spent five years in a sales and marketing co-ordinator role. He then worked in Australia before heading back to Korea, becoming director of the overseas promotion team in 2014. Most recently he has been head of the brand strategy group.

Academy 2018 offers Infiniti and beyond for student engineers

Infiniti has launched the fifth edition of its Formula 1 talent search, where it picks seven of the best young engineering students from across the world to work with both the Infiniti road car operation and the Renault Formula 1 team.

This year the Infiniti Engineering Academy will also be bringing the competition to grands prix, with six of the seven regional finals held track-side during an F1 race week. The finalists will be given access to the Renault pit lane, garage and motorhome areas just ahead of the race weekend and during the final they will have to carry out challenges under the watchful eye of chief technical officer Bob Bell.

Aimed at engineering students looking for a career opportunity of a lifetime, the Academy offers a unique 12-month placement to work alongside world-leading engineers at the cutting edge of the automotive and motorsport industries, complete with travel, accommodation, a salary and access to an Infiniti company car.

From the applications received the top 70 engineering students, the 10 best from each region, will go through to one of the seven regional final events.

Cyril Abiteboul, managing director of the Renault F1 team, said: 'Attracting top new talent is crucial for success in F1, and the Infiniti Engineering Academy helps us do that. It's a fantastic initiative that takes recruitment in F1 to a whole new level, and brings new and diverse talent to the sport, which is crucial to its future development.'

For more information visit the website at: academy.infiniti.com

The regional finals for this year's Infiniti Academy are to take place in the pits and garages at GPs

RACE MOVES – continued

XPB

McLaren has joined Ferrari and Mercedes on the board of Formula 1, where it will be represented by its executive chairman **Sheikh Mohammed Bin Essa Al-Khalifa**, of McLaren's biggest shareholder, Bahrain's sovereign wealth fund, the Mumtalakat Holding Company. McLaren was first offered a seat on the F1 board by **Bernie Ecclestone** as part of past Concorde Agreement negotiations, but it had previously declined to take up the opportunity.

Josh Frankos, the front tyre changer on the No.43 Richard Petty Motorsports Chevrolet driven by **Darrell Wallace Jr** in the NASCAR Cup Series, suffered a hand injury before the Pennzoil 400 at the Las Vegas Motor Speedway. **Michael Hubert** took his place for the race.

NASCAR has announced the 20 nominees for its Hall of Fame Class of 2019. On the list are a number of names from the engineering and business side of the sport, including **Ray Fox** (engine builder, crew chief and car owner); **Joe Gibbs** (team owner); **John Holman** and **Ralph Moody** (co-owners of Holman Moody Racing); **Harry Hyde** (crew chief); Roger Penske (team owner); **Jack Roush** (team owner) and **Waddell Wilson** (engine builder).

Barney Visser, the owner of NASCAR Cup operation Furniture Row Racing, has returned to the paddock after suffering a heart attack that led to him undergo bypass surgery last year.

Rodney Childers, the crew chief on the Stewart-Haas Racing No.4 car in the NASCAR Cup Series, has been fined $50,000 after the Ford he tends failed post-race inspection at Las Vegas – an event it won – due to problems with a brace for the rear window, and a rocker panel extension that was made from the wrong material. The No.4's car chief, **Robert Smith**, received a two-week suspension from NASCAR competition.

Raj Nair, executive vice president of Ford North America and a driving force behind the return of the Ford GT and the company's GT racing effort – and also the head of its American motorsport programmes for a while – has now left the company. This follows investigations into reports of inappropriate behaviour which, according to a Ford statement, was 'inconsistent with the company's code of conduct'.

Well-known motorsport journalist and broadcaster **Henry Hope-Frost** was killed in a motorbike accident in March, aged 47. Hope-Frost was especially known for his work at Goodwood and for the popular live interviews he conducted on the main stage at the Autosport International show.

