>> Leena Gade returns to IMSA's pitwall for Mazda – see p5

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September 2020 • Vol 30 No 9 • www.racecar-engineering.com • UK £5.95 • US $14.50

Alfa Romeo C39

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The ‘new normal’

Racing returns with a shake up of team structure, functions and roles

We’re racing again! After a five-month pause, the IMSA WeatherTech SportsCar Championship re-started at Daytona International Speedway on July 4, right where it left off at the end of January.

The re-start provided us with a welcome change, but also a new challenge. I’m happy to admit I felt apprehensive about going on a ’plane again, and the prospect of wearing a face mask throughout a transatlantic flight.

Heathrow was eerily quiet, and the Department of Homeland Security check freaked me out when they said they had been waiting eagerly to meet me! The ’plane carried 60 passengers to Miami and there were only two of us in my cabin, so I felt safe, and going through security in Miami for my connecting flight to Charlotte was nice and quiet, too. But then boom! The connecting flight was packed, and there was no social distancing at all. So, feeling a bit traumatised upon arrival in Charlotte, I went straight to bed.

New protocols

IMSA has tried to bring back racing as soon as possible, and that meant new protocols. Both Daytona and Sebring were restricted to 15 people per car, including drivers and team management. What that means for everyone is a total shake up of team structure, functions and roles. At the best of times, established teams have developed a hierarchy and work schedule around the team they believe can win races and championships. Maybe it should be easier than it seemed to adapt but, knowing from larger teams how much more you can do with resource, it’s daunting to reinvent the wheel.

Add to the mix the fact we had only just fully taken the helm of the Mazda Motorsport race programme and there are two possible outcomes: either it works, or it doesn’t.

Taking a core group of personnel over from last season meant the basic function of the team took a familiar shape. Expectations and communication lines had to be formed and managed in a matter of weeks. And then possibly the hardest and most untrusted part of the equation: team communications to those outside the track in Toronto and the UK.

A reduced number of crew members means new challenges for teams

When you have never had a high-speed internet link, the cost is the first shock you have. This is often followed by surprise at how to set things up, before a touch of cynicism that everything will work first time. Maybe that’s just me, but at Daytona it all worked perfectly. With intercoms plugged in, my performance engineer was talking to me like he was there, only invisible. Any time the mouse moved on the telemetry screen of its own accord, I found myself mildly impressed that our communications hadn’t stumbled.

That first race event was challenging. Daytona in July is a very sweaty place, and we had two major thunderstorms that threw schedules into disarray. Teams were restricted to their garages and not allowed to mingle, and supplier support engineers were not allowed entry into our garage. That made it quite a surreal experience, with an almost odd air of isolation within our own bubble.

Eventful race

I race engineer the no.77 Mazda for Multimatic and we had an eventful race. On the back foot after no running in FP1, FP2 was a bit better and we took second place in qualifying. I’ve never qualified below pole at Daytona so this was annoying. The race didn’t pan out as planned for the no.77 but, with the sister car taking the win, it was a rather brilliant one-two for the team.

As a team, we set out to do what we needed to: finish a race while working in this ‘new normal’ environment, and that’s what we did. As a new team who don’t know any different to operations with 30 people per car vs 15.

I found it refreshing that back at the workshop, the dynamism and resourcefulness of the crews has meant our workload, though high, has been incredibly efficient. There have been no stupidly late nights and, although we’ve worked six-day weeks and had a large issues list, we went into Sebring two weeks later as a massively improved team.

During lockdown, at home with my mum, cats and an incredible vegetable patch, I didn’t miss racing. It was a time to chill, something I haven’t done since my short IndyCar stint. And it was just the tonic I needed because coming back to racing, I’ve found a new energy and vigour that I last had during my Audi days.

The challenge to use as few people as possible to run a team isn’t one you often encounter, and a few improvements have been quickly noted. With robust internet links, we’ve increased efficiency and reduced costs as less people at the track means less money spent on travel and hotels. Our drivers now strap each other in during a stop, so no driver helper either.

To make strides between races, you need to debrief, and we’ve been disciplined with a small team into doing this two to three days after an event. That gives us time to make fixes before the next race. It still needs refinement, but distributing the tasks has been less disruptive than I thought. There have been stumbles, but overall efficiency has been good.

Whilst the US currently has some eye-watering numbers of Covid infections, everyone on the team has taken precautions not to leave themselves exposed and IMSA has done an incredible job keeping us all safe at the track. That’s helped confidence going back to racing.

Daunting as it was to travel to Florida twice in three weeks, our job was simple – get championship points, and that’s what we did. We adapted and evolved and I firmly believe this has been for the better as we’ve been forced to think laterally to get the same result.

More of the same please, the 2020 challenge so far has been quite the buzz!

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

The challenge to use as few people as possible to run a team isn’t one you often encounter

Representative inspiration

Increasing diversity can only be a good thing for motorsport

In my years as a motorsport engineer, a particular memory that will stay with me is a time I attended an MIA conference in 2019. It was held at Force India's HQ and lots of senior motorsport representatives were present. It was a great event as I had the opportunity to network and engage in some very interesting conversations, but rarely in my adult life have I felt 'all eyes on me' in such an intense manner. Reason being I was the only attendee of dark skin, and I definitely felt it.

There was no overt negativity aimed towards me, but I felt a strong sense that, because of my appearance, I was an unknown and extraordinary quantity. I felt the uncertainty and unfamiliarity that comes with being a black man in a predominantly white space.

While I feel it's important to add that, professionally, I would consider that day a positive experience, it certainly drove me to examine why I am such an unfamiliar sight in those spaces, and why there is such a stark lack of diversity in motorsport engineering.

Where do they go?

I went to Sussex university, where my engineering classes were very ethnically diverse. Perhaps 50 per cent of my graduation year was of non-white heritage, so I'm aware there are many qualified black and 'other' engineers out there. But why are they not making it to motorsport?

It's not for lack of talent, nor for lack of interest in the sport. The show of support from the black community to Lewis Hamilton winning his first Formula 1 championship is testament to that. Powerful indeed. I can only attribute this lack of diversity to the presence of real, or implied, barriers to entry. After I graduated I never felt motorsport was inclusive to those that don't fit a specific, narrow path to entry. The main route into high-level motorsport pivots around securing graduate placements, seemingly only offered to candidates from a select number of prestigious, not-so-diverse universities.

When one of the most highly regarded representatives of motorsport exerts that 'The institutional barriers that have kept F1 highly exclusive persist,' we must listen. So what's really going on? Without understanding why, it's impossible to implement a solution. As engineers, we know this more than anyone.

With the focus it has been receiving in recent weeks, motorsport has seemingly shown itself to be open to the discussion that its racial diversity needs work. There is a wealth of data to support the advantages it brings to productivity, employee engagement and the value gained through different approaches to problems.

A wealth of untapped talent from the BAME community has not made it to top flight racing

Motorsport is unique within engineering in that it requires us to draw from and utilise learning from such a wide range of engineering disciplines. It's also a form of competition, and nothing drives advancement and innovation like competition. But as an incubator for technology relevant to the wider engineering world, it has an importance to us all and, while the spectacle is great, we have to ask ourselves 'what is our real objective here?'

So, what might action for diversity and inclusion look like? An intelligent place to start is with examining the concept of cultural memes. It's appropriate here in the sense that they have the power to encourage or discourage certain behaviours, desires and beliefs. The lack of black representation within motorsport establishes a cultural meme that it's not a space for us.

A world of heroes

Watching the world as a child, nothing is as effective at inspiring an 'I want to do that, too!' mentality as representation. Seeing someone you can visually identify within a certain space, whether its sport, politics, medicine or engineering is important . We all need heroes.

Before anything else, though, engagement must be cultivated. Outreach initiatives are great for this, and practices such as internship and mentorship programmes would give aspiring black engineers the much-needed experience required to get involved. I've tried to do my part in this by holding STEM and motorsport workshops for children in a number of London schools. The Hamilton Commission is working towards a similar aim, but ultimately that approach needs to start in the minds of chiefs and department managers, where meaningful changes to the organisation can start.

Let us dream further. Imagine the impact a black motorsport team would make in challenging perceptions and representing the sport, while also encouraging graduate engineers. Not to mention the economic and commercial possibilities of engaging an entirely new demographic in the engineering, supply chain, advertisement and broadcasting of motorsport.

There's a lot of change happening in 2020. The process of change is initiated by a catalyst, which encourages reflection and consideration of where we are and where we're going. Let us all ensure we are part of that change.

Jahee Campbell-Brennan is a motorsport and automotive engineering consultant and director of Wavey Dynamics Ltd.
jcb@waveydynamics.com – open to dialogue

Without understanding why, it's impossible to implement a solution

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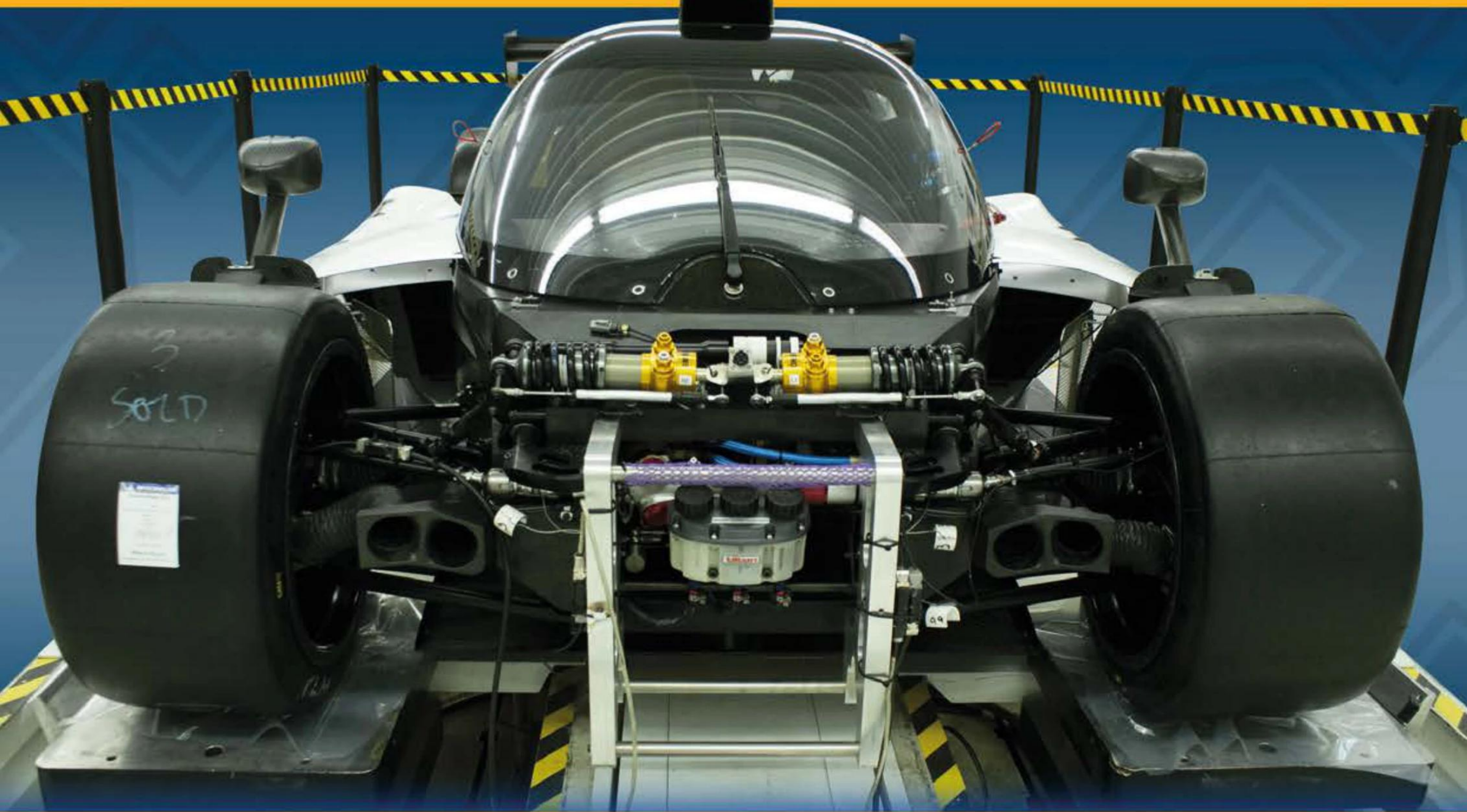

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Face value

It's what's under the skin (and behind the scenes) that counts

On face value, Andrew Green and his design team at Racing Point have done an exceptional job in producing a 2019 Mercedes-like car, a move which has propelled the team to much nearer the front of the F1 grid. However, results haven't quite met initial expectations.

No matter how intense the scrutiny, their engineers cannot know – just from observation, anyway – such details as the W10's suspension set-up and diff' settings, let alone PU and braking energy recovery calibrations. This information is crucial, in wet conditions especially. This might explain the poor performance of the cars in the Styrian GP's soaking qualifying, in stark contrast to their pace in dry practice.

In any case, having a good car, even a great one, is only going to lead to success in current F1 racing if the operation and preparation of it is virtually flawless, and the drivers able to consistently extract the maximum performance required. The team strategy and race tactics must be absolutely on the ball, too. Plus, of course, being on top of tyre management in all conditions.

All of this perhaps illustrated the BWT-sponsored team's relatively underwhelming race result at the first weekend at the Red Bull Ring, after such a promising qualifying. However, round two at this great little circuit redeemed matters in part, vital for the big-hitting Racing Point team.

Identical or not?

It's now when the team can capitalise best on its chassis performance, before it gets out developed by its competitors as the season progresses. At time of writing, however, Renault has just registered a protest with the FIA over the RP20's brake ducts. The French team claims they are identical to Mercedes' and therefore not permitted – perhaps hoping more such 'identical' parts might be revealed as a result?

While it's good to have another team near the front, a grid made up of copied designs is not what F1 should be about and one can understand the unrest this has created among many of the teams (although Mercedes have been conspicuously quiet). What has been highlighted by the competitiveness of a year-old concept is the equipment advantage the Mercedes drivers have consistently had.

Without taking anything at all away from Hamilton's mind-blowing pole lap, the Dual Axis Steering (DAS) fitted to the Mercedes W11 possibly gives a bigger advantage in the rain, due to the potential for achieving better front tyre heating and the greater corner turn-in 'bite' the driver-adjusted toe out might give.

I really don't know what Nikolas Tombazis and his FIA technical colleagues were thinking when they allowed Mercedes to develop this device. Just when agreement on the need for much-needed cost reduction is accepted, what is the point in nodding something through that adds complexity – and therefore expense if other teams must follow it – and is, at best, still questionable regarding its legality?

Racing Point's front brake ducts are under protest as Renault accuses them of being identical to last year's Mercedes W10. The case continues…

There is no denying the fantastic pace of the Silver, sorry, *Black* Arrows. Red Bull and Honda are clearly further away than they expected, which has to be quickly addressed if 2020 isn't to become another Mercedes win-fest.

I can't see Ferrari digging itself out of the hole it's made any time soon. Can the Reds' fall from fastest on the straight to one of the slowest be in part explained by the team kidding itself before over the real level of its PU's performance? Was it so blindsided by the advantage it had when exploiting the dubious loophole in fuel flow monitoring that it took pressure off other means of extracting engine power? If yes, and it's bitten the team's collective *derrières*, it serves 'em right.

On top of which, its chassis is poor, judging from both drivers' wet qualifying performance when sheer grunt isn't as important. It's not an excuse, but the very costly *faux pas* executed first by Vettel and then Leclerc in successive races can, at least in part, be attributed to low qualifying positions. This would explain their almost desperate overtaking manoeuvres, trying to make up places as early as possible.

Lack of understanding

It's difficult to understand how an operation as well-funded, resourced and experienced as Ferrari can produce a new car, under relatively unchanged technical regulations, that has followed the wrong aero concept for the second successive year. There's a serious lack of understanding and direction in the Italian team right now, which is not good for F1, especially with Mercedes so dominant.

Mercedes' rapid fixing of its first race gearbox weakness in less than a week contrasts with Renault failing to prevent a repeat of the radiator leak issue that took out one car from each event. Remedial action was taken, it appears, but it wasn't sufficiently effective. Does this highlight the difference in reaction time and thoroughness of the German vs the French team? Does it also show why Mercedes is at the top of the F1 mountain, while Renault is still struggling to climb it?

A better pace was evident from the black and yellow cars as some compensation, good news for Alonso.

I can't help wondering if Team Haas' ongoing lack of competitiveness may be partly due to its unique structuring of design, manufacturing and team spread over several countries. It worked well initially, but over time the drawbacks of remote working, time differences and, in my experience, inevitable defensiveness between the parties when things become difficult may now be a weakness. Regardless, its engineering strength remains badly below par. The American-owned and identified team is important for Formula 1 and Gene Haas needs to see positive results to continue spending.

