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Le Mans triple beckons ahead of Hypercar era

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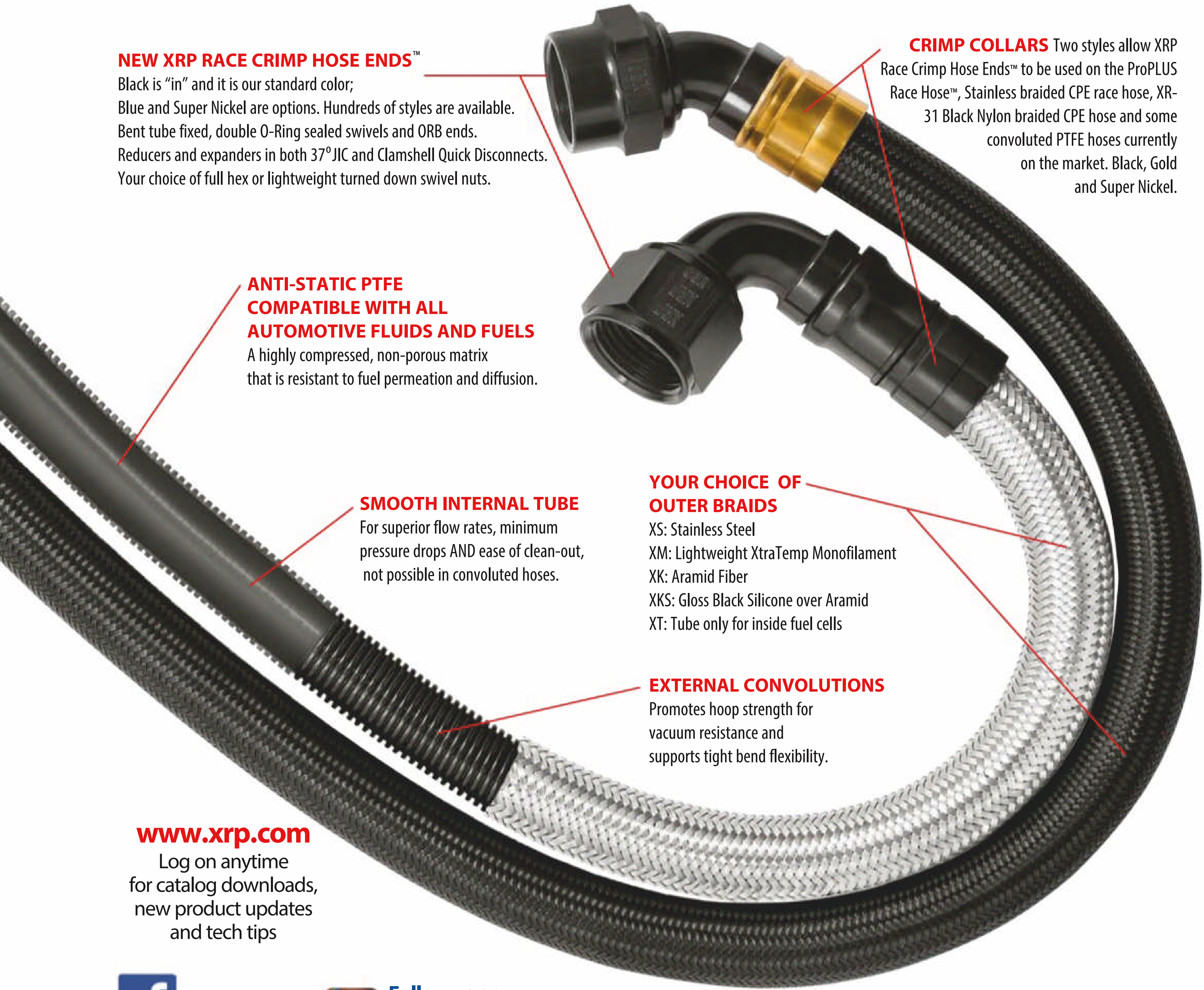

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THE XTREME IN RACECAR PLUMBING

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Volkswagen Motorsport South Africa brings the Golf 8 GTi to the track

Engineering is cool

Now we just need to convince the younger generation of that fact

This year has been tough on everyone. The Covid pandemic has caused chaos across the world, but I find myself particularly annoyed by what some of the recent decisions made here in the UK mean for the generation that, in five to 10 years, will be a part of the workforce trying to fix the mistakes my generation and those before have made.

To fix those mistakes, they need a good step into their careers, which for many start with their GCSE, A Level and Highers grades, and the results fiasco over the past couple of weeks in the UK is not the start these young people need.

My parents came to England in the 1970s from India with one goal: to provide their children with an education that would set them up for an independent future. They left behind their family and friends, brought one suitcase, their college degrees and a real sense of sacrifice. At the time they arrived, neither my two sisters nor I were born. Yet my parents knew they wanted their future children to have the privilege of a British education.

That education took place in urban state schools in London, but also for more than two years in India. Doing well at school wasn't optional for us but, by the same token, all three of us wanted to be the best in class and we really enjoyed learning, both on our own and with classmates. It helped that our parents were always interested in the countless facts we shared with them.

My family was not rich or privileged. My parents worked every hour they could to save money for our university education, and having the best start in our careers was the single most important goal for them. For that, we are all so grateful. Without that start, I don't think I would be where I am today, a qualified engineer who is working in motorsport.

Inner beauty

Engineering is pivotal to so many aspects of the technology we take for granted in life. So much so that to list everything with an engineering element to it would likely be impossible. But that is the beauty of it, and the resourcefulness to find solutions to everyday problems come from engineers. Irrespective of background, engineers find ways to create new ideas and improve people's lives. But to get those engineers, you need to inspire kids to think about the industry from an early age.

For as long as I can remember, engineering has always been short on bodies, be they university-qualified graduates or apprentices. It is often an unseen career for so many kids, one they sometimes only find out about once they meet an engineer in adult life. There are plenty of reasons for this and, although some steps have shown improvements in numbers, the industry is still suffering shortfalls.

At a time when we have all had to realign ourselves with new social protocols and really look at how we were living, engineering and science has never been more important.

XPB

Motorsport is just one avenue, engineering is everywhere around us

I don't know how many engineering places were available for 2020-2021, and I don't know how many were needed to fill the void, or how many will graduate into the field. What I do know is that if my degree was anything to go by, after year one we lost 20 per cent of the class, and another 10-15 per cent over the next two years. Once qualified, only a handful actually went on to work in the industry. The current uncertainty around the world is not going to help the shortage, but there is now a real opportunity for the industry to attract more talent.

By stopping our daily routines, so many of us have opened our eyes to how we were operating and its consequences. So, as we are emerging from a short pause, we have never been given a better opportunity than now to operate differently and make advances to a brighter future. That can start with new engineering solutions, and delivering them quickly. The speed of possible delivery should be obvious by the quick turnaround that so many niche engineering companies (motorsport included) made during the early stages of the pandemic to the medical industry. This is the engineering field we need to exploit and capitalise on to attract a new generation. It's the living proof of what engineering can do to make things better.

Career path

There are going to be students this year who may have to re-take exams and re-apply for courses, or those who have to take a year out. There will be those who have to reconsider whether they carry on studying or delay, and those who might look at today's world and wonder whether they should change their chosen career path completely. These are the group who could be our next generation of engineers.

Motorsport is at the sexier end of the engineering spectrum, but there are so many other fields that are crying out for bodies. As engineers in this business, I do believe we have a unique chance to influence young people to consider a career with us and build a better future.

Engineering in racing provides a snapshot of the rapid thinking and approach to solution finding in the wider industry. Engineers are adaptable creatures, always thinking about how to make improvements, or finding a new technology to progress advancement. Engineers love the word 'why?' and that leads to doing things differently. Having had a rough ride this year, the teens of today are probably using the very same word quite a lot at the moment.

If we as engineers can show them that their impact on society through engineering can make things better for everyone, we might just stand a chance of attracting a few more bright, creative, enthusiastic bodies to this fabulous industry.

Uniquely, becoming an engineer can be through an apprenticeship or via university, so it does present a solution for students currently re-evaluating where they go next. At a time of uncertainty in so many fields, becoming an engineer has never been cooler.

Leena Gade is the vehicle dynamics centre manager and race engineer at Multimatic Engineering, UK

A unique chance to influence young people to consider a career with us and build a better future

The trouble with tyres

Cloning gives way to rubber as the major topic of conversation around F1

Let's be honest. Brake ducts have long been allowed to also function as effective aerodynamic devices on F1 cars, which reinforces Renault's right to protest Racing Point on the basis of obtaining these now 'non-listed' items from Mercedes. But what everyone is really waiting to know is whether there was any forbidden technical collusion between Mercedes and Racing Point that has allowed the latter to construct such an apparently detailed clone of the former's 2019 car.

I can understand and respect Lawrence Stroll being adamant in defence of his team and reputation, hence the protest against the FIA-imposed punishment. However, if one sticks one's head above the parapet to the extent Racing Point has, with its alleged copy of a whole car, one should expect to be shot at. Some might say (politely) they were taking the Mickey, but I don't recall Toto Wolff ever getting quite so het up before…

Headline news

While being honest on this front, let's also be frank that, no matter how dedicated a Lewis Hamilton supporter one might be, there was an element of schadenfreude in seeing the mighty Mercedes team trip over itself at Silverstone. Might they have thought to run less downforce overall to protect those fragile Pirellis and avoid the heat and stress build up that occurred?

As a consequence, as well as car cloning, the headlines around the world are once again occupied by F1 tyres. And I can do no better than quote Hamilton on the basic issue concerning this:

'Moving forwards, they're probably not going to be able to do it for next year, but for 2022 we need a better tyre. We need a tyre that gives us more grip, better safety, and enables us to drive closer to cars and give you guys and the fans better racing.

'Right now, we're [doing] a serious amount of management. I don't think that's what the fans want. That's not what a racing driver wants, to have to manage it behind a car, multiple seconds behind, because the tyres are not good enough.

'So we want to help Pirelli make a better tyre, if they can. And that's obviously the question.'

A very important question. Could it be that, in certain combinations of circumstances, the stresses now being imposed on a vital component that hasn't changed in concept since its invention in 1888 are becoming incapable of being handled? To me, disproving this is that:

- Michelin and Dunlop provide tyres that have managed perfectly with high downforce, heavy and high torque-delivery LMP cars over a range of circuits covering multiple stints.
- Firestone's superspeedway tyres cope well with the high-*g* banking and 240mph+ speeds of IndyCars. (Firestone imposed a 35-lap restriction prior to the first oval event this year, but given the adoption of the new Aeroscreen and its effect on weight distribution, combined with Covid-19-limiting testing, this appeared a sensible precaution).

XPB

Tyre management has become an even more critical aspect in Formula 1 racing in 2020, and even the drivers have called for a change

It is true that every tyre has a wear and degradation curve, and if some teams push beyond these boundaries – as appeared to be partly the case at Silverstone – they should anticipate trouble. This appears to be the most tyre-destroying circuit on the F1 calendar, but elevating pressures the way Pirelli did in reaction surely only emphasised a fundamental weakness in the product the company is providing. Increasing static pressure to 27psi in a front tyre originally designed for circa 22psi can't be right.

Remember, just half-psi changes were used as one of the tools by which car performance could be adjusted, before high minimum pressures were mandated at Pirelli's request.

It wasn't a big surprise that the degree of blistering, and ultimate carcass failure, was not repeated in Spain. Even so, combined with the circa 110kg starting fuel load (I remain a firm advocate of refuelling stops) cars circulating in a train some eight to 10 seconds off qualifying pace when they should be fighting for position is a ridiculous situation.

Every car / driver will use tyres differently, every tyre will be fractionally different, and track conditions can change lap by lap. Trying to get all that right in a qualifying and race situation is therefore something of a lottery if the operating range is very narrow, as it is with Pirelli.

Sympathy for the devil

I have some sympathy for the Italian make. It is pushed and pulled in too many directions. It has been heavily involved in front line motorsport since the very beginning, and I don't like to see a decade-plus commitment rewarded with public failures. It must also be acknowledged that drivers these days regularly abuse their tyres over kerbs and rough run-off areas, seemingly without any thought to the damage they might be causing. It seems that for such a critical component, neither the FIA nor the teams devote sufficient in-depth analysis, let alone track-testing opportunities, that are not just tacked on to a race weekend.

Nonetheless, the simple fact is that Pirelli continues to get it wrong. And so do the rule makers. Blistering and degradation also occur in the rubber manufacturer's one-make supply to F2 and F3. While, as with Verstappen's defeat of Mercedes at Silverstone, this has provided some unexpected and exciting late-race drama, and while tyre management should undoubtedly be part of a racing driver's skill set, it shouldn't create a lottery. A major re-think of the company's approach to tyre design is essential, and every reasonable avenue should be explored so improvements don't have to wait until 2022 and the introduction of 18in wheels and low-profile tyres. Certainly, any continuation of the current tyre dilemmas could easily spoil the much-vaunted and desired benefits of the new chassis regulations due to come into force then.

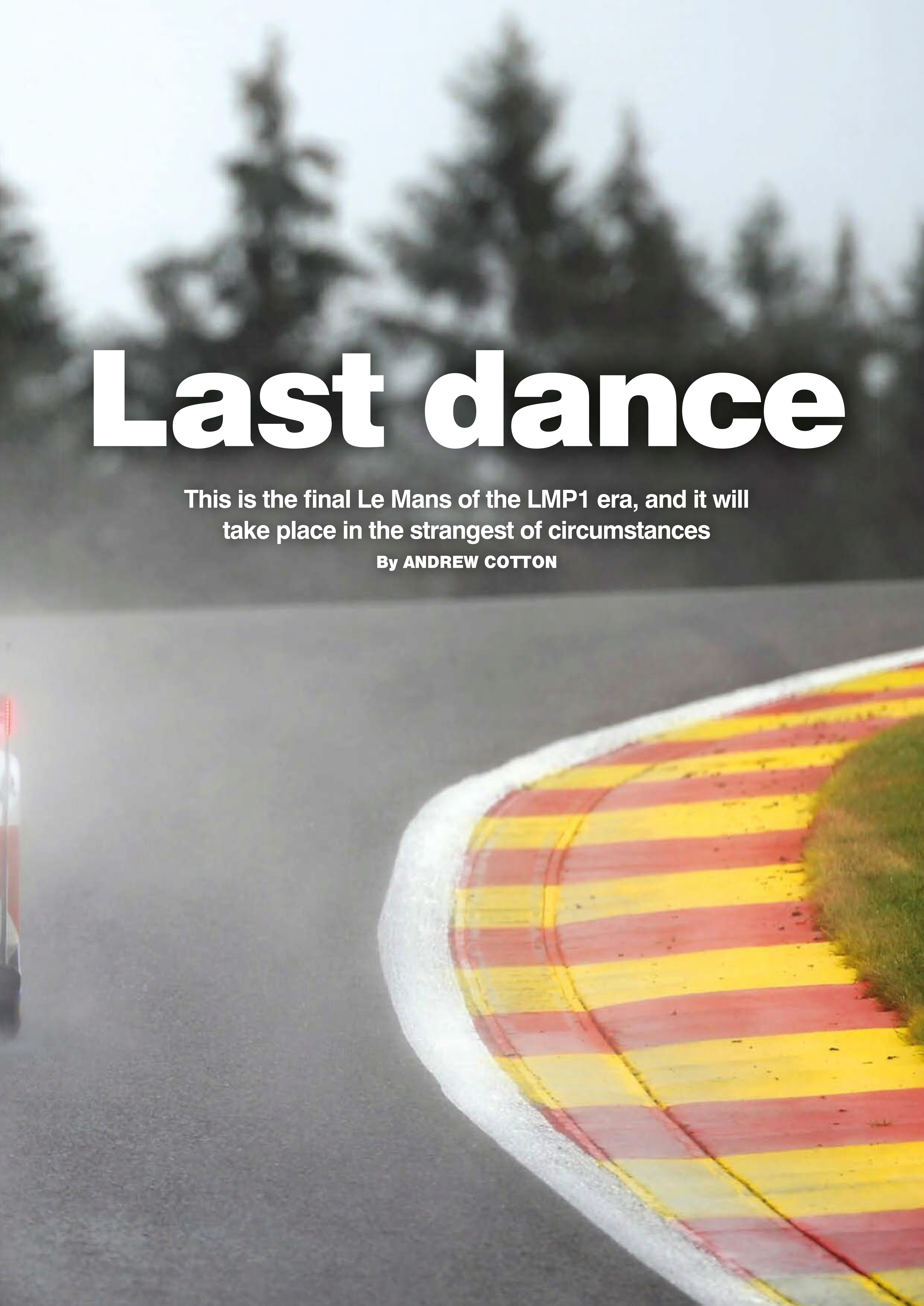
I don't like to see a decade-plus commitment rewarded with public failures

Le Mans 2020 will see the back of the LMP1 hybrids that, arguably, have produced a golden age of endurance racing

Last dance

This is the final Le Mans of the LMP1 era, and it will take place in the strangest of circumstances

By ANDREW COTTON



This year's 24 Hours of Le Mans will take place not only behind closed doors and without many competitors from IMSA, but it will also be the last time the LMP1 hybrids will grace the Sarthe circuit. It brings to an end a period that started with the advent of the World Endurance Championship and involved full factory development programmes from Toyota, Audi, Porsche and Nissan.

Next year, the Hypercar regulation set will replace these regulations which have remained similar since 2012. These are hybrid prototypes that will be performance balanced. In 2022, the Hypercars will be joined by LMDh, which has a regulation set based on IMSA's existing DPi philosophy.

The entry list for the 2020 edition of Le Mans boasts 60 cars, but the majority of the grid is made up of LMP2 and GTE-Am cars, which feature no fewer than 47 cars between them. It is a stark reminder to the regulation writers that they should build the grid from the back, looking after their privateers ahead of manufacturer needs as, when the chips are down, they always rely on those who choose to spend their own money.

Golden opportunity

It seems with the Hypercar regulations that the FIA has not yet learned that lesson, but the ACO's inclusion of LMDh does open the door to low-cost manufacturer entries that are supported, or even led, by high-quality privateer entries. For such a team, the coming years are a golden opportunity to win endurance racing's greatest prize.

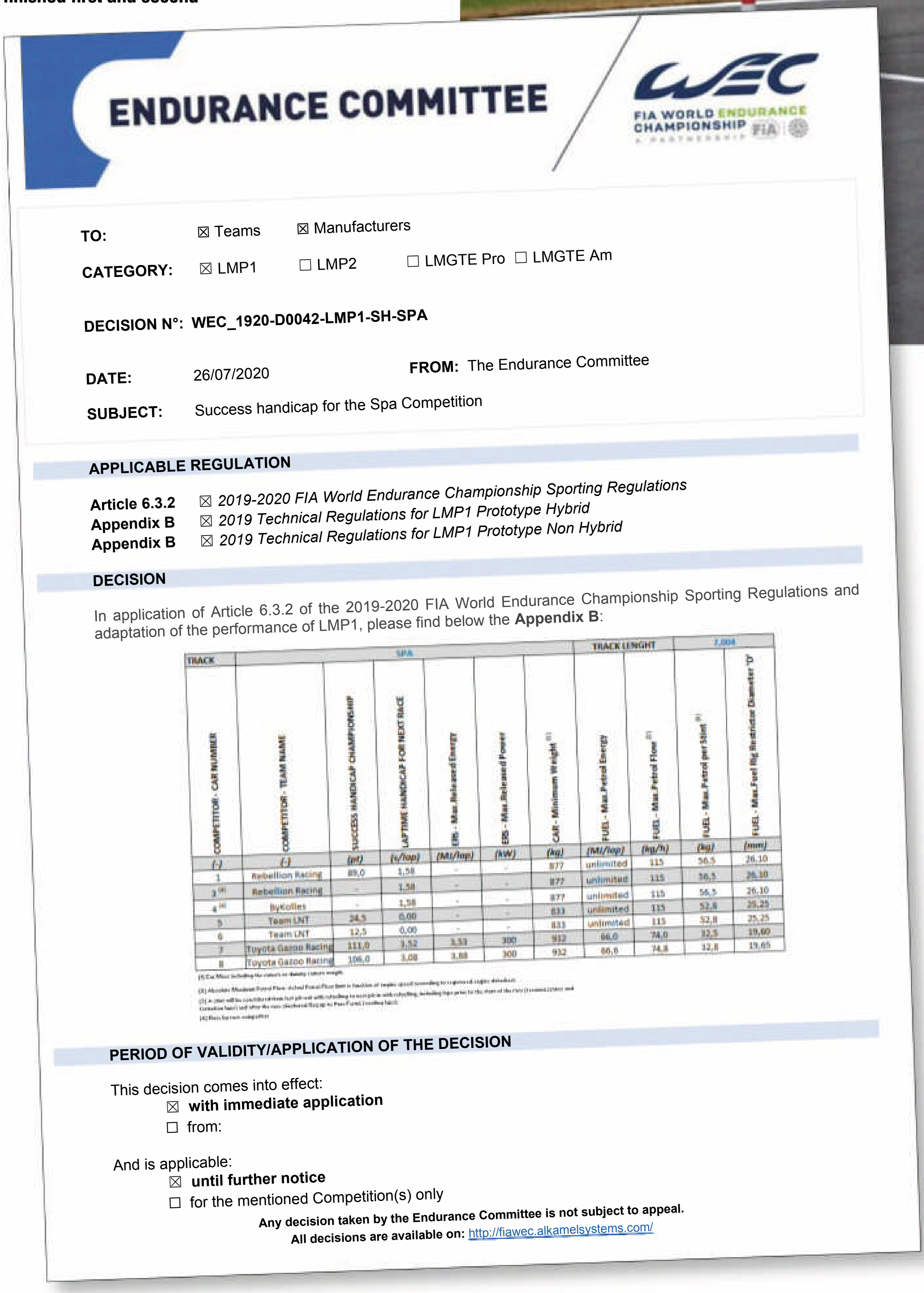
Of the six LMP1 cars that have had their entries accepted this year, just two are hybrids, both from Toyota which has raced in the WEC since 2012. The remaining four top class prototypes are from privateers. While the rest of the WEC season has seen the hybrid and non-hybrid concepts performance balanced, the Le Mans race will not feature that same balancing process, and the ACO has yet to announce how it will retain some semblance of competition during this last 24-hour race with these cars.

The race is the penultimate round of the World Endurance Championship that has struggled to cope with the loss of Nissan in 2015 after just one race, Audi in 2016 following the VW Group's dieselgate scandal and Porsche in 2017. Toyota has carried the series since then with its TS050 that was introduced in 2016 and which has had its performance steadily pared back race-on-race this year through an extraordinary range of balancing performance measures.

These measures were actually devised by Toyota and accepted by the other LMP1 teams before the start of the season, but the jury is out on whether or not the system has been successful. A lap time handicap was calculated based on championship points scored the previous race and the circuit length of the next race.

A lap time handicap was calculated based on championship points scored the previous race and the circuit length of the next race

Toyota had low-speed, first gear issues at Spa with both cars, so it cannot be taken for granted the cars will win at Le Mans, although that is likely grasping at straws



ENDURANCE COMMITTEE

WEC FIA WORLD ENDURANCE CHAMPIONSHIP

TO: ☒ Teams ☒ Manufacturers

CATEGORY: ☒ LMP1 ☐ LMP2 ☐ LMGTE Pro ☐ LMGTE Am

DECISION N°: WEC_1920-D0042-LMP1-SH-SPA

DATE: 26/07/2020 FROM: The Endurance Committee

SUBJECT: Success handicap for the Spa Competition

APPLICABLE REGULATION

Article 6.3.2 ☒ *2019-2020 FIA World Endurance Championship Sporting Regulations*
Appendix B ☒ *2019 Technical Regulations for LMP1 Prototype Hybrid*
Appendix B ☒ *2019 Technical Regulations for LMP1 Prototype Non Hybrid*

DECISION

In application of Article 6.3.2 of the 2019-2020 FIA World Endurance Championship Sporting Regulations and adaptation of the performance of LMP1, please find below the **Appendix B**:

TRACK	SPA						TRACK LENGHT		7,004		
COMPETITOR - CAR NUMBER	COMPETITOR - TEAM NAME	SUCCESS HANDICAP CHAMPIONSHIP	LAPTIME HANDICAP FOR NEXT RACE	ERS - Max. Released Energy	ERS - Max. Released Power	CAR - Minimum Weight [1]	FUEL - Max. Petrol Energy	FUEL - Max. Petrol Flow [2]	FUEL - Max. Petrol per Stint [3]	FUEL - Max. Fuel Rig Restrictor Diameter 'D'
(-)	(-)	(pt)	(s/lap)	(MJ/lap)	(kW)	(kg)	(MJ/lap)	(kg/h)	(kg)	(mm)
1	Rebellion Racing	89,0	1,58	-	-	877	unlimited	115	56,5	26,10
3 [4]	Rebellion Racing	-	1,58	-	-	877	unlimited	115	56,5	26,10
4 [4]	ByKolles	-	1,58	-	-	877	unlimited	115	56,5	26,10
5	Team LNT	24,5	0,00	-	-	833	unlimited	115	52,8	25,25
6	Team LNT	12,5	0,00	-	-	833	unlimited	115	52,8	25,25
7	Toyota Gazoo Racing	111,0	3,52	3,53	300	932	66,0	74,0	32,5	19,60
8	Toyota Gazoo Racing	106,0	3,08	3,88	300	932	66,6	74,8	32,8	19,65

PERIOD OF VALIDITY/APPLICATION OF THE DECISION

This decision comes into effect:
☒ **with immediate application**
☐ from:

And is applicable:
☒ **until further notice**
☐ for the mentioned Competition(s) only

Any decision taken by the Endurance Committee is not subject to appeal.
All decisions are available on: http://fiawec.alkamelsystems.com/

The Balance of Performance system at Spa in August should have crippled the Toyota, but the cars finished first and second

LMH and LMDh

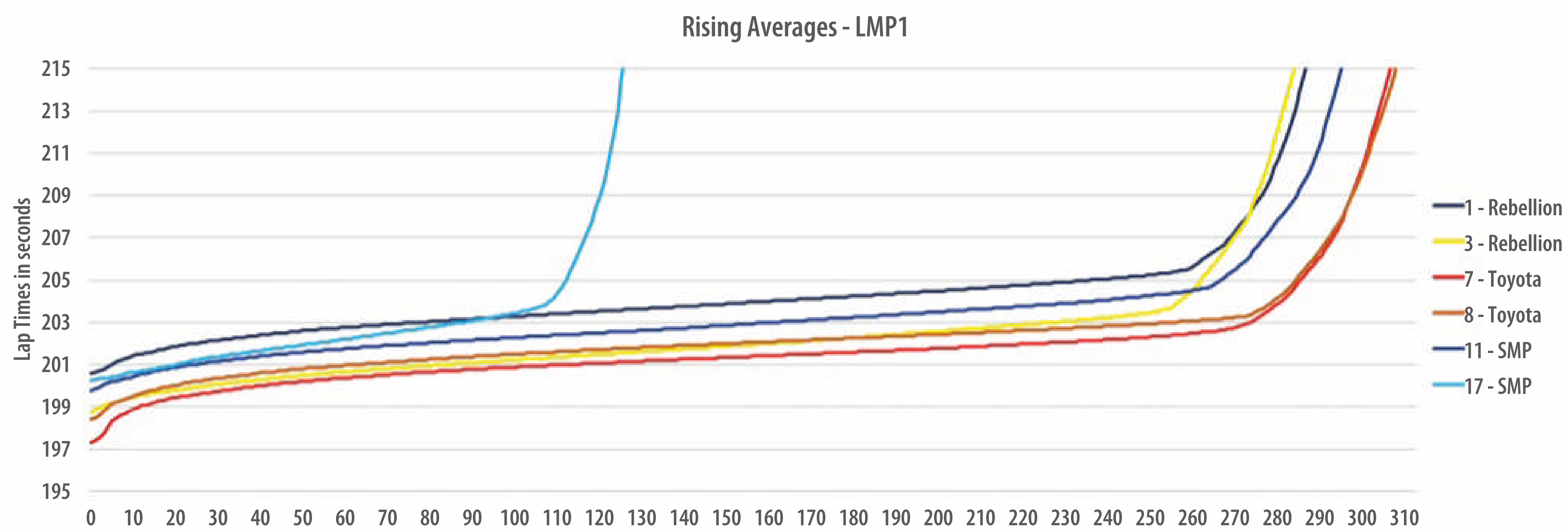
At Le Mans in September the Automobile Club de l'Ouest will announce the final regulation set for the LMDh prototype category that is scheduled for introduction in 2022. The regulation is based on IMSA's Daytona Prototype International (DPi) regulations that uses four chassis manufacturers (Dallara, ORECA, Multimatic and Ligier) with homologated running gear, including the gearbox. Manufacturers will be able to produce engines and aero kits that fit the base chassis and it seems this will be a popular move as manufacturers look to privateer teams to represent them in competition as they do in GT3 racing.

The alternative is Le Mans Hybrid (LMH), which allows a manufacturer to develop an entire car from the ground up, including the hybrid system. Development is limited for five years, which should keep costs under control.

'Let's hope that many OEMs join the group in LMH or LMDh,' says Bouvet. 'At the end of the day, we don't really care [which way they access the top class at Le Mans]. This will be one category. The approach we took was to allow [every concept] and that was a simplification. The LMDh regulations we took a step further.

'Manufacturers' needs have changed in the last four years compared to what they were doing five years [ago]. Diesel was one problem, and now Covid is another step. Where we stand with this 'Global Prototype', we just simply give manufacturers three different ways of building a car – either Prototype, LMH with road car technology and styling, or LMDh, which is a prototype but from constructors. We have given them the opportunity to satisfy their need.'

The WEC season has seen the hybrid and non-hybrid concepts balanced, but the Le Mans race will not feature the same process



The no.7 Toyota was fastest overall at Le Mans in 2019, the no.3 Rebellion second fastest. The rising averages table clearly shows the no.8 Toyota lacked pace compared to its sister car and should be discounted in the EoT calculations this year

The system involved limiting power output, as well as increasing or decreasing weight. In theory, it has worked as Toyota won four of the races leading up to Le Mans and the privateer Rebellion team two, showing that under these conditions the privateers were capable of winning races.

Pros and cons

In practice, however, the quality of racing has been poor as competition between the two cars of the same team has been limited by the car-specific penalties.

'The idea behind it was to try to have some close racing between manufacturers and privateers this year, as we don't have so many cars running,' admits the ACO's technical director, Thierry Bouvet. 'If [manufacturers and privateers] would finish five laps apart, we would have been criticised anyway. There have been some pros and cons, and this system was discussed among all the LMP1 teams, accepted and it was all agreed. We had to try something.'

That something involved complex computer programs that actually simulated the entire championship, despite the cancellation of various races and a changing calendar that meant the 2019 / '20 season did not finish at Le Mans in June, and the new 2020 / '21 season did not start as planned in September with the Hypercars.

'EoT is just pushing [up] cost. Especially in this crisis, it makes absolutely no sense. Manufacturers now just want to spend less'

Thierry Bouvet, ACO technical director

Toyota – the consistent improver

Toyota is the last of the manufacturers still standing after successive rivals ditched their programmes for various unrelated reasons. The Japanese manufacturer has released details of its development curve since it first joined the WEC in 2012, showing a dramatic drop in fuel consumption, increase in power and reduced lap time in the past eight years.

Comparing 2012 with the best of subsequent years, 10 seconds has been shaved off the fastest qualifying time, from 3m24.842s at the start of the programme to 3m14.791s in 2017. A similar amount has come off the fastest race lap, from 3m27.088s in 2013 down to 3m17.297s in 2019.

Perhaps more significant is the fastest 20 per cent of laps in the race, which in 2012 was 3m28.82s compared to 3m19.10s in 2018.

A big jump in performance came in 2016 after Toyota introduced a smaller engine and switched from super capacitors to a battery energy storage system. Total braking energy recovered jumped from 41 per cent to 51per cent, and fuel consumption dropped from 1358kg of fuel in 2015 to 1202kg in 2016.

The Toyota TS030 was rushed to the track when the Japanese manufacturer first entered the WEC in 2012 after Peugeot abruptly stopped its LMP programme. Performance in all respects has improved dramatically since

Rebellion qualified on pole at Spa, which showed it had the pace to compete, but over a full stint, particularly the first one, it could not translate that position into race pace

'It was all computed,' confirms Bouvet. 'We had different simulations and we played championships in simulation and refined [using] all the knobs. As we saw in the first race, the gap between hybrid and non-hybrid was big, so the knobs had to be tuned up a little bit. We then had two races where Toyota won, and after that Rebellion.

'If you look at the championship different cars have won races, but there was not so much close racing.'

Perfect performance

This was something of a concern for the privateers that competed in the WEC prior to the 2019 / '20 season. The performance gap between the privateers and manufacturer hybrid cars was supposed to be managed by the Equivalence of Technology, the table by which the best of the technologies was balanced. Should a team extract everything from their equipment, they would be able to compete at a level that the table predicted. Anything less than the very best would see them fall far short of expectations, and that happened with regularity as the privateers in particular struggled to maintain perfect performance throughout the endurance races. It cost the series various teams that accused the regulators of unfairness.

'EoT is just pushing [up] cost,' says Bouvet who expects costs to drop with Hypercar. 'In this crisis, it makes absolutely no sense. Manufacturers want to spend less money.'

LMP2 – safety in numbers

The LMP2 class is dominated by ORECA and Dallara chassis, with only three teams choosing the Ligier baseline for the 24-hour race. Each of the cars is powered by Gibson's GK428 4.2-litre V8 engine that is the European standard in the European Le Mans Series and World Endurance Championship. The company also supplies IMSA teams, and produced the GL458 for Rebellion's LMP1 programme.

With 24 cars in the class, LMP2 will be hotly contested. It is also the only category in which there is tyre competition between Goodyear and Michelin, with four teams on Goodyear.

For 2021, Michelin will supply the top prototype class and GTE-Pro, while Goodyear will supply the customer LMP2 and GTE-Am classes.

The LMP2 category features no fewer than 24 entries and, although lacking in pace compared to the LMP1 cars, it wasn't that long ago (2017) that Jota almost pulled off a shock win when the hybrids struck trouble. A repeat this year is possible

The series has lost the SMP team and its pair of AER-powered Dallaras after last year's Le Mans, Dragonspeed's Gibson-powered Dallara and will, at the end of this season, lose Rebellion. Toyota and Glickenhaus have confirmed entries for 2021; Peugeot has confirmed it will join later, while ByKolles has yet to announce when it will enter.

Would Bouvet consider that the Balance of Performance measures, however successful they may be judged this year, were actually an admission of failure that the EoT did not deliver what the privateer teams needed in these times of crisis?

'It reflects the gap between privateers and OEMs, and we need to have a different philosophy of thinking,' admits the Frenchman. 'Jumping to the [forthcoming] years, we are more in that philosophy in not defining *how* you achieve the target, but *what* is the target. That is what we are doing with Hypercar.