Eric Neve, who until recently worked at Eurosport Events (the promoter of the World Touring Car Championship, which becomes WTCR from 2018) is now team manager at WTCR team DG Sport Competition. Neve was also involved in Chevrolet's WTCC effort, until it finished in 2012.

Members of the Walkinshaw Andretti United Australian Supercars squad are to support Andretti Autosport's IndyCar team in May's Indianapolis 500. Extra crew will be needed for the big race because Andretti intends to expand its IndyCar commitment from four full-time cars to six.

◆ 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**

Cyan of the times

It's a world champion touring car outfit with technical facilities that are the envy of most other teams, and yet Volvo works operation Cyan Racing has yet to announce a programme for this season. *Racecar* went to Gothenburg to find out why

By ANDREW COTTON

Off the record conversations are normally entertaining, particularly with championship managers such as former WTCC manager and TCR founder Marcello Lotti. The Italian hinted for years that Volvo was coming to the WTCC and a toe-in the water entry in 2011, with Robert Dahlgren and the C30, was only the start. The programme, which aimed to develop a racing engine based on the next generation of Volvo powerplants, was run by Polestar Racing, Volvo's partner team; but this project only lasted a year.

Under its new TC1 regulations, introduced in 2014, the series had Honda, Citroen and Lada onboard, but once again the rumours were there; Volvo was coming back. And it did in 2016. Polestar had been sold to Volvo in 2015 – and is now its electric development team – but Cyan Racing ran the WTCC programme so successfully that it became a double world champion in 2017, winning both the manufacturers' title and drivers' title, the latter with Thed Bjork.

Along the way, Cyan owner Christian Dahl built a new factory on the outskirts of Gothenburg, complete with its own driver in the loop simulator, dynamic engine dyno and a workshop that rather beggars belief, housed in the central well of the building – and as Dahl and I talked four immaculate WTCC cars sat in their respective bays, now all redundant following the move by the WTCC from TC1 to TCR regulations this year.

For Cyan Racing, the logic of entering the WTCC under the TC1 regulations seemed sound; it had ambitions to race in the top touring car series in the world, and there was only one to consider. Today, it has other options, including the development of a TCR car with Volvo, an electric TCR with Polestar, a Class 1 car (although frustratingly there are no regulations yet announced and doubts remain over the future direction of the DTM), or an electric rallycross car.

Collector's items

As far as other business is concerned, well unfortunately the company does not believe in selling cars, as the third floor of this stunning building proves, complete with Volvo's touring car racing history stretching back to 2001, while also including cars that are part of its current motorsport activities. Dahl says that, of course, the team can become a customer supplier if it wants, but so far it has retained even the Australian Supercar chassis that it raced from 2015 to 2017.

Cyan Racing is responsible for Volvo's racing activities and up until this season that meant running its flagship programme in the WTCC

Volvo's single-season WTCC campaign with the C30 in 2011 was run by Polestar Racing. The marque returned in 2016

'I have been doing motorsport since I was seven and my father before me,' says Dahl. 'It was not that I was looking at different options in life. I wanted to compete myself, and when I realised that I wasn't good enough, I wanted to stay in the business so I started to build cars. That is quite easy when you have the possibility, in 2015 when we sold the company or before that, to invest in motor racing because that is what I like to do. That was the reason for starting the performance business too, to reach the possibility of the World Touring Car Championship.'

Stealthy development

For many, the timing of Volvo's commitment in 2016 was odd: just as the new TC1 regulations came into force, and Citroen was dominating the series having started development far earlier than anyone else, other than Cyan Racing, which had been developing under the radar for 18 months.

'To reach the World Championship itself was a big target, just to get to the grid,' says Dahl. 'We could see that there was a big gap between the Volvos on the street and on the track. It took off better than I planned. We did a year in 2011, and the plan was to do the new V40 afterwards, but that didn't materialise, and so we did the Solution F car [for Swedish touring cars] where you put the radio control body on it; the engineers were crying for three years, but we could put resource into performance and that's why we stayed in the business for so long and continued to grow.'