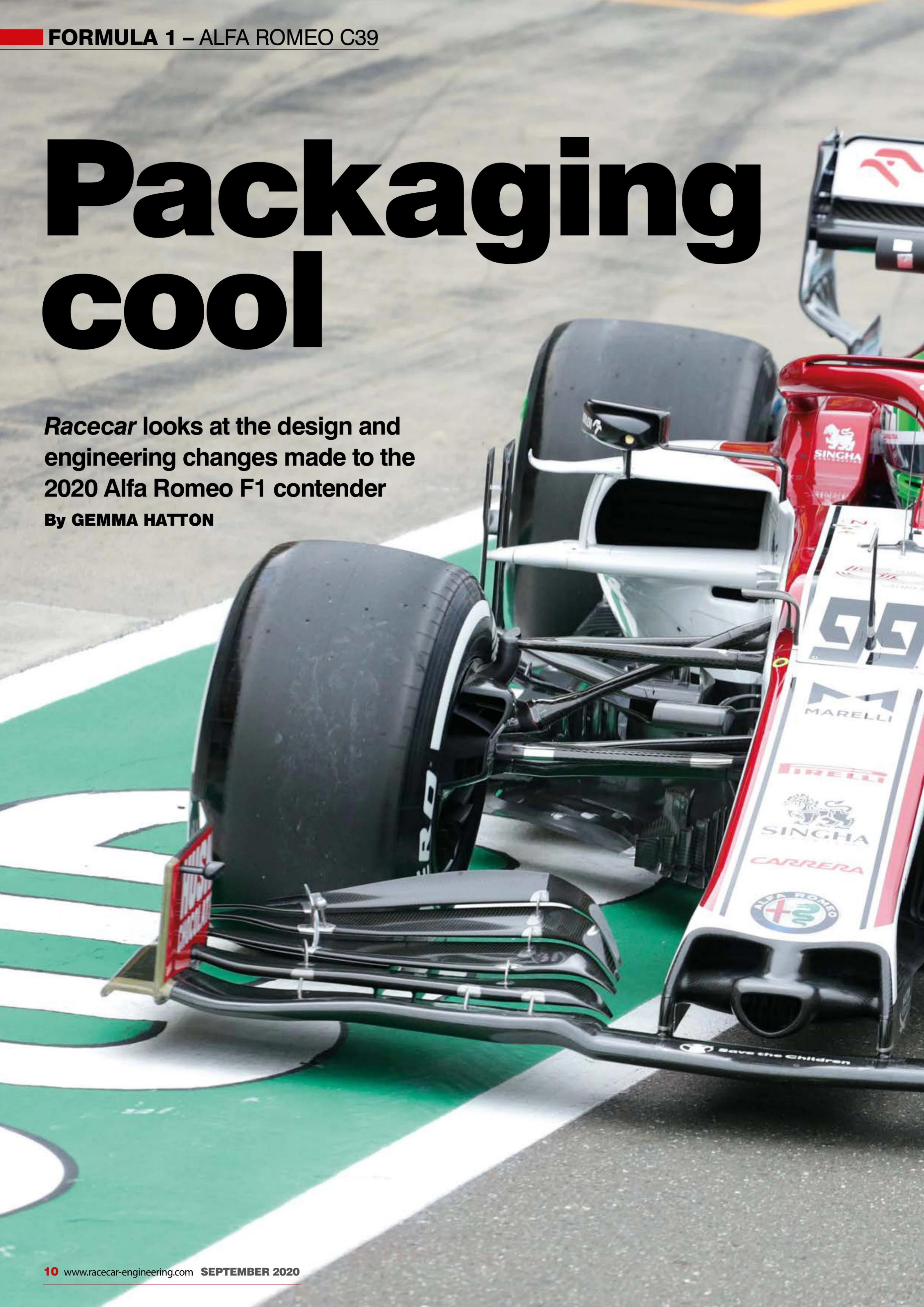
Fantastic job, though, for all involved in making these two welcome races happen.

A grid made up of copied designs is not what F1 should be about

Packaging cool

Racecar looks at the design and engineering changes made to the 2020 Alfa Romeo F1 contender

By GEMMA HATTON



‘It’s the usual process of constant improvement, but it’s a brand new car’

Jan Monchaux, technical director Alfa Romeo Racing

The front wing is the most extreme example of an unloaded design, where the height of the main element decreases from inboard to outboard and generates less downforce, but promotes outwash

For the second season running, one of the most interesting cars in the Formula 1 pitlane is not a Mercedes or a Ferrari, but an Alfa Romeo. Cast your mind back to the beginning of the 2019 season, when the technical regulations encouraged simplified aerodynamic design, with wider front wings, standardised end plates and complex structures on front wings banned. Alfa Romeo's C38 arrived at pre-season testing with the most extreme example of an 'unloaded' design, which quickly made it the talk of the town.

As a reminder, this is where the height of the front wing elements dramatically taper downwards from the nose to the end plates, reducing downforce but promoting outwash. This year's C39 generated slightly less technical discussion at pre-season testing, but the concepts under the skin of the red and white car are just as radical.

The 2020 season is one of anniversaries. Not only does it mark 70 years of Formula 1 itself, but also 50 years of Sauber Motorsport. During that time, the team has competed in 28 F1 seasons, the last two under the Alfa Romeo banner, a manufacturer which in turn is celebrating its 110th anniversary this year.

Throughout Sauber's 486 F1 race career, the team has claimed 27 podiums and scored a total of 922 points. The Swiss outfit has also been successful in sportscar racing, winning the 24 hours of Le Mans in 1989 and securing the crown of overall sportscar champions two years running in 1989 and 1990.

Visible changes

Like most 2020 cars, the C39 is an evolution of last year's contender, as teams try to balance developing this year's racer whilst also laying the foundations for the revolutionary 2021, now 2022, regulations. That said, the C39 has seen its fair share of changes.

'The C39 is a natural evolution of last year's car, even though it doesn't share a lot with its predecessor,' reveals Jan Monchaux, technical director at Alfa Romeo Racing. 'We have been improving our car but, apart from maybe rims and tyres and some internal components, there is barely a single visible part that is the same. It's the usual process of constant improvement, but it's a brand new car.'

This is immediately visible, as the C39 sports a new nose design, along with new bargeboards and brake ducts. An s-duct has also appeared on the Alfa for the first time and the shape and set-up of the engine air intake has seen some significant changes, hinting towards an improved cooling strategy.

In terms of suspension, both front and rear have been developed, along with the dampers, to make the car easier to drive over the kerbs. The front upper wishbone is now exposed, with the track rod relocated to a more aerodynamic-friendly position, allowing more efficient use of space for the higher scoop inlet of the new brake ducts.

The bargeboard area of the C39 has seen significant development when compared to last year's C38 (right)

The C39's s-duct outlet is low down the nose and flat, in contrast to the higher, protruding outlet of the Red Bull RB16 (right)

Aggressive cooling

Amongst a few very interesting technical highlights is the new car's cooling strategy. The team have chosen a more aggressive solution this year, and the result is a more conventional air intake design.

'We have followed some obvious trends with the cooling, and therefore the packaging, which led us to change the whole concept,' explains Monchaux. 'We used to have a kind of blade and now we run a sort of A-shaped roll hoop. The aim is to simply better re-distribute the cooling between the sidepods and the centre part of the car.'

To achieve effective cooling of the engine and gearbox, as well as the hybrid systems, clutch, hydraulics and suspension, a complex array of radiators and intercoolers are used. The location of these are predominantly split between the two sidepods and the centre of the car, underneath the top engine cover.

One of the most important considerations when a team defines its overall cooling strategy is to decide how much of that cooling should come from the sidepod coolers and how much should come from the centre coolers. For Alfa Romeo, the focus was

'We've been making step improvements on the cooling within the sidepods, but it wasn't enough to then just say we can live with a much smaller radiator'

on maximising the performance of the centre cooler and, consequently, optimising the engine air intake, too.

'You want to achieve effective cooling in the most efficient way possible,' says Monchaux. 'From our own measurements and simulations we think that having a somewhat larger air inlet at the top is quite efficient because you have high energy air that is not disturbed by any kind of bargeboard, front wing or suspension. So, you have good quality air with a high mass flow compared to what you can get into the sidepods.

'On top of that, you also benefit from running the sidepods as tight as possible.'

Tighter sidepods mean a slimmer car, which improves overall aerodynamic efficiency. This is the main reason why most teams have focussed their efforts on improving packaging, streamlining sidepods and engine covers to achieve a more compact rear end. However, within those narrower sidepods, large radiators and the associated pipework all have to be packaged effectively and efficiently, and that's where the real engineering challenge lies.

'Either you have a technology, such as some of the top teams, who package all the coolers they need in a very small area and then you don't necessarily need to have coolers in the centre,' highlights Monchaux, 'or, like us, you want to package your sidepod coolers smaller. But there is only so much you can achieve with current radiator technology, so you still have x kilowatts that needs to be cooled, and that drives the dimensions of the centre cooler.'

High quality air

With the focus firmly on the centre cooler, the next challenge was to maximise the performance of the inlet to ensure high quality air feeds the radiator within.

'We wanted to maximise the inlet in the centre, and there we realised that the traditional roll hoop offers a little bit more margin to maximise the cooling than the one we had before because of the rules. With the current rules we also saw we were gaining performance with tighter sidepods,' Monchaux continues.

'We've been making step improvements on the cooling within the sidepods, but it wasn't enough to then just say we can live with a much smaller radiator. So, the rest of the cooling capacity we needed had to be put on the centre [cooler].

'To really maximise this, we saw that having a more aero-friendly inlet was beneficial so that's been driving the concept. Overall, in pure terms of weight, we're not talking about a lot, but it is slightly heavier than the previous topology we had.'

To make the sidepods smaller without sacrificing cooling potential, some top teams utilise twisted coolers within the sidepods, which means they can demand less cooling from the centre cooler and can therefore reduce its size. However, this technology does not come cheap, and Monchaux believes there are still further gains to be made without such an investment.

'If we could find ways to somehow have more intelligent cooling, and not have a separate circuit for everything, then potentially we could afford to use smaller coolers in the centre.

'If I could, I would do small coolers in the sidepods and almost nothing in the top engine cover so I could really optimise the

The unique two-tiered arrangement of the engine air intake has been refined to a more conventional A-shape on the C39, compared to the split oval on the C38 (right)

volume of the top engine cover, similar to the Ferrari, whose central cooler is probably five times smaller than ours.'

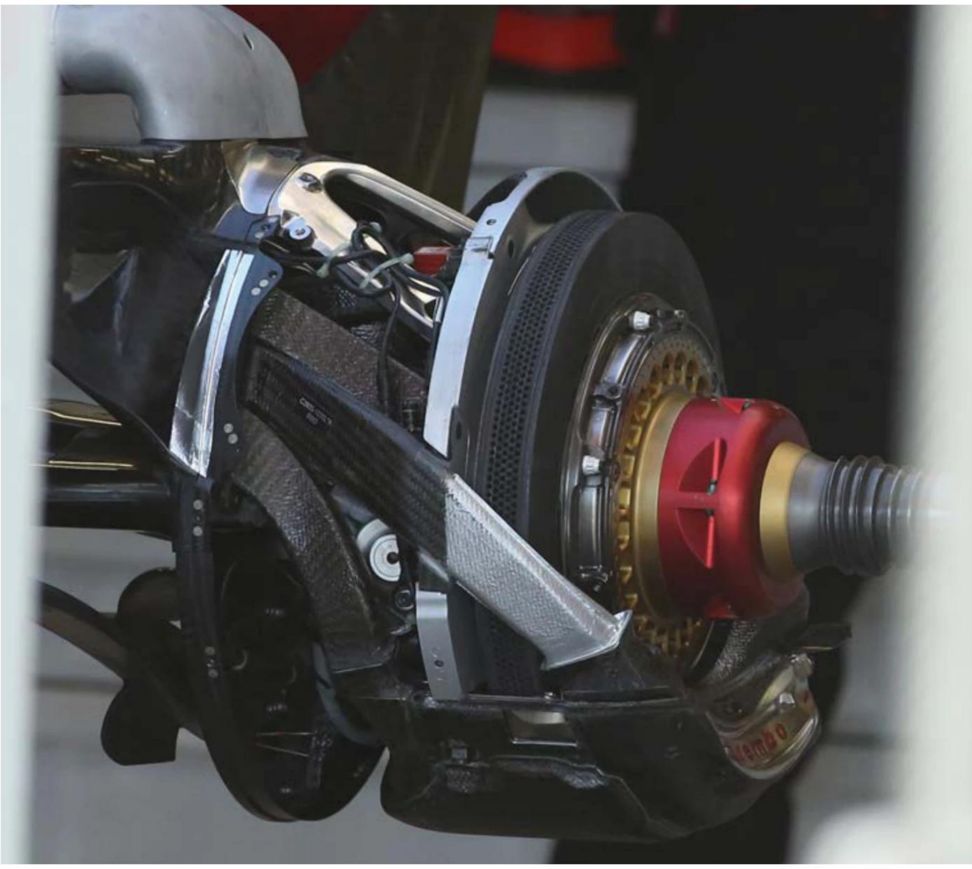
Exiting the coolers is hot air, which needs to be dealt with as effectively as possible to minimise its impact on any aerodynamic devices. 'You want to have high energy flowing above the diffuser so less blockage,' says Monchaux. 'Then it's about where do you exit the hot air from the coolers, and this is where the trends are also now converging.

'But where do you put the outlets? If you have it too low then you will spoil the diffuser, if you have it too high then you might pay the price on the rear wing, so it's about some optimisation work, which each team has to find for themselves.

'What you mainly want is to make sure that with the sidepod you have a lot of clean air following with the hope that you can also energise the diffuser sidewalls, so you don't want any blockages.'

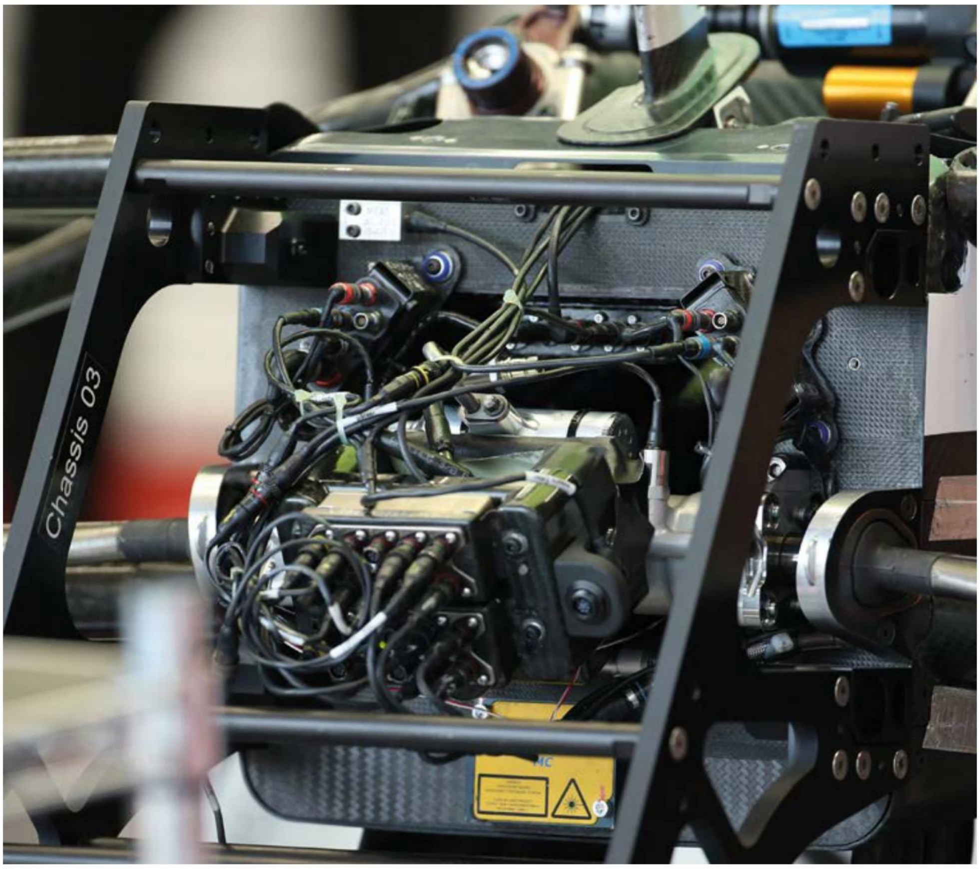
Unloaded philosophy

Naturally, aerodynamics has also been a key focus for the C39. The unloaded front wing philosophy of the C38 has been retained, but the shape of the nose inlet has morphed from a narrow slit into a rounded triangle.



The left rear wheel assembly of the C39, with the upright and cooling channels for the brake caliper and disc visible

The focus was on maximising the performance of the centre cooler and, consequently, optimising the engine air intake, too



Detail of all the electronics that are packaged within the nose assembly

'You've got mainly two schools of thought – teams either have a blown nose or they don't. Put simply, it depends on how you generate your front balance,' highlights Monchaux. 'It's quite obvious we don't have a very loaded front wing, especially on the tips. But we still need to generate some balance, and there are several ways to do that.

'For us, having those features on the nose is somehow helping us to generate additional balance. It may be a consequence [of running an unloaded front wing] because we need to generate some load on the front axis, but we don't necessarily do it massively on the tips, we need to do it somewhere else.'

Another aerodynamic change for the C39 is the s-duct. Although run at a few races last year, this will be a permanent feature on the C39. This is where inlets, either at the front or side of the nose, ingest turbulent air surrounding the front wing through an s-shaped duct within the nose and release it towards the cockpit. The cockpit is an area of turbulence, so routing dirty air from the front wing to this area has less overall impact on the aerodynamics than if this flow were allowed to continue downstream towards aerodynamic devices such as the underfloor. One by one teams have been gradually adopting this technology over recent years and, among this year's contenders, McLaren is the only team not to run one.

The Alfa Romeo's s-duct design follows that of Mercedes, where the outlet is completely flat and just below the bridge of the nose. Conversely, the s-ducts on the Red Bull and Alpha Tauri are located on the bridge of the nose and protrude outwards.

Monchaux explains their purpose: 'These s-shaped ducts are just a slightly more elegant way to drive the air we are catching at the inlet of the nose and blow it where we think it's important to be blown.

'It's also saved us a little bit of weight and it's slightly better for aero, but I wouldn't say it's a game changer.'

Incorporating channels into the structure of the nose presents its own manufacturing and design challenges. 'It's quite a challenge for the structure as you still need to crash the nose and that crash test is not inferior. Clearly, when you have some exotic internal ducts that are eating space that you would like to put some structure in, it makes life a bit more complicated for the guys in the design office.