'Hypercar has been set as a BoP category and we know a lot [about this] from LM GTE. We just have to push a bit more the complexity of capturing all the performance of the car. It will be more the reasoning, or philosophy, than equivalence of technology.'

Jewel in the crown

The Le Mans race will not have the same performance balancing measures as other races in the WEC as it is the jewel in the series' crown, hard enough to win in the first place, and the governing bodies did not want to have teams manipulating results in the races ahead of Le Mans in order to gain an advantage there.

However, without the BoP in place, Toyota could normally expect to have the same advantage as last year over the non-hybrid privateers. Although the no.7 Toyota was clearly fastest overall, it didn't win thanks to a late puncture, but the rising averages table shows it had a comfortable pace advantage over even its sister car. The ACO has yet (at time of writing) to publish the table for Le Mans, but it is likely to be based on the performance of the no.7 car, not the no.8, or even Rebellion's no.3 that was, for half the race laps, second fastest on track.

'Obviously a race average [is affected] if you are three laps ahead, which means that you are probably not pushing as hard as you would if you had someone 10 seconds behind you,' says Bouvet. 'We are currently doing the analysis, and we are in the process of defining everything for Le Mans this year. We did not want to [show what we were going to do] before the last WEC race preceding Le Mans because people could have gambled, and we didn't want that.'

What that infers is the EoT table will be manipulated to help the privateers in order to produce a race. With just six cars in LMP1 this year, including two Rebellions, one Ginetta and one ByKolles, having Toyota not walk away with the title is preferred.

'We obviously have the WEC system, which was clear from day one that Le Mans would be out of that,' says Bouvet. 'No one wanted it that someone would play a fake game all year and then come to Le Mans with a light car and win it. So, we removed Le Mans from the equation.

'Then, obviously, we have all the data in front of us, be it Le Mans data, last year's timing and scoring or all the evolution through the year to create a balance of technology, especially for Le Mans.'

> **'No one wanted it that someone would play a fake game all year and come to Le Mans with a light car and win it'**
>
> *Thierry Bouvet, ACO*

Michelin, sole supplier to the LMP1 category, brought a new front tyre for the privateers who are not allowed to have four-wheel-drive systems and so have different requirements for their front tyres than the hybrids. The tyre was designed specifically for cars not producing energy through the front tyre in terms of drive, but has not proven successful. Teams report they cannot get the front to work, particularly in the colder conditions expected in September.

Performance parameters

From the ACO's point of view, analysing the performance of this new tyre is not easy. 'Last year there were more cars in LMP1 so it is not the same competition, and the LMP1 privateers did not race in the same condition as last year due to weight changes,' says Bouvet. 'Even taking the sensitivity of weight and power relative to LMP2 as a reference, the gap between LMP2 and LMP1 can be analysed, but LMP1 would have different weight between the races and that would affect the tyres. Probably they could play more with weight distribution for example.'

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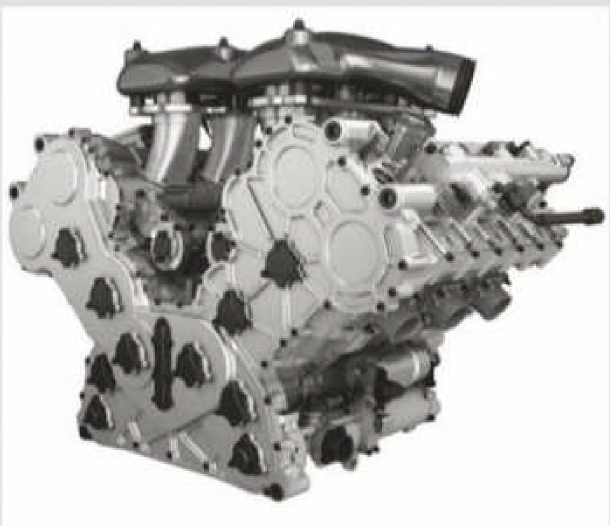
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Toyota may be favourites to win at Le Mans, but they are not bulletproof

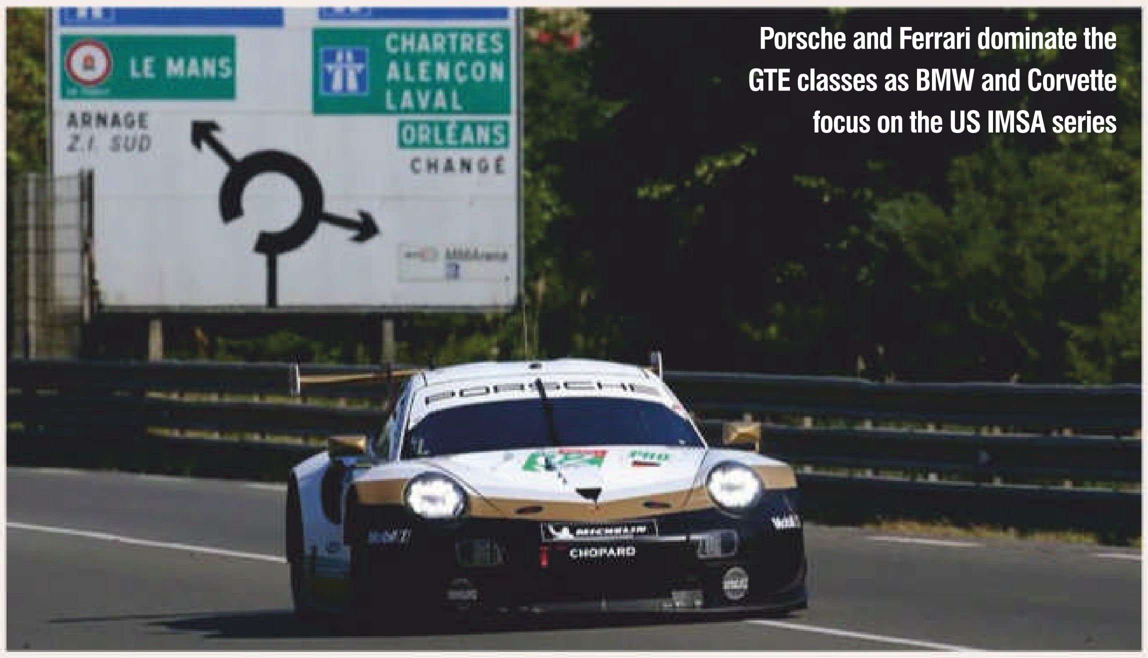
Ginetta showed well in Bahrain, but pit stops were not slick and the cars slid backwards down the order. Just one of the cars is entered at Le Mans this year

GT and GTE

The GT classes make up half the grid, but are stacked heavily in favour of the 'Am' class for GTE cars that are more than a year old. Three Ferraris will take on two Porsches and two Aston Martins in the seven-car Pro class, while the Am class has Porsche and Ferrari's duopoly broken only by two Aston Martins for TF Sport and Aston Martin Racing.

Corvette will not race its C8.R, that has dominated in IMSA since the restart in July, at Le Mans this year due to Covid restrictions, coupled with a condensed IMSA schedule. That schedule has also meant Porsche has not sent its US team. Risi, on the other hand is not contesting the full IMSA series and therefore has prioritised Le Mans with its Ferrari.

The Pro class is governed by an automated Balance of Performance system that has been agreed by all manufacturers and will form the basis of the Hypercar / LMDh class when the categories are mixed in 2022.



Porsche and Ferrari dominate the GTE classes as BMW and Corvette focus on the US IMSA series

There is another performance parameter that must also be considered, and that is the teams' performance in the pit lane. While Toyota and Rebellion have been racing all season, Covid limitations accepted, LNT and ByKolles have not raced in the series this year and cannot hope to be as slick in race conditions as those with race experience.

Reliability issues

Toyota will not be under pressure on pace this year. The Japanese manufacturer has a new, low-downforce aero kit for Le Mans, which debuted in competition at Spa mid-August. However reliability is by no means assured. At Spa, both of the TS050s suffered from a loss of power at low speed and in first gear.

While the crew of the no.7 car were able to sort the issue by going up the gears and then back down again, the crew of no.8 did not have the same luck. For the Rebellion team, even with their race experience, the cars did not race well at Spa and finished far behind.

Toyota may be favourites to win at Le Mans, but they are not bulletproof. The night running will be around three hours longer in September than June, temperatures could well be lower and, as they always say, Le Mans chooses its winner. With 24 cars in LMP2, a reliable run could see a surprise result.

Creating strength while remaining sleek was a tough job for the Dallara designers and FEA technicians

Engineers had to consider the loads the air velocity and pressure field…provoke on drivers' bodies. And the aerodynamic forces acting on the driver's head

Screen test

Continuing to chart the aerodynamic development of the IndyCar Aeroscreen

By Francesco Manara, Marco Milanetti, Dallara design

Even though the Aeroscreen only hit track in an official event in 2020, and the operative design phase only started in 2019, IndyCar had been collaborating with Dallara Automobili on its development since 2017.

As a popular adage says, Rome wasn't built in a day, though, and it took a great deal of time and effort to study and optimise all its elements properly, involving multiple different aspects and engineering disciplines. In this article, we will go behind the scenes of the Aeroscreen's aerodynamic development.

Looking at the overall dimensions of the Aeroscreen, one could imagine a high impact on the aerodynamic performance of the car in terms of drag increase and downforce alteration. Actually, most of the job concerned other aspects of its aerodynamic behaviour.

Of course, the aero coefficients that determine car performance were constantly monitored during its development, but they were not the only driving factor. Most of the downforce produced by open-wheel racecars comes from the front and rear wings and from the underwing, while the top part of the car body is not as crucial. For this reason, the impact of the Aeroscreen on downforce is generally quite limited. As can be seen from **Table 1**, the impact it has on drag is also lower than one might expect, thanks to its streamlined design, which gently deflects the air from its original path.

Table 1: Effect of Aeroscreen introduction on drag and downforce coefficients in speedway and road course configurations

Configuration	ΔCd	$-\Delta Cl$
Road course – high downforce	+0.2%	-1.5%
Oval speedway – low downforce	+2.4%	-1.6%

In addition to the turbulence introduced on the upper body, the Aeroscreen also marginally affects the flow over the rear wing. This is where the most loss of downforce occurs in high downforce condition. In this case, the rear wing downforce loss comes with a bit of drag reduction (called induced drag), which is why no overall drag increase is seen in road course trim.

In low-downforce speedway spec, the load generated by the rear wing is much smaller, and most of the downforce loss comes from the turbulence induced on the upper body itself. As a result, in speedway trim the drag increase is higher since there is no gain of induced drag. All in all, the downforce loss in road course trim is mainly responsible for a lap-time increase of about two tenths of a second, while the drag increase is slowing the Indy 500 average speed by about two mph.

This, however, is only one side of the coin, as the increased weight and higher c of g caused by the Aeroscreen installation also contribute to a performance reduction.

Driver comfort

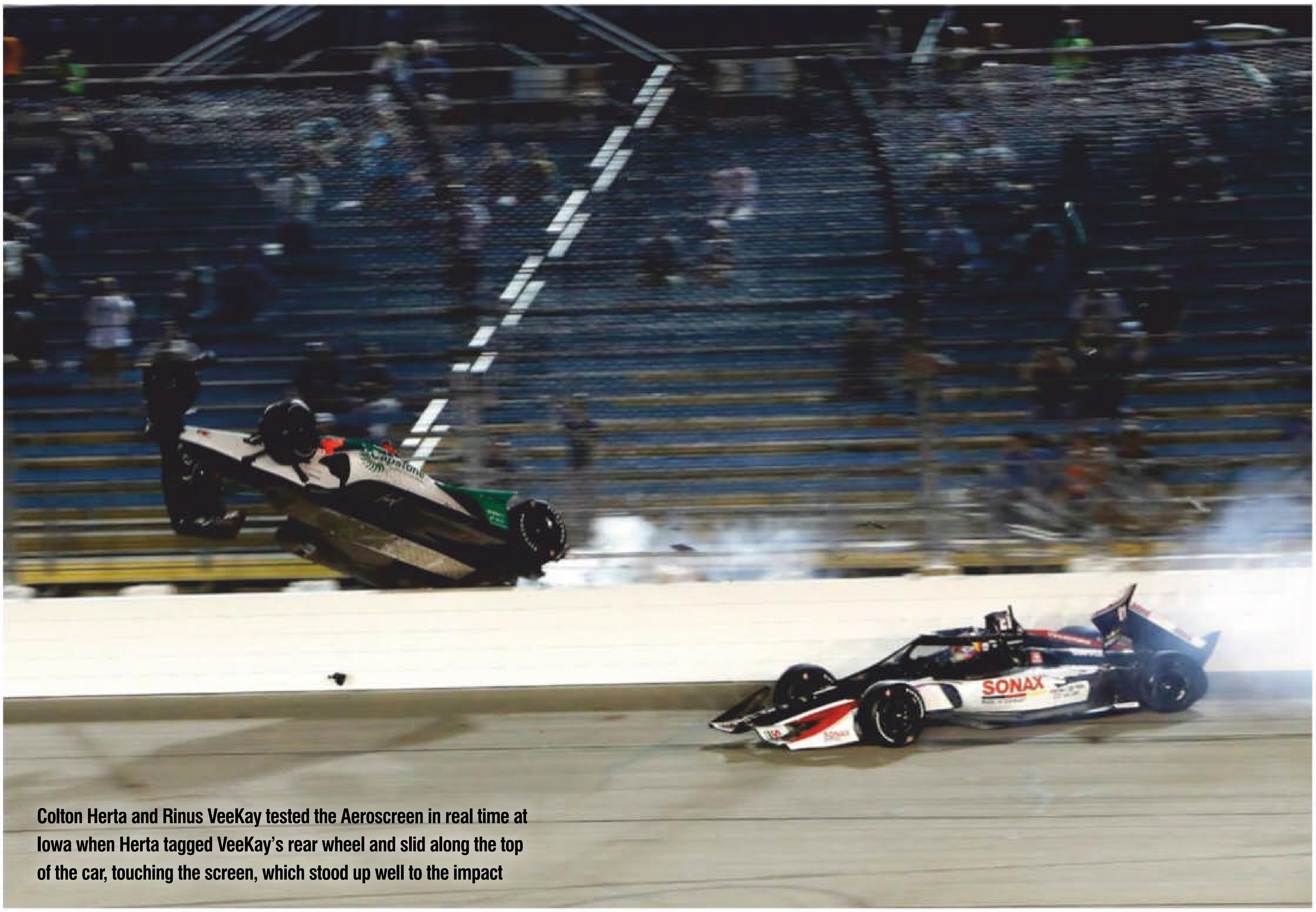
Equally, if not more important, in its development were comfort and driver visibility. Moreover, as we will go on to see, driver comfort creates different challenges and implies different requirements when running in road / street courses compared to when racing on ovals.

In additional to multiple, and possibly conflicting, targets, the engineers had to deal with several boundary constraints, requiring creative solutions and compromises.

IndyCar defined severe structural specifications in order to guarantee the highest possible driver protection standards. The system must be able to bear 150kN without breaking, and has to properly shield the driver's head from any errant debris. This definitely implied a strong limitation on the shape of the structure and thickness of the screen.

The ballistics of possible debris coming from other cars in case of accident was the key factor in defining the shape and height of the polycarbonate screen itself.

The downforce loss in road course trim is mainly responsible for a lap-time increase of about two tenths of a second



Colton Herta and Rinus VeeKay tested the Aeroscreen in real time at Iowa when Herta tagged VeeKay's rear wheel and slid along the top of the car, touching the screen, which stood up well to the impact

481.576 MPH

9 Hot Rod Trophies

3,156 HP

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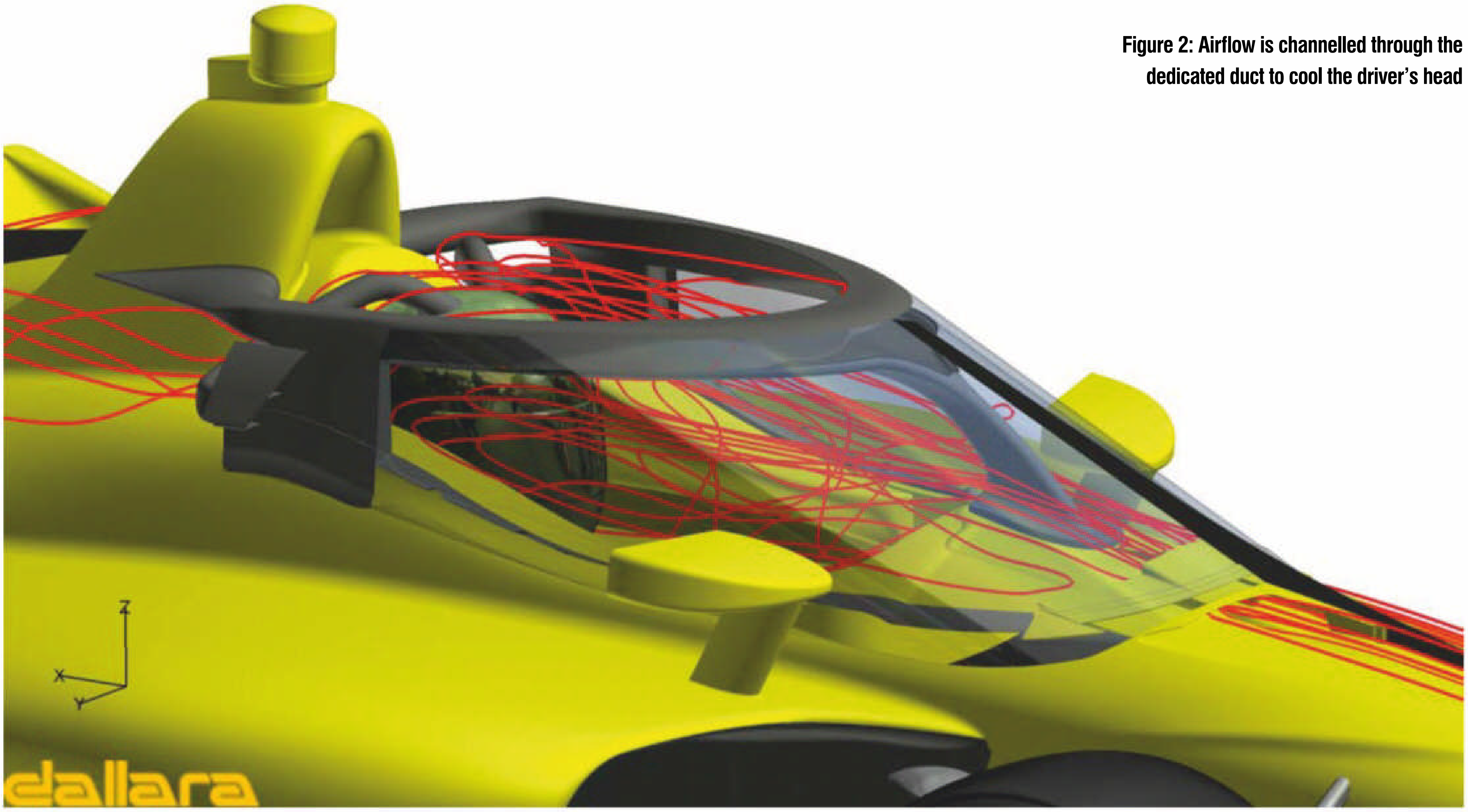


Figure 2: Airflow is channelled through the dedicated duct to cool the driver's head

Finally, the structure was designed over the existing DW12 chassis. This represented a big challenge as the packaging of a racecar is always very tight, and the installation of a completely new system on an existing car is commonly quite complex. This was only made possible through a close cooperation with Dallara, which designed the current chassis eight years ago and followed the history of this car through the DW12 seasons, the AeroKits era and the new Universal AeroKit generation.

Field of vision

The necessary visibility represented an additional limitation in the design of the lower structural frame for the assembly, both in terms of driver field of visibility and refraction angle of the polycarbonate screen.

In 2017, during the development of the 2018 Universal AeroKit, car aesthetics represented a critical design factor, aiming to offer the best show from every point of view. After the enthusiastic reviews garnered in the first two seasons of the new kit, there was a risk such a visually intrusive device would spoil the look of the car. While the Aeroscreen is undoubtably better looking than F1's flip-flop-like Halo, Dallara had a constant interaction with IndyCar to harmonise the new components with the existing design of the car, even in the small details.

In such a complex scenario, a special effort was required to make the aerodynamic solutions work without jeopardising all the other aspects involved.

Focussing on aerodynamics, IndyCar has represented one of the most iconic open-wheel and open-cockpit formula cars since the early 20th century. But with the introduction of the Aeroscreen, the single-seater chassis borrowed some features of a closed-cockpit car, not least the necessity to provide a sufficient level of cooling for the driver sitting inside the cockpit.

Keeping cool

We all have experienced how easy it is to catch fresh air opening our car's window when travelling at speed. For the same reason, cockpit ventilation was not a concern for high-speed, super-speedway races such as the Indy 500, but became absolutely critical on lower speed street and road course tracks, where collecting the right amount of air into the driver area is more of a challenge.

In order to guarantee driver cooling in all conditions, many different geometries were evaluated using Computational Fluid Dynamics (CFD). All concepts were based on the principle of drawing fresh air from outside, and blowing it into the cockpit to cool the driver. In this regard, some help came from Dallara's experience with the design of closed-cockpit endurance prototypes. In such cars, an inlet tube is used to send fresh air into the cabin from the outside, and most drivers direct the air jet towards their helmet in order to enhance and cool the air they breathe. Don't forget, these drivers are top-flight athletes!

So most of the effort focussed on a duct blowing towards the upper part of the driver's body. The aerodynamic team then designed a new damper cover panel to accommodate an air intake just in front of the Aeroscreen bottom frame. A duct channelled the air between the windscreen and the chassis, guiding the flow towards the driver.

Dallara had a constant interaction with IndyCar to harmonise the new components with the existing design of the car, even in the small details

Figure 2 shows how the air energy flow entering from the damper cover duct creates the appropriate ventilation inside the cockpit and ensures the correct air circulation around the driver's head.

The biggest challenge in this part of the design process was finding room for the duct amongst the dampers and electronics. In addition, in order to also provide cooling to the lower part of the body, two nostril-like ducts were fitted on the nose to intake air and stream it to the driver's legs.

Head work

As noted earlier, oval and road course races come with different requirements. At road and street courses, drivers have to face the physical effort of acceleration change and multiple turns in different directions. On speedway circuits, drivers reach the highest

An important part of the aerodynamic development was attempting to restore the same forces experienced without Aeroscreen on the drivers' helmets

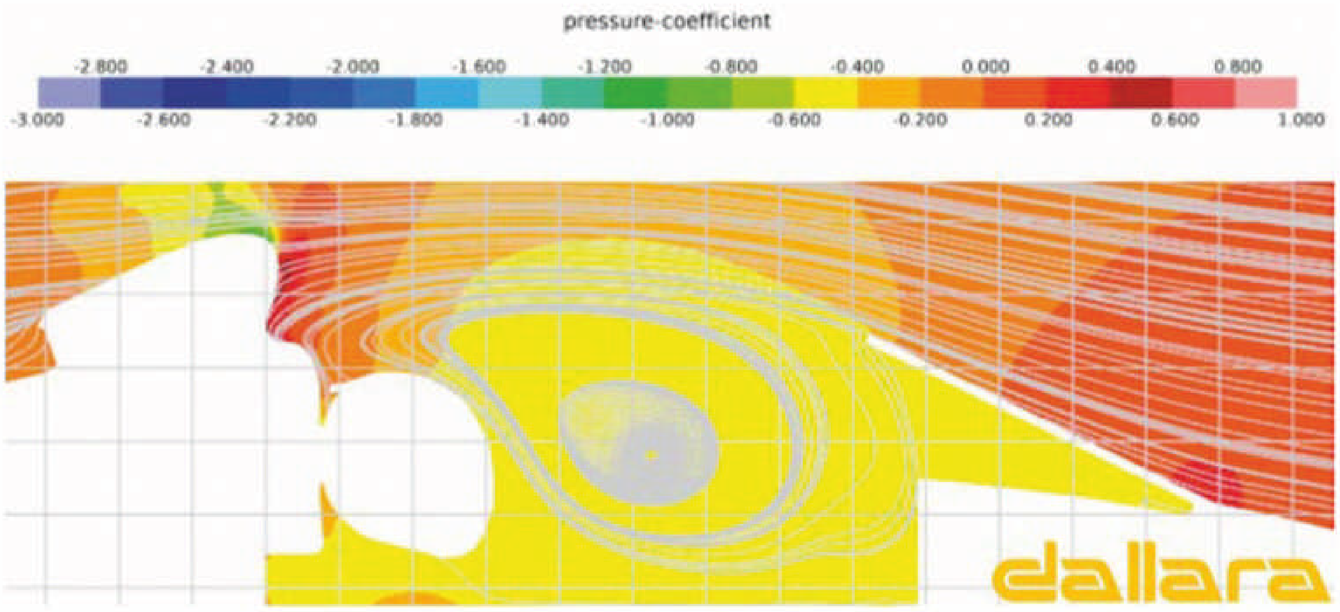


Figure 3: CFD of first prototype windscreen. The airflow stagnation point is shown by the orange behind the driver's helmet

speeds, upwards of 230mph, so engineers had to consider the loads the air velocity and pressure field at these speeds provoke on drivers' bodies. And the aerodynamic forces acting on the driver's head.

In the very first test with a prototype Aeroscreen in 2018, drivers reported the feeling of having their head 'pushed forward'. When running the first CFD simulations, it became evident the airflow stagnation point created by the Aeroscreen behind the driver's head was responsible for the forward force felt by the drivers (see **Figure 3**). In addition, an effect of the Aeroscreen was it modified forces in the vertical direction. For some options, it can also switch from pushing down on the head (negative z force) to sucking it up (positive force). **Figure 7** shows the strong increase of forward push and **Figure 8** the big reduction of vertical force caused by the first prototype model of Aeroscreen.

Frame optimisation

An important part of the aerodynamic development was attempting to restore the same forces experienced without Aeroscreen on the drivers' helmets. The part with the greatest influence on this vertical force was found to be the top frame of the screen. The aerodynamic department tested several solutions in this zone, and the best versions were sent into production.

The first option included a top fairing with a sharp trailing edge. A second solution was a top fairing with a domed profile. The third version included a family of winglets (with different camber and incidence) to be installed on the domed faring.

It turned out the solutions that improved the vertical load condition were not the best ones to reduce the load in forward direction. According to CFD, the geometry with a sharp top fairing was able to mitigate the stagnation point behind the driver's head (**Figure 4**). This can be deduced by the switch from orange to yellow in the zone behind the helmet.

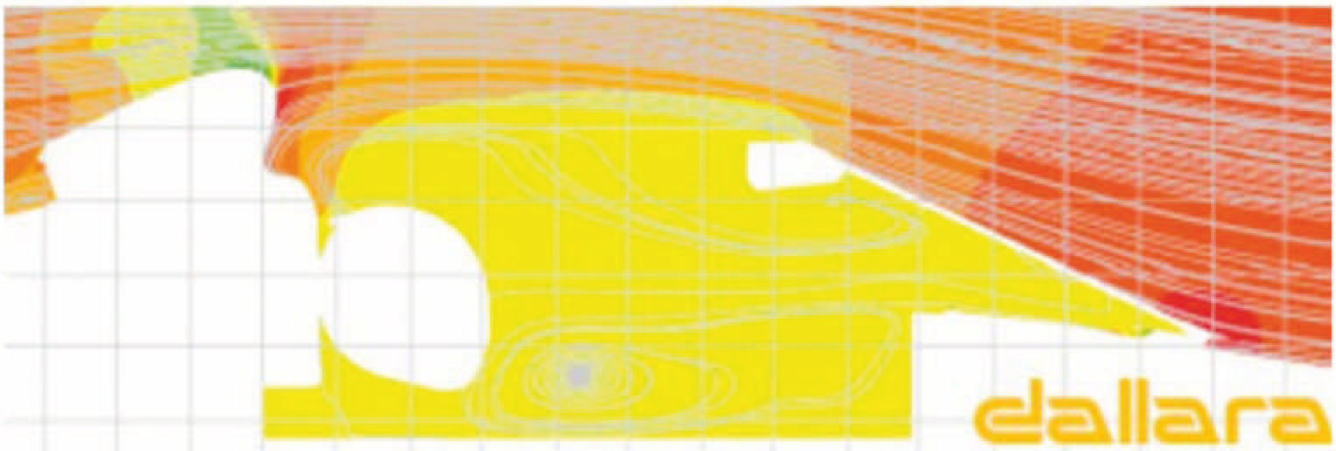


Figure 4: CFD of sharp edge top fairing showing improved airflow over the first prototype shown in Figure 3

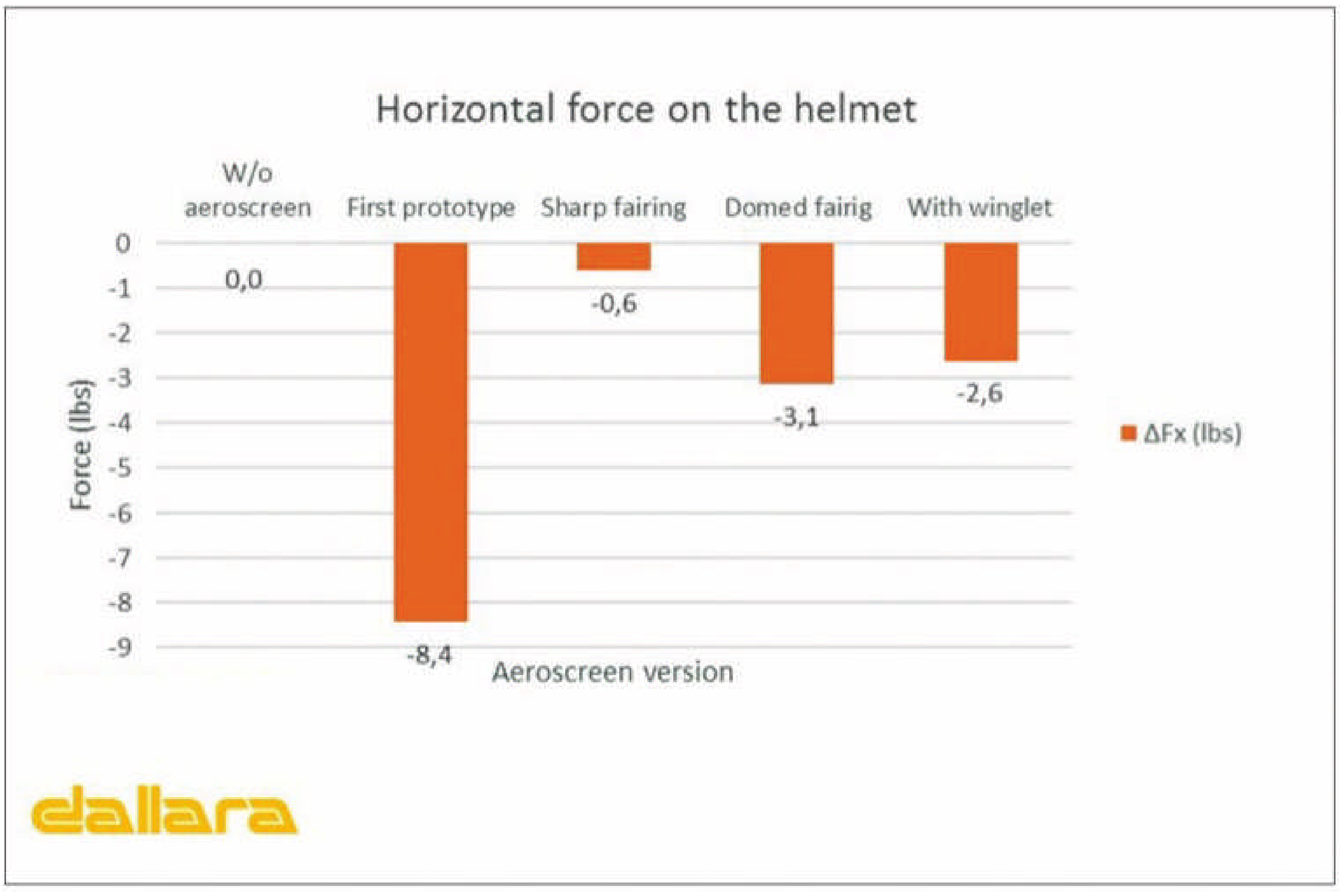


Figure 7: Horizontal force on the helmet calculated for different options of Aeroscreen (negative means forward directed force)