Works team

The Polestar company, started by Dahl, had developed a motorsport-derived software upgrade for Volvo production cars, giving them more power and had, before the sale of the company to Volvo, sold almost 100,000 kits, including 22,000 in the last year before the sale. Dahl continued to keep an eye on the touring car scene on behalf of Cyan Racing in order to advise Volvo on where to invest in racing programmes.

'We go to the relevant meetings because that is our part of the corporation and we keep an eye on the landscape. It has been a wobbly landscape but we have to recommend things,' says Dahl. 'In the past we have had some choice but it has been relatively easy to see where motorsport is heading and if you want to do it on a global level, and in touring cars, it is very seldom that you have more than a few options. You have a world championship or some sort of international championship. When we signed the contract for WTCC in 2015, we had been developing the car for one and a half years before that because I saw that this was the only way it could be. We were sure that it would be needed, and it was because that was the direction at the time. But one and a half years later, in Argentina, Francois [Ribeiro, WTCC boss] took me to one side to say "good that you are here, but changes are coming".'

'If you want to be in motorsport on a global level, and in touring cars, it is very rare that you have many options'

That was a surprise to Dahl and to Volvo, particularly having made such an investment in a new state-of-the-art factory, but there is more to this relationship than just WTCC. There is, says Dahl, a disconnect with racing and other major organisations in that the commercial rights are sold, rather than turned into a profit centre. And Dahl does not see the factory as an investment on which to make money; but rather as strengthening the ties between Cyan and Volvo, to which legally it is tied as the sole racing partner.

'Regarding the building, it was a huge investment at the time, before we sold the [Polestar] company, even if the fluffy puffy bits weren't in there, then,' says Dahl. 'If you do that, you have a place where Volvo can take the partners and the dealerships and so on and then companies and customers can host them in a different environment than just the race track where you put them in the promoters' hospitality and give them a sandwich. That is what is usually done, but this programme is much more commercially driven.

'Financially I don't get all the money back in 12-15 years, but it is a lot easier if you are not a public company; I don't have to answer to anyone. If I want the building I can make it work financially. It was never that you made a calculation of what happens in 10 years' time, it was what was needed to take the project to the next level. We took it to the world championship, and of course we expected more than two years at it before they changed the regulations, but we want to stay at this level. If it is called the WTCC, or WTCR TCR international or Class 1, the highest level of touring car racing is where we want to be.'

The next step

Right now, touring car racing has no obvious direction. The increased emphasis on hybrid and electric mobility has forced race teams and organisers down that route, and there is no doubt that Cyan Racing will have to develop battery technology to compete in future, but this is not necessarily the long-term future of racing.

The Williams-built wind tunnel model of the title-winning Volvo S60 WTCC car is displayed in exploded form at the Cyan base

'They changed the regulations three years ago, and again now, and in 2020 we are not sure what is coming,' says Dahl. 'If we were doing a Class 1 car, I would like to start building an engine now. They have the five manufacturers [interested in Class 1] after Mercedes left, but to have someone new you need to have presented the new regulations. For Cyan Racing, I would just like to be in the highest level of touring car racing. For me, I prefer touring car than rocket ship. If you look at NASCAR or the other successful touring car series, they are built from road cars, and not a carbon tub with a plastic bodyshell on them.

'For credibility, to build it for a motorsport manufacturer, it is good that you have a body in white [steel] somewhere in there, even if there is carbon on top of it. For Polestar [in e-racing], there are bigger manufacturers than them, so it would be good if not the most expensive regulation steps in after what we had [before]. TC1 was fantastic in terms of technology, for being able to talk about the car and present it as a manufacturer and as a team, and there was nothing wrong with the racing on the track. We lacked cars, but there was overtaking and good racing, and the tough side was the promotion. I don't think that changing the regulations will help anything.'

