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Glickenhaus 004C

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Formula 4 hybrid

Entry-level single seater goes electric

Beyond the pink

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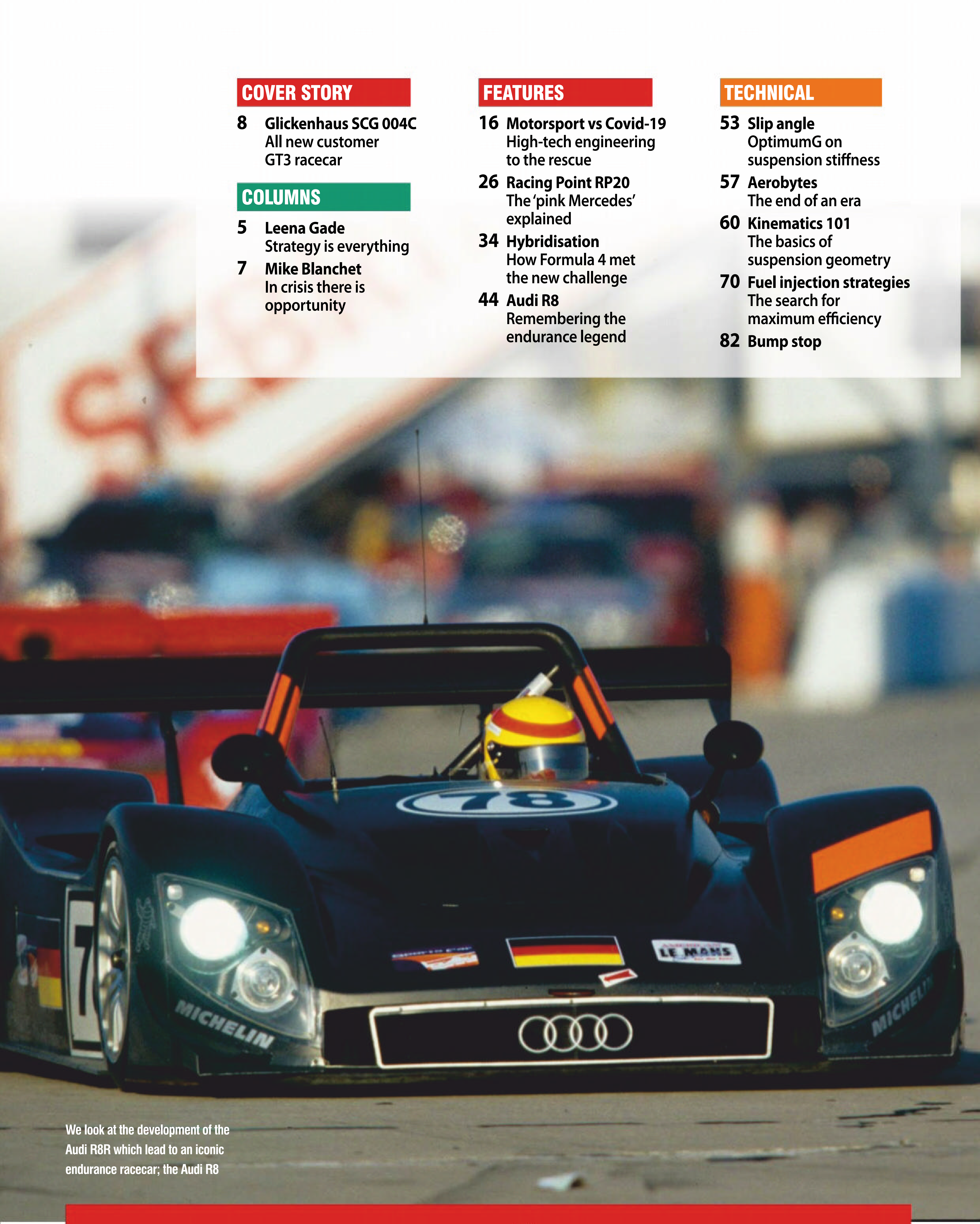

We look at the development of the Audi R8R which lead to an iconic endurance racecar; the Audi R8

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Strategic planning

A good race engineer will have a plan until the race, when you have to change it

In these days of social distancing, I have found myself devising a strategy to get myself and my mother safely through our daily 45-minute walks through suburban London.

Pre-pandemic, walking around London was already a little tricky. Seeing a Londoner approach can induce mild panic; should I keep to my trajectory and hope they move, or will we have an awkward, side-stepping stand off? Should I say 'Good morning' or will they think I am crazy?

I worked out that early morning walks are best as there are fewer people around but we never make it, so we've gone for the next best thing; early evening walks.

On our first outing a jogger came up behind us on a pavement two people wide, with a three metre grass verge alongside. Now, I sometimes jog, and I'm acutely aware that when you come running up behind someone you can startle them, so I generally make some sort of noise to warn them I'm coming past. I then take the grass verge route so I'm the regulation two metres apart.

Unfortunately, said jogger clearly had no strategy. She made a late, split-second decision and tried to pass right next to my mum, who I then pulled suddenly out of harm's way. That spooked the jogger and she swore at us as she went past. My typically polite mum then apologised to the jogger, and a little while later told me off for berating the jogger's obvious incompetence!

This situation need not have arisen if the jogger had planned and executed a better strategy.

Crystal ball

When it comes to racing, there are a few factors that usually dictate how decisions are made. Most of the time, they are based on the information you have to hand at that moment, because trying to guess the future is not a reliable method.

Some years back, I was part of a team competing at the Spa 24-hour race. On the Sunday morning it became clear heavy rain would arrive close to the end of the race. With a few hours in hand, there was plenty of time for people to overcomplicate the options. Thunderstorms are incredibly hard to predict and so, with such an unknown entity, you almost have to deal with it when it arrives. At least, after doing the obvious and having wets ready to go. Then, once there is an indication of intensity and when it will arrive, either commit to pitting and bolting them on or stay out and ride the wave.

Either way, at some point in the process the racecar will be on the wrong tyre for the conditions. But by communicating to the driver that things may get a little slippery, you have at least a fighting chance of being prepared.

Of course, much of the decision comes from knowledge of how the different tyres work in the rain, and also knowing whether the driver can under drive a car enough to still be fast out on track on the wrong tyres. This knowledge was available in this instance; what wasn't known was what decision the race director would take when torrential rain hit 30 minutes before race end, initially only on the run up to the Bus Stop but soon after across the whole track. A window of opportunity was available to pit and switch to wets, just as things were getting tricky.

However, with so much time before the rain arrived to think about scenarios, a team member believed there was a chance the race would be red flagged and that would be the end of the race.

After a number of cars aquaplaned off, some shunting, the race director called a full course yellow (FCY), not a red flag. That put the car down to P5 from P2 within 20 minutes, only gaining one place from an infringement by another car.

Maybe the outcome would have been the same had there been simpler thinking, but it was clear afterwards that basing strategy on second guessing someone else's decision isn't successful.

Making decisions early based on good intel is key to keeping it clean on the track

Having race engineered a few races with pivotal moments that defined the strategy, I know such decisions aren't easy to make. And even when you're basing decisions on what appears to be reliable information, you have to be aware that in this business there can be fake news, too.

But as the angry jogger proved, trying to make strategic decisions on the fly is never a good idea.

The knowledge

Going into a race having done all your preparation work is key to making the right decision at that critical moment. When you have the knowledge and compare it to where you are in reality, the strategic decision becomes simpler. And with less overthinking, there is less chance of error.

Consequently, I think I always make decisions in my daily life with strategy in mind. I can't help it. I always choose a seat in the forward part of a 'plane so, when I get off, I reduce the need to overtake other passengers. Should there be a staircase to connect the gate to a walkway, I'll take that and scoot past the crowds on the escalator. In my head, it's all about the path of least resistance that means it will be faster from A to B.

Returning to our London jogger, how much planning did she really need to execute the overtake safely and with minimal fuss? She had all the knowledge at her disposal. She could see us from quite far away and our trajectory was clear. She knew she had to pass with a two metre gap. She knew there was sufficient space beside us on the grass. She knew her approach speed and our walking speed, and could roughly estimate our convergence. She could see the path in front was clear. She also knew we were very unlikely to know she was there.

Even allowing for processing all that information, I reckon it would take about five seconds to make a qualified decision and, if done early enough, allow for a double check just before the decision to commit a line was needed. But she didn't do any of that. Instead she got me into trouble with my mum. Unforgivable.

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

Trying to guess the future is not a reliable method


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If the cap fits…

In disruption there is opportunity to improve things on a grander scale

Due to its overhanging gloom, I had intended to avoid writing anything this month that involved Covid-19. However, such are the potentially far-reaching effects of this nasty pandemic on, in particular, F1, it's difficult to avoid doing so. Sorry.

It is clear that many organisations and individuals are going to lose a lot of money because of Covid-19-induced race cancellations, even if events are able to go ahead some time before the end of this year. *Force majeure* is a legal term that must have been exercising the lawyers of not only the teams, but also the myriad of suppliers that support the F1 circus recently. It is a common clause in contracts that essentially frees both parties from liability when an extraordinary event, or circumstance beyond their control, prevents fulfilment of obligations.

Force majeure

The State of Emergency, such as many countries have imposed because of the virus, should certainly come under the heading of *Force majeure* , but interpretation of a law is everything, and I'll bet an enormous amount of wrangling has been going on between parties' lawyers as to whether this clause absolves one or the other from breach of contract, and hence penalties or damages claims.

A similar argument will be taking place regarding claims for compensation against insurers under business interruption policies. Good luck.

While sympathising with Liberty, race promoters and many others, on delving even further into this highly complex scenario, the by-no-means-guaranteed survival of some of the teams is, unsurprisingly, a hot topic. Williams F1 being forced into mortgaging its property and even the 'family jewels' F1 car collection, selling off its engineering arm and raising loans is one example of how seriously this has to be taken.

Delaying the 2021 rules package by a year, while disappointing given its much-anticipated aid to closer racing, was a sound move. So is the ban for this year on both car and power unit development, including for 2022 regulations, or at the very least the introduction of a token system.

At time of writing, the 2021 team cost cap has been lowered from $175m to $150m as part of cost-saving measures. Zak Brown and others are pushing for a further reduction (some might see the irony in McLaren pushing for more cost cutting when, under Ron Dennis' control, the team was probably the one that most ramped up the cost of F1 in order 'to dominate', to quote RD).

Formula E's Alejandro Agag has suggested the cap should be reduced drastically to $75m, but he's surely overlooking the immediate negative impact that would automatically follow such a downsizing of staff and facilities. There would be a huge number of redundancy pay-offs, together with long-term supply contracts and equipment leases needing to be renegotiated, or terminated prematurely with penalties. These are just some examples of, in fact, additional short-term costs that would be incurred.

XPB

A reduction in the Formula 1 cost cap is undoubtedly a good thing, but too much too soon will have drastic, and negative implications on the entire motorsport supply chain

Long-term savings will be realised, but first one has to get over this hump. While I agree cost cap reductions are much needed, they have to be applied in steps, to permit this major downsizing to be thought through and constructively applied. For immediate relief of the most financially at risk teams, I wonder if *force majeure* could be invoked by the commercial rights holder for a more equitable distribution of 2019 F1 team money (which is paid in arrears). This could begin now, as an emergency, side stepping the endless deliberations on achieving this for the future.

While 2020 income is not known, the freezing of R&D expenditure and furloughing of employees is a corresponding saving, and it behoves those with the lion's share of the money to look sensibly at the big picture. Helping to maintain a healthy grid of cars should be more important to them than short-term self-interest, at least temporarily. Pigs might fly as well, I guess, but quick action of significance is nevertheless needed.

Quick change

To look more on the bright side, a possible positive result of the coronavirus disruption is this opportunity, using unforeseen circumstances, to make changes quickly that would otherwise be argued over and drag on interminably. This could be the case regarding the allocation of the aforementioned F1 money each season, and cost reduction concerning the racecars and the way in which they are operated.

Similar benefits sometimes happen in times of war and civil unrest, but the chance of doing this needs to be taken quickly because once normality returns, memories quickly fade and defending one's corner reverts to taking precedence again. Strike while the iron is hot is extremely apt advice to follow, and FIA president, Jean Todt, has had extraordinary powers granted.

Ways of reducing the expense of designing, developing, manufacturing and running F1 cars have almost been done to death. A lower cost cap is almost certainly the most significant action, but there are alternative approaches that might help narrow the performance gap. Open sourcing of technical information concerning their cars and PUs by teams at the finish of a season is one. This would be anathema to most people, I accept, but a major boost to those who are struggling. While accepting the huge difficulties in a) persuading teams to go along with this, b) ensuring the details released have not been 'doctored' to mislead and c) deciding on exemptions and never allowing cloning, one can also argue that teams relying too much on this will always be at least six months behind.

Also, as I have commented in a previous column, the temptation to modify and tinker with even the best designs frequently introduces negative side effects.

A complicated business, isn't it?

Strike while the iron is hot is extremely apt advice to follow

Gentleman Jim

Road car, track car, race car. James Glickenhaus' SCG 004C offers an affordable, driveable option for the customer GT racer

By LAWRENCE BUTCHER

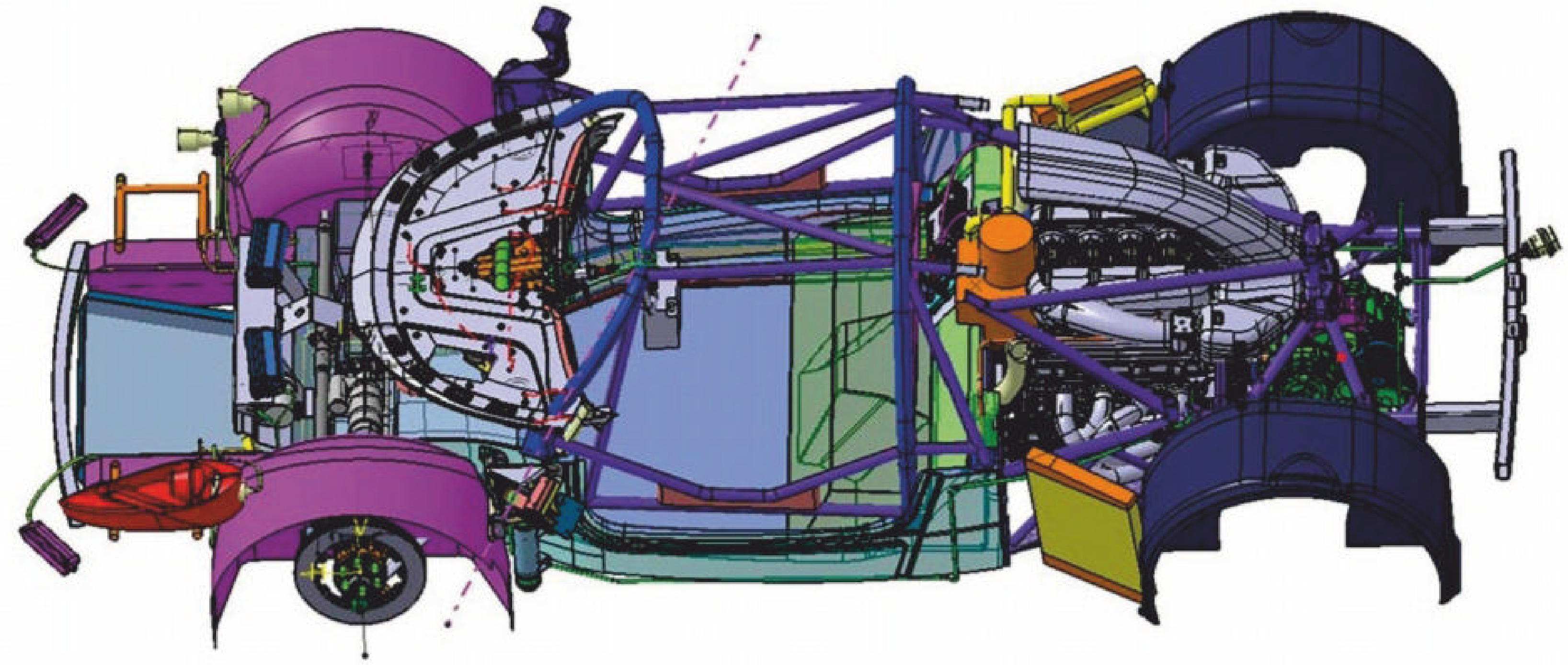
‘The ultimate track day vehicles that a customer can use for 100 hours on track before it needs a rebuild or service’

James ‘Jim’ Glickenhaus and his eponymous company, Scuderia Cameron Glickenhaus (Cameron is the surname of his wife, Meg) have developed something of a reputation as the romantic, old school ‘*garagistes*’ of modern Sportscar racing.

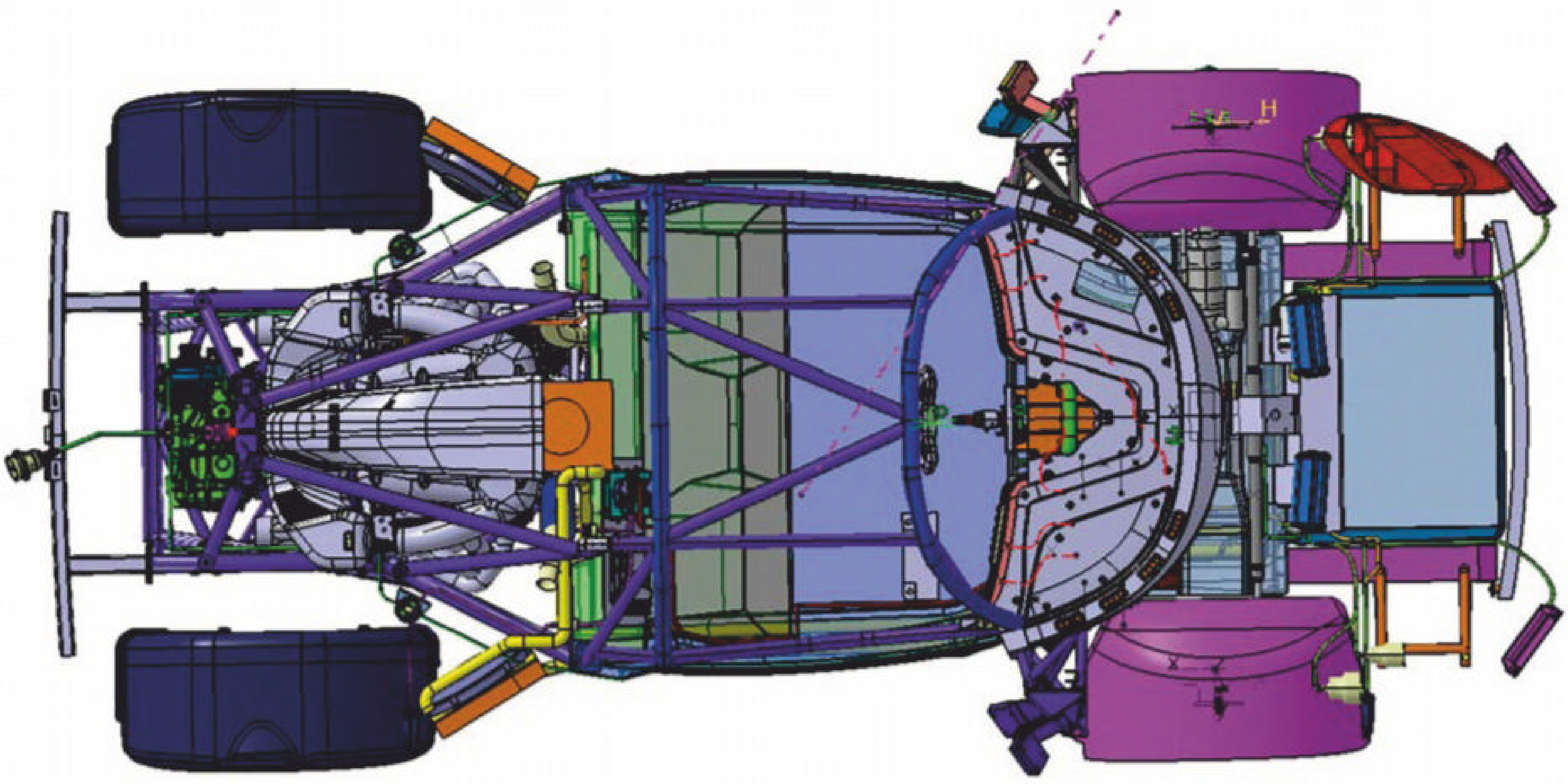
What started off as a project building an homage to the iconic Ferrari P3/4, the Pininfarina-redesigned, Ferrari Enzo-based SCG P4/5, has morphed into a company producing bespoke road and racing cars.

The SCGP4/5 gave birth to a *Competizione* version in 2011, built around a Ferrari 430 which would go on to finish 12th and first in class in the 2012 N24. This was the first car to be badged as an SCG following a dispute with Ferrari over use of the company’s emblem. Glickenhaus very publicly, via the medium of YouTube, levered the Prancing Horse from its nose and hand drew SCG’s motif and the initials SCG in its place.

The next logical step was to produce a car entirely of its own, which took the form of the SCG 003 (originally called the P33), a mid-engine machine with a composite tub and a no compromise aero package.



Car is based around a carbon tub with a central driving position. Road car versions have provision for two passengers, seated either side just behind the driver



Using lessons learned from its SCG 003 predecessor, the 004 was designed with simplicity, serviceability and ease of repair in mind

Available in race, track only and road versions, the car cemented Scuderia Cameron Glickenhaus' reputation as a *bona fide* operation, and the 003C saw action at the N24 and various VLN races between 2015 and '17.

Low-volume manufacturer

While the 003 and its variants were the genesis of SCG as a company, they paved the way for the firm's escalation into a fully-fledged, low volume Sportscar manufacturer. Glickenhaus is nothing if not ambitious in his aims and, in late 2017, announced SCG would be building a new car, the 004S, along with a racing variant, the 004C.

Like the 003, the SCG 004 is available as a road-legal GT 004S; a road-legal but track-orientated version, the 004CS; and the full competition-spec 004C, all fitted with GM-sourced V8s in various states of tune.

The 'S' version has a nominal output of 650bhp and is available with a traditional manual transmission, while the track-focussed 'CS' version offers 800bhp, a dual-clutch, semi-auto gearbox and other high-performance options. The 'C' is a GT3/GTE-spec racecar.

The SCG 004 is based around a central carbon tub, which in road car trim seats three, the driver sitting centrally and slightly ahead of two passengers. An additional benefit of this is that the driver is afforded considerable side impact protection compared to a GT car with a more traditional seating arrangement.

At the front, the double wishbone suspension mounts directly to inserts in the carbon structure, with the dampers sited just below the lower edge of the windscreen, actuated by rockers.

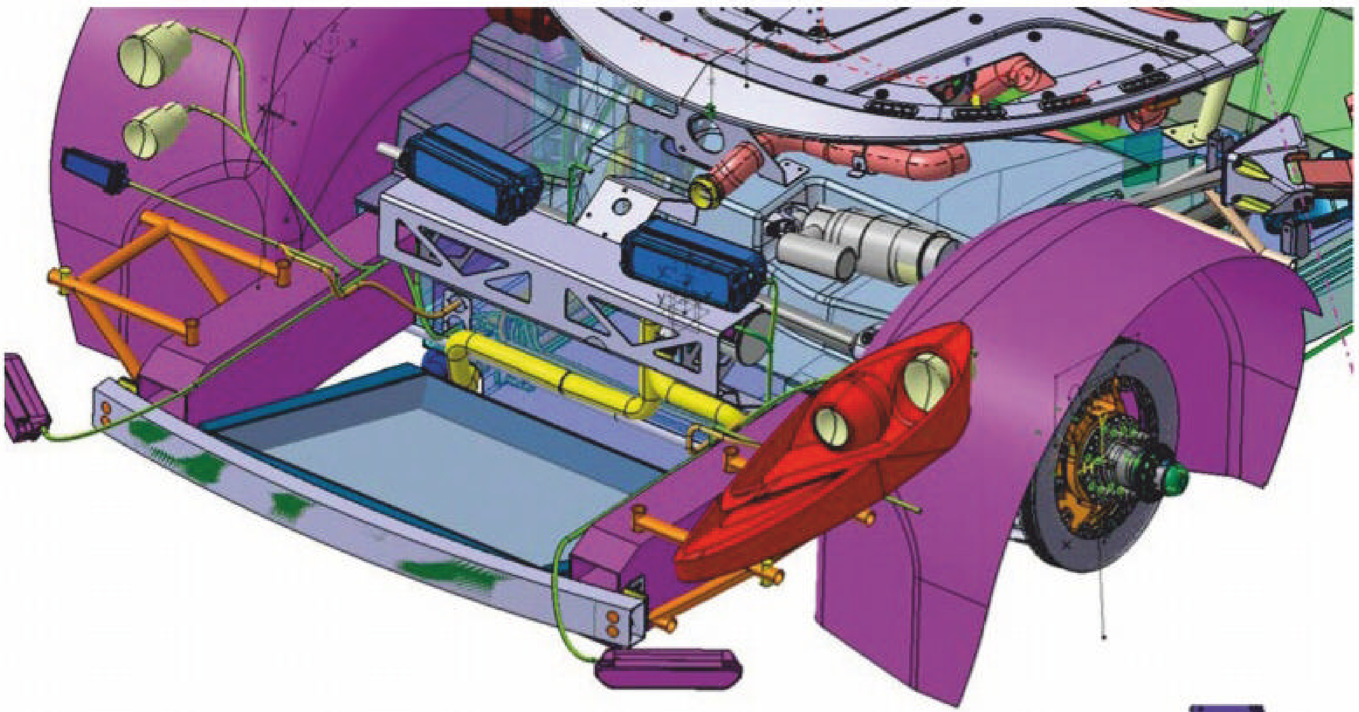
Extending forward of the tub are two square section, aluminium crash structures, between which sit a heat exchanger. The front and rear uprights are machined billet aluminium, as are the upper front wishbones. The lower front and rear wishbones are fabricated steel.

The rear bulkhead of the tub acts as the mounting for subframe assemblies that carry the suspension and drivetrain. The engine is not a stressed member and it, along with the transmission, is supported by a tubular steel structure that triangulates from the tub to the transmission and rear suspension mountings.

At the rear, the unequal length double wishbone suspension is affixed to a triangulated ladder frame, the inboard coilover dampers are arranged horizontally across the car, again actuated by rockers.

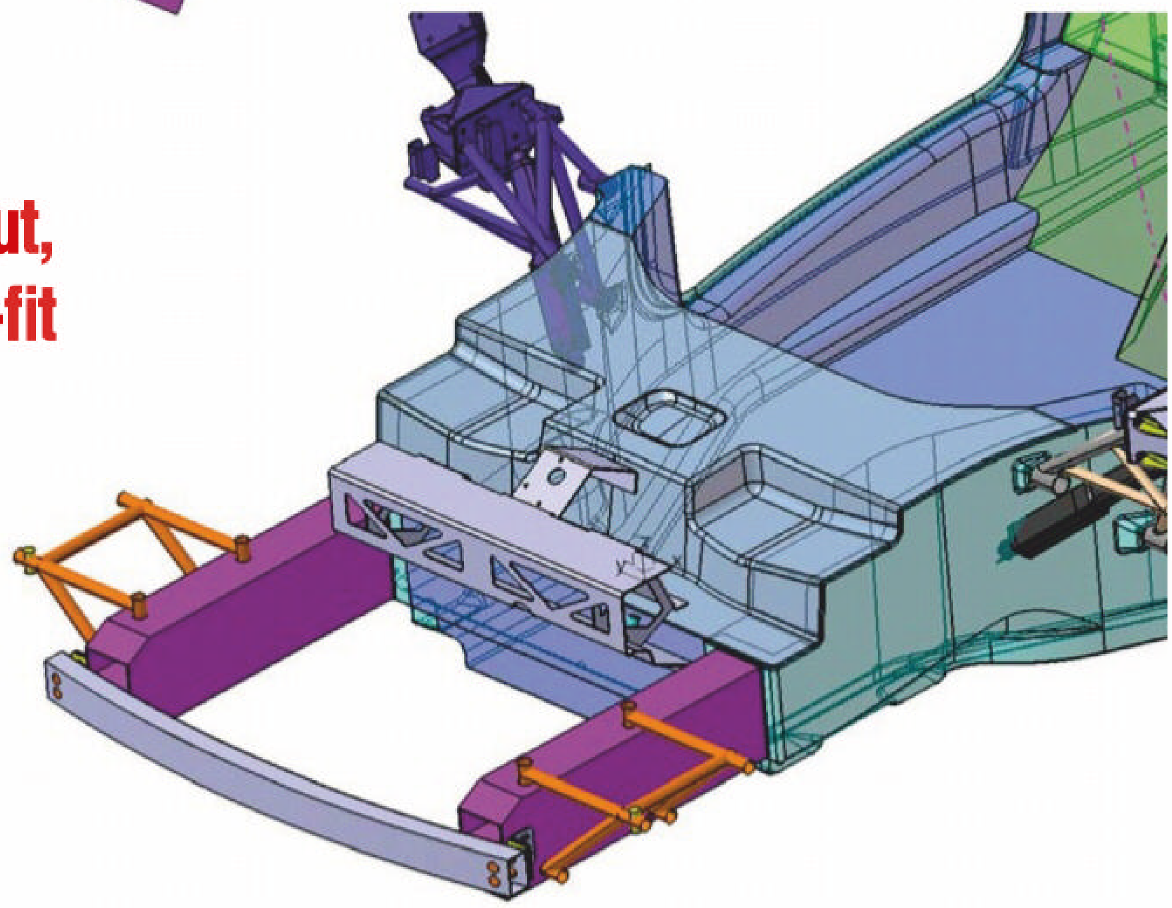
The compact sequential transmission is produced for SCG by Xtrac, with the gears in a transverse arrangement. On either flank of the car, below the rear quarters, sit cooling radiators, fed by ducts sculpted into the sides of the body. The main engine air feed is situated on the roof.

The carbon tub is augmented by an extensive steel roll over structure, which features front and rear hoops and extensive bracing. Though some GT cars, such as the GTE-spec Ford GT, incorporate the rollcage within the composite chassis structure, for the 004C a standalone 'cage was necessary, as Glickenhaus explains: 'There is a GT3 regulation that states



Horizontally-mounted, rocker-actuated dampers sit just ahead and below the windscreen and a large heat exchanger lies flat ahead of the front axle line

You can pull the engine out, replace the clutch and re-fit the engine in one hour



Front suspension mounts directly to the carbon tub, and there are twin aluminium crash structures ahead

you cannot have the roll over structure within the carbon monocoque. The rollcage inside the tub is simply to comply with the homologation.'

Modularity in design

According to Glickenhaus, the company learnt a lot from the 003 project, which it then applied to the racing version of the 004. 'One of the biggest lessons we learned was about complexity,' he says. 'We learned that the simpler a racecar is to construct, the more straightforward and cheaper it is to build and fix, and that is important. Another thing was the importance of modularity in design. We wanted to take that concept as far as we could in the SCG 004 so it is more accessible to work on.

'For example, one of the targets we achieved through design in the SCG 004C is you can pull the engine out, replace the clutch and re-fit the engine in one hour. That is a huge step forward compared to its predecessor.'

With its main target market being endurance racing, the necessity of easy repair extended to all aspects of the car: 'There are other operational things you only learn through experience. For example, we had a crash at the Nürburgring at night in the SCG 003C, and it broke a headlight. It took us 16 minutes to repair that damage. At the end of the 24-hour race, we finished eight minutes off the lead. If we could've changed it in eight minutes, we would have been in contention for the overall win.'

To prevent this scenario happening again, on the 004C the light cluster is part of the nosecone and the whole unit quick disconnects from the car, using a central wiring harness.

'If the same damage were to occur, we would simply take the nose off, quick disconnect the light clusters from the primary harness, swap the nose for a new one with the lights embedded, connect the new assembly and send it back out. That can now be done in 20 seconds,' reports Glickenhaus.

In other areas SCG, working with long time Italian engineering partners Podium Advanced Technologies (responsible for the 003C and construction of all of SCG's racecars), has been able to take advantage of technology not widely available when the 003 was designed and built.

'There are design optimisation programmes that weren't around when we designed the 003C,' says Glickenhaus. 'Using those, we have been able to achieve things like a reduction in the weight of the suspension components by 3kg per corner when compared to the 003C.'

Another interesting feature of the 004C, which bears a similarity to the approach taken to serviceability in rallying, is the uprights are shared side to side. Through the use of various bolt-on brackets, left and right units can be swapped, cutting the number of spares a team needs to stock and saving manufacturing costs.

Cost reduction

All versions of the 004 will run a derivative of GM Performance's 6.2-litre, all-aluminium, LT4 V8. In racing trim, it is naturally aspirated and more heavily modified, while the track day 004CS will have a simpler supercharged version.

Another significant improvement, or lesson, we learned from the 003C project was one of cost

The use of a large capacity V8 is a departure from the forced-induction V6 used in the 003C, but for one simple reason, as Glickenhaus explains: 'Another significant improvement, or lesson, we learned from the 003C project was one of cost. We wanted to lower the running cost for racing the 004C compared to the 003C. The twin-turbo, 3.5-litre Honda V6 engine, developed by Autotecnica Motori for the 003C was exceptional, but it was expensive, and it was complicated.'

This doesn't mean, however, that SCG has simply bolted in a road car engine which can be bought as a complete unit from any number of aftermarket suppliers. 'The GM V8 engine we have chosen for the 004C sees substantial modification from the original engine, including eight more port-located fuel injectors and several other tweaks to improve the performance,' insists Glickenhaus. 'But it is still considerably more cost effective [than the V6].'

He notes that using a highly strung, bespoke race engine is unnecessary as GT3, which is the car's primary target market, is performance balanced. 'GT racing is a BoP category. You don't need to make much more than around 500bhp because the BoP typically settles at about 500bhp for a lightweight Sportscar like ours.'

Further aiding cost control, the running time for the V8 engine is 80 hours before a rebuild is necessary, significantly longer than the Honda V6 unit. The rebuild costs of the replacement parts of the GM V8 engine are also considerably lower than those of the Honda.

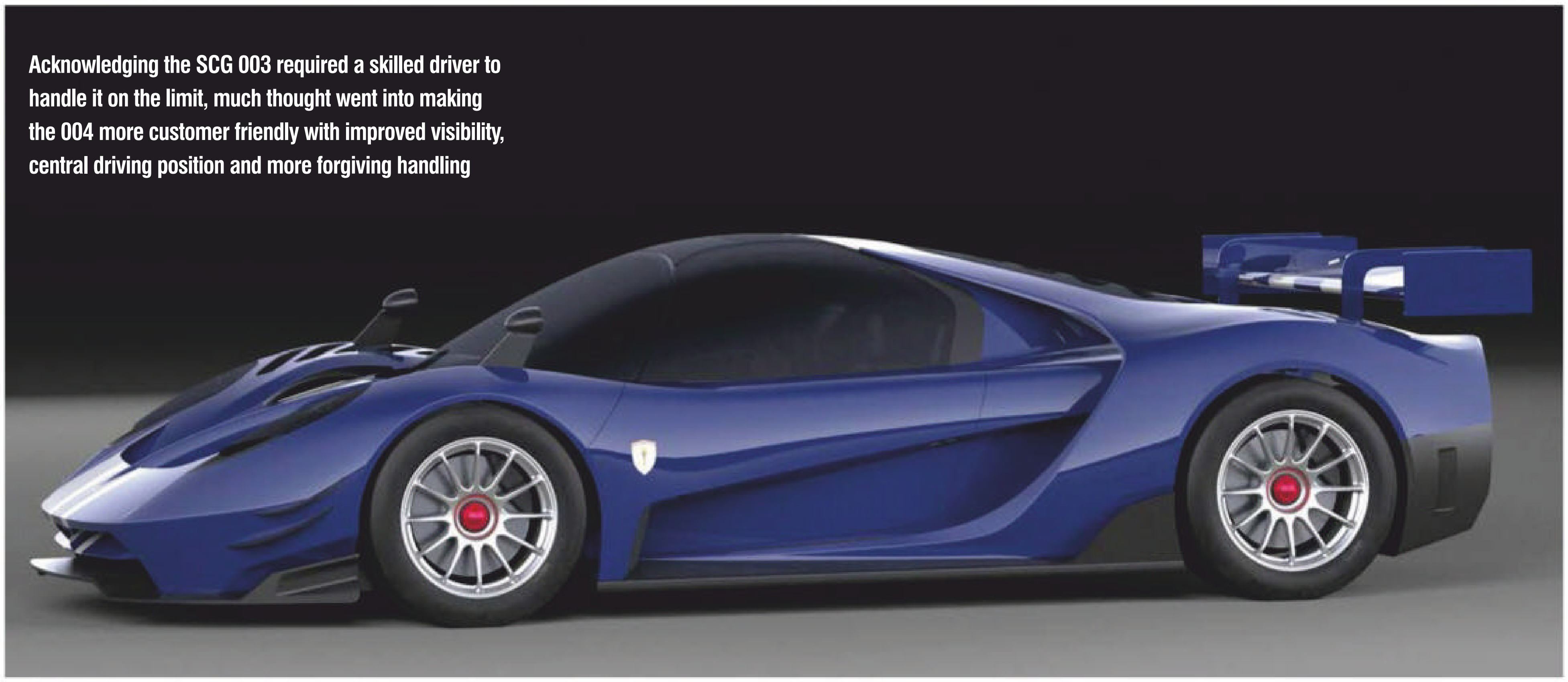
Aero balancing

The 004 shows clear styling influences from both the P4/5 and the 003, though the new car has been subject to greater aerodynamic development than any of its predecessors. 'We have tremendous aerodynamic efficiency for a GT3 car, and that has significantly increased from the 003C to the 004C,' states Glickenhaus.