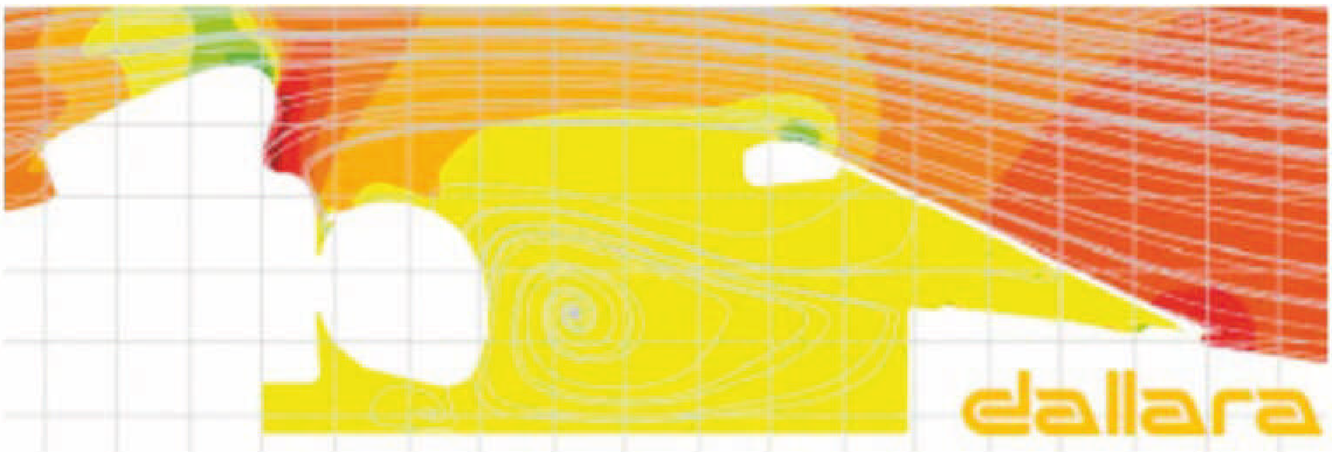


Figure 5: CFD of rounded top fairing

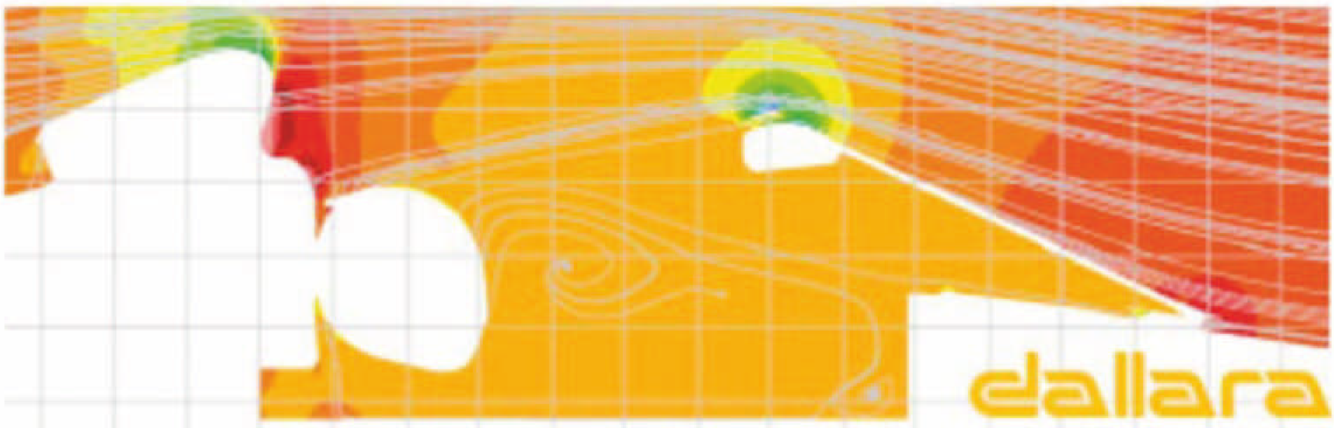


Figure 6: CFD of rounded top fairing with winglet

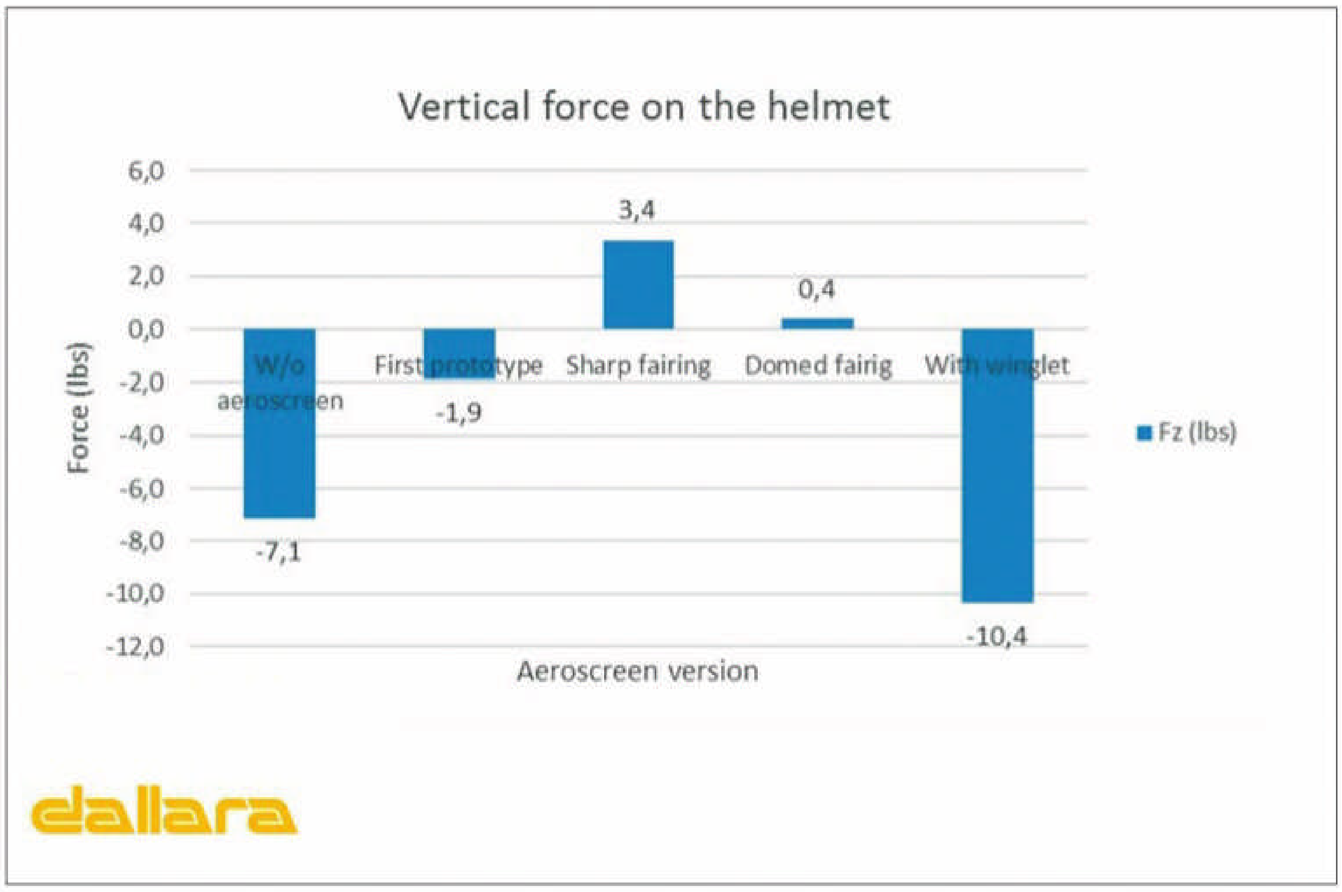


Figure 8: Vertical force on the helmet calculated for different options of Aeroscreen (positive means lifting force)

Figure 7 shows how the sharp top fairing restored the original force on the helmet in the forward direction but, in turn, increased lift on the driver's head (**Figure 8**).

Conversely, the rounded fairing with a winglet completely re-established the initial force in vertical direction (**Figure 8**), but made the ahead pushing worse (**Figure 7**). Incidentally, note in **Figure 6** how big the flow deflection towards the driver's head is from such a small winglet.

The domed top faring without the winglet met in the middle (**Figure 5**).

So, as always happens in engineering work, a compromise had to be accepted, trading off vertical and transversal loads. The last word upon which compromise to choose was up to the drivers. After having discussed the results together, IndyCar and Dallara decided to test the different solutions for cooling and aerodynamic loads on track.

Racing environment

On-track testing is of great importance to validate simulations in every aspect of motorsport, and the Aeroscreen activity made no exception. After some preliminary tests in 2018, the first prototype was tested in all racing environments in three back-to-back weekends in October 2019, at Indianapolis Motor Speedway (speedway), Barber (road course) and Richmond (short oval).

At Indianapolis, drivers tried four different versions of the upper fairings and their feedback was that the vertical load on their helmet was not as annoying as the forward suction, so they chose the solution that minimised forward load. That was the sharp top fairing version.

For the cooling side (tested at Barber), on the other hand, they were not fully satisfied. In this phase, collaboration among all the different parties involved was key to achieving the desired result. The teams and engine constructors (Chevy and Honda) were crucial in the liaison work with the drivers, who always have the last word when speaking of track tests, and contribute to finding the best solutions.

Drivers…always have the last word when speaking of track tests, and contribute to finding the best solutions

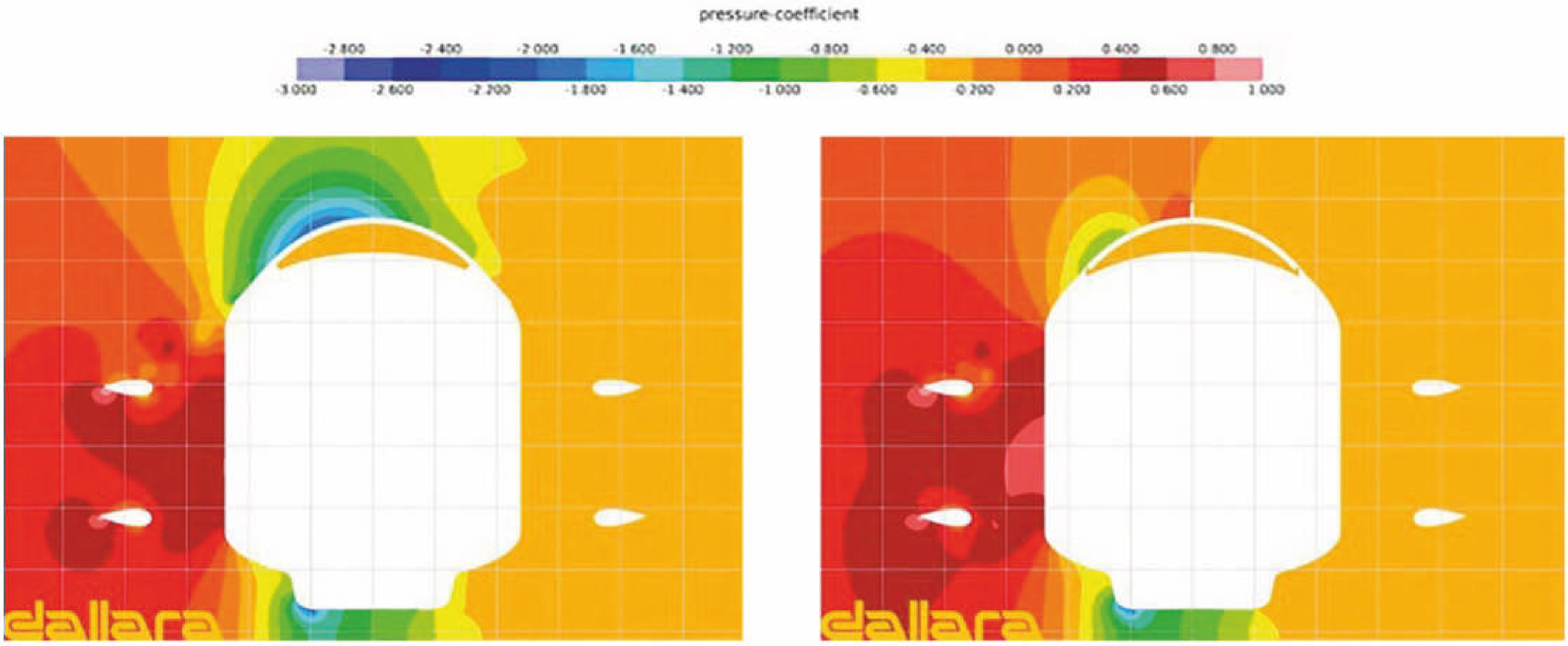


Figure 9: Cross section of CFD flow in 90-degree spin simulation, with Aeroscreen wicker (right) and without (left)

Among the options brought by the constructors on track, the most effective one was a duct drawing air from beside the Aeroscreen and pumping it directly into the top of the helmet and into the mouth section. It was then a Dallara job to develop it further into the definitive shape. It was also decided that the final part of the damper cover duct be optional, so it can be designed according to specific driver needs.

Aero stability

Still, though, the job was not finished. Since the design of the DW12 in 2010, Dallara and IndyCar have focussed their attention on the risk of car flips, or take offs, in the event of an accident. Therefore, any modification that affects the aerodynamics of the car requires CFD simulations be performed to assess the impact on this 'aero stability' behaviour. As those risks are exacerbated with car speed, the recurring conditions at Indianapolis are usually replicated and simulated.

When considering a car spun 90 degrees with respect to its direction of motion, the curved surface of the Aeroscreen provided an increased low-pressure area on the upper part of the car, meaning a higher lift and a higher take-off risk. In **Figure 9**, on the left, this suction is represented by the light blue / green bubble on the screen top surface.

A wicker running all along the screen centre line, which in normal conditions has very little influence, causes an interruption of this upper suction and greatly reduces the risk of take off in a spin condition. As you can see, the blue bubble completely disappears in the CFD image on the right of **Figure 9**.

Another potential and understated issue investigated was the so-called 'Detroit Race 1' phenomenon. When a damp track is covered by a lot of dust and dirt particles, the drivers experience an annoying accumulation of muck on their helmets, requiring them to wipe their visors. This condition often occurs at the Detroit event, and is more critical during the first race, hence the name.

The Aeroscreen is equipped with tear-off films to facilitate cleaning at pit stop, but drivers cannot manually wipe the Aeroscreen during a session as they used to with their helmet visors. For this reason, IndyCar requested a study of the areas where the dirt would drop off with a higher probability. Dallara once again made use of its CFD technology to simulate the phenomenon.

In the simulation, the flow was injected with some virtual particles. The engineers prescribed the diameter and density of these particles and were able to see how they are carried by the air, under the assumption that the velocity field is not modified by the presence of the dirt particles themselves. The flow was injected with a high enough number of particles that distribution could be obtained by looking at where they were trapped on the Aeroscreen. The portions where a higher amount of particles impacted the screed defined the most critical areas for dirt in the Detroit Race 1 scenario.

The most important parameter guiding any dirt deposits are the characteristics of the particles themselves. If particles are heavy, they impact the screen uniformly, and the aerodynamic field will not deviate their trajectory significantly. On the other hand, CFD showed that with lighter particles, given the flow field around the Aeroscreen, some areas are more critical for dirt deposition, and **Figure 10** shows the results of the simulation.

The blue points show where particles injected into the fluid impact on the polycarbonate screen. Their distribution suggests a higher concentration of deposition is expected in the central and lower part.

This tool still needed to be validated after the first few races, but it could give important information on how to minimise this annoying effect in the future.

Figure 10: CFD prediction of dirt deposition upon the polycarbonate screen of the Aeroscreen

Working smart

How a New Zealand-based engine builder is combining technologies to make small batch motorsport parts more accessible

By CHARLES CLARKE

Readers might remember that in *Racecar Engineering* V28N5 we featured the Hartley V12, a naturally aspirated V12 engine, based on 5.0-litre Toyota castings, which produces about 750bhp at 9500rpm.

Since then, the Palmerston North, New Zealand-based company behind it has produced a second version of this potent powerplant, designated Prototype Number 2, which has twin turbochargers and is estimated to produce upwards of 1500bhp on full boost, and a more modest 1050bhp at 12psi of boost pressure.

While the figures for both units are impressive, equally noteworthy is the way they are produced. This is because, in order to speed up manufacture and reduce cost, Nelson Hartley, co-owner and engine designer (and, incidentally, brother of former F1 and LMP1 driver Brendon) at Hartley Engines and Motorsport, has taken to making some of its parts using 3D printing, instead of traditional machining.

For example, instead of machining the entire intake manifold from a solid billet, the flanges have been water cut from 8mm aluminium sheet stock, the throats 3D printed and the throttle bodies sourced from the standard Hartley Engines parts bin.

The Hartley 3D printed plenum is capable of withstanding heat far in excess of standard intake air temperatures

Zero leakage

Assembled, it is lighter, less expensive and less machine intensive than the previous billet part the company used on Prototype Number 1. And because of the quality of the 3D printed surface, internal flow characteristics are as good, if not better.

'Because you can get some leakage between 3D printed layers, I coated the internal surface of the throats with one layer of epoxy,' explains Nelson. 'Then to test the strength of the 3D printed plastic, I put 100psi into the throat of the 3D printed fabrication and got zero leakage.

'The throat itself is 2mm thick and stiffening ribs add an extra 1.5mm thickness. So the whole construction is only 3.5mm thick and yet can withstand 100psi easily.'

The material used in its construction is similar to CRP Technology's Windform. It has chopped carbon fibres in it, but no carbon fibre strands. It also prints like a normal fused deposition 3D printer filament.

According to Hartley, the 3D printing phase for all throats was about three hours per runner, representing a time saving of about two days over what would have been a three-day billet machining operation.

'No one else seems to be using this kind of hybrid construction,' says Hartley. 'I don't know why, it's relatively easy and produces such a nice product. It's a little fiddly but, once you refine details like common sizes and jigs to drill the holes, it works very well.

'It also only weighs about 1.3kg which, for a consumer product, is really light.

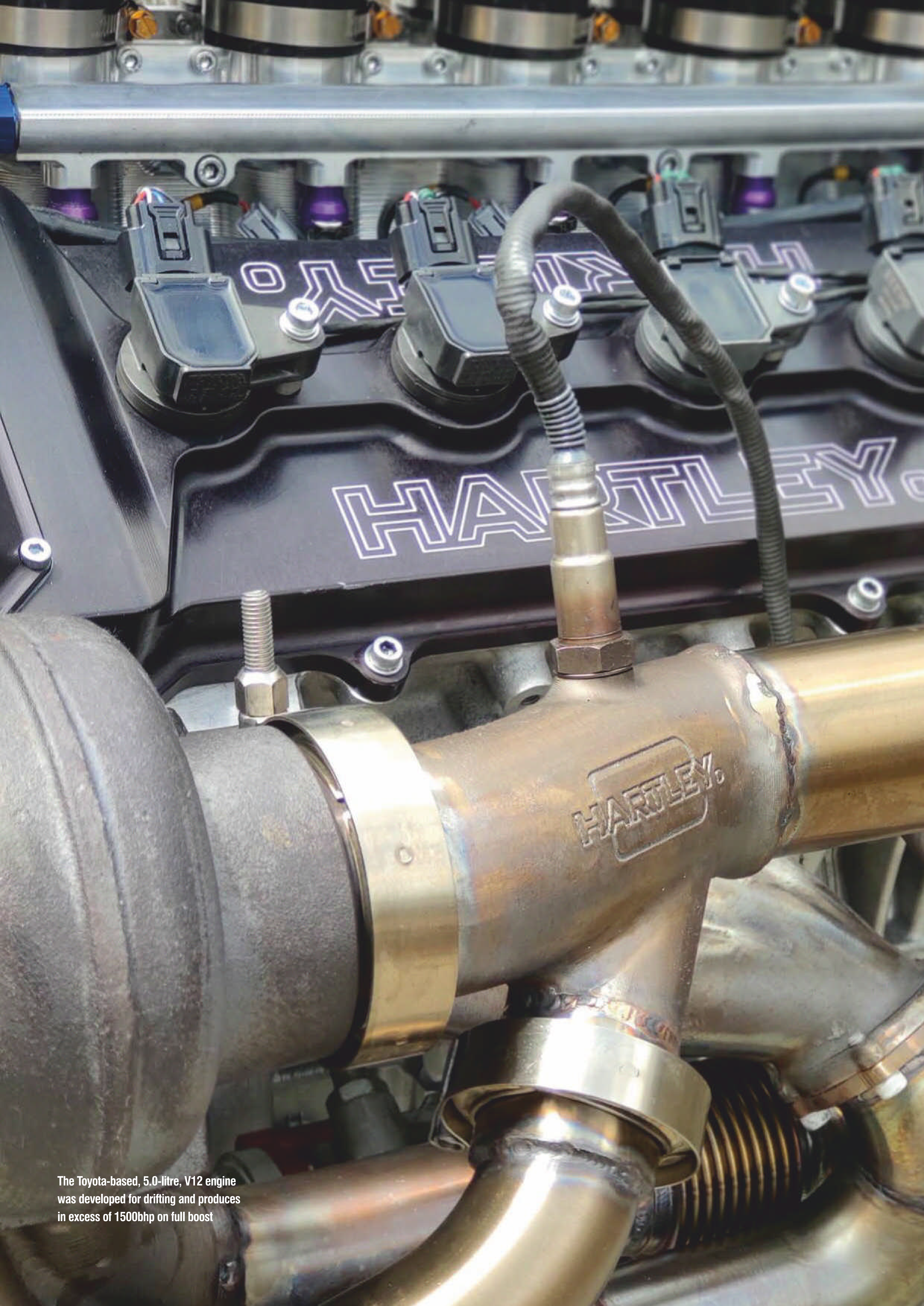
'An F1 team is going to make it all out of carbon and it's going to weigh 500g, but the people I'm trying to make manifolds for aren't competing against them and don't have the resources to fit such delicate carbon parts.

'No one else seems to be using this kind of hybrid construction'
Nelson Hartley, co-owner and engine designer at Hartley Engines and Motorsport

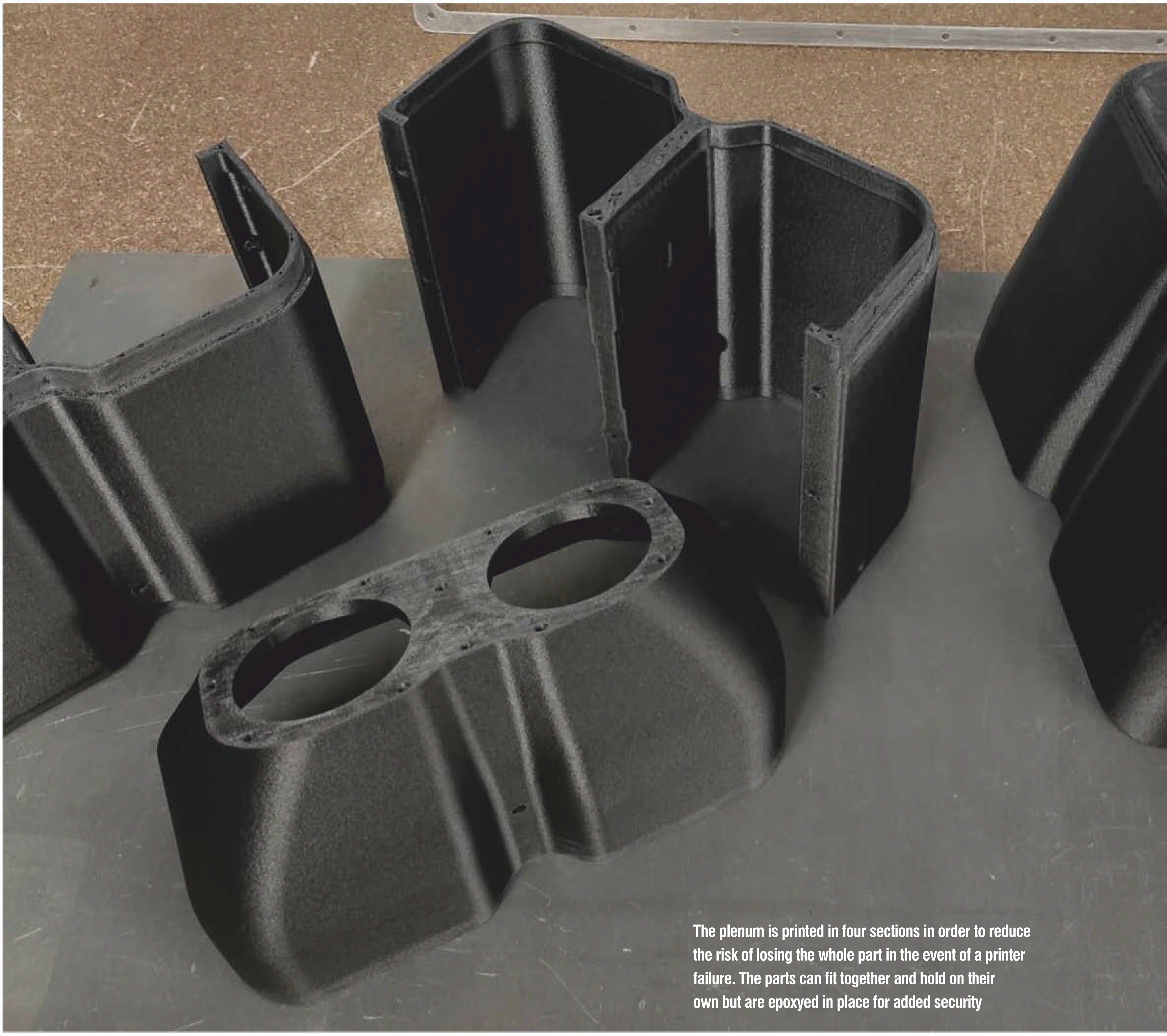
You need aluminium flanges to survive in a typical track garage environment.'

'I could probably make the same part out of billet at roughly the same weight. We could make the aluminium part as light, especially if we investment cast, but with billet machining there are always restrictions where you can get a tool, which restricts design freedom.

'I know I can make a hybrid version lighter yet, but it's not just about that. I'm saving time, there is more design freedom and no waste.'



The Toyota-based, 5.0-litre, V12 engine was developed for drifting and produces in excess of 1500bhp on full boost



The plenum is printed in four sections in order to reduce the risk of losing the whole part in the event of a printer failure. The parts can fit together and hold on their own but are epoxyed in place for added security

Similarly, once the pieces are designed, there is very little operator involvement with the 3D printing process and design iterations can be made on a part-by-part basis.

Print farm

The printers currently used to achieve appropriate layer build up and envelope are modified commercial printers, but Hartley's plan going forward is to have a print farm of six to eight printers continuously working away in the background.

'The high-end, high-temperature, commercial-grade printers are far outside our price range [between $50,000 and $150,000 each], so I have been modifying much cheaper 'consumer-grade' printers to do the same thing as the much higher end machines but at a fraction of the cost, albeit with a lot of my own testing and development.'

'The printing is not particularly easy with moderate equipment, but we are getting it more dialled in by the day,' says Hartley.

After extensive research, all the intake parts are made from Ultem 1010 mixed with carbon fibre, also known as PEI.

The Ultem plastic performs well, especially in the way it deals with heat, as Hartley explains: 'I can heat the plastic parts in the oven at 200degC, and then take them out and sit them on the bench and, within 30 seconds or so, they are at room temperature. A piece of aluminium would hold that heat for hours.'

The plenum

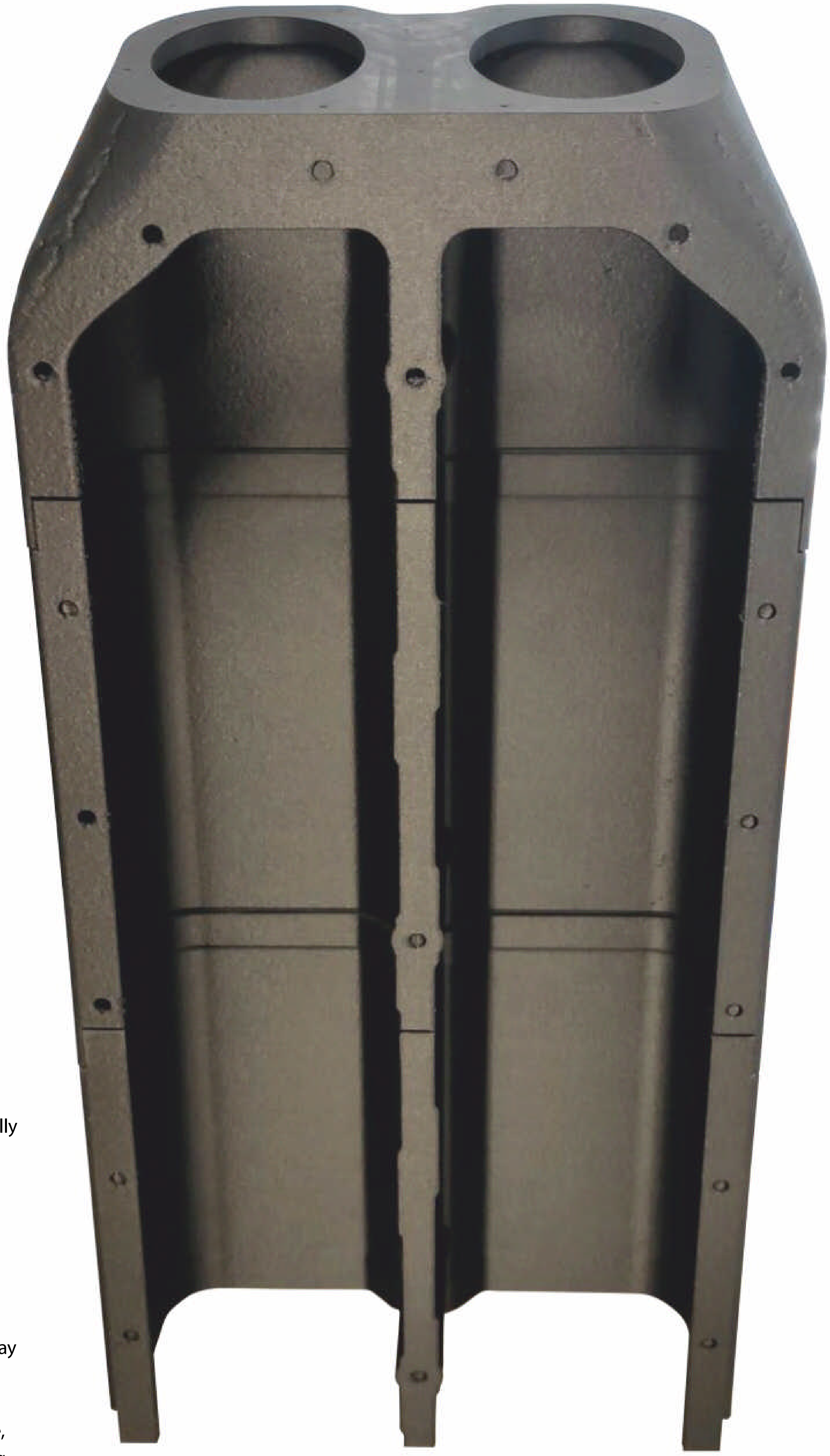
The most significant development for V12 Number 2 is the 3D printed plenum. This is made in four sections, which are stiffened and glued together. The printed part is covered with a single layer of carbon fibre pre-preg cloth, which produces a very light, very strong, impervious plenum. The entire 3D printed part is effectively a mandrel for a hybrid composite, monocoque, carbon fibre, 3D-printed plenum chamber.

Each part of the 3D printed mandrel shape is printed vertically and is self-supporting. Hartley says because of the way it has been designed, the whole assembly would even hold itself together when fixed to the engine, though for security and to ensure positive sealing, the unit is epoxied together.

The layering technique used in its construction builds up in a honeycomb fashion, so there is significant inherent wall thickness to provide strength and stiffness.

The mating flange to the air box is created by bonding a 1.5mm thick aluminium plate to the 3D printed flange. This is more durable than just a 3D printed plastic surface, and can

‘The thing that gets their attention is the cost. A hybrid composite plenum is about half to three quarters the cost of a billet machined one.’



be sanded and silicon can be used to seal the air box if that is deemed necessary.

The whole assembly should be temperature stable to about 150degC, way above normal intake temperatures, which shouldn’t reach much over 50degC, especially as the plenum is on top of the engine, even further away from the heat source.

Printer sensitivity

‘At the moment, the problem with printing upwards is my current printer doesn’t have enough sensitivity to ensure a stable, viable print as the height increases,’ says Hartley. ‘Say it gets 90 per cent through the print, which might take 50 hours on a large part like the intake plenum, and the process has a failure, you have to scrap the whole part. By making the plenum in four pieces, we are limiting the potential for expensive failure.

The four-part plenum assembled and ready for use. Parts are made from Ultem 1010 mixed with carbon fibre

The total material cost for the 3D printed part of the plenum is around $200, which is trivial compared to the cost of billet aluminium, and the waste involved in machining this part from solid.

'Because of the cost implications alone, I can't understand why more people aren't using additive manufacturing in motorsport,' says Hartley. 'Okay, it's true you have to design from the outset to make parts using 3D printing, it is not just a question of taking a part that was designed to be machined from solid and 3D printing it instead, but the benefits far outweigh the downsides.'

The hybrid plenum is probably twice the weight of a thinner, carbon-only turbo plenum, but there are hidden benefits to this, as Hartley explains: 'Something that is often overlooked with large, thin, intake plenums is the way the pressure and pulses distort the part. With enough surface area, a straight carbon fibre, or even aluminium sheet metal intake, can start to vibrate like a drum, which has a negative impact on the air pulses.'

The exhaust system

'Similarly, for the exhaust manifold for the turbo set-up, I've taken a completely different approach,' continues Hartley. 'Traditionally, you would use thick-walled steam pipe for an application like this, which is very limited in sizes and curves, and basically nothing flows very well as it all has to be chopped and welded, which is a lot of work.

'This design for the [3D printed] exhaust manifold uses the same algorithms I would use to design an exhaust port in a cylinder head. All the curves are tangentially continuous, with no interruptions, so it will flow like an exhaust port should.'

With the printed exhaust manifold, the 3D printed parts are sent to the foundry and used as plugs for traditional investment casting in stainless steel. Because these parts are plugs in the casting process, they are made of a relatively cheap filament plastic, typically around NZ$30 (approx. £15 or $20) per kg. They are not part of the final structure and are thrown away after the investment mould has been made. Using the less sophisticated material also means they print at twice the speed of more complex material.

'All I would then need to do is design the fixture, which is relatively easy using plate cutting,' expands Hartley.

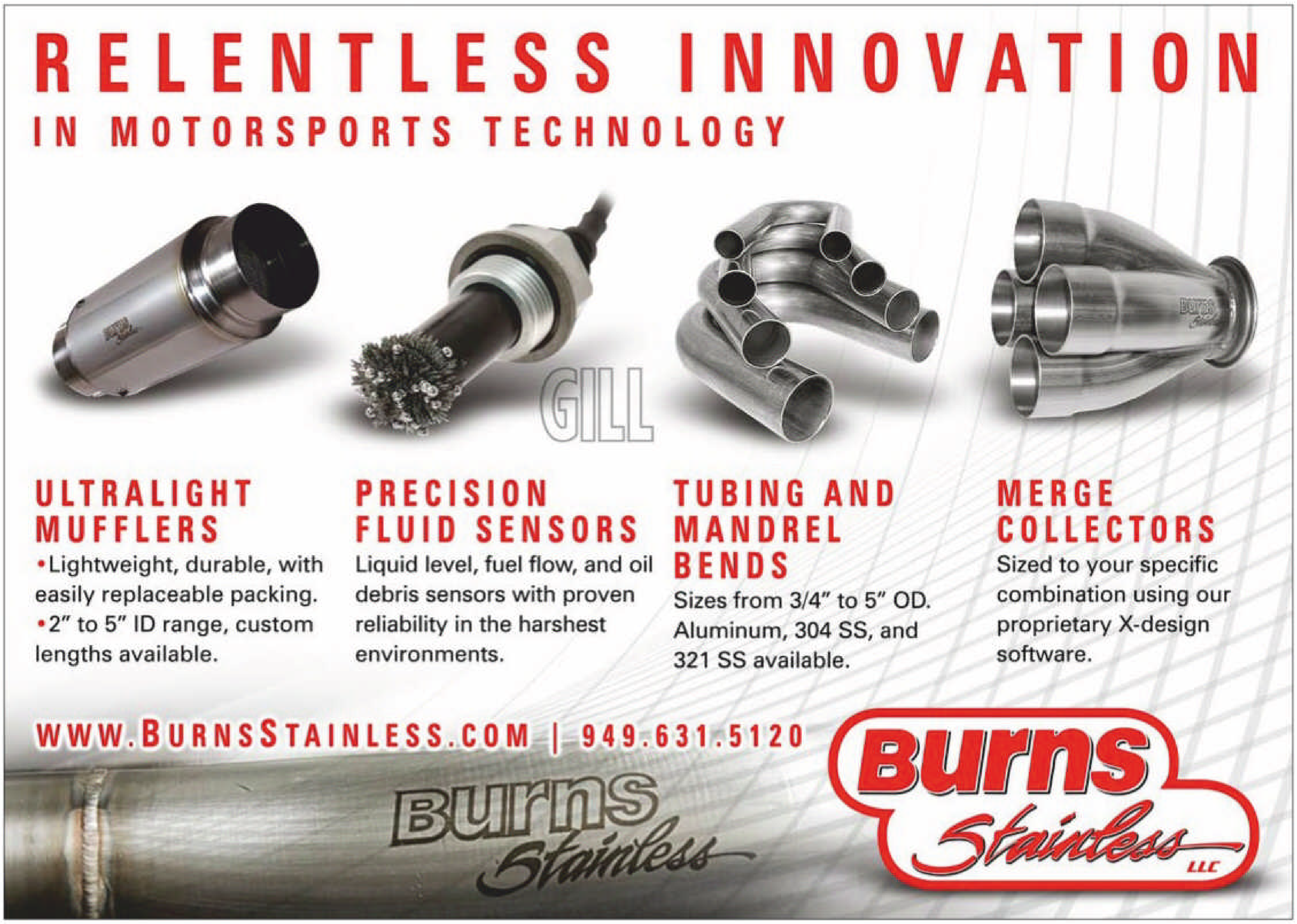
'The entire manifold set-up is pretty thin at around 2.5mm. We could have made it thinner still, but I wanted to add extra thickness to retain a bit of heat for the turbo.