'In this case, the aerodynamic gains are sufficient to justify the nice challenge for the FE [finite element] and composite guys.'

Restricted development

Looking at the future picture of Formula 1, which is only now beginning to come back into focus, 2022 will be the year F1 enters a new era, with a radical new set of technical regulations. Consequently, all 25 days of the 18in tyre development programme, which was originally scheduled to take place this year, have been postponed to 2021.

Developing a mule car for tyre testing, in conjunction with competing in a race season and trying to set everything up for a revolutionary set of regulations, is a tough task for any team. Yet despite this, all teams committed to developing a mule car for the original tyre tests and so will most likely take part when the programme re-starts in 2021. In other words, learning about the new 18in rubber is deemed important enough to justify the cost and development time required to get ahead for 2022.

Unsurprisingly, though, the regulations governing mule car development at this time are very restrictive. 'It has to be an old car, and the changes you are doing have to be minimal to accommodate the new tyres,' explains Monchaux. 'As a small team, we also didn't want to spend a fortune on developing it. So we effectively raised the complete car, cut the sides and dropped the floor to make space for the new tyre. That then allows us to run exactly the same suspension we would normally run.

'It has been a relatively reduced exercise to limit the resources devoted to this. At the end of the day, you will be running a car with new tyres, but not so new aero, so you need to take all the results with a pinch of salt.

'These tests will be important for the tyre engineers to start to get to know the tyres, but it's like a sneak preview.'

Challenge ahead

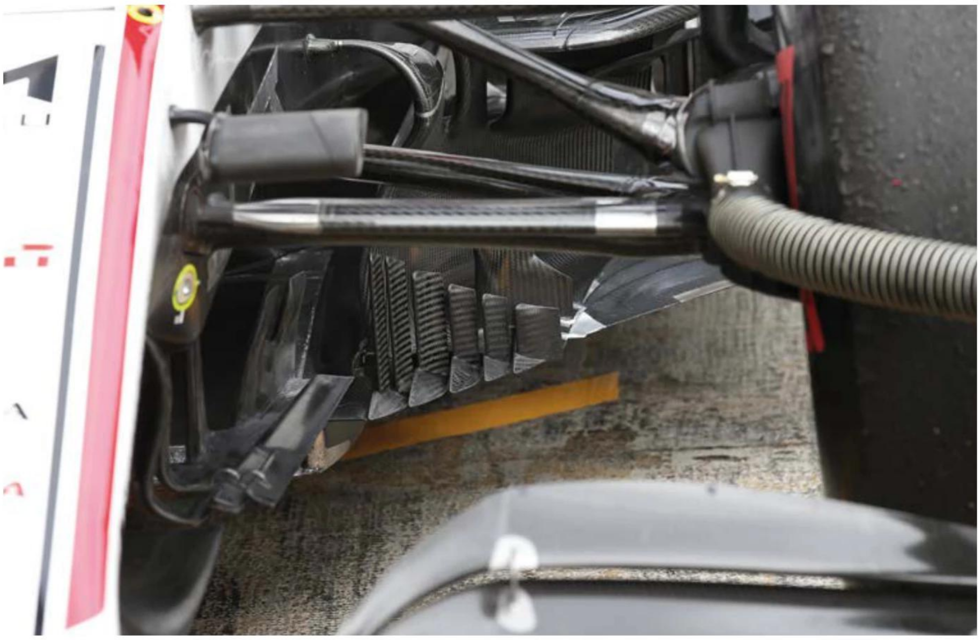
Optimising the suspension to not only accommodate the new low-profile tyres, but also maximise aerodynamic performance, will be a fascinating challenge for all teams ahead of the new rules introduction in 2022.

'The front and rear suspension are going to be an interesting topic from a structural point of view, but also for the aerodynamics,' agrees Monchaux. 'Because all the bargeboards are disappearing and all the artefacts we use to try and control the flow around the front tyre are disappearing, too. I wouldn't be surprised if teams spend an incredible amount of effort on the front suspension to try and get bits of the effects they used to generate with other means.

'On the rear, it's also going to be very interesting because of the relatively aggressive diffuser and undertray. Depending on where you want to position your car, you obviously don't want to have the lower wishbone collapsing into the diffuser roof, so I'm quite curious to see where we will end up.'

With 2020 Monchaux's first full season as technical director at Alfa Romeo, it will be fascinating to see how the C39 performs. But maybe more importantly, how its performance improves throughout the remainder of the season.

The 2020 season was always going to be a challenging one for teams as they prepare for the monumental changes heading the way of Formula 1 – and that was before an unprecedented global pandemic threw the whole thing into disarray. Now, with a drastically compressed season that only started in July, teams will be pushed to their absolute limits, financially, technically, physically and mentally.



Both the front and rear suspensions have been developed to make the car easier to drive over kerbs

TECH SPEC: 2020 Alfa Romeo C39

Power unit:
2020 Ferrari Hybrid 1.6-litre V6; 90-degree bank angle; 80mm bore; 53mm stroke; four valves per cylinder; max speed: 15,000rpm; direct injection at 500bar; battery energy: 4MJ per lap; MGU-K max speed: 50,000rpm, max power: 120kW; MGU-H max speed: 120,000rpm

Chassis:
Carbon fibre monocoque

Front suspension:
Double wishbone, inboard spring and Multimatic pushrod-actuated dampers

Rear suspension:
Multilink, inboard hydraulic pull rod-actuated suspension

Brakes:
Brembo six-piston calipers; Brembo carbon-composite discs and pads

Transmission:
Ferrari eight-speed, quick-shift, carbon gearbox, longitudinally mounted, carbon-composite clutch

Dimensions:
Length: >5,500mm; width: <2,000mm; wheelbase: approx. 3,600mm; height (without overhead camera): 950mm; track width front: 1,650mm, rear: 1,550mm; weight: 746kg minimum (including driver)

'We effectively raised the complete car, cut the sides and dropped the floor to make space for the new tyre'

High frequency control

The rise and fall of inerters in motorsport

By LAWRENCE BUTCHER

Mechanical inerters, comprising a rotating mass on a ball screw, first appeared in Formula 1 in 2005, and for some time McLaren had a monopoly on the technology, thanks to a smart commercial agreement with the original inventor of the device, Professor Malcom Smith at the University of Cambridge.

The team managed to keep a lid on its new tuning device for some time, referring to it as J-dampers, the J standing for jounce (a combination of jolt and bounce). It even came up with a name for units of inertance, zogs.

From the very start of their development for racing, in 2003, Penske Racing Shocks was involved with inerters, but could not use any of their knowledge in the public domain until 2008, when the company entered into a commercial agreement with Cambridge as McLaren's exclusive deal lapsed.

Since then, inerters have become commonplace on cars in the series and have been subject to extensive development, with a number of different variations on the theme now used. And from its single-seater roots, the device has found favour in many other areas of motorsport, too.

The most obvious applications were in series with similar budgets and development needs as Formula 1, for example, the LMP1 class at Le Mans. A glance at the back of either Porsche 919 or Audi R18 reveals the presence of an inerter. IndyCar also adopted the device, with the first appearing on a DW12 in 2012. But outside of circuit racing, inerters have also seen use in some surprising places.

One of the first markets for Penske's inerters, which may come as a surprise to some, was NHRA drag racing in the US. Specifically, the Pro Stock class, arguable the most refined cars currently racing on the quarter mile. In a field where the top 20 entrants are often separated by just a few hundredths of a second, any incremental advantage is seized upon, and inerters provided such an advantage.

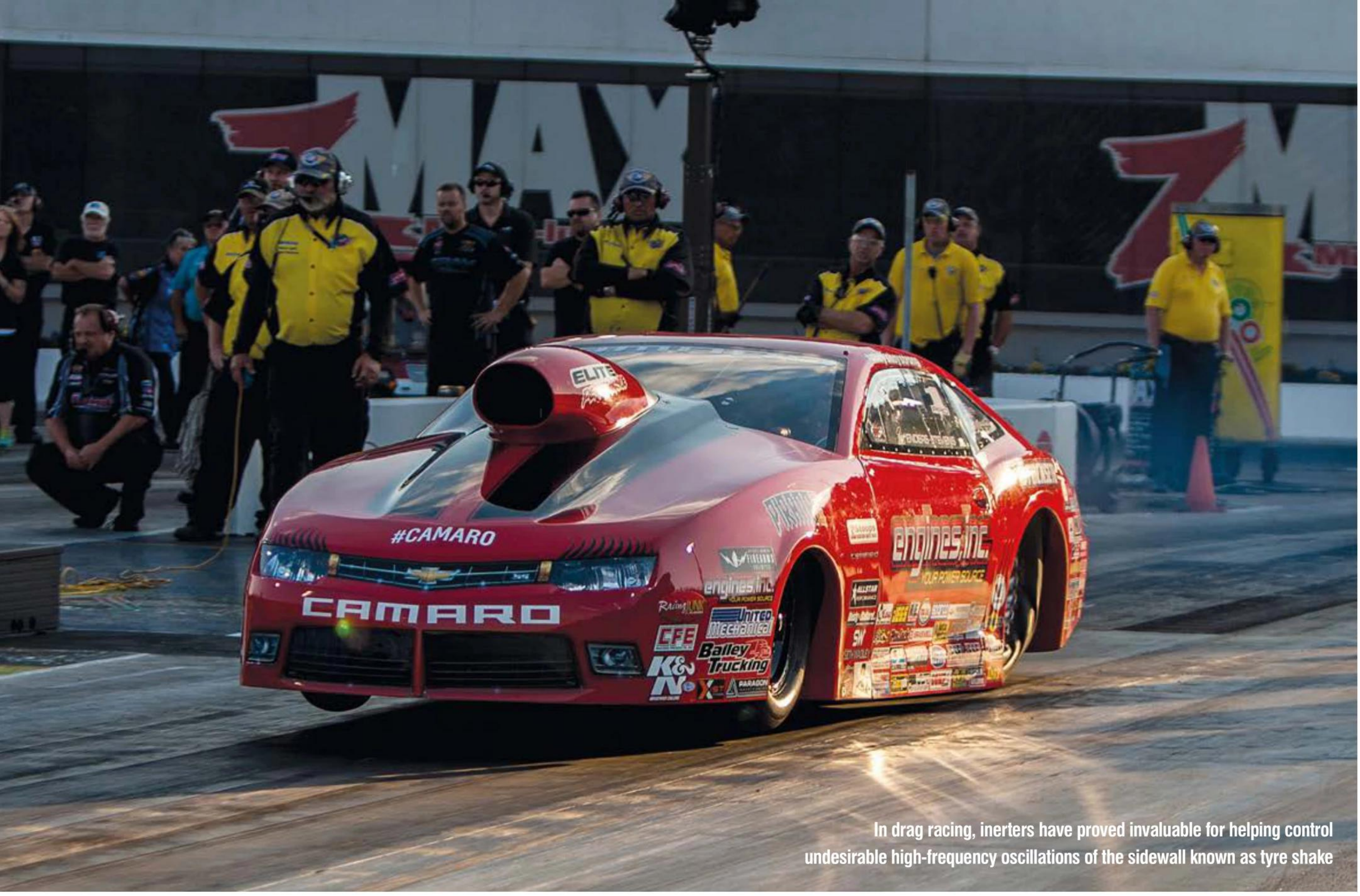
Up on the tyres

Why? One reason; tyre shake. This is a phenomenon peculiar to drag racing where the rear tyres grip, then release grip, setting up a violent oscillation of the sidewall that feeds back into the chassis. Counterintuitively, tyre shake occurs when not enough power reaches the tyre. In drag racing parlance, when there is not enough drive at the axle to get the car 'up on the tyres'.

A drag car relies on a measured amount of tyre slip. If the tyre doesn't slip a certain amount, it winds up like a rubber band and the highly flexible carcass will deform so much the tyre climbs over itself.

In series such as Pro Stock, margins are so fine that crew chiefs push their set-ups to the limit, treading a fine line between tyre shake and smoking the tyres (the condition where the tyres lose too much grip and spin out of control). With the margins so tight, if they are too conservative with the set-up the car will be out in the first round of qualifying.

There are many ways to adjust how a 'doorslammer' drag car launches. The fuel delivery and ignition timing can be altered to



In drag racing, inerters have proved invaluable for helping control undesirable high-frequency oscillations of the sidewall known as tyre shake

The inerter sits in the same position as a regular damper but works in a different way, helping control wheel speed and take energy out of the tyre in a shake scenario, allowing for more consistency with a given set-up

'It allows you to tune the car in a window that was just not possible before'
Aaron Lambert, Penske Racing Shocks

change power delivery to the wheels.

The clutch, where one is used (lock-up torque converters are now the favoured option in Pro Mod, which we will come to later), is a multi-plate unit with its lock up controlled by a series of adjustable, weighted arms that increase clamping pressure as rpm rises.

It's effectively a mechanical traction control device. The rear suspension (always a four-link), combined with damper and wheelie bar settings can also be altered to adjust the dynamic weight transfer on launch.

Tuning window

This is obviously a very basic summary of an exceptionally complex juggling act, but get any of these settings wrong and the tyres will either shake or spin too much. Here is where an inerter can help, as it provides a means by which the oscillations in the tyre can be controlled. Aaron Lambert of Penske explains: 'It allows you to tune the car in a window that was just not possible before. The main thing we used to deal with in drag racing is the fact that as you are trying to accelerate the tyre, you get high-frequency movements and fast accelerations in the tyre sidewalls. Once that happens, the tyre starts to shake.

'What the inerter does is, instead of letting that shake continue to build, it takes the energy out of the tyre and allows the tyre time to recover. It also allows the guys to miss the set-up a bit more, giving the crew chiefs a bigger window to work within. That lets you be more consistent.'

Penske's drag racing inerters look externally similar to their standard shocks, but inside the damper tube there is also a ball screw arrangement. Unlike in a formula car, where an inerter often takes the place of a third element, drag cars run either MacPherson strut or, in some cases, double wishbone suspension.

'The hard part about that is making everything compact, while retaining the functionality,' Lambert notes. 'There is not one part of the inerter damper that is the same as the regular damper, beyond maybe the mounting points.'

They are also about five times the price of a standard damper, but in Pro Stock, where the general rule of thumb is $100,000 per 100th of a second and consistency is everything, they quickly became a must-have item for all the top teams.

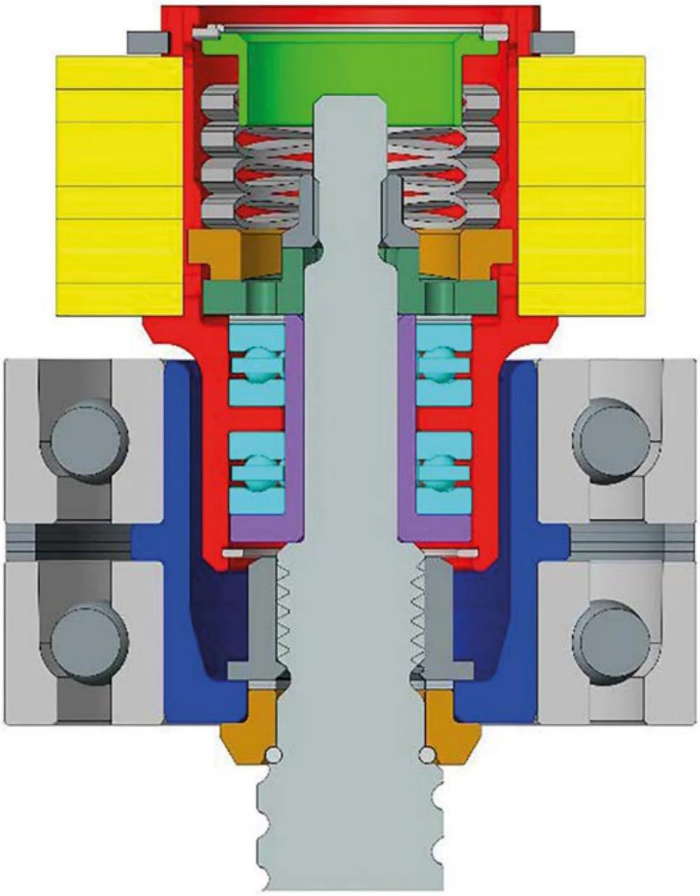
'They let you tune the car differently, and [they] may be two hundredths faster. You can install the units and it will let you run a different gear package, a different engine tune or a different four-link set-up that will let you put more horsepower to the ground. With the inerters you have a lot more control over wheel speed,' explains Lambert.

In short, drag racers can run harder than track conditions would otherwise allow with a non-inerter-equipped car.