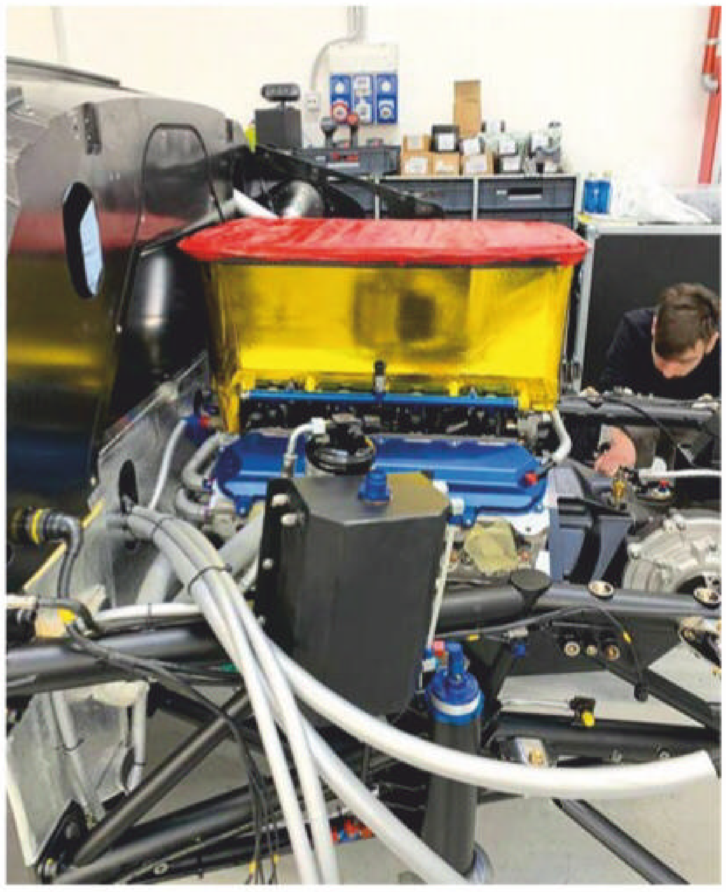
The focus of the aero development programme was not merely performance, but also making that performance accessible. 'The 003C was an incredibly aerodynamic car, though it had two issues,' concedes Glickenhaus. 'The first was that it was very pitch sensitive, which meant you needed a very accomplished driver to drive it at the limit. The other was it was a high-speed [low downforce] car so, although it would reach 300km/h at the Nürburgring, its characteristics made it hard to drive.'

To keep running costs down, all versions of the SCG 004 use variations of the GM Performance, 6.2-litre, aluminium LT4 V8, as used in the Z06 Corvette. Engine development is by Italian firm, Autotecnica Motori

004C engine will be naturally aspirated and feature eight additional direct port injectors. Nominal power output is around 500bhp, as any more would be held back by BoP anyway. Transmission is an Xtrac sequential unit



Acknowledging the SCG 003 required a skilled driver to handle it on the limit, much thought went into making the 004 more customer friendly with improved visibility, central driving position and more forgiving handling



Twin cooling radiators mount at an angle either side of the engine, while the main air intake is through the roof structure

Design optimisation since the 003 has seen a reduction in weight in many components, such as the fabricated steel rear wishbones

As a general theme, the 004C is intended to be relatively benign, though not by any means slow

With customer drivers in mind, ensuring the 004C did not have similar traits was a key goal for the design team and the new car is said to be a far more forgiving beast, behaving consistently across its entire operating range.

The development work undertaken involved increasing frontal downforce, which greatly improved front-end grip and high-speed stability. The extra downforce has come with a drag penalty but, once again given the nature of BoP, this is not a concern. 'It had considerable effect on the vmax we can achieve, though that isn't an issue with a BoP formula as it will be brought into contention with the other cars regardless. The overall result [is] a vehicle that can reach its potential for more of the race than the 003C.'

Customer care

With the 004C destined to be a customer racecar and given the wide spread of ability levels within GT racing, it needed to be adaptable, as Glickenhaus notes: 'Ease of set-up and flexibility in set-up for different drivers was a huge consideration for the 004C. That was as much for the benefit of our company's in-house team as it is for customers.'

The 004C consequently has a number of traits that make it inherently driver friendly. For example, the central seating position and generously glazed greenhouse which, says Glickenhaus, 'makes it feel much more like a single seater to drive, and therefore should give the driver better vision, which should help performance for less experienced racers.'

As a general theme, the 004C is intended to be relatively benign, though not by any means slow. Unsurprisingly, given his keen sense of racing history, Glickenhaus draws a parallel with one of the legends of endurance racing. 'The Porsche 917s are an excellent example of a range of cars that take every element of brutal power for outright performance, but at the expense of driveability. The margin for error when driving a Porsche 917 is so small that it doesn't bear thinking about. We didn't want to go down that road with any version of the SCG 004. That was part of the design philosophy.'

Glickenhaus makes no secret of his desire to see a return to the halcyon days of Sportscar racing, where you could drive your racecar to the track, race it and then drive back home again. However, despite doing just this with the 003C several times, he is pragmatic about the fact it is much harder to achieve in the modern era. That said, it would be perfectly feasible for a customer to convert their 004S to GT3 spec, if they so wished.

'The amount that needs changing is not as much as you would think,' says Glickenhaus. 'The rollcage is the biggest single structural change. The engine in the 004C is tuned and has some features on it to survive 24-hour race situations and the gearbox is a completely new unit. Additionally, when it comes to customers, we are entirely prepared to provide race support at any order of magnitude they desire. This ranges from running cars within the SCG 'factory' effort through to simply supplying cars with a couple of embedded engineers for trackside support.

Loss leader

'The racing side of the SCG venture isn't particularly lucrative,' admits Glickenhaus. 'The motivation is to fuel our passion and give us a publicity platform for our range of road cars.

Unequal length double wishbone rear suspension mounts to a ladder frame bolted to the rear bulkhead of the carbon tub. Damping is by horizontally-mounted inboard coilovers with rocker actuation

Extensive roll over structure is steel and a separate item to the carbon tub to conform to GT3 regulations

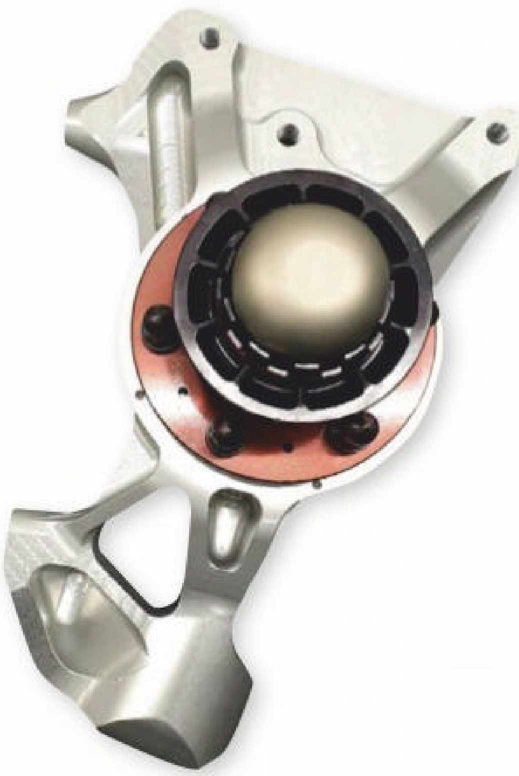
All uprights are machined aluminium, fronts are interchangeable

We are entirely prepared to provide race support at any order of magnitude [customers] desire

'To put it into perspective, our SCG 004C costs the customer 550,000 Euros [approx. $600,000], which is price competitive to the Porsche 911 GT3R and McLaren 650S GT3 cars.'

He acknowledges these large factory efforts have better profit margins thanks to higher volume production that can drive down the price of supply parts, but that's the lot of the low volume car manufacturer in today's modern racing world. 'They have many orders at a time, so are ordering 20 or 30 of the same parts from suppliers at an one time. Whereas we make ours one at a time,' laments Glickenhaus.

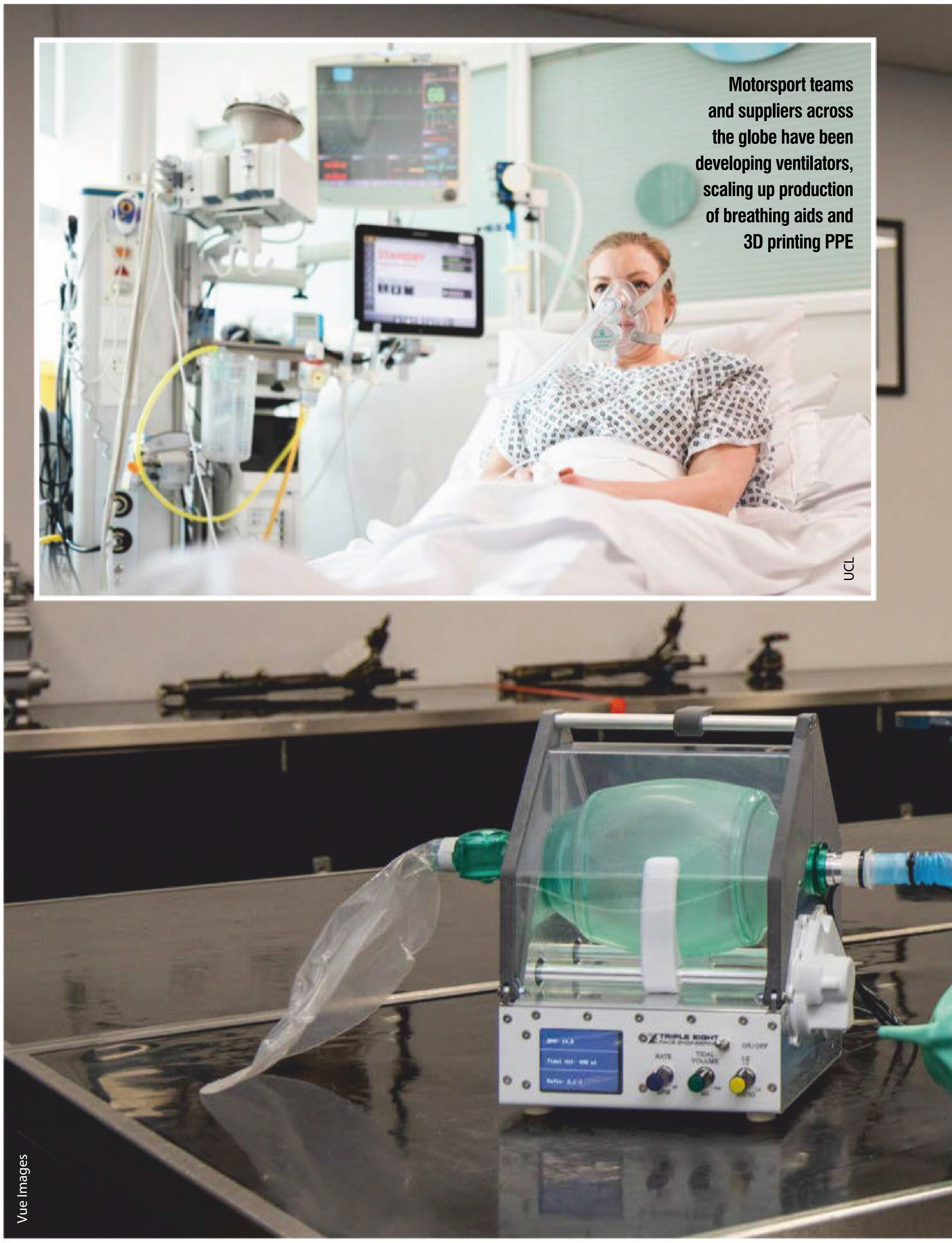
With other projects on the go, including the Baja 1000-winning Boot and the SCG 007 Le Mans Hypercar, the team is busy but needs the 004 to be a commercial success. 'We are primarily a road car manufacturer who races because we are passionate about it, and it promotes the company,' says Glickenhaus. 'We have positioned our products as the ultimate track day vehicles that a customer can use for 100 hours on track before it needs a rebuild or service. For the race version, we wanted to enter the most competitive and high-performance level of racing for GT cars, which is GT3.'



Call to arms

Never before has the world witnessed such a coming together of industry with one common cause – to defeat an enemy we cannot even see

By GEMMA HATTON



Motorsport teams and suppliers across the globe have been developing ventilators, scaling up production of breathing aids and 3D printing PPE

UCL

Vue Images

The main positive that has emerged from the chaos caused by the coronavirus pandemic has been unity. Whether it is people singing together from their balconies, clapping for the UK's National Health Service (NHS) or dancing in the streets at a time when everyone is forced apart, strangely the world seems closer together. It is no different in motorsport.

Teams, drivers and suppliers across the world have been forced to ditch their normal racing routines and instead have been doing whatever they can to support the fight against Covid-19. Drivers such as Alexander Sims have been collecting personal protective equipment (PPE) and delivering it to the NHS trust. At the time of writing, Sims had collected over 40,000 pairs of gloves and 200 face masks.

Stepping up

Meanwhile, Mercedes HPP has reverse engineered a breathing aid for rapid manufacture and the seven UK-based Formula 1 teams have united for 'Project Pitlane', which will assist the UK government in the manufacture of vital medical devices.

Simulation companies have developed open source lung models; Dallara has optimised a Decathlon snorkelling mask; NASCAR is 3D printing face shields and Supercar Championship teams have built their own ventilators. Nearly every motorsport supplier who owns a 3D printer or CNC machine is, at time of writing, manufacturing PPE and/or ventilator parts for the cause.

As every country around the globe continues to face major shortages in breathing aids, test kits, PPE and other hospital equipment, motorsport is stepping up to help where it can.

But why motorsport? After all, motorsport specialises in bespoke prototypes, not hundreds of thousands of mass-produced components. Considering every racecar is effectively a one-off prototype built from thousands of specialist parts, and even 'spec' racers are made in small volumes which are then optimised to suit each driver, it is surprising to think the racing world can be of any help at all in this pandemic. However, the rapid response nature of motorsport, along with an abundant and adaptable supply chain that is crammed with pioneering engineers and innovative companies is exactly what the world needs right now.

Currently, all of motorsport's efforts can be divided into four main strategies: 1) developing new breathing devices; 2) optimising existing breathing devices; 3) retro-fitting alternative breathing devices; 4) rapidly manufacturing PPE.

Project Pitlane

Arguably, the most impressive example of motorsport unity is that of 'Project Pitlane'. In mid-March, the UK Government put out a call to arms to UK industry. Formula 1, along with

The rapid response nature of motorsport, along with an abundant and adaptable supply chain… is exactly what the world needs right now

Australian Supercar team, Triple Eight Race Engineering, has developed its own ventilator by adapting an ambulance resuscitator. The unit drives a set volume of air and oxygen into a patient's lungs

the seven UK-based F1 teams (Mercedes, Red Bull, McLaren, Renault, Racing Point, Haas and Williams) and their representative technology arms (Williams Advanced Engineering, McLaren Applied Technologies, Red Bull Advanced Technologies etc.) joined together to help manufacture and deliver respiratory devices. This challenge has been divided into three workstreams: reverse engineering existing medical devices; support in scaling the production of ventilator designs as part of the VentilatorChallengeUK consortium and rapid design and prototype manufacture of a new device for certification.

Led by Catapult, which is a group of UK manufacturing research centres, VentilatorChallengeUK brings together engineering companies from the motorsport, aerospace, automotive and medical sectors to rapidly manufacture ventilators. Other companies involved include Airbus, GKN, Ford, Rolls-Royce, Siemens and BAE Systems.

'It is the most extraordinary coming together of a variety of industries that will absolutely help us to beat the coronavirus,' says Rosa Wilkinson, communications director at High Value Manufacturing Catapult. 'What I have seen is people who are absolutely giving their all to this project from every industry, including the race teams. They are not pausing for breath. They are just getting on with the job because they understand the national need.

'Some people may wonder why Formula 1 teams, aerospace and automotive companies are still going to work. Well, it's because they are helping the nation in its moment of greatest need, and we should be celebrating them.'

Before the UK government's call to arms, Catapult initiated conversations with a range of companies as it was clear the demand for hospital ventilator equipment would dramatically increase. By the time the government released the specification of the rapidly manufactured ventilator system (RMVS), Dick Elsey, CEO of High Value Manufacturing Catapult, had a pretty clear idea of what was already out there, what could be done and the companies that had both the desire and capability to rapidly manufacture them.

'We were then able to move very swiftly to identifying two devices. One from a company that currently produces ventilators, and another which is a new device put together from existing technologies,' continues Wilkinson. 'We got the formal order for 10,000 ventilators – 5,000 of each device – and we started to put everything together to get cracking. That involved ensuring all the engineering and design work had been completed, as well as a clear bill of materials.

'We also needed to understand what the supply chain needed to look like, what could be produced at the existing sites and how we could complement that by extending production in other locations to enable us to really deliver what the government had called for.'

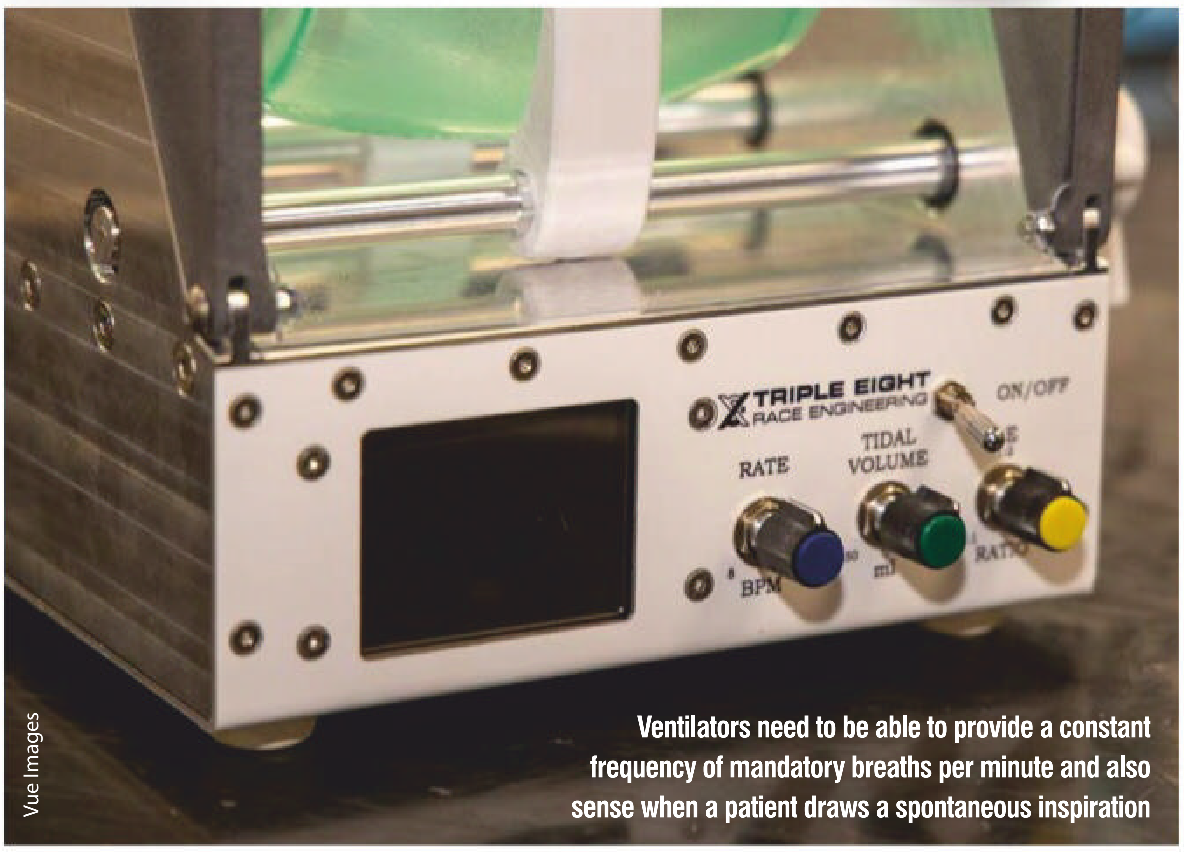
Support and development

The new device is the Penlon ESO2, which can be assembled from materials and parts already in production. This helped it to roll off production lines as early as the second week of April. The device already on the market is the Smiths ParaPAC300 ventilator, a compact, lightweight unit that delivers mechanical ventilation, demand and free oxygen therapy and continuous positive airway pressure (CPAP).

F1 teams have not only been contributing to the development of the new Penlon device, but also providing additional manufacturing support to help scale up the production of the Smiths device, too. For example, all three arms of McLaren have been involved. The race team's machine shop has manufactured ventilator components, while McLaren Applied Technologies has supported the device build assessments, particularly around electronics and circuit boards, and McLaren Automotive has

‘We’ve done in two or three weeks what it would normally take a company probably a year or more to do’

Both Williams and McLaren have been re-engineering the manufacture of the Smith’s ParaPAC300 ventilator to scale up production



Vue Images

Ventilators need to be able to provide a constant frequency of mandatory breaths per minute and also sense when a patient draws a spontaneous inspiration

designed and built test equipment to ensure the ventilator units meet all the relevant functional and safety requirements.

Meanwhile, over 50 staff from Williams Advanced Engineering (WAE) have helped develop 3D CAD models for the bill of materials, as well as re-engineer the manufacture of the ParaPAC300 device. The rapid prototype processes used by the race team enabled WAE to produce a number of prototype components within only two weeks. It is this rapid response capability that made motorsport teams such an attractive alliance for Catapult.

‘Race teams are absolutely used to innovating very rapidly as that’s how they stay ahead of the competition,’ highlights Wilkinson. ‘Secondly, they understand the challenges of high precision, high quality engineering. Thirdly, they have existing capabilities and facilities. And finally, they were determined to make a contribution to the national effort.’

Tight regulations

Another parallel between the medical and racing worlds is a set of tight regulations. Despite the Penlon ESO2 being made up of existing technologies, the regulations still classed it as new and so it had to be approved by the governing body, the Medicines and Healthcare products Regulatory Agency (MHRA). However, as the Agency was involved in the development of the device right from the start, approval was granted within a few days and clinical trials will have been completed by the time you read this.

‘What we have done is effectively set up everything so this device can roll off the production line very swiftly,’ concludes Wilkinson. ‘We’ve done in two or three weeks what it would normally take a company probably a year or more to do.’

‘To provide some context, Penlon and Smiths ordinarily have combined capacity for between 50 and 60 ventilators per week,’ explains Catapult’s Dick Elsy. ‘However, thanks to the scale and resources of the wider consortium, we are targeting production of at least 1,500 units a week of the Penlon and Smiths models combined, within a matter of weeks.

‘Ventilators are intricate and highly complex pieces of medical equipment, and it is vital we balance the twin imperatives of speed of delivery with absolute adherence to regulatory standards needed to ensure patient safety.’

Supply chain

Unsurprisingly, the government’s call for help was answered by almost every motorsport company or supplier, big or small. Yet you may wonder why the final consortium is only made up of the biggest players in the industry. Well, established companies are easier to mobilise for a rapid response and, while this may be initially frustrating for the smaller suppliers, work will gradually filter down the supply chain.

For example, McLaren Racing has confirmed it is working with around 100 of its suppliers on ventilator projects, and with each F1 team relying on some 400 suppliers, this collaboration will help to support the entire supply chain.

‘The way it has been handled is absolutely the right way, which is to select a consortium of bigger companies that can then start to drill down into the supply chain,’ says Kieron Salter, director at KW Special Projects who, along with many others, campaigned to be part of VentilatorChallengeUK. ‘We’re now starting to see a little bit of work flowing through to us, but mostly to other machine shops and other F1 suppliers. So, although we haven’t been directly involved as contributors, I think the process has worked out well and it’s a really good story for the motorsport ecosystem.’

Meanwhile, in Australia

Boosting the production of ventilators is currently a global concern and, elsewhere in the world, race teams and suppliers have also been working hard to find solutions. Triple Eight Race Engineering, last year’s runner up in the Australian Supercars Championship, has designed and built its very own ventilator.

‘Australia is a bit different to Europe and the USA because we don’t have any major manufacturers of these devices,’ highlights Jeromy Moore, technical director at Triple Eight Race Engineering. ‘It’s a bit of a wild west down here where we’ve got all the brains but no manufacturers. So, in order to get something that’s functional and can do the job well, we have to make it ourselves.

‘Also, race teams in Australia are quite different in that we are more closed loop, so race

Above and left: Mercedes HPP improved the manufacturability of the UCL-Ventura breathing aid to make it more suited to mass production. The UK Government has now ordered 10,000 of these devices

engineers are also designers, so we can go from design to manufacture to implementation all in house and relatively quickly.'

Rather than reinventing the wheel, Triple Eight opted to work with an open source design of an ambulance resuscitator, which it could then optimise as a ventilator. This meant the device was not only already medically approved, but also the right size and incorporated all the necessary fittings and safety devices such as over pressure valves.

Mechanical ventilators are designed to ensure the patient receives the correct volume of appropriate gases to satisfy their respiratory needs, without damaging the lungs, impairing circulation or increasing patient discomfort.

'There are lots of different ways to do it, but the basic principle is to supply either pure air or a mixture of different ratios of oxygen into the patient, predominantly automatically,' explains Moore. 'The patient will likely be unconscious and so you have to pass in a metered quantity of air of a certain volume, frequency and maximum pressure. You can achieve that in different ways. As we're adapting a bag valve mask, or hand-operated resuscitator, it's easier to work to the volume-driven method. So we are adapting that design to automate it and also manage the mixing of the oxygen to whatever specific ratio is required.'

This volume-driven mode also makes it relatively easy for the ventilator to then conduct mandatory inspirations at specific frequencies. A breath is defined as an inspiration paired with an expiration of the same relative size. Therefore, a mandatory breath is essentially a breath where the machine controls the timing of the inspiration. These can be set to a specific frequency between 10 and 30 breaths per minute. However, ventilators also need to have the capacity to cope when the patient wants to draw a spontaneous inspiration.

'We have designed a system into our ventilator that senses when a patient is trying to breathe and then provides a pressure-supported breath into the patient. That's just another control system you have to get right and of course it is absolutely critical that you don't over pressurise or overflow the patient,' continues Moore.

'There are a lot of complex items within a ventilator. Oxygen is quite volatile, so you have to ensure the right oxygen feeds all the valves, as well as having precise control of the sequencing and timing of the automatic inspirations. The good thing is we are working in conjunction with medical clinicians who have been providing feedback all the way along through our design process.'

(Therapeutic Goods Administration) before clinical trials begin.

'It has been flat out over the last few weeks as we've effectively changed tack from a motor racing team to a medical supply team,' reflects Moore. 'Just like a racing series, there has been a set of regulations, and understanding these has been a challenge because they have been constantly changing. Another issue has been getting the parts because manufacturing is slowing down, part supplies are drying up and shipping has become increasingly difficult.

'We're now at the stage where we're looking at how to improve the design to roll it out in much higher quantities'

The engineers at Triple Eight used SolidWorks to digitise the designs, which were then used to 3D print prototypes of the various mechanisms to ensure they functioned correctly. Once refined, the team's CNC shop manufactured the first real parts. However, despite Triple Eight's CNC machine shop being an impressive facility for a race team, it doesn't have the capacity to churn out thousands of parts for ventilators.

'We're now at the stage where we're looking at how to improve the design to roll it out in much higher quantities,' says Moore. 'We're looking at fabrication of some folded sheet metal, but also injection moulding of plastic parts, which makes sense as higher quantities can be punched out quicker and cheaper.

'We're also working with our partner, PWR, who make radiators for F1. Currently, they have a lot of machine time available so are ready to go once we press the green light.'

At the time of writing, Triple Eight was finalising the development of a MkII ventilator design, which will then be given to clinicians for trialling on test devices. Once approved, it will then need to be certified by the TGA

'We're obviously used to solving problems and identifying solutions as quickly as possible but, instead of making a racecar go faster round a track we have tried to make a system to save lives, which is so rewarding.

'Overall, we hope these devices aren't required, but we need to make them just in case, and if we can play a part in saving at least one person's life then it makes it all worthwhile.'

Reverse engineering

Aside from optimising the design and production of ventilators, motorsport is also working on reverse engineering and retro-fitting a variety of breathing aids. These devices aim to help patients cope with symptoms either at home or in hospital, without the need for invasive mechanical ventilation. This will not only reserve the limited number of ventilators for the seriously ill, but reduce overall demand.

Mercedes HPP has been working together with engineers from University College London (UCL) and clinicians at University College London Hospital (UCLH) on the UCL-Ventura, which is a CPAP breathing aid. These are currently used by the NHS and differ from

‘It took only 100 hours from the initial meeting to the production of the first device’

ventilators by pushing an air / oxygen mix into the mouth and nose at a continuous rate. So effective are these devices that reports from Italy and China suggest around 50 per cent of patients that were given CPAP did not need to use a mechanical ventilator, and were therefore kept out of intensive care.

The project involved disassembling an off-patent device and reverse engineering its design. By using computer simulations, the device was then optimised to improve its manufacturability, making it easier to scale up production. It took only 100 hours from the initial meeting to the production of the first device. A second version was then developed, capable of reducing oxygen consumption by as much as 70 per cent compared to the first.

The UCL-Ventura has now received MHRA approval, and all the details required to make the device are available for manufacturers to download for free at a research licensing website developed by UCL Business.

After the UCL-Ventura completed patient evaluations at UCLH and other London hospitals, the UK Government put in an order for now fewer than 10,000 devices.

All of these are being manufactured at Mercedes HPP headquarters in Brixworth, where the 40 machines that would usually be manufacturing F1 pistons and turbocharger parts are now producing medical equipment that could help save lives.

Open source snorkel

Dallara has taken the development of breathing aids a step further, by defining a way to re-engineer a Decathlon snorkelling mask into a non-invasive respirator. Working together with the Hospital of Parma, Dallara utilised its thermodynamic and CFD skills to improve the efficiency of an ISINNOVA valve that can be put into the off-the-shelf snorkelling mask, converting it into a respirator.

The CAD model, as well as installation instructions for the valve, are both open source so, technically, anyone with a domestic 3D printer and a Decathlon snorkelling mask can make a respirator at home for approximately $40. That is not necesarily the idea though.

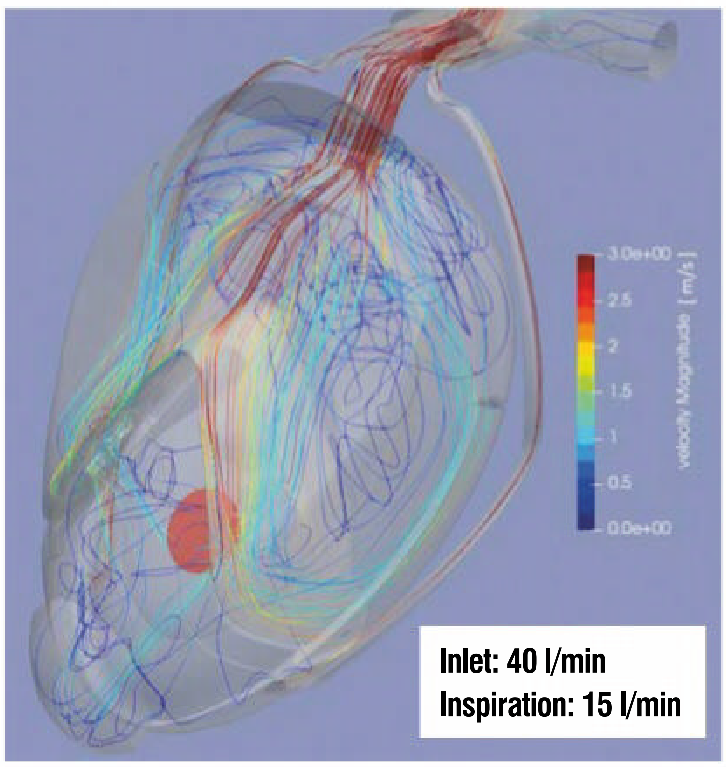
‘We were inspired by an idea from a doctor from Brescia,’ explains Gianmarco Beltrami, marketing and communications director at Dallara. ‘The idea was studied and implemented with the rationale of having an easily useable device at a time when medical devices are not easy to find. It had to be low cost, reduce environmental pollution and work with few resources, such as just oxygen.’

However, despite the oxygen consumption of this device being much lower than that of an intensive care respirator, it is still high enough that it has to be used in a hospital environment. Furthermore, the use of any such device has to be supervised by a trained clinician, which pretty much rules out home use, but if it potentially helps free up vital intensive care beds it is still a very worthwhile aid.


The 40 machines at Mercedes HPP HQ that would normally be manufacturing F1 powertrain components are now producing the UCL-Ventura device


Dallara has optimised a valve (red) which allows a regular Decathlon snorkelling mask to be converted into a non-invasive respirator

Right: **Dallara used its thermodynamic and CFD expertise to analyse and refine the behaviour of the airflow through the valve and into the mask**



This face shield is the result of a collaborative effort between KW Special Projects and Respolab. It has been designed with a longer term view in mind and could be used after the Covid-19 pandemic, when minimising the spread of viruses will continue to be a concern

Left: Many companies, such as 3T additive manufacturing, have been 3D printing headbands for face shields for hospital workers

Another way motorsport has been helping hospitals is in the production of PPE. Suppliers who normally use additive manufacturing to produce prototype parts are now switching their machines to print face shields and other protective equipment.

3D printing

'A lot of companies have been getting involved in the face shield activity, and I think that's a really good demonstration of the capabilities of additive manufacturing in terms of distributed digital manufacturing,' highlights Salter. 'You've got this open-source idea where a design is available to everybody, and anyone who has some equipment, whether it's one machine or 20, can start making stuff. Even if they're only able to make 10 a week, multiply that by the number of companies with those machines and suddenly you've got a distributed supply chain across the whole nation, and globally.

'The reality, however, is it's not the right way to do it. The limitation at the moment with the face shields is they take a long time to print and are quite expensive to make that way. We have three industrial FDM [Fused Deposition Modelling] machines and, because each face shield takes around 15 minutes to print, we can make about 200 per day, which isn't many. They also consume expensive types of FDM material.'

Clearly, injection moulding is better suited to rapid manufacture of simplistic parts like this and, once the tooling has been made, these machines are capable of knocking out many parts per minute at much cheaper cost.

'The reason people are turning to 3D printing is because, traditionally, making the tools for injection moulding could take up to five weeks,' explains Salter. 'So, although it takes 15 minutes to 3D print a face shield, that 15 minutes starts right now.

'The best compromise, perhaps, is for someone to 3D print the tool, which might take a few days, and then injection mould the parts from a 3D printed tool. Our RPS NEO SLA machines are capable of printing hard, ceramic-based or epoxy-based injection moulded tools. These won't have the same life as those made from steel or aluminium, but you get to production much quicker.'

It takes around 15 minutes to 3D print a face shield on a Stratasys FDM machine. Injection moulding would greatly speed up the process, but the tooling could take weeks to manufacture. 3D printing the tools for injection moulding could be the solution

'Suddenly there are shortages of simple parts that were previously readily available'

At a time of global crisis, the demand for equipment that could help save lives needs to be satisfied instantly, which is why everyone rushed to help. However, a better strategy may be to analyse the design and manufacturing problems with more of a long-term view.

Long-term view

'No one has had good visibility of how long all these problems are going to last, and what further problems are likely to come up in the future,' says Salter. 'There's a very short-term view on things at the moment because people are thinking about saving lives now rather than coming up with something that may have to wait a couple of weeks, but is a better plan.

'For example, we're working with RespoLab on designing a new, high-volume production face shield and respiratory mask system that probably won't be ready to solve the immediate PPE requirements due to development and certification lead times, but will be a short-to-medium-term solution for when we come out the other side and realise virus control will become increasingly important in the future.'

It's not just respirators and face shields in short supply either. With shipping more difficult than ever, factories shut down and part supply shortages, companies are turning to local 3D printers to manufacture other products, too.

'We've had quite a lot of inquiries for face shields for people who still need to go to work in banks, shops and utilities, as people are now becoming much more conscious about having some level of personal protection,' continues Salter. 'We've also been involved in some R&D work on test kits, and on how we can short cut the manufacturing of hand sanitiser dispensers.

'It's fascinating to see what problems are coming out of the woodwork when the conventional supply chain becomes overloaded. Suddenly there are shortages of simple parts that were previously readily available, so we're looking at how we can mobilise the supply chain and manufacture parts locally.'

As the world progresses through this Covid-19 pandemic and continues to learn, more new problems will continue to surface. But the one guarantee in these ever-changing times is no matter what the problem, companies involved in motorsport, teams and suppliers are here to help.

Motorsport rises to the challenge – tech highlights

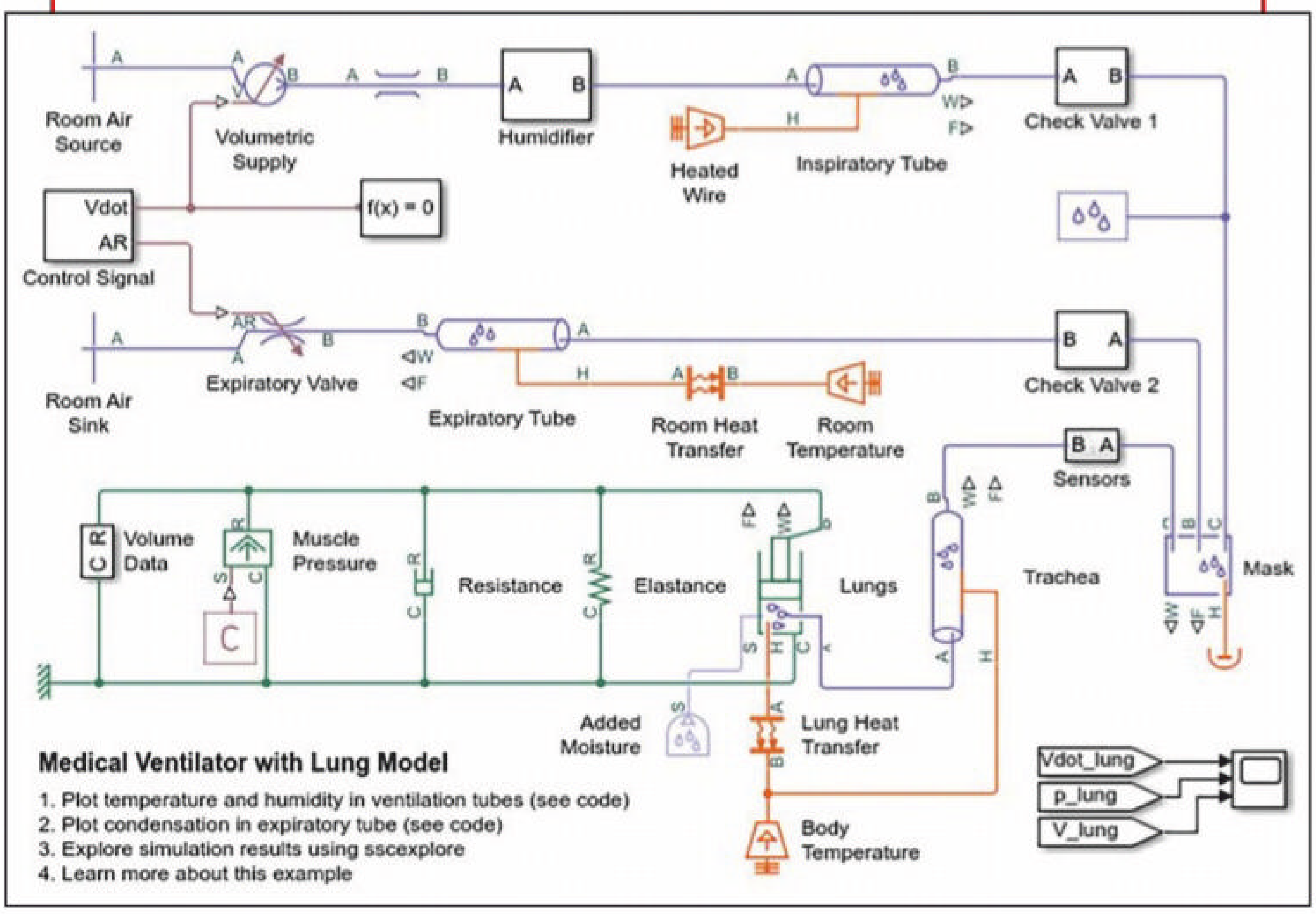
McLaren

In addition to building ventilator test equipment, McLaren Automotive have also designed bespoke trolleys that ventilators will be fixed to for use in clinical settings. Just like McLaren's road and racecars, the trolleys had to be crash tested to ensure they complied with strict regulations.