'The pattern also includes the wastegate tube and the O_2 sensor boss, so it is a lot cheaper than fabricating it, and I can use manifold-type curves to improve the flow characteristics over those I could achieve using fabricated steam pipe, so it's a win-win.'

Exhaust ports are printed in one piece, rather than being a complex, fabricated part with multiple welds. Flow characteristics can therefore be optimised

This design for the exhaust manifold uses the same algorithms I would use to design an exhaust port in a cylinder head

As the 3D printed exhaust parts are a sacrificial plug for investment cast stainless steel components, the material used in their construction is a cheaper filament plastic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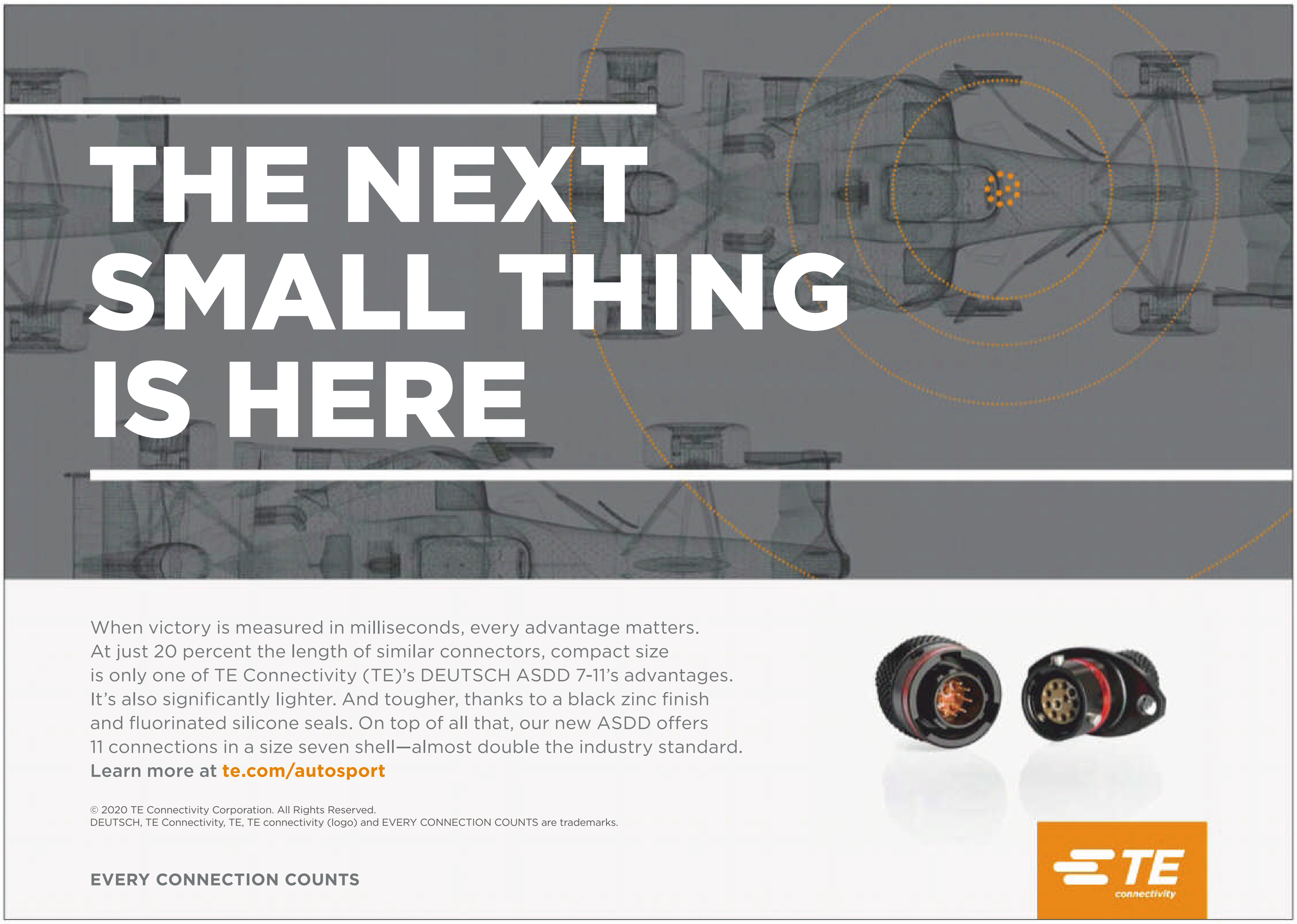
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Items such as the intake manifold on the Hartley V12 are a hybrid design, using lightweight and cheap 3D printing for the throats and water jet-cut 8mm aluminium for the flanges

In designing an exhaust system for a V12 with turbos, space is a real issue. Using this exhaust port flowing technique produces a much better exhaust manifold and allows the package to be as tight as possible. It's a bit like designing optimal ports for a cylinder head without the casting in the way.

Design philosophy

As with most new methods of manufacture, there is a tendency to replicate designs manufactured in other, more traditional ways. The whole point of the hybrid composite approach is you can actually change the way you design a traditional component, specifically for the 3D printing environment.

'In the case of the intake manifold, if I was to make it from billet aluminium the whole design would be completely different,' concurs Hartley. Though in this case, a combination of manufacturing techniques has proved to be the answer.

'Profile cutting is cheap, fast, accurate and, provided you're using the same plate thickness and individual items are nested together in the cutting process, there's very little waste, so it makes a lot of sense to use profiled flanges. But then use 3D printed parts for the tubular elements.'

Good engineering practice involves looking at the whole design and construction process and figuring out how a piece can be made more quickly and more cheaply. And in the case of motorsport components, invariably lighter and stronger, too.

'Rather than only using the tools you've got, sometimes it's better to look at the tools you *could* get to do a better, more sustainable and more economical job.

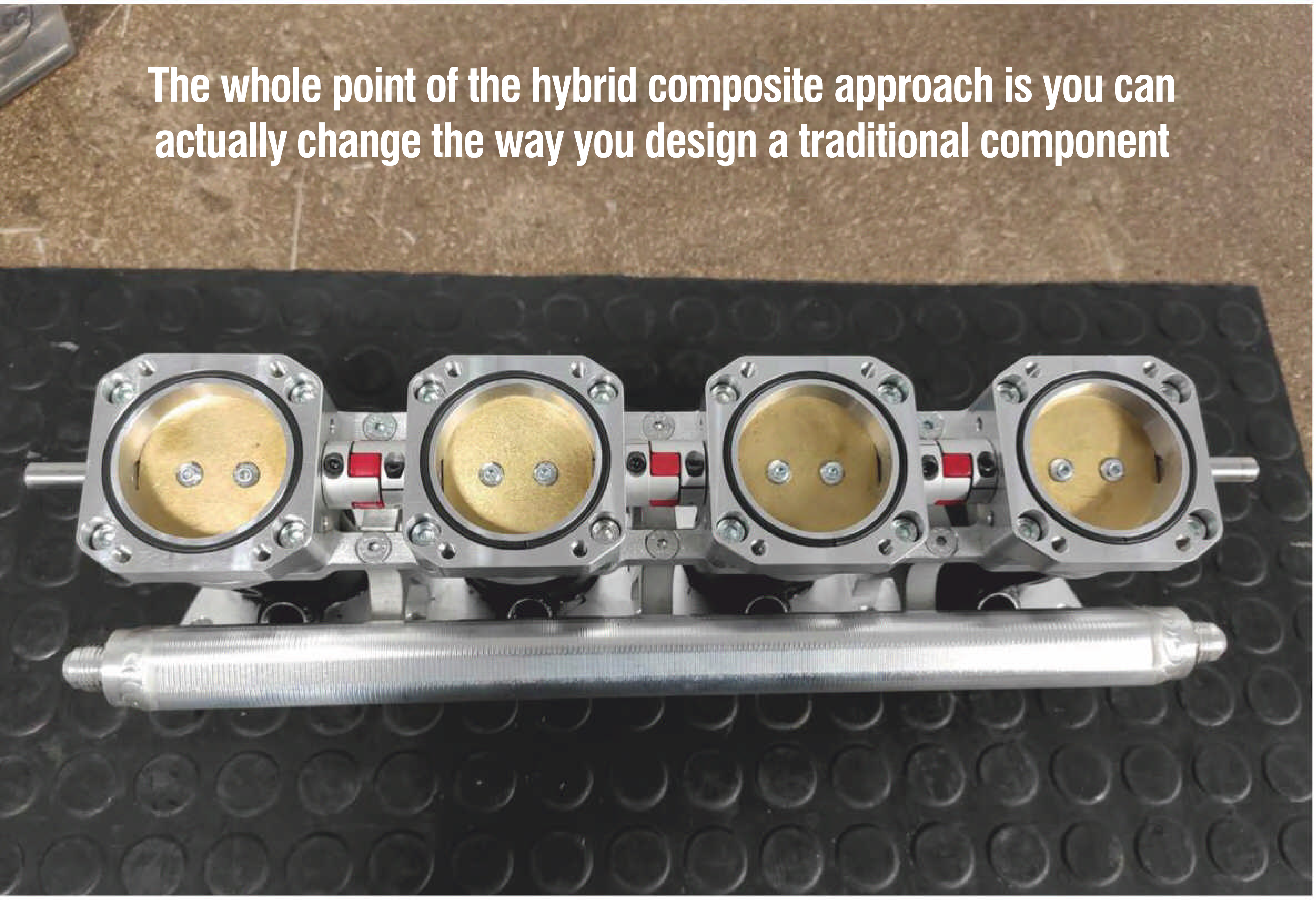
'Most people don't really understand this argument, but the thing that gets their attention is the cost. A hybrid composite plenum is about half to three quarters the cost of a billet machined one. Tell people that and they start to take notice.

'I'm not sure how the market is going to react yet. I haven't posted any pictures online, or tried to promote the technique until I've proven it on something significant like the twin-turbo V12 engine.'

There have been other instances where intake manifolds have been produced with 3D printers, but they have tended to be made with expensive, high-end plastics and on $500,000 machines. A plenum made this way would cost about $5000.

'I've managed to make one affordably on relatively modest equipment,' says Hartley.

The 3D printed plenum is covered with a single layer of carbon fibre pre-preg cloth, making for a light, strong, impervious part



Hartley produces more than just V12 engines and the 3D printing technique will accelerate development. The plan is eventually to have a continuously running print farm

'The printed plenum is hollow, it has a 1mm wall thickness and a lattice / honeycomb construction internally, so it's not really that different to traditional composite construction. I've just reduced the overall number of processes involved.'

The future

'To take this approach to the extreme, I would like to print something like an electric motorcycle without building a single tool for any of the carbon parts. This technique lends itself to making virtually anything using 3D printed structures as the core of any carbon fibre structural part, just without any tools.

'The electric energy side interests me, so this project has two goals, from a structural point of view and an electric propulsion viewpoint. An electric motorbike is something I could ride round the pits at a racetrack, so it's a test bed and wouldn't have to perform really well to prove the concept.

'For a motorsport product, you have to do more testing and optimisation to make sure it's right, whereas a novel item either works or it doesn't, but it helps me cut my teeth and learn about it without too much pressure for it to be right first time. It's a low pressure way of testing a new design philosophy.'

'My concept is that you print the core, carbon either side and then cure the whole structure in one go, saving considerable time and process. For short production runs, the savings are significant as no tooling is required, and design changes are easy. You don't have to worry about draft angles or any of the other design details you have to consider using traditional tooling and carbon lay-up techniques.'

The obvious way

'I'm not claiming I am doing anything unique with our work here. I've no doubt F1 teams are already making parts like this, as to me, it's the obvious way to make one-off carbon parts. When you see how complex F1 wings are, I don't see how they can be making tooling for all their new wings using conventional carbon part production. It's just not cost effective or time efficient. They must be printing these parts as they change the details so regularly.

'I'm not trying to achieve F1 chassis quality,' continues Hartley, 'but I think I can print a hollow motorbike frame and wrap it with pre-preg carbon, using some pretty high-end plastics and minimal material. Then, if I want to make a design iteration, I don't have to re-tool, I can just adjust the design to print a different part with a different shape.'

These plastics can handle high temperature and high pressure, they are good for 200degC (150degC is as much as you would use to cure most pre-preg parts), so it's safe to assume they could be used in conventional autoclave cure.

'I have seen some of the Formula SAE teams are making carbon monocoque chassis parts using low temperature cure resin infusion, and they say it's as strong as conventional autoclave cure pre-preg. Some of their finishing quality isn't that good, but they have access to some good technology from professional teams and industry, so it can be a good source of information.

'I like to think that once this is done and tested, I will be designing and making components for people rather than just building engines,' concludes Hartley. 'I'd like to develop a design studio alongside the engine building business. This twin-turbo V12 is the prototype and a validation of the process. But rather than the traditional design studio approach, I would like to spend half my time making parts, and the other half coming up with innovative ways to make the parts more cheaply and more effectively.'

Next generation Golf has hit the track in South Africa ahead of a planned assault on the TCR series

Local heroes

Volkswagen Motorsport South Africa has a rich heritage of engineering racing machines for the home market and, for 2020, has developed the world's first competition Golf 8 GTi

By RICHARD GOODING

High-profile activities have shaped Volkswagen's motorsport participation over most of the past decade. The top-flight Polo R WRC won the FIA World Rally Championship for four consecutive seasons from 2013, and the Golf GTi Touring Car has dominated international TCR series since 2016. A customer sports racing programme similar to that of the Polo GTi R5 cars the Hanover-based Volkswagen Motorsport outfit also builds, the GTi TCR has been phenomenally successful for the German manufacturer in terms of wins and exposure, and has even inspired a road car with the same name.

The arrival of the eighth-generation Golf has yet to see the racing TCR updated but, away from the glare of the official home motorsport activity, the world's first Golf 8 racer has been unveiled. Volkswagen Motorsport South Africa announced the Golf GTi GTC (Global Touring Cars) circuit racer in July 2020. A locally-engineered racer, the GTi GTC will defend Volkswagen's current Global Touring Cars championship title.

The South African team is used to developing its own product. The Polo Cup series was launched in 1997, and is one of the most popular one-make series in the country. Locally-built Polo rally cars for the national rally championship have also emerged from the outfit's workshops in Johannesburg.

Volkswagen Motorsport South Africa first competed in GTC when the championship arrived in 2016, using locally-engineered Jettas. South Africa's premier motorsport series, GTC fields 2.0-litre turbocharged cars with shared control components including a common chassis and running gear, ECU, suspension and tyres. Inspired by the V8-powered and series-controlled Supercars Championship in Australia, cost was a vital ingredient of the GTC recipe. Local OEM participation is high, and key manufacturers taking part in the series alongside Volkswagen include Audi, BMW and MINI.

Rapid development

With the South African arrival of the Golf 8-based GTi road car due in 2021, the decision was taken to promote the brand and build the first Golf 8-based racer. Built on the foundations of the Jetta GTC, development of the GTi GTC was fast.

'The building of the new tubular chromoly chassis took around three weeks,' confirms Mike Rowe, head of Volkswagen Motorsport South Africa. 'Stiffer than before, the main changes were in the material specification and some small improvements to the design.

'The biggest challenge was getting body panels for the new Golf as it had only just gone into production, but we got amazing support from our colleagues in Germany.'

Affordable programmes

The amount of local content and input has, in part, been dictated by the carry-over parts from the Jetta racer, but also currency fluctuations. 'The budget was not huge as it was only for the new chassis and body panels,' says Rowe. 'As a region, we have always been autonomous in terms of our motorsport programme. Our proximity to Europe and the unique challenges we face in South Africa mean we have to ensure our programmes are affordable and suit our needs.

'The reason we've done most of it locally is because our exchange rate is so terrible, to both the pound and euro,' continues Rowe. 'If we have to buy stuff in, it just makes everything so expensive…But I think it's good for our local industry. Over time we've had to become quite self sufficient, otherwise all the programmes just get so expensive.'

Consequently, the chassis is manufactured in South Africa by WCT Engineering and assembled by Nathan's Motorsport. The suspension is also manufactured in South Africa,while the car was designed by Volkswagen Motorsport South Africa.

TECH SPEC: Volkswagen Golf 8 GTi GTC

Chassis
GTC tubular chromoly with Volkswagen Golf 8 GTi body shape

Engine
Turbocharged 2.0-litre EA888 four cylinder; Life Racing engine management; Carrillo con rods and pistons; dry sump

Power
496bhp; 600Nm maximum torque

Transmission
Albins six-speed sequential transaxle with Shiftec paddle shift

Brake calipers
Front, six-pot calipers; rear, four-pot calipers

Brake discs
Front, Brembo 360mm; rear, Brembo 340mm

Dampers
Ohlins

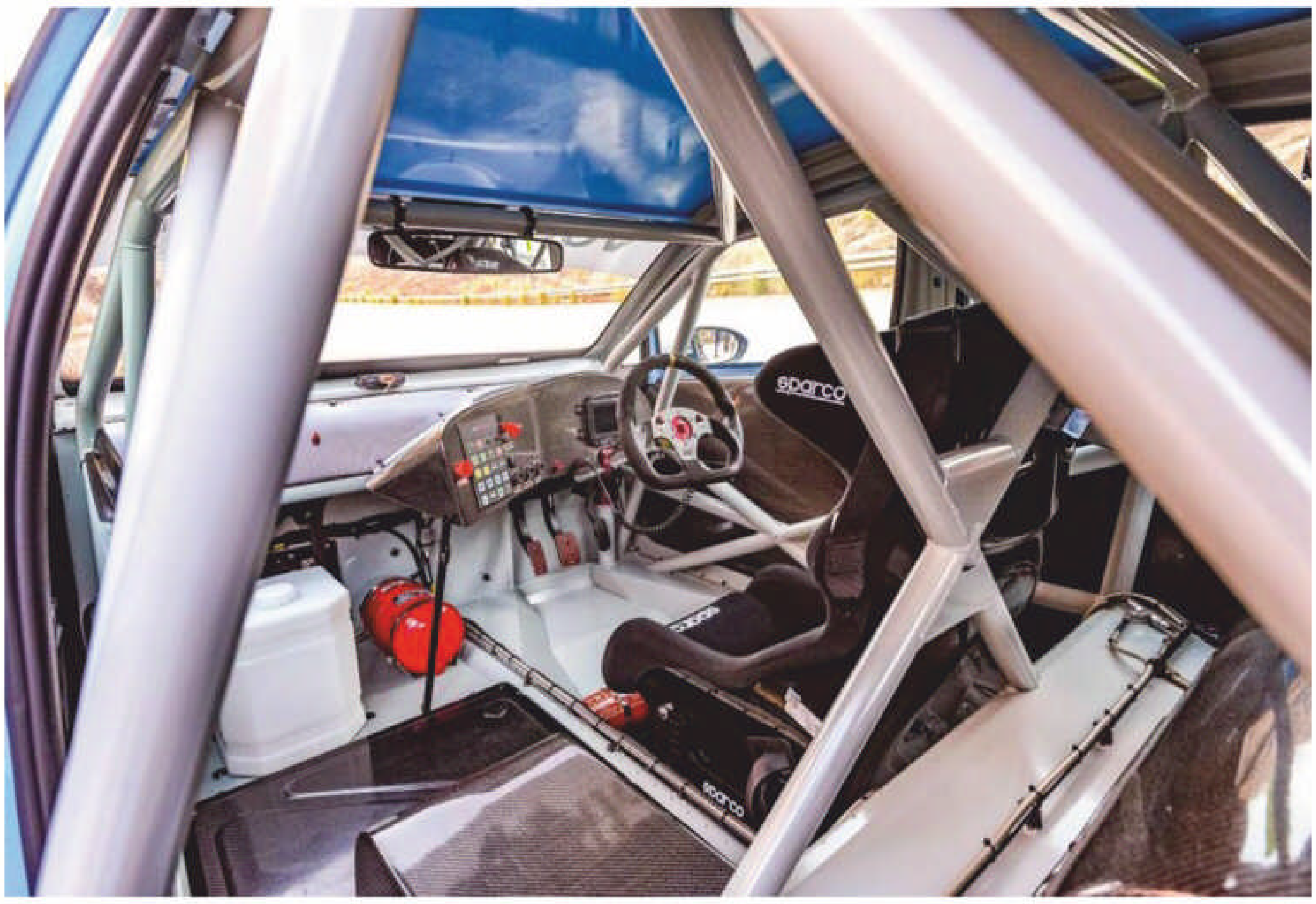
Tyres
Dunlop 280/680 R18

Tight restrictions and GTC control regulations curtailed a degree of independent development, says Rowe. 'The series is quite restrictive, but there are limited areas where we have some freedom. Technically, the car is almost a complete carry-over from the Jetta GTC. The main changes come in the positioning of the intercooler and rear wing.

'Other than specifics around your body shape, the one area where we do have some freedom is in the engine calibration, but we also have to work around fixed parameters for ignition timing and boost.'

The reason we've done most of it locally is because our exchange rate is so terrible

The new Golf was unveiled in July 2020 and will defend VW's current Global Touring Cars title



KEY SUPPLIERS

Engine
CP-Carrillo (con rods and pistons)

Dampers
Ohlins

Transmission
Albins; Shiftec

Brakes
Brembo

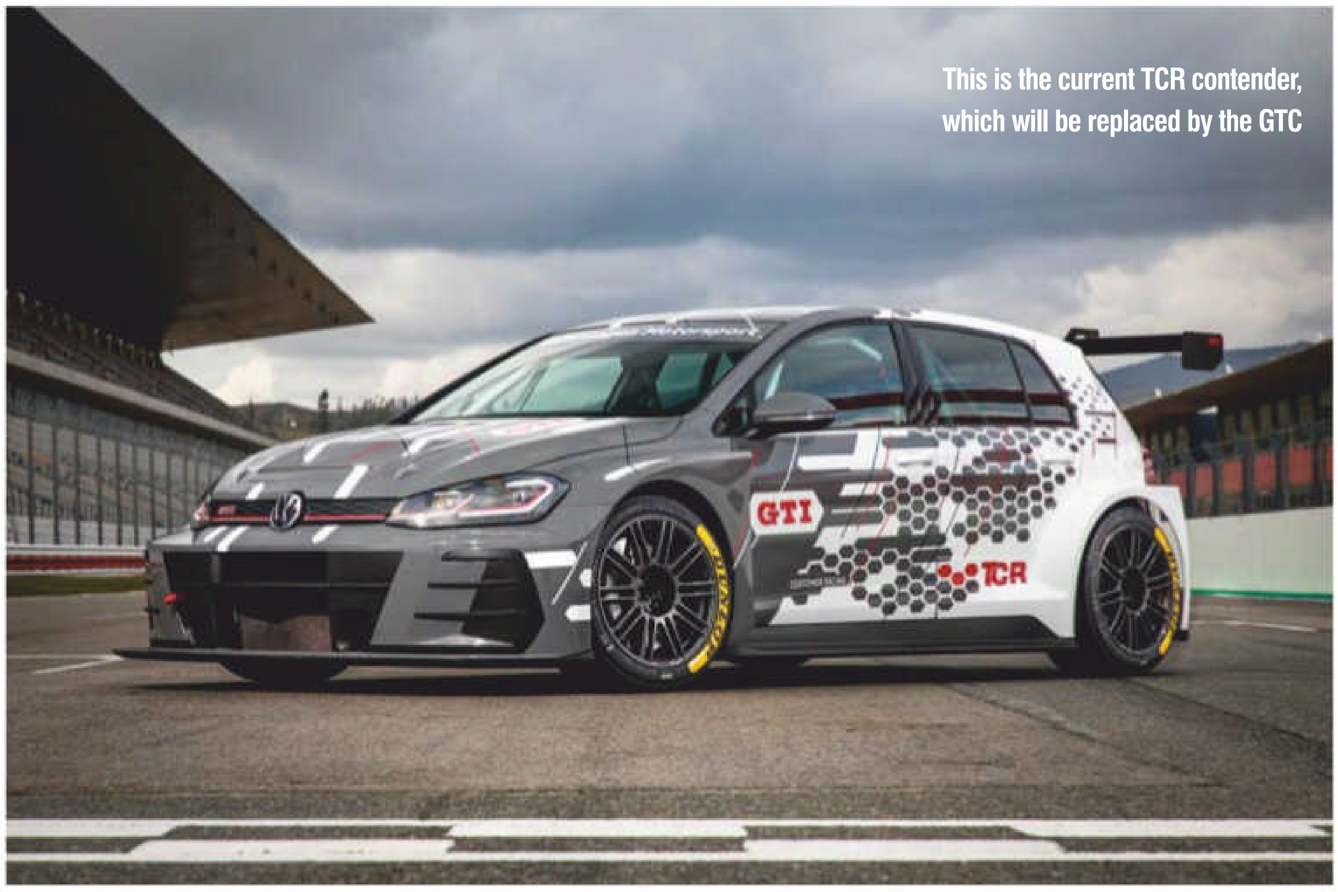
Wheels
GTC

The Golf GTC relied heavily on the Jetta (below) in order to keep the development costs under control, but support was forthcoming from Volkswagen Germany in terms of bodywork design and aero

The one area where we do have some freedom is in the engine calibration

The GTi GTC runs a Golf R EA888 2.0-litre engine (essentially the same unit as in the new, eighth-generation Golf GTi road car), but fitted with competition-specification and UK-sourced Carrillo con rods and pistons, and Life Racing engine management.

'Other than the fitting of a dry sump and the series-regulated rods and pistons, the engine is completely standard,' Rowe confirms. Compared to the 340bhp Golf GTi TCR racers, the GTi GTC is a monster of a machine. Maximum power of 496bhp and 600Nm of torque ensures the rear-wheel drive GTi GTC is an all-out Touring Car racer, living up to VW's much-loved and long-lived 'GTi' and 'R' sub-brands image.



This is the current TCR contender, which will be replaced by the GTC

Installation issues

'By design, a four-cylinder engine is not the smoothest of engines, so we had some installation issues,' recalls Rowe. 'In 2018, we were running quite a lot more power, but you stretch everything, and we came to the conclusion the spectator sitting on the grandstand doesn't know if it's half a second slower. So we turned them down again…We don't port the engine or change the camshaft and the exhaust manifold is a machined part to take a slightly bigger turbocharger.'

Power is transmitted to the track by a six-speed, sequential Albins transaxle featuring Shiftec paddle shifts.

A 270bhp Polo takes over the mantel in the GTC2 class, with support from VW in the form of its R5 rally car styling

'The Albins transaxle unit is very, very robust and we've been running it now for years. It's super reliable, which makes the running cost of the cars very good,' Rowe comments. 'Because the transmission is in the rear, we run a balancing flywheel – a sort of dummy flywheel that doesn't operate a clutch. We just use it to balance the drivetrain.'

Series-controlled Ohlins dampers look after body control, while Brembo braking components with both four and six-pot calipers – clamping 360mm / 340mm front and rear discs respectively – scrub off speed.

'We have to purchase most of the components from the series owner,' reports Rowe. 'The safety equipment is from Sparco, and all Volkswagen components are obviously sourced by ourselves.'

Even the aero package is controlled. The rear wing is regulated by its position in regard to the chassis. 'It has to stay where it is relative to the chassis,' says Rowe. 'There's a certain dimension from the rear wheels and for height. So the wing is pretty much where it was on the Jetta, but on that it was sitting on top of the boot, and now it's in free air.'

Testing programme

The car's testing programme has been as swift as its development. 'The initial shakedown was at a test facility called Gerotek and have had one test at Zwartkops Raceway, west of Pretoria. Based near the team in Johannesburg, Keagan Masters, 2019 GTC champion, headed up the testing programme and drove the car at Gerotek. Alongside Masters, the 2016 near-production GTC2 class winner, Daniel Rowe, also drove the car at the Zwartkops trial.

Despite being very much a locally-engineered product for the local market, Rowe thinks the GTi GTC may go on to find homes further afield. 'We will make cars available to buy for customers in South Africa. But, should there be an enquiry from outside South Africa, where the car can compete in a series where it can be competitive, it will definitely be considered.' The Golf was scheduled to debut at the second round of the South African Endurance Series in mid-August 2020, as part of a reduced GTC season.

Supa hero

Alongside the Golf GTi GTC, Volkswagen Motorsport South Africa has also engineered a baby brother to compete in the new SupaCup class, which replaces the aforementioned GTC2. The Volkswagen Polo often tops South Africa's passenger car sales charts and the SupaCup Polo builds on the success of the 201bhp Polo GTi racers that compete in the local Oettinger Polo Cup series. The SupaCup cars gain a power bump and feature more aggressive looks.

Wearing a similar body kit to the 270bhp Polo GTi R5 rally cars built by Volkswagen

TECH SPEC: Volkswagen Polo SupaCup

Chassis
Volkswagen Polo bodyshell fitted with rollcage

Engine
Turbocharged, 2.0-litre EA888 four cylinder;
MoTeC engine management

Power
308bhp (335bhp with push-to-pass function); 420Nm max torque

Transmission
M-Trac six-speed sequential with MoTeC paddle shift (locally developed)

Brake calipers
Front, six-pot calipers (locally developed); rear, standard Polo GTi

Brake discs
Front, Powerbrake; rear, standard Polo GTi

Dampers
SAX (locally developed)

Tyres
Dunlop 240/650 R18

The GTC Polo's mini-Touring Car look is backed up by more firepower than either the GTi circuit racers or the rally machines

Motorsport in Germany, the SupaCup Polos differ from their rallying counterparts by way of larger sills and front bumpers.

'All the patterns and moulds are made here,' states Rowe. 'Compared to the R5, the front opening for the bumper, the rear door fender and panel are very different.'

The GTC Polos' mini-Touring Car look is backed up by more firepower than either the GTi circuit racers or the rally machines. A 308bhp, 2.0-litre, turbocharged EA888 four-cylinder engine nestles under the bonnet, capable of 420Nm of torque. But a 'push-to-pass' function takes power up to 335bhp for five seconds, once per lap. The system is adjusted from circuit to circuit.

High interest rate

A total of 11 cars have been built for the SupaCup series and Rowe states that this time the project was not necessarily one which was considered for a wider audience.

'The SupaCup Polo evolved from a project car we were building for our own use for hillclimbs and some PR activities,' he says. 'We showed the concept at a motor show in August 2019 and interest was astounding. We have built 11 cars so far and, if the current interest turns into orders, then we will likely sell four or five more units.'

With cost an important consideration, the bang for buck the SupaCup Polo offers is strong. 'It is unbelievable value for money, and the car is very quick,' continues Rowe. 'With the current exchange rate [being so poor], we have no choice but to be innovative and support ourselves.

'Something we want to consider for 2021 is an offering for international drivers to compete in SA on a rent-a-drive basis. With the exchange rate as it is, it will be very cheap to compete in SA,' says Rowe enthusiastically. And although the SupaCup Polos are right-hand drive, Volkswagen Motorsport South Africa can also build left-hand-drive racers.

In order to make racing accessible, two Polo GTis, financed by VW South Africa, are entered in the Oettinger Polo Cup to enable young drivers to step up from karting

Local talent

Aside from the locally-developed racing machines, Volkswagen Motorsport South Africa also nurtures and promotes young, local driving talent. May 2020 saw the start of a partnership with Squadra Corse to make motorsport more accessible in the country. A pair of Polo GTi racecars will be made available to the team to facilitate the progress of their drivers from karting to national circuit racing and the very competitive Oettinger Polo Cup. Volkswagen Motorsport South Africa will also provide funding.

Fiercely proud of its local content and market, Volkswagen Motorsport South Africa has aligned itself with VW South Africa's 'Drive Local' marketing message

Fiercely proud of its local content and market, Volkswagen Motorsport South Africa has aligned itself with Volkswagen South Africa's 'Drive Local' marketing message. The Polo and Polo Vivo are made in the company's Uitenhage plant, and the racing-focussed 'Drive Local, Race Local' missive resonates strongly with the ethos of Volkswagen's South African motorsport team. After all, building and racing locally is something it has necessarily been doing for decades.

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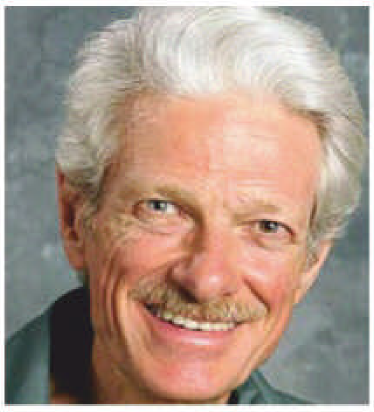

Swings and roundabouts

More thoughts on swing axle suspensions and the benefits of a drop snout chassis

By MARK ORTIZ

British car manufacturer, Triumph, used an additional 'swing spring' on its small-chassis models to reduce elastic roll resistance, but it was not a true pioneer in this respect

Q Thank you for your interesting article on the Corvair, (*RE* V30N8) and the swing axle design that so attracted Nader's ire. In it you listed several car manufacturers that used this cheap and simple suspension but omitted the car whose designers evolved the swing axle more successfully, and cheaply, than most.

Standard Triumph chose the swing axle for its 'small-chassis' series of models, the Herald, Spitfire, GT6 and Vitesse.

Motoring journalists knew as well as designers how to get such an axle to 'jack-up' and did so (for their photographers) immediately, giving the cars a poor reputation. Triumph replied for the more powerful GT6 and Vitesse by adding a lower wishbone, but the design was heavy and expensive.

As you say, 'what works best for a swing axle is stiff springing in ride…and soft springing in roll', but you only gave Formula Vee as the example. Triumph came up with the 'swing spring' that did just that, by allowing the transverse spring to pivot in the centre, which reduced the roll resistance of later cars by 75 per cent! This most successful modification is, I believe, unique, and I feel Triumph's ingenuity should have been recognised.

THE CONSULTANT

A The 'swing spring' is one of many ways to skin this particular cat. The oldest I know of is Mercedes' third coil spring.