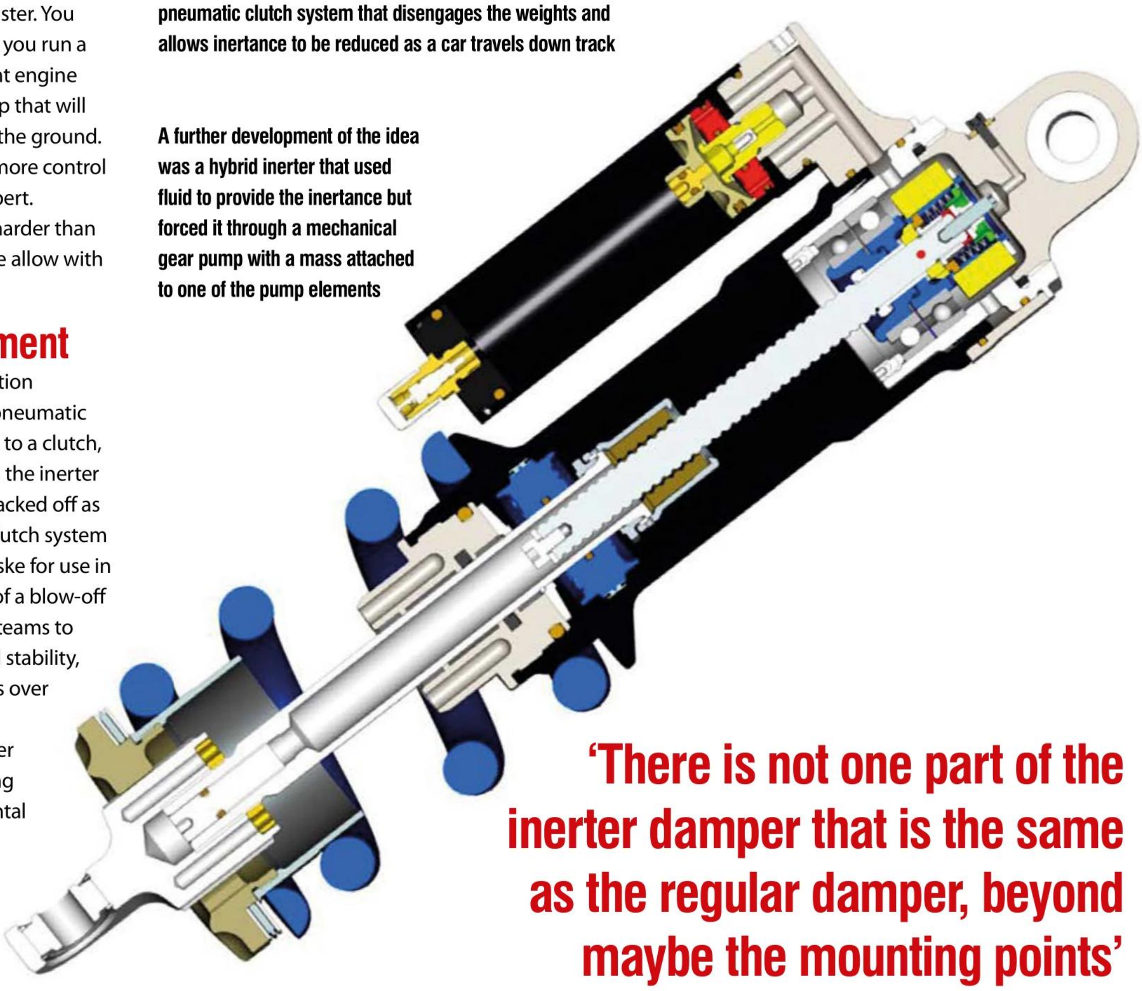
Pneumatic adjustment

One very drag racing-specific option Penske offers on its inerters is a pneumatic adjustment system. This is linked to a clutch, which disengages the weights in the inerter and allows the inertance to be backed off as the car runs down the track. (A clutch system was originally developed by Penske for use in IndyCar in 2012, along the lines of a blow-off valve on a damper. This allowed teams to run high inertance for low-speed stability, but not suffer any adverse effects over kerbs or high-speed bumps).

Drag strips tend to be bumpier towards the finish line, and having a too stiff set-up can be detrimental when running at 250mph+. The pneumatics are therefore controlled by a timer, which is pre-set prior to a run (in the same way all systems are in NHRA, by regulation).



Penkse drag racing inerters feature a timer-controlled pneumatic clutch system that disengages the weights and allows inertance to be reduced as a car travels down track



A further development of the idea was a hybrid inerter that used fluid to provide the inertance but forced it through a mechanical gear pump with a mass attached to one of the pump elements

'There is not one part of the inerter damper that is the same as the regular damper, beyond maybe the mounting points'

Aaron Lambert, Penske Racing Shocks

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'In drag racing, our tyres are just huge, undamped springs and they can go crazy when the harmonics get to a point that the tyres start shaking'

Rickie Jones, RJ Racecars

Clutch-equipped mechanical inerters enjoyed a brief period of acceptance in rallying (and Rallycross), where they were used to help control ultra high-frequency suspension and tyre movements, but were banned from the categories in 2018

Drag racers have been using pneumatically-adjustable dampers to alter the attitude of the car as it runs down the strip for some time, and this is an extension of that concept. '[Originally] we were only running the inerters on half the tracks we visited,' points out Lambert, '[but] with pneumatic adjustment, we can tune it to match the whole of every track.'

The effectiveness of inerters is confirmed by Rickie Jones of RJ Racecars, who run and build the multiple championship-winning cars of Pro Stock outfit, Elite Motorsport. 'In drag racing, our tyres are just huge, undamped springs and they can go crazy when the harmonics get to a point that the tyres start shaking,' explained Jones at an NHRA round in 2019.

'That is something the inerter has really helped with, especially as the tyres can get out of control really fast, moving at frequencies a conventional damper cannot deal with. The way that stuff has trickled down from Formula 1 is really cool.'

Pro Mod and Rally

Inerters did not stay the sole preserve of Pro Stock for long, and were quickly picked up on by racers in Pro Modified, too. This is the class that sees doorslammer cars with up to 4,000bhp, using nitrous, supercharged or turbocharged engine combinations to run mid-five-second passes at over 260mph. Interestingly, according to multiple NHRA Pro Mod champion, Rickie Smith, speaking at the PRI show in 2019, inerters work particularly well on cars with nitrous combinations, due to the fact the first shift point occurs very soon after launch (nitrous cars tend to run five-speed transmissions with lock-up torque converters).

'It is so critical because we are trying to change gear in a nitrous car a second into the run. Maybe at 1.2. That is right around the shake zone for everyone that runs big tyre cars [as all Pro Mods are]. It doesn't matter if you are talking Pro Mod, Top Fuel or Pro Stock. In that zone, the car is trying to fall off the tyre. The inerter stops that as soon as the tyre starts to shake.'

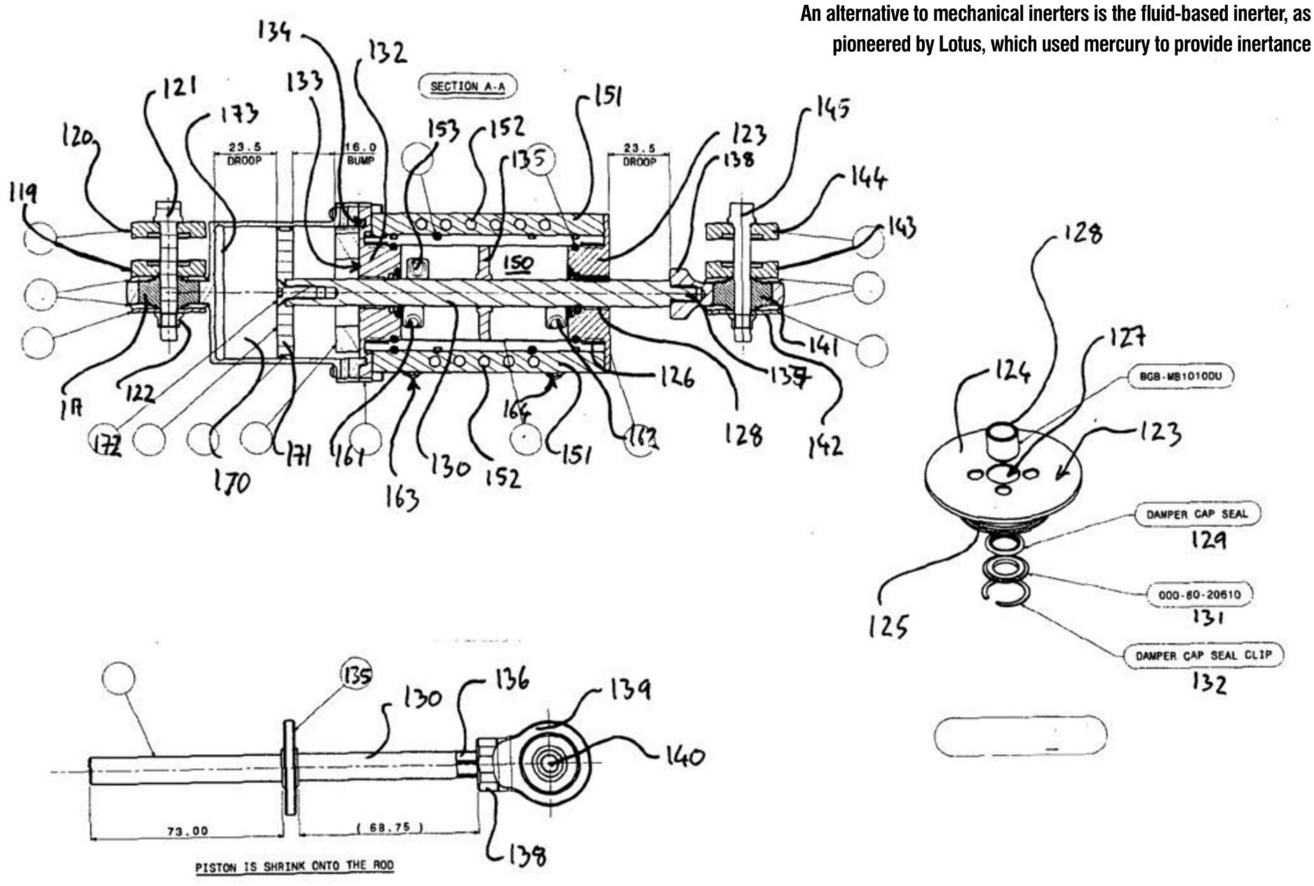
With a nitrous car, he pointed out, an additional level of instability is added due to that first gearshift. 'With a blown or turbo car, the former will not shift until about two seconds, the turbo will be running to around 2.4. When you just drive through the shake zone, you can do other things to counter the effect. You can pull a bit of timing out, things like that. But importantly, you're not making that gear change to further upset the tyre. We have to make that shift though.'

It is for much the same reason that inerters are commonplace in Pro Stock, which has a similar first shift point. It is noteworthy that Smith, who has also run turbo Pro Mods, says

The main reason behind the WRC's wish to ban inerters was cost

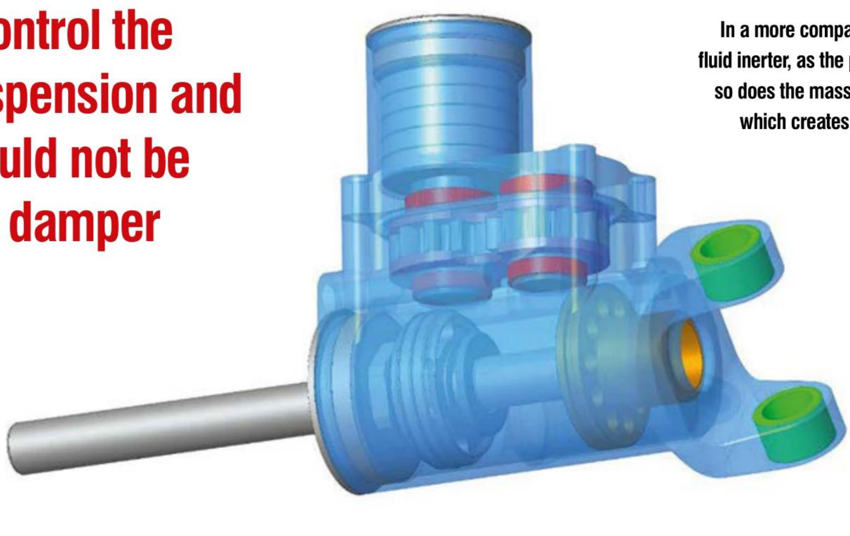
inerters were less beneficial with that package, and so he reverted to standard dampers.

Another motorsport arena where inerters started to find favour with some teams was the WRC, though their development (along with most details on dampers) has been kept tightly under wraps. Unfortunately, they were banned at the end of the 2018 season, at least in the form of mechanical inerters. The same was true of Rallycross, where Penske worked with some teams on a similar technology before it was outlawed by regulation.



An alternative to mechanical inerters is the fluid-based inerter, as pioneered by Lotus, which used mercury to provide inertance

Inerters were used to control the very high frequency suspension and tyre movements that could not be handled by a traditional damper



In a more compact gear pump fluid inerter, as the pump rotates, so does the mass, and it is that which creates the inertance

Again, inerters were used to control the very high frequency suspension and tyre movements that could not be handled by a traditional damper. The demands of rallying are, however, unique in racing. Cars have up to 300mm of suspension travel with shaft speeds of 10m/s, which brings with it additional concerns, as MSport technical director, Chris Williams, noted at Rally GB in 2019. 'Depending on what type of inerter system you have, I would say there are some out there that are almost dangerous in rallying. I would be worried about the amount of suspension travel there is, how you can accelerate that inertance.'

Despite this, there were certainly teams experimenting with mechanical inerters, likely using a clutch mechanism to disengage the unit at very high damper speeds, similar to those used in drag applications.

Which brings us to an alternative to the mechanical inerter, using a fluid-based system. This approach was pioneered by Lotus in Formula 1, and it patented the technology in 2010. Penske has also developed fluid inerters, and there are essentially two different types.

Fluid inerters

The first, which Lotus ran, uses a helical duct filled with fluid (in the case of Lotus this was mercury). As the fluid is forced through the duct, it provides inertance. Mercury was chosen in this instance because its high density allows a small amount of fluid to provide a high inertance effect.

The second type is a hybrid between a mechanical and fluid inerter, whereby fluid is forced through a gear pump, with a mass attached to one of the pump elements. As the pump rotates, so does the mass, creating the inertance effect. The benefit of this approach being the length of the inerter can be kept short, as a long duct does not need to be accommodated. Penske has produced versions of both types of inerter. For rally use, the logical choice would be a helical inerter, as the very long damper body used provides plenty of space to accommodate a duct. As one WRC engineer noted, 'There are ways of doing it, and people are using them, but whether they are getting them to work consistently and repeatably is the question.'

Further complicating matters, damper internals are almost free for WRC teams and

‘In terms of technology development, they are really dying off’

Aaron Lambert, Penske Racing Shocks

there is no limit to the variations they can use through a season, provided the external elements remain unchanged. This means the level of inertance could be changed from round to round to tune them accordingly, either through the use of different ducts or by varying the density of fluid inside.

Interestingly, the FIA has also sought to close up the regulations to prevent the use of fluid inerters, which could be seen as a workaround to rules outlawing mechanical inerters, which rely on banning rotating masses in the damper.

MSport’s Williams suggested a way this can be achieved in 2018: ‘You put a maximum duct length into the regulations, because you need a very long duct to accelerate oil over quite a distance. You also need volume, so you need coils of duct and very heavy oil.’

As they currently stand, WRC regs appear to limit the use of hydraulic inerters by specifying a maximum fluid density in the dampers of 1g/cm^3. But even this limitation could be circumvented through the use of the aforementioned gear pump inerter.

The main reason behind the WRC’s wish to ban inerters was cost, and one technical director *Racecar* spoke to put this into context: ‘The inerter dampers we were offered were about €16,000 (approx. £14,495 / $18,315) per damper. That means a set of dampers would be more than a transmission.’

Engineers will be engineers though and, while still team principal at Hyundai, Michele Nandan admitted the team was working on devices to achieve the same effect as an inerter but ‘using a mass-based system.’ That neatly swerved any rules issues.

Other applications

There are several other areas of racing where inerters have been tried, or it is suspected they are being used. Penske ran a test at Charlotte Speedway with inerters fitted on the rear of a NASCAR Cup car. According to a presentation it gave in 2018, driver feedback was positive: ‘Definitely more rear grip than before, but it was really harsh over the bumps. There’s a bump in T3 that occurs as the car lands, and it’s really harsh over that. But the car recovers really quickly from the bumps. It feels like there’s absolutely no movement in the back, but an increase in rear grip.’

The chances of NASCAR ever allowing them in competition, however, is nil.

There are also rumours that inerters have been deployed in Moto GP, and Penske has certainly worked on motorcycle applications. It has been suggested Ducati has used some form of hybrid inerter / mass damper to control the rear tyre ‘chatter’ racing motorbikes can experience.

Alas, inerters have been slowly but steadily banned by regulators. Formula 1’s new rules forbid them from 2022, as do the FIA’s Hypercar regulations that will start in 2021. They showed considerable potential in Dirt Late Model racing, but the technology was pre-emptively banned. On all counts the bans have come in the name of cost reduction. In the words of Penske’s Lambert, ‘In terms of technology development, they are really dying off, unfortunately.’

The blocking of any development pathway is sad from an engineering perspective, but even more so when it leads to greater spending by teams trying to replicate the now lost means of control. Once Pandora’s box of previously unobtainable chassis control was opened, it was never going to be closed easily.