Meanwhile, the McLaren Composites Technology Centre has donated 100 face masks, 35 boxes of gloves and 30 overalls to the UK's National Health Service.

MathWorks

To help companies who are developing ventilators, MathWorks has released a Simscape medical ventilator model that is free to download. The model has pressure-targeted, closed-loop controls on stateflow and is ready to generate arduino embedded code. The company has also published a moist-air library of custom components, as well as two lung models, to allow engineers to simulate and test the effectiveness of their ventilator and controller designs.



CRP Technology

Italian 3D printing company, CRP Technology, has used its additive manufacturing expertise to produce several functional prototypes of valves for emergency respiratory masks. Termed 'Charlotte valves', these are similar to the ones Dallara has also produced (see p20) and can similarly be used to convert an off-the-shelf Decathlon snorkelling mask into a breathing aid.

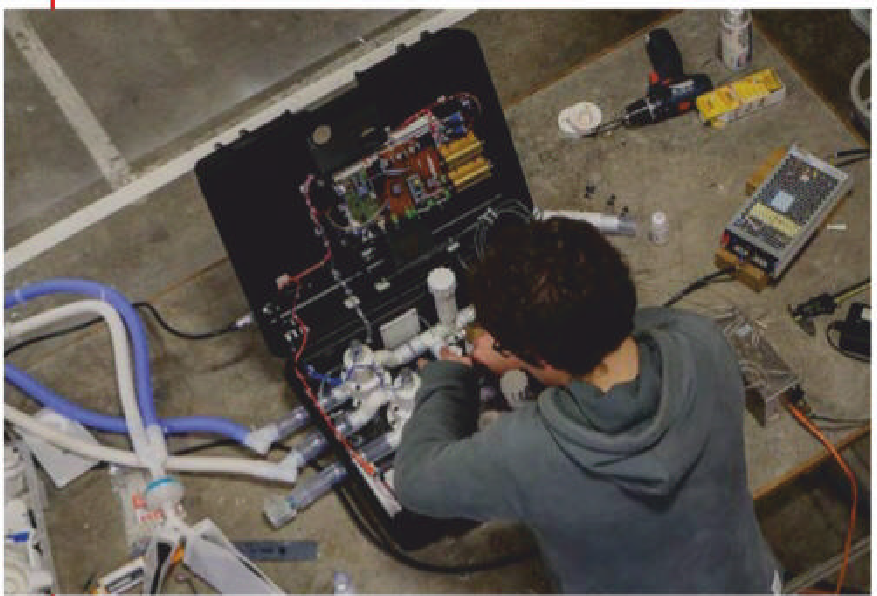
Michelin

Michelin, alongside a group of other companies in France's Auvergne-Rhône-Alpes region, has developed and manufactured a re-usable OCOV mask. Instead of an FFP1 or FFP2 (Filtering Face Piece) face filter, this mask features a flexible facepiece that covers the nose, mouth and chin. It has been designed to provide an effective seal between the atmosphere and the person's face, and the use of five washable filters means it can be re-used up to 100 times. A prototype batch of 5,000 units were being made at time of writing, but the goal is to manufacture over five million masks by the end of June.

MIA

Racecar Engineering is a member of the Motorsport Industry Association (MIA) who are working hard to support the motorsport supply chain in these difficult times. The MIA, as the accredited trade association for motorsport, represents our industry to government and on industry forums. It is in direct communication with key government departments – the Department for International Trade and Department for Business, Energy and Industrial Strategy amongst others.

For the latest UK government updates, advice, support and opportunities, visit the MIA's Covid-19: Guidance and Resources page at www.the-mia.com/page/COVID19guidance



Prodrive

A team of 12 Prodrive engineers have been working with Cambridge University, the Whittle Laboratory and 12 other partners on the Open Ventilator System Initiative (OVSI). This is a pressure-based system with the capability to use external oxygen and mix it with ambient air. Prodrive has helped develop a simplistic, affordable design, using readily available components. The idea is this ventilator can be built by engineering companies around the world, helping countries to meet their local medical needs, both now and in the future.

Titan

Titan, a company that usually develops engine, steering and limited slip differentials for F1 and other motorsport series, has completely re-purposed its factory to help manufacture parts for ventilators. The 25-strong assortment of CNC milling machines and lathes are now working six days a week, 24 hours a day, producing components for several of the government-led ventilator projects in the UK.

All change

It may look like the RP20 is just a copy of last year's Mercedes W10, but the new car required a substantial amount of technical development

Pit lane jibes at the 'pink Mercedes' overlook the engineering challenge Racing Point committed to when it changed from a high-rake to low-rake philosophy for 2020

By GEMMA HATTON

'The risk was basically to tear up what we've done in the past few years and start again from scratch'

One of the major technical talking points of the 2020 grid has been Racing Point's so-called 'Pink Mercedes'. The team's RP20 model was attributed this nickname at pre-season testing because it appeared to be the doppelganger of last year's Mercedes W10. But surely copying another team's concept requires minimal expertise, and is therefore of little interest to *Racecar Engineering*? Not quite: The transformation from Racing Point's traditional car concept to that of the more modern Mercedes-esque solution marks the team's biggest engineering challenge to date.

The Silverstone-based team has been through many iterations. Starting off as Jordan Grand Prix in 1991, the team was then sold to Midland in 2005. Racing one year under the Jordan name and another as MF1 Racing, it then became Spyker in 2007, followed by Force India in 2008 and then Racing Point 10 years later.

This was the team's biggest engineering challenge to date

Often regarded as the underdogs of the pit lane, the team became renowned as the most 'efficient' in F1, scoring the highest number of points per pound spent in 2015 and 2016 when it finished fourth in the Constructors' Championship. However, since dodging administration in the summer of 2018, the team has struggled to recapture its former success, finishing seventh in the Constructors' Championship in the last two seasons.

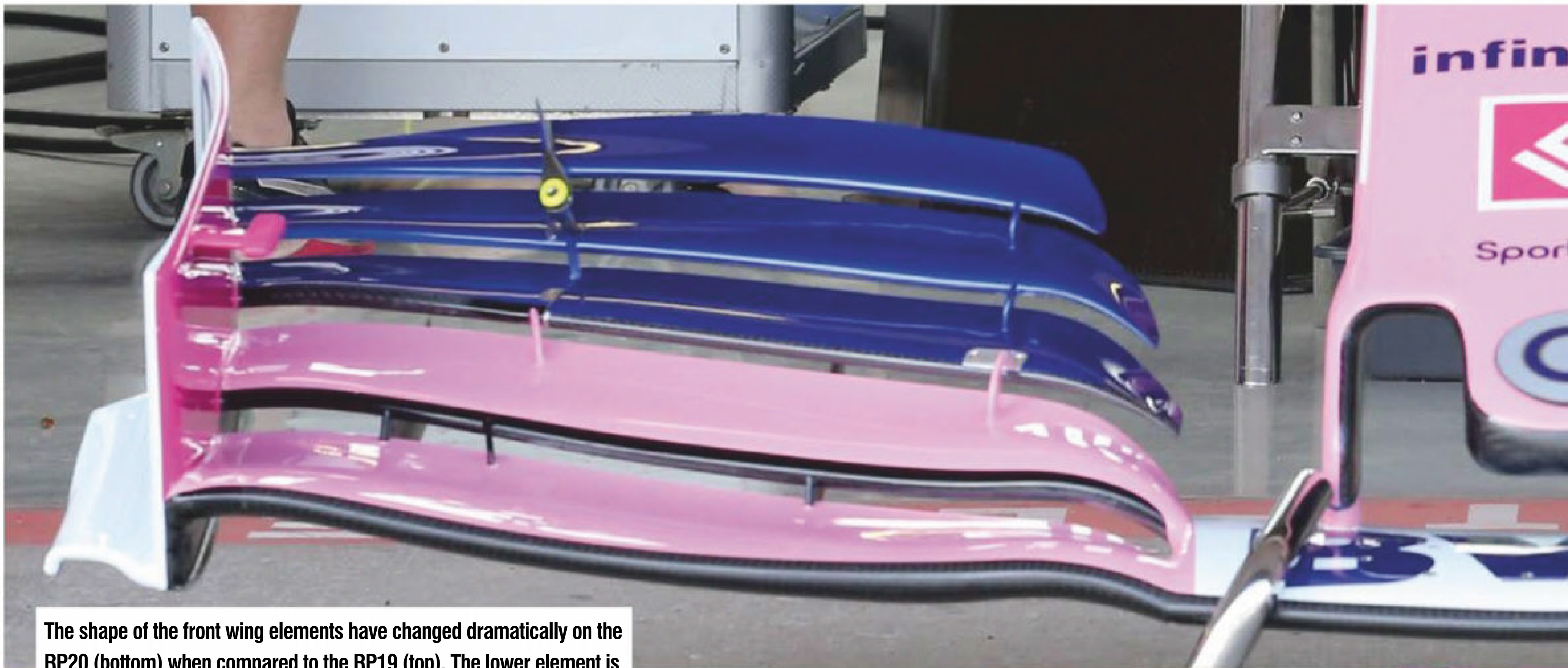
'We have tried many avenues with the old [car] concept to try and make an inroad into the Achilles heel that has dogged the cars for the last few years,' reveals Andrew Green, technical director at Racing Point.

'The drivers have been feeding back, race after race, year after year, the same comments that we weren't really making big inroads into the characteristic they kept complaining about.

'When we saw how the RP19 was developing, it wasn't making the gains we were hoping for. It became clear that if we carried on the route we were going we would end up, at best, where we finished the championship last year. Our progress wasn't strong enough to move forward and that just wasn't acceptable. So, it was time to try something new, to take a risk and I think we've taken a very, very big risk with what we've done with this car.'

High-rake concept

The concept Racing Point has been chasing over the last few years has been the high-rake philosophy, which the likes of Red Bull Racing

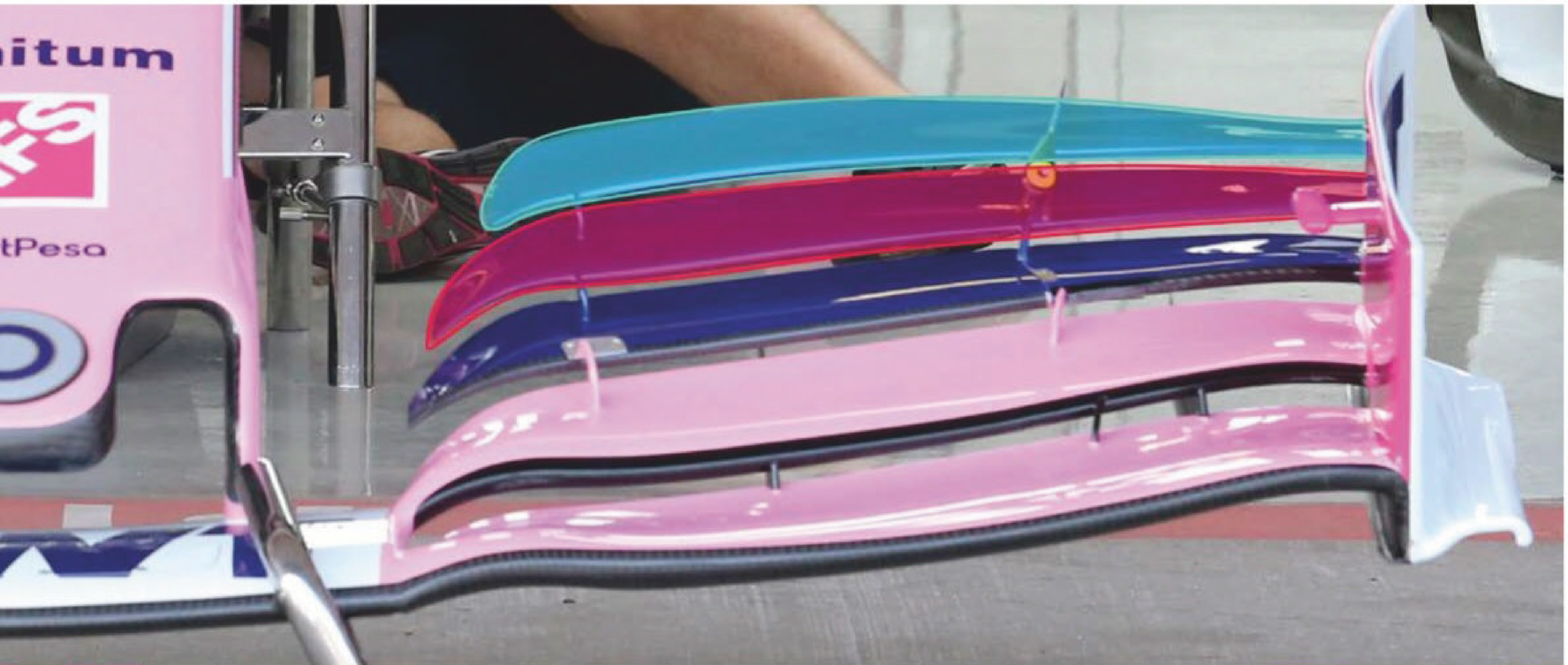


The shape of the front wing elements have changed dramatically on the RP20 (bottom) when compared to the RP19 (top). The lower element is no longer attached to the main plane and the nose is much narrower

For 2020, the front and rear brake ducts are 'listed parts' and so have to be designed by the team

has unquestionably mastered under the technical leadership of Adrian Newey. By raising the rear end, not only does the centre of gravity increase, but so does the natural effect of the diffuser. Furthermore, by running the front wing lower, front lift can be generated without taking too much energy out of the airflow, leaving more energy for the rear end to extract. These two factors combined lead to the underfloor producing higher downforce when compared to a low-rake car with the same floor area.

High-rake cars also run steeper wing angles to maximise lift but, of course, this increases frontal area and therefore also has the effect of increasing drag. Low-rake cars, on the other hand, usually have less drag penalties but often need to have a longer underfloor (and therefore a longer wheelbase) to produce the same amount of downforce. This generally leads to a slightly heavier car, leaving less ballast available for the team to tune weight distribution with.



Overall, there are pros and cons to both high and low-rake philosophies. The trick is to pick one or other and stick to it throughout the whole of the car's development cycle.

'We set off on this route many years ago, along with a few other [teams], who reverted from a lower rake car to a much higher, Red Bull rake-type car,' says Green. 'You build up years of data and information about what's good and what's bad and which direction to go.

'But eventually, for us, it was starting to peter out and it was a question really of should we just carry on, or should we stop and try something new? If so, it is a case of throwing almost everything you know out the window and starting again. It is as close to a clean sheet of paper as you can get.'

Low-rake concept

Around the time of the German Grand Prix last year in July, Racing Point took the decision to switch to a low-rake concept for its 2020 contender. In addition to poor performance, this decision was also driven by the fact Racing Point run a Mercedes power unit, transmission and some outboard suspension components. As all of these components have been optimised to suit Mercedes' low-rake car concept. Developing a high rake car using major components that are better suited to the opposite philosophy is challenging.

'As we've found in the last few years, trying to develop the high-rake Red Bull philosophy

Racing Point took the decision to switch to a low-rake concept for its 2020 contender

was becoming increasingly difficult with a gearbox and hardware from Mercedes as they use a different philosophy and are the only ones on the grid doing so,' explains Green. 'It's very difficult to try and develop a car around a different philosophy from the underlying architecture you already have.

'So, we posed ourselves a question; should we move across and try and develop a car to a different [low-rake] philosophy? It just made sense to do what we've done, which is to take the underlying architecture we've had from Mercedes for many years now and work with that. We decided to take a risk, and the risk was basically to tear up what we've done in the past few years and start again from scratch.'

However, the timing of this decision also coincided with when Racing Point switched from using the TMG wind tunnel in Cologne to the Mercedes wind tunnel in Brackley. Coincidence? 'I think that's more or less a coincidence,' confirms Green. 'We saw the same results and it reinforced our opinion. We changed tunnels because we wanted to see whether the data we were getting from the RP19 was any different in a different tunnel.

TECH SPEC: RACING POINT RP20

Engine
Mercedes-AMG F1 M11 EQ Power+ 1.6-litre V6 turbocharged and energy recovery system.

Chassis
Carbon fibre composite monocoque with Zylon legality side anti-intrusion panels.

Suspension
Aluminium uprights with carbon fibre composite wishbones, track rods and pushrods. Inboard, chassis-mounted torsion springs, dampers and anti-roll bar assembly.

Wheels
BBS. Front: 13 x 13.7in, rear: 13 x 16.9in.

Clutch
AP Racing.

Brake system
Brembo brake calipers and in-house design brake-by-wire system with carbon fibre discs and pads.

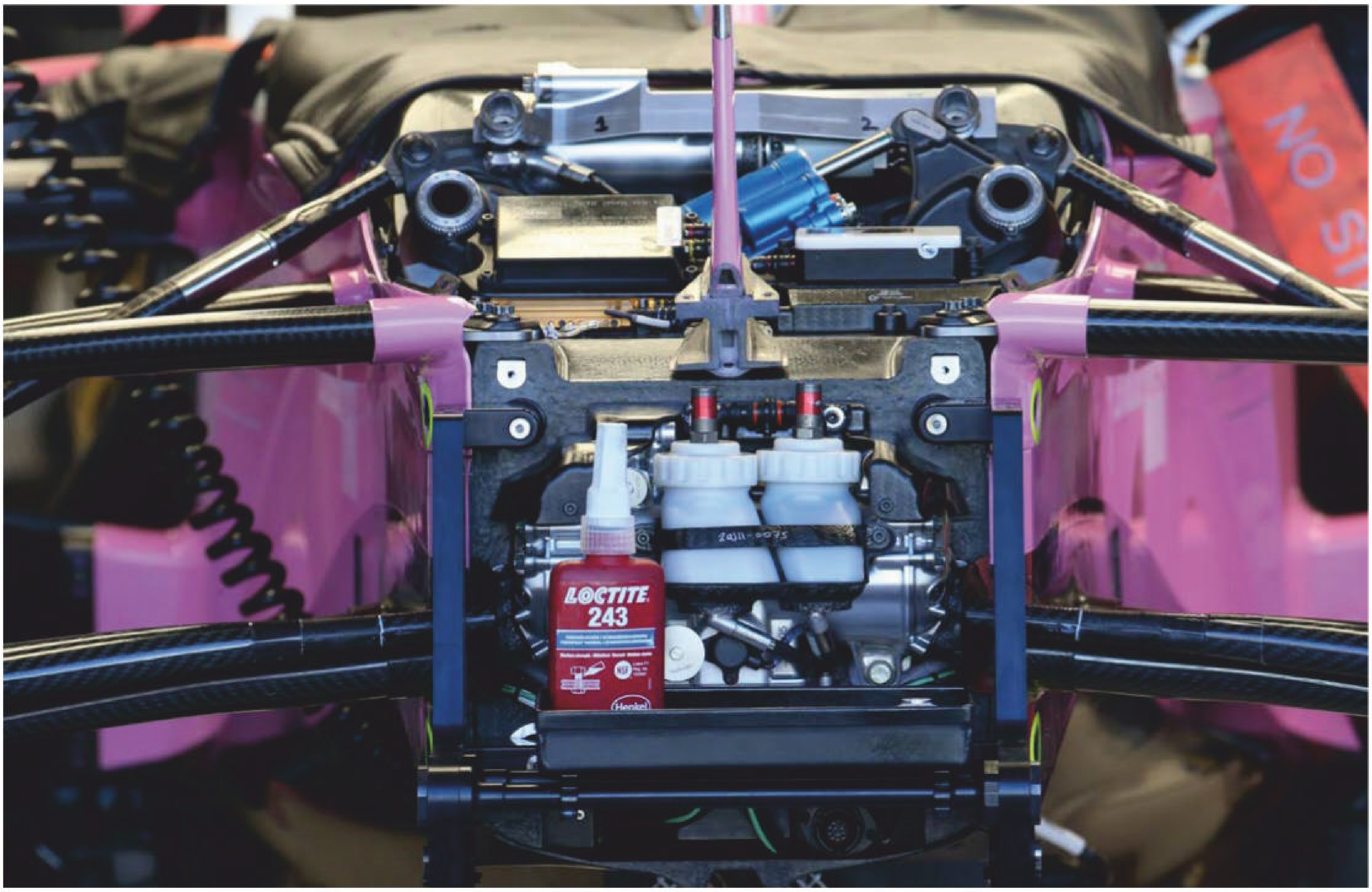
Transmission
Mercedes GP eight-speed, semi-automatic.

Electronics
FIA single ECU with in-house design electrical harness.

Dimensions
Width: 2,000mm, length: 5,600mm.

Weight
746kg (including driver, excluding fuel).

Weight distribution
Between 45.4 and 46.4 per cent.



Beneath the nose of the RP20. The blue part is the roll damper

Were we missing something fundamental by testing at TMG? And the answer was no, we were getting the same sort of results, seeing exactly the same sort of trends. So that [wind tunnel change] didn't really play into it, it just added more weight to the decision.'

Of course, teams copying or 'replicating' each other's concepts or trick technologies is not new to Formula 1. If the 2020 season had continued as normal, how many teams would have arrived at the Barcelona round (usually when teams bring major updates) with a Mercedes-style DAS system that could be deployed? From the comments of some technical directors and team principals at pre-season testing, the answer is that it would have been highly likely.

Nothing new

'Lots of cars look like other cars up and down the pit lane. I don't think ours is particularly any different to anybody else's in that respect, and I don't think what we've done is particularly new as far as taking a team's concept and doing it ourselves,' says Green. 'That's been prolific in Formula 1 since the very first days. Think back to double diffusers, blown diffusers and Coanda exhausts. [Teams] take concepts and turn them into their own and we've done exactly the same.

'My question would really be why hasn't anyone else done this before? When we look back on it, I think crikey, this is something maybe we should have done much earlier.'

Furthermore, with the current model of the 'big three' teams supplying hardware to smaller teams, it is little wonder these smaller teams eventually converge to the underlying philosophies of their bigger brothers.

'It makes sense to take a philosophy from the more successful teams and it made a lot of sense for us because of the hardware we are having to run,' explains Green. 'Trying to fight and develop a car using a different philosophy from the hardware you're getting is a real struggle. So, I can see why if you're a team of Red Bull and you get a gearbox and suspension parts from Red Bull, the chances are you're going to be looking at a Red Bull-type philosophy to complement it because that's what it's been designed for.'

The regulations have implemented some control over the number of components the smaller teams can buy, defining 'listed parts'. These are components designed by the team to which the team holds the intellectual property (IP), although the design and manufacture of the parts can be outsourced.

Current listed parts include the survival cell, front impact structure, roll structures, bodywork and also, for 2020, the front and rear brake ducts. However, as this list increases, the opportunity for teams to collaborate diminishes.

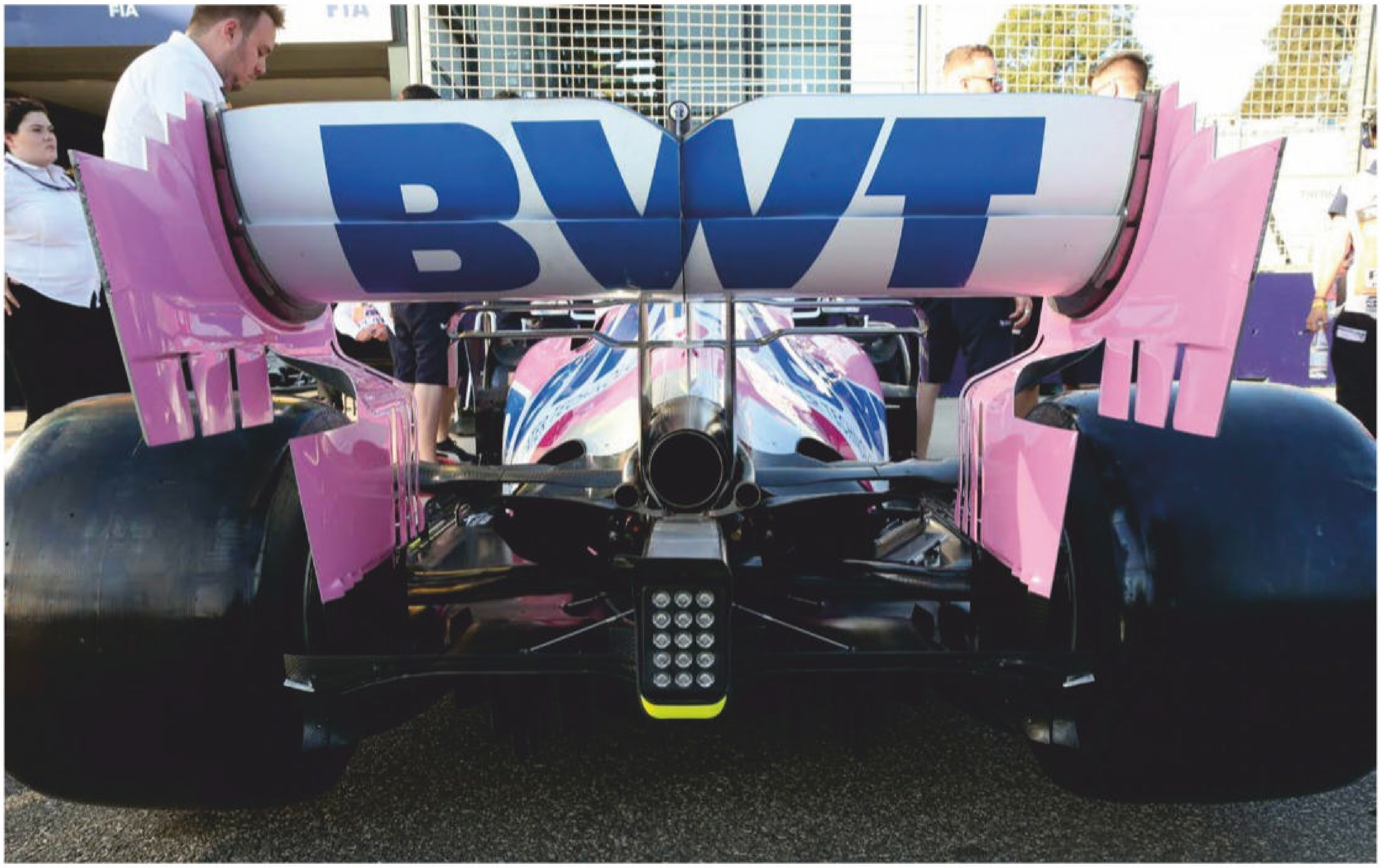
This is why for 2021, now 2022, F1 will boost the amount of standardisation allowed by the regulations in an attempt to cut development costs. So, despite the RP20 looking similar to the 2019 Mercedes W10, by regulation the chassis, aerodynamic devices, internal suspension components and steering rack, along with the listed parts mentioned earlier and some smaller parts, are all Racing Point.

'Anything to do with the chassis, which is effectively a non-transferrable component, or listed part, we prefer to keep in house because everything is linked. We want to develop our own suspension, wishbones and everything because it's all linked to the chassis,' continues Green. 'Our cooler concept has also always been Racing Point design, and that's different to where Mercedes have it for sure.'

Financial stability

The recent financial stability bought to the team by Lawrence Stroll has been a key factor in enabling Racing Point to invest its resources into

'We're in a much better place now and have the capability to make changes to the car we've never had the opportunity to do before'



The RP20 runs a Mercedes power unit, transmission and outboard suspension components so it was a logical step to switch to the lower-rake philosophy of Mercedes

making this concept switch. 'It's a big change. It's not something we've ever considered doing before because we didn't have the resources, we didn't have the people and we didn't have the funding to do this sort of project. So now we have, we decided to do it,' explains Green.

'It's not insignificant the amount of work that has to go into understanding another team's philosophy from the outside looking in. It is a huge amount of work to get to a level of performance where you think you're ahead of where you were before. It's a big challenge.'

Traditionally, Racing Point (and in the past, Force India) was famous for carrying over as many parts as possible from one year to the next in an attempt to reduce costs. Yet now in this resource-rich era of the team, along with the change in concept, the 2020 car shares few parts with its 2019 predecessor.

'We're in a much better place now, and have the capability to make fundamental changes to the car we've never had the opportunity to do before,' says Green. 'Before, we were forced to carry over the chassis, we had no choice. But if we didn't carry over those parts and do what we did, this team would not be sitting here today, and we would not be going into 2021 as a works Aston Martin team. We would have been gone.'

Diminishing returns

This does not make the RP20 the most expensive car produced by the team. 'What turns a car into an expensive car is when you continue to update it and eke out performance with big upgrades, but only very small returns,' reveals Green. 'Last year was our most expensive season because we pushed hard to get the performance out of that car. Yes, we saw some limited success, and by the time it got to Abu Dhabi the car was in a better place. But that was after a huge push, and we could see the returns diminishing so it was time to try something else.'

Replicating another team's concept is one thing, making it work is another

However, replicating another team's concept is one thing, making it work is quite another. With each one of the 14,500 components that make up a modern F1 car optimised to suit a particular car's design, engineers have to fully understand the principles behind each part.

'Copying something means nothing unless you understand the philosophy behind every single component and exactly what it's doing, otherwise it just doesn't work,' explains Green. 'That's why it was such a big risk for us because it was putting faith in the aerodynamics team to say, "Go and understand this and let's see whether we can replicate it."'

Despite running a Mercedes power unit, the RP20's cooling concept is very different in design

So is the fact that the RP20 is so similar to the Mercedes W10 an astonishing achievement by Racing Point, or an indication that the pink team may have received a helping hand?

Green insists this was not the case. Each team receives thousands of high-resolution photos of its competitors every race weekend, and a trained eye can extract a lot of information from these spy shots. However, there are striking similarities between the RP20 and W10. 'There was no data transfer,' confirms Green. 'It's not allowed in the regulations. It never has been, and it never will be, so all that is Racing Point. We have the same view as everyone else, and there's nothing special in the information we've got. All we've got is what we see and that's what we started from.'

Certainly, the RP20's initial performance at pre-season testing was impressive, with positive feedback from both the drivers and the team. However, when the 2020 season eventually gets going, it will be interesting to see the race pace of the RP20 and how it progresses throughout what's left of the season. Only then will we find out if Racing Point has fully understood its new, Mercedes-esque solution.

Positive outcome

In the meantime, the coronavirus pandemic has caused chaos for the entire motorsport industry. Consequently, the introduction of the 2021 'revolutionary' regulations will now be delayed until 2022, with this year's cars now carrying over to the 2021 season. This is a positive outcome for Racing Point as it means its RP20 will race for more than one season, increasing the value of the huge investment and effort that has gone into the car's development, although at time of writing, the length of the 2020 season is still a big unknown.

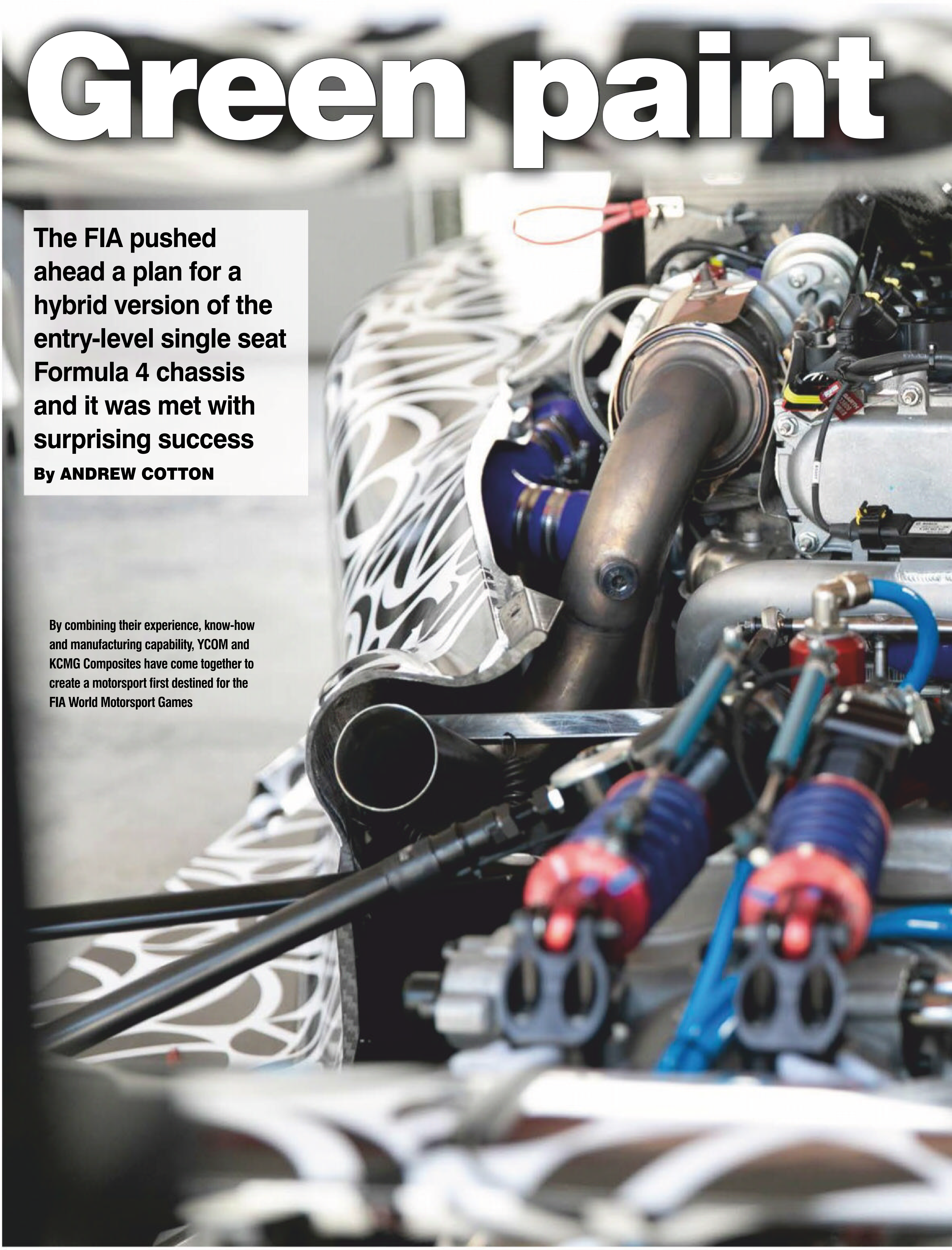
The 2021 season will mark another huge change for the Silverstone-based team, as it will enter the Championship as a full Aston Martin works team. At the end of March, the shareholders of Aston Martin Lagonda approved a £536 million investment, along with £260 million from the Yew Tree Consortium, a group of investors led by Lawrence Stroll. This means Aston Martin will create its own works F1 team, while Stroll will adopt the position of executive chairman of Aston Martin.

'There is a massive, massive buzz in the team right now,' smiles Green. 'From where we were two years ago, which was hanging on by a thread to get to a race, to where we've ended up now is incredible. And we've fundamentally kept the same core of people, which is great.

'I'm very proud of what the team has done and I'm proud of everything we have put into this car so far. It really has been a tremendous effort by everybody.

'From the outside, it probably looks to some people like we've just copied a Mercedes, but it's absolutely nothing like that. The whole project has been a huge challenge.'