For those unfamiliar with it, the swing spring is a transverse leaf spring similar to the one the Spitfire / Herald suspension already had, only stiffer and rubber mounted. This allows the spring to swing as the suspension displaces in roll, but the rubber resists this a bit, allowing the system to act like the original with a camber compensator added. Or maybe a bit better, with fewer parts.

I have not investigated the patent situation surrounding this device, but would surmise the swing spring would probably be a patentable invention.

The swing spring reduces the *elastic* roll resistance by about 75 per cent, compared to (I guess) an identical leaf spring rigidly mounted. The system still has a lot of geometric roll resistance, and still jacks quite a bit. Indeed, Triumph could have just mounted the spring so it could swing freely, eliminating rear elastic roll resistance entirely. This would make the system functionally equivalent to a 'zero roll' set-up on a Formula Vee.

Triumph could have just mounted the spring so it could swing freely, eliminating rear elastic roll resistance entirely

The system would still produce substantial geometric roll resistance, and accordingly considerable load transfer and jacking when cornering. However, I doubt it would have been patentable like that.

Another way to reduce jacking and limit oversteer is to add front anti-roll bar stiffness. The less load transfer the rear has (meaning the more the front has), the less the rear swing axle system will jack.

Depending on tyres, road surface and rear toe setting, swing axles can produce judder on the inside wheel when we reduce rear load transfer. I have seen this with Mk3 Spitfires, on the street, on street radials. This is sort of the y-axis analogue of rear wheel hop in braking with a lot of rear brake and anti-lift. Swing axles can also judder on the outside wheel.

Free lunch

The bottom line is there is no way to make a swing axle suspension as good as more complex forms of independent suspension. The Triumph swing spring does not produce handling equal to the earlier GT6 suspension. However, it is somewhat lighter, definitely cheaper, and a significant improvement over the earlier swing axle set-up. And it achieves this all essentially for free – really no additional parts at all. So, to that extent, it is indeed a clever solution.

In theory, GM could likewise have used a swinging leaf spring on the Corvair – basically a multi-leaf camber compensator – and dispensed with the coil springs, although there might be structural reasons why that wouldn't work, at least not without re-engineering the engine and transaxle mountings. Those mounts would then be holding the back of the car up, and significant bending loads would be applied to the transaxle and engine.

Snout and about

Q Hi Mark, I wanted to thank you for the Chassis Newsletters. I reference them all the time when setting up our cars. The photo (right) is from a race at Portland International Raceway where we won the big-bore vintage race in this former Mark Martin Winston Cup car from when Mike Laughlin 'drop snout' perimeter chassis were supplied to Roush Racing (and a number of others).

Steve Hmiel, Mark's crew chief, said in an interview I saw recently they used the Laughlin chassis at Roush for 'flat tracks', including road courses. Steve said they built a total of 46 cars from the late 1980s through to 1994 (the year the interview was videotaped for broadcast).

Steve was crew chief for Mark Martin there through 1996 and says they used one of three drop snout versions of the Laughlin chassis during their emergence as a winning team in the early to mid-1990s on flat tracks with the cars.

Can you clarify why the evolution of drop-snout cars' geometry there, and later the use of it on Hendrick chassis cars, so improved overall geometry?

For any interested readers, here is a link to one of several YouTube editions of the aforementioned interview: www.youtube.com/watch?v=XiUUIJBL9nU

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A For those unfamiliar with these cars, they have a perimeter ladder frame made of 2 x 3in rectangular tubing, with a lot of added round tubes providing crash protection and triangulation. The rectangular rails are out in the rocker box region at the cockpit. Forward of the firewall they run inward and upward to a point about midway along the engine, and then horizontally straight forward again. This portion is called the snout. This, together with the front 'cage structure, is called the front clip.

Ex-NASCAR Winston Cup car uses a Mike Laughlin 'drop snout' frame with steeply angled upper control arms for a low wheel rate *and* low roll centre

The upper control arms are a tubular a-arm with a solid cylindrical-bushed cross shaft. The cross shaft bolts to a plate bracket welded onto the top of the frame rail. This means the frame rail constrains the height of the upper control arm pivot axis. Lowering the rail lets you lower that pivot axis. That, in turn, permits more camber recovery in roll for a given roll centre height, or a lower roll centre height for a given amount of camber recovery.

When considering NASCAR vehicles, especially from this period, it's important to remember many of their design features are about working the rules. There were rules about static ground clearance, and rules about spring rates. There were even rules about the proportions of the lower control arm, which controlled spring-to-balljoint motion ratio.

To get the car's front valance as low as possible on a flat track, while still passing inspection, it was desirable to have a wheel rate as low as possible and, ideally, make the front end jack *down* in cornering. One way to reduce the wheel rate when the rules lock you in on rate at the balljoint is to use a very short front view swing arm length. To get that *and* a low roll centre at the same time, you need the upper control arms to slope downward toward the frame quite steeply.

As related in the video you refer to, Laughlin offered three standard snouts: regular, dropped (down 1.5in, or about 38 mm), and half-drop (down ¾in, or about 19 mm).

CONTACT

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

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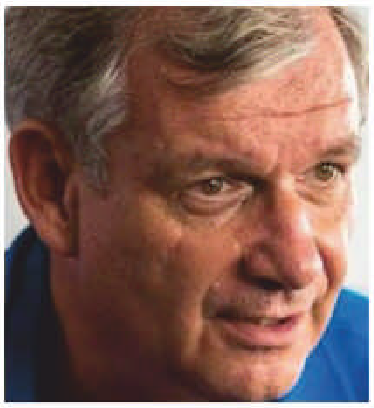
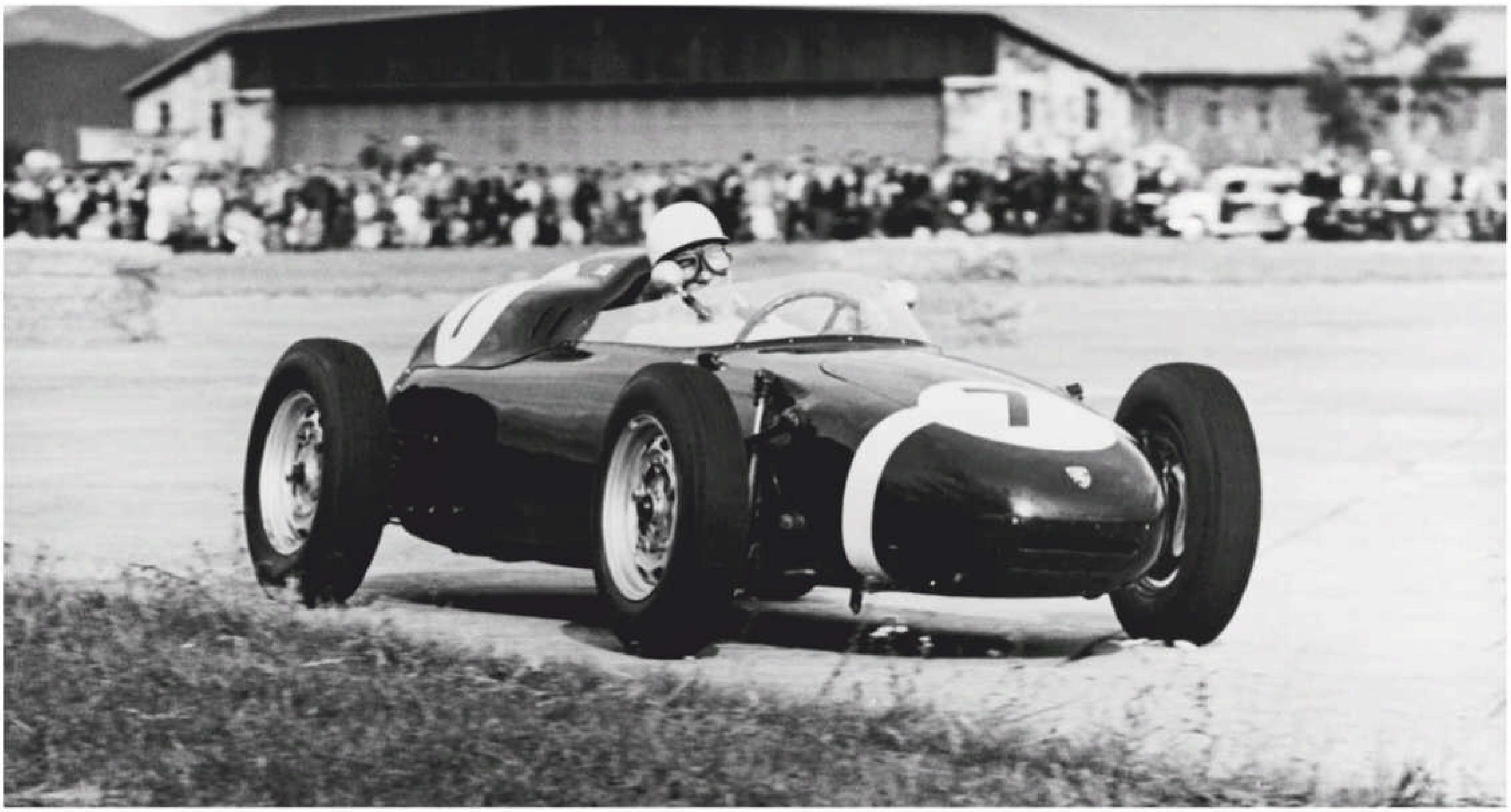
When considering NASCAR vehicles… it's important to remember many of their design features are about working the rules



On the throttle

OptimumG's data master expands our knowledge of data analysis techniques

By CLAUDE ROUELLE



Racecars have come a long way since this 1960 Formula 2-winning Porsche 718/2 but driver throttle input through corners remains a critical part of race technique

If you've been following this year's series of articles from OptimumG, you know we have shared some of the data analysis techniques used by our engineers in their day-to-day racing activities. So far, we have presented steering and braking performance metrics, and this article will focus on the throttle channel.

Of the three driver inputs, the throttle has two main functions: accelerating the car and, in some cases, using longitudinal tyre grip to balance it.

The tricky part is applying the *correct* amount of throttle. A driver can easily apply too much, too little, too fast or too slow. As a driver moves to higher racing series, which typically means more engine power, the more difficult it is to find the perfect throttle modulation.

Before we start looking at ways to analyse the throttle channel, using key performance metrics, it is important to first understand what a throttle trace looks like. **Figure 1** shows a throttle trace for a long corner.

A throttle chart will have throttle percentage on the y-axis, the value going from zero to 100 per cent. Zero means the throttle is closed, at 100 per cent the throttle is fully open. The x-axis can either be in distance or time.

In **Figure 1**, the driver is applying full throttle up until the 3750m marker, but then releases the throttle and is braking to enter the corner. The driver picks up the throttle at 3825m on corner exit.

Similar to the V29N4 edition where we broke down the different stages of braking, we will be applying the same methodology in this article for the throttle by looking at the different stages during corner exit: 'Start Corner Exit', 'Middle Corner Exit' and 'End Corner Exit'.

Start Corner Exit begins with the initial application of the throttle. Being smooth on the throttle is crucial here (see *RE* V29N1 to further understand what we mean by smooth). If the driver applies too much throttle, or too quickly, it can create an understeer behaviour in the car due to longitudinal weight transfer from the front to the rear axle. Additionally, the driver could be creating unnecessary wheelspin.

On the other hand, if the driver doesn't apply *enough* throttle, or at a slow rate, it could be an indication of driver / lap time improvement, or not enough available grip, either from the road or tyres.

Middle Corner Exit is the longest section. The driver gradually increases the throttle as they are exiting the corner. In **Figure 1**, the corner we are analysing has a peculiarity and is characterised by having a late apex. This is confirmed by the fact that, from

The driver reaching a steady state (equilibrium) point of the car tells the race engineer there probably isn't any additional grip available

Figure 1: Throttle trace by sections, comparing with an ideal line

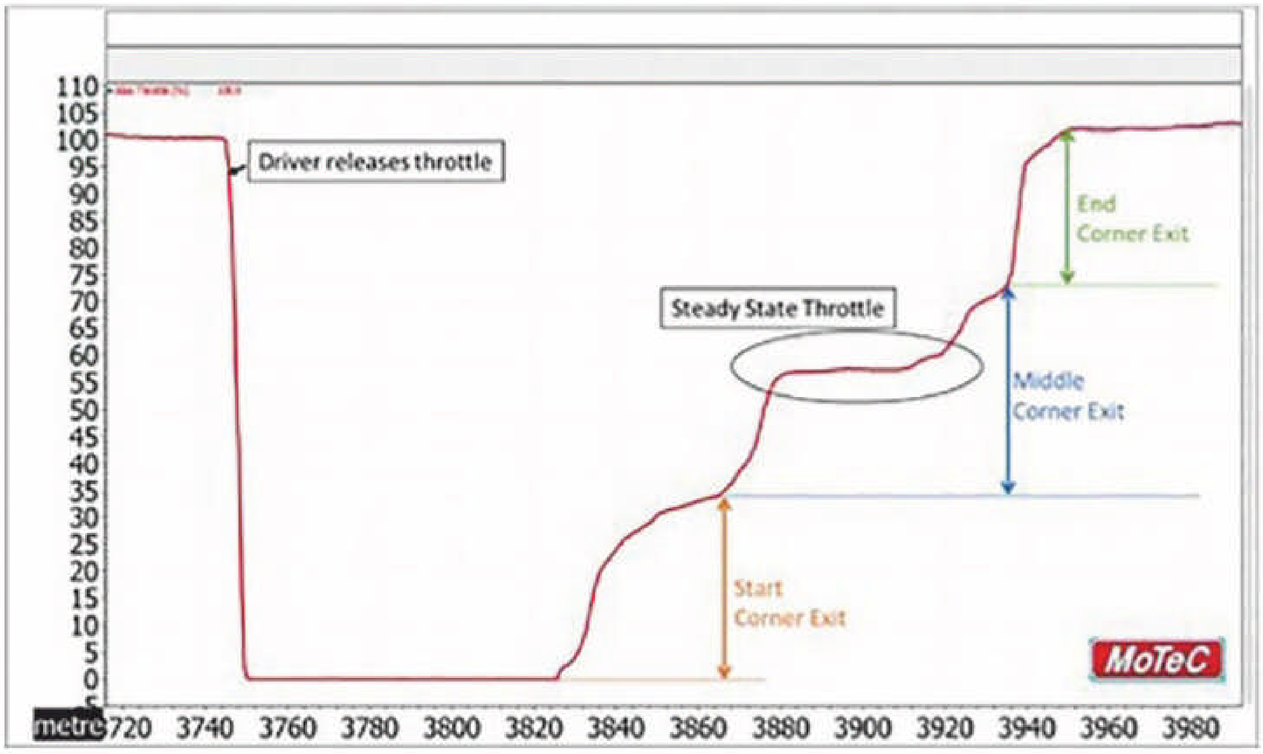


Figure 2: Throttle comparison between two drivers in the same corner

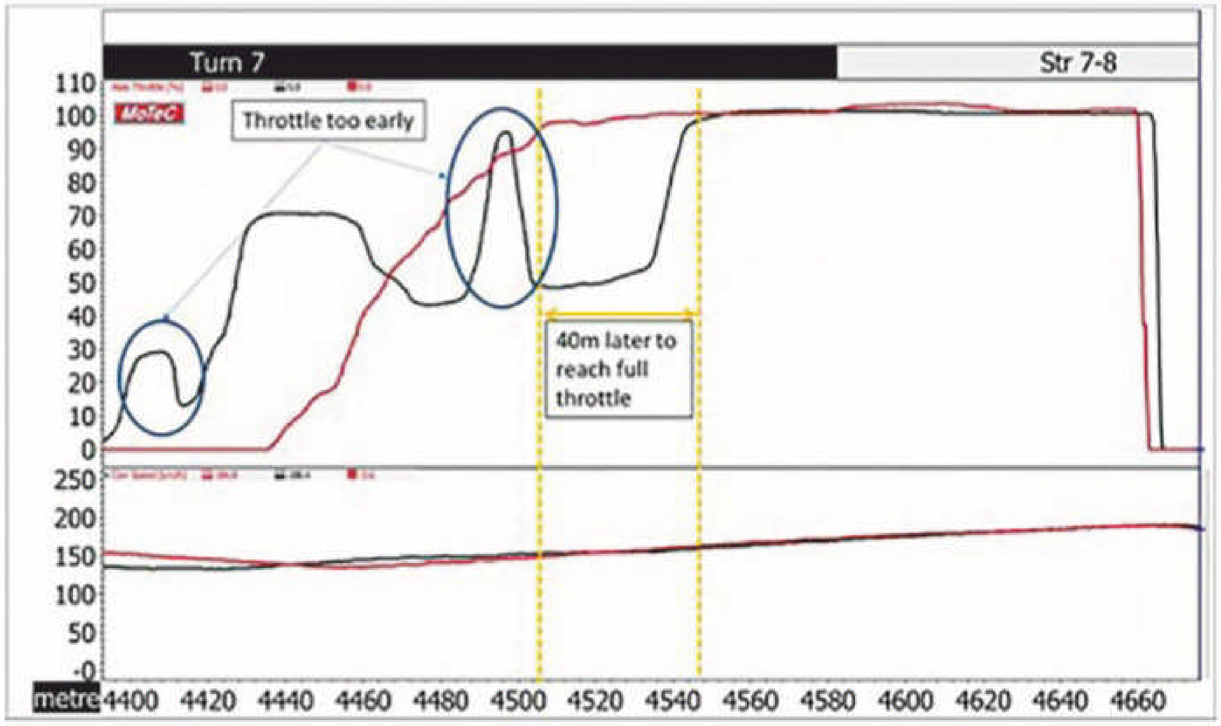
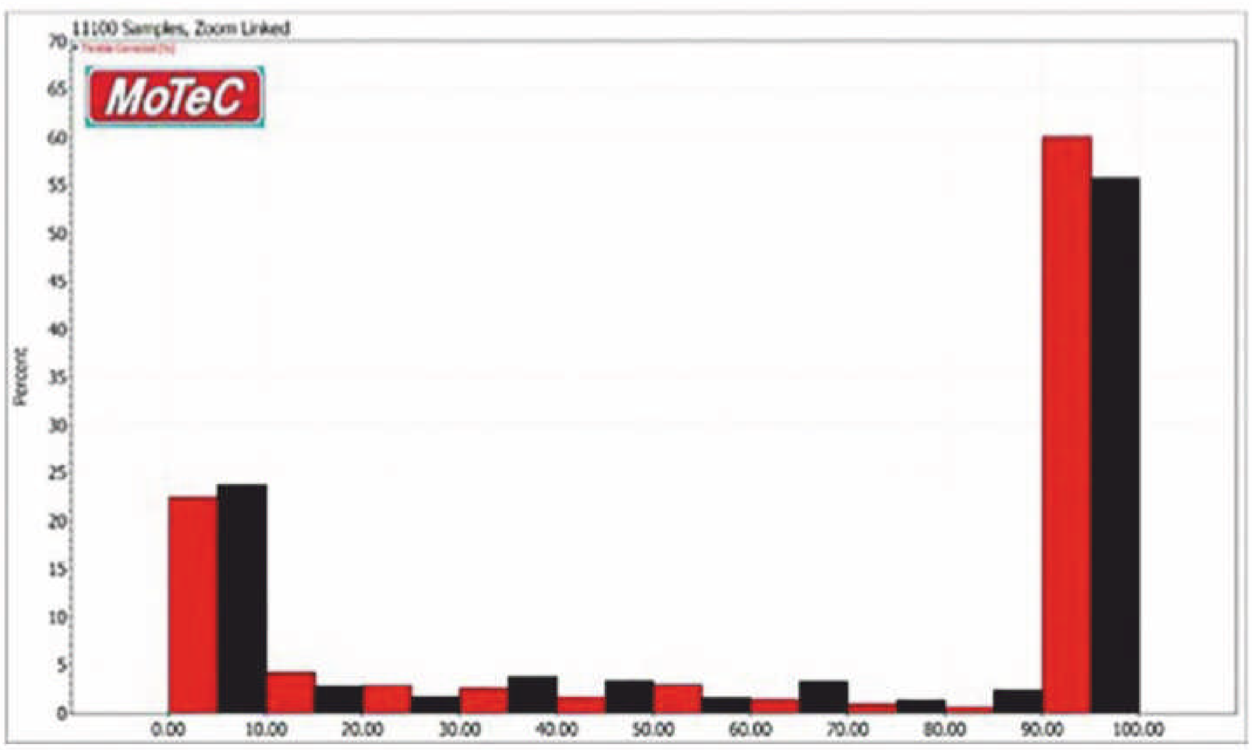


Figure 3: Throttle histogram for two different drivers on their fastest lap



3880m to 3920m, the driver is maintaining a constant ('steady state') throttle, keeping the car at a relatively constant speed. The driver reaching a steady state (equilibrium) point of the car tells the race engineer there probably isn't any additional grip available.

The length of the corner, as well as the type of trajectory used, will play an effect on how long this steady state throttle will be.

End of Corner Exit is the final section, characterised by a rapid increase to 100 per cent of the track trace, which is possible because the driver is no longer tyre limited. In that state, the driver can apply 100 per cent throttle without having to worry about wheelspin.

Smooth and steady

With the throttle trace sections defined, and an understanding of what a throttle trace looks like, let's make an exercise and analyse the throttle trace of two drivers. **Figure 2** shows the data of two drivers negotiating the same corner. The upper chart contains the throttle trace, the lower chart the car's velocity.

Already at the beginning, we can see both drivers have different throttle traces. The driver with the black trace applies the throttle sooner than his counterpart. This happened because they braked too hard and / or too early, so reached the corner later than expected. The driver then tries to compensate by applying the throttle earlier. With the traction ellipse definition in mind, the driver then has limited longitudinal grip available because the tyres are probably close to their maximum lateral grip. When the driver tries to accelerate, if the wheels spin, they need to lift off the throttle, creating that up and down throttle trace. In the end, the driver gets back to full throttle 40m later compared to the red driver.

The red driver, had a smoother and quicker rise of the throttle and exits the corner with a higher speed compared to their peer. The red driver has a higher average throttle position compared to the black driver.

Throttle histogram

A typical first analysis of the throttle trace is a throttle histogram. A histogram represents a distribution of data. The values are separated into bins, which represent a series of intervals, and we can count how many values are in each interval. For convenience, MoTec i2 comes with a pre-built histogram, the user just needs to click on Add -> Histogram. A window will pop up, and the user selects which channel they want to create a histogram for. In **Figure 3** (a histogram obtained from MoTec i2), we separated in bins of 10 per cent.

In **Figure 3**, we are comparing two different drivers on their fastest lap.

The red driver had a faster lap time compared to the driver in black. By looking at the histogram, we can see the red driver has a higher percentage at full throttle (90-100 per cent) and a lower percentage at no throttle (zero-10 per cent).

If we look at partial throttle (11-89 per cent), we can see the black driver spent more time in that area compared with the red, and that the driver was modulating the throttle, which we saw in **Figure 2**.

Alternative view

A histogram provides an alternative to a time / distance chart. It offers an overview of the complete lap. Unfortunately, in a fast-paced environment, a data engineer doesn't always have time to look at each lap's throttle histogram but, to obtain an overview of the lap section, a simple and useful performance indicator is to calculate the throttle average (see **Table 1**).

Again, for convenience, MoTeC i2 allows users to create the maths channels to calculate the throttle average.

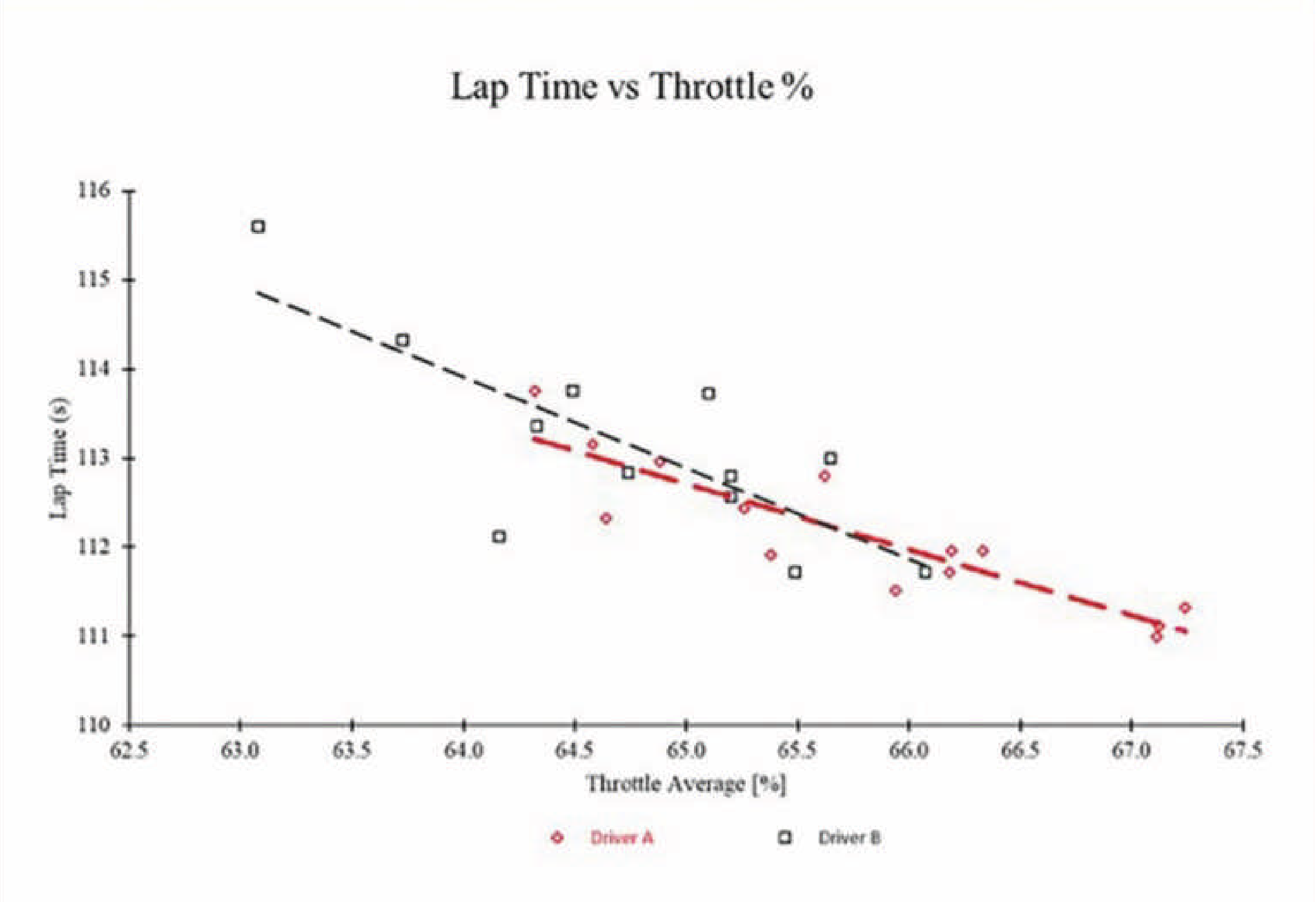
'Wtat_mean' is the function that calculates the average by summing all the select channel values and dividing them by the total number of data points. Alternatively, in MoTeC i2 by going to Add-> Channel report, the user can create a channel report and select the average. This option will show a table with the average per lap, which is easier to further analyse.

Figure 4 shows the results of using the throttle average maths channel and plotting it against lap time.

At first, the obvious conclusion is that the more time on average the driver spends on throttle, the lower his lap time is. We can also see that, depending on the driver, there could be a stronger correlation with the throttle average. In this case, by looking at the slopes we can see driver B has a higher sensitivity to the throttle average on his lap time compared to driver A. Also, notice that driver B has a wider variation of lap time, which could indicate the driver is modulating the throttle. If the values are lower than the driver's throttle average, it's an indication that a safety car has been deployed, or the driver is trying to save fuel or tyre wear.

To obtain an overview of the lap section, a simple and useful performance indicator is to calculate the throttle average

Figure 4: Driver A (red) and B (black) comparison between lap time and throttle average



Key points

Most data analysis software have an option to calculate the average for each lap. This number will be different depending on the circuit, car and driver. In general, the more time spent at full, or nearly full, throttle, the lower the lap time. This might not always be the case, though, as a driver who carries more speed in the corner will get on the throttle later, which will lower the throttle average. It is up to the engineer to look at multiple laps and find a baseline to compare drivers.

A histogram is a useful tool to quickly assess the driver's throttle profile, as long as he is being smooth or modulating the throttle.

Throttle position is one of the simplest channels that can be used, and shows us one of the vehicle's main controls.

Naturally, we have simplified our observations here by only looking at the throttle channel. To perform a complete analysis, it is necessary to plot at least one more channel to get a fuller picture of what is happening in the corner. Some other channels we suggest are rpm, GG Diagram and speed.

It is up to the engineer to look at multiple laps and find a baseline to compare drivers

As a tip for the reader, you might create a key performance indicator called throttle smoothness to smooth the throttle channel and compare it with the raw channel. Look up our article in *RE* V29N1 and you will see how to apply what you learn for steering smoothness to the throttle metric.

Table 1: Average throttle maths channel

Maths channel name	Maths channel equation
Throttle average	stat_mean(**'Throttle'** [%])

Slip Angle is a summary of Claude Rouelle's OptimumG seminars. These are held worldwide throughout the year. The Data Driven Performance Engineering seminar presents several data acquisition and analysis techniques which can be used by engineers when making decisions on how to improve vehicle performance.

OptimumG engineers can also be found around the world working as consultants for top level teams.

Check out our seminar calendar on the website: optimumg.com/calendar

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Power play

Spec Hybrid systems are coming for professional and customer racing

By LAWRENCE BUTCHER

Slowly but surely, hybrid systems are starting to creep into race series across the globe, with electric assistance no longer reserved for the rarefied heights of Formula 1 or LMP1. This is understandable, with even the most basic hatchback from most manufacturers now available with at least a 48V mild-hybrid system, it is to be expected that demand for their use in motorsport will grow.

If anything, it is surprising it has taken so long for them to arrive. Hybrid road cars have been widely available for two decades now, with the rate of uptake among the buying public increasing considerably in the past five years. As Matthias Dank, director of motorsport at McLaren Applied points out: 'The need for people to adopt hybrid systems [in racing] has been there for a long time. The major reason being they are road relevant. We are stuck to IC engines for some time to come and manufacturers want to gain efficiency by hybridising their systems.'

There are multiple reasons for this delay. The most significant being most series' regulations do not permit their use, which is closely related to another hurdle – cost. Series' organisers have been cautious not to introduce extra expense to competitors that have long been feeling a financial squeeze (well before Covid-19 came along).

Racing, even at a junior level, is formidably expensive and hybridisation can only compound this. Combine these issues with the inexorable march of spec racecars, and the opportunity for a constructor or individual

team to take a punt on hybridisation outside top-level racing has not been available.

However, times are changing, and hybrid powertrains are due to arrive in a number of series over the next couple of years. Looking ahead, IMSA's LMDh rules and IndyCar's upcoming regulations both specify a spec hybrid, with NASCAR due to follow suit at some point after its Gen 7 cars finally hit the track. Meanwhile, 2022 will see the WRC running hybrids, again a spec system, and the UK's BTCC hybrids go live in the same year.

The sweet spot

It should be noted that none of these upcoming hybrid systems will have performance comparable to, for example, the WEC, where outputs of up to 300kW were seen in the heyday of LMP1. Power like that comes with a hefty price tag, more than many teams' annual budget. Instead, the various proposed spec systems are in the 20-100kW bracket. This would appear to be the sweet spot where a system has enough power to make a noticeable difference to performance (or at least not detract from it once system weight is accounted for), yet still be manufactured at an acceptable cost.

Several factors have combined to make hybridisation of cost-constrained series feasible. Specifically, the price of high-power density motor and power electronics, along with compact, high-power battery systems has reduced significantly in recent years. Or to be more accurate, there is greater experience across a wider field of suppliers in how to extract performance without breaking the bank. Be that through deeper understanding of the technology or economies of scale.

But why the drive towards spec systems? The simple answer is cost control, as Dank explains. 'If you see how Formula 1 adopted hybrid systems, it was at huge cost and there was considerable performance difference between those that spent lots of money and those that didn't, or who were less lucky with their initial decisions. Then, Formula E came along, where everything was a spec system from the beginning, with freedom opened up gradually, and Formula E still has much closer performance between cars and reasonable cost. If you have an open system, there is the risk of huge expense and enormous performance difference.'

Before the team's withdrawal from the championship, Pierre Budar, former technical director at the Citroën WRC team, made the following astute observation from the perspective of a major OEM: 'The best way to introduced hybrids is probably the cheapest way. But we also have to be clever enough to demonstrate that the hybrids will bring new options for using the cars. For example, running 100 per cent electric in town. Also, if there is additional technology in the car, you want it to benefit performance as well.'

System architecture

Excluding the multiple MGUs seen in F1 and WEC, a hybrid system will normally consist of four main components: the motor generator unit (MGU), a battery (or other energy storage system), a DC-DC converter and electronics for motor control. How these are all situated within a vehicle depends on its architecture.

For example, in the case of the 2022 WRC cars, the hybrid components will be packaged in the centre and rear of the chassis, enclosed in their own safety cell within the confines of the existing rollcage. The motor is to be mounted to the rear differential, which eases integration of the spec system (supplied by Compact Dynamics) given the different engine and transmission combinations in use, while the battery and control electronics will be sited behind the driver.

From a packaging perspective, this is less than ideal. Cooling anything at the rear of a rally car is tricky, but as Toyota's WRC technical director, Tom Fowler, notes; 'there are a lot of safety aspects to consider, one of which is ensuring anything that has a possibility of posing a safety hazard is within the car's safety cell. As soon as you move in front of the [front] bulkhead, it just broadens what you need to do to make it all safe.'

NASCAR is another championship to have chosen a rear-mounted motor. The Gen 7 cars will run an Xtrac-supplied rear transaxle, which has provision for the installation of an MGU. In the BTCC, which allows both front and rear-wheel-drive cars, regulators (and supplier, Cosworth) have settled on two motor locations. For front-wheel-drive cars, the motor is situated next to the engine, while in rear-drive applications it is mounted in the longitudinal transmission's bellhousing.

Battery location is another consideration and, as with the WRC, the BTCC has opted to place its (1.5kWh) pack within the rollcage, replacing the cars' existing ballast box, which usually holds success ballast. In the case of IMSA, and likely IndyCar, battery location will follow current formula and Sportscar practice and situate the batteries in some of the volume currently occupied by the fuel cell.