Problem solving

Having successful promotion of the championship, and a large audience, leads directly to the technical regulations, and guides where the series are all going, Dahl believes. 'The first order problem is that if you have a good return on investment, nobody is arguing about the details, whether or not it is my engine, or my front suspension from the standard car, or is it electric or hybrid,' Dahl says. 'If the return is there, you spend money, and you present marketing value, then it is not as important the exact specification of the regulations. When you are having a tough time defending a return on investment, then you have the second order; which is what the car looks like, or what engine is in it. Basically, what you pay for is contact with the audience and if that one is there, then you cannot argue that it is wrong.'

Aussie rules

Having been involved in Australian racing the team is well versed in how touring car racing can be done in a cost-effective way, while linking with the audience to which the manufacturers want to sell cars. For Dahl, that link brings in sponsors that do pay for the racing, and are not just technical partners, or stickers on the racecar. Although the technology is not the highest in the world, the racing draws a huge audience.

'V8 Supercar is not the most up to date technology, but they have the audience so no one is complaining,' says Dahl. 'It's the same in a lot of the US championships; they have the audience and that justifies the investment. I think that the spectacle has been overlooked. What is strong in V8 Supercars, for example, is the code of conduct between the stewards and the drivers. It is like having an impolite kid. If you are not on top of him he will do what he wants. But not if you do this "you stay in your room for two hours". That balance is so good in Supercars. You can go side by side for four corners in Supercars because if you make a mistake and you are the bad guy then you are penalised, but in European racing the respect is not there, and there are always racing incidents here and there. In Australia, it is clear who made a mistake and they are penalised.

'In Europe, they bring lawyers to the track to represent the team. I have never heard of that in Australia,' Dahl adds. 'It is quite different how they look at it, and the championship in Australia is healthy. They complain like everyone does, but everyone is making money there, and that's the championship as well as the teams.'

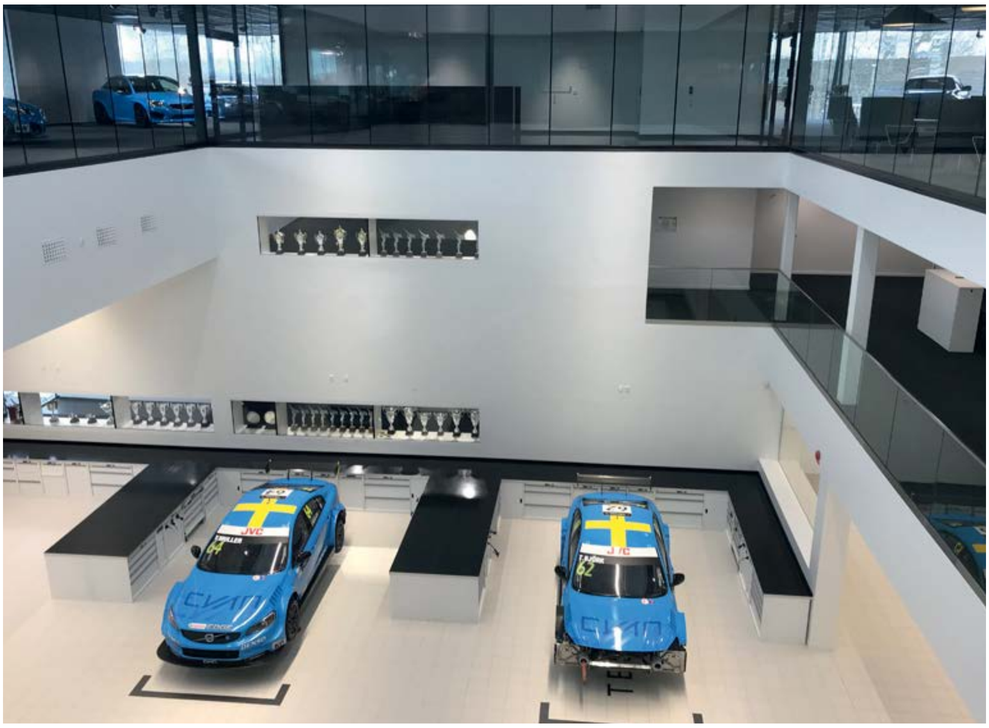
> 'They changed the regulations three years ago, and again now, and in 2020 we are not sure what is coming'