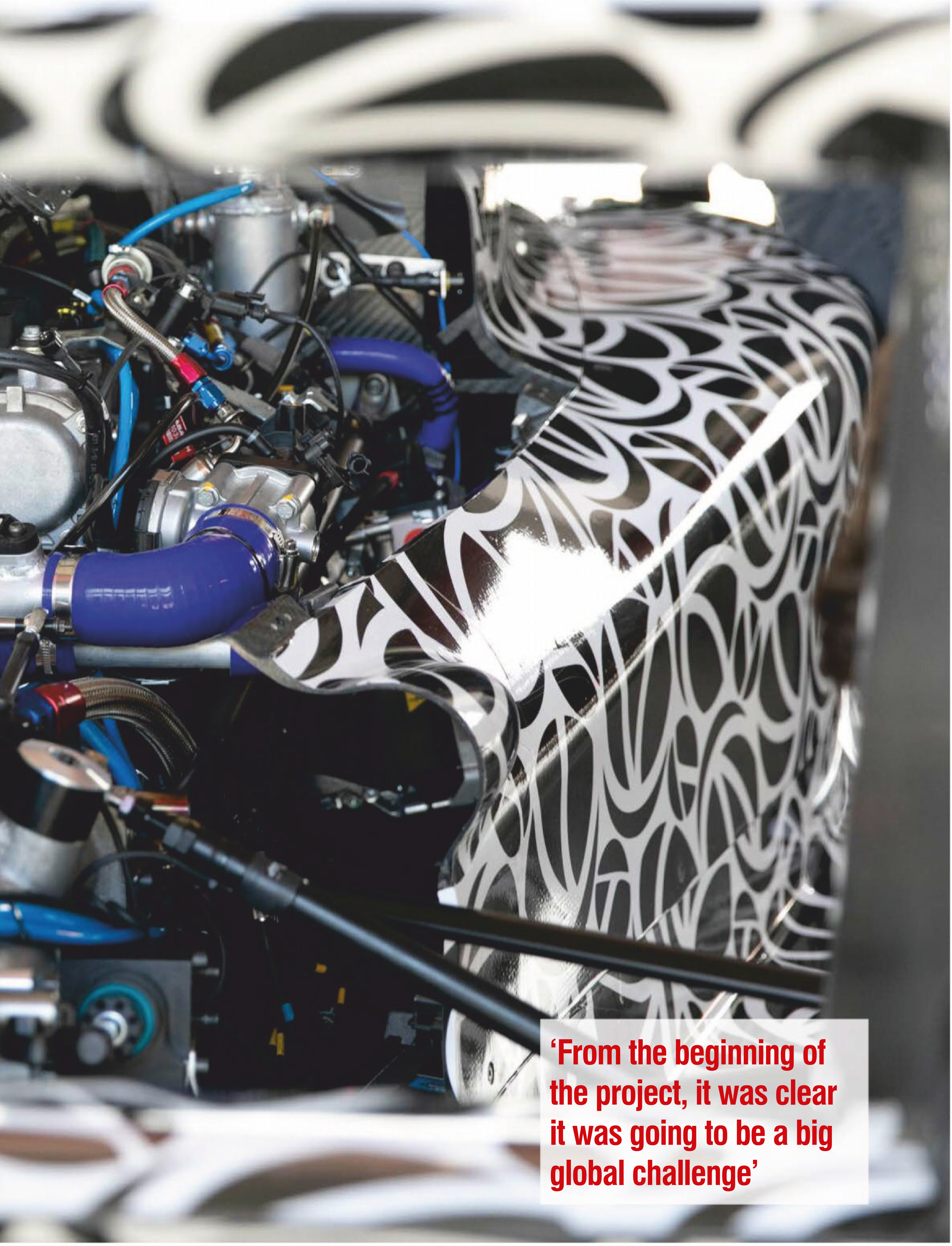
Green paint



The FIA pushed ahead a plan for a hybrid version of the entry-level single seat Formula 4 chassis and it was met with surprising success

By ANDREW COTTON

By combining their experience, know-how and manufacturing capability, YCOM and KCMG Composites have come together to create a motorsport first destined for the FIA World Motorsport Games



‘From the beginning of the project, it was clear it was going to be a big global challenge’

While the world of Formula 1 and the World Endurance Championship have run hybrids since 2014, other series are looking to introduce the technology into their racing programmes in the next set of regulations. Thanks to Covid-19, those plans have now largely been delayed in all categories, but the entry level Formula 4 has already achieved their introduction.

The story behind how this car came about is fascinating. The original intention of FIA was to run a F4 World Final, bringing together the best drivers and teams from the US, European and Asian Formula 4 series in a single shootout at the Macau Grand Prix in November. If this sounds familiar it should, the circuit has hosted just such an event for Formula 3 since 1983.

However, as Formula 3 regulations separated around the world and reduced the impact of the World Cup at Macau, so did Formula 4 regulations, with each region using different chassis and there is a huge weight difference between them all. To bring them together under one grid was not going to be possible, so another solution was sought.

World Cup

The concept of an F4 World Cup then reared its head. This was the FIA-backed Olympics of motorsport, called the FIA Motorsport Games. Organised by FIA and Stéphane Ratel's SRO,

YCOM managing director, Nicola Scimeca

'The design work done in Italy, the composite manufacturing in Taiwan'

The car was a clean sheet of paper design, with the first two moonocoques built by YCOM in Italy and then everything, including the tooling, transferred to KCMG in Taiwan where the other 28 cars were built

TECH SPEC: F4 KC-MG01

Engine
1.4-litre turbocharged Abarth internal combustion hybrid engine; Magneti Marelli ERS system that can store 53W.

Power
176bhp, 12kW from the ERS.

Suspension
Front and rear double wishbones with pushrods, adjustable anti-roll bars and twin non-adjustable Sachs dampers.

Monocoque and bodywork
Carbon fibre.

Aerodynamics
Front wing with non-adjustable mainplane, rear wing with two aero profiles and adjustable mainplane.

Brakes
AP Racing two-piston, radial-mount calipers and brake pads. Brembo cast iron, ventilated discs.

Transmission
Sequential Sadev six-speed gearbox with Magneti Marelli EGA and paddle shift.

Fuel system
Premier FIA FT3, 41-litre volume tank.

Wheels
OZ Racing; front 8 x 13in, rear 10 x 13in.

Dimensions
Length: 4,510mm; height: 980mm; wheelbase: 2,753mm.

Weight
635kg.

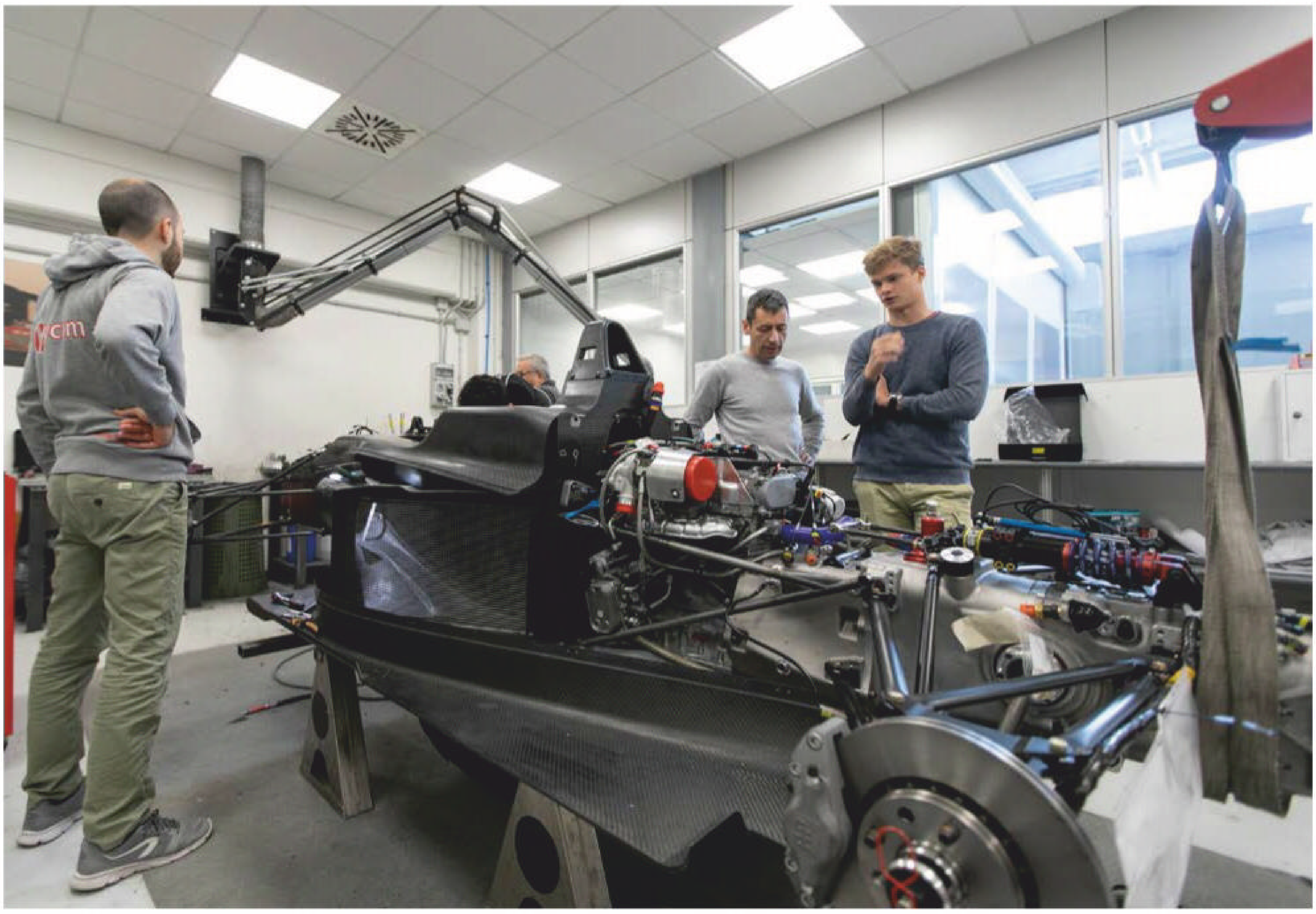
Safety features
FIA F4 homologated carbon fibre composite front and rear crash boxes; FIA homologated Halo system; anti-intrusion front and side panels; FIA homologated rear central and rear wing end plate lights; OMP six-point safety harness; electrically-activated OMP ultralight extinguishing system with control box; FIA homologated ADR system; FIA F4 homologated steering column; FIA F3 homologated roll hoop; FIA homologated Cortex wheel tethers; removable head protection; removable seat according to FIA standards.

The first Formula 4 in history with the Halo and a hybrid powertrain

it was held for the first time in Rome, Italy at the end of October 2019. There, national teams were pitted against each other in various forms of motorsport, with the idea of trying to recreate the multi-discipline nature of the original Olympics. This was a perfect opportunity to create an F4 shootout, but there was still a need for a common car.

The story of the F4 KC-MG01 started in Macau in 2018. After the Formula 3 race during the Macau Grand Prix, KCMG's CEO, Paul Ip, met YCOM's managing director, Nicola Scimeca, and the two agreed that the combination of know-how and experience in their companies was sufficient to manufacture a completely new car for the Games.

'From the beginning of the project, it was clear it was a big global challenge,' says Scimeca. 'The process involved the realisation from a blank sheet of paper to 30 completely new cars, with the design work done in Italy, the composite manufacturing in Taiwan,

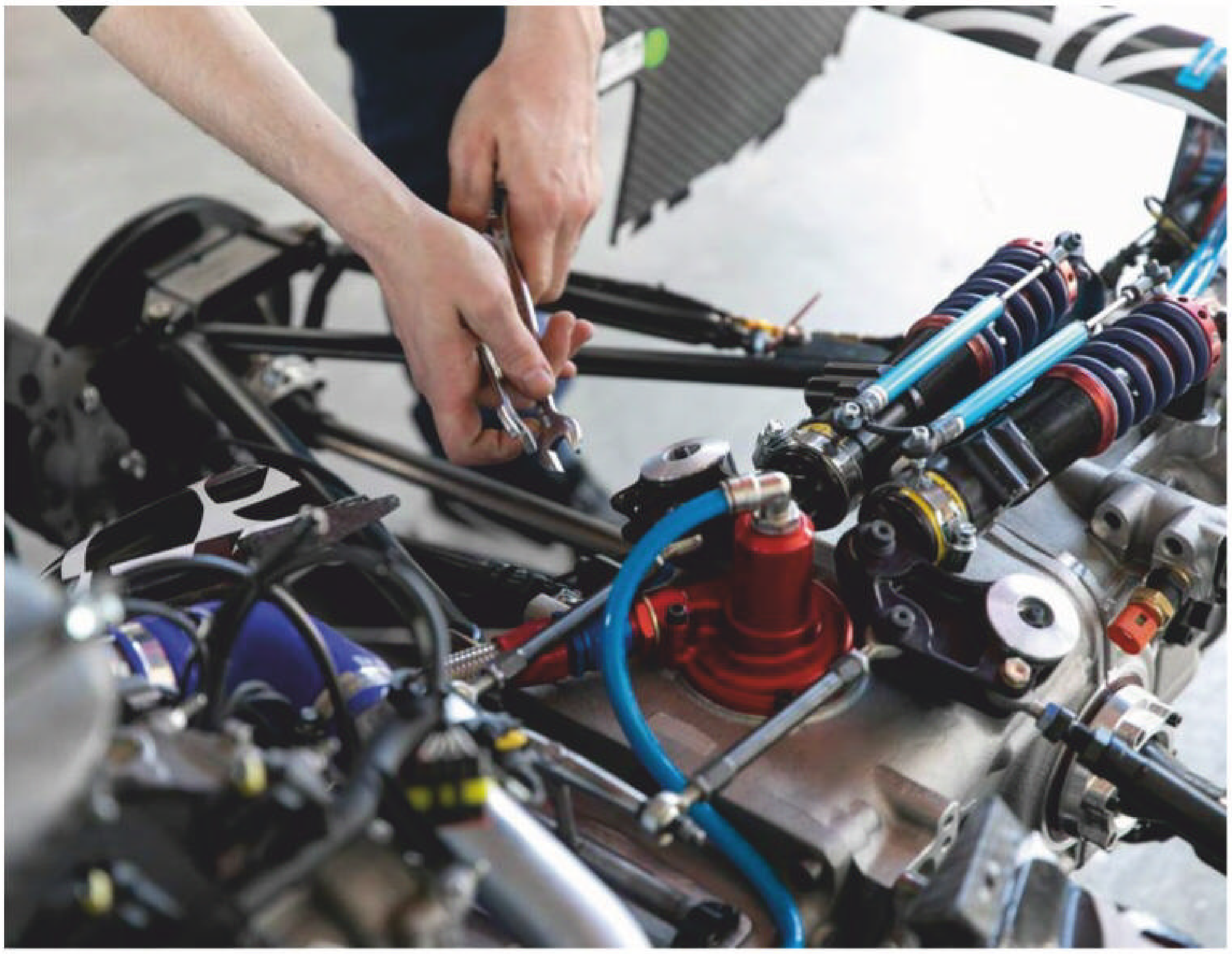


AP Racing and Brembo supplied brake components, the six-speed sequential transmission came from Sadev complying with FIA rules, and interacting with suppliers all over the world within 11 months.'

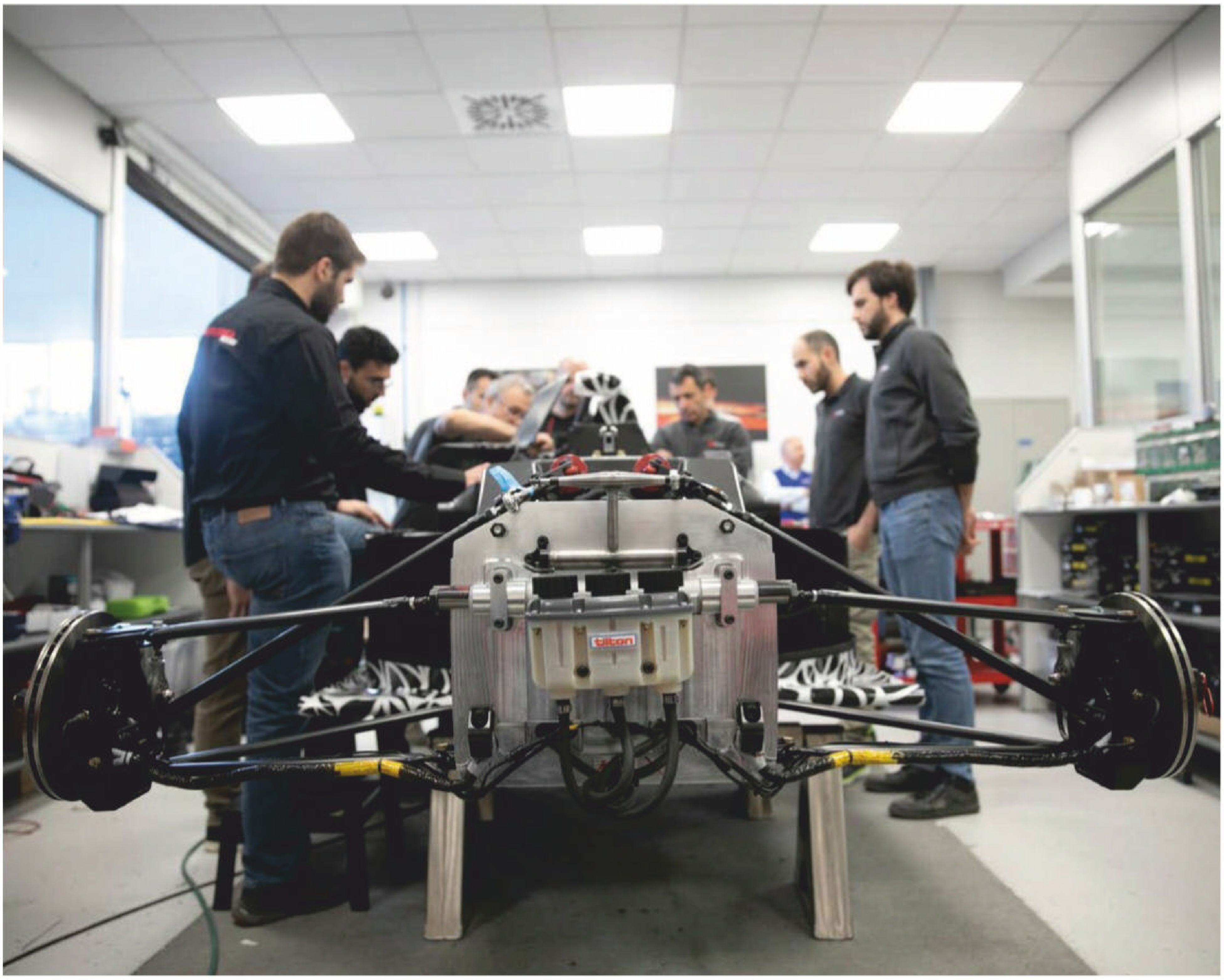
To add to the burden, the car was also supposed to encompass the very latest in current motorsport technology. In fact, KC-MG01 is the first Formula 4 in history with the Halo and a hybrid powertrain, the first single seater with these features outside F1. There is an MGU able to generate 12kW and a super capacitor, which accumulates energy under braking and releases it under acceleration.

Previous experience

At first KCMG, with YCOM support, studied the current Formula 4 cars on the market, but not in order to base its design on that of other chassis makers; the aim was to have a leg-up on the competition. At the end of the design process, the result was a completely new car. YCOM already had some previous experience of designing and building a modern single-seater racecar as it had developed the Formula 3 car for Russian team Artline. 'That car basically had a Formula 1 monocoque in terms of safety, but was developed to Formula 3 regulations,' explains Scimeca.



Suspension uses double wishbones with pushrods, adjustable anti-roll bars and twin, non-adjustable Sachs dampers



The chassis made in Taiwan were tested at YCOM and passed all the required static and torsional tests. It later transpired the bodywork was a perfect fit to the chassis, too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The design of the F4 car started in December 2018 and the first test of car no.001, homologated to 2019 Formula 4 regulations, was held in Italy at the beginning of May. In May and June, the car tested for more that 3,000kms, before production of the cars started in earnest. Final shakedown testing of all the cars was done between August and September of 2019, before the start of its racing career at the end of October that year.

Made in Taiwan

The first two monocoques were built at YCOM, and then the tooling, along with the bodywork, was sent to the KCMG factory in Taiwan where the rest of the cars were manufactured, initially under close supervision by YCOM staff. This unusual move required a degree of understanding from the FIA.

'Changing suppliers is normally not allowed,' notes Scimeca, 'but we had the same tools, same people, just a different location.

'We had the same tools, same people, just a different location'

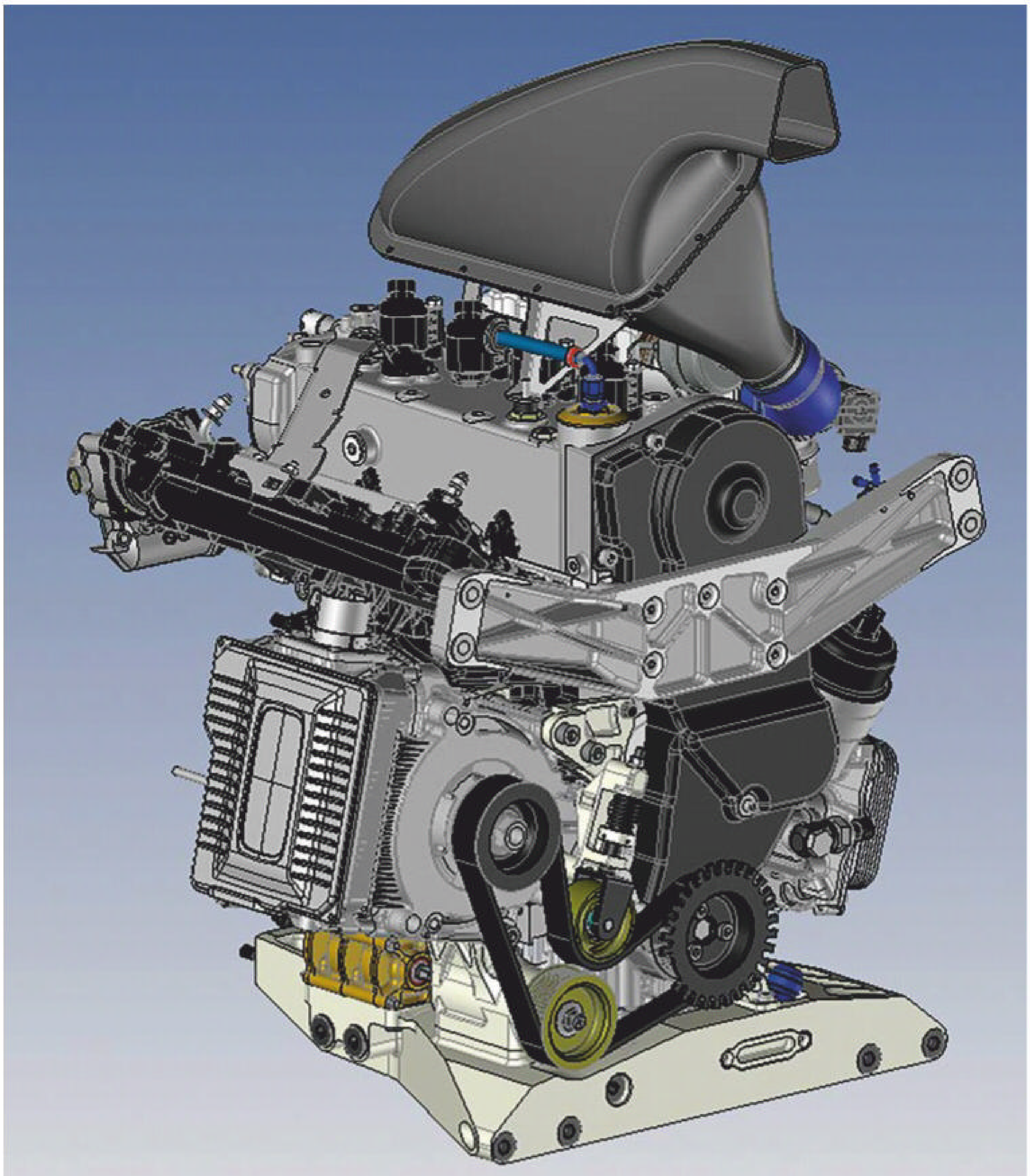
'The materials came from Taiwan, even for the monocoques that we did here [in Italy]. There was complete synergy between the engineers from YCOM and KCMG. They came here for the first two monocoques and we went there for their first one and, in the end, we were impressed. The quality of the monocoque was perfect and the weight spread was correct.'

The chassis from Taiwan were each tested at YCOM and passed the required static and torsional tests, an impressive achievement for a new chassis building company that also had to integrate the high safety standards required with the introduction of a Halo.

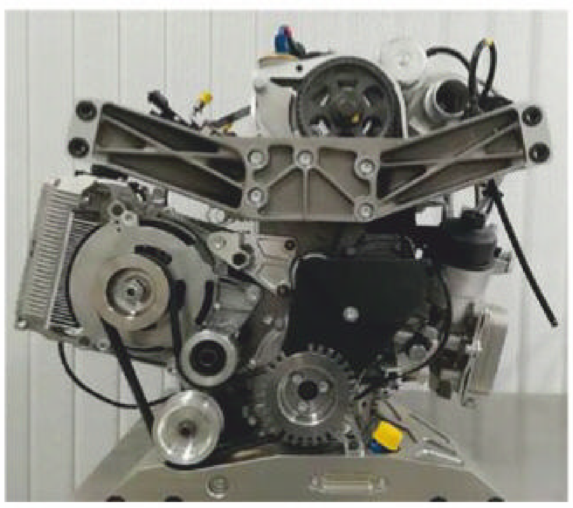
Hybrid thinking

So far, so good. YCOM had a project it could bury its teeth into and demonstrate its knowledge of modern single seaters, while KCMG Composites had an opportunity to provide the cars and show off its advanced composite manufacturing capability in Taiwan. A market would be created for this one-off race, but where did the idea come from to make this car a hybrid?

'Autotecnica Motori presented an idea with Marelli Motorsport to make a hybrid installation, although not much development had been done at that stage,' says Scimeca. 'The presentation was a great success, and the FIA decided to introduce this concept in the car.'



The power unit is a 1.4-litre turbocharged Abarth engine producing 176bhp, combined with a 12kW ERS



The hybrid unit is a production based MGU from Fiat Chrysler Group, developed for the car by Magneti Marelli and Autotecnica Motori

The low voltage of the ERS makes it relatively safe for the mechanics working on it and could have far reaching applications across a number of different motorsport series

So, the hybrid powertrain for KC-MG01 was developed for this car by both companies, but the basic principles of the system could quite easily be used for future generations of Formula, GT or Touring Cars.

The powertrain solution the team settled upon was the Fiat Abarth F4 engine and a production-based MGU from the FCA [Fiat Chrysler] Group that had been used in one of its mild hybrid cars. It was the best solution to an otherwise expensive hybrid system, and produces about the right amount of power.

Race series around the world are looking for this golden ticket of hybridisation for a cost to encourage manufacturer participation and to keep racing relevant to production car technology, and appear to be settling on between 10-20 per cent of the ICE power as a target power output for the hybrid system.

Energy solution

The Abarth engine produces around 176bhp, including 12kW coming from the 48V energy recovery system. Regeneration occurs during every braking event and energy is released every acceleration, but the difference between a hybrid and non-hybrid version of the same car on lap time is minimal, due in part to the 40kg weight of the hybrid system.

Energy from the MGU system is held in a supercapacitor, which is known to be quick to charge and discharge, a perfect solution for this type of application. The capacitor is housed under the fuel tank.

'It was not easy to develop the software itself, the calibration and the strategy,' says Scimeca. 'Although it's an entry level category, the complexity is still high.'

The low voltage means it is relatively safe to work on for the mechanics, but managing the system, and particularly the electronics, was something of a challenge due to the pioneer phase of the technology.

The cars were each run by Hitech GP, which took its race teams from the W-Series, which also features 20 cars, and turned up at Vallelunga to take part first in a lottery-style draw to ascertain who ran which chassis.

Perfect fit

The bonus at Vallelunga for KCMG and YCOM was that, while the bodywork had already been liveried for each individual country, no one knew which chassis or engine they would receive. That meant that each set of bodywork had to fit to each chassis perfectly, a fit that is pretty hard to achieve in motor racing. YCOM had a room set up at the workshop to help teams with bodywork fitting, but in the end it was not needed as the components coming from Taiwan were a perfect fit first time.

'Even in high-end racing series it's difficult to swap bodywork between cars of the same team because they are adjusted for each monocoque,' notes Scimeca. 'This means the quality of the bodywork is paired with the quality of the design with a perfect execution. Normally you can adapt holes a bit, or trim lines and edges to help with fitting. Some regulations are even written so you can re-drill holes to make the body fit.

'We normally work on high-end projects for OEM, but we didn't change our design method for this Formula 4 project, and this was the perfect way of working between two companies on opposite sides of the globe.'

Young drivers from Australia to Russia, Finland to Hong Kong took part in the race, which was mechanically problem free all weekend, again an impressive achievement for a new car. Cooling is always critical on hybrid installation, but in this case the MGU only required air cooling. 'If you go up with the power on these systems you need to have liquid cooling,' says Scimeca. 'The complexity of the installation comes from having the turbo on one side of the engine, the MGU the other.'

The way for this competition to develop might be for the FIA to start offering Super Licence points for the race, but at present, the target was just to get the idea off the ground and run the cars over three years before introducing the next stage in the technology.

Which leads on to the question, what about low-cost electrification in motorsport?

Next generation

'There are around 500 latest generation F4 cars in the world,' says Scimeca. '[It could be done] by replacing the ICE engine with a battery and a motor, but keeping the bellhousing and gearbox case. A conversion kit to electric would need to be aligned with the price of an entry-level car and, right now, there is nothing available to do this, but soon there will be!'

Lastly, other than supporting KCMG on this exciting challenge, what was in it for YCOM? YCOM is working on several different projects from endurance to single seater, but most are confidential. Whatever the future of the individual companies, it appears Formula 4 has achieved the hybridisation concept that is being spread around the various series and, in the process, a close bond has been established between the companies involved that could have far reaching implications throughout the sport.

F4 has achieved the hybridisation concept that is being spread around the various series

The pioneering nature of the project led to some interesting challenges. Now the car is finished, development can continue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The first of the gang

It has been 20 years since Audi first won the Le Mans 24 Hours with its now iconic R8, but the development phase of the car was anything but easy

By ANDREW COTTON

The R8 firmly established Audi in endurance racing

Audi's R8 Le Mans Prototype set a new standard in endurance racing. The car won for the first time at Sebring in 2000, and that year went on to record the first of five wins at Le Mans. The legend grew with every race. Tom Kristensen, Emanuele Pirro and Frank Biela won Le Mans three times together between 2000 and 2002, Audi drivers won the American Le Mans Series every year from 2000 to 2005 for Audi Sport North America, Team Joest and Champion Racing, and the European Le Mans Series for Apex Motorsport. The car looked unbeatable.

The R8 firmly established Audi in endurance racing at a time when the sport needed the stability. From 1999, when six manufacturers competed, just three continued in 2000 including Cadillac, Chrysler through its Mopar brand and Audi. BMW continued in private hands, but it was a shock to the system after the drama and excitement of 1999.

Audi had contested the 1999 race and was relieved to come out of it with a podium on its first visit to Le Mans. The brand had arrived in endurance racing to great fanfare in December 1998 with a presentation of a prototype in Berlin that bore more resemblance to its future production cars than the cars that actually raced.

The R8 was Audi's first ever attempt at a fully fledged prototype, having previously only ever developed racecars from production 'shells and the 3.6-litre V8 was the manufacturer's first dedicated race engine since the 1930s.

As it was all new, there was a steep learning curve for the Ingolstadt team of designers and engineers before the start of one of the most successful Sportscar racing programmes ever.

Audi had flirted with the idea of running a GT1 car at the height of the FIA GT Championship when Porsche, Mercedes and BMW (through McLaren) were contesting this new global series in 1997. However, despite a presentation from Richard Lloyd with a complete car design, the decision was taken by Audi management to instead go to prototype racing at Le Mans with an all-new, carbon fibre tub car designed in-house at Audi Sport.

Short cut

Audi knew that it needed to take short cuts to the top and buy in experience. The appointment of Team Joest was logical. The team had won Le Mans in 1984 and 1985 with the privateer Porsche 956, and again in 1996 and 1997 with the Porsche WSC. The team was available to take on the project to win Le Mans with Audi and had the expertise the manufacturer needed.

However, the first prototype was due to be delivered in 1998, and Audi management had reservations that this deadline would be achieved. Audi bought a factory in Norfolk, England that had the facilities required to build a prototype, and the decision was taken to spread the bet and build two versions of the R8.

The 3.6-litre V8 was the manufacturer's first dedicated race engine since the 1930s

Racing Technology Norfolk (rtn) was an early version of Toyota's TMG facility in Cologne and Toyota Team TOM's had run out of this factory for years before Audi acquired it. However, the R8R programme was nine months into a difficult development programme when Audi bought the facility so there was no option to switch the programme to the UK factory. Instead, when Dr Franz-Josef Paefgen, chairman of the Board of Management of Audi AG, aired concerns about the German team delivering on time, rtn was commissioned to develop a closed car, the R8C, alongside the German open-top prototype.

'It was the first time this group of people [in Audi Sport] made a prototype from zero,' admits Wolfgang Ullrich, then head of Audi Motorsport, of the R8R programme.' [Chief designer] Wolfgang Appel had done a lot of different things before, but nothing like this.

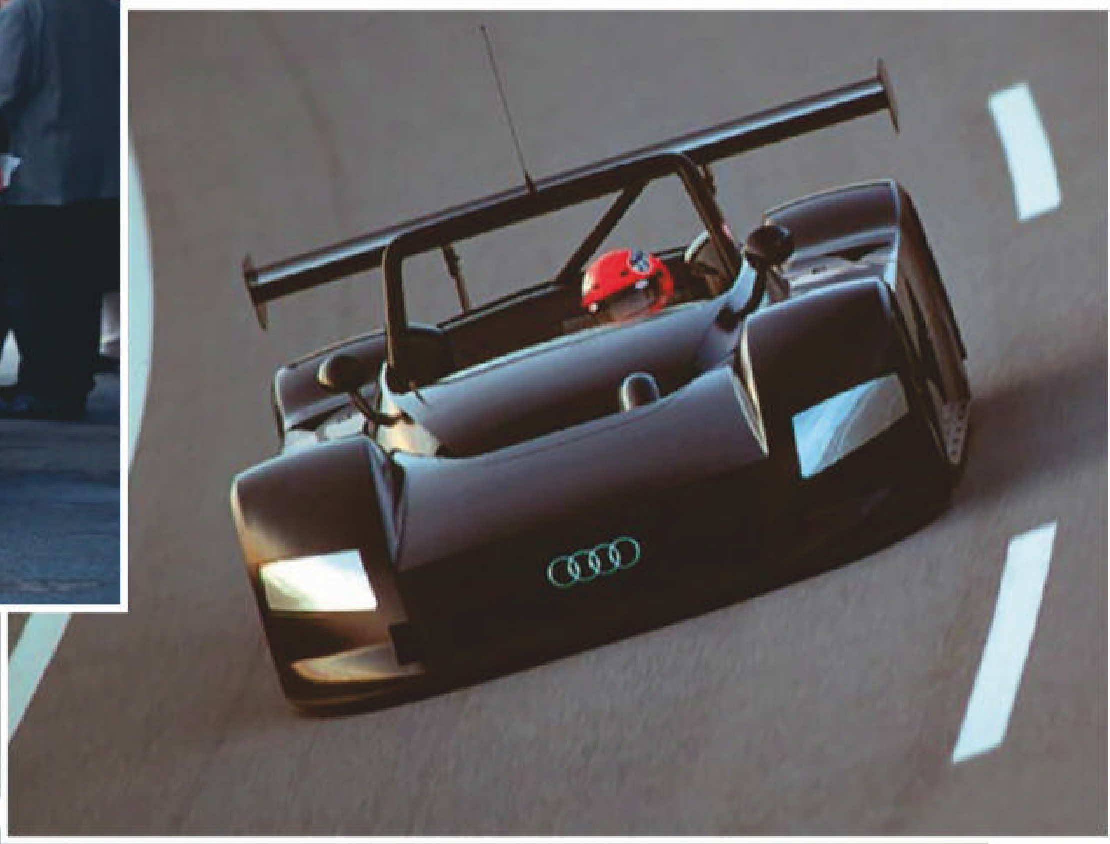
'There was competition, and at the end we made both concepts. The R8R was a concept we started first, and then we said okay, by the rule book maybe you are better with a closed car.

'When the game started with Le Mans, I had a group of people that, up until then, had always been taking a raw bodywork from the production line to make a racecar out of it. They had never before done a white sheet of paper, or monocoque design.

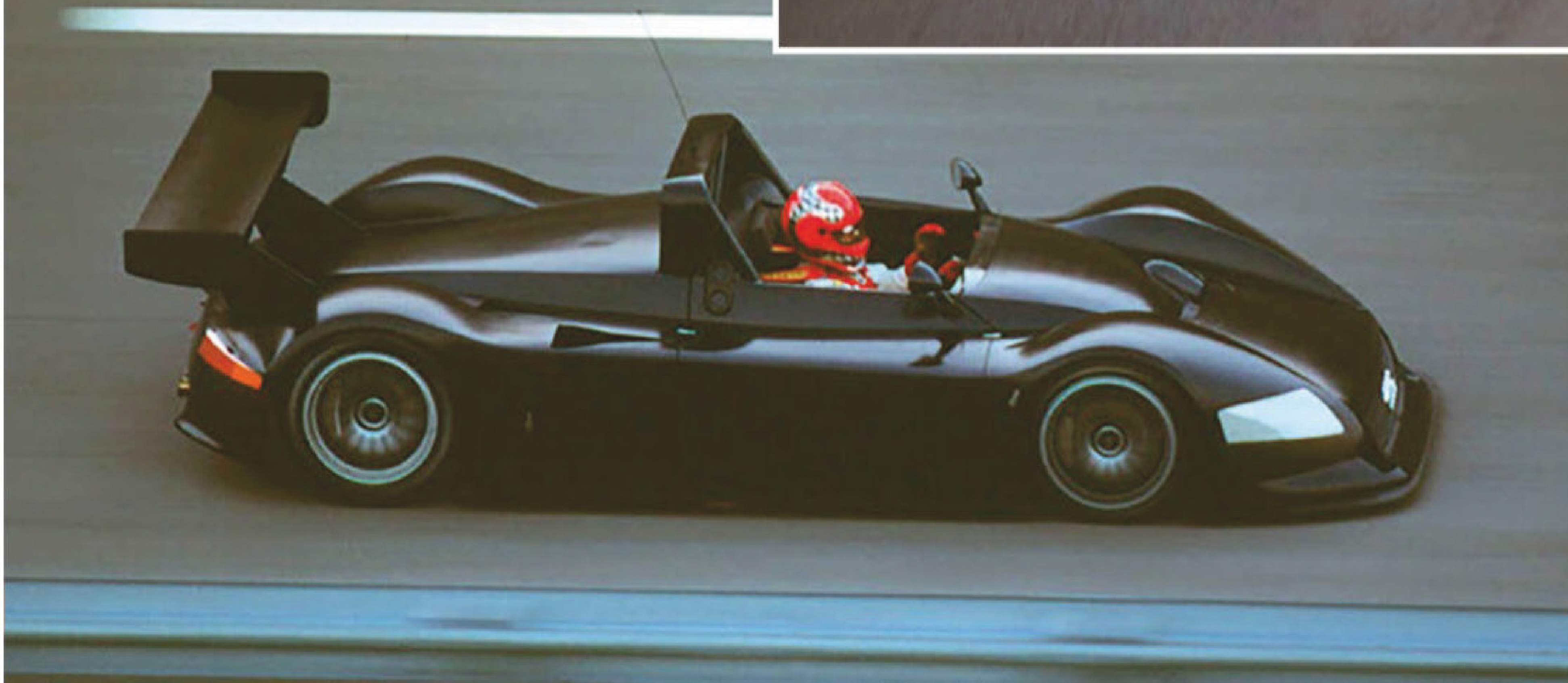
'Dr Paefgen thought maybe [we wouldn't be able to] make it, and I announced very loudly in Berlin that we were there to win it in the first year! To which he said, "We should take experienced people from England."'