Motor variations

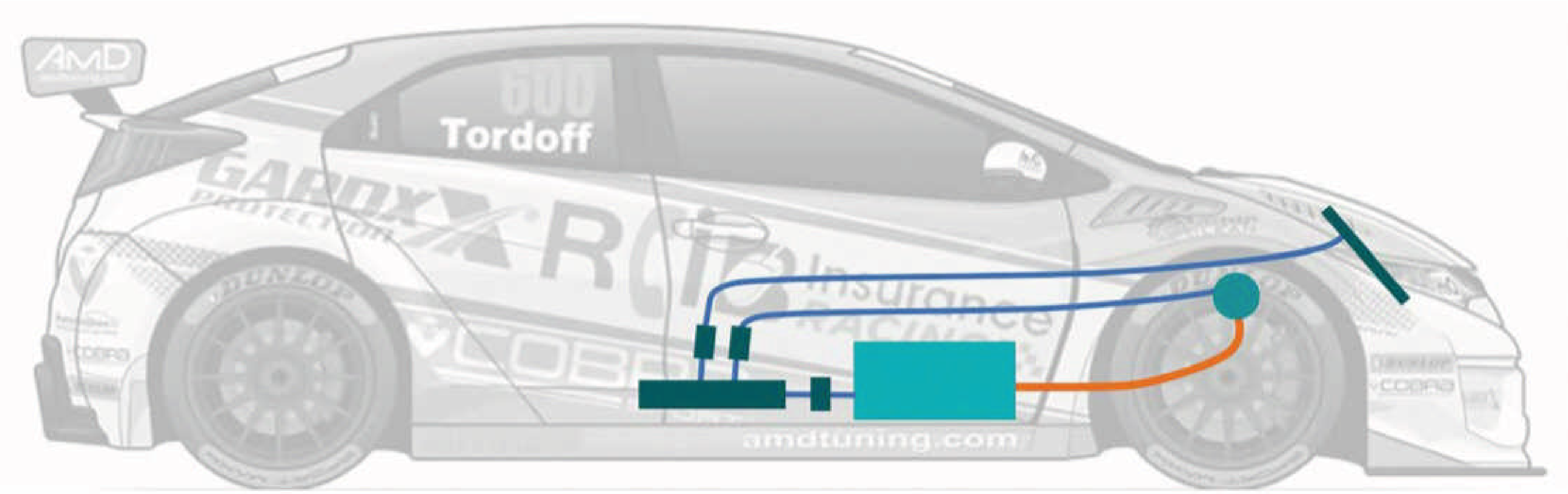
High power density motors are now relatively commonplace. The majority used in current racing applications, be it Formula E, F1 or the WEC, are permanent magnet, synchronous types, with radial flux architectures tending to be more common than axial flux.

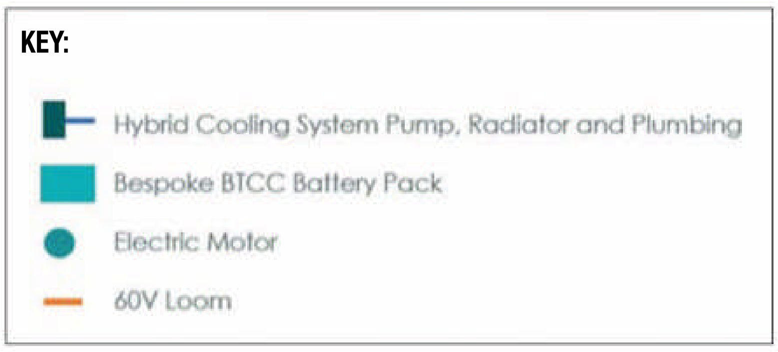
Most of the coming spec hybrid systems will operate in the 400V plus range, which helps maintain efficiency. The BTCC is an outlier here, having opted for a 50V system, which greatly reduces the safety requirements that come with handling and packaging higher voltage systems. A low-voltage approach is feasible for the BTCC as the power of its hybrid is low at just 30kW, which means some issues surrounding the high current draw inherent with a low voltage / high power system are circumvented.

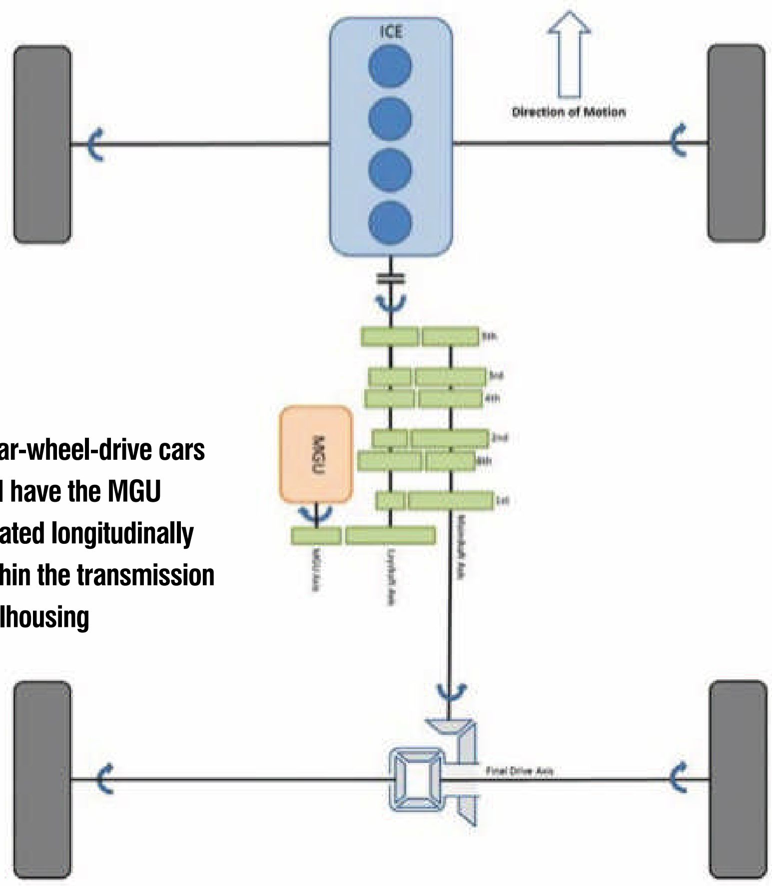
Motor costs can be minimised through careful design, with many manufacturers utilising a single motor architecture that can be scaled for different power levels or package sizes. Here, even small compromises on elements such as motor size and weight, or continuous power output, can have a significant impact on cost. As with so much in engineering, finding the final five per cent of performance is what ramps up the price.

Taking the motors produced by UK supplier, Integral Powertrain, as an example, the company applies its CTB (Core Technology Bespoke motor) principle to its design. In essence, it's a combination of several bespoke design tools, coupled with a number of proprietary motor technologies.

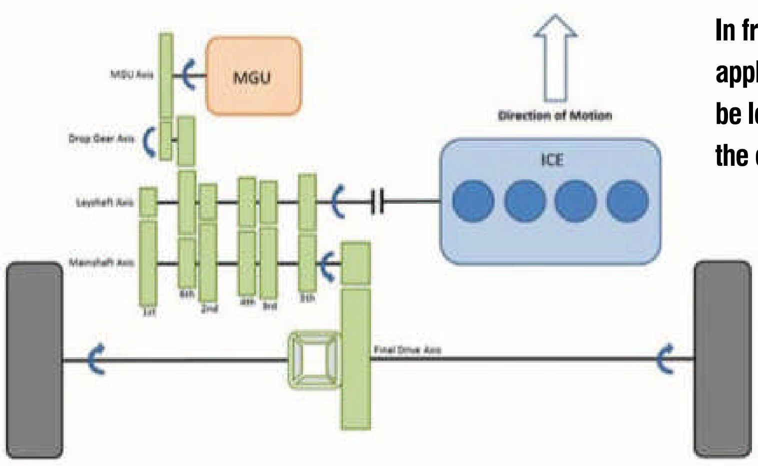
BTCC hybrid schematic, showing the position of the cooling system and the two options available for FWD and RWD applications





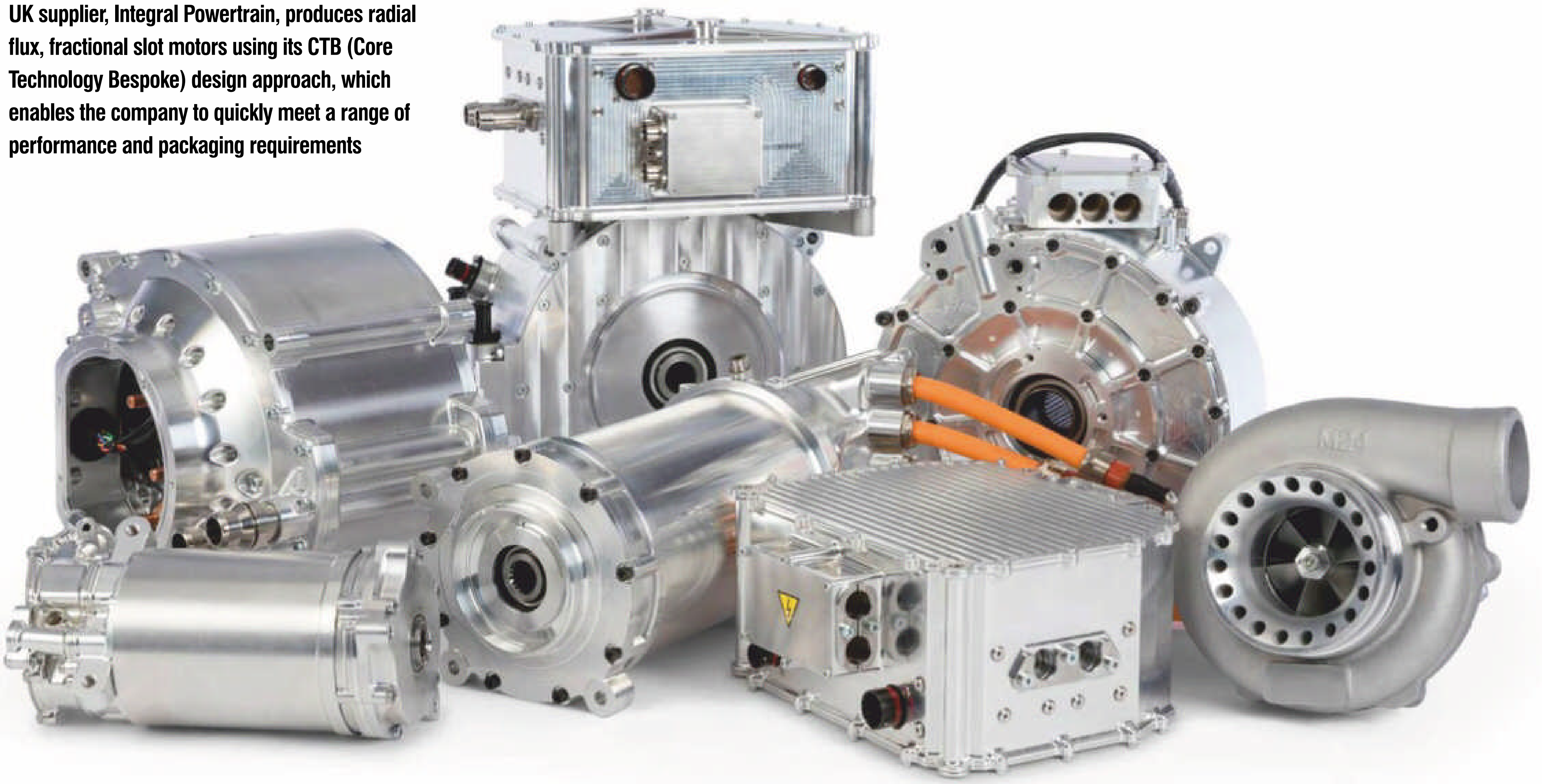


Rear-wheel-drive cars will have the MGU located longitudinally within the transmission bellhousing



In front-wheel-drive applications it will be located alongside the engine

UK supplier, Integral Powertrain, produces radial flux, fractional slot motors using its CTB (Core Technology Bespoke) design approach, which enables the company to quickly meet a range of performance and packaging requirements



Phi-Power axial flux motor

Integral Powertrain radial flux SPM (Surface Permanent Magnet) motor

Most of the coming spec hybrid systems willl operate in the 400V plus range, which helps maintain efficiency

The culmination, it says, is an ability to rapidly create a motor specification to match the needs of a given project from a cost, performance and packaging perspective. As Simon Mead, chief engineer at the company explains; 'some people will want motors that are pancake shaped, some need them long and thin. We can support those differences from the same core technology.

'Across all of our motor families – be it a 4kW motor through to 5mW [Integral's biggest motor concept] – we apply what is fundamentally the same technology. They are all radial flux, fractional slot machines, whether they are IPM (interior permanent magnet) or SPM (surface permanent magnet) machines. The magnetics will change [between units] to some degree, but effectively, the core technology is the same.'

The choice of a radial flux topology over axial flux is simple. 'We have demonstrated we can scale that technology to high volumes,' says Mead, 'and it suits both very premium motors, but also those that need to be produced at a low cost. What we really focus on is the detail inside the machines to make them in the best way possible.'

This detail includes ensuring mechanical and electromagnetic losses within a motor are minimised, for example by devising ways to channel coolant to the most important areas, such as the stator and rotor windings.

'Our motors are typically 98 per cent efficient,' continues Mead. 'You can't have high power density without having low losses. If our machines were only 95 per cent efficient, they would be a lot bigger for the same power output.'

One significant benefit of having an efficient cooling system is that higher performance magnets can be used, without fear of overheating them. Samarium cobalt is favoured in many motor applications because they can be run at high temperatures without de-magnetising, although in terms of magnetic performance they are far from ideal. If a motor can be run in the region of 80-90degC, neodymium magnets, which are cheaper and more effective, can be used.

Battery systems

'Battery systems are a real cost driver,' says Dank. When it comes to energy storage for a hybrid, lithium ion batteries are the go-to solution. Though systems like super-capacitors and flywheels have been used in racing, the consensus is that lithium battery technology has now reached a level of maturity where it is the best option.

To address a couple of basics, the energy density of a given size of battery dictates how long the hybrid can be deployed for, while the power density governs the maximum power that can be extracted from it at any one time (as well as how quickly it can be recharged). In the past, you could have one or other of these qualities – a fast discharging battery with good power density or a low power battery with high energy density. However, various improvements in battery chemistry in recent times have reduced this compromise to an extent. This was one of the reasons Toyota switched from a super capacitor system for its TS050 LMP1 to batteries.

The nature of the racing series a hybrid is deployed in will also define the characteristics of the battery. For example, a system for NASCAR will have a very different energy use profile compared to an IMSA sportscar. Taking the NASCAR example, superspeedway races will feature minimal regeneration, except for a few very heavy braking events for pit stops, while short tracks such as Bristol or Martinsville will have heavy braking ie regeneration opportunities every few seconds. Here, the battery would need a good energy / power density balance to accommodate these differing demands.

This same scenario could also be considered for the WRC, where stages can range from long, flat-out blasts on such as Rally Finland to the tortuous, twisty gravel stages of Wales Rally GB. Conversely, the BTCC only tends to race on relatively short circuits, so yet another different power / energy density balance could be struck.

The challenge for a spec system supplier is to find the ideal battery chemistry, without resorting to costly bespoke cell development, coupled with a suitably robust battery architecture and cooling system, to meet the specific needs of different series.

The challenge for a spec system supplier is to find the ideal battery chemistry, without resorting to costly bespoke cell development

On this last point, batteries are very particular when it comes to thermal management. Not only do they need to be kept below certain temperature thresholds, but to operate at their most efficient they cannot be overcooled either. Any spec hybrid racecar needs to have a battery cooling system that is flexible enough to be integrated into different vehicle types without either of these elements being unduly compromised. Here, the BTCC has a neat solution up its sleeve.

For a start, cooling systems are one area where teams have considerable design freedom. But to ensure consistent performance of the hybrid system cooling, TOCA, the series' organiser, has mandated two separate coolers, located under each headlight, with one handling motor and power electronics, the other battery cooling.

Despite only using a 'safe' 50V system with 30kW motors, the BTCC is forging ahead with hybrid technology, playing close attention to crucial elements such as thermal management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Power electronics and are just as vital to a hybrid system as the battery or motors, and can be the source of considerable efficiency gains. For example, silicon carbide (SiC)-based power semiconductors are seeing increasing use in road cars and have been employed for some time now in racing. This is because SiC devices have much greater temperature resistance than traditional silicon-based IGBTs (Integrated Gate Bipolar Transistors) and operate at higher switching speeds, reducing losses in both power electronics and motors.

Electronic advances

Until quite recently, racing power electronics predominantly relied on SiC IGBTs, due to their low losses at high switching speeds and voltages, but there is an increasing move towards using MOSFET (metal–oxide–semiconductor field-effect transistor) technology in applications up to around 800V.

Gallium nitride-based power semi-conductors, which can operate at even higher speeds than SiC, are also now starting to appear, though these are currently expensive and so do not fall within the realm of cost-controlled spec hybrid systems.

But much like batteries and motors, as the development of SiC devices has advanced, so their relative price has reduced, both in terms of absolute component and overall hybrid system costs. The latter because the greater efficiency they provide creates savings in other areas, such as reduced battery capacity requirements.

Again, many companies offer a range of power electronics based around a common architecture, which can be scaled to suit customer needs in terms of power, package size and cost. For example, McLaren Applied, which has offered motors and control electronics for some time, deploys a modular approach to allow rapid tailoring of its systems to a specific application. Dank explains: 'For example, if a customer wants good power density, they would go for a six-phase motor and inverter. So one of the things we do is build all our inverters to support six-phase. This means the same basic inverter design can run either two three phase motors or a single six-phase unit. Before, you would have needed either two units or a bespoke developed part.'

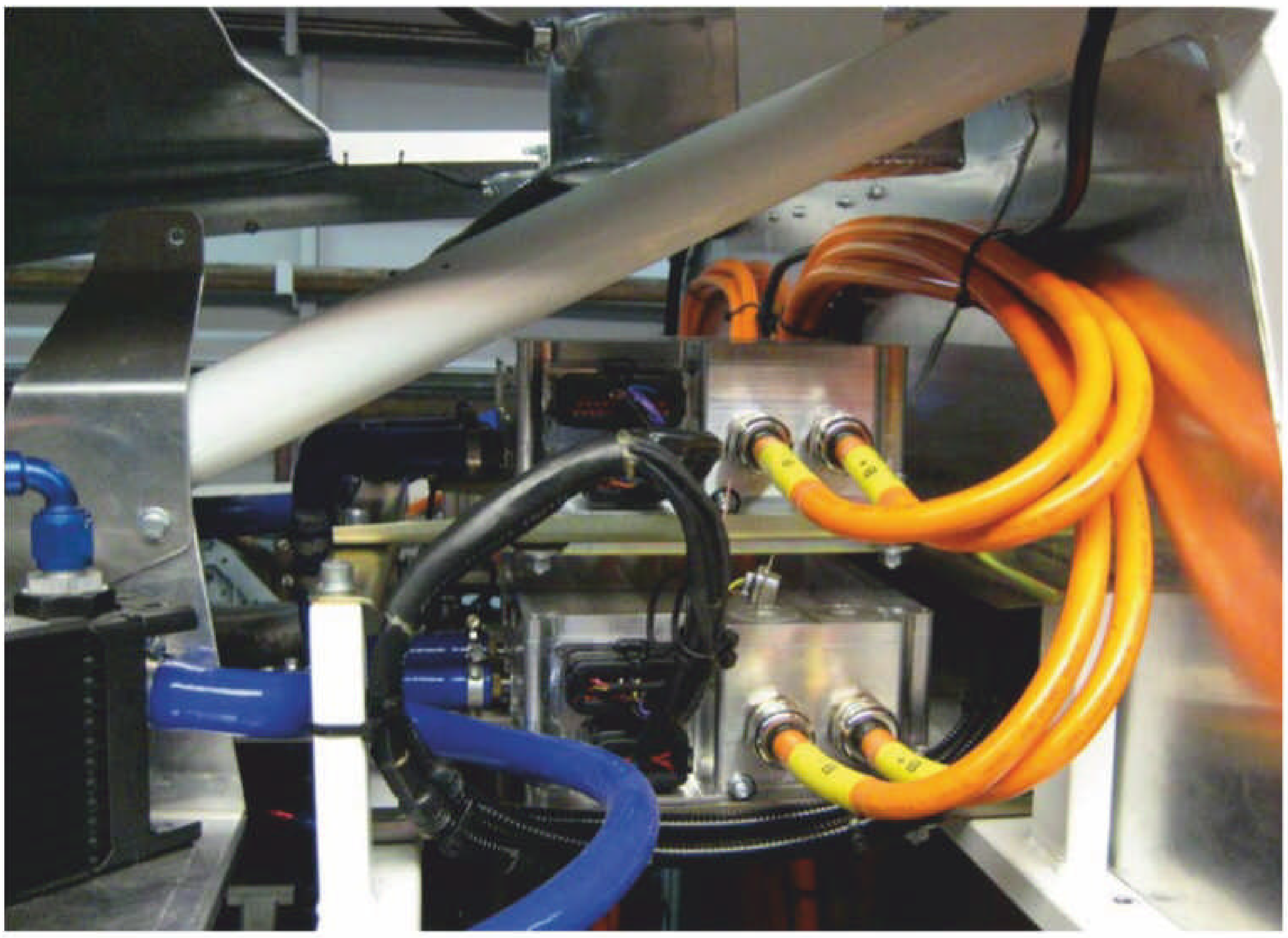
Keeping control

As the well-known marketing slogan goes, power is nothing without control, and the software and vehicle control units (VCU) that complement both motor and battery systems, as well as governing the complex interactions between IC engine and electric drive, are key to an efficient overall system.

The ability to alter the operating parameters of a hybrid gives considerable scope for competitors to maximise the

McLaren hybrid motorkit

Many companies offer a range of power electronics based around a common architecture



The electronic system in the OSCar electric rally car from Latvian company Drive eO, the first hybrid to complete Rally Dakar

performance of even a spec system and, as such, regulators are understandably anxious to retain control over their utilisation. Certainly, the potential for system tuning to be a performance differentiator should not be underestimated.

'With a spec system, the performance is the same, but people learn how to use it. Even though Formula E was a spec system in the beginning, performance was dictated by how teams developed their power strategy and energy management,' points out McLaren's Dank. This, he says, led to some counterintuitive means of maximising whole-lap performance.

'There were some very interesting things came in Formula E where, for example, it makes more sense to coast into a corner because more energy can be recuperated, which means more energy out of the corner.'

Some series, such as the BTCC, plan to give competitors considerable freedom over the deployment and mapping of their spec systems (though all will use the same, Cosworth-supplied software and controller), while others want to nail down development as tightly as possible. This latter approach does not sit well with engineers used to homing their respective powertrains.

For example, the WRC is looking to not only mandate the control software, but also the maps teams use.

'The deployment of the hybrid system will be under FIA control,' explains Toyota's Fowler. 'They are talking about having a specified deployment strategy, so the whole system, including the control, will be outside our control systems, and we would just have a link to tell it when to do things.

'Now, that might seem really nice to someone writing it down but, in reality, it is not that simple. We will still be spending some time trying to work out how to make the best of the system.'

Diversity of design

It would appear then that standardised hybrid systems are going to be the norm for many series, even those where there is still considerable engineering freedom in other areas of car development. However, Dank is of the opinion that through careful opening up of rules over time, there is potential for diversity of design to return without rapidly escalating costs. He also notes that the engineering challenge of spec systems should not be underestimated, particularly due to the approach many series have taken to the tender process for aspiring suppliers.

'One thing that has been tough for suppliers in the recent tenders [from various series] is the full system requirement. Because batteries are so vastly different from the other areas of the system in terms of development, someone who doesn't make batteries as a core competency will never be as good as someone who does.

'Then on the other side, looking at the power electronics, really knowing how to do things like stack the SiC components, is very different from the battery chemistry side. I'd split tenders for a battery and a hybrid powertrain, and that will create more interesting spec systems.'

> **The ability to alter the operating parameters of a hybrid gives considerable scope for competitors to maximise the performance of even a spec system**

While the imposition of any 'spec' components to racing is anathema to most engineers, in the case of hybrids the potential for rapidly escalating costs is considerable. As such, it is an understandable approach for series keen to keep grids full in straightened times. Though many will bemoan the lack of engineering diversity such systems bring, perhaps the flipside is that the road-relevant message of hybridisation will bring more manufacturers and sponsors onside? This, in turn, will keep money flowing into racing to facilitate development in the areas where innovation is still allowed.

XPB

WRC hybrids for 2022 are expected to have the main components packed in a centrally-located safety cell and the Compact Dynamics-supplied motor mounted to the rear differential

No matter how much data you have, or how much you *think* you know, rubber will always prove you wrong

Wearing thin

Accurately predicting the changing behaviour of tyres is key to winning races, yet it's a science that continues to baffle engineers

By GEMMA HATTON

Understanding, measuring and minimising tyre degradation is the golden ticket to race wins and championship trophies across the spectrum of motorsport. Yet, despite some of today's teams being equipped with entire departments of tyre engineers, and having access to advanced, real-time tyre models, the specific behaviour of tyre degradation continues to baffle them.

This is predominantly due to the viscoelastic nature of rubber. A viscoelastic material is one which exhibits a mixture of recoverable elastic deformation and permanent viscous deformation. In other words, once rubber has been deformed and the load removed, it returns to its original shape, but only after a period of time. This time, or lag, between when the load is removed and the rubber returning to its original shape is called hysteresis, and during hysteresis a portion of the supplied energy is dissipated as heat.

The specific behaviour of rubber depends on the duration of this hysteresis, the amount of heat generated during the process and the rubber's modulus. However, these three attributes also vary with stress frequency (the amount of times the rubber is stressed) and temperature. So in motorsport, when tyres are subjected to continually changing loads and temperatures, you can start to appreciate the complexity of tyre behaviour, and how difficult it is to accurately predict.

Generating grip

Now we understand a bit about the behaviour of rubber as a material, next we need to get our heads round how tyres generate grip. This is done in two main ways: molecular adhesion and indentation. As the name suggests, adhesion occurs at a molecular level where, as the tyre rotates, the rubber molecules bond to the track and are then stretched. The rubber's viscosity resists this deformation, which generates a friction force. The bond is then broken, and the rubber relaxes, ready to bond again.

Indentation, on the other hand, is where the roughness of the track 'excites' the rubber and, as it doesn't return to its original shape, this asymmetrical deformation generates a friction force. Overall, a rubber's flexibility and hysteresis help generate the friction forces that produce grip, and rubber exhibits maximum hysteresis and suitable flexibility when it is close to the glass transition temperature. This is why tyre temperature is so vital when understanding degradation.

Unfortunately, measuring tyre temperature presents another conundrum because, ideally, you want to measure the bulk temperature, which is in the centre of the tyre. But until sensors are developed that can measure *through* rubber, only the carcass temperature can be measured. This is currently done through a TPMS (Tyre Pressure Monitoring System) sensor mounted directly onto the wheel rim where an infra-red (IR) element measures the temperature of the underside of the carcass.

Measuring temperature

The tyre's surface temperature can also be measured using infra-red sensors that, in F1 for example, are mounted either on the front wing or on the rear floor. These measure the distribution of temperature across an array of points on the surface of the tyre.

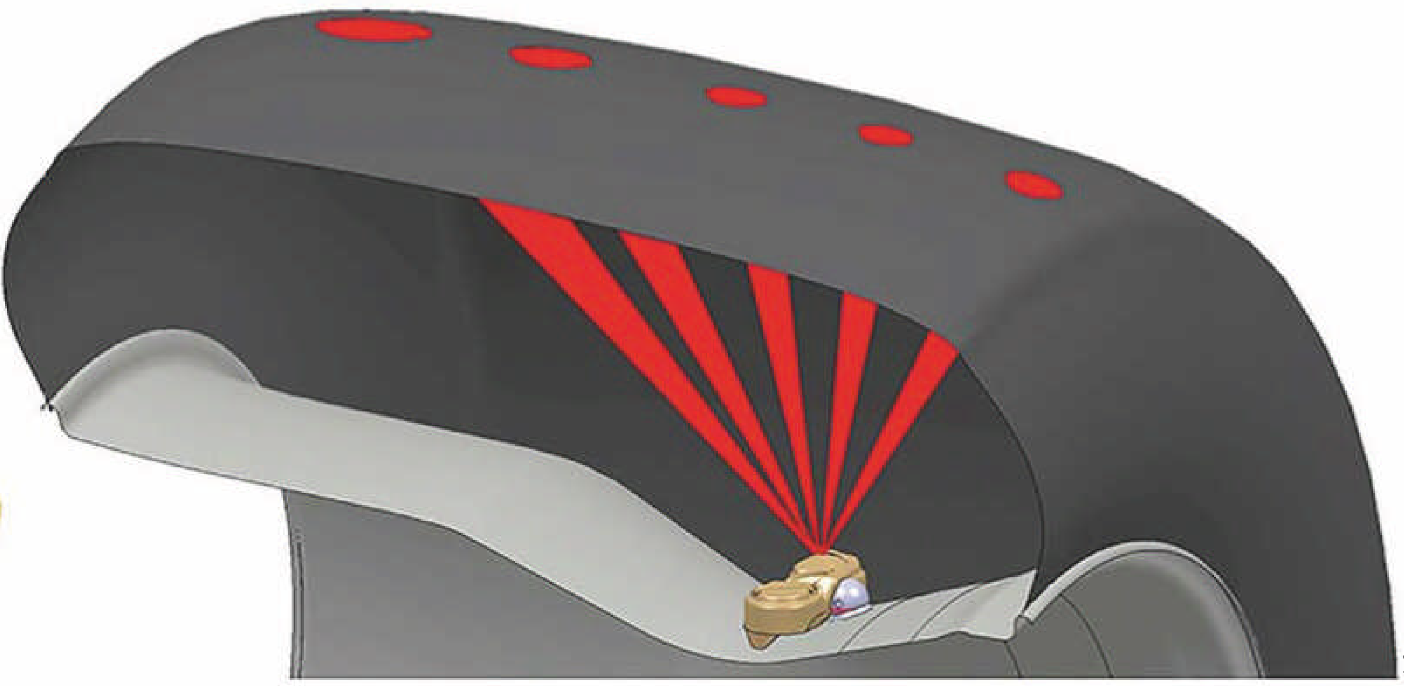
IR guns and hand-held probes can also be used to measure surface temperature. Although this gives a good indication of when the surface is overheating, it can be a misleading metric. For example, whenever the tyre slides, or experiences a flat spot, this will cause a spike in surface temperature but have minimal effect on the bulk. Therefore, when determining the thermal state of a tyre, engineers either rely on the carcass temperature, as this is closest to the bulk, or calculate bulk temperature, which is what Formula 1 teams do.

The specific behaviour of rubber depends on the duration of this hysteresis, the amount of heat generated during the process and the rubber's modulus

'There's a million different ways of measuring the bulk temperature, and every team will have its own way of doing that,' reveals Jody Egginton, technical director at Alpha Tauri. 'We'll know the gas temperature, carcass temperature, surface temperature and the rim temperature. From amongst all of that, you can derive a bulk temperature. So essentially you take those four measurements and come up with a metric.'

Once the bulk temperature has been defined, teams can then start to understand whether the tyre is within its optimum working range. This is essentially the window of bulk temperatures where a tyre generates the most grip. Keeping the tyres within this window is the challenge. As a racecar drives round a track, each of the four tyres are loaded differently, and consequently have different variations in bulk temperature.

However, the nature of each circuit plays a major role in tyre temperature and consequent wear. In F1, high-speed, long-duration corners subject the fronts in particular to high lateral loads, which overheats the surface, often leading to graining. This is why the front left suffers such high graining and wear at Silverstone. While circuits with lots of lower speed, sharp corners



bf1systems

TPMS sensors are mounted to the rim and an infra-red element measures the temperature of the underside of the carcass

lead to the rears overheating as drivers subject them to high longitudinal loads when they accelerate out of corners.

The trick is to balance the grip across the axles to achieve a stable car that the driver can handle. The moment there is a loss of grip, the car will either understeer or oversteer and the tyre will be dragged across the track, which will induce surface and / or thermal degradation.

Types of degradation

'There are two, potentially three, types of tyre degradation, and each type has different subgroups depending on where you are with the car,' explains Egginton. 'Firstly, there's wear degradation where you are simply wearing the rubber [on the tyre surface] away. As you do that, tyre adhesion reduces and there's less rubber available to generate heat, so it's more difficult to keep the tyre within the correct thermal state.

'Then there's thermal degradation where you're overheating the tyre, so it's not operating within its optimum working range. In some respects, that's also linked to a third type of degradation, which is chemical, because the composition of the rubber compound itself is also degrading.'

Surface or wear degradation can manifest itself in several different ways, but each results in surface damage, which reduces the contact patch area, leading to lower overall grip. The most common type is graining. This is where the tread heats up more than the carcass of the tyre and small sections of rubber begin to break away from the main compound.

Graining is a common sight in most motorsport categories and indicates the surface of the tyre is overheating. The consequent radial ridges produced reduce the contact patch between tyre and track, reducing available grip

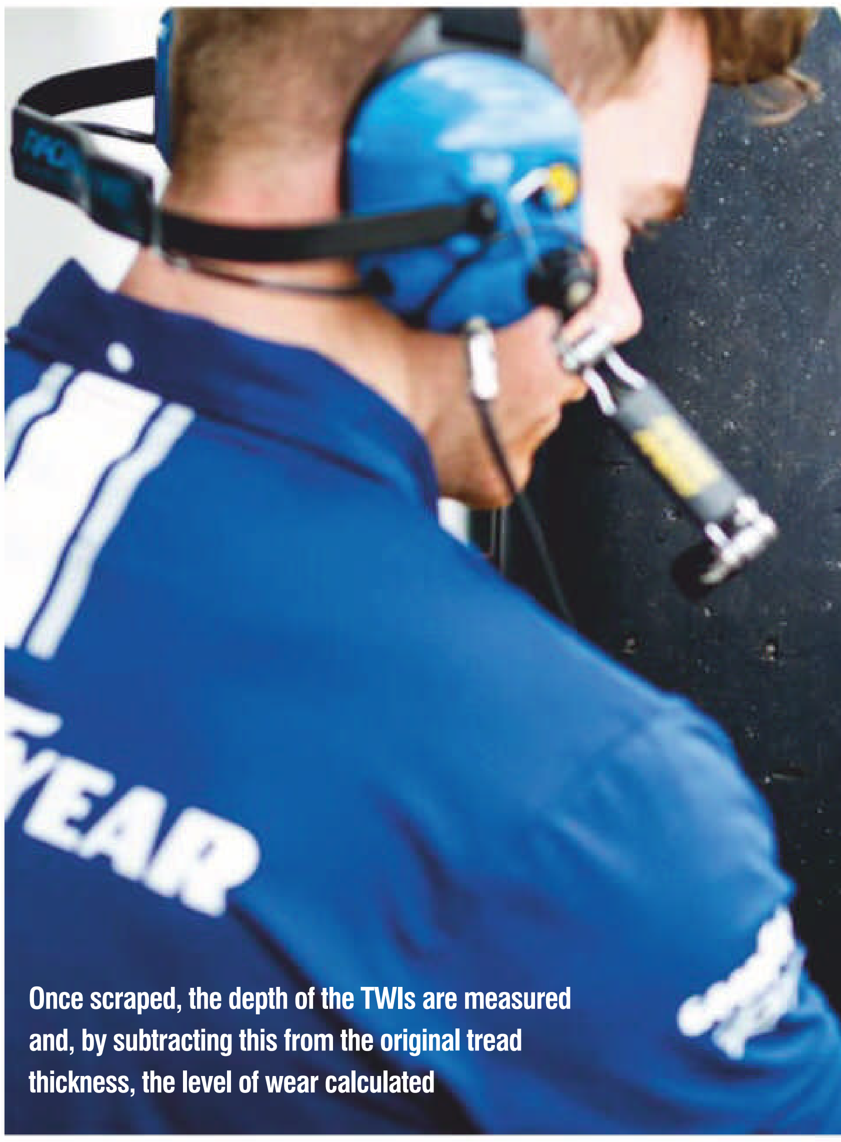
Due to the lateral force exerted, these rubber particles are then rolled across the surface and re-stick to the tyre, creating wavy ridges towards the outside of the tyre. Graining can also occur when the tyre is cool, known as cold graining. This is where the tread is too cold and the outer layer effectively shears away from the main body of the tyre as it slides, causing narrower and linear ridges.