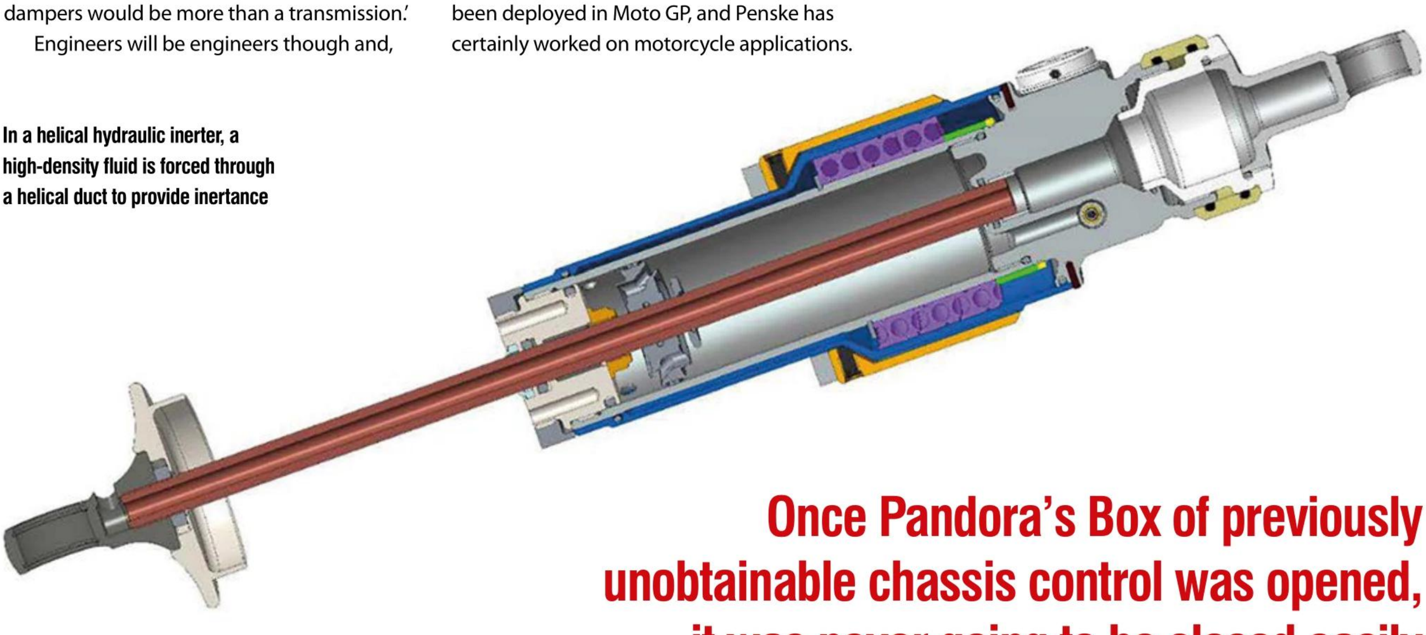
Theory of operation

Inerters are often characterised in terms of an electrical circuit. The suspension spring is an inductor, the damper a resistor and the inerter a capacitor.

In the same way that a damper creates force relative to velocity, and a spring creates force relative to displacement, an inerter creates force via acceleration. This acceleration reaction is what Professor Smith at the University of Cambridge identified as previously missing from traditional vehicle suspensions, which rely solely on dampers and springs.

As a vehicle’s suspension compresses, the spring stores energy while the damper tends to dissipate, or control, the energy of the suspension movements. As the suspension moves faster, the damper forces change according to the damper’s characteristics.

There comes a point where the suspension can reach a speed and / or frequency at which the spring and damper are no longer working in phase with the suspension movement. At high frequencies, the traditional spring and damper arrangement cannot keep up with the actual suspension and tyre movements, and will begin to lag. Incorporating an inerter can help counteract that problem, effectively storing the excess energy in the suspension, either via a ball screw in the case of a mechanical system, of by displacing fluid in a hydraulic one.



In a helical hydraulic inerter, a high-density fluid is forced through a helical duct to provide inertance

Once Pandora’s Box of previously unobtainable chassis control was opened, it was never going to be closed easily

Dragonspeed Racing entered the 2019 Indy 500 as rookies, but with a highly experienced race engineer. Paul Thomas takes us through the experience of learning Indy's unique set-up process

By ANDREW COTTON

Four corners, four straights

It is now a long-debunked theory that oval racing is just about making a car turn left around four corners. Preparing the car for one of the greatest races on earth, the Indianapolis 500, is as complicated as any other racetrack, more when you consider the speeds and forces involved in straight running or in an accident. Then there's the fact the series has a one-make chassis supplier in Dallara, plus a spec tyre from Firestone.

In order to get the most out of the package, a team has to have an intimate understanding of its car and the track, and the relationship between the two, in order to give the driver their best possible chance of success. That was why, when Dragonspeed Racing announced it was going to the Indy 500 in 2019 with a rookie driver, Ben Hanley, it was widely assumed they would have difficulty even making the cut for the race itself.

The fact they did owed as much to the engineering expertise behind the preparation of the car as to Hanley's driving.

The car qualified on the ninth row of the grid at an average speed of 227.482mph, just over 2mph down on pole-sitter, Simon Pagenaud. That was a huge improvement over the team's first practice session in the week leading up to the race, when Hanley was more than 7mph slower that the fastest car of Will Power.

In the race itself, the team's Chevrolet lasted 54 laps before a driveshaft bearing failed and Hanley retired just 45 minutes into the race. However, while several other high-profile teams and drivers failed to make the grade, to have even started was a fantastic achievement for the team.

Expert advice

The team's lead race engineer, Paul Thomas, could not have arrived at the track with more racing experience (see sidebar p36). With a wealth of information specific to the Indianapolis track available from Chevrolet, along with test sessions in the simulator and a practice on banking, pre-race preparation was detailed, yet the team still recognised it needed some expert advice for the race itself, and so leaned on experienced engineer, John Dick, to back up the already highly experienced race engineering team.

A baseline set-up came from Chevrolet's pre-race information that the American engine manufacturer supplies to all its customer teams. The team then started its preparation by using the engineering resources and simulator of Pratt and Miller, the company and race team that builds and runs the Chevrolet Corvettes in IMSA, as well as providing support to Chevrolet in other racing activities, including IndyCar. That helped familiarise Dragonspeed with the Indianapolis circuit itself, and with the challenges that lay ahead in terms of car set-up and running around this unique track.

'[Chevrolet] provide a lot of history with the car on the racetrack, a lot of information and simulation and calculation,' agrees Thomas. 'They then provided simulation software, and that gave me a spotlight to start with on what the car needed.

'I read through all this information to try to understand the specific nature of the oval racing, and Indianapolis especially.'

The differences in set-up are peculiar to a track engineer more used to flat earth racing, and Thomas knew that. 'When the car is on track in the corner, it's neutral and flat and equal,' he explains. 'It has to have equal load distribution to make it work, but statically [the set-up] is completely alien to me.'

Circuit characteristics

The basic characteristics of the circuit are that it is a 2.5-mile rectangular oval, featuring 9.2-degree banking in each of the corners and zero degree on each of its four straights. It has two 1000m straights, two 'short chutes' of 200m each between turns one and two, and turns three and four, all linked by four geometrically identical 400m turns.

The turns are anything but symmetrical, however, in terms of how they are used in practice. Speeds in qualifying approach 230mph, significantly slower than the outright lap record set by Arie Luyendyk in 1996 at 237.498mph, but still impressive. There are very few corners in traditional road courses that demand such cornering speeds, and so to set a car up to solely lap such a track requires forensic analysis.

The forces generated on the car even at the lower speeds compared to those of the '90s are extraordinary, and the key to success is having all four Firestone tyres working to their maximum capacity all of the time. For that to happen, the static set-up is unusual in that all four corners of the car are different, including springs and wheel alignment.

The static set-up is unusual in that all four corners of the car are different, including springs and wheel alignment

'What was most interesting for me was the experience when the car's mechanical set-up was more of an influence than the aerodynamics,' notes Thomas. 'You think that to go flat out at 230mph in normal racing it is all aerodynamic. The driver is at full throttle, so more load is more drag, less load is less drag. But in IndyCar racing it is all about diagonal weight transfer, and mechanical control is the most important thing to maintain the contact patch.

'When you want to change the balance of the car you get more tuneability from changing one spring, which is a totally different mindset to what we do with a conventional car on a conventional track.'

Confidence trick

Setting the car up correctly is paramount for the speed required to get into the race, and then to try to win it, but it is also critical for driver comfort. Asking a driver to basically drive at a wall of tarmac that arcs to the left while travelling at speed, they have to be entirely confident of how the car will react to their input. Failure to do so, or a sudden

At Sebring this year, the car was tested with the new Aeroscreen fitted. If all goes to plan, the team will be at Indy with it in this guise in August

change in circumstance, such as moving out of the slipstream of another car, can lead to dramatic and sometimes painful accidents.

Tyre management

As with all things to do with racing, a huge part of the set-up revolves around tyre characteristics. 'He didn't take much time to get up to speed, which is very unusual for a driver,' says Thomas of Hanley. 'We did one test in Texas prior to the Indy 500 so he had some idea what the banking would be like, and how it would affect the car, but that track is small. In the pits it was like watching tennis in that the car would disappear from view on the left, and shortly after return on the right. I think the lap time was about 20 seconds.

'At Indianapolis, there is a different angle of banking and you are at much higher speed, so it's really tough for a driver to adapt to that.'

Hanley, who also raced the team's LMP1 car in the FIA World Endurance Championship, is known to have a good feel for tyres having tested extensively in GP2 and GP3, and so was able to adapt relatively quickly to their characteristics. However, for the engineers, managing the tyres in terms of car set-up was also an entirely new method.

'Everything is massively sensitised,' says Thomas. 'The tyre pressure grows over a four-lap qualifying run. That affects the ride height, the balance and it affects the tyre stiffness. It's micro-sensitive to moving the car, and the driver has to adapt to that.

'To make things more complicated, all four tyres have individual stiffnesses as well, it is not a symmetrical tyre set-up. The people at the front do a good job of managing the thermal energy going into the tyre. That is the biggest sensitivity to improve upon.'

'All four tyres have individual stiffnesses as well, it is not a symmetrical tyre set-up'

Get that thermal energy through a tyre correct, and the chances are you are going to have a quick car in qualifying. 'On one lap you can see maybe a 20degC rise in the compound temperature in a corner,' explains Thomas. 'Then it recovers on the straight, and then you get another 20degC rise in the next one. The problem is that on the fourth lap you might see a 50degC rise in temperature.

Engineering the driver

In the qualifying session the cars run alone for four laps and the average is counted as the overall speed and lap time (writes Paul Thomas). Given the variation, not only in car performance but also tyres, during this run this is no matter of chance. It requires stringent control in all areas of preparation to give the driver their best chance of even qualifying for the race.

However, a lot is expected of the driver too, and the graphs here demonstrate what they have to achieve. In Graph 1, illustrated are two qualifying laps, the last run to get into the race. The black trace is lap 1 of the run, the red trace is lap four. From top to bottom, the traces are rpm, speed (the black reference line is 230mph), balance, front tyre temp, rear tyre temp and throttle.

Both demonstrated laps are full-throttle laps, and the drop in rpm and speed is due to tyre drag through the corners. The balance pattern means the higher the line, the more the car has a tendency towards understeer. When the line is on the horizontal grey line, the car is neutral. When it's underneath the grey line, the car is oversteering.

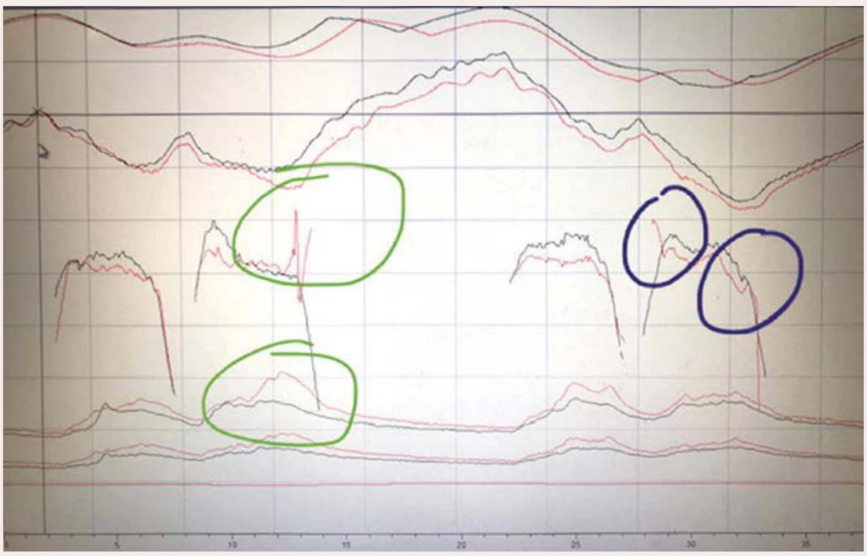
What's interesting in the red lap (lap four of the qualifying run and the last qualifying lap to get into the race) is you can see the car balance is neutral in T1, and entry to T2 is neutral, but see the front tyre temperature increasing mid-corner where the car is sliding. Ben feels this, but has to keep full throttle otherwise the car doesn't get into the race. You see the balance spikes vertical high at the end of the corner then sharply spikes low. This is the front tyre giving up and losing grip.

Ben has kept full steering lock and full throttle throttle to stop sliding into the wall, inducing power understeer. Then, as he starts to wind out lock for the back straight, the car snaps to oversteer (highlighted). This is the typical accident you see with any car PUS to POS (power understeer to power oversteer) but this condition is magnified at Indy as the car is travelling at 102m/s at this point.

The last corner is interesting. Look at the balance, it starts much higher which means the car

Chris Green Photography

Driver, Ben Hanley (middle) talking to lead engineer, Paul Thomas (right)



Graph 1: Laps one (black) and four (red) of qualifying traces, (top to bottom) rpm, speed, balance, front tyre temp, rear tyre temp and throttle. The horizontal black reference line is 230mph

As an engineer trying to balance that, even during a qualifying session, but then also during the race, that's a massive ask.

'It's fascinating because you can be really forensic with the car. You need to be a lot more accurate in how you set the car up, how you control the tyre, how you manage the energy going into the tyres and do it really accurately because you only have four corners and it's a confined environment. But then, that's before you get into temperature variations or anything like that.'

Micromanagement

Giving the driver confidence means micromanaging each lap. With the tyres changing their individual characteristics according to the position on track and length of stint, the driver has to have a clinical knowledge of what the car will do. That means the race engineer coaching them in detail to explain that turn in from one lap to the next might need to be three metres earlier to avoid upsetting the car balance over, for example, a bump (see sidebar).

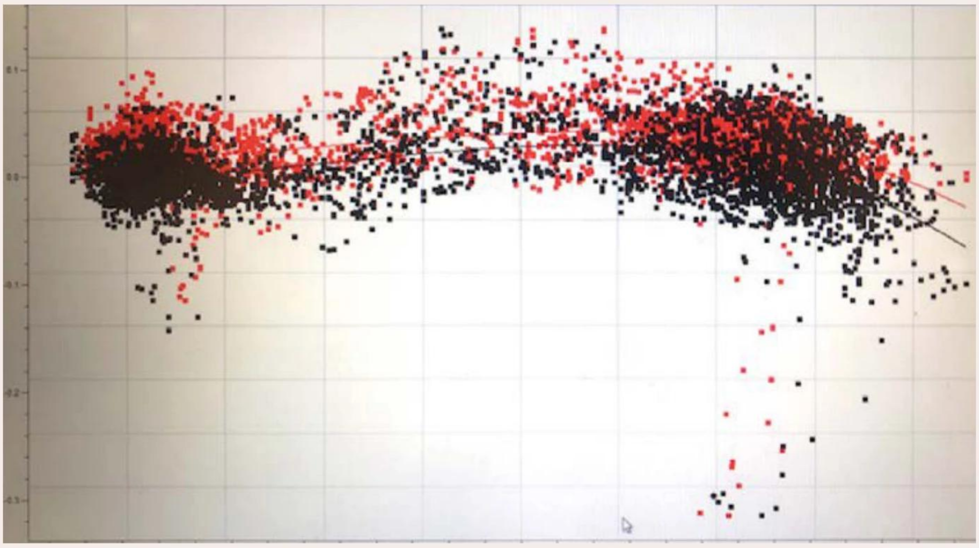
There are other challenges that need to be overcome in order to nail qualifying, and they are specific to the Indianapolis circuit. Get them wrong, and even the best of drivers will fail to qualify with the margins so tight.

'For example, you run the car on low boost leaving the pits and then there is an optimum point on the warm-up lap you use when the driver needs to switch to maximum boost,' explains Thomas. 'Too early and you put more heat into the engine before the start of the lap. Too late and you lose the acceleration of the extra boost before the line. That's a really critical point to balance the temperature and power, but it is a well-simulated point.'

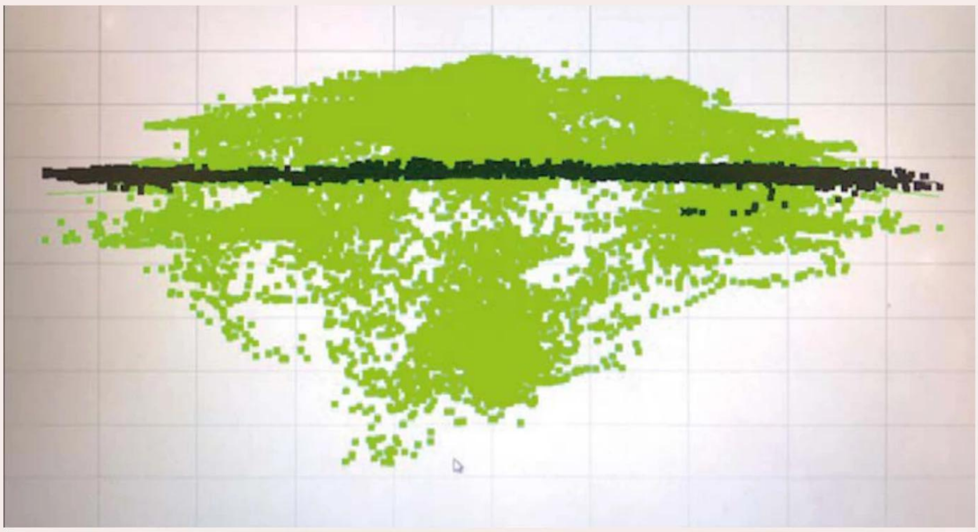
For a driver to go into qualifying where speeds are at their maximum, the set-up needs to be perfect. Despite his experience and the support of Chevrolet, Thomas was happy to receive the expert advice of Dick, who was able to provide something of a sanity check to proceedings. Dick was race engineer for Rahal Letterman Lanigan Racing as head of research and development for the IndyCar programme, having first joined CART in 1987 as a race engineer. He won the 1990 Indy 500 with Luyendyk, and so brought with him a wealth of understanding of car set-up specific to this track.