Double top

Even more memorably, this was the first time one manufacturer had entered two prototype concepts to contest the top class, LMP for open cockpit cars and LM GTP for closed cars. At Le Mans in 1999, Audi, Panoz, Courage, Pescarolo, BMW and Nissan all competed in the LM P900 class, while Toyota, Mercedes and Audi's R8C were built to LM GTP regulations.



The Audi R8R was designed and developed in Germany, but the layout borrowed heavily from the Ferrari 333SP. It was even referred to as the Ingolstadt Ferrari for a while



Never before had one manufacturer debuted Prototypes in both LMP and LM GTP classes at the same event. It was a formidable display of technology

Both Audis featured an all-new, 3.6-litre V8 engine produced by Ulrich Baretzky, Audi Sport's head of engine technology, but there was a crucial difference in the drivetrains of the two concepts. The R8R ran with a Ricardo gearbox, the R8C with Xtrac.

While Audi Sport UK pressed ahead with its car in isolation, the Audi R8R that was being developed in Germany bore a striking resemblance to the Ferrari 333SP, having based its design on the already successful model. It was similar enough to the Ferrari that the team called it the Ingolstadt Ferrari.

The basic packaging of the car saw the positioning of the radiators and the double roll hoop a carry-over from the Ferrari, although the finer details, such as the front suspension pick-up points, were different.

The radiator at the front was clearly an issue in the first test at Sebring. 'Emmanuele Pirro drove the car and complained at the heat coming into the cockpit,' remembers Ullrich. 'I told him that the Ferrari had run like that for years and no driver had been grilled, but he was not amused. He came into the pit lane in Sebring and made a sign for me to come over to the car and said I should drive it down the pit lane and back to the tent. I did it and for sure it was warm, but in Spa I think they would have asked for this heating. Not at Sebring, though.'

Teething problems

The R8R was pronounced ready to run at Sebring in March 1999 but, with such a new programme, there were teething problems in testing. The strength of some of the carbon fibre parts commissioned from various companies in Germany were found to be inadequate.

'The R8R was flexing on the front so much, we were testing in Daytona at the end of 1998 and there was a Riley and Scott private team that were pit in, and we were pit out,' remembers Team Joest's technical director, Ralf Juttner. 'Michele [Alboreto] always pitted complaining that the car was vibrating like hell. We tried using wires to hold the splitter lip, but over 250km/h everything was flexing. Once, on the radio he said he was coming past the pits and for us to watch. The thing was flexing.

'Watching the car going down to the first corner, we had a team of 30 or 40 engineers, all in Audi red, and the privateer team were just four. They watched the car as well and, as it went into turn one, they turned to us and applauded. It was so embarrassing.'

Joest had already worked with David Price at Surrey, UK-based DPS Composites on its 962 and WSC car and knew the company was capable of producing the quality of parts needed to make the R8R work properly. As this version of the R8R was left clearly wanting, a secret design was commissioned. It involved a whole new front end that fitted within the original bodywork but improved airflow and strength.

'A designer we knew very well made a new design of the front end, including the splitter, the nose and the radiator, ducting, radiator mounts and fixation, but with the same aero,' recalls Juttner. 'Dr Ullrich knew about it, but the


In early testing the R8R was found wanting. Carbon fibre parts proved too weak and flexed, while drivers suffered excessive heat in the cockpit due to the front-mounted radiator

design department didn't. The underfloor was all the same, but the mounting was different, and this time it was designed for stiffness, built by [David Price at] DPS.

'At one stage in the programme we mounted the new parts to the car and had to raise the ride height five times. We showed them what a difference it made, even though the shape was the same, just much stiffer, and that changed their approach, but I remember it led to a little bit of friction at the time.'

Race debut

The endurance racing programme was a steep learning curve for Audi's motorsport department, but with the challenges faced in preparing the car now either in progress or solved, it was time to go racing.

Sebring in March 1999 saw the debut of the new car, but the bumpy Florida circuit is unforgiving and ambient temperatures, even at that time of year, are usually high.

'It was jumping and was a pig, it was ridiculous,' remembers Juttner. 'We really felt for the drivers, but the biggest issue that year was the reliability of the gearbox. The car that finished third at Sebring, with Michele Alboreto, Dindo Capello and Stefan Johansson, ran the last few hours with only two or three gears.

'When we opened the gearbox after the race, it was like a blown-up pinball table. We were lucky to finish at all, but we did complete the race and that was good.'

Understandably, the team went to Le Mans in June that year with trepidation. Throughout testing, the gearboxes had problems, and the team knew it was unlikely to get through the whole 24 hours without issue.

'When we approached Sebring in 1999, we had experienced massive problems with gearboxes in testing, and it was always dog-ring failures, nothing to do with the drivers or the electronics,' says Juttner. 'We had a guy in Bavaria who had made a pneumatic system for bikes and he knew [Audi designer] Wolfgang Appel. He came up with a system for the R8R. We had it at a test and it was a disaster. We had new parts from Germany flown in and were ready to go early afternoon, but had to stop again in the early evening because of gearboxes. Within a few laps we had dog-ring problems again, so we threw it out thinking it was the problem and didn't work.

'In hindsight, that decision was premature. Later, we found that just a few parameters were wrong between the engine and gearbox but we were already nervous so went back to the original gearshift mechanism. We went to Le Mans with both cars fitted with a standard manual gear lever, and Audi came with two systems of the Megaline. The idea was to give one to Audi Sport UK and we would run the other. Audi UK didn't want it; they thought it was too late to put it in but we put it on both our cars, and it worked.

'We were pretty sure we wouldn't make [the finish] with the system we had, so there was a question of what to do. We had to try something and, looking at it now, it was the right decision.'

R8 interim

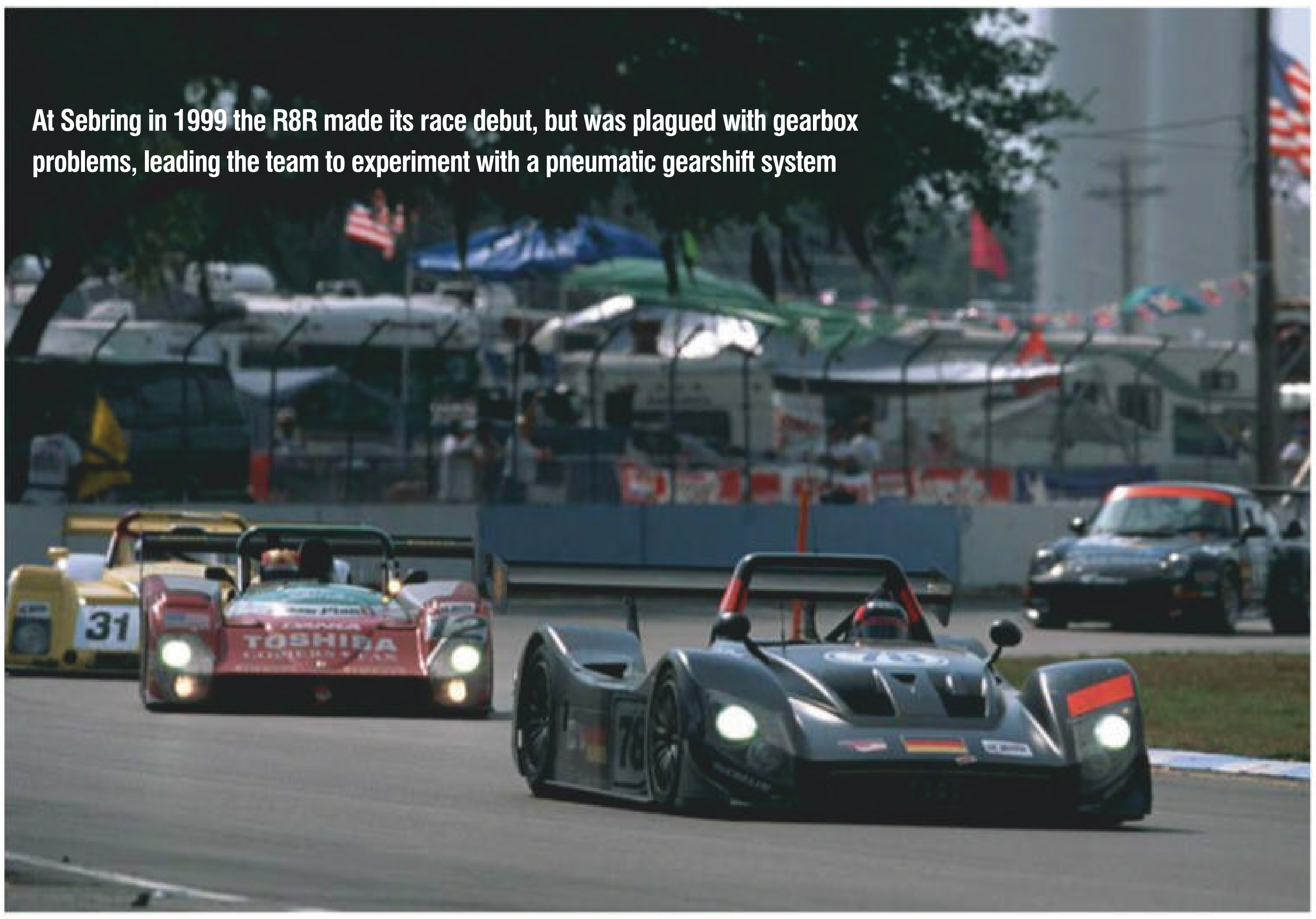
The cars ran at Le Mans in 1999 and finished third and fourth, but the design of the next car, an all-new R8, was already well underway and by the end of the year it was ready to start testing. A new quick-change rear end had been designed but Joest had to make use of the R8R once again to put miles on this new back end.

'When we went to the R8, we went to test at Sebring and here at Joest we had built a mule, an interim car, which was the chassis of the R8R but with the rear end of the new Audi R8,' explains Juttner. 'That was not that easy, though, because in the R8 the engine was fully stressed, whereas the R8R had a subframe. We had to modify the R8R chassis to take engine mounts that in this situation had never been designed to take the loads. In the fuel cell we had tubes and all sorts, but it all worked as it should although it didn't conform to regulations.

'The R8 interim car was already so much better than the R8R. [Team Joest chief engineer] Jo Hausner said we should put the same springs and dampers in the car that we had in the race in 1999 [for back-to-back testing] and Tom [Kristensen] did his first test with us with Audi at that time. He was selected by Mr Hausner to sit in the car and jump around the Sebring circuit. We had decided to give the car to the new guy to lose his teeth, but to our surprise the handling wasn't that bad.'

The second R8 became available for the race, and the team was then complete. Kristensen, who had won Le Mans in 1999 for BMW, was placed alongside the established Touring Car stars Biela and Pirro while Allan McNish, winner for Porsche in 1998, lined up alongside Alboreto and Capello. The two Audis started on the front row of the grid and finished the race in first and second position after completing more than 1,300 miles and setting a fastest race lap 1.5s quicker than the previous record.

Despite the convincing one-two position, the two R8s did not have a perfect race. Biela lost time when he accidentally turned off the electronics switch, while Alboreto suffered a puncture that damaged the front bodywork. However, the main issue was the brakes. Biela stopped after eight hours for a three-minute bleed of the brakes, handing the lead to McNish. The Scot continued without bleeding the brakes and, with Capello, led in the last hour.


At Sebring in 1999 the R8R made its race debut, but was plagued with gearbox problems, leading the team to experiment with a pneumatic gearshift system

'It was jumping and was a pig, it was ridiculous'

Team Joest technical director, Ralf Juttner

Brake dancing

Light rain and fading brake pressure caused the Italian to do a half spin, which was enough to bring the sister car within striking distance. 'The car's brakes were worsening, and Emanuele [Pirro] was going very well in the other Audi. With just 20 minutes remaining, he went ahead of us,' said McNish at the time.

There was much work to do on the cars post-Sebring. The brake issue was partly to do with the bumps around the track, but the team also strengthened the uprights and hubs ready for Le Mans and changed the brake seals and fluid to prevent the same thing happening again.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The new R8 arrived in 2000 and scored a convincing one-two victory on its debut at Sebring, though this time suffered brake problems

Le Mans demands less of the brakes than Sebring, but Audi was taking no chances, having committed three of its new cars to Le Mans to try to win the trophy for the first time.

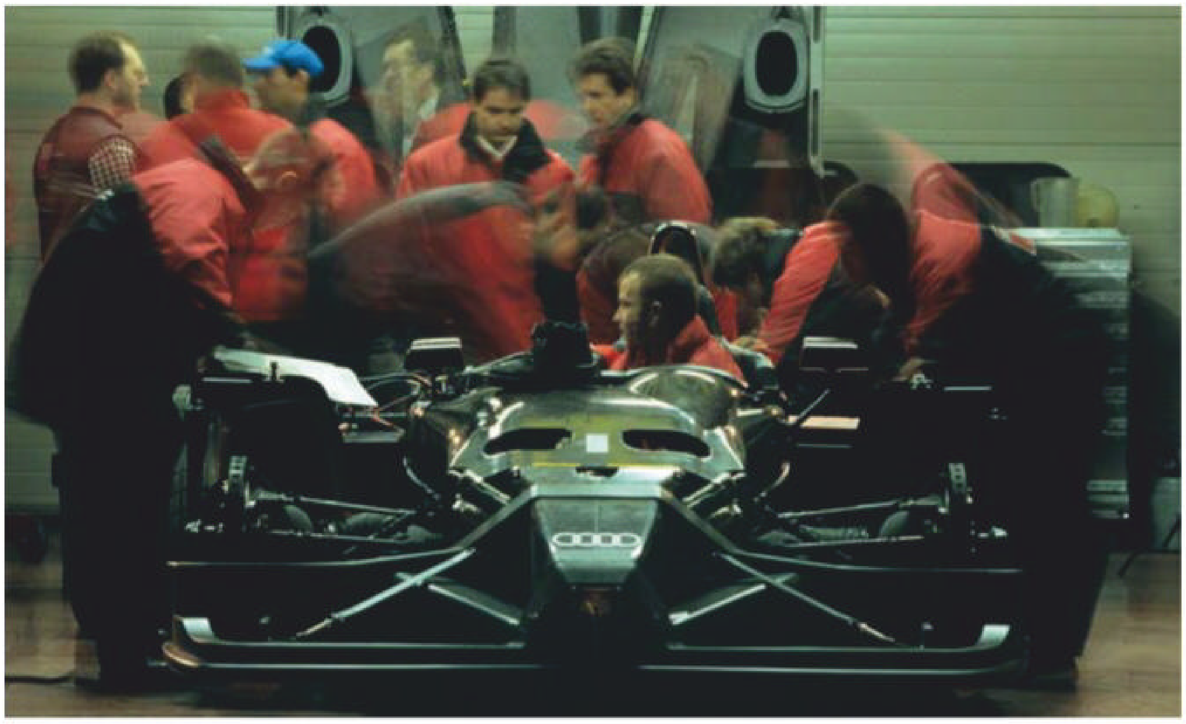
The new R8 had been on the design board since before Easter in 1998 and was a step change in design concept, with new tub, layout, weight distribution and aero. This was a totally new car, taking all the learning from the early experience of the R8R and improving upon it.

Different future

As a post-script to Audi's triumphant debut of the R8 at Sebring, there were two further races of the American Le Mans Series, one at Charlotte in North Carolina, the other Silverstone. With the R8s being prepared for Le Mans and unavailable to race, the R8R was put back into service.

'The drivers that knew the interim car from the test wanted to have that car for the races, but we only had one car, so who should have it?' recalls Juttner. 'It was not legal anyway because of all the changes inside the fuel cell and so on, but they really wanted to race it!'

While the open prototype had found some kind of favour with the team, the R8C had a different future ahead of it. The Volkswagen Audi Group had by then developed its W12 engine and wanted to race it, and the rtn team in the UK had a car that the Group thought could be adapted to take the engine. Ultimately, the changes required to accommodate the cooling, already marginal with a 3.6-litre turbo V8 but impossible to achieve with a 6.0-litre W12, meant it was cheaper and quicker to design a new car to accommodate the engine. The R8C was therefore parked while a new car was designed and built, though ultimately it never ran with the W12 engine. Although the engine bay was large enough to take it, the engine was shelved after a test in the back of a Lola.



With a new tub, layout, weight distribution and aero, the 2000-era R8 was a brand new racecar

The new car then sat with no engine and no future until it was fitted with the same 3.6-litre V8 twin turbo that had been used in the R8C in 1999, was painted green, and went on to compete at Le Mans in 2001 as a Bentley.

The R8 meanwhile, took its first win at Le Mans in 2000, the three cars taking the first three positions overall and the car went on to a glittering career on both sides of the Atlantic defining an era of Sportscar racing and changing Audi's sporting profile forever.

The new R8… was a step change in design concept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Suspension stiffness

Knowing your suspension goals is one thing, determining what stiffness values are required is another thing altogether

By CLAUDE ROUELLE

As we have discussed in previous issues of *Racecar Engineering*, your suspension goals on a racecar will differ depending on application, so setting your goals early on in the design process is one of the key steps in ensuring a good design philosophy. Another important step to define is the desired amount of movement you want your suspension to have.

It is useful to describe the different ways a suspension can move. A conventional suspension has four degrees of freedom so we need four independent coordinates to uniquely describe the position of all four wheels with respect to the vehicle body. One common set of coordinates used to describe the various types of suspension movement are shown in **Figure 1**.

Heave motion describes all four wheels moving, an equal amount, vertically. Roll motion describes each pair of side wheels moving an equal but opposite amount. Pitch motion describes each pair of end wheels moving an equal but opposite amount. Warp motion describes each pair of diagonal wheels moving an equal but opposite amount.

These four coordinates are referred to as suspension modes. Typically, a vehicle does not move purely in any of these modes. For example, when the vehicle rolls in a corner it is usually accompanied with some amount of heave, and even some pitch, due to the difference in jacking effects at the front and rear of the vehicle. When a single wheel moves up, it can be thought of as a combination of heave, roll, pitch and warp movement in each of the different modes.

This concept is useful as we often want different amounts of movement in all four modes, and / or stiffness, due to each of the modes being caused by a different physical scenario. Heave is primarily due to vertical loading, including crests, troughs and downforce. Roll is primarily due to cornering. Pitch is primarily due to braking and accelerating. Warp is primarily due to road unevenness.

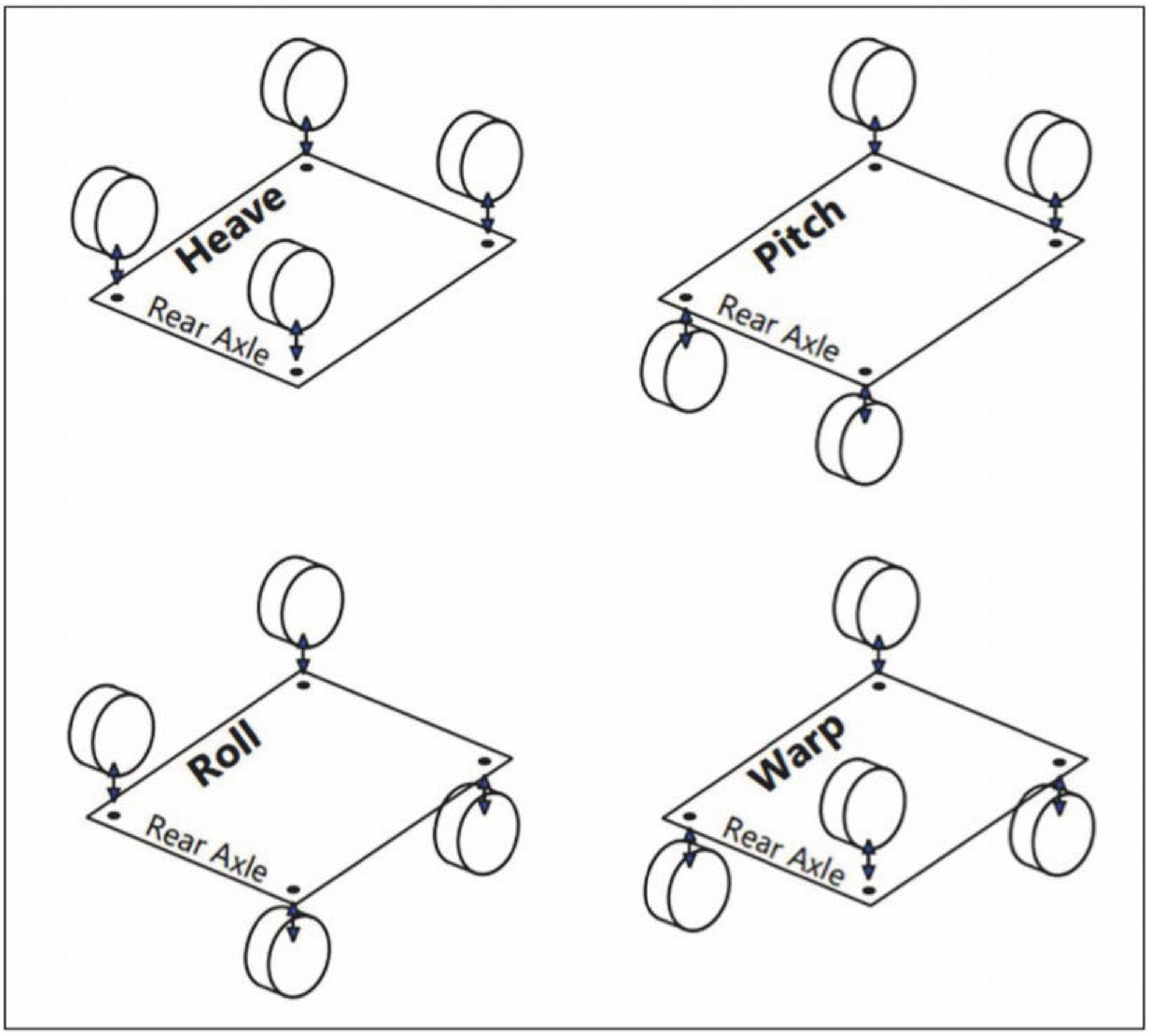

Figure 1: The four different modes of suspension motion

Table 1: Methodology to select spring stiffness

Method	Description
First method	Copy or approximate a similar vehicle suspension that run on similar tracks. Use the suspension and springing layout as an initial baseline and adjust through testing
Second method	Select a suspension type and the required spring stiffness to prevent unwanted movement under worst case loads
Third method	Select the desired suspension stiffness (eg heave, pitch, roll and warp) and choose the springing layout that best meets these requirements

Determining stiffness

When a suspension moves, there is some resistance to the movement. This is due to the various combinations of springs, anti-roll bars, dampers and compliance in the system. Determining what stiffness values are desired is not a simple task. **Table 1** summarises a few different ways this can be achieved.

The first and second methods described in **Table 1** are most useful when a vehicle already exists, or a particular layout is required. The third method is useful when the vehicle is still a concept, or we can freely change the suspension layout. It is a useful, high-level method as

A conventional suspension has four degrees of freedom

Many of these factors are difficult to evaluate quantitatively, hence many are determined from experience instead

we do not have to say exactly what springs are required, only to specify what the overall effect of the various spring combinations is going to be. You can decide on the specific implementation once you know what it is you want.

In general, there are many conflicting requirements that contribute to determining the desired suspension stiffness. Some factors that need to be considered are described in **Table 2**. It is important to note that many of these factors are difficult to evaluate quantitatively, hence many are determined from experience instead.

Table 2: Design stage

	Factors	Description	General trend
Design stage	Bumps and undulations	The amplitude and frequency of any bumps or undulations on the racing circuit	Large bumps require softer suspension
	Rules limitations	If the rules dictate a minimum or maximum suspension travel or stiffness, this will impact on suspension choices	This is a limit or boundary on the suspension design that must be adhered to
	Tyre	The tyre vertical stiffness can impact on spring selection. To have the same equivalent ride rate or suspension travel, different suspension stiffness is required	Softer tyre leads to a stiffer suspension
	Centre of mass (CM)	The height of the vehicle centre of mass is influenced by the amount of suspension travel. More travel requires a higher ride height and a higher CM	More travel = higher static CM
	Aerodynamic control	If the aerodynamics are attached to the vehicle body, then suspension movement can have a large impact on performance. Suspension travel can influence the position and orientation of aerodynamic devices	More travel = more spring mass movement
	Vehicle response	A stiffer vehicle tends to respond to inputs quicker	Quicker response = stiffer suspension
	Vehicle performance	A vehicle that can produce greater accelerations will produce more suspension movement given the same spring rate	Greater performance leads to a stiffer suspension

Key points

It is difficult to give generic advice for selecting stiffness values as the goals for different vehicles can vary drastically. The best thing to do is to decide what goals are most important for your particular case and how to meet them.

Once you know the requirements, then you can decide what combination of spring elements (corner springs, anti-roll bars, heave springs, four-wheel interconnection etc.) best meets the set requirements.

For example, if you decide that one of your goals is to have very little roll movement then you will need a very high stiffness in roll. You may set another goal that you want some pitch movement for driver comfort, but limit the movement to 5mm of travel at either wheel. Based on the load case that causes the most pitching, you can determine what your required pitch stiffness would need to be. Another goal may be to limit the heave movement to 100mm for aerodynamic concerns.

Finally, let's say you want the reaction loads on the tyres to vary as little as possible, so you decide to minimise the warp stiffness.

With these four requirements you have determined the required stiffness values in heave, pitch, roll and warp movement. The next step would be to pick a suspension layout that achieves this.

Choosing your suspension goals depends entirely on application, and to an extent how much comfort you want to afford your driver

Slip Angle is a summary of Claude Rouelle's OptimumG seminars.

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Balancing act

We round off our project on the Mk1 Escort RSR by looking at some alternative routes to that all-important downforce balance

By SIMON MCBEATH

Tim Foxlow's Escort RSR runs with 2.5-litre Duratec power in a Saloon and Sportscar championship in northern England and Wales. Originally manufactured by SHP Preparations, this example is beautifully prepared by Chris Mellors and team at MEM Motorsport (a company renowned for top-flight rally builds, including the Proton IRIZ R5 WRCar).

Our initial wind tunnel run revealed that not only did the car have a rear-biased downforce balance, as driver feedback and visual impressions suggested, but it also had significant positive lift at the front. We saw in our last two issues that we were able to obtain a good downforce balance primarily with lots of attention to this front end. The starting numbers and the balanced set-up numbers obtained by this process are shown in **Table 1**.

As delivered to the wind tunnel, the Escort RSR exhibited significant front lift and rear-biased downforce

Illustrations: Simon McBeath

Winging the changes

We came to this session equipped with two alternative, less potent rear wings, both of the writer's design. One was much smaller, both less cambered but of the same span and at the same notional location on the car, because the expectation was the car was 'over-winged' with its well-cambered, 310mm chord device.

Reductions in the original wing's angle didn't make as much difference as they should have, leading to suspicion that the wing was probably stalling across its centre section at all angles tested, as explained in our April issue. As it happened, after seeing the baseline run results, we changed our approach to focussing initially on reducing the front lift to obtain a reasonable balance. This inevitably created a stronger front end for our two less potent wings to try to balance, but nevertheless the data gathered enabled some other, better balanced set-ups to be worked out.

The first alternative wing, designated SM172, is a 225mm chord, medium-camber device that quite clearly would not balance the car with the same front-end package that balanced the original wing. But, by testing the wing at three angles we obtained information on the response to angle changes and were able to compare effectiveness with the other wings (**Table 2**). Note that all lift coefficients are negative apart from rear downforce at the lowest wing angle tested, which produced a tiny amount of rear lift.

The second alternative wing, designated SM183, is a 300mm chord, medium-camber device that, prior to our session was considered by your writer to be the most likely candidate for a more efficient overall set-up for the Escort. This wing was tested at four different angles and the results are shown in **Table 3**.

With both of these wings, it was apparent that rear downforce gains tailed off around the seven to eight degrees region, and the smoke plume on the SM183 at the steepest angle showed flow separation under the centre of the wing. Furthermore, the wing height was barely above a region of recirculating airflow behind the steeply angled rear windscreen, the flow

Table 1: Initial and balanced coefficients

	CD	CL	CLfront	CLrear	%front	-L/D
Initial	0.474	-0.202	+0.163	-0.365	-80.4%	0.427
Balanced	0.495	-0.447	-0.200	-0.246	44.8%	0.902

Table 2: Coefficients with the SM172 wing

Angle, deg	CD	-CL	-CLfront	-CLrear	%front	-L/D
-1.8	0.448	0.242	0.278	+0.037	115.1%	0.539
5.5	0.461	0.307	0.257	0.051	83.6%	0.666
7.8	0.466	0.320	0.251	0.069	78.4%	0.686

Table 3: Coefficients with the SM183 wing

Angle, deg	CD	-CL	-CLfront	-CLrear	%front	-L/D
0	0.457	0.306	0.255	0.051	83.3%	0.669
3.8	0.467	0.350	0.241	0.110	68.9%	0.749
7.3	0.480	0.388	0.228	0.161	58.6%	0.809
10.3	0.492	0.405	0.219	0.186	54.1%	0.822

The 300mm chord SM183 wing set at zero degrees separating at the top of the rear windscreen, so higher wing locations would undoubtedly have been more effective.

So, although the car fell just short of the target of around 50 per cent front with the SM183 wing and the front end as configured, it would quite probably have achieved a balanced set-up had it been at, say, roof height and in more energetic flow.

Takeaway counts

Having added as much front downforce as we could with available parts to try to obtain a balanced 'high downforce' set-up, the alternative approach to achieve a balance is to remove front end parts and run less rear wing. As mentioned earlier, the rear downforce gains of the alternative wings were tailing off at steeper wing angles, so a lower drag balance would be achieved at somewhat lower angle. For example, the SM83 wing at the 7.3-degree angle. Looking at line three in the data for the SM183 wing in **Table 3**, we can consider what front end modification(s) would be required to achieve the balance we were looking for.

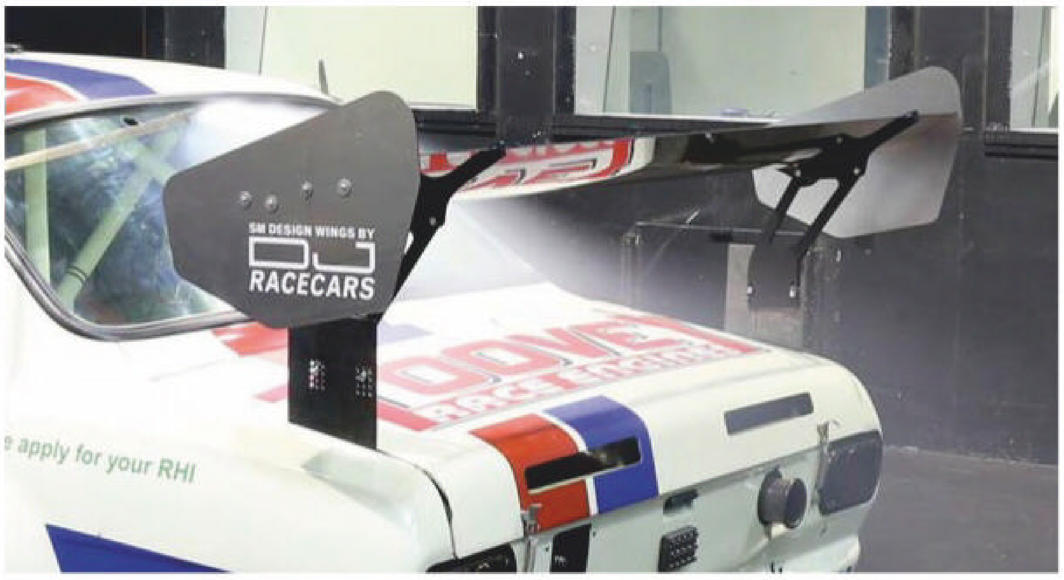
As highlighted in our previous issue, the last front end items that were added to try to balance the original wing were the dive planes (DPs). If we subtract the changes, or 'delta (Δ) values' that the dive planes made to the drag and lift coefficients with the SM183 wing at 7.3 degrees, this will give a theoretical set-up in that configuration. This approach is not without risk, but it will give a fair indication. **Table 4** shows the outcome – a set-up with very similar drag to the initial baseline, but with an aerodynamic balance close to ideal.

Applying this approach further (with the risk of additional inherent error at each step!), let's apply the theoretical removal of the dive planes, splitter end fences, wheelarch Gurneys (WAGs) and 25mm of splitter extension that were highlighted in the last issue to the data in the top row of **Table 3**, with the SM183 wing at zero degrees, to see what the numbers might look like in a 'low-drag' configuration.

The final adjustment was to add 0.5 degree of wing angle to refine the theoretical balance. The delta values of this wing angle adjustment were calculated from the changes made by the first 3.8 degree wing angle increase shown in **Table 3**. **Table 5** reveals all, showing a balanced downforce set-up with a drag coefficient 11.6 per cent lower than the initial baseline value, and 15.4 per cent lower than the almost balanced set-up with the original wing.

More usefully, two alternative set-ups with very similar balance were now available with the same wing, one with 12.9 per cent less drag, the other with more than double the downforce. Dependent on which set-up best suits the car at any given circuit, these options provide a useful range from which to choose.

Racecar's *thanks to Tim Foxlow, MEM Motorsport and DJ Engineering.*



Flow separation and steeply angled flow from the top of the rear windscreen

At its steepest angle, and at this low mounting height, stall was apparent under the centre of the wing

Table 4: Theoretical adjustments to the car's set-up (delta values give as counts, where one count = coefficient change of 0.001)

	CD	-CL	-CLfront	-CLrear	%front	-L/D
SM183, 7.3deg	0.480	0.388	0.228	0.161	58.6%	0.809
Subtract DP deltas	+1	-31	-44	+13	-	-
Theoretical outcome	0.481	0.357	0.184	0.174	51.5%	0.742

Table 5: Theoretical adjustments to the car's set-up with the SM183 wing at zero degrees

	CD	-CL	-CLfront	-CLrear	%front	-L/D
SM183, 0.0deg	0.457	0.306	0.255	0.051	83.3%	0.669
-DP	+1	-31	-44	+13	-	-
-Splitter fences	-15	-40	-40	-1	-	-
-WAGs	-24	-61	-66	+4	-	-
-25mm splitter extn.	-1	-15	-20	+3	-	-
+0.5deg wing angle	+1	+6	-2	+8	-	-
Theoretical outcome	0.419	0.165	0.083	0.078	50.3%	0.394

Writer's footnote

This is my last Aerobytes column for Racecar Engineering *as I head into semi-retirement. So, I would like to offer my heartfelt gratitude to all the excellent people, past and present, at MIRA for the wind tunnel opportunities, and at what used to be Advantage CFD (now TotalSim) for providing CFD-based material for the first 27 of the 196 columns to date. Also to the kind folk who brought their cars along for our wind tunnel sessions, to the readers who shared enthusiasm and interest, to former editor, Charles Armstrong-Wilson, for creating the idea and to all his successors for their ongoing support. It's been a privilege and a fabulous experience. Thank you.*

Simon McBeath, SM Designs.