Current thinking

The European model does appear to be going to electric, or hybrid, and with the launch of e-TCR, that means Class 1 if it happens must consider hybridisation too. To stay ahead of the curve, therefore, Cyan Racing must delve into the world of electric mobility. 'Maybe it will change in five or 10 years again, but everything will be electric,' says Dahl. 'Regardless of government investment or not, we have to invest in electrification or knowledge of electrification. Championships usually start with a motor, which is fixed, and then you can do something with the motor or the software, and then maybe something with the batteries, but Cyan has to invest in it. If you don't start, you will be left behind. It may sound super stupid but it is quite easy to invest in it. There are only a few manufacturers in battery cells, but how to put them together and manage them with cooling and charging? That is reasonably okay to invest in, and we have to enter that.

'When you read that Porsche and Audi should put together their Le Mans effort for Formula E, [then] maybe it is too late for Cyan Racing, but the latest addition is e-TCR, and I am sure that Class 1, if it does happen, cannot happen without electrification while e-TCR is around. And e-rallycross is a strong option; if it gets less

Cyan Racing does not like to sell on its racecars and the third floor of the building pays homage to Volvo's touring car racing ventures since 2001



Now redundant WTCC racers sit in a pristine workshop at the base of a well-shaft running through the centre of the building

physically dirty [with racing] in cities, and would be more premium, then that is an option.'

While the FIA and manufacturers in Europe ponder the long-term future of electric and hybrid mobility, there are other technologies that are likely to take over within the next 10 years, and for Cyan Racing that means it needs to be ready to adapt early and provide a proper development programme. 'It is politics and other stuff that decides what we will run on when the lithium and oil has stopped; so you have to have your radar on,' says Dahl. 'It is easy to say you don't need a simulator because in the WTCC you can test as many days as you want, but in Formula 1 you have eight test days and that [was] so easy; just a few sentences in the regulations that say you cannot test, so then you have to run away and invest in a simulator. It is the same thing, you can do motorsport without electrification for a couple of years, but you do have to start [preparing] now.

'We did ethanol engines for six or seven years in Sweden, but we only promoted it for two years because the policy changed, and it promoted natural gas,' Dahl adds. 'That was what was on everyone's lips. It is all much higher than what motorsport can affect, in terms of the future, but when it happens you have to be an early adopter.'

Waiting game

While Cyan does not have a racing programme in 2018, Dahl is relaxed. There are options in the future, he's in the driving seat and is waiting to see how the landscape appears in the next year or two. 'I won't have wasted money on this building because there are no touring cars around, there always will be,' he says. Once the top class of touring car racing makes itself visible, there is little doubt that Cyan and Volvo will consider it. They were testing something at the beginning of March, but they wouldn't say what. Almost certainly it was the next stage touring car.

Cyan Racing's facility boasts its own high-end driver in the loop simulator system (above) as well as a dynamic engine dyno

WTCC trophies, for the 2017 manufacturers' and drivers' championships, are a reminder of what this race team is capable of

The International Journal of Motorsport Technology
Racecar engineering

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Subscriptions
Tel: +44 (0)1858 438443
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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
ROW (12 issues) £98
racecar@servicehelpline.co.uk

Back Issues
www.chelseamagazines.com/shop

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

Old world charm

The Sebring 12 hours was what everyone expected: hot, bumpy and the racing was wonderful. But in the paddock there was a clash of two worlds. This was highlighted in two separate incidents; one when Gianmaria Bruni ripped the rear of his Porsche GT off having run off a kerb mid-race, and another when Tristan Vautier somehow managed to drive straight into the wall at the exit of Turn 17, spreading tyres and various bits of Cadillac across the circuit, which caused damage to following cars.