Knowing the unknown

With such unusual characteristics to contend with for a circuit-based engineer such as Thomas, it made sense to bring in some specialist knowledge.



Graph 2: Lateral and longitudinal acceleration in laps one (black) and four (red) at Indy. Tyre drag and steering input out of the corners accounts for the small deceleration and acceleration variations



Graph 3: Comparison between Le Mans (green) and Indianapolis (black) showing bigger decelerations and accelerations and left / right laterals experienced at the French circuit. At Indy, it is pure lateral, with no major acceleration inputs

is understeering. What has happened is that the front tyre has given up and there is limited grip. Ben has felt the tyre drop performance in T2, managed the temperature rise in T3, but now on T4 entry he has to turn in earlier, anticipating the entry understeer. Mid-corner the car tends to neutral, then understeer and then oversteer – that's Ben drifting / sliding the car through the last corner.

At that point the car is swimming on the tyre, the compound has lost significant performance. Again, though, he has to keep full throttle otherwise the team doesn't get into the race. That's quite impressive talent I think.

Graphs 2 and 3 show the lateral acceleration (X-axis) and longitudinal acceleration (what the tyre has to accept in terms of force). Again, there is a black trace for lap one, a red trace for lap four.

The car is full throttle so effectively steady state. Tyre drag produces the small deceleration values. Likewise, winding out steering onto the straight creates the small accelerations between corners. There is obviously heavy lateral saturation in left-hand turns!

'At that point the car is swimming on the tyre, the compound has lost significant performance'

'Going into the Indy 500, I didn't know the unknowns,' admits Thomas. 'I could see what the set-up would be. I could see what I thought was important, but I didn't *know* what was important. Having John was really a steadying reference board. With the track temperature and track condition, where the track is actually influencing the car, he could identify it, so we didn't react to a specific track condition.'

Once the car has made it through qualifying, focus shifts more towards the driver and providing the tools they need to manage the race conditions, running in a pack with all the dirty air created by the cars in front and alongside, as well as the rare chance to run in clear air.

Feel the force

Managing temperatures in the wake of another car is nothing new to racing. Nor is the turbulence drivers and their cars have to deal with. However, at 230mph the forces generated under the rear wing of the leading car are extraordinary, and for drivers following in their slipstream there is some specific car management that needs to be done.

The loss of downforce over a front wing while following another car clearly reduces load, and therefore helps increase top speed, but as soon as you pull out of the slipstream to pass, load is added suddenly on the front, which can upset the rear of the car, quickly leading to snap oversteer.

Drivers have a weight jacker, an electrically-adjustable hydraulic system on the suspension that works diagonally across the car to increase or decrease weight on a particular corner of the car. Each click of a button shifts the weight balance incrementally, and is a key tool to lapping the Indianapolis track quickly and safely negotiating traffic.

'In close proximity to the other cars at that speed [the turbulence] is unbelievable. It is like going into a washing machine,' says Thomas. 'The aero changes massively based on your proximity to another car at that speed. You try to get close at 230mph and the driver has influence to change the roll bar stiffness, and you have a weight jacker on the car, and you have to use that.

'Like anything, though, if you run too close to the car in front you lose front [aero] so then you have to compensate. The driver can compensate but then suddenly they are not in proximity to other cars, just the turbulence in traffic, which ultimately you can't compensate for. The main thing is you don't have a consistent load, so it is really, really difficult.'

Air quality

Teams do run more downforce in race trim than in qualifying, so the cars start with more overall load, but that actually magnifies the change from running in dirty air compared to then being in clean air. It also increases the load on the tyres that then have to be managed in a different way to maintain performance through a run.

'It really all comes down to how you manage the tyre,' says Thomas. 'The temperature gradient, you put into the tyre, and then in terms of compliance on the suspension. It's difficult.

'You have to make the car as neutral as you can, but with the understanding that if it is too neutral following another car, you are going to have too much understeer. So

'You have to make the car as neutral as you can, but with the understanding that if it is too neutral, following another car you are going to have too much understeer'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'It really all comes down to how you manage the tyre'

you need to be positive but then, like in the situation when you come out from behind another car, you can have snap oversteer, so it's quite tough to get right.'

Clearly, getting the car into precisely the right attitude in traffic, or in clean air, is challenging enough, and that's before you get to the differences in air and track temperatures and how they affect the performance of the overall car, and the tyres.

Despite all this, Thomas remains undaunted. With one Indianapolis 500 now under his belt, he is looking ahead to a return to the 'Brickyard' for a second attempt at the race with the team.

In order to do that, preparations have changed slightly from the first attempt. This time the team will go to the Multimatic rig in Canada for suspension testing, in an effort to increase their understanding of what is required to set the car up for this most unusual of races.

'We will do some test days there, just to look at the energy load going to the tyre and optimising the damping to control that better than we did last year,' concludes Thomas. 'To me, that's the critical thing as it helps to not degrade the tyre too much.'

CV – Paul Thomas

Paul Thomas has had a very varied career in engineering, and in his early professional life worked with three exceptional racecar designers.

'At TWR as a junior engineer in the 1990s, I worked with Tony Southgate, who was a great man who has done everything in motor racing,' remembers Thomas. 'He gave me a lot of his time and knowledge, and I helped him with the wind tunnel model of the Nissan R390 at Imperial College. I did the mechanical design, electrical design, data and systems engineering, gearbox and gearshift development… everything, including sweeping the floor, and turned the lights out at the end of the day. It was brilliant race car engineering schooling.'

Thomas then took that work ethic and expertise to Toyota and worked on the GT-One and on the team's Formula 1 programme. There, he worked with Andre de Cortanze, before he left and went to work with Peter Elleray on the Bentley Le Mans programme, which was victorious at the French classic in 2003.


John Brooks

Thomas can now add the Indy 500 to an already impressive résumé of engineering experience

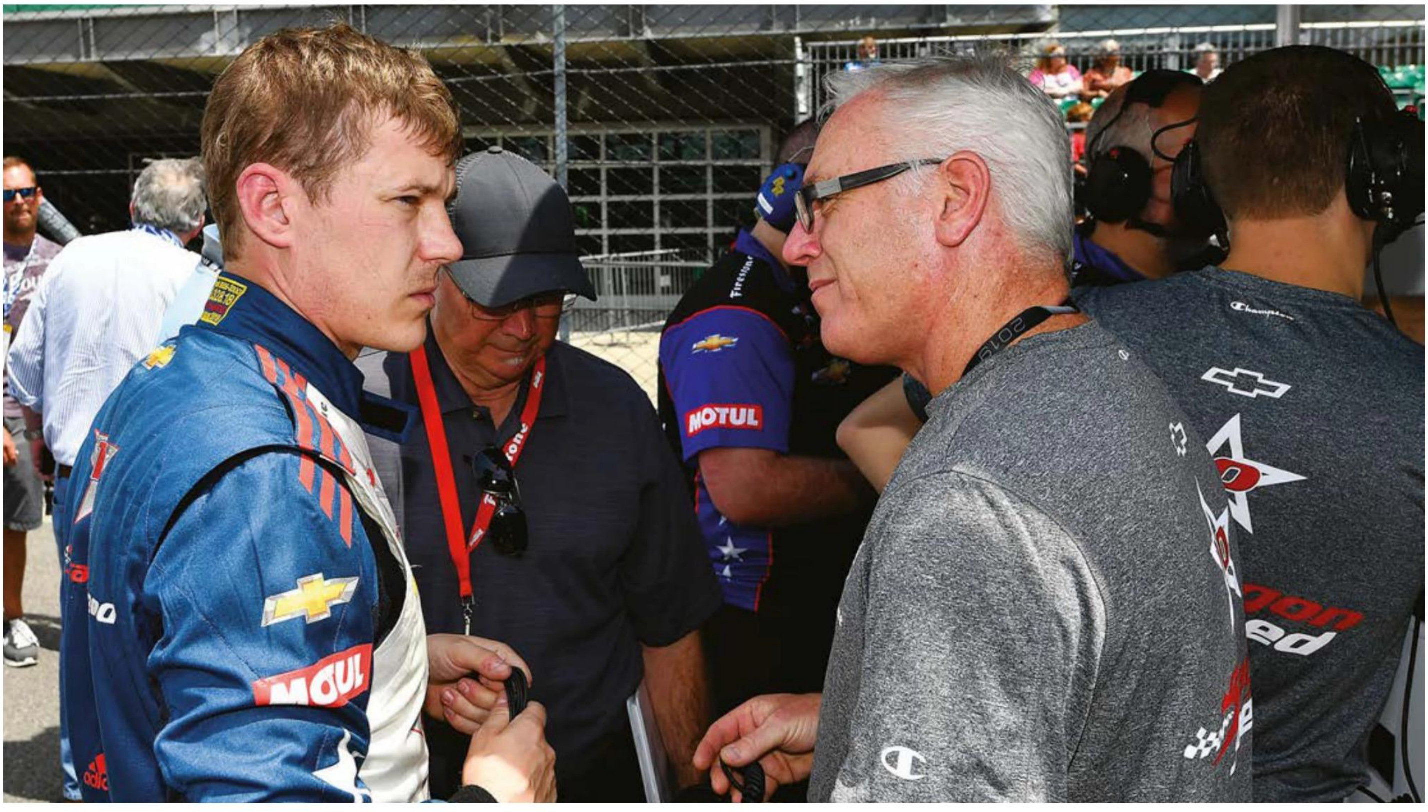
I did… everything, including sweeping the floor, and turned the lights out at the end of the day

Following that, he set up his own consultancy in 2005, with a speciality of working at Le Mans. However, he also worked in other race series, including the DTM, GP2, Superleague, GP Masters and GT, and been involved in start-up new technologies around emission reductions and energy efficiency, including being involved in some EV road car programmes. He is currently working on a zero emission commuter pod.

Thomas also raced 125cc Gearbox karts in Kerpen whilst at Toyota, raced Radicals in the UK and Europe learning about aero and achieved his International C race licence and drove the previous generation of LMP2 cars in testing until 2015.

'Maintaining full throttle at Signe corner at Paul Ricard was mentally challenging,' he recalls of that. 'I have been lucky to engineer multiple Le Mans winning drivers, help build teams that won five ELMS championships and work with two former Formula 1 world champion drivers.

'I also helped build a team starting from zero into winning Le Mans [P2] and the European championship twice.'



With a new driver in Hanley (left), an inexperienced (at Indy) lead engineer in Thomas (right), it was a wise move to bring in Indy 500 veteran, John Dick (centre), for his experience

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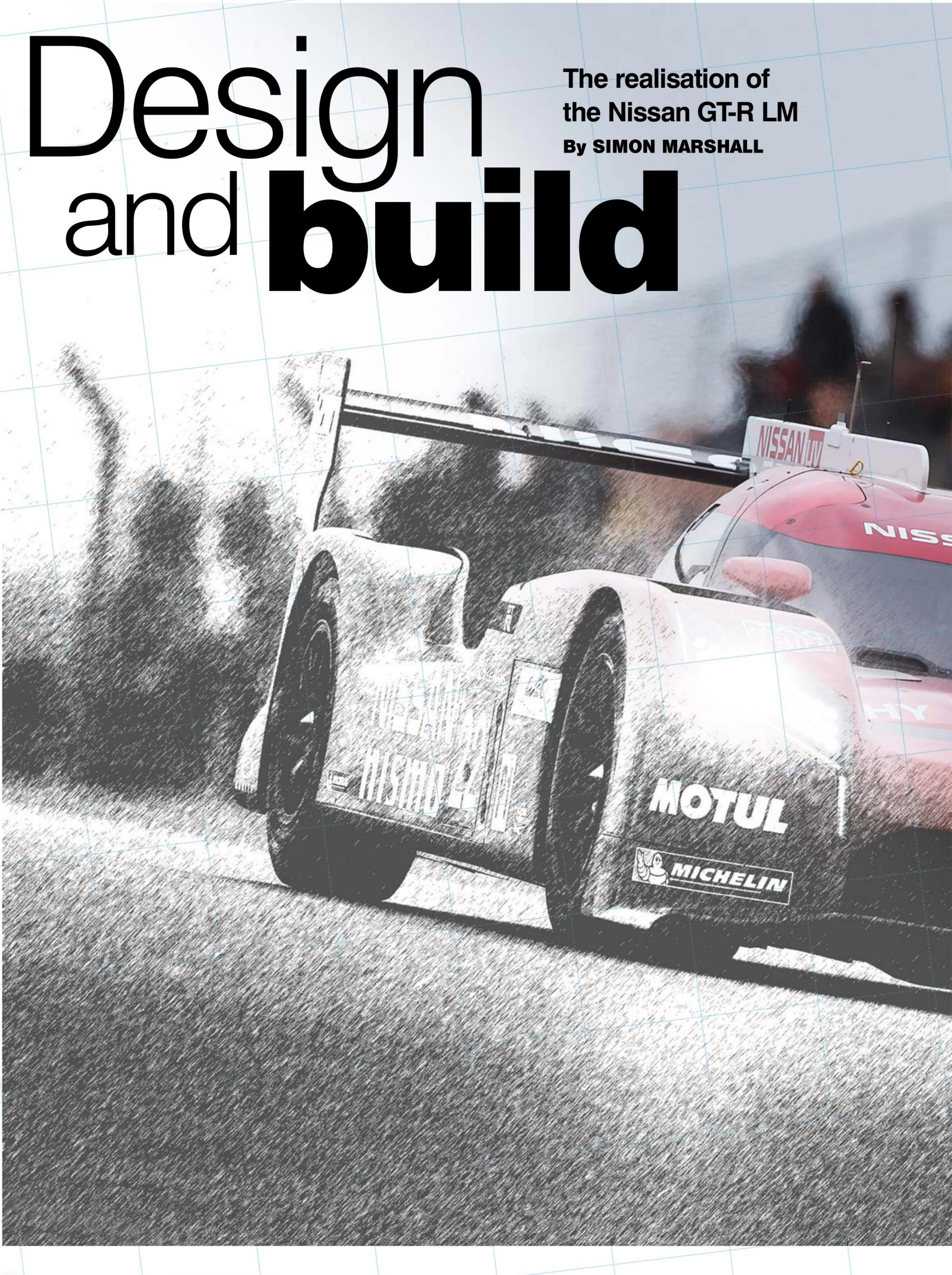
Design and build

The realisation of the Nissan GT-R LM

By SIMON MARSHALL



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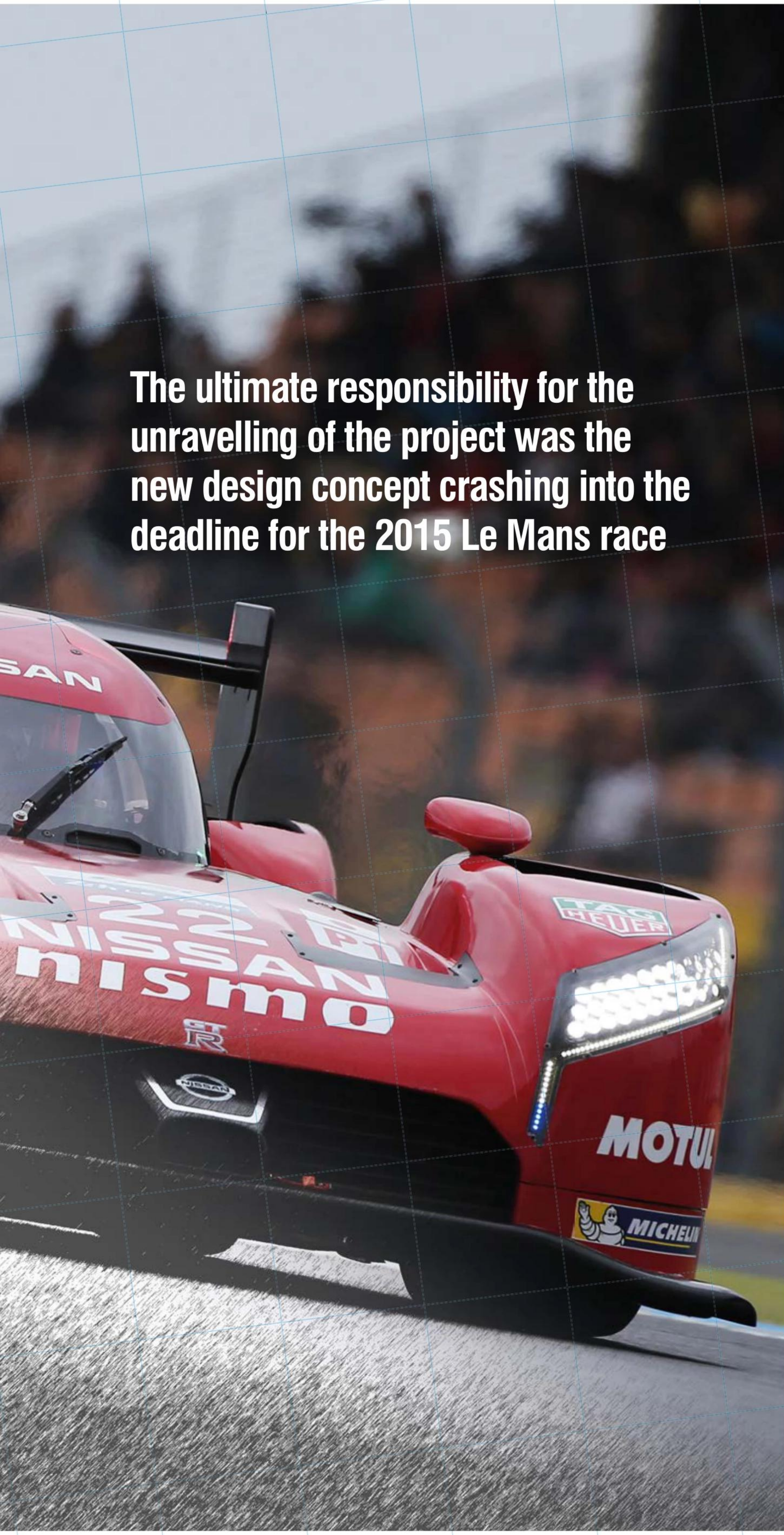


The ultimate responsibility for the unravelling of the project was the new design concept crashing into the deadline for the 2015 Le Mans race

Ricardo Divila's first article about the Nissan GT-R LM was the first of three planned to outline the audacious concept, revealing the promise of performance, the complexities involved and the compromises made.