Then there is blistering, which is where the middle of the tread effectively reaches the boiling point of the rubber and small bubbles begin to form. If the temperature continues to rise, these bubbles explode, rupturing the surface of the tyre and leaving holes of boiled rubber. Blistering is more common in F1 and usually occurs along the centre of the rear tyres and on the inner shoulder of the front tyres as this is normally the hottest area.

As rubber generates its own temperature through hysteresis, the thicker the rubber, the more heat it generates and so the likelihood

Tyres have a series of tread wear indicators (TWI), which are different depth holes used to measure the wear of the tyre. But before they can be 'read', any pick up has to be heated and scraped off

Clement Marin



Once scraped, the depth of the TWIs are measured and, by subtracting this from the original tread thickness, the level of wear calculated

Blistering, where hot spots within the tread form bubbles that explode and rupture the tyre surface, often occurs on the centre of the rear tyres and on the inner shoulder of the fronts as this is where the tyres are hottest during use

of hot spots increases. Interestingly, this is why harder compounds can sometimes suffer more from blistering, because they have lower wear rates, which means there is more rubber to overheat.

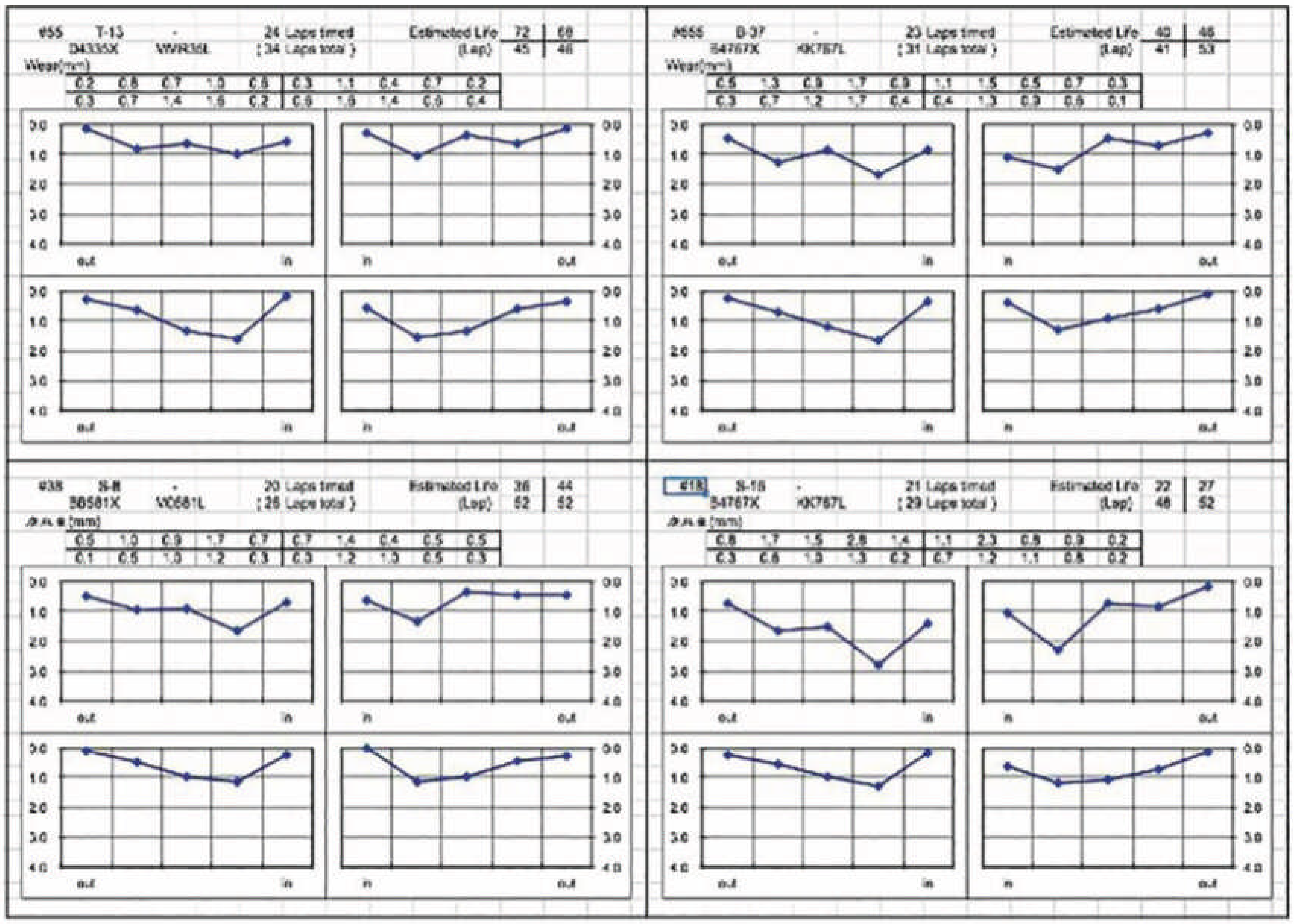
Over the cliff

Both blistering and graining result in the removal of rubber, and so can quickly wear out sections of the tyre. But even when there is no evidence of surface degradation a tyre wears, which is why the track 'rubbers in', and why we see marbles on the side of the track. Less rubber means less heat generation and so, as the bulk temperature decreases, so does grip, which then leads to sliding and further wear and the cycle repeats. This is often referred to as the 'cliff' and is the stuff of nightmares for every driver and team alike.

Unfortunately, like all things with rubber, wear is non-linear and varies across the width of the tyre due to the variation in pressure experienced throughout the contact patch. Consequently, tyre wear not only differs for each corner of the car, but also depends on the type of compound, the nature of the circuit, micro and macro roughness of the track and ambient and track temperatures. In some cases, wear can be so extreme that a tyre can wear right down to the belts.

'If you run a tyre that is completely worn, you expose the construction. In that case you take a lot more risk because the construction is not protected by the tread,' explains Mario Isola, head of F1 and Car Racing at Pirelli. 'If you then hit debris, or hit a kerb, you take the risk of damaging the construction. If you do

Wear is non-linear and varies across the width of the tyre due to the variation in pressure experienced throughout the contact patch



The result is a wear profile that illustrates the amount of tyre consumed at each TWI, for each of the four tyres on the racecar. The wear pattern of four different sets are shown here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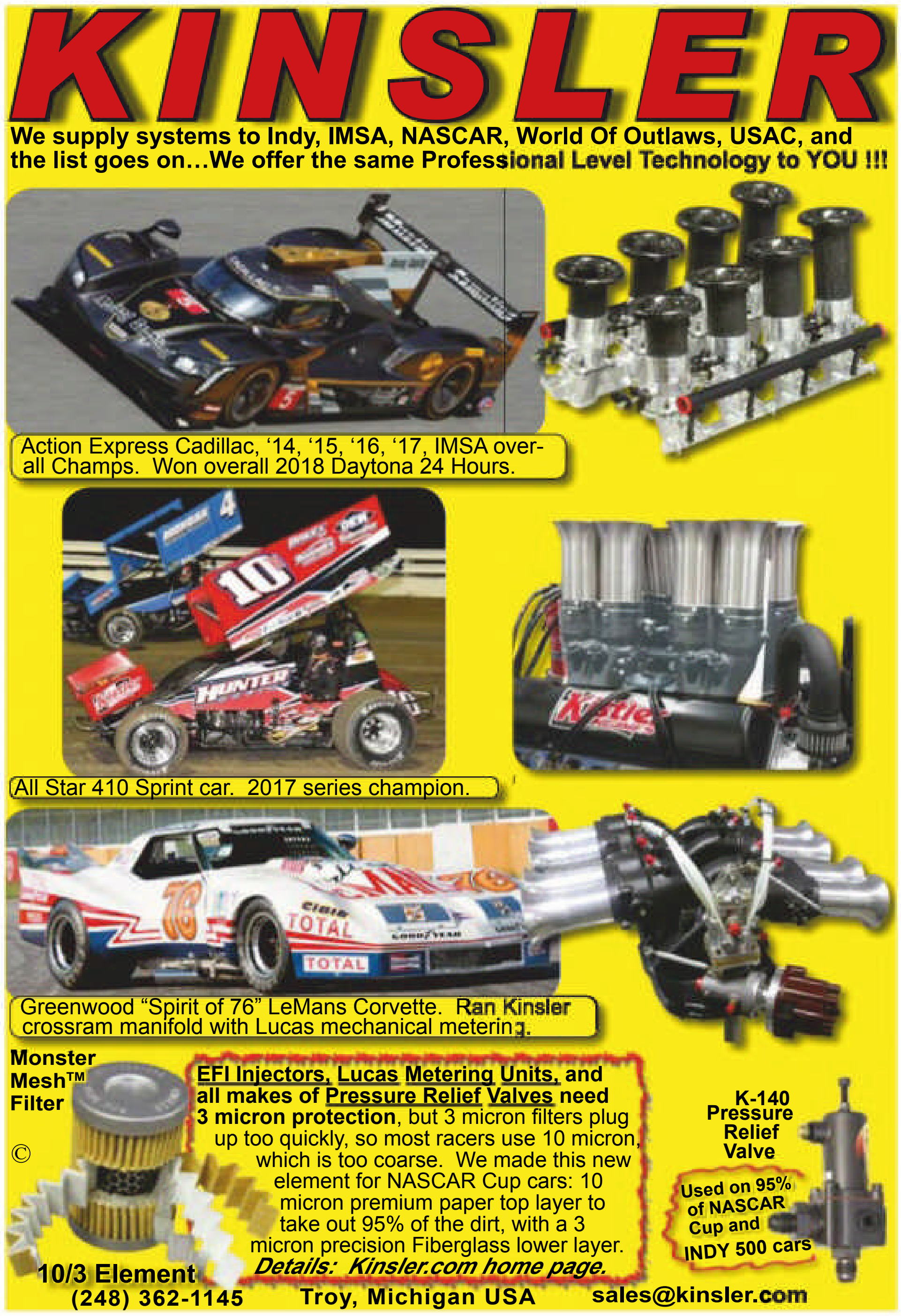
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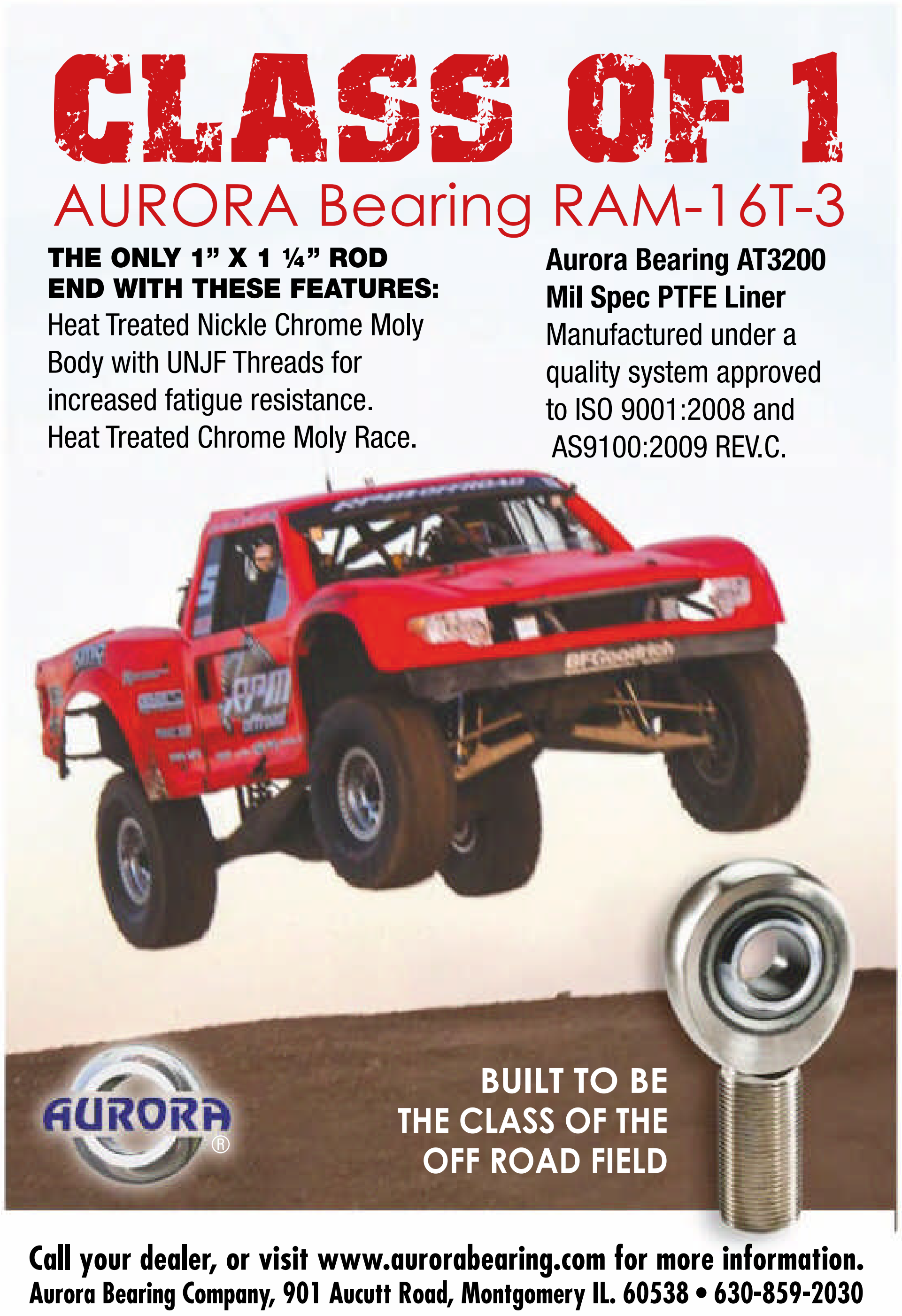
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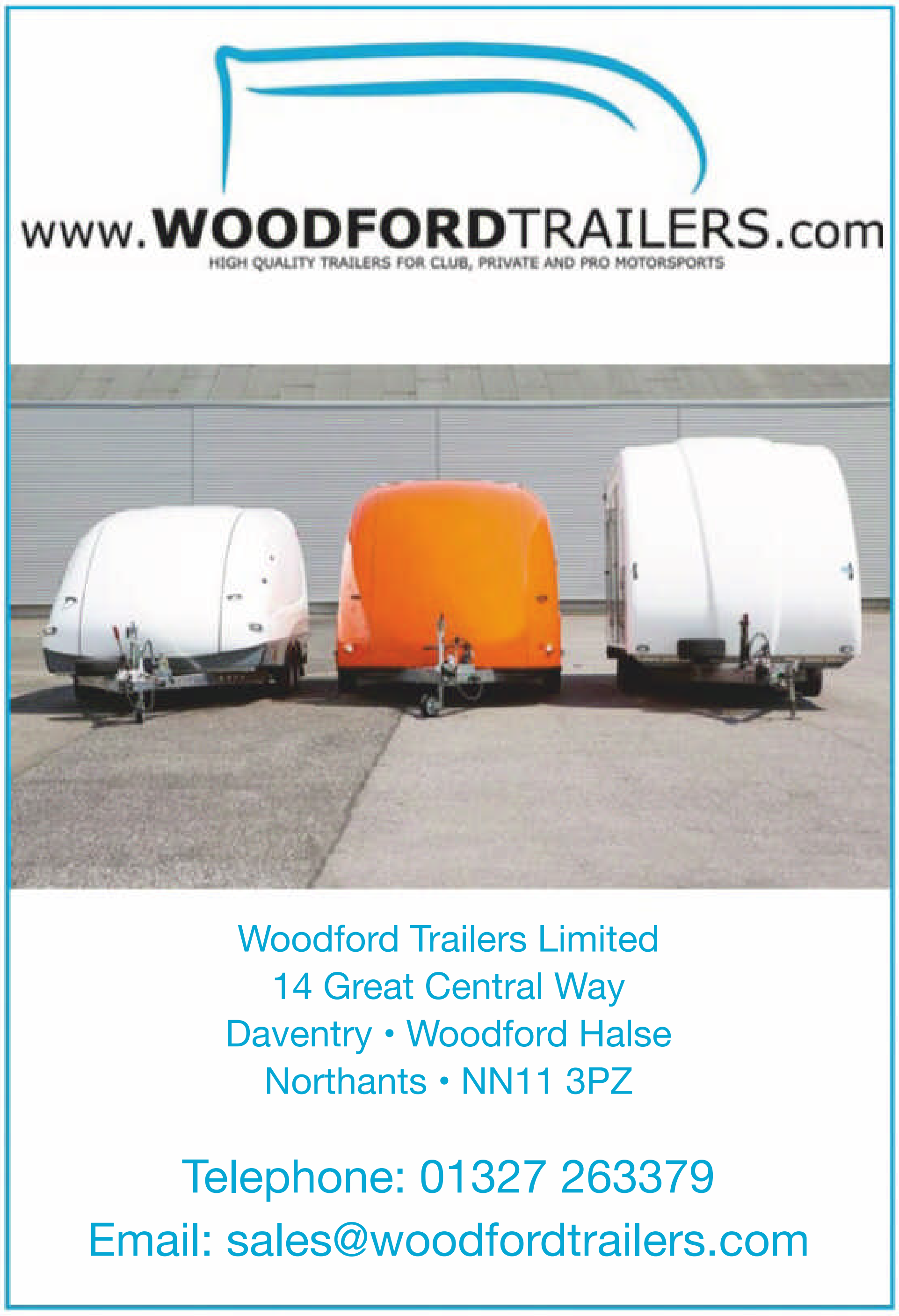
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that, particularly in high severity circuits, it's easy to have a loss of air and then a deflation where you have to stop the car.' (Or not in the case of Hamilton at the British GP this year!).

Pressure evolution

Tyre pressure is another factor that greatly affects degradation because it changes the size of the contact patch. In F1, Pirelli prescribes minimum starting pressures, so all teams leave the box with the same tyre pressures. As the tyres warm up, pressure increases, and the tyre effectively 'balloons', resulting in a much smaller contact patch. However, high running pressures strengthen the sidewall and help maintain the integrity of the tyre, which is why Pirelli will often increase its recommended minimum starting pressures after Friday running.

'Having a higher pressure obviously helps the construction but, on the other side, there is the risk of more overheating, and in some cases a bit more blistering because of the reduction in the footprint area,' confirms Isola.

So, on one hand you have the tyre manufacturer boosting pressures, resulting in a smaller contact patch, while, on the other hand, you have teams trying to reduce pressures and maximise contact patch size.

'The curveballs come when they [Pirelli] up the minimum pressures,' says Egginton. 'The more air they demand you have in there, the further it probably takes you away from the optimum operating range of the tyre. So we try to minimise the pressure evolution using techniques like rim cooling, which will change the way the tyre operates.

'Normally, you want to run the fronts as cold as possible. If you run anything else it's difficult to manage the bulk temperature.'

Tyre modelling

Given all these variables, how *do* teams predict and manage tyre degradation? Well, first they try to model it, but generating reliable, accurate tyre models is very difficult.

'We have a baseline tyre model and we will change some of the settings in there based on Friday data. Or, if we don't feel we've learnt anything representative, we'll leave the historical data in the model,' explains Egginton. 'We then apply our normal offsets and variables based on temperature, track evolution…all the boring stuff.

'In the race, the model updates constantly. Pace is a big factor, of course, so we're constantly manipulating that but, if the driver doesn't listen to instruction, we'll see directly what's going on with tyre wear and energies.

'So we're instructing the driver based on a live model and how far we think that tyre will go. If we have a view on how far it needs to go, and we're not getting there, we either change strategy or react accordingly.'

One of the key metrics used in tyre models is tyre energies. This is a much more reliable way of calculating the available performance because it incorporates the effect of sliding into the wear calculation. You can assume a tyre leaves the garage with 100 per cent energy and the amount of slip measured by slip angle sensors, along with corner severity, wears the tyre and consumes that energy. You can then forecast whether the tyre will have enough energy to last to the end of the stint and can employ strategies to manage tyre life.

'We get very excited about tyre energies as they are an important part of determining where we are with tyre life,' says Egginton. 'Based on what that tells us, as soon as the tyres stabilise, we might tell the driver to tyre manage in high-speed corners, conduct more lift off in certain areas, be more careful with tyre slip when exiting a low-speed corner or be careful with the brake moment balance.

'That metric gives us the ability to try to manage the energy and the slip and tells us if we're doing the right things to have enough tyre until the end of the race.

'We effectively drive to targets derived from the model. The driver is just validating

'The stronger and stiffer compounds generally have more thermal stability than the softer ones'

Mike McGregor, manager of sales, testing and track support at Goodyear

'We get very excited about tyre energies as they are an important part of determining where we are with tyre life'

Jody Egginton, technical director at Alpha Tauri

what the model shows us. We'll only ignore those targets if we're fighting for points, or the driver is really struggling.'

Differing strategies

Tyre models have therefore become a vital tool when managing tyre degradation, but the specific strategies can vary dramatically between different types of motorsport.

'One of the big differences between endurance racing and Formula 1 is that in endurance racing, the primary focus is achieving the least amount of degradation possible, not necessarily peak performance, because it's not sprint racing,' highlights Mike McGregor, manager of sales, testing and track support at Goodyear. 'In some races, we do over 700km on a single set of tyres, which is around three Formula 1 races. Our target at Le Mans, for example, is four stints, and we design the tyres to be as consistent as possible throughout that distance.'

One of the tricks tyre manufacturers use to manage degradation for different circuits and conditions is to design a range of compounds, selecting the most appropriate to avoid overheating issues. 'Generally, we step the compound range up and our range is designed so that, in theory, we can always go to the stiffer compounds to avoid overheating issues,' reveals McGregor. 'The stronger and stiffer compounds generally have more thermal stability than the softer compounds. So we can run the softer compounds at Le Mans at night. But if you were to try and run that in the true heat of the day at Silverstone then, yes, you might suffer from overheating.

'But we tend to recommend compounds so before we even get to that position, we're running a slightly stronger tyre.'

Some forms of tyre degradation can actually be recovered from. For example, light graining can be worn through, removing the ridges to increase contact patch and grip, but this usually only works for a short period of time before the tyre begins graining again.

Surface overheating can also be reduced by driving technique, such as lifting off

Rallycross tyres

Each category of motorsport demands a different type of tyre, and one of the most brutal environments a tyre has to endure is that of World Rallycross (RX). Supercars that boast 600bhp run on a mixture of asphalt and unsealed (gravel) surfaces, complete jumps that are 2.0m high and accelerate from 0-60mph in 1.9s, which is faster than F1. These extreme longitudinal loads require a robust tyre with an extremely strong construction.

'It all comes down to the way you lay up the plies of the tyre to achieve a construction that can withstand the loads during jumps, starts, impacts and kerbs,' explains Matthew Vincent, materials development manager at series supplier, Cooper Tires. 'The sidewall in a World RX tyre has some additional reinforcement in it, and even the compound we use in the sidewall itself has to be specifically tuned for abrasion resistance because there is a lot of contact and rubbing on the sidewall.'

Unlike most GT and Formula tyres, Rallycross tyres have a very wide working temperature range because there are no tyre ovens or blankets. Therefore, the tyre has to be able to work straight from the standing start at ambient temperature.

'We use a control tyre in World RX so there's only one compound of dry tyre throughout the whole season,' says Vincent. 'The calendar means track temperatures can vary from 5degC to 40degC, so the working range has to be broad. Normally, the optimum temperature for the compound is anywhere between 70degC and 120degC.

'Despite each race only being five or six laps, these tyres generate a significant amount of heat and it's not uncommon to see temperatures above 120degC in hot conditions.

'Actually, this is where the gravel sections of track really help. Because they are lower grip, it gives the compound a chance to cool down. If the track was all tarmac, we'd probably find the compound getting too hot and dropping out of the optimum performance window.'

Thicker treads

This high heat generation is partly due to the thicker treads run in rallycross tyres, around 8-10mm, compared to GT tyres, which are approximately 4mm thick. Interestingly, despite these thicker treads and high temperatures, blistering and graining are not a problem in World RX, so the only degradation teams have to manage is wear. These wear rates mostly depend on the nature of each circuit, as well as each team's unique set-up.

'Historically, some tracks had extremely high wear rates. This was predominantly down to the nature of the surface,' explains Vincent.

World RX tyres have to work in ambient temperatures between five and 40degC, operating temperatures between 70 and 120+degC and be able to withstand a brutal working regime

'Now, the modern materials used to generate the unsealed surfaces wear in a more consistent and even way. So you'll get a gradual drop in the coefficient of friction over the weekend, but the track doesn't wear like it used to, or suffer from rutting.'

Rallycross tyres also need to cope with a wide variety of set-ups because teams are relatively unrestricted when it comes to suspension design. The GCK Megane cars, for example, feature a radical suspension layout with inboard brakes (see *RCE* V29N8). Surprisingly, despite this diversity, the running pressures of World RX cars are similar because all teams are trying to run the lowest pressures possible for a grip advantage at the start.

The only degradation teams have to manage is wear

'The danger when running low pressures is, if you hit a kerb in the first corner, you could knock the bead of the tyre off the rim, so we've done a lot of work over the years on bead design to avoid that,' says Vincent. 'The teams are pretty good at knowing what the limits are, and so run sensible pressures. It also depends on how they want the car to drive as some drivers like a soft set-up.'

As with most championships, the future seems to be electric and with Projekt E racing for the first time this season, there are even more factors to consider. 'It will be interesting to see how much the cars vary in the electric championships,' says Vincent. 'Projekt E runs on our ACB11 tyre, but with electric cars you have to consider the extra weight and additional torque. So we may have to increase the strength of the case, or maybe develop a wider tyre in the future.'

through high-energy corners and controlling slip, along with adjusting brake balance, rim cooling and improving overall car balance.

Driver influence

'The influence of the driver should not be underestimated,' admits Egginton. 'These guys are quite good at managing tyres. They can implement a small amount of lift off and, if split up correctly in the right areas around the track, you can do it without losing lap time. That's quite a nice trick for bringing tyre and brake temperatures down.

'A lot of what is said over the radio [during a race] has already been discussed, so the drivers know what deltas to drive to. That way, when you switch to plan b – provided they remember of course – they will adapt the tyre management to make sure the tyre lasts for the new stint length.'

Educating drivers is particularly important in endurance racing where driver ability and experience can be very varied. Key to a good stint time, rather than a lap time, is not to lock up a tyre, particularly in the first of a multiple-stint run but there is more to it than that. Working the tyre properly through a variety of temperatures and track conditions is also critical and to achieve that engineers have a lot of educating to do. 'One of the big things we've worked on over the last 10 years is driver KPIs,' says McGregor. 'In endurance racing, you have a mixture of drivers from full-time professionals to gentlemen drivers, so we try to work with them as much as possible to manage things like steering input, brake regression and throttle regression so they're not overdriving the tyre in critical areas. It's all about managing the performance of the tyre and deciding when you put it into the tyres.'

In conclusion, no matter how much data you have, or how much you *think* you know about how a tyre will perform on any given track and condition, racing rubber will always prove you wrong.


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The British Rallycross Championship has kicked back into life with renewed vigour post-Covid and has electric technology in its sights

By ANDREW COTTON

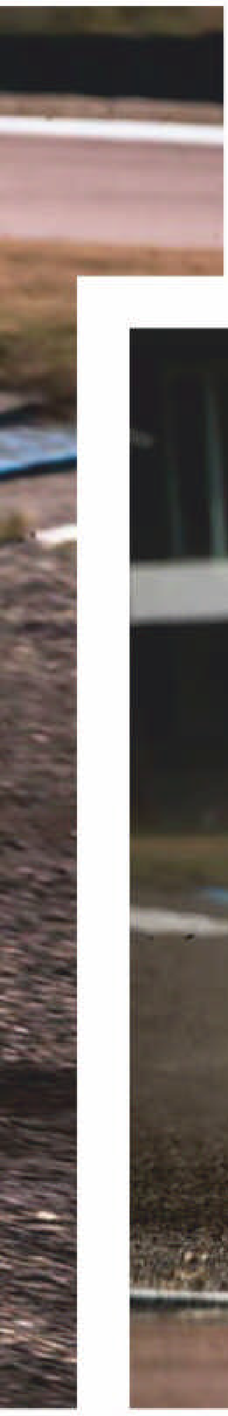
The British Rallycross Championship is set to include electric cars at low cost as early as next season as the organisers look to keep up with the changing trends in motorsport. Pat Doran, who owns the Lydden Hill circuit in Kent and who is driving the changes in the sport says there are a number of options currently being considered for the series next year.

Rallycross perfectly lends itself to the introduction of electric technology. With short races and just five cars per race, balancing the performance of electric and traditional drivetrain technology is not an issue, and the racing is likely to be spectacular.

In 2017, *Racecar Engineering* featured the work of the Stohl Advanced Research and Development company, STARD, which started by developing an electric rally car but switched to Rallycross as the discipline increased in popularity recently. The company converted a Peugeot 207 Super 2000 to an electric powertrain with one motor per axle, each coupled with a limited slip differential. By having separate motors front and rear with no mechanical link between them, sequential

Traction control is banned in British Rallycross and its illicit use is relatively easy to police, say the organisers

Balancing the performance of electric and traditional drivetrain technology is not an issue, and the racing is likely to be spectacular



With short stints and five 600bhp cars per race, Rallycross is an explosive and spectacular form of motorsport

torque control can be achieved through the use of a MoTeC M150 vehicle control unit. However, British Rallycross operates on a different level to the world stage, and the budget may not be there in order to make STARDS' proposal a reality.

'We know it is going to happen. We can't stop it, we don't want to stop it,' says Doran of the introduction of electric technology. 'We have two ways of going. You have the STARD way, which is basically an electric car that is a lot of money [to buy] and a lot of money to run, and another firm that says you can convert a normal rally car into electric for a very small amount of money, which the economics are going to tell you to do.

'If you have a four-wheel-drive Fiesta or a two-wheel-drive Mini you can enter the class. You have the car and you have to buy transmission and the unit. We can go down either. We haven't decided [which].'

The introduction of electric into national series is the next step for electric technology. Arguably, the British series is ideally placed to make the change, thanks to a new drive from Doran and the introduction of a multi-nation tour of the UK over the next few months. The 2020 British Rallycross Championship started in England at the end of August before it moves to Scotland, Wales and finishes the season at Mondello Park, Ireland in November. Organisers have reverted to traditional marketing techniques to support this, inviting Sir Chris Hoy, the UK's most decorated Olympic cyclist, as part of a link up with British cycling, while Isle of Man TT legend, John McGuinness, will drive the celebrity car at the Scottish round.

National needs

The regulations broadly follow those of the FIA world series, certainly in terms of the safety elements, but technical changes have been made in order to keep control of costs that are more aligned with a national series.

The electronic management systems have been pared back as the needs of a national championship are far less than those of an international series. '[For] the world [cars] you have to have computers looking at other computers, which we don't have in the British [series],' continues Doran. 'We simplify things.

The regulations from the start are framed in such a way as to encourage teams *not* to spend money but instead enjoy their racing

We don't even have homologation. We could have but we don't. We have Group B and cars from the 1990s racing together and, realistically, from 2000 onwards competitors can go into the Supercar category. They are our two big classes. The rest of [our regulation set] is led on safety, upgrades of seats, petrol tank lives and so on. You can only do so much [modification] to the original chassis.'

Achievable goals

The national series has moved away from key elements of the world series, including the mandating of turbos from Garrett. The British series uses Borg Warner turbos that are more than capable of handling the engines. The cars run with 45mm air restrictors to limit power to around 600bhp, which is achievable for most engine tuners. Fuel and tyres are spec and provided by the organisation, the former by Vital Equipment, the latter Cooper.

The regulations from the start are framed in such a way as to encourage teams *not* to spend money but instead enjoy their racing, while embracing as broad a range of machinery as possible. An older version of a British Rallycross car, for example, can still run to within half a second of a newer, WRC-spec version. And although they run in different races, car age is no barrier to entry.

Onboard telemetry transmission between car and pit is banned, other than for official timekeeping purposes. Active suspension is outlawed, as is traction control. There are very few spec components on the car, which makes life a lot more interesting for the teams and their potential suppliers.

Having worked with the FIA and built cars for the world series, Doran admits he is now jaded working with the French, which also explains the direction change towards independence from the world regulations.

Historic cars like this Audi Quattro are always a crowd pleaser on the Rallycross circuit, where cars from the 1990s and 2000s race closely together with very few spec components between them


Pat Doran, former British Champion and UK track owner, is driving a raft of changes in the sport

'You have a 45mm restrictor and you have a certain amount of fuel. What do they think you will do, run the Cosworth backwards or something?'

'We found we were fighting the FIA,' says the former champion driver. 'On a whim they would change things. One car gets agreed by the FIA and MSA (Motorsports Association), and the next year the main hoop has to go back 20mm, so you have to rebuild the car in two weeks. We found the likes of Prodrive and MSport know how to deal with that, but as a Rallycross team we didn't appreciate the amount of work it would be to keep the FIA happy. They had 3D CAD, while us with four cars, it wasn't simple stuff.

'We run a Cosworth system, which costs about £25,000, but [with the former World Rally Championship cars] we had to have a Marelli system to overlook the Cosworth and the programming that has to go in to make them work is incredible. We don't do that now. We have the Marelli disconnected. It is not about stopping anyone cheating, the Marelli system is only there to watch what the Cosworth system is doing.'

Under control

While the British regulations are more open, the major concern is the use of traction control, which is specifically banned in Rallycross, be it World Championship or British. Clearly, investment in an intelligent system would be expensive for teams but while the World cars have cash thrown at the problem, British teams don't have that option. However, Doran appears not to be concerned.

'Realistically, there isn't a lot you can do,' he says. 'You have a 45mm restrictor and you have a certain amount of fuel. What do they think you will do, run the Cosworth backwards or something? The [stewards] can see if you have [done anything illegal]. You are not allowed any active on the traction control. If you manage to turn the ALS switch off and back on, that will get you kicked out of the event and you would see the data.