Watching all of this was FIA WEC race director Eduardo Freitas, and it was easy to see the calculations going on in his mind. The Sebring circuit is a world away from where the FIA tracks are in terms of layout, surface and perhaps safety. Bruni ripping the rear from the Porsche on a kerb came with a simple explanation from his co-driver, Earl Bamber: 'We don't have the argument about track limits here, that's what happens if you go off.' There are plenty of other challenges should you go off, or break down. Alligators, for instance, if you get stranded out on track, particularly during testing. You just don't get that in Europe.

Vautier's accident and resulting wreckage would also have had the Portuguese with his head in his hands. Although the driver was assessed and released from the medical centre, one of the tyres from the stack had rolled, or been carried, to Turn 1, the length of the start/finish straight. It may well have been taken there by the CORE Autosport ORECA, which suffered a broken splitter for the rest of the event.

> **Anything that holds together at Sebring will probably be fine at Le Mans**

Drivers also wore tape around their necks and down their backs, likely due to help their muscles after a punishing stint over the famous bumps of the old airfield circuit, and with the FIA WEC planning a race at the track next year, it's a worrying time for those who love this place, and others like it. The bumps at Sebring are part of its charm, part of its character, and manufacturers of cars and tyres go there for what is basically a high-speed shaker test. Anything that holds together there will probably be fine at Le Mans. Audi used to do the 12 hours and then stay on to test for another 12 hours on Monday without having touched the car in between. But it's hard to see a driver such as Fernando Alonso racing there, although the Spaniard will have to as part of his Toyota commitment in the WEC in 2019.

However, resurfacing to eliminate the bumps and suit LMP1 cars (and others) would start the circuit down a slippery slope. The nature of the track would change completely, a high grip surface would see speeds increase, lap times drop, spectators suddenly too close to the action and so moved back. Anyone who has watched any car around Turn 1 in qualifying, the driver mastering the enormous bump on exit having already negotiated one of the true great corners in racing, will attest that this is a wonderful sight. And in the old days you could stand inside Turn 17 as the cars came through almost beneath your feet; Porsche 997s traditionally on three wheels, the right front clawing the air rather uselessly.

The US circuits retain their charm because they are different to European tracks. They are not designed to run with F1 cars; if they were, the run off areas would be far wider, and the surfaces far smoother. But where is the challenge there for other series? One of the problems with the Tilke circuits is that the club racers turn up and have nothing to shoot for anymore. At dinner with Porsche driver Laurens Vanthoor, the Belgian who won the 2016 FIA GT World Cup in Macau upside down and on fire, he said that given the option he would choose the US circuits every time. They present a challenge, a certain danger that he liked. No one wants to see someone killed or injured, but a driver has to have consequence in the back of his mind.

Vautier's accident may have sent wreckage down the track, but he was not hurt, and having gone to Sebring for almost 20 years I can't remember a driver being seriously injured in the 12 hours. Sure, there have been some big accidents; Andy Wallace after a brake failure in his Cadillac; Timo Bernhard while testing for Audi; but both returned to action. Steve Soper memorably wiped that same wall as Vautier with his BMW V12 LMR, to the bemusement of the team. 'Steve, there's been a shunt at Turn 17,' said his team manager David Price as the dust rose from a monumental impact. 'Dave, it was me,' was the response over the radio. *Autosport's* Damien Smith and I asked Soper what happened as he walked back to the pits carrying his helmet. 'I crashed,' he said.

Quite what the 1000bhp Toyota TS050 will look like around Sebring on a fully rubbered-in circuit and with all competitors on Michelin tyres, I have no idea. But I do know it will be spectacular. Toyota personnel at the track on a fact-finding mission ahead of next year's race admitted that they had not yet put the circuit into their simulator at team HQ in Cologne. They considered that they would need different dampers on the driver seat to fully simulate what it would be like for their drivers. Perhaps some rally shocks would do? I missed seeing Freitas at Orlando airport on Sunday night, too. I can imagine that he was steadying himself for next March.

ANDREW COTTON Editor

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