Divila, known to us as 'the advisor', was assigned to the programme by Nissan, and held the key to the green light for this project (as he had for Ben Bowlby's previous Nissan projects, DeltaWing and Zeod).

He was the eminent racing enthusiast, with a long devotion to Nissan in particular. He exuded confidence in his racing business, which told of many years working trackside with drivers, mechanics and engineers in a calm, level-headed manner. He had his hand in all elements of the GT-R LM project, but was recently called by a higher power, and so I will carry the baton for this second article covering the design and build of the car.

The exploitation of the open front downforce regulations, paired with the forward weight bias of a front engine, the necessity to harvest under braking at the front, and the plan to deploy the ERS at the rear was, in theory, a perfect plan. But you know what they say, 'In theory, theory and practice are the same. In practice they're not.' We could have produced a winner, but so many things had to be invented and executed perfectly for the whole project to work.

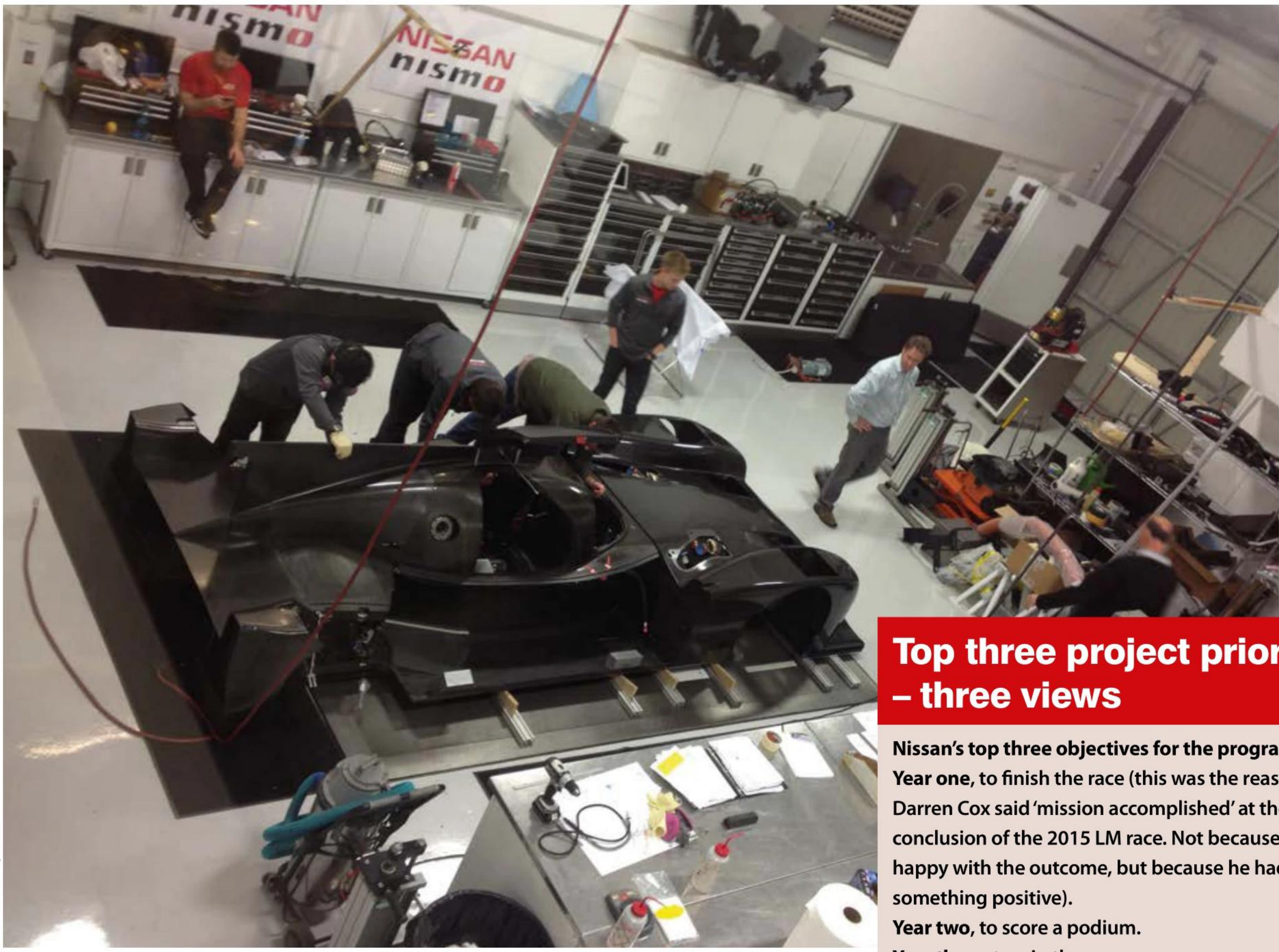
It has been well documented that various components contributed to the difficulties in birth, testing and racing. But the ultimate responsibility for the unravelling of the project was the new design concept crashing into the deadline for the 2015 Le Mans race.

The design department

I got the call from Ben about the LMP1 project in February 2014, 16 months ahead of the Le Mans race. The concept wasn't revealed to me until I agreed to join the project and joined Zack Eakin (chief engineer) over dinner in Santa Ana, California. Imagine my surprise when I was told we were making an LMP1, but with front engine, front-wheel drive. Strangely, it still fitted the rule book, and besides, it gave me the chance to return to Dan Gurney's All American Racers [AAR] headquarters for the design and build.

The design team was larger than for the DeltaWing, but still very small for an LMP1 outfit, plus we had to expand into the ever-increasing (as we found) electronic and data demands of the LMP1 class.

Some design elements would bog us down due to the unique nature of the project. These things lingered on the drawing board



SSM (courtesy AAR)

December 2, 2014: work almost finished at Dan Gurney's All American Racers in Santa Ana, California

and sucked up valuable time. New concepts, design, manfacturing and testing, all with significant time line and budget risk.

At times I wondered why we were pursuing this concept when we could put together a conventional LMP1 car quite easily, and then concentrate our man hours on the ERS system, for which we had no experience. The fact was that there was zero budget from Nissan for an Audi / Porsche / Toyota clone; our budget was soley for a FF LMP1 car. Nissan was, through DeltaWing, Zeod and GT-R LM, boldly exploring new concepts in racing and road car applications.

Everyone hired for the project was living in digs, quickly rented houses and hotels for the design, build, testing and racing phases of the project, originally based in California. Eighty per cent of the design and electrical staff put on fireproof overalls and became the test and race engineering staff, while 90 per cent of the mechanics building the car in California became the test team in the USA, UK and also the race team at Le Mans.

AAR was originally planned to be the race team, as well as the composites, machining and fabrication manufacturing group. However, the organisation pulled out before the first track test due to other business commitments, and the ballooning of the scope of the project.

As a result, part-way through the design and build phase, with track testing imminent, Ben Bowlby had to start an entirely new company, BBR, and form a race team with new equipment in new premises in a different state of America. This was a huge disruption to all parts of the programme.

BBR subsequently rented an ex-Champ Car workshop in Indianapolis and moved in at Christmas in 2014. Job offer letters were sent out on January 1, 2015 as we were all employed by a new company now.

BBR lost some members during this process due to the change in location and the arduous working schedules. Others became 'fly-ins' for the remainder of the project. Personally, I had to ditch the rental house in Irvine, California, move my family back to Atlanta, sell the house and buy a house in Indiana to continue with the project.

The holy trinity

It's quite a challenge, especially with a new car design, to negotiate with the FIA, WEC and ACO all at the same time. The FIA homologates the cars in accordance to its written regulations, and is mainly concerned with safety in motorsport. The WEC, which relies on the ACO for the Le Mans branding, is keenly interested in what's in the pipeline and concentrates on BoP, technical matters, the

Top three project priorities – three views

Nissan's top three objectives for the programme:
Year one, to finish the race (this was the reason Darren Cox said 'mission accomplished' at the conclusion of the 2015 LM race. Not because he was happy with the outcome, but because he had to say something positive).
Year two, to score a podium.
Year three, to win the race.

The top three key points for the technical success of the project:

1. Ultimate ERS recovery from the front wheels and deployment through the rear.
2. Efficient front downforce with the use of through ducts (this was not conceived as a low-drag feature, it aided front downforce).
3. Efficient tyre use through weight distribution (as was a goal with the DeltaWing, but now with a different layout for a different set of goals).

The top three priorities that consumed much of Ben Bowlby's waking and sleeping moments:

1. Safety. Not to put the driver, crew or spectators at undue risk.
2. To stay afloat financially, as he was now fighting for the livelihood of a growing crew, all of whom knew this was an unconventional long shot.
3. To get the concept through its first Le Mans race.

Nissan was, through DeltaWing and GT-R LM, boldly exploring new concepts in racing and road car applications

SSM

Through ducts meant the radiators had to go in front of the engine. This was a logistical nightmare as the inevitable splitter change took an hour in the race as a 1.5in quick release coupling was too big to package, so the system needed draining, re-filling, bleeding and heating

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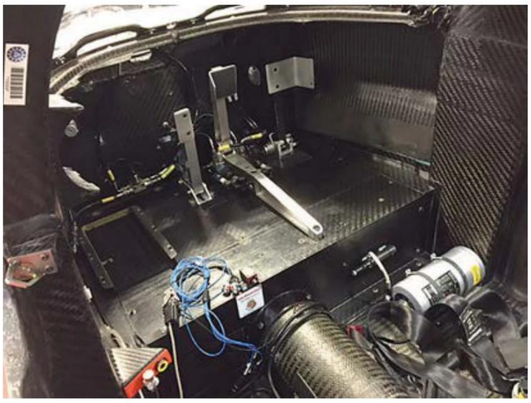
The mid-part of the through ducts are absent in this photo, but it shows the air passage where normally you would expect to find rear suspension. You can see the front air jack legs sticking out from the ERS module ahead of the chassis

[The ACO] embraced the novelty of this car for the show it would bring, but didn't move an inch on the word and intent of the regulations



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Raised pedals were required to clear the ERS gears. The beam from the brake pedal mounting was used to react to brake pedal forces in a very stiff fashion, with the master cylinders fixed to it

SSM

A willing (or unlucky) crew member could crawl in and clean the inside of the through duct, but needed assistance in extraction

races and the championship. The ACO has to put on the show once per year, and relies on the revenue from manufacturers, sponsors, advertising and ensure the safety of its circuit.

Nissan, meanwhile, confirmed commitment to the ACO with a hefty entry fee.

The three factions aren't connected at ground level, so that's where the Technical Working Group (TWG) comes in.

This committee of manufacturers and rule makers is concerned with future regulations and the minutiae of how to actually apply the ever increasing pile of requirements to put a top level sportscar on track (as can be seen in the homologation documents: fuel allocations; fuel monitoring; data logging; safety recovery; headlights; tail lights; brake lights; rain lights; leader lights; flashing lights; yellow lights… There are a lot of lights!

How were we to conduct business in the TWG meetings without the other manufacturers knowing what the car layout would be? The plan was revealed to the ACO *et al* at the end of 2013 after plenty of cryptic regulation clarifications, and the ACO embraced the novelty of this car for the show it would bring, although didn't move an inch on the word and intent of the regulations.

During 2014, the cat was out of the bag to other manufacturers, to which Ben received support, encouragement and intrigue.

The confidential FIA homologation process began seven months ahead of the final deadline, and took many man hours from the constructor to meet the demands. Every element had to be documented and presented in detail to the FIA. We were behind schedule at this time and could only provide CAD images of many features as photos weren't available. The FIA would then pick these apart. But, if it passed muster, the car would be safe from protests, complaints and attacks from any other competitor.

At the time, the FIA, WEC and ACO required their own separate data logging system and transmission from each car: GPS; driveshaft torques; accident data recorder; timing transponder; leader lights; fuel flow meter; fuel temperature; fuel pressure; boost pressure; oil catch tank level; cockpit temp. This system wasn't used for running the car, and the constructor bore all the costs.

Car layout

With this FF layout, we created a packaging nightmare. The through ducts stole real estate but, most importantly, the radiators and rear suspension had nowhere to go, which created additional headaches later on.

It was clear to us at the time that Audi, who were the front runners, were cautiously exploring and testing the merits of two, four, six and eight MJ energy recovery systems. Audi had used a 2MJ system in 2014 and had compromised wisely between theoretical power, actual deployment dynamics, reliable harvesting and system weight. By the time 2015 rolled around, Audi had upgraded to 4MJ per lap, giving up to 200kW (270bhp) acceleration power boost, for about three seconds. This had jumped to 450bhp by 2016 with the introduction of the 6MJ system.

The Nissan GT-R LM concept boasted an 8MJ kinetic flywheel ERS that, while possible in theory, had not been conceived in reality, and would come at quite a price.

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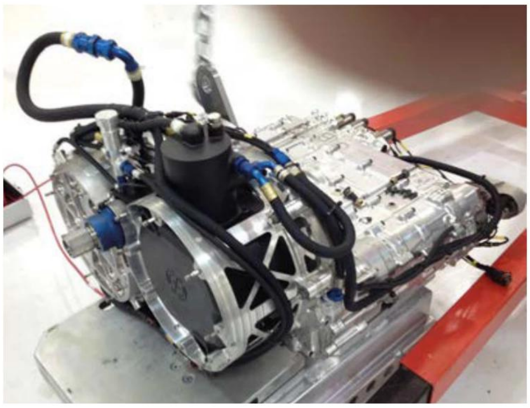
The lifting test at Le Mans that's part of the scrutineering process shows how far forward the centre of mass (indicated by the yellow arrow) was in the GT-R LM. A typical P1 car would have the lifting inserts at the rear of the cockpit



Brian Oeters

Zack Eakin

Flybrid two-flywheel ERS was a bold move and promised a potential 700bhp of accelerative power for five seconds, but its multiple wet clutch actuation proved its downfall in practice and reliability issues eventually sidelined the system completely

Bowlby understood such a system would be expensive to design and manufacture, and would be heavy and potentially unreliable. Plus it would cost more than seven seconds a lap if it wasn't functioning.

A single flywheel Flybrid ERS had been used, with some difficulties, on the Dyson LMP2 car in the ALMS, but a two (larger) flywheel system was planned for the GT-R LM.

It was apparent early in testing that the complexity of its multiple wet clutch actuation was a practical handicap. The well worked out flywheel vacuum system was a sound concept but, within a few seconds of harvesting, the energy had been sapped by the system drag in the clutches.

Marc Gene tested the system at Sebring in early 2015, and on occasions it worked, but when the harvesting routine faltered, the brakes overheated. When deployment was successful, it lacked the punch promised.

Flybrid was sold to Torotrak during this time and, by the time Le Mans 2015 arrived, the ERS system was a million-dollar anchor.

The numbers game

The numbers game involving how much energy the car burns, how much energy is available under braking, the logistics of capturing it, how heavy the system will be and how much the FIA allow you to deploy is intriguing, to say the least.

The 138MJ of petrol allowed per Le Mans lap (for the 8MJ class), with 68.5l in the tank, gives a normal range of 14 laps at about 7.8mpg, of which 13 laps is the safe target. To achieve this meagre fuel allowance, though, the ERS must be working as planned, and the end-of-straight lift and coast strategy comes into play. Imagine if your ERS system doesn't work, and you have to lift early on the straights to still conserve fuel.

Our drivers had the incongruity of having the 'beta' Energy Specific Lap Time routine cut in abruptly at various inopportune moments, including dangerous fuel cut-outs in front of the grandstand as a last autonomous attempt to conserve fuel before the end of lap.

A braking event from 325kph (200mph) to 100kph (60mph) reduces a 1000kg car's energy by 3.7MJ. This order of braking occurs approximately seven times at Le Mans, which equals 26MJ. The eight MJ restriction on deployed ERS energy therefore seems like easy, free energy. In theory.

So we're expending 138MJ in chemical energy per lap, and harvesting only (ideally) eight of 26MJ through braking, giving us the most fuel-efficient racecars ever made.

Our flywheels weighed 8kg each. Spinning at their advertised maximum of 60,000rpm they would hold 2.6MJ of energy. How much power should the flywheels have? Spun up to 2.6MJ, it should give 520kW (700bhp) of accelerative power for five seconds.

Taking into account the apparent system losses, to lose half the flywheel rpm diminished the energy to just 25 per cent of the optimum, yielding only 175bhp for five seconds, but ultimately the system was disconnected for other reliability issues.

The engine

The specially-made Cosworth 3.0-litre DI V6 was efficient and reliable, and did everything it should. I haven't seen a photo where you can actually see the engine, though, as it's buried under layers of systems. Controls, wires, fluids, cooling, turbo controls, ERS business, more wires. It's a mechanic's nightmare, and it took hours to get the engine out of this car.

We had around 370kW (500bhp), but with the fuel allotment per lap, and the fact we still had to hit the 13 lap fuel target without ERS, we couldn't use all the power available. The exhaust exit through the turbo was efficient and direct with very short three-into-one headers to the turbo, then out through the bonnet spewing hot gas around the a pillars.