'In the British [series] it is not hard to police traction control. We do police it, we do have restrictions.' A low-cost alternative to the FIA's solution is key to success at domestic level. 'I don't mind policing cheating. It is the stupid rules [that the FIA] make [I mind] that don't make a difference [and cost money].'

The British series has multiple categories from historic cars to supercars and the Swift Cup, which is a cost-effective introduction, but Doran has his eyes on other forms of competition to join the already impressive stable of cars. His latest idea is to bring Trophy Trucks to the bill and he has even built a truck with a view to running it alongside the current cars. He hasn't worked out if the powertrain will be electric or V8 diesels yet, but they will definitely be spectacular and that's a hallmark of his vision for the series.

He is even thinking of introducing a drift challenge, even though it is not Doran's favourite type of motorsport. 'People have gone to drifting now. I call it skidding,' he says.

'The vision for the next three-to-five years is a spectacle. If you want to do Rallying, that's great, but if you want to bring your family and sponsors, you have to come here.'

Hand calculation

Why these simple mathematical checks are as important now as they have always been

By **DANNY NOWLAN**

A recurring theme in my *Racecar Engineering* articles over the years has been the importance of hand calculations. Sadly, this is a discipline that has been atrophying.

The purpose, therefore, of this article is to highlight what I consider to be the most important hand calculations any performance / data / race engineer has to have at their fingertips.

Downforce

The first example I want to discuss is hand calculation of downforce. I realise that for some of you reading this, the feeling here could very well be exasperation, but it blows me away the number of professional race engineers I meet who not only can't do this, but think it is impossible.

What I am about to show needs to be one of your first go-tos, particularly if you are dealing with an aero car.

The language of aerodynamics is CLA, CDA and aero balance. Mathematically, this is expressed as **Equation 1**.

Here, a_x is the inline acceleration, *T(rpm)* is the engine torque in Nm, *gr* is the gear ratio (in terms of torque multiplication from engine to gearbox), *rt* is the rolling radius of the tyre and *FSi* are the individual spring forces that are in N.

Let's illustrate via example. The best place to take your numbers for hand calculating downforce is at the end of the longest straight with minimal lateral acceleration. Also, remember to zero the dampers on the ground as it will make your life a lot easier.

For this example, we will take the numbers as illustrated in **Table 1**. Here, all motion ratios are damper on wheel, and the gear ratio is engine / wheel velocity. For simplicity, I've omitted bump rubbers. **Calculation 1** gives us the results of crunching the numbers.

Damping ratios

The next point to discuss is damping ratios. One of the things I have stated on a number of occasions previously is that damping behaviour is not driven by the magnitude of the numbers, but the rate. The numbers you see in the peak force vs damper curve are a consequence of this. The way you non-dimensionless this is with damping ratio, and the formulation for this is shown in **Equations 2** and **3**.

For our example here, let's assume a quarter car mass of 125kg, a spring rate of 800lbf/in or 140N/mm and a damping rate at the damper of 17,900N/m/s. Let's assume the motion ratio is 0.75. Crunching the numbers, we see the results in **Calculation 2**.

These are your damping ABCs. Do not underestimate their power.

EQUATIONS AND CALCULATIONS

Equation 1

$$C_L A = \frac{\sum_{i=1}^{4} F_{s_i}}{\frac{1}{2}\cdot\rho\cdot V^2}$$

$$C_D A = \frac{T(rpm)\cdot gr/r_t - m_t a_x}{\frac{1}{2}\cdot\rho\cdot V^2}$$

$$awf = \frac{\sum_{i=1}^{2} F_{s_i} + \frac{m_t a_x h}{wb}}{\sum_{i=1}^{4} F_{s_i}}$$

Equation 2

$$\omega_0 = \sqrt{\frac{K_B}{m_B}}$$

$$C_B = 2\cdot\omega_0\cdot m_B\cdot\zeta$$

Equation 3

$$\zeta = \frac{C_B}{2\cdot\omega_0\cdot m_B}$$

Where:

K_b = wheel rate of the spring (N/m)

C_b = wheel damping rate of the spring (N/m/s)

m_b = Mass of the quarter car

ω_0 = natural frequency (rad/s)

ξ = damping ratio

Calculation 1

$$\begin{aligned} FtDownforce &= MR_f\cdot k_f\cdot(FL\_Damp + FR\_Damp) \\ &= 0.9*140.1*(10+10) \\ &= 2521.8N \end{aligned}$$

$$\begin{aligned} RrDownforce &= MR_r\cdot k_r\cdot(RL\_Damp + RR\_Damp) \\ &= 0.8*140.1*(15+15) \\ &= 3362.4N \end{aligned}$$

$$\begin{aligned} C_L A &= \frac{FtDownforce + RrDownforce}{0.5*1.225*(220/3.6)^2} \\ &= 2.57 \end{aligned}$$

$$\begin{aligned} AeroBal &= 100\cdot\left(\frac{FtDownforce + \frac{mt\cdot g\cdot a_x\cdot h}{wb}}{FtDownforce + RrDownforce}\right) \\ &= 100\cdot\left(\frac{2521.8 + \frac{500\cdot 9.8\cdot 0\cdot 0.3}{2.6}}{2521.8 + 3362.4}\right) \\ &= 42.9\% \end{aligned}$$

$$\begin{aligned} C_D A &= \frac{gr*T/r_t - m_t\cdot g\cdot a_x}{0.5*1.225*(220/3.6)^2} \\ &= \frac{3*200/0.28 - 550\cdot 9.8\cdot 0}{0.5*1.225*(220/3.6)^2} \\ &= 0.937 \end{aligned}$$

Calculation 2

$$K_B = MR^2\cdot SR = 0.75*0.75*140*1000 = 78750$$

$$C_B = MR^2\cdot C_{DAMP} == 0.75*0.75*17900 = 10070$$

$$\omega_0 = \sqrt{\frac{K_B}{m_b}} = \sqrt{\frac{78750}{125}} = 25.1 rad/s$$

$$\zeta = \frac{C_B}{2\cdot\omega_0\cdot m_b} = \frac{10070}{2*25.1*125} = 1.6$$

Table 1: Sample values for an aero hand calculation

Item	Quantity
Front motion ratio	0.9
Rear motion ratio	0.8
FL damper / FR damper	10mm / 10mm
RL damper / RR damper	15mm / 15mm
Front spring	140.1N/mm (800lbf/in)
Rear spring	140.1N/mm (800lbf/in)
Torque at rpm	200Nm
Rolling tyre radius	0.28m
a_x	0g
Vx	220km/h
Gear ratio value	3
m_t	500kg
h	0.3m
wb	2.6m

EQUATIONS AND CALCULATIONS

Equation 4

$$\Delta L_x = \frac{a_x \cdot m_t \cdot h}{wb}$$

$$\Delta L_y = \frac{a_y \cdot m_t \cdot h}{tm}$$

Where:

dL_x = longitudinal load transfer to longitudinal acceleration (N)
dl_y = lateral load transfer to longitudinal acceleration (N)
a_x = longitudinal acceleration in m/s^2
a_y = lateral acceleration in m/s^2
h = c of g height (m)
wb = wheelbase of the car (m)
tm = mean track of the car (m)

Calculation 3

$$\Delta L_x = \frac{a_x \cdot m_t \cdot h}{wb} = \frac{1*9.8 \cdot 500 \cdot 0.3}{2.7} = 544.4N = 55.6kgf$$

$$\Delta L_y = \frac{a_y \cdot m_t \cdot h}{tm} = \frac{1*9.8 \cdot 500 \cdot 0.3}{1.5} = 980N = 100kgf$$

Equations 5–10

$$rcm = rcf + wdr*(rcr - rcf)$$

$$hsm = h - rcm$$

$$rsf = (krbf + kfa)*ktf/(kfa + krbf + ktf)$$

$$rsr = (kfb + krbr)*ktr/(kfb + krbr + ktr)$$

$$prm = rsf/(rsr + rsf)$$

$$prr = (wdf*rcf + prm*hsm)/h$$

Where:

rcm = mean roll centre (in m)
rcf = front roll centre height (in m)
rcr = rear roll centre height (in m)
wdr = weight distribution at the rear of the car
wdf = weight distribution at the front of the car
h = c of g height of the car (in m)
rsf = wheel spring rate in roll for the front (in N /m)
rsr = wheel spring rate in roll for the rear (in N/m)
ktf = front tyre spring rate (in N/m)
ktr = rear tyre spring rate (in N/m)
kfb = spring rate of the rear coil, acting at the wheel (in N/m)
$krbr$ = rear roll bar rate (in N/m)
prm = lateral load transfer due through the sprung mass
prr = lateral load transfer distribution at the front
tm = mean track of the vehicle

Equation 11

$$WR = MR^2 \cdot k$$

Calculation 4

$$rcm = rcf + wdr \cdot (rcr - rcf) = 0.1 + 0.5*(0.25 - 0.1) = 0.175m$$

$$hsm = h - rcm = 0.5 - 0.175 = 0.325m$$

$$rsf = \frac{(krbf + kfa) \cdot ktf}{kfa + krbf + ktf} = \frac{(50+50) \cdot 305}{50+50+305} = 75.3N/mm$$

$$rsf = \frac{(krbr + kfb) \cdot ktr}{kfb + krbr + ktr} = \frac{(50+10) \cdot 305}{50+10+305} = 50.13N/mm$$

$$prm = \frac{rsf}{rsf + rsr} = \frac{75.3}{75.3 + 50.13} = 0.6$$

$$prr = \frac{wdf * rcf + prm * hsm}{h} = \frac{0.5*0.1 + 0.6*0.325}{0.5} = 0.49$$

Equation 12

$$L_1 = \frac{wdf \cdot m_t \cdot g}{2} + \frac{awf \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} + \frac{prr \cdot m_t \cdot a_y \cdot h}{tm}$$

$$L_2 = \frac{wdf \cdot m_t \cdot g}{2} + \frac{awf \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} - \frac{prr \cdot m_t \cdot a_y \cdot h}{tm}$$

$$L_3 = \frac{wdr \cdot m_t \cdot g}{2} + \frac{awr \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} + \frac{(1 - prr) \cdot m_t \cdot a_y \cdot h}{tm}$$

$$L_4 = \frac{wdr \cdot m_t \cdot g}{2} + \frac{awr \cdot C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot V^2}{2} + \frac{(1 - prr) \cdot m_t \cdot a_y \cdot h}{tm}$$

Where:

$L_1 - L_4$ = tyre loads on tyres 1 to 4 respectively (N)
wdf = weight distribution at the front
wdr = weight distribution at the rear = 1-wdf
m_t = total car mass
awf = front aero distribution
awr = rear aero distribution = 1-awf
C_LA = downforce coefficient x area
h = c of g height (m)
tm = mean track of the car (m)
a_y = lateral acceleration (m/s^2)
prr = lateral load transfer on the front

The next point to discuss is calculating weight transfer. The ability to calculate weight transfer for a given lateral and longitudinal acceleration is a key skill for any data engineer and is presented in **Equation 4**.

Now let's say we have an F3 car that weighs 500kg, has a wheelbase of 2.7m, a mean track of 1.5m, a c of g height of 0.3m and is subject to a lateral and longitudinal acceleration of 1*g*. What **Calculation 3** tells us is that for a 1*g* acceleration, the loads longitudinally on the front and rear axles have shifted a delta of 55.6kg. Side to side, they have changed by 100kg.

The magic number

Let's now look at the close cousin of weight transfer, which is calculating lateral load transfer distribution. The reason I mention this is because it is often referred to as 'the magic number'. While this is overstating things a bit, the 'magic' comes from the fact the number represents the trade off between grip and balance that works for a particular driver. How you calculate this is shown in **Equations 5** to **10**.

If I'd been really cruel, I could have combined this in one equation. However, the reason I've broken it down into its constituent parts is so you can see how the numbers evolve and can then create an Excel spreadsheet based on this. Also, all the spring rates you use here have to be in wheel rates, as opposed to rates at the damper. The conversion is shown in **Equation 11**.

Here, *WR* is the wheel rate, *MR* is the motion ratio expressed as a damper / wheel ratio and *k* is the spring rate at the damper.

Let's walk through an example. Some sample parameters are presented for a road course Stock Car in **Table 2**. For brevity, all numbers are quoted as wheel rates.

Crunching the numbers in **Calculation 4** tells us that 49 per cent of the load transfer of this car occurs across its front axle.

Tying this all together, we can use the load transfer equations and the lateral load transfer equation, together with our aero knowledge, to nail down the tyre loads on the car. This is presented in **Equation 12**.

This is an invaluable addition to any set-up sheet because when you make a set-up change you can instantly see what the tyre loads are going to be for a given lateral acceleration and speed. This isn't simulation, but it gives you a good visualisation about what is going on with the car.

Table 2: Stock Car parameters

Quantity	Value
c of g height	0.5m
front weight distribution (wdf)	0.5
front roll centre height	0.1m
rear roll centre height	0.25m
mean track	1.7m
front wheel rate	50N/mm
front bar rate	50N/mm
rear wheel rate	50N/mm
rear bar rate	10N/mm
front and rear tyre spring rate	305N/mm

Note when starting to use this, begin with fixed aero values and linear spring rates. It's a good first position because it's simple and is your first step in becoming numerically literate about racecar set-up.

Calculation toolbox

The next point that should be in your calculation toolbox is knowing how to calculate the roll of a racecar and translating this to damper movement. Just so we are clear, for the time being I'll present everything in wheel rates, and I'll also assume symmetry, linear springs and bars. For any NASCAR / oval racers reading this, that's okay as the asymmetric case is a super set of this. Our terms will be as follows:

k_f = front spring rate (N/m)
k_{rf} = front roll bar rate (N/m)
k_{tf} = front tyre spring rate (N/m)
tf = front track (m)
k_r = front spring rate (N/m)
k_{rr} = front roll bar rate (N/m)
k_{tr} = rear tyre spring rate (N/m)
tr = rear track (m)
t_m = mean track (m) (equivalent track at the c of g)
h = c of g height
rc_m = mean roll centre (equivalent roll centre height at c of g)
ϕ = roll angle (rad)
w_f = differential wheel displacement at the front (m)
w_r = differential wheel displacement at the rear (m)

Crunching the numbers here becomes very interesting. Assuming symmetry, the results can be shown in **Equation 13**.

Our next step is to tie in wheel movement with the roll movement. Since the force on the front spring will be the same as the tyre, the results are shown by **Equation 14**. Similarly, at the rear we have **Equation 15**.

To avoid any confusion here, I've taken the absolute value of roll angle in **Equations 14** and **15**. If we substitute **Equations 14** and **15** into **Equation 13**, we can now solve for the roll angle. Doing the algebra, it can be shown as in **Equation 16**.

At this point you might be thinking that's great, but how do you actually use this? To quote the Joker from *The Dark Knight*, let me show you a magic trick. Or at least, let me show you **Equation 17**.

Here *roll$_f$* is the differential of the front damper displacements divided by two, and *roll$_r$* is the differential displacement of the rear dampers divided by two. Again, this is all at the wheel, and I'm taking the absolute value of roll angle.

Before illustrating this with a hands-on example, let's say you are in a situation where you are lucky enough to run load cells. Let's say you're even luckier and they are mounted on the push rod. In this case, we have as shown in **Equation 18**.

Here, *force_roll$_f$* is the front differential loads divided by two and *force_roll$_r$* is the rear differential loads divided by two. To find the true roll rate, you simply do the algebra in **Equation 17**. However, this comes with a very important caveat. Load cells are a bit like romantic movies or fish and chips. They are either really good or really bad. So, if the numbers look stupid, they probably are.

EQUATIONS AND CALCULATIONS

Equation 13

$$-F_{yt}\cdot\frac{(h-rc_m)}{2}=0.5\cdot tf\cdot(k_f+k_{rf})\cdot(0.5\cdot tf\cdot\phi-w_f)+0.5\cdot tr\cdot(k_r+k_{rr})\cdot(0.5\cdot tr\cdot\phi-w_r)$$

Equation 14

$$(k_f+k_{rf})\cdot(0.5\cdot tf\cdot\phi-w_f)=k_{tf}\cdot w_f$$

$$\therefore w_f=\frac{0.5\cdot tf\cdot\phi\cdot(k_f+k_{rf})}{(k_f+k_{rf}+k_{tf})}$$

Equation 15

$$w_r=\frac{0.5\cdot tr\cdot\phi\cdot(k_r+k_{rr})}{(k_r+k_{rr}+k_{tr})}$$

Equation 16

$$\phi=\frac{-2\cdot F_{yt}\cdot(h-rc_m)}{tf^2\cdot(k_f+k_{rf})\cdot\left(1-\frac{k_f+k_{rf}}{k_f+k_{rf}+k_{tf}}\right)+tr^2\cdot(k_r+k_{rr})\cdot\left(1-\frac{k_r+k_{rr}}{k_r+k_{rr}+k_{tr}}\right)}$$

Equation 17

$$0.5\cdot tf\cdot\phi=roll_f+w_f$$

$$0.5\cdot tr\cdot\phi=roll_r+w_r$$

Equation 18

$$(k_f+k_{rf})\cdot roll_f=force\_roll_f$$

$$(k_r+k_{rr})\cdot roll_r=force\_roll_r$$

Calculation 5

$$\phi=\frac{-2\cdot F_{yt}\cdot(h-rc_m)}{tf^2\cdot(k_f+k_{rf})\cdot\left(1-\frac{k_f+k_{rf}}{k_f+k_{rf}+k_{tf}}\right)+tr^2\cdot(k_r+k_{rr})\cdot\left(1-\frac{k_r+k_{rr}}{k_r+k_{rr}+k_{tr}}\right)}$$

$$=\frac{2\cdot1320\cdot1.01\cdot9.8\cdot(0.495-0.04)}{1.49^2\cdot(0.95^2\cdot40\times10^3+0.64^2\cdot32.461)\cdot\left(1-\frac{0.95^2\cdot40\times10^3+0.64^2\cdot32.461}{0.95^2\cdot40\times10^3+0.64^2\cdot32.461+305\times10^3}\right)+1.472^2\cdot(40\times10^3+61.119\times10^3)\cdot\left(1-\frac{40\times10^3+61.119\times10^3}{40\times10^3+61.119\times10^3+305\times10^3}\right)}$$

$$=4.592\times10^{-2}\,rad$$

Calculation 6

$$w_f=\frac{0.5\cdot tf\cdot\phi\cdot(k_f+k_{rf})}{(k_f+k_{rf}+k_{tf})}$$

$$=\frac{0.5\cdot1.49\cdot(4.592e-2)\cdot(0.95^2\cdot40+0.64^2\cdot32.641)}{0.95^2\cdot40+0.64^2\cdot32.641+305}$$

$$=4.77mm$$

$$w_r=\frac{0.5\cdot tf\cdot\phi\cdot(k_f+k_{rf})}{(k_f+k_{rf}+k_{tf})}$$

$$=\frac{0.5\cdot1.472\cdot(4.592e-2)\cdot(40+61.119)}{40+61.119+305}$$

$$=8.42mm$$

Calculation 7

$$roll_f=0.95\cdot((0.5\cdot1.49\cdot4.592e-2)\times10^3-4.77)=27.96mm$$

$$roll_r=((0.5\cdot1.472\cdot4.592e-2)\times10^3-8.42)=25.37mm$$

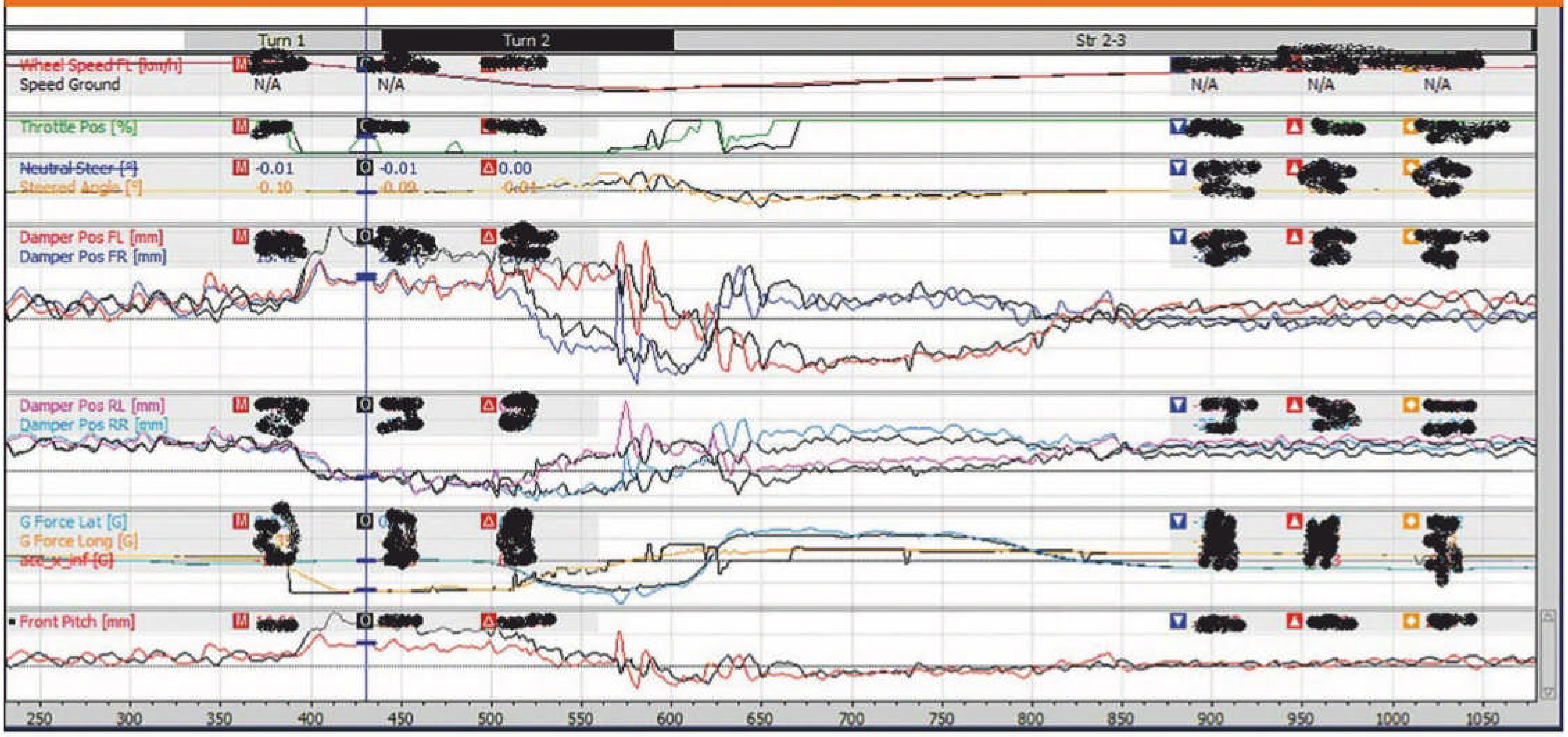
Table 3: Basic sim validation vehicle parameters

Parameter	Value
Vehicle mass	1320kg
rcm	41mm
tf	1.49m
tr	1.472m
t_m	1.4828m
k_{sf}	40N/mm
MR_{msf}	0.95
k_{rf}	32.461N/mm
MR_{rbf}	0.64
k_{tf}	305N/mm
k_{sr}	40N/mm
MR_{msr}	1
k_{rr}	61.119N/mm
MR_{rbr}	1
k_{tr}	305N/mm
c of g height	0.495

Table 4: Performance parameters

Parameter	Value
Vehicle mid-corner speed	127.66km/h
a_y	1.01g
Front roll	27.6mm
Rear roll	25.04mm

Figure 1: Non-correlating front pitch data (actual data coloured, simulated black)



EQUATIONS AND CALCULATIONS

Equation 19

$$k_b = \left(\frac{180}{\pi}\right)\cdot\frac{M}{\deg}\cdot\left(\frac{2}{t^2\cdot MR^2}\right)$$

Calculation 8

$$k_b = \left(\frac{180}{\pi}\right)\cdot\frac{M}{\deg}\cdot\left(\frac{2}{t^2\cdot MR^2}\right)$$
$$= 57.295\cdot 2000\cdot\left(\frac{2}{1.6^2\cdot 1^2}\right)$$
$$= 89525N/m$$
$$= 89.53N/mm$$

Calculation 9

$$LT_{SM} = \frac{F_{BF}\cdot\left(h-pc_f\right)+F_{BR}\cdot\left(h-pc_r\right)}{wb}$$
$$= \frac{9.8*1224.5\cdot(0.43-50e-3)+9.8*885\cdot(0.44-180e-3)}{2.794}$$
$$= 2408N$$

Calculation 10

$$\partial Damp\_ft = \frac{0.5*LT_{SM}}{k_f\cdot MR_f}$$
$$= \frac{0.5\cdot 2408}{122.6\cdot 0.63}$$
$$= 15.6mm$$

Table 5: Example Touring Car parameters

Variable	Value
Front motion ratio (damper / wheel)	0.63
Front spring rate	123N/mm
Front braking force	1224.5kgf
Rear braking force	885kgf
Front pitch centre	50mm
Rear pitch centre	180mm
c of g height	0.43m
Wheelbase	2.794m

Let's now put **Equations 14** to **16** to work through a couple of examples. The first we'll discuss is sim validation. The parameters for this example are shown in **Table 3**, while the simulated rolls are shown in **Table 4**. Working the numbers for **Equation 16**, the results are as seen in **Calculation 5**, and the wheel movement from this is as found in **Calculation 6**. Consequently, the wheel movement converted to the damper will be as shown by **Calculation 7**.

As can be seen, while the numbers are not an exact match due to the effect of damper force, they are very close, which means you now have a powerful tool to quantify what is going on in roll.

The next example is converting bar rates presented in N/deg to N/mm (**Equation 19**). This is another of these really simple things but, if I can get some use out of this, chances are you might get some out of it, too.

Here, *kb* is the bar rate, *M*/deg is the bar rate quoted in Nm/deg, *t* is the relevant track and *MR* is the motion of the bar. Working an example, assuming a bar moment of 2000Nm/deg, a motion ratio of one and a track width of 1.6m, we have **Calculation 8**. It's a simple calculation, but still a great one to have in your engineering toolbox.

Why bother with all this? Well, you use this when simulated and actual data don't correlate. A couple of years ago I had a Touring Car customer who couldn't correlate their front pitch data. This situation is illustrated in **Figure 1**.

As can be seen, the correlation is very good, with the exception of braking. Rather than saying simulation is a waste of money, hand calculations help isolate the problem.

Sanity check

One of the variables ChassisSim returns is the applied longitudinal forces and pitch centres. This allows you to sanity check the numbers from your simulation results. I can't give specifics on this example, but let me walk through how you would do it. Firstly, let's look at some parameters for an equivalent Touring Car, as shown in **Table 5**.

Calculation 9 allows you to hand calculate what the expected pitch should be, while **Calculation 10** shows what you should expect to see at the damper.

When this was calculated on the actual car, the simulated data was found to be behaving as it should. This is an instant red flag that something is not right, and shows why you're naked without hand calculations.

In closing, what has been presented here are what I consider the core hand calculations every race / data / performance engineer needs to have in their intellectual toolbox. Know these and the end results will take care of themselves.

State of flax

As Formula 1 looks to the future, a viable, sustainable and economical substitute for carbon fibre could provide multiple answers

Formula 1 is a hotbed of innovation, and carbon is one of the mainstays of the modern motor racing era. From the first carbon monocoque chassis that McLaren developed and raced in its MP4/1 in 1981, the material has become ever more prevalent and now makes up around 70 per cent of current car's structural weight.

Despite its benefits, there is no doubt that using it carries a negative environmental impact so Swiss company, Bcomp, has been at the forefront of developing an alternative. It has already made significant impact on various top-level areas of the sport, including the DTM and GT racing. Now, however, the company has moved into Formula 1 with McLaren, developing a natural fibre racing seat for the team, the first Formula 1 car part to be made of renewable textile fibres.

By optimising the mechanical properties of flax fibres through fabric architecture, it's been possible to make a seat with the required strength and stiffness, but with a 75 per cent lower CO_2 footprint compared to its carbon fibre counterpart.

'The use of natural fibre composites is the latest example of pioneering, composite materials innovation at McLaren,' says McLaren F1 team principal, Andreas Seidl. 'Not only does this solution provide equivalent performance to carbon fibre, it represents another step forward in our evolving sustainability programme, while underlining our commitment to helping F1 turn its ambitious sustainability strategy into action.'

The McLaren seat is the first F1 part made from natural fibre

It has a 75 per cent lower CO_2 footprint compared to its carbon fibre counterpart

Global issue

Bcomp CEO and co-founder, Christian Fischer, agrees this is an important first step. 'Sustainability and decarbonisation is a global issue, and it is fantastic to see motorsport embrace carbon alternatives, paving the way for widespread adoption within large-scale mobility applications.

'McLaren has always been a pioneer within the sport, in terms of both composites and sustainability. It feels like the perfect match and is a great honour to collaborate with such a prestigious brand.'

Primarily used in the production of linen, flax is a versatile plant that has been around for millions of years. It differs from many biomaterials in that it's ideal for use in crop rotation programmes and can be grown without directly competing with food crops. Flax is a CO_2-neutral raw material and its fibres are biodegradable. At the end of the seat's life, for example, it can be ground down into a new base material or thermally recycled without residual waste, rather than end up in landfill.

Inspired by the thin veins on the back of leaves, Bcomp's proprietary powerRibs™ technology provides a three-dimensional grid structure on one side of the seat, which is then used to reinforce Bcomp's optimally spun and woven flax fibre reinforcement fabric, ampliTex™. Made by twisting flax fibres to form a thick yarn, the powerRibs™ act as a backbone to the ampliTex™ flax fabric that is bonded to it.

Since 2019, a minimum driver weight of 80kg has been mandated in Formula 1 and, if a driver weighs less than that, ballast must be used, and crucially it must be located within the immediate area of the driver's seat.

'With the introduction of the new regulation in 2019, the seat now forms part of the driver's weight budget, so it's over engineered as a result,' explains McLaren F1 principal composites engineer, Steve Foster. 'And with Carlos [Sainz] and Lando [Norris] weighing in at 72kg and 68kg respectively, there's plenty of scope to do that.'

Safety first

When it does break, unlike carbon fibre the flax-based material is not prone to brittle fracture and splintering. The ductile fracture behaviour of natural fibre composites opens the door to a multitude of other possibilities, too.

One of the most dangerous aspects of an on-track incident today are the shards of carbon fibre that result from a collision or failure. By using natural fibre composites in other areas such as front wing end plates and the floor, it's possible to reduce carbon fibre debris and therefore the risk of punctures, and potentially puncture wounds.

'With the introduction of the [2021] budget cap, the cost of materials is going to be a big focus, and the use of natural fibre composites has the potential to help in this area,' acknowledges Key. 'We're working with Bcomp to confirm that natural fibre composites are a viable, sustainable and economical substitute for carbon fibre in some applications, both on and off the car.'

Areas outside the car can include most of the moulds used in component manufacture. Carbon has low thermal expansion properties, and flax fibres also possess this property, potentially making them a suitable tooling material. So, even if the part being produced isn't made from natural fibre materials, the tool to produce it could be, leading to a further reduction in cost and carbon footprint.

Images courtesy of McLaren Racing

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Reality check

The good, the bad and the safety in motorsport

There has been some debate on social media following the Indy 500 about whether or not the race should have been red flagged and started again for a shootout to the flag. It was clear the clean-up operation following Spencer Pigot's accident was going to take some time, and that if the red wasn't shown the race would finish under caution. Television fans were therefore denied the chance to see a battle for the win to the flag so, on that level, I can understand the debate.

However, while it is not certain that it would have changed the result, there is a high likelihood that Scott Dixon, with more fuel on board and having led the most number of laps, would have taken the lead from Takuma Sato and become what I guess would be termed a 'just' winner. Except racing doesn't work like that. It never has, and should never in future either.

If you start manipulating races according to fairness, it's a slippery slope. What happens if, for example, Porsche dominates the IMSA race at Virginia International Raceway on the same weekend as the 500, but is denied a win by punctures and accident damage that was not its fault? Should that require a re-start so the team can sort out their set-up properly? Of course not.

> **If you start manipulating race results according to fairness, it's a slippery slope**

Safety first

The safety car debate still rages and, despite the blind acceptance now that it's a part of the modern sport, I still hate its application in Europe. In the US, drivers and teams have accepted that the field bunches up behind the safety car and any advantage is lost (or gained if you are the following driver). Sometimes the intervention works in your favour, other times it works against you and so the theory says, on balance, it will even itself out.

In Europe, however, great effort is spent in ensuring that whatever lead you have amassed, you keep, although frequently there are mistakes made and then spectators throw up their arms in despair.

Were fans robbed of a sprint to the finish at Indy? I don't think so. The race was good throughout, there was great racing, good overtaking moves and brave strategy calls. The race had everything a fan could want, other than that last sprint to the flag. I don't think that it needed it. I was sorry for Dixon that he should trail over the line in second having led more than half the race and didn't have the chance to challenge, but he will go again next year.

One thing that did spring up at Indy was the strength of the Dallara chassis after some sizeable accidents. Drivers came away from the race apparently without serious injury, despite hitting walls, and the pit lane entry, at high speed.

In the run up to the race, Fernando Alonso highlighted how fast the cars are travelling when, having dropped a wheel onto the concrete at Turn 4, his accident lasted until he came to rest in the pit lane near the Dragonspeed pit. Modern safety structures, both in terms of car design and track safety, have certainly made the racing safer.

'Screen test

Which brings me onto the subject of the Aeroscreen. No, the drivers are not as visible as they were before its introduction, which is a shame for the fans. But, having read and published the stories on why the 'screen was introduced over the Halo, I have viewed the on-track incidents differently and come to appreciate the device.

The Aeroscreen is designed to prevent small particles of carbon fibre entering the cockpit following the kind of high-speed incident that is a feature of Superspeedway racing. Formula 1, and other European single-seat racing, is more used to lower-speed accidents, and therefore the Halo works better for them.

As Dallara itself writes in these pages, it relied on its experience building closed-top prototypes. I do remember Audi campaigning vigorously not to have a closed car on the basis that fans want to see who is driving, but that was shouted down and so the R18 was born to take on the closed cars from Toyota, Peugeot, Porsche and Nissan.

Despite what I consider a successful Indy 500, I have now written off 2020 in terms of normality and await 2021, a Covid vaccine, and a return to our sport as we know it. In the meantime, I look to Le Mans later this month and wonder what that is going to look like. The dynamics of the 24-hour race are totally different to Indianapolis, but the audience is equally dedicated, and hopefully television coverage will be both vast and popular.

There is a saying that Le Mans chooses her winner. The safe money is, of course, on Toyota but, with only six cars in LMP1, the race could throw up a surprise result. And given the unpredictability of 2020, that's not unexpected, is it?

ANDREW COTTON Editor