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

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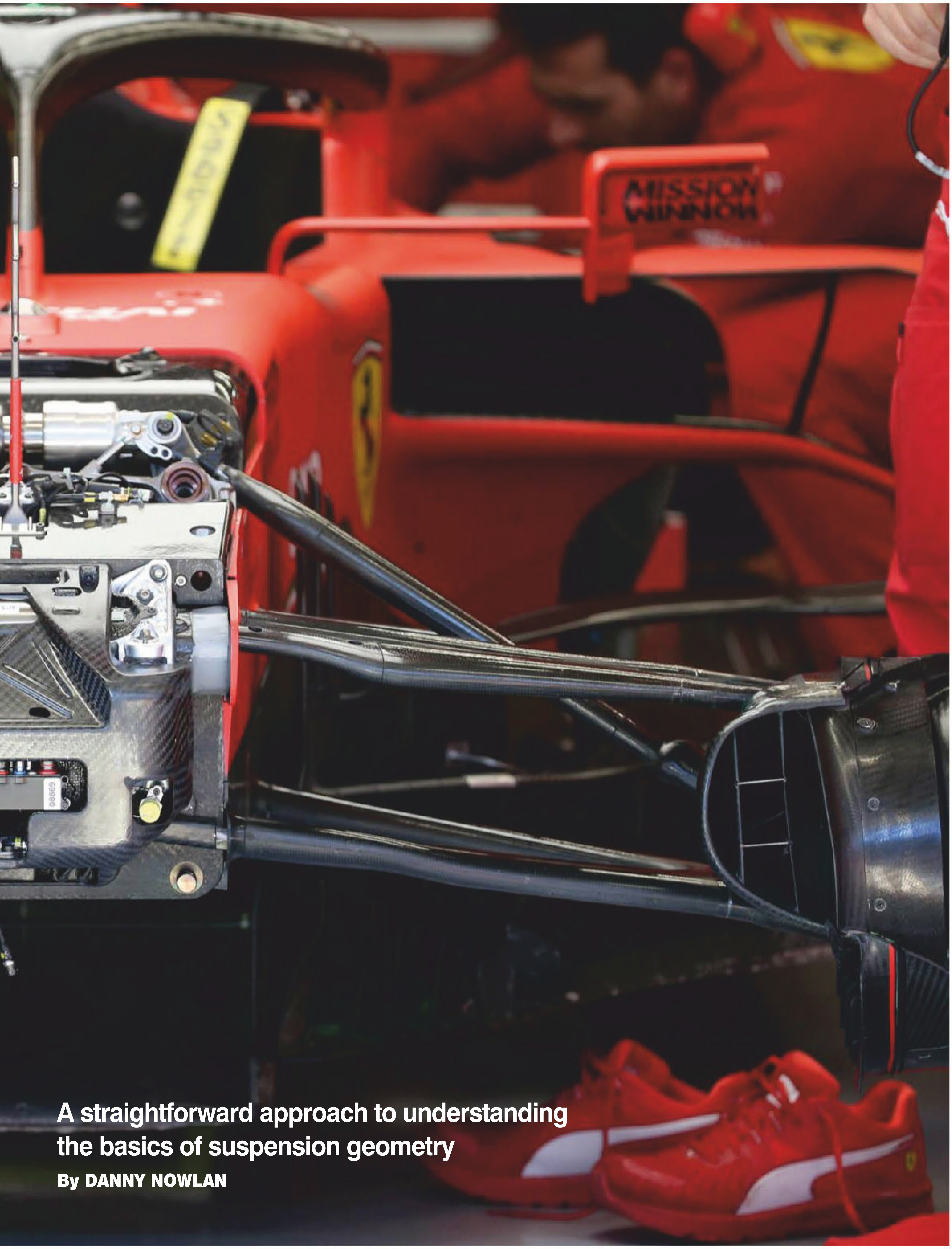
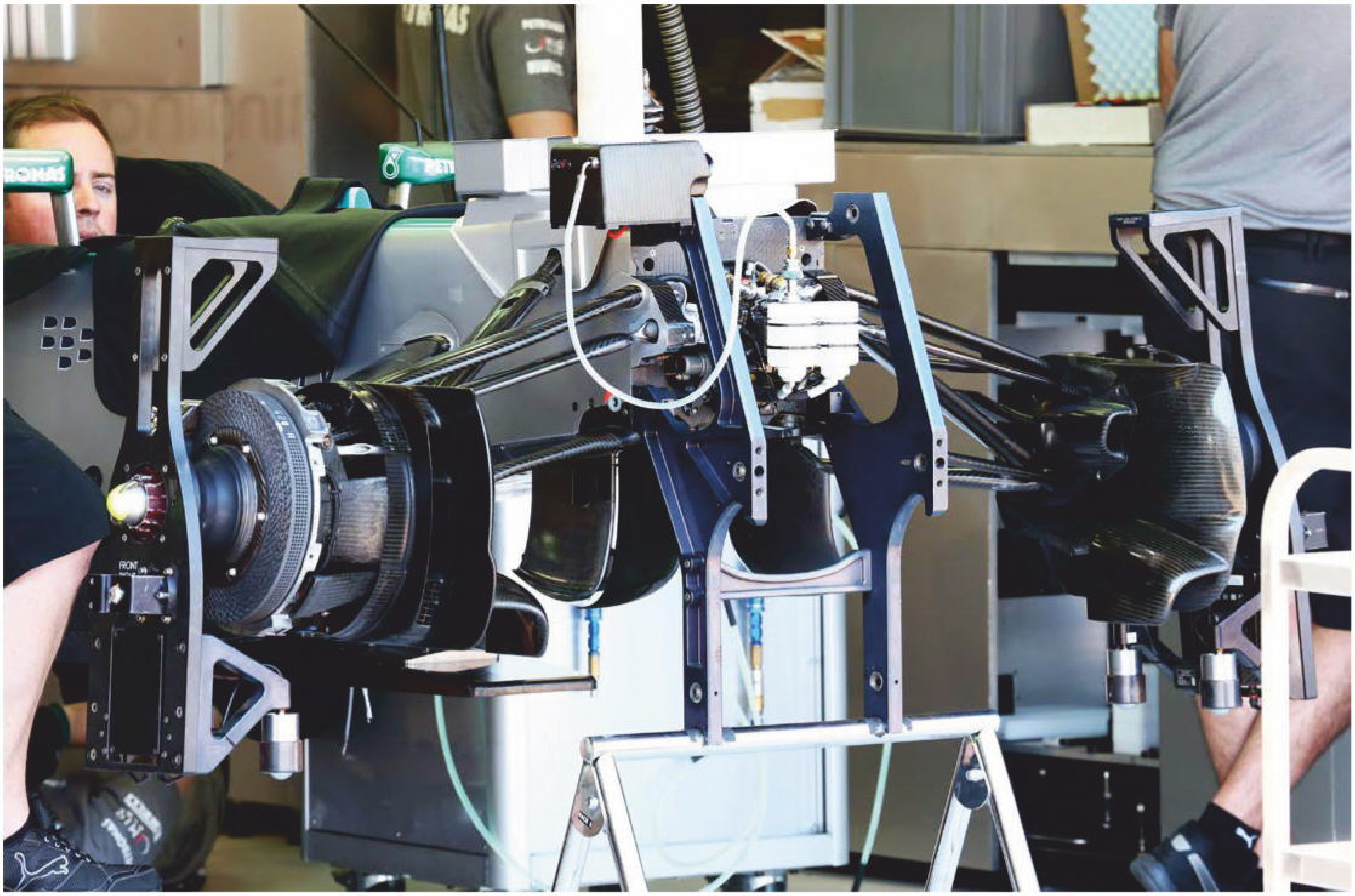
Kinematics 101



A straightforward approach to understanding the basics of suspension geometry

By DANNY NOWLAN



Suspension geometry does three things: controls the steer angle of the tyre, the camber of the tyre and the forces applied to the sprung and unsprung mass. That's it

One of the most hotly debated, yet most misunderstood, subjects in racecar engineering is kinematics. If you want to start a brawl in a bar full of motorsport engineers, just suggest a discussion on horizontal roll centre location and then sit back and watch the sparks fly.

Yet the crazy thing is, when you strip back suspension geometry to its basics, it is not only easy but remarkably straightforward to understand. The goal of this article is to lay this all out in black and smudge.

At its core, suspension geometry does three very simple things. These are:

- Control alignment (steer angle) of the tyre.
- Control the camber of the tyre.
- Regulate and control the forces applied vertically and laterally to the sprung mass and unsprung mass.

That's it. The first two are controlled by 3D Cartesian geometry. The last element pops out in a Free body diagram analysis. However, the problem we face is because suspension geometry linkages with the automobile just happened, as opposed to being designed from the ground up, this is where the misconceptions crept in. Combine this with motorsport's resident technical hysteria / outright hostility to any analysis more complicated then 2+2 = 4 and all hell breaks loose. But, as we are about to see, things really aren't that complicated.

Instant centre

The first concept to understand in suspension geometry is the instant centre. A really simple way to think about this is the point the wheel effectively pivots around. To find this is simply connecting the dots, as illustrated in **Figure 1**.

It is no accident that I have shown the longitudinal case with the lateral case. One of the biggest misconceptions in suspension geometry is that the lateral and longitudinal cases are firewalled. As we will soon see, this is absolutely not the case.

The significance of the instant centre is it controls how the wheel pivots about the chassis. The ramifications of this laterally are illustrated in **Table 1**.

In suspension geometry design, there will always be a dance between the two competing requirements shown in **Table 1**. For example, in something like a Baja buggy application

The thing that drives suspension geometry behaviour is force application points

The most significant impact of suspension geometry is that it dictates how the tyre forces are transmitted into the sprung and unsprung mass

Figure 1: How to find the instant centre location

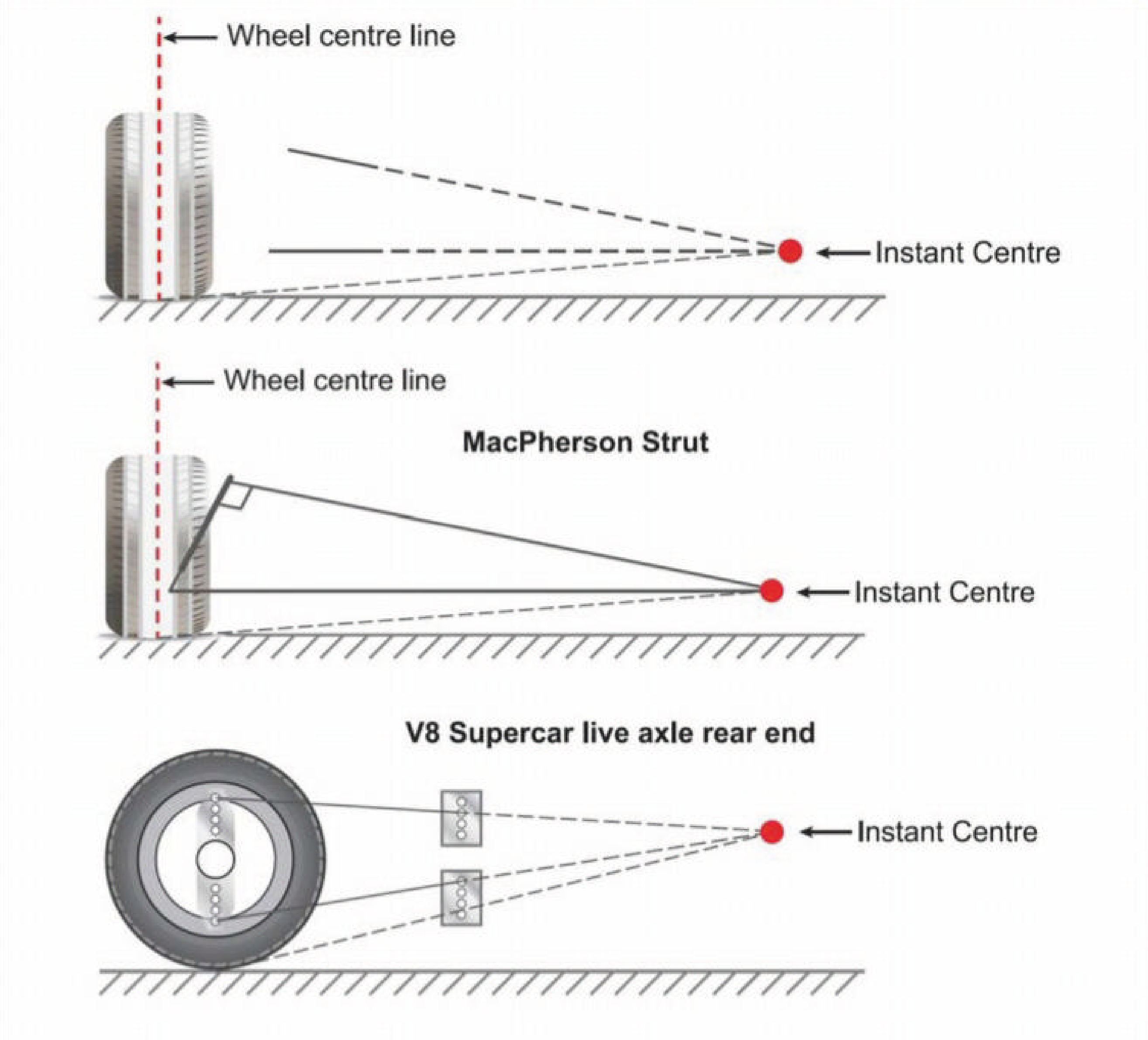


Table 1: Rough rules of thumb on camber gain

Instant centre length	Comment
Short	Very good for camber recovery in corners, not so good in pitch
Long	Great for minimising camber loss in pitch and heave, not so great during cornering

EQUATIONS

EQUATION 1

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} = l$$

EQUATION 2

$$\alpha_1 = \delta - \frac{a \cdot r + V_y}{V_x + tr \cdot r}$$

EQUATION 3

$$\alpha_2 = \delta - \frac{a \cdot r + V_y}{V_x - tr \cdot r}$$

Here we have:

α_1 = slip angle of the front left (rad)
α_2 = slip angle of the front right (rad)
a = distance of front axle to the centre of gravity (m)
r = yaw rate (rad/s)
V_x = forward speed (m/s)
V_y = lateral speed (m/s)
tr = front track (m)

running on dirt you have high power but low grip. In this situation you want long instant centre locations because the wheel movement is so large. In an application like a NASCAR on a super speedway where you have smaller wheel and body movements, a shorter instant centre might play to your advantage. As always, this will be dictated by what the tyre wants.

Toe and bump

The second thing to understand about suspension geometry is how it controls the tyre orientation, or what is often referred to as toe and bump steer. Of all the elements of suspension geometry, this pops out really easy in 3D Cartesian coordinates. Effectively, the driving requirement to figure this out is the lengths of the suspension must be constant. Then, for your xyz coordinates, you are solving that shown in **Equation 1**.

In maths speak this says the distance between two points in the suspension linkages needs to stay constant. The great thing about CAD packages like Autocad and SolidWorks, for examples, is you can solve this very easily. That being said, from time to time they can get a little funny in terms of solving for distance. This is the one area where kinematic programs such as SusProg and WinGeo are very reliable.

There are still a couple of rules of thumb to observe with how you arrange the toe links. Where practical, you want the steering link as close and as a parallel to either the top front wishbone link or, at the rear, the rear top wishbone link. Geometrically, this ensures you don't have any nasties to deal with.

From time to time you will want to exploit some bump steer parameters to fine tune your response. For example, you may want a bit of variation to help in tyre temperature generation (a rumour I heard was a Formula 1 team was crazy enough to use it for this very purpose) but treat this as advanced territory. To quote Mr Miyagi from *The Karate Kid*, "First learn stand, then learn fly."

Ackermann steering

One issue that should be addressed, however, is how to use Ackermann steering. The concept dates back to the infancy of the car, when the idea of a car doing even 20 km/h in a corner was unheard of! Ackermann steering emerged to ensure the inside tyre would track nicely since it had to follow a different line to the outside tyre.

As cars became faster, lighter, and tyres improved, the reasoning for this fell apart for most applications. The thing to understand about Ackermann steering is the bulk of it will be dictated by the front slip angle equations, shown in **Equation 2** and **Equation 3**.

Of course, **Equations 2** and **3** assume the c of g is in the middle of the car. For a right-hand turn, **Equations 2** and **3** show you want more turn angle on the outside tyre then the inside tyre. But if you look at the numbers even for an 80 km/h turn, what you actually need are very subtle differences. I invite the interested reader (uni engineering students, young engineers, that means you) to run the numbers.

So, when the car's turning is dictated by grip, you actually need anti-Ackermann.

By far the most significant impact of suspension geometry is that it dictates how tyre forces are transmitted into the sprung and unsprung mass. This is where all the drama comes from, and what generates the most controversy. In fact, probably the longest garden path automotive vehicle dynamics was ever led up was the concept of the lateral and vertical location of the roll centre being the point not only where the car rolls but where forces are applied. The symmetric case is shown in **Figure 2**.

I can tell you right now this is where some readers are about to hit the rev limiter because the only case where this holds true is the symmetric case. Indeed, I would contend the biggest misconception in all suspension geometry is the concept of the horizontal roll centre location. As we are about to see, this is not what drives roll centre.

The thing that drives suspension geometry behaviour is force application points. I am often credited with this, but the gentlemen who first coined the phrase was the late Bill Mitchell of WinGeo fame. Regrettably, Bill had to leave the party too early, but the paper Bill wrote on this topic I regard as a massive contribution to the science of vehicle dynamics.

Here is the thing about force application points – the proof is very simple, as I detail in my book, *The dynamics of the race car*.

When the car's turning is dictated by grip, you actually need anti-Ackermann

EQUATIONS

EQUATION 4

$$D = d_y + \frac{1}{2}\cdot\left(c_y - d_x \tan(\theta)\right)$$

For the oval guys reading this, I worked a full proof for the asymmetric case as well. For now, though, let me show you the highlights package, illustrated in **Figure 3**.

For convenience, I have labelled the positive axis y and the horizontal axis x. This is perfectly okay, provided you are consistent with your axis system. Besides, what we are really after is the lateral moment about the c of g. Sparing you the maths by taking free body diagrams about the unsprung mass and the c of g, the lateral moment arm of the lateral forces about the c of g is shown in **Equation 4**, above.

If we go through and look at the geometry, it can be shown that the distance between the roll centre and the c of g is exactly the same value as **Equation 4**. This is what drives load transfer and jacking forces into the c of g.

Figure 2: Kinematic roll centre definition

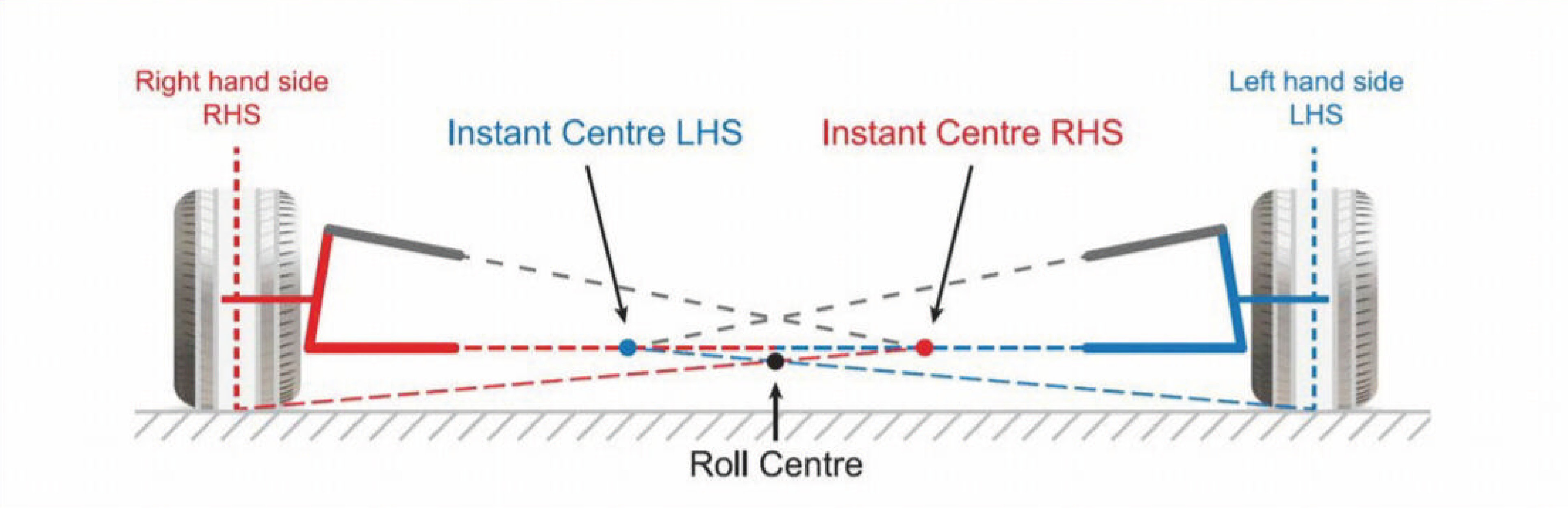
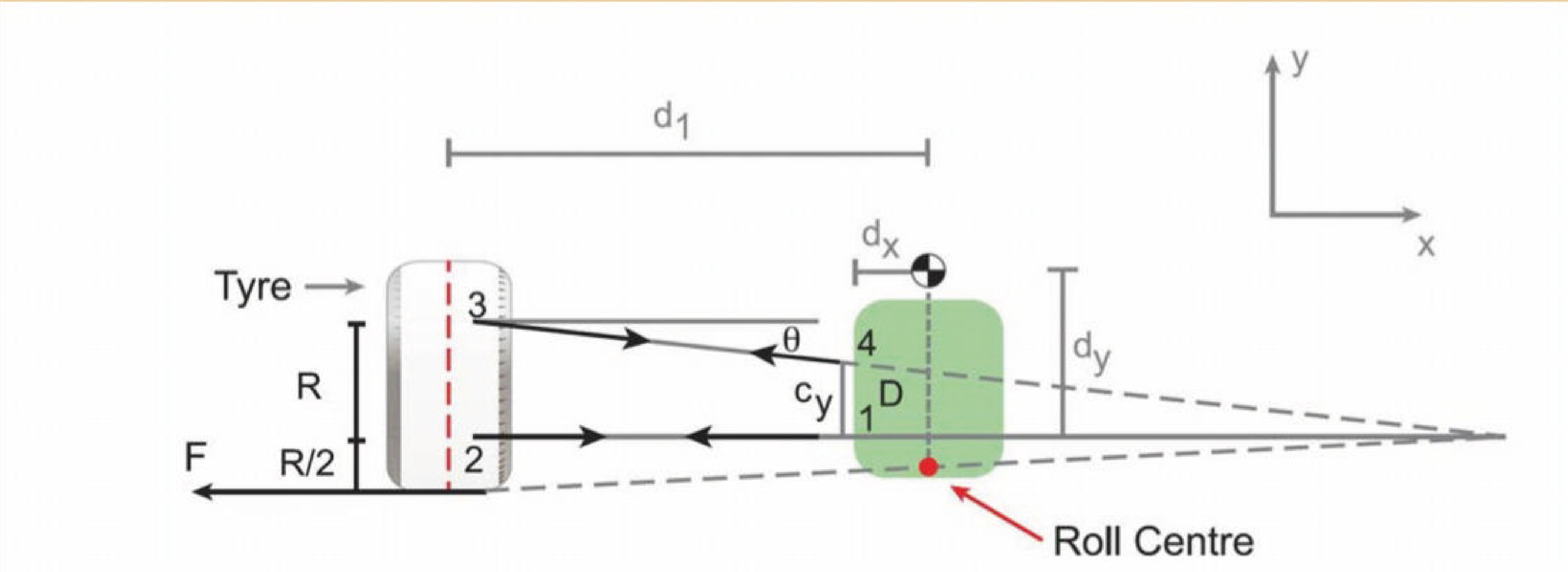


Figure 3: Symmetric suspension geometry arrangement



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The other big misconception of suspension geometry is that the longitudinal case (anti-dive / anti-squat) is divorced from the lateral case

The huge mistake I made 24 years ago when I did this proof is to assume this extrapolated to the lateral location of the roll centre of the car. I freely admit now I was wrong.

What the highlights package of this illustrates is the force application points are driven by moments and forces about the sprung mass and the c of g of the sprung mass.

The following is a brilliant summary of how you derive force application points in the general sense, as illustrated in **Figure 4**.

If you want the first order effect of what drives suspension geometry, **Figure 4** nails it in a nutshell. It not only dictates the moment of the sprung mass, but the jacking force as well. If there is only one thing you are going to take away from this article, this is it.

Some of you might now be thinking, this is all well and good for a 2D diagram, but how does it translate into the 3D case? The answer can be readily shown by a free body diagram, but the highlights package is shown in **Figure 5**.

This is simply the intersection of the wheel centreline and the xz plane of the car. To any university students and young engineers, I leave the proof of this in your hands.

The other big misconception of suspension geometry is that the longitudinal case (anti-dive / anti-squat) is divorced from the lateral case. Not only is this not the case, the longitudinal case is nearly identical to the lateral case. I should also add that anti-dive and anti-squat are the most poorly explained and

Figure 4: Force application points (FAP) definition

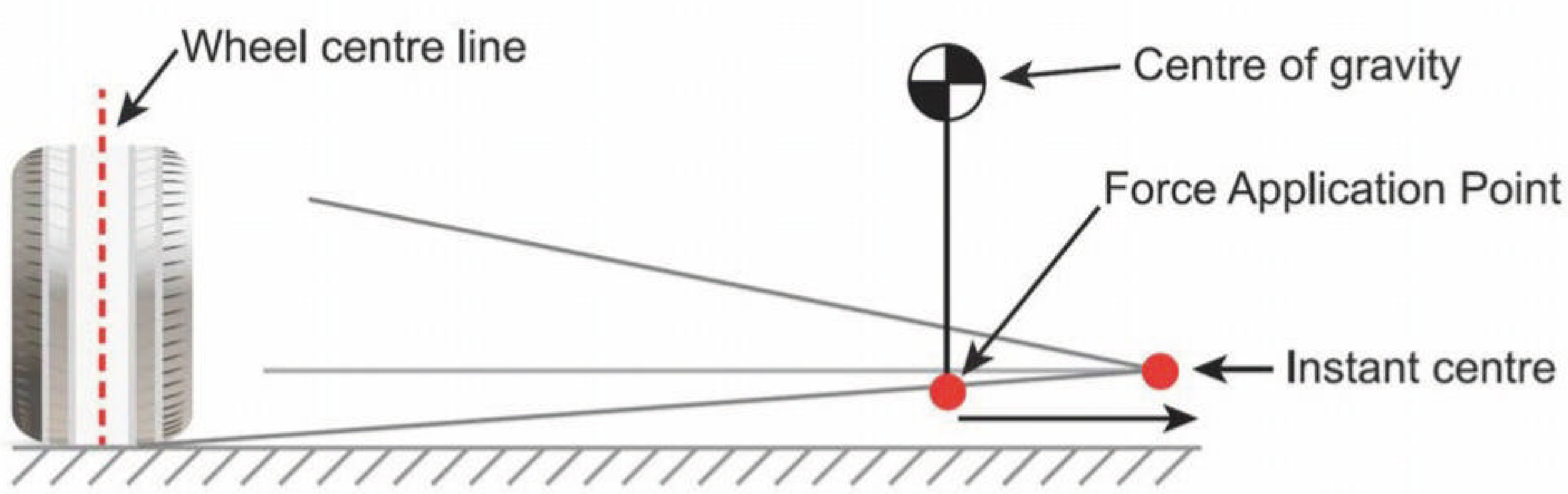


Figure 5: How to find the 2D points for 3D suspension geometry

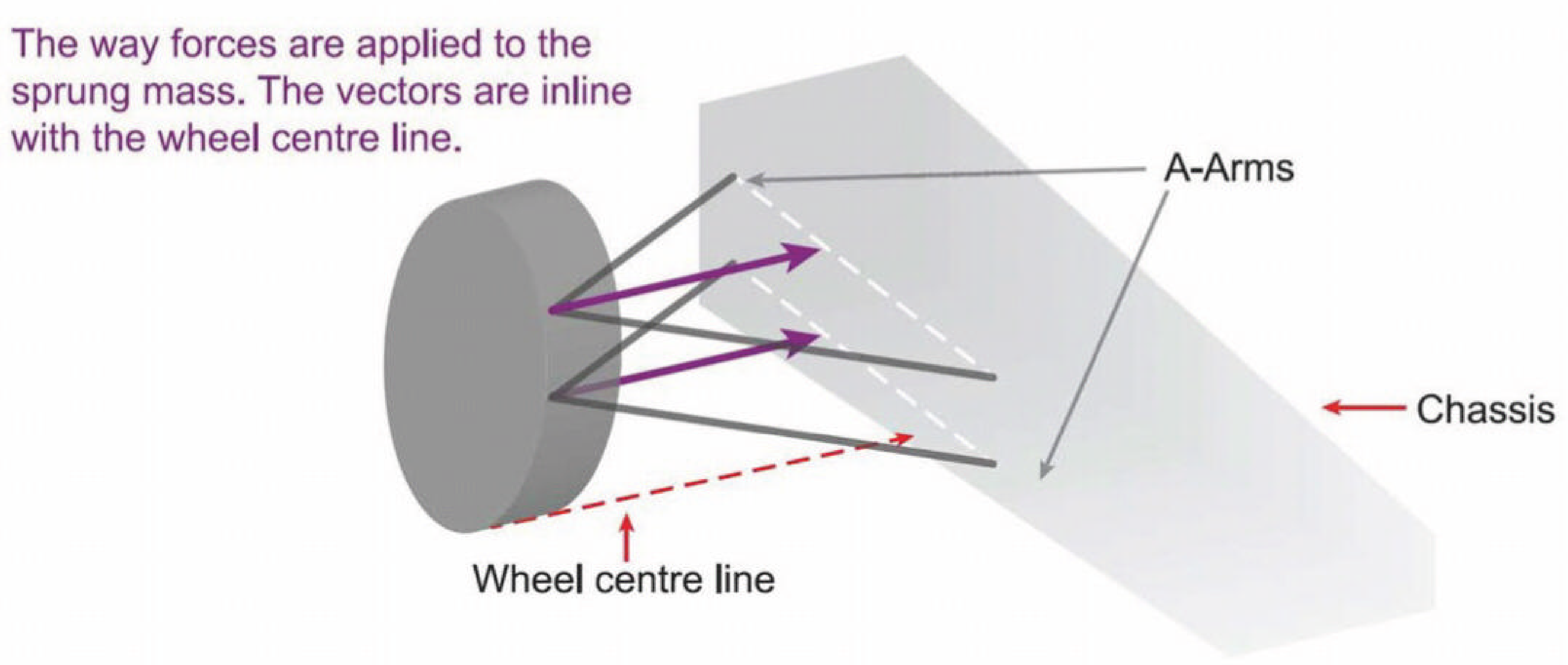


Figure 6: Longitudinal force analysis

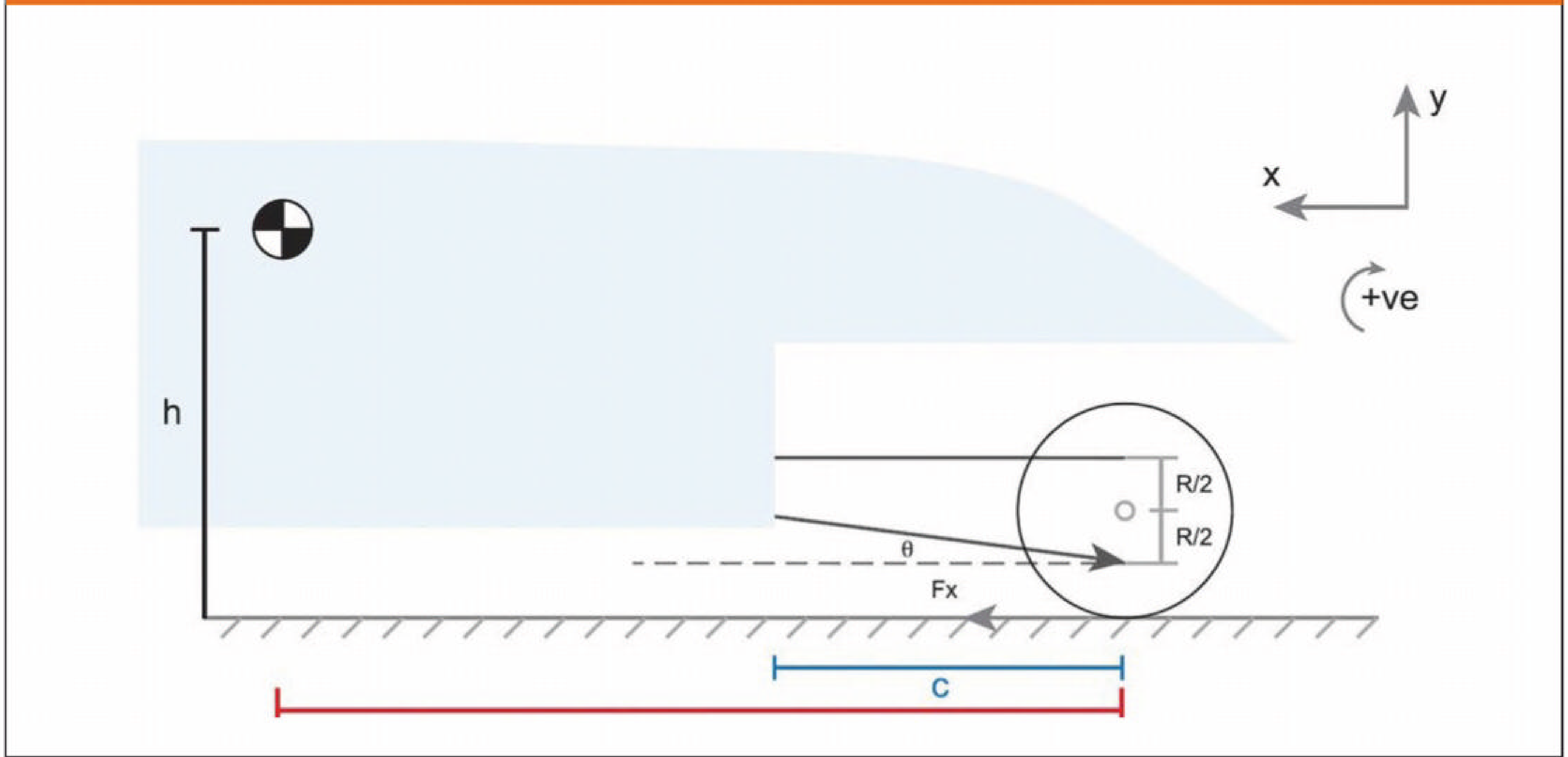
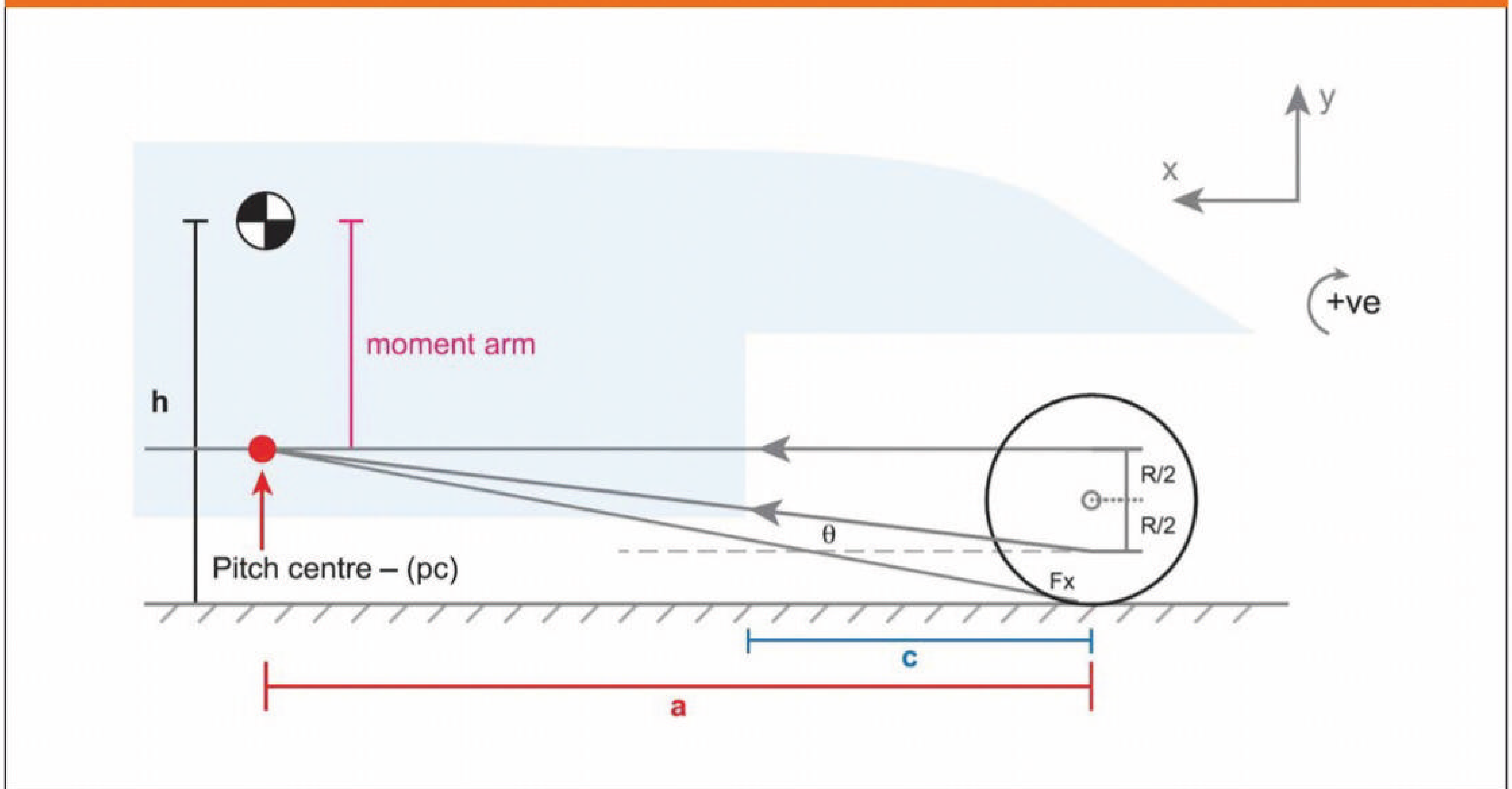


Figure 7: Illustration of how to find the longitudinal pitch centre for the force applied at the axle



vague definitions in all of automotive vehicle dynamics. This goes for both road and racecars. The good news, however, is that once you take the force application points of the lateral case and apply it to the longitudinal case everything will slot neatly into place.

Let me walk you through the proof. I'm going to assume this is a braking/accelerating situation where the torque is applied at the axle. In braking, we are talking outboard discs, and in acceleration we are talking a live axle arrangement, illustrated in **Figure 6**.

Going through the same process of doing a free body diagram of the hub and then taking a free body diagram of the sprung mass, it may be shown that the force application point becomes that shown in **Figure 7**.

The question now has to be asked about what happens when the torque is applied inboard? That is to say when we have inboard brakes and an independent rear end in acceleration? The answer, I am happy to report, is laughably easy. Doing a bit more analysis, the result is shown in **Figure 8**.

Once you start using force-based anti-dive and anti-squat you never look back

What happens here is you find the instant centre as normal, and then drop it by the rolling radius of the tyre. It's as simple as that. Again, the proof is in my book. This is not a series of shameless plugs, it's just the proof runs to some 20 A4 pages and doesn't translate well into the modern format of *Racecar Engineering*.

To wrap this up, it might be instructive to summarise this as a simple number. For force-based anti-dive and anti-squat, a very useful definition is shown in **Equation 5**.

Once you start using force-based anti-dive and anti-squat you never look back.

Now, at this point I realise some of you will think I've just challenged a lot of conventional wisdom. But remember, what has driven this analysis is that all vehicle motion is about forces and moments about the centre of gravity and the unsprung mass. The moment equations that drive all this reflect that these elements aren't rotating with respect to each other. Simple.

I'm fully prepared for some of you to read this and then write to me (or in to the editor) and say I'm a muppet and that I have got it wrong. While everyone is entitled to their view, everything I have written here is what drives the maths behind ChassisSim and, without it, correlation like that shown in **Figure 9** would be nothing more than a pipe dream.