The inlet route was more tortuous, through the filter inside the front crushable structure, split into left and right, through the wishbones and into the turbo. Then it took a crazy path forwards under the top wishbone, back under the turbo, through the intercoolers and finally into the plenum.

The engine was advertised at 500bhp, but produced more like 550bhp (410kW), limited by the amount of fuel flow allowed in the 8MJ class, assuming we would be generating our own free accelerative power.

The fuel flow (governed power) is based on the architecture of the engine and its inherent brake specific fuel consumption (BSFC). BSFC is equal to fuel flow / power, but as the engine's BSFC is largely designed in, its power is equal to fuel flow / BSFC.

Consequently, if you reduce the fuel flow rate, the power comes down at the same rate, following the basic rule of less energy in equals less energy out.

By the time Le Mans was on top of us, though, we had to bail out of the 8MJ class and beg forgiveness in the 2MJ class.

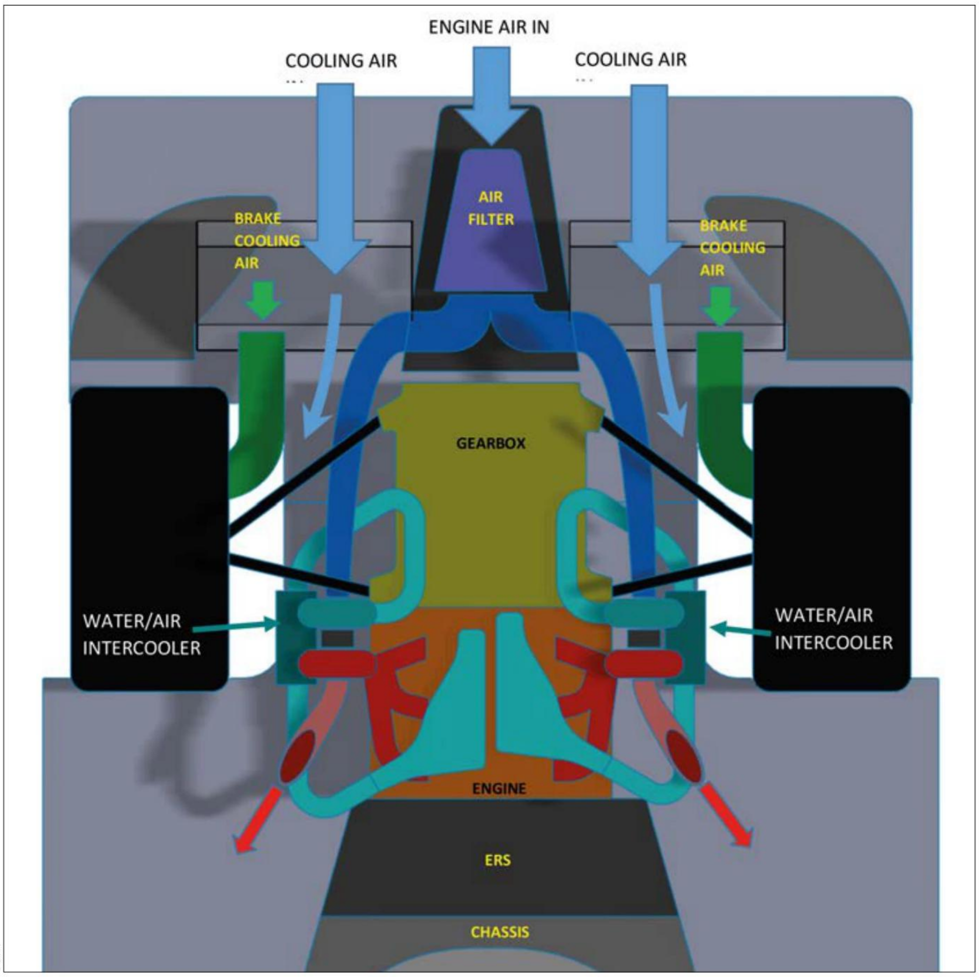


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Diagram showing the tortuous intake route. Cooling air exits aft of the radiator over the bonnet and around the cabin. Brake cooling air is taken from the back side of the radiators, 80degC air to 600degC brakes still representing a good 'delta T'

Zack Eakin

Somewhere beneath all that lot is the specially made Cosworth 3.0-litre V6 direct injection engine, which proved itself efficient and reliable, even if it was a mechanic's nightmare to access it

Table 1: Energy loss in a braking event from 200mph to 100mph

GT-R LM P1		BRAKING DECELERATION	Regular P1	
200 mph	100 mph	200 mph	200 mph	100 mph
0.58	0.15	Brake *g* from aero drag	0.69	0.17
0.15	0.15	Brake *g* from engine braking	0.15	0.15
2.27	2.70	Brake *g* from brakes and ERS	2.17	2.68
76	90	% of braking from the brakes and ERS	72	89
83		AVE % of braking from the brakes and ERS	81	

The upside was we increased our fuel flow number from 89kg/h to 94kg/h. The downside was the fuel cell size was the same so, if we wanted to use the additional power available for a better lap time, we had to stop more often to re-fuel

Here's that relationship in figures:

Eight MJ class:

89,000g/h / 410kW = 217g/(kWh) BSFC

Two MJ class, rearranging the equation:

94,000g/h / 217g/(kWh) BSFC = 433kW (580bhp).

Braking events

A 'spin off' from the ERS malfunction was insufficient brake cooling and high wear. A manifestation of the integrated nature of the car concept, disrupted by the ERS system.

As seen in the **Table 1**, a braking event from 200 to 100mph reduces the car's energy by 3.7MJ, which in 2.1 sec with a 3*g* average deceleration accounts for 1.7MW (2300 bhp). Power being equal to energy / time.

From Divila's data in the first article, a 1000kg LMP1 (with fuel and driver on board) with L/D 5.2, 48 per cent front aero and 42.6 per cent front weight bias would have to absorb approximately 60 per cent of its braking effort (0.6 x 0.81 x 2300bhp = 1118bhp) into the front brakes and ERS. The rear mass and rear downforce bias make rear braking an important part of the equation.

The GT-R LM with lower drag (L/D 6.66), 65 per cent front aero and 66 per cent front weight bias would have to absorb more like 80 per cent (0.8 x 0.83 x 2300bhp = 1527bhp) of braking effort into just the front brakes.

The other LMP1-H cars are absorbing some of the front brake energy onto their hybrid systems. Even though we could assist the front brakes with engine braking, very long lift and coast before braking was still required to assist both fuel economy and brake effort. We were really doubly screwed.

The PFC carbon brake discs were initially given a small cooling duct, but that grew in size at each test, with the ducting becoming more elaborate within the tight confines of our packaging, culminating in a full brake drum to manage the air around the disc.

Front suspension

Two points spring to mind with a high-power FWD car: poor traction and torque steer. However, the rear-drive ERS should have brought the car to a speed where front downforce would take care of traction issues.

Torque steer can be mitigated by ensuring the line from upper and lower outboard wishbone joints hits the road close to the tyre contact patch centre, but this is a packaging problem with wide wheels and large brakes. To solve it, the lower wishbone was made as a separate front and rear leg, attached to the upright with their trajectories intersecting at the virtual lower balljoint position.

With the ERS off the table, though, the front traction was poor due to necessarily high spring rates to deal with the amplified front mass and front downforce. Another twist was that the front wheels were changed late in the game (March 2015) from 16in to 18in diameter to package the largest brakes allowed. That meant a change to short, stiffer sidewall Michelin tyres, and the drivers being ordered to keep off the kerbs at Le Mans to preserve the front suspension pieces. Cue another lap time penalty.

In the next article we'll look at Michael Krumm's techniques for racing front-wheel-drive cars, exploiting their inherently stable nature under power, and living with the potential understeer and traction problems.

Rear suspension

Through ducts and tunnels have failed in the past as there tend to be cooling elements, driveshafts, wishbones and other factors disturbing the flow, and the work arounds to accommodate clean, square-section ducts in the GT-R meant the rear suspension and driveline was ultimately compromised, causing an inefficient structure and overly complex rear suspension.

The scale of the rear suspension wishbones was as shocking to the establishment as the front suspension of the DeltaWing. They were all 200mph parts carrying an LMP car, just not carrying much of it. The wishbones were tiny, short pieces, with an upright spring / damper operated by the lower rocker arm and, most challenging, the hydraulic anti-roll bar. There was no way (within reasonable weight) to oppose the relative movement of the LH and RH wheels.

How would you do it? A long torsional element the width of the car, inside the rear structure wings, would have to be of very large diameter to be stiff enough. We couldn't run any links through the duct, so long-time AAR engineer, John Ward, got together with Penske to arrange the transfer of fluid, via valves positioned ahead of the rear crash box.

The non-articulating ERS driveshafts ran at low level from the rear differential through the lower structure beneath the through duct and raised up to the super short, outboard, articulating driveshafts.

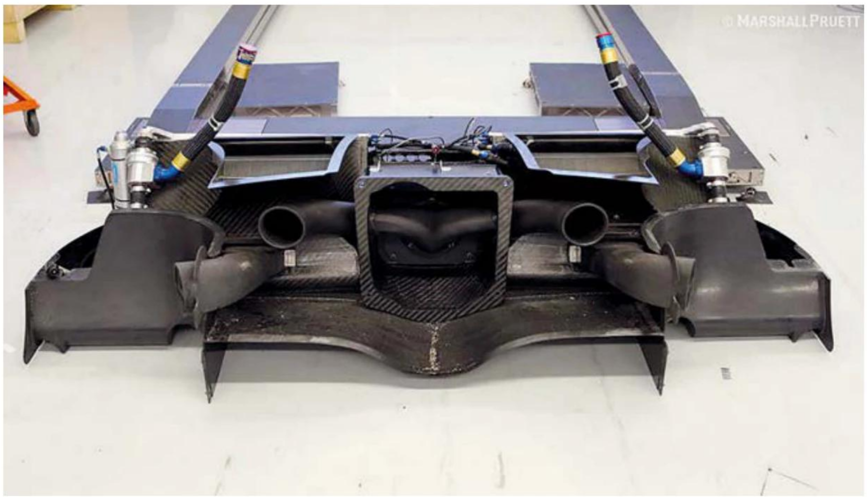
The lower rocker arm between the rear structure and the upright, supporting the lower damper mounting in the middle, would prove to be another weak link on track, which we'll talk about in the next article.

Aero programme

Ben's first of many CFD runs with TotalSim UK, was in November 2013 and continued to August 2014. The production-spec body shape was set, and the CFD programme resumed through to April for Le Mans-related brake cooling and front sensitivity issues.

SSM

The engine cooling air follows a short path with the exit in the middle of the bonnet. To achieve the downforce and drag targets, the airflow in the front-splitter-to-through-duct system could not be disrupted



Marshall Pruett

Later shot showing the back side of the nose and the engine air filter. The y-pipe took air to each turbo. The new water and oil radiator thermostats can be seen outboard, together with the water accumulator (air spring) on the left. Note the brake ducts here are still the small Le Mans type

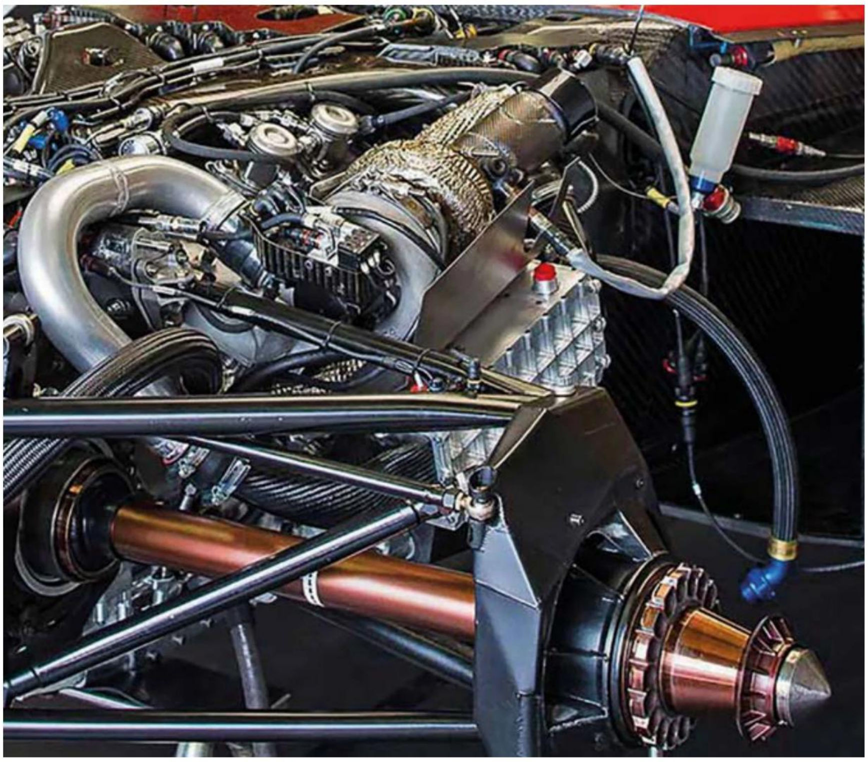
The rear suspension and driveline was ultimately compromised [by the through ducts]

Smooth and discreet at first, brake ducting was initially taken from inside the front radiator duct

SSM

The final 'catcher's mitt' brake duct and radiator inlet splitter seen in 2015 post-Le Mans trim

The numbers were real, but early track testing and subsequent full-scale tunnel tests showed a severe sensitivity to low front ride height with maximum rake



This detail of the AAR-fabricated front suspension shows the sturdy Metalore driveshaft, sized for engine power and also for harvesting duty. You can also see the oil / air turbo heat exchanger under the turbo

In the DeltaWing programme, TotalSim ran simulations every night, and CAD revisions were made every day for 100 days. With the GT-R LM car we racked up more like 4000 runs which, although expensive, is way cheaper than a scale model wind tunnel programme.

Speaking of which, we also had a 40 per cent scale model wind tunnel programme running in the Mercedes tunnel at Brackley, UK during October to December 2014, led by our race engineer Andy Brown. This was at the behest of Nismo, who were sceptical of the numbers we were generating in CFD.

The drag threshold was set by Ben to give a theoretical maximum speed at Le Mans powered by this engine. The downforce would be developed to give us a peak L/D of 7.4 in Le Mans trim.

Initial lap sims used Chris Murphy's Race-Sim. These showed there wasn't much lap time gain by going from L/D 7.4 to eight (unlike from four to 4.5, for example, which showed a big gain).

SSM at AAR

The rear suspension, due to packaging constraints caused by the through ducts, was overly complex but very fine in construction

The numbers were real, but early track testing and subsequent full-scale tunnel tests at WindShear, NC. showed a severe sensitivity to low front ride height with maximum rake, as many have found with sportscars, and we couldn't shake ours off for quite some time. We returned to WindShear for a second test with countermeasures in mind, but it was still with us at Le Mans, so we had to avoid certain set-up conditions. We will cover the symptoms and cure in the next article.

Structural testing

In November 2014, we sent front and rear crash boxes for baseline impact tests. This is a zero-stress start to the testing, which feeds back to design at an early stage when there's still plenty of time to react. We didn't need to be present, as the guys at CAPE (Center for Advanced Product Evaluation, Indiana) are FIA certified and have worked with us on many FIA and non-FIA projects. Interestingly, CAPE are part of the IMMI group, a global seatbelt manufacturer.

I made calculations for crushable structures derived from empirical data of crush energy per kg of material in 20mm increments (for the carbon inner / outer skin).

Starting with the full KE of the vehicle (or sled), 99.96MJ (1020kg at 14m/s), each 20mm increment would take away a certain amount of energy and decelerate the car / sled until the energy and velocity reached zero. Hopefully, within the length of the nose.

This was quite tight as we were also packing the nose with the car's air filter, and there was a power steering pulley protruding into that area, all which effect the pack up of the crushed material. Some negotiation was due between the crash testing requirements and other architectural features of the design.

The crash force at the nose-to-gearbox interface peaks at about 450,000N, (about 44 tons) from the 45*g* deceleration spike, and that is then transferred to the front of engine, minus the energy of the gearbox mass.

The regulatory crash test speed of 14m/s is only 31mph, but the impact is into a 100 per cent unyielding steel and concrete block, which, with FIA circuit safety design, should never be encountered.

In my experience, chassis no.1 is taken by the race team to start building into a complete car as the track tests are fast approaching. The car is assembled and disassembled with new additions as they become available, wiring is mocked up and later laid in to stay, the fuel system mocked up and eventually sealed in and the cockpit furnished and refurnished a few times. I, meanwhile, start crash testing chassis no.2.

That was sent to the next private crash test on December 15, 2014, which was when we found a weakness in the bonded front roll hoop. It let go at about seven tons of the 7.5ton test load. Not up to scratch but still very strong. My decision to bond in the front roll hoop wasn't a good one, but we were committed to the design and chassis no.3 was already in the works. The old hoop was cut out of chassis no.2 and more attention paid to the bonding preparation and glue gaps for the FIA test in March. The crash test schedule didn't affect the track test schedule (as was reported at the time), as the chassis no.1 racecar was still being built in California.

In February 2015 we hit a bump in the road concerning some unwritten definitions and unspoken formulations from the FIA.

The 'chassis' extends from the foremost front suspension mounting to the rearmost rear suspension mounting.

The survival cell is the part of the car that includes the fuel tank, from 150mm ahead of the drivers' feet, pedals un-depressed, to the bulkhead behind the fuel cell.

The cockpit is the volume inside the car, defined by the regulatory templates that houses the driver and, amongst other things, 'electronic controls'.

Moving goalposts

The FIA then