In the correlation, one trace is actual, the other is simulated. The closeness of this in both pitch and roll speaks volumes of the veracity of what we have just discussed. If this wasn't the case, I wouldn't have a viable business.

In summary, what has been discussed here lays out in black and white the basics of suspension geometry. If all you take from this is the following, remember suspension geometry does three key things: it controls the steer angle of the tyre, the camber of the tyre and the forces applied to the sprung and unsprung mass. It really is as simple as that.

EQUATIONS

EQUATION 5

$$ads\_fact_i = 100 * \frac{pc_i}{h_{cg}}$$

Here:

I = the pitch centre at each individual corner of the car
pc_i = the pitch centre of each individual element
h_{cg} = the c of g height

If you can get your head around the fact that when it comes to understanding forces, everything is driven by force application points, then your understanding of suspension geometry as a whole will just fall into place and life at the track will be so much easier.

Figure 8: What happens to the pitch centre when the torque is reacted at the axle

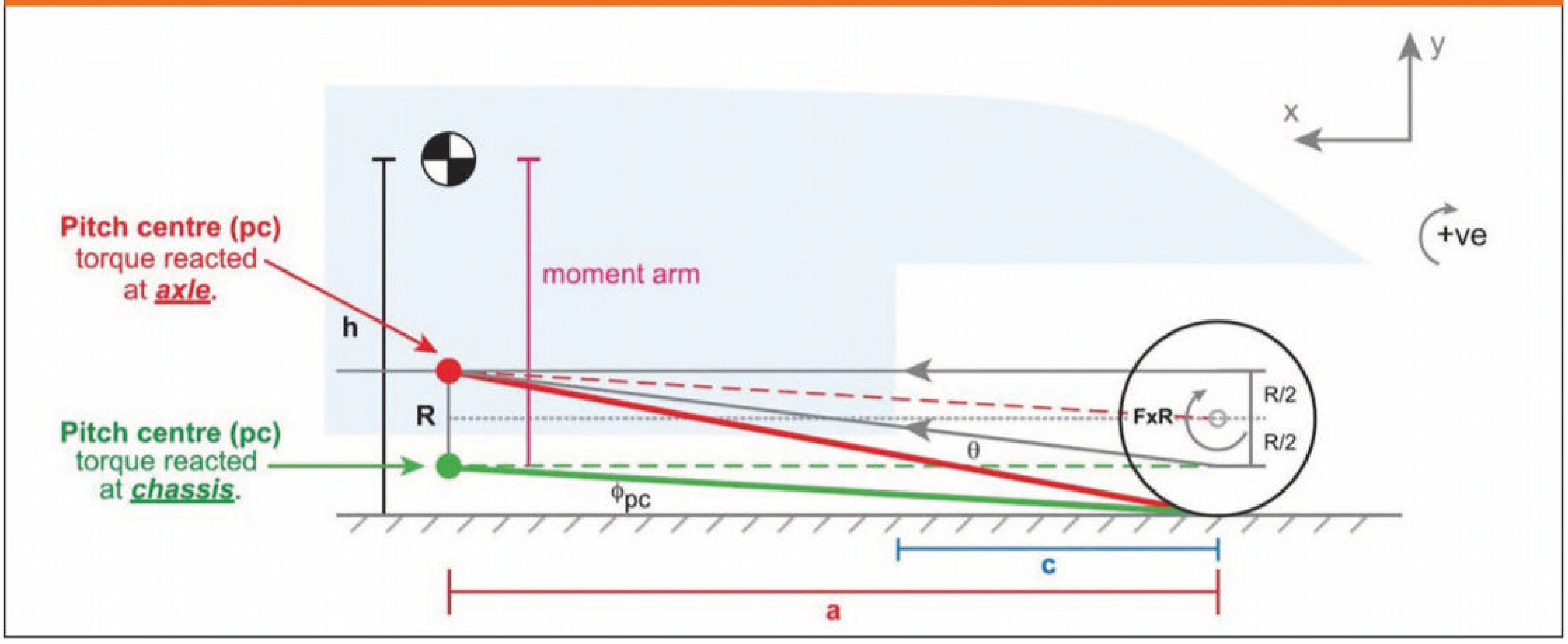
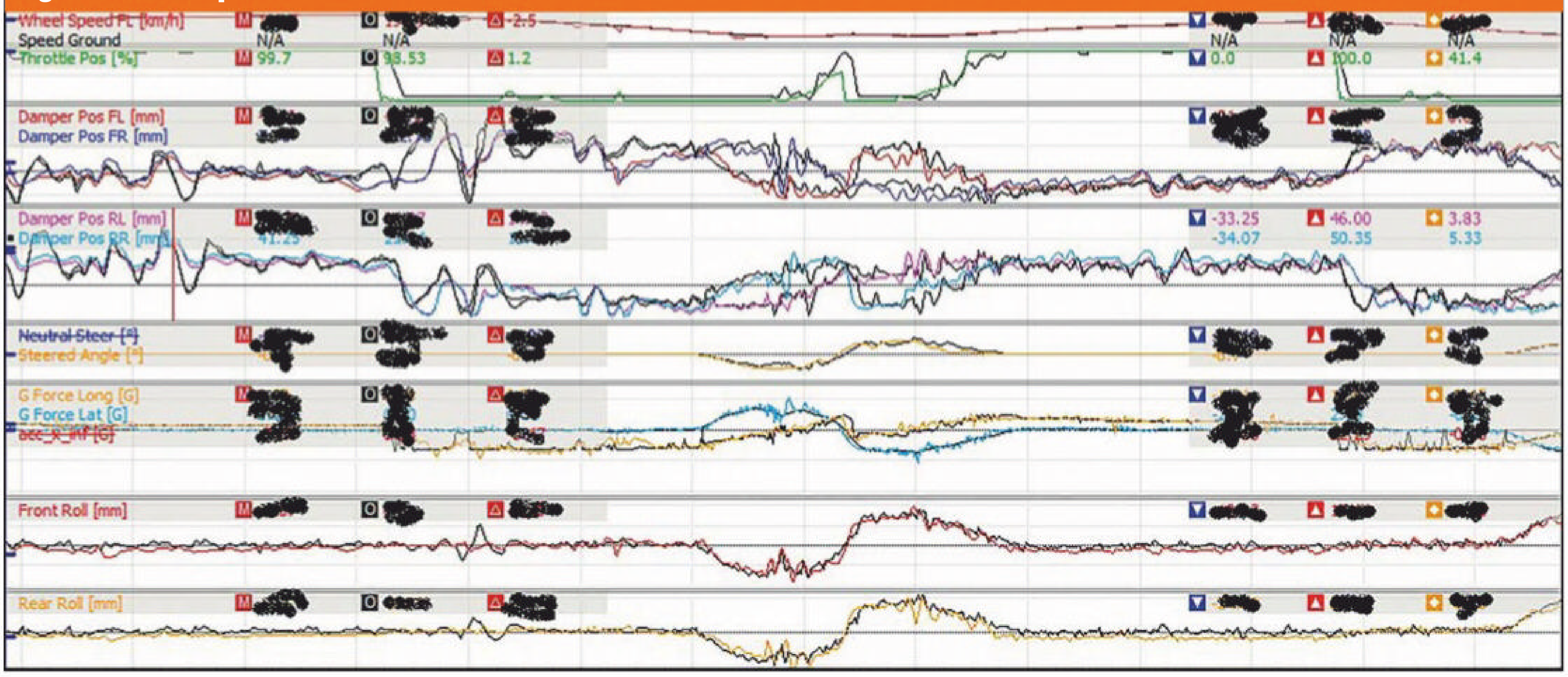


Figure 9: V8 Supercar correlation

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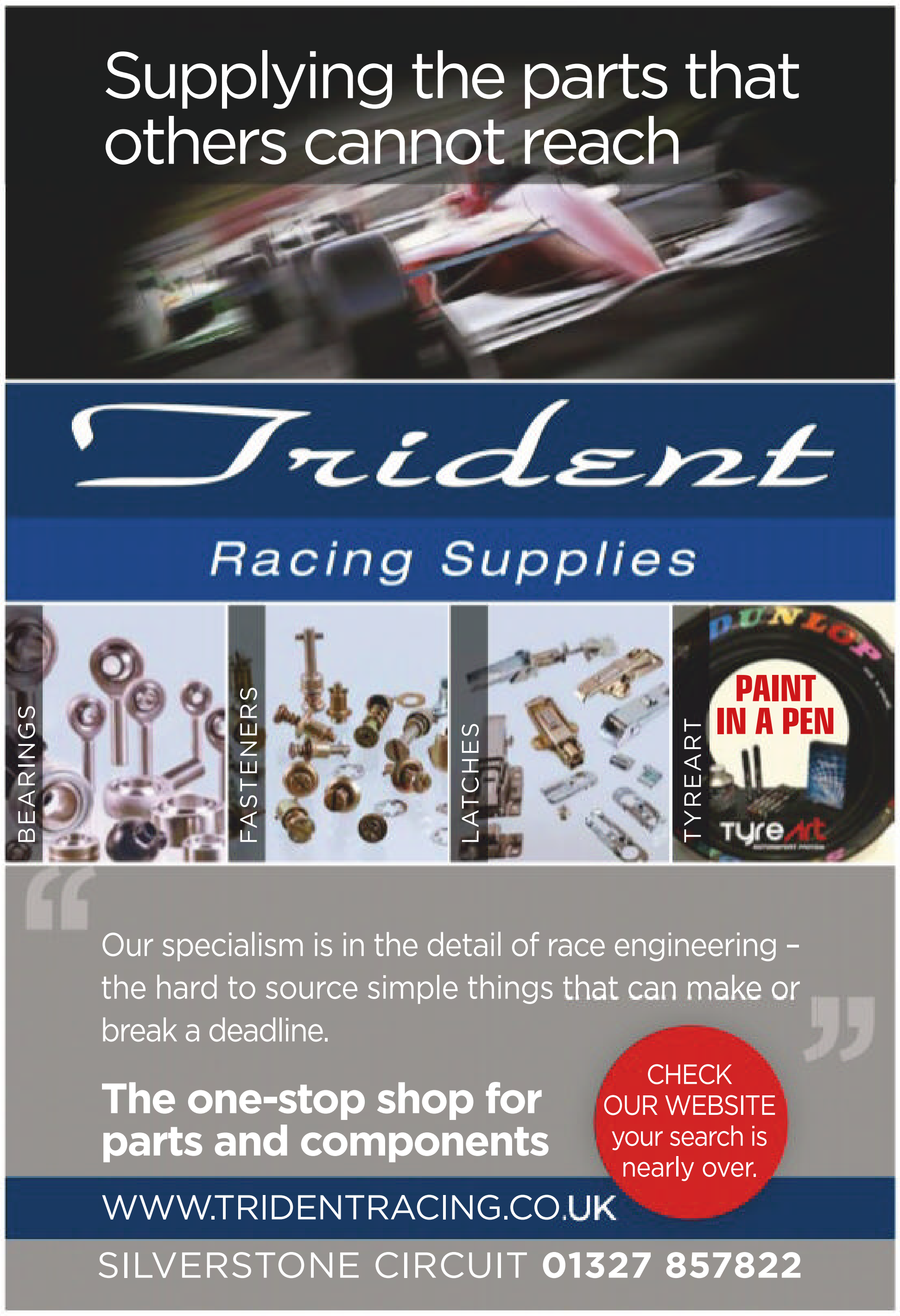
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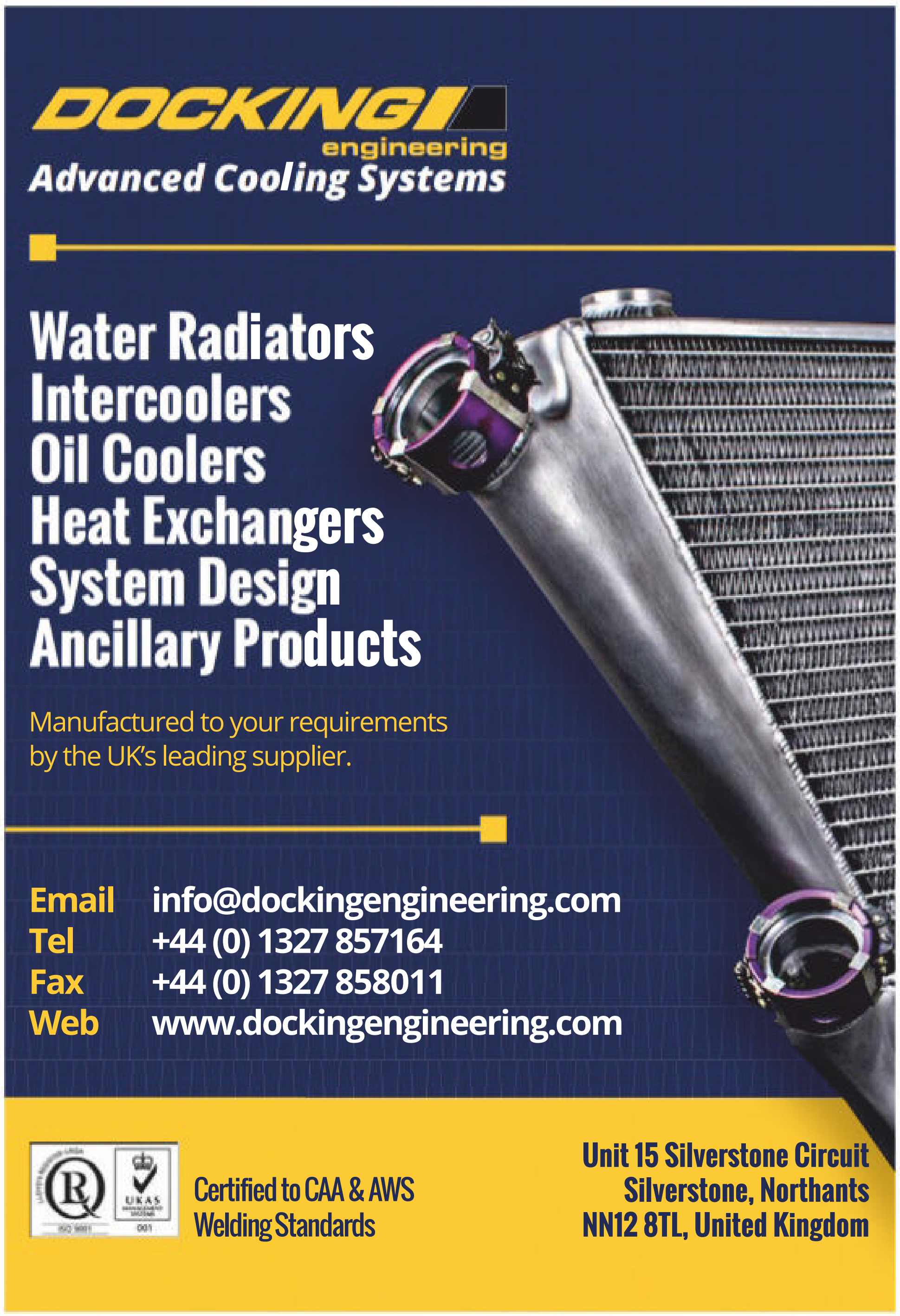
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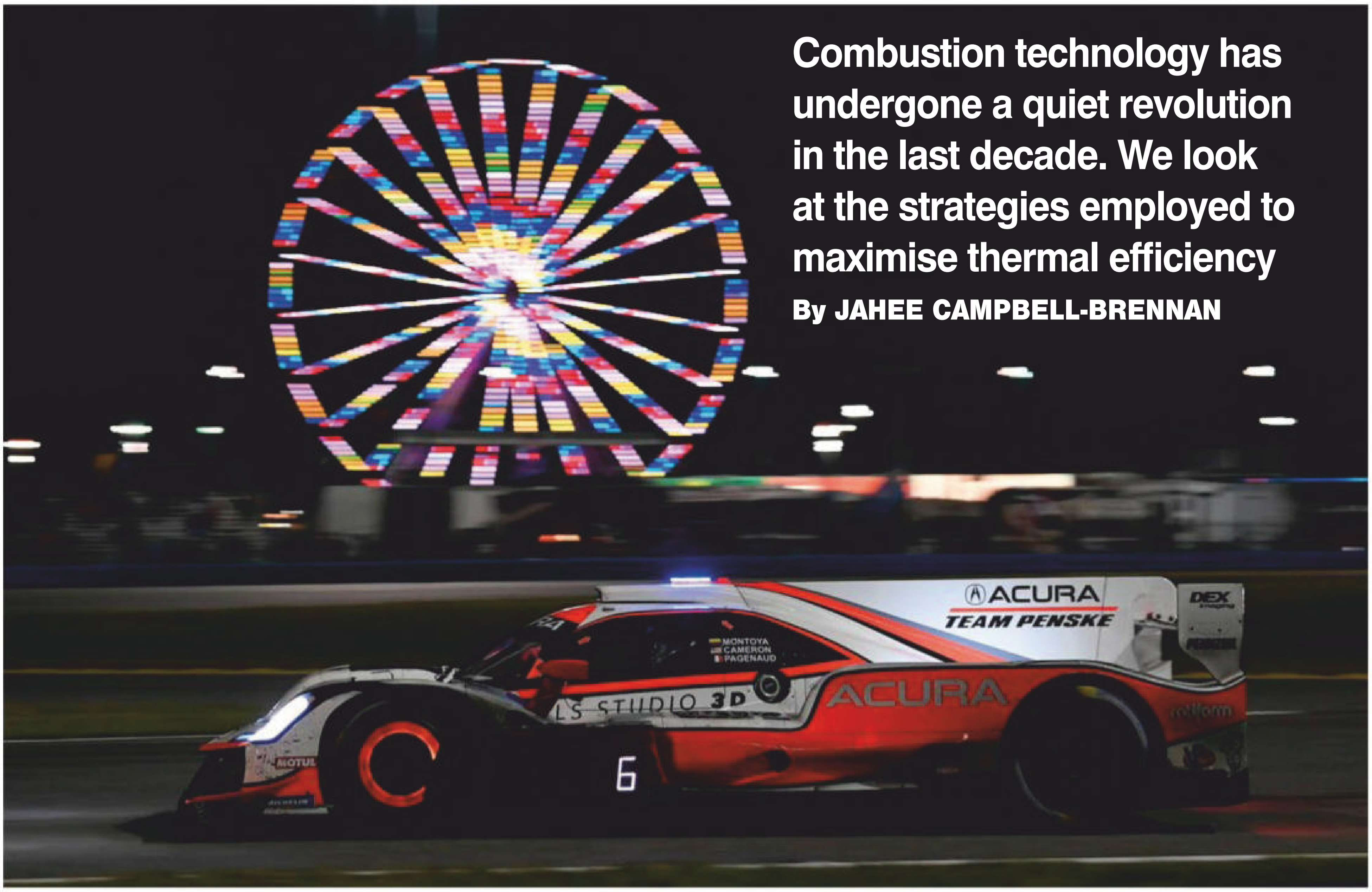
Feel the burn

Combustion technology has undergone a quiet revolution in the last decade. We look at the strategies employed to maximise thermal efficiency

By JAHEE CAMPBELL-BRENNAN



Honda / LAT images

Honda Performance Development (HPD) DPi car features a high efficiency GDI engine, based on the manufacturer's road car variant

Thermal efficiency is a term that has been thrown around engineering circles for decades. While not necessarily immediately obvious in definition, it is one of the primary measures of internal combustion engine performance.

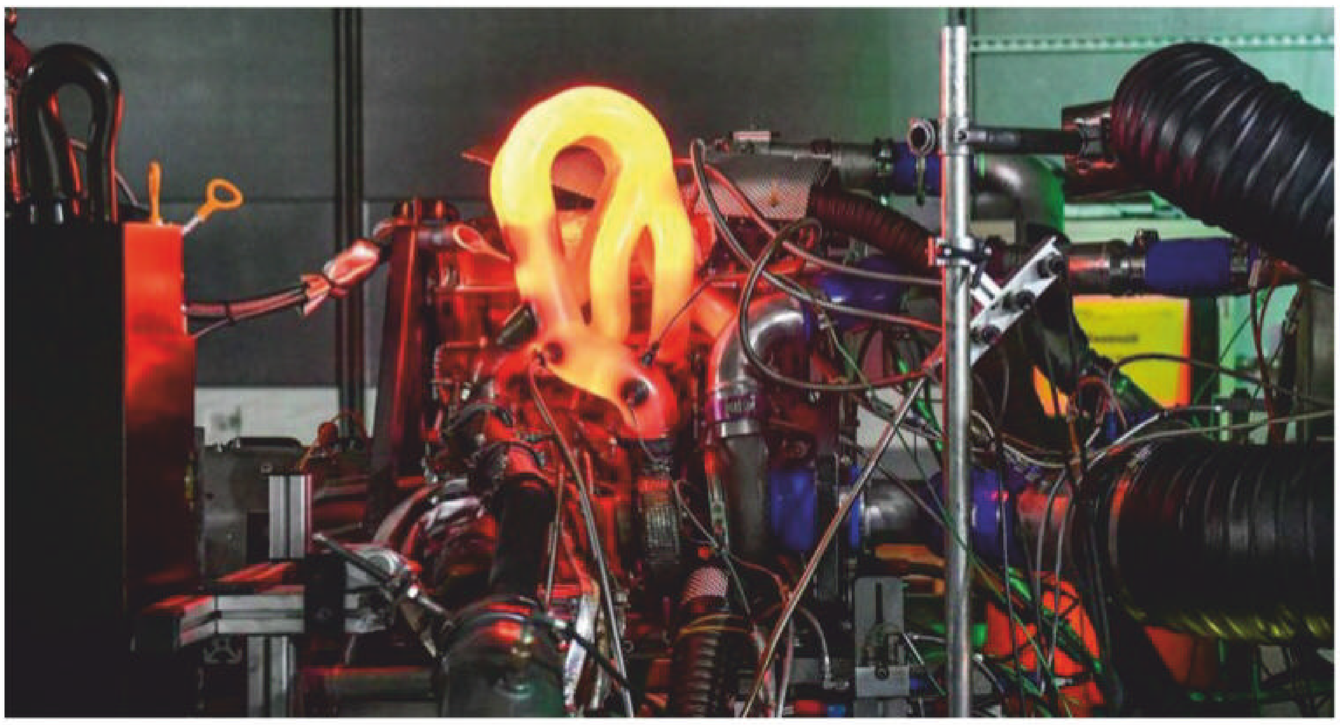
Last month, *Racecar Engineering* explored the journey of efficiency, specifically within Formula 1 development, over the last years. Building on that, in this article we will explore the technical advancements in depth with the aim of understanding how they have advanced the combustion process to extract maximum energy from fuel.

Being a hydrocarbon, petrol contains chemical energy that, upon oxidisation (combustion) is released as heat energy. The energy contained within the atomic bonds of a fuel is measured by the amount of heat released in its combustion, in joules (J), which establishes the link between the amount of fuel burned and the heat, or thermal input.

In the context of engine performance, measuring thermal efficiency allows us to satisfy questions such as how much fuel is needed to generate a particular amount of engine power?

Considering a more technical definition, we understand it as the engine output (kW) measured at the flywheel, divided by the fuel energy (kW) supplied to the engine. The two have an inversely proportional relationship so, if the fuel required for a given power output decreases, thermal efficiency increases.

Road car engines have been focussing intensely on maximising thermal efficiency for decades now, as lower fuel consumption is a clear selling point for any potential consumer. Motorsport, on the other hand, hasn't traditionally shared the same concerns. Historically, power has been generated without



Heat rejection can be so high that exhausts glow red, indicating temperatures over 800degC, as seen on this 2019 Audi DTM

much emphasis on efficiency, but nowadays the two sectors are steaming ahead on the same mission, just with very different driving forces.

Perhaps one of the biggest moves towards high thermal efficiency technology was made within endurance racing in 2006 when Audi saw the potential in using diesel as the fuel source for its R10 LM P1. In terms of straight performance, it had no advantage over its petrol-fuelled competition. The element that made the car so successful was that it had potential to spend less time in the pits refuelling, and therefore more time out on the track, where it matched its competitors' power. We all know what a success that car was.

In motorsport today, signals to the importance of a high efficiency can be observed through the downsizing and turbocharging of engines, attributed to the introduction of fuel flow restrictions. The philosophy here is that if you can extract more work from a unit of fuel than your competitors via a higher thermal efficiency, you're at a clear advantage. Furthermore, transferring that advantage increases the relevance between motorsport and road car technology.

The huge improvements we've seen in thermal efficiency in recent years we owe to advancements in engine technology, architecture and control systems. Combined, they have taken us from a point where an efficiency in the ballpark of 30 per cent was standard, to where we are today, F1 engines operating at close to 50 per cent.

The 2006 Audi R10 TDI was a revolution in technology driven by the search for increased thermal efficiency

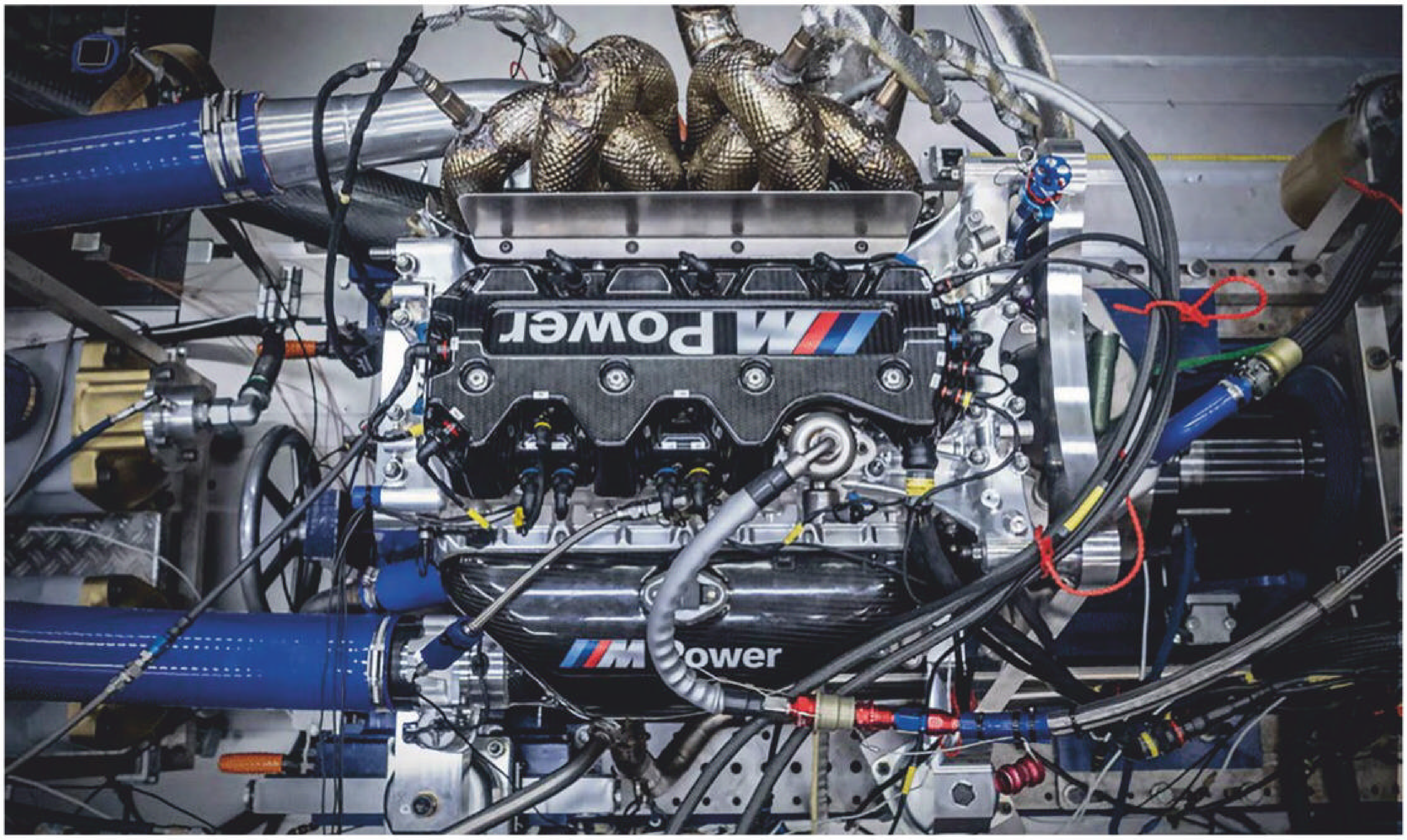
Mechanical loss

So, we've established that, primarily, the thermal efficiency of an engine is a measure of how efficient it is at extracting combustion energy and using that energy to drive the crankshaft. Being a mechanical component, the engine has inherent frictional and pumping losses associated with reciprocating and rotational motion, as well as the intake and exhaust of air.

The trend of downsizing works in favour of managing these mechanical losses. It reduces pumping loss in the intake system through a lower number of cylinders, and friction due to lower bearing counts and a smaller swept area, which reduces frictional input from piston rings. This is fairly elementary.

But to explore and better understand the intricacies of the combustion process, we must enter the world of thermodynamics. Considering the first law, we to remember that the total energy of a system remains constant as it is converted. In our internal

The importance of a high efficiency can be observed through the downsizing and turbocharging of engines



DTM saw the introduction of downsizing, turbocharging and DI technology as fuel flow limits were added to the regulations. The result was four cylinder, 2.0-litre engines with 610bhp combustion engine case, from chemical energy to kinetic, heat and sound energy.

Logically then, the larger proportion of energy we can liberate from the fuel into force on the piston, the less is rejected as heat and sound and the more thermally efficient we are. Likewise the cooler the exhaust gas, the more efficient the process.

The second law of thermodynamics is also relevant to efficiency but, lest this feature expand into a lecture, we won't go into explicit detail, just explore it a little more elegantly.

Uncontrolled combustion

In the context of basic engine architecture, a fundamental way to increase efficiency is to increase the compression ratio of an engine. But here comes one of the main problems with spark ignition and short-chain hydrocarbons such as petrol and high compression ratios – uncontrolled combustion.

With the highly compressed volume at TDC that higher compression ratios bring, conditions can become conducive to a phenomenon called pre-ignition, in which the fuel / air mix auto-ignites prior to the intended ignition event.

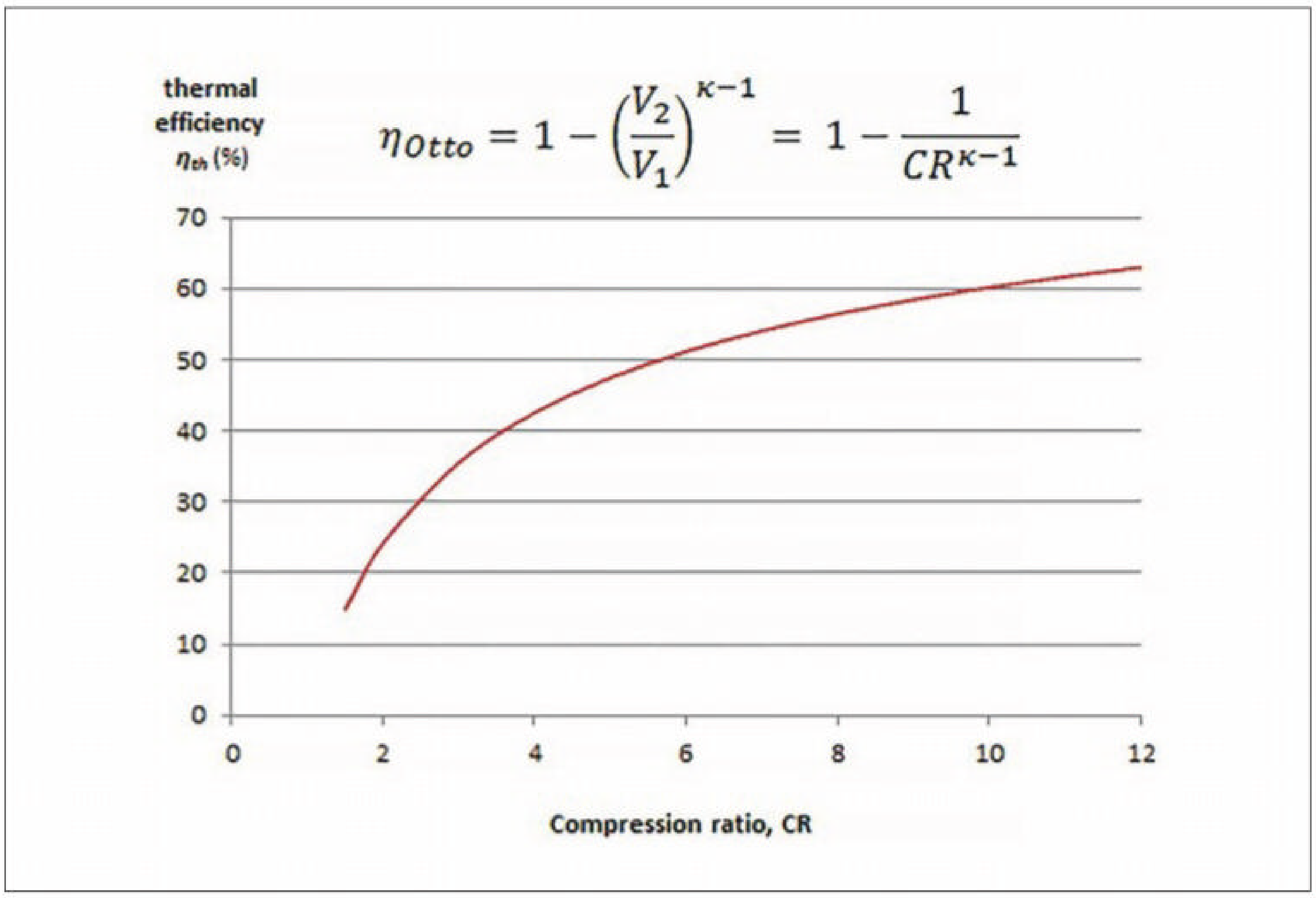
In a similar sense, during the main combustion event the rapid rise in in-cylinder pressure and temperature can cause fuel mix in

A fundamental way to increase efficiency is to increase the compression ratio of an engine

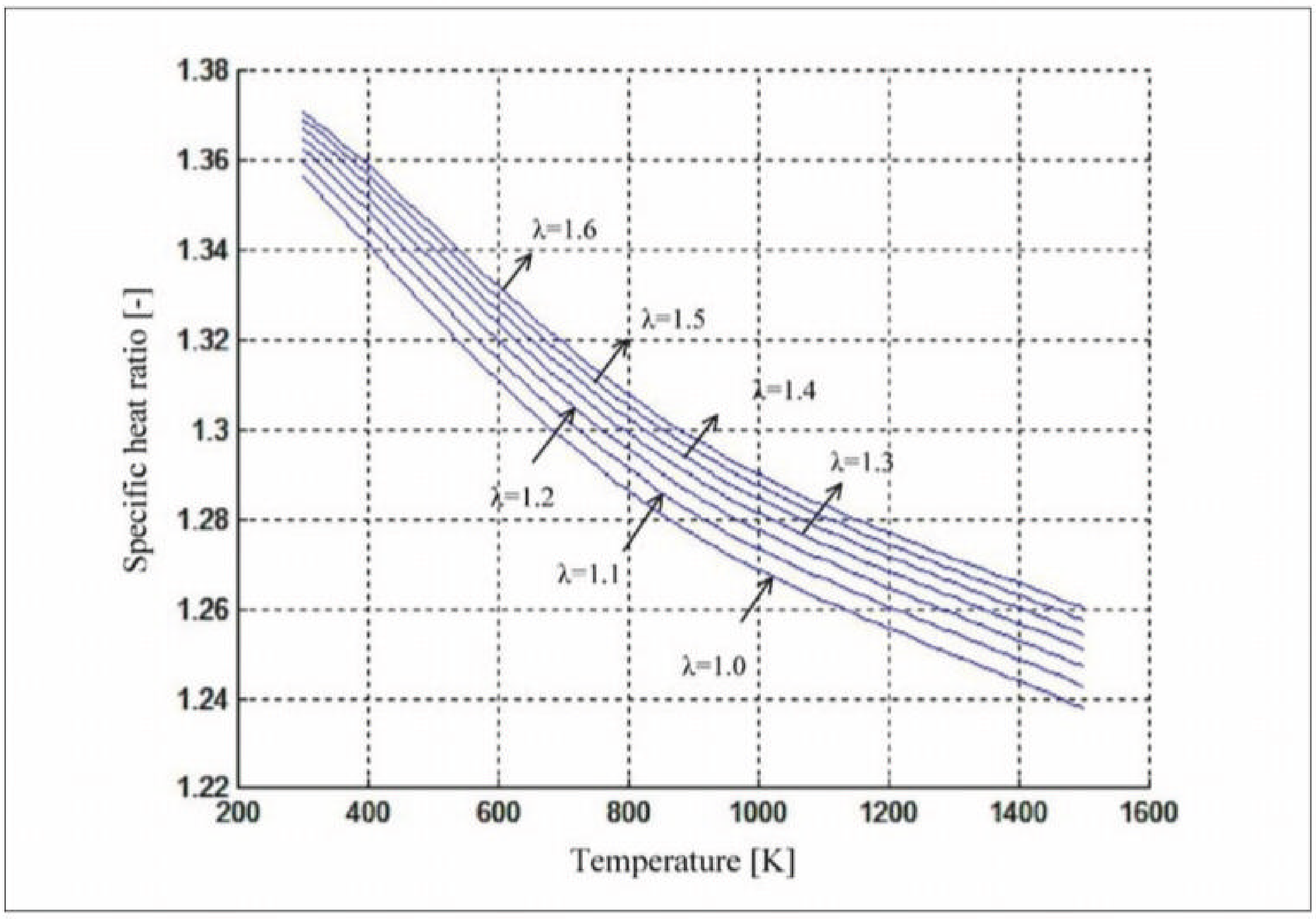
the far edges of the cylinder to 'explode' prior to contact with the advancing flame front, which is burning in a controlled manner. This causes a detonation, otherwise known as knock. As we will discover, the onset of knock is one of the biggest obstacles limiting efficiency and performance of spark ignition race engines and dominates our actions towards engine tuning.

Not only do these phenomena physically damage the engine with very sharp pressure increases, they are negative for the combustion process as the result is wasted energy. Ultimately, this is inevitable at a certain point when using petrol as a fuel, especially with port fuel injection (PFI), where the pre-mixed fuel and air intake charge is introduced into the combustion chamber at the beginning of the compression stroke. The high pressure and temperature experienced here create ideal conditions for auto-ignition.

The real revolutions in thermal efficiency were enabled by the emergence of



Relationship of thermal efficiency (h) with compression ratio (CR). From the formula we can see as CR increases, h follows



Knock event chart

advancements in fuel injection strategies and our understanding of how the combustion process works via CFD. Most significantly with gasoline direct injection (GDI).

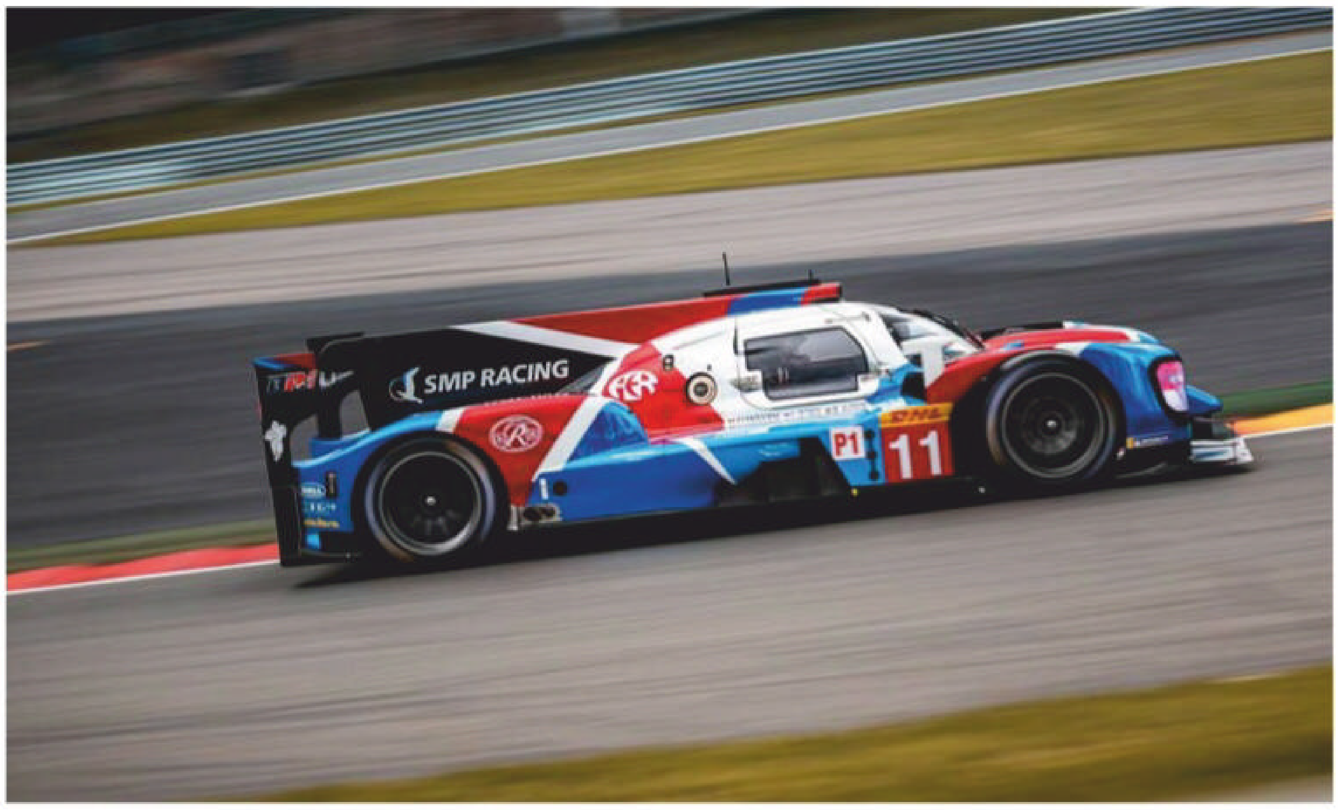
GDI is a technology that offers much of the answer to the problem of pre-ignition. The key difference here is that fuel is delivered into the cylinder independently of the air, allowing the injection system to precisely control the timing of its introduction, the location and trajectory of the spray. Controlling knock, however, is a different proposition.

The fuel mix is made deliberately rich, which does two things to its behaviour. Firstly, the phase change experienced when the liquid fuel is vaporised in the hot chamber absorbs energy, lowering the temperature within the chamber.

Section view of a GDI injector

Bosch

Gone are the days of running deliberately rich and unburnt fuel, and therefore useable energy, being thrown away by simply dumping it out of the exhaust pipe



These days, with strict fuel flow limits in place, racecars use a lean combustion philosophy and burn fuel very effectively

The real revolutions in thermal efficiency were enabled by the emergence of advancements in fuel injection strategies

Secondly, it increases the thermal mass of the charge, which indicates that it will require more heat energy to reach the point of auto-ignition.

When you're designing engines for efficiency, though, this is something you cannot tolerate as it results in unburnt hydrocarbons leaving in the exhaust.

Sam Borgman, technical engineer at Life Racing Ltd. explains further: 'Old PFI engine designs used to run rich as a prevention against knock. With an excessively rich mix, you'd get a whole bunch of fuel that would be pushed ahead of the flame front until it reached the upper piston ring, where there physically wasn't enough oxygen to combust it. Any fuel that wasn't ignited by the main combustion event therefore didn't have enough oxygen to burn, preventing knock. With GDI techniques, though, you can create the same effect with a lean mix, which allows a much more efficient combustion.'

The drive for lean combustion is not solely to reduce knock though. There are distinct benefits to burning a lean charge (λ (Lambda) > 1.0). It increases thermal efficiency but presents certain challenges, which require some particularly innovative thought to overcome. Challenges that become way more manageable with GDI.

Lean approach

'We're at a point in technology now with regard to race engines where you either use GDI or you don't bother turning up,' continues Borgman. 'Race engines must maximise the quantity of air and fuel consumed, but the demands of fuel flow limitations dictate the fuel must be burnt very effectively, every time, without misfires. You just can't achieve this without using a lean approach.'

But what does a leaner mix actually mean for combustion, and why is it an advantage? It's a clear relationship up until the point at which λ hits 1.0 where, under stoichiometric conditions, maximum torque is produced. Yet with λ now reaching well above 1.0, what is the benefit?

From much intense research on combustion in lean conditions, we understand that as λ increases above 1.0, the mixture burns slower, yet burns a higher mass fraction of total fuel available with each cycle, yielding increased combustion efficiency.

Further to this, the specific heat ratio of the mix increases with λ, which means the energy required to increase the temperature of combustion becomes greater, resulting in a cooler, more thermally efficient burn as a greater proportion of the combustion energy available drives the piston.

The downside to lean combustion is that the cycle-to-cycle variation (CCV) increases as combustion becomes more stochastic.

'If you're operating with high CCV, your mean ignition timing ends up retarded as you try to control your knock events. If you can reduce CCV, you can then advance timing, which helps your performance. This is the Holy Grail of performance tuning. Improving mix preparation, in-cylinder mixture behaviour and how the combustion process happens all improves CCV,' explains David Salters, technical director at Honda Performance Developments.

In the mix

GDI introduces a number of injection strategies to optimise lean combustion that just aren't possible with PFI. You have the freedom to create a largely homogenous charge, equally distributed within the combustion chamber but injected in a very specific manner to support favourable combustion. Or, you have the option of creating a stratified charge that produces a heterogenous composition of air/fuel mix at different places around the cylinder.

'At an in-cylinder level, the first thing we see is that mixing is far more important with GDI as there is just less time for the fuel to mix before spark,' notes Dan Probst, senior principal applications engineer at Convergent Science. 'The way in which the charge is delivered has a huge influence on the combustion process, and stratification can be quite a big influence with this.'

Offering a further perspective, David Salters comments that: 'Homogenous charges are very useful but in some cases, if you're trying to prevent knock, then perhaps you'd want to stratify your charge, creating a leaner air-fuel ratio (AFR) at problem areas that won't ignite so readily, while maintaining rich elsewhere to promote the combustion behaviour you want. It really depends on what you're trying to accomplish.'

Let's not neglect the advances the humble injector has bought to the party to enable these strategies to be realised either. 'Relative to PFI, which might typically operate at a maximum of nine bar, it's very common to see GDI pressures exceeding 350bar,' comments Phil Ellisdon, managing director of injector diagnostics experts, ASNU. 'Injector delivery times have reduced by a large amount with the introduction of GDI technology, where they typically have less than 5ms to deliver the entire charge at wide open throttle.'

This level of pressure increases fuel atomisation and surface area for combustion, but it also introduces kinetic energy to the intake charge, with the benefit of added rotational motion through swirl and turbulence. This also helps with the speed of flame propagation.

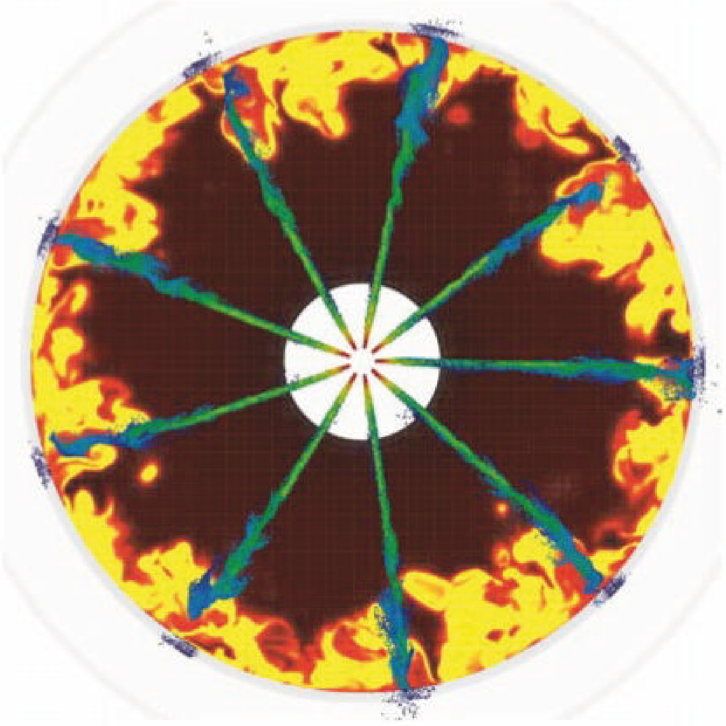
Maximising the benefit this increased kinetic energy brings, a technique of using multiple injections can be used, adding to the main combustion event with a smaller secondary injection just before ignition to add kinetic energy and a level of stratification to the charge.

Due to the very short period of time these injectors have to open, deliver their charge and close again, GDI injectors require a lot of energy to create the ideal 'square edge' opening profile.

High voltage

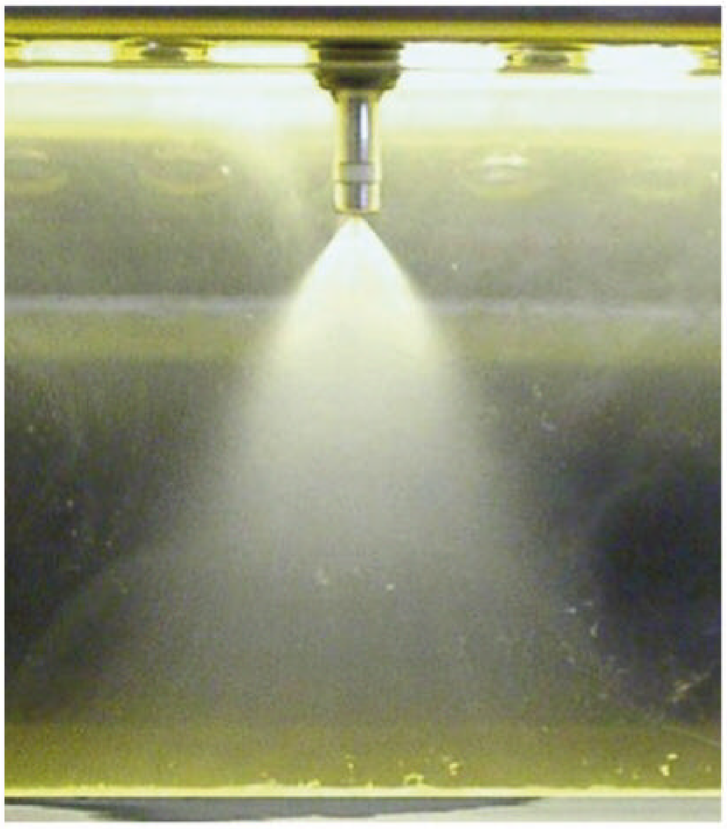
'GDI injectors have moved into high voltage territory due to the power demands new injection strategies place on them,' adds Ellisdon. 'PFI injectors would run easily on 13.8V but certain types of GDI injectors are all the way up at 60V today, it's quite a change.'

'You do reach a point of diminishing returns with injection pressures,' contributes Salters. 'Nozzle diameter and orientation influence how the mix is distributed. Air is entrained by increased atomisation, which is something that can be made useful, but smaller droplets have less kinetic energy and so penetrate less into the chamber. It's quite complicated and results in a trade off. This is certainly an area where CFD has helped hugely in our understanding.'



Convergent Science

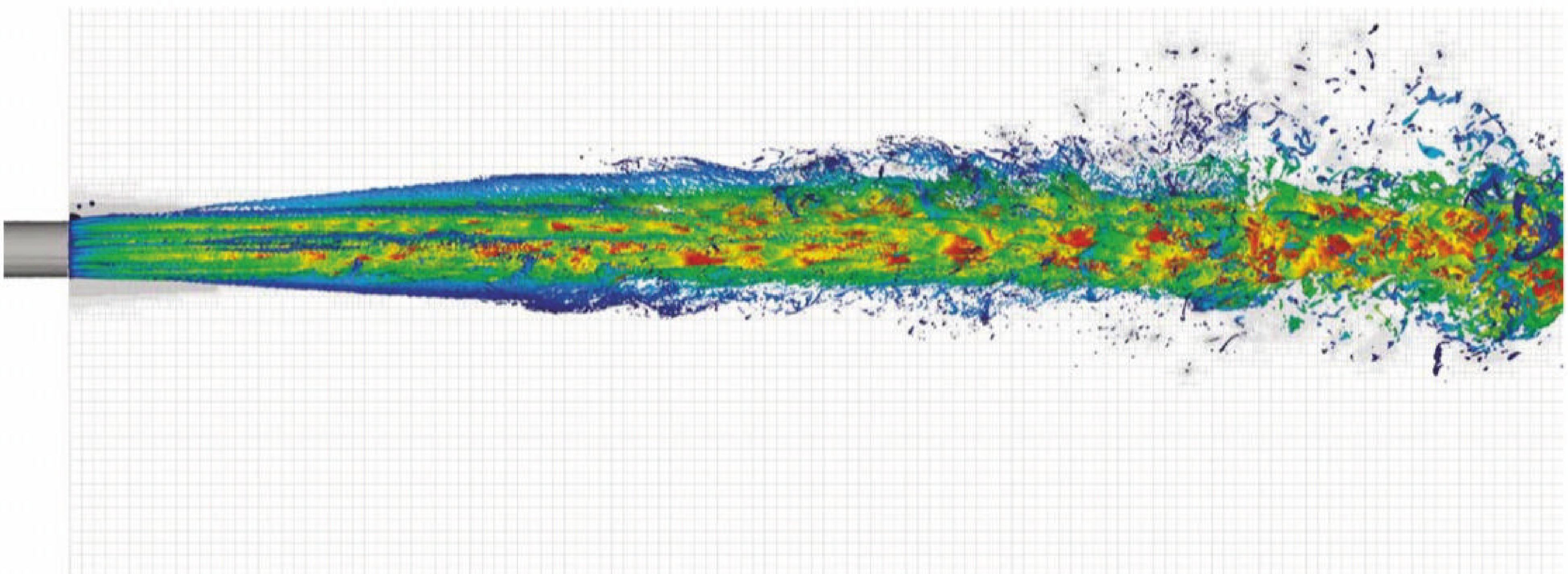
CFD modelling can give critical insight into injection mixing



ASNU

Typical GDI spray pattern

'GDI injectors have moved into high voltage territory due to the power demands new injection strategies place on them'



Convergent Science

Volume of fluid technique can be used to model multi-phase flows, such as injector flow within a combustion chamber

A great deal of this learning on GDI injection techniques has emerged directly through advances in CFD techniques, which have enabled us to explore our understanding of fuel delivery and combustion behaviour in ways previously not possible.

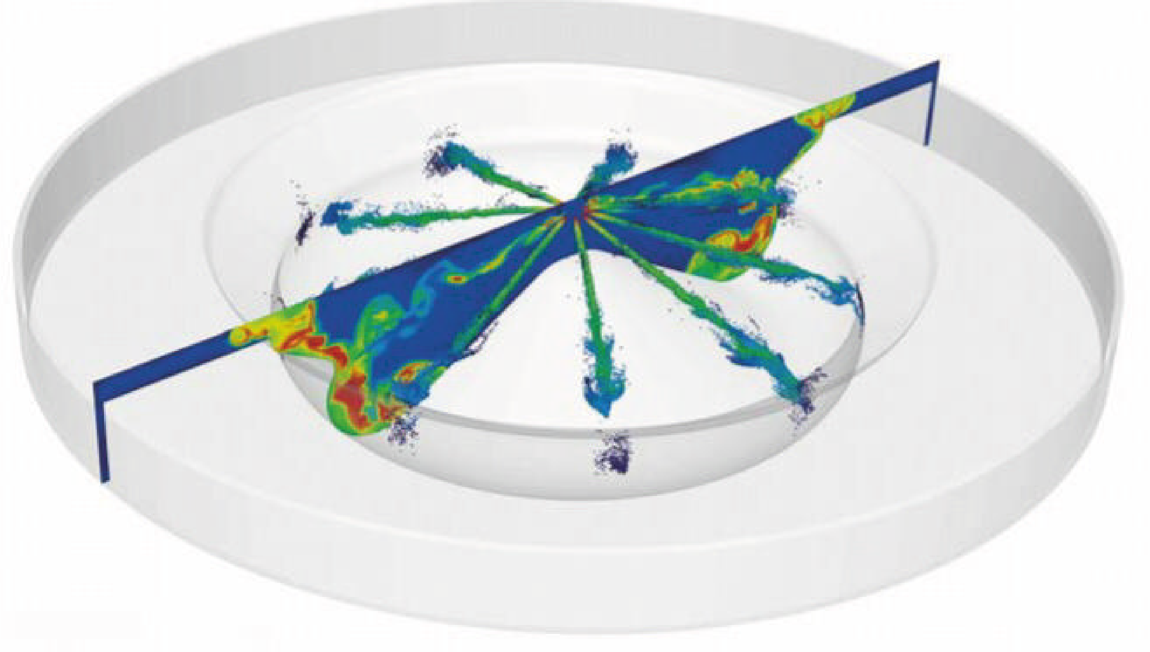
Diagnostic view

'Recent advances have been made as a result of the growth of computational power. The ability to perform higher resolution simulations have allowed the codes to develop proportionally, too,' adds Probst. 'With GDI, where mixing is more important, it gets a little more challenging to predict, but you learn a lot with CFD tools. It's very powerful in the way we can look inside the combustion [process] and see what's going on in a diagnostic point of view. That level of analysis would be extremely difficult and expensive experimentally.'

The outputs from such CFD studies allow a precise understanding of the temperature and pressure at discrete volumes in the combustion chamber throughout a combustion event. And detailed knowledge of multi-phase flows, flame speeds and burn characteristics enable powertrain engineers to create the geometries and conditions required to get the most out of any given platform.

'Today's complex models iterate cell by cell to perform detailed chemistry calculations at each cell to model the species, temperatures and thermodynamic conditions and calculate reaction rates from first principles. All this was unimaginable a few years ago,' says Probst.

To capitalise on these advancements in combustion understanding, engine control



Convergent Science

The ability to explore the combustion process frame by frame has been invaluable in the advancements of combustion techniques

Pre-chamber ignition offers you the ability to introduce multiple, distributed ignition sources

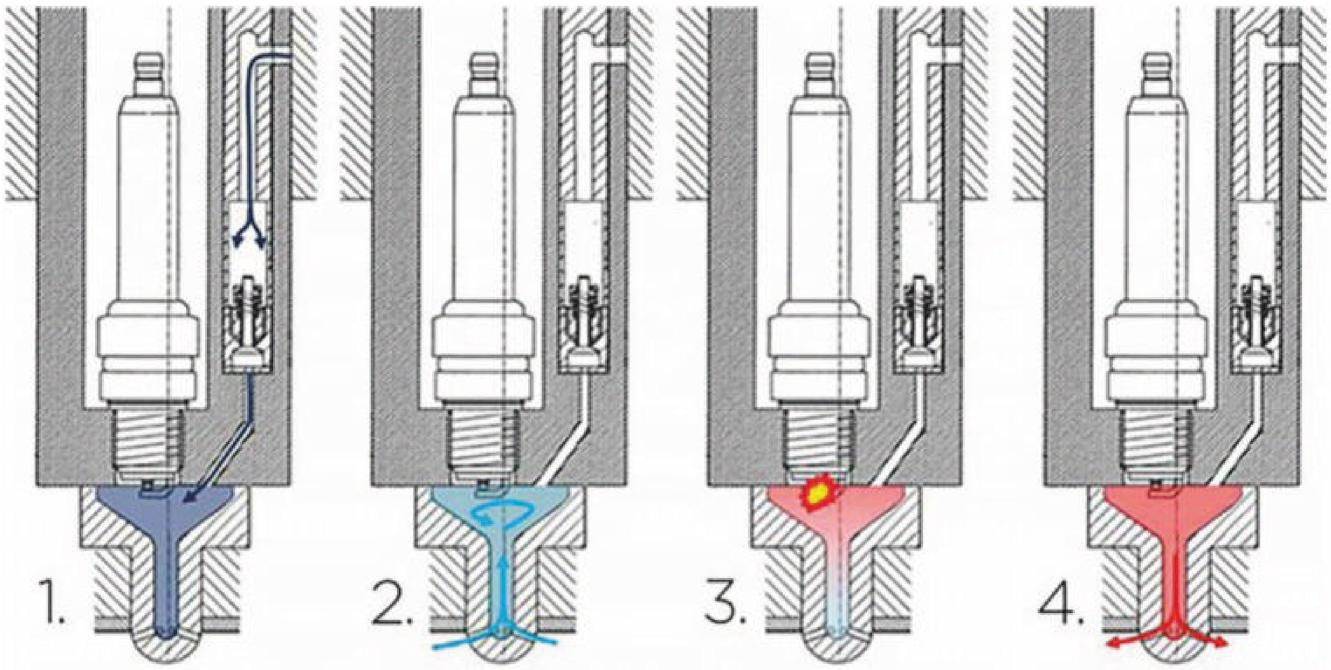
systems, both hardware and software, have been required to develop at the same pace, or even faster. Particularly with regards to the speed of control and the quality of knock detection and reaction algorithms, where much recent work has been done.

'One of the key targets of combustion modelling is trying to predict how and when knock occurs. It can be quite difficult to measure in fact, and it really dictates how far you can push your engine with regards to performance, so it's important to understand,' comments Salters. 'It's a real expertise, and an area that receives a fair amount of resource within a programme.'

We mentioned earlier the relationship with lean running and CCV. One of the effects of this is the possibility that a proportion of very lean intake charge remains unburnt after the main combustion event. If this charge is not ejected in the exhaust stroke, it can find itself in the compression stroke of the next cycle, where pre-ignition may be encouraged by parts of the chamber like hot exhaust valves, causing a phenomenon known as 'mega knock'.

'Mega knock is something we have to be very careful with as we run ever leaner. I've seen it max out cylinder pressure transducers rated at 800bar and put dents in piston crowns. It can literally shake dyno cell walls,' exclaims Borgman. 'We have to be really clear in our strategies to understand what situations are conducive to it, and then steer the engine away from them through control software.'

The 2019 season brought a major change to racecar powertrains to increase their relevance to road car technologies



Pre-chamber ignition: 1. Fuel into the pre-chamber; 2. Fuel travels into main combustion chamber where a lean air / fuel mix is established; 3. Spark plug ignites richer pre-chamber mix; 4. Turbulent, high-speed flame flows into main chamber

Pre-chamber ignition

The issue of knock management combined with the drive to run leaner with higher compression ratios has driven the race engine scene to explore the technology of pre-chamber ignition to increase the lean limit. This technology has enabled huge leaps in thermal efficiency to be made by allowing very lean mixtures, with λ up to around 1.35 to be run.

'A considerable issue with lean running is the reduction in speed of combustion,' explains Salters. 'Pre-chamber ignition provides a solution for this through introducing multiple, distributed ignition sources. Primarily, this speeds up combustion and reduces CCV, therefore mitigating knock.'

With pre-chamber ignition, the spark plug and injector are no longer directly located at the cylinder head and are separated from the main combustion chamber via a much smaller, secondary, pre-chamber. The injector opens and delivers fuel to this pre-chamber. From there, it travels to the combustion chamber where it mixes with the intake air, creating a mix lean enough that it otherwise wouldn't be ignited by the relatively low energy of the spark plug. At the same time, a richer, ignitable condition is created within the pre-chamber.

As the spark fires, the resulting flame front is ejected through carefully designed nozzles, which disperse it and create turbulence as it moves into the main combustion chamber where the bulk mix is ignited.

The result is a very lean, fast and thermally efficient burn. Importantly, it reduces CCV, which allows operation closer to the 'edge' to be maintained to draw maximum performance from the fuel without risking knock events.

Earlier we drew the link between higher compression ratio and increased efficiency, generating higher combustion pressures and benefitting from a long expansion stroke. Yet, using a traditional Otto cycle, the cylinder is still at high pressure at BDC, wasting a significant portion of the combustion energy as exhaust. In an ideal situation, at the end of the power stroke

One of the key targets of combustion modelling is trying to predict how and when knock occurs

the cylinder would be at ambient pressure, but this just isn't the reality with an Otto cycle.

In recent times, a method of operating with a reduced effective compression ratio, while at the same time maintaining a larger expansion ratio, has regained prominence for its efficiency advantage. By delaying the closure of the intake valves, the Atkinson cycle allows some of the intake air to escape during the beginning of the compression stroke.

This, of course, means the quantity of air in the combustion chamber is reduced so you can burn less fuel, but the advantage is that a higher proportion of work is extracted from the combustion event. With high-boost turbocharging, volumetric efficiency can be sufficiently increased that you are able to burn the required level of fuel and meet specified power level targets.

A combination of working with some level of late intake valve closure and pre-chamber ignition would yield a very efficient, high power engine. I'd dare to guess many of the high efficiency LMP engines are playing with this strategy; Formula 1 certainly is.

Even with the advances in combustion efficiency and the reduced heat rejection it brings, there is still a huge proportion of fuel energy that does not produce work and exits straight out the exhaust as waste. As we have established, any waste of energy must be scrutinised on this road.

Turbocharging has been playing an increasingly large role in engine technology, particularly as downsizing reduces the displacement of engines. Capturing all that wasted kinetic, heat and sound energy is great for volumetric efficiency, but it really only allows you to burn more fuel, it doesn't actually change how the fuel is burnt.

There have been efforts to increase compressor efficiency and make the unit more effective at generating boost, but this is more related to engine power. Alone, it doesn't have a significant influence on engine efficiency, aside from increasing combustion pressure.

Turbo limiter

'With downsized engines, the turbocharger is becoming the limiter of performance in the engine,' says Lex Winder, engineering manager at Van Der Lee Turbos. 'This pushes us to search for efficiencies in turbocharging solutions to deliver the power and efficiency teams need.'

Being rotational devices, much effort is focussed on inertial effects to improve the compressor efficiency. Anyone who has noted the rather muted sound of recent turbo race engines can attest to the quantity of sound energy removed from the exhaust gas by modern turbocharging.

'Today's turbos necessitate the use of technology such as aluminium-titanium alloys to reduce rotational inertia on turbine wheels. We also use ceramic roller bearings to ensure we're maximising the response of the system in the sense of frictional losses,' adds Winder.


Van Der Lee

Turbo efficiency is linked to many things, including geometry of turbine and compressor wheels

There are times, though, when the turbine is producing more work than is required from the compressor. If there was a method of capturing the excess energy and storing it for redeployment when the converse condition is realised, turbocharging would be even more effective in complementing an engine's thermal efficiency. E-turbo anyone?

Ricardo Klijnman, who works in technical engineering also at Van Der Lee, concurs: 'There's a lot of flexibility required in turbo design as there are many ways of achieving what is required with respect to boost levels and efficiency. One of the things that is particularly interesting currently is e-turbos.'

With traditional turbocharger technology, a compromise on turbine sizing is needed to operate optimally throughout a relatively large engine speed range. This has necessitated the use of wastegates to prevent overspeed and either incurring internal damage or over-boosting the engine.

Klijnman elaborates: 'The general approach with e-turbos is to optimise turbine size for high rpm mass flows, and use the motor to augment compressor speeds at lower rpm to achieve boost targets. This also has the advantage of removing the need for a wastegate.'

Increased efficiency will take us a significant step towards reduced CO_2 emissions

The wastegate, effectively acting as a bypass for exhaust gas and, as its name suggests, is wasteful in its action. It 'throws out' kilowatts of potential power, which is a big no no if you're searching for efficiency.

Recovering and then deploying this energy back into the system to the benefit of efficiency is invaluable. Such high thermal efficiencies would not be possible without it.

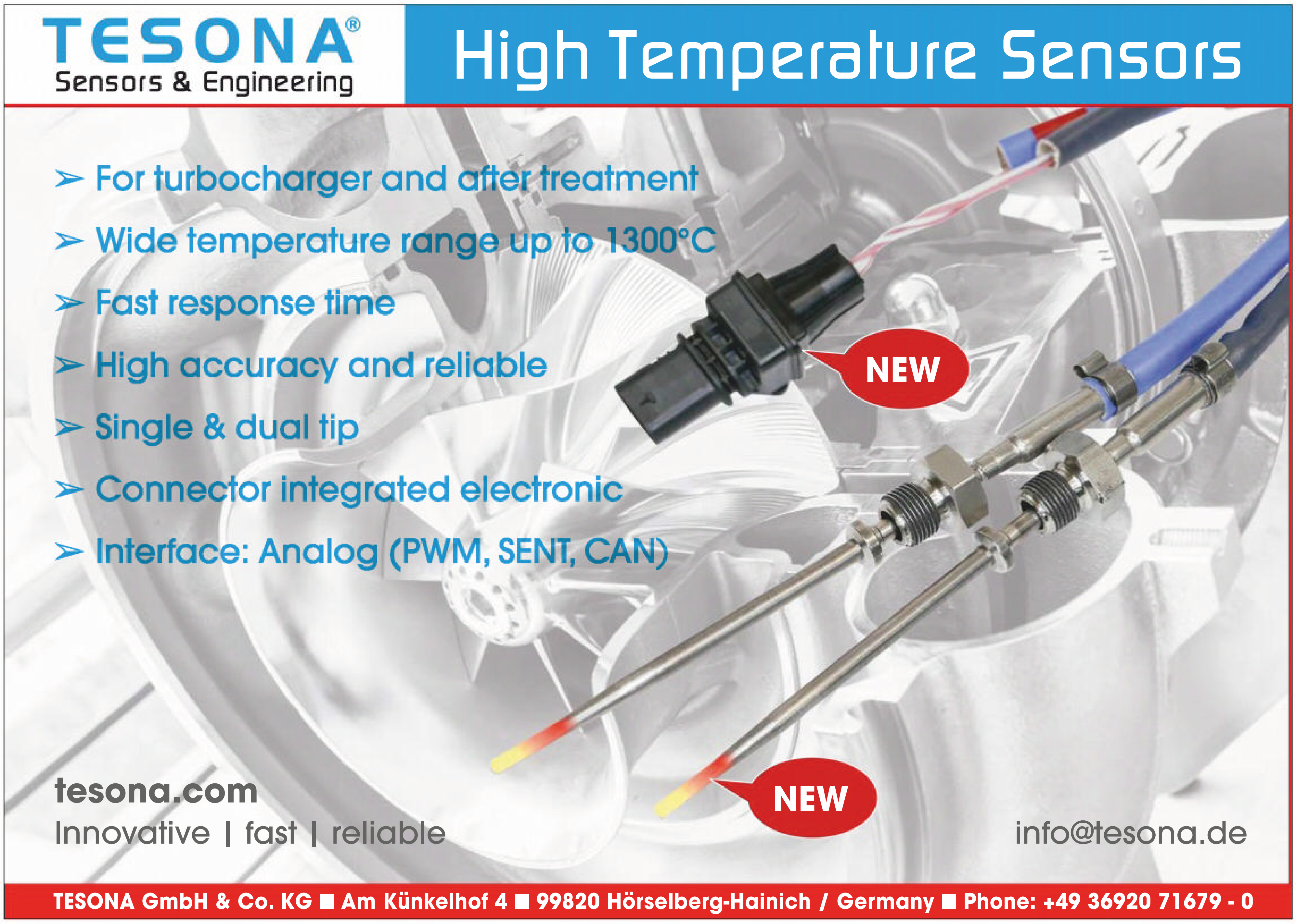
Quiet revolution

Advances in combustion modelling processes have allowed massive leaps in terms of combustion optimisation, which has been instrumental in bringing us to the high efficiency level we are at today.

There's more to it than just clever engineering though, as David Salters emphasises: 'A part of the journey to improved engine performance is of course the engineering, but often the people behind these achievements, and the processes that allow them to develop the tools and technology, go unappreciated. None of the advancement happens without a really competent and ambitious team behind it.'

But where might these advancements take us in the future? 'There is a growing trend in control for peak cylinder-by-cylinder pressure detection,' concludes Sam Borgman. 'The benefit is to have the freedom to precisely tune each cylinder's ignition advance and injection to bring a uniform combustion in each cylinder to really extract maximum performance.'

Most important to look forward to, however, is the transfer of this technology from motorsport to road cars, where increased efficiency will take us a significant step towards reduced CO_2 emissions. This is the year that manufacturers face heavy fines for not meeting stringent targets and motorsport could be at the heart of that development technology.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Email: racecarengineering@subscription.co.uk
Online: www.subscription.co.uk/chelsea/help

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

Subscription rates
UK (12 issues) £89
ROW (12 issues) £100
racecar@servicehelpline.co.uk

Back Issues
www.chelseamagazines.com/shop

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

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

THE CHELSEA MAGAZINE COMPANY LTD

www.racecar-engineering.com

The moving target

The delay to the various schedules due to coronavirus has left race series, manufacturers, teams and drivers, as well as technical support staff, with an interesting squeeze on their time before the end of 2020. The longer the shutdown continues, the less time is available to hold races in the remaining autumn months in Europe before the weather becomes poorer for racing. As this is written, the Belgians and Germans have cancelled all large gatherings to the end of August, although there are special meetings taking place to see whether or not sporting events can be exempt from this ban.

While racing fans are starved of competition other than sim' racing, race teams are faced with the prospect of either furloughing staff or shutting down altogether until a clearer picture of when they can restart work emerges. When racing does get going again, everyone will need to start making decisions in a hurry. Porsche recently confirmed it would prioritise factory competition for its drivers, mechanics and teams, leaving the customer racing departments needing to find their own drivers for various events, and possibly leaving some races without the support that was expected.

The clash

Before the Belgian and German shutdowns there were only two clashes in Porsche's GT schedule, revealed director of motorsport, Pascal Zurlinden. Now, however, with the Spa 24 Hours moved to a date later in the year, and a calendar to be built around it, there will almost certainly be further clashes that will create the need for alternative choices to be made.

With additional time on their hands, a lot of people are heading down memory lane

It is not only manufacturers considering where to place their drivers. For many, it is critical there are as few clashes as possible in a normal racing calendar so they can compete in multiple series. As well as the opportunity to earn being reduced, teams who normally farm out their engineers and mechanics to other teams in non-competing series will see further reductions in opportunity there. It will also be more challenging for suppliers to the individual series as they will be forced to make decisions where to send key personnel.

Porsche driver, Kevin Estre, highlighted another potential side effect around this new schedule; if Le Mans goes ahead in September as planned, the teams have already by regulation selected their tyres for the race originally scheduled for June. The weather is likely to be much cooler in France in September, certainly the nights will be three hours longer, so tyre choice made by all teams so far in advance will almost certainly be wrong.

However, while the crisis could be considered all doom and gloom, there are some bright spots. With additional time on their hands, a lot of people are heading down memory lane, and I was inadvertently taken there during April. On social media I was tagged in looking back at GT racing in the late 1990s and early 2000s, and I remember those races with affection. The cars were fantastic, the drivers operated under the radar and were allowed to get away with far more than today's rather more polished products. The racing was more about the competition than about marketing and was fun.

You had to be there

I often returned home to have to explain to my family that no, I hadn't made any money attending these races, but I had to be there. It's challenging to explain that to a young family and have them understand when they are not involved in racing, and when my wife was considerably more successful than I.

To be honest, standing in an empty paddock, with empty grandstands, with drivers wondering how they could possibly sell this package to their sponsors, I sometimes worried that the story to the family wouldn't seem in any way convincing.

But the teams were led by giant characters who would sacrifice everything to get the car on track. While Lawrence Pearce and I rarely saw eye-to-eye, he was one of the purest racers I ever met. Such were his exploits that last year a fictional book was written by someone who was closely involved in the team at the time. Everyone was called a 'clown' in the book, though Lawrence used considerably more colourful language at the time.

On track, the Lister Storms battled the factory Chrysler Vipers, then the customer Vipers, before the GT1 era started to come on song in 2004. Winning was everything for Lawrence, especially when the odds were stacked against him.

Back then, the paddock was something of a travelling circus. There were a lot of laughs, some extraordinary sights and sounds (I can't forget standing on a makeshift bridge on a street tack in Bucharest as a V12 Lamborghini hit the brakes from high speed and downshifted under my feet in preparation for taking the first corner) and we all had a lot of fun. Maybe, when the current unimaginable situation is resolved, racing will veer back there a little more in future!

On a personal note, readers will notice that this month we do not carry a column from Ricardo Divila. He has been unable to work recently and we wish him well in his recovery.

ANDREW COTTON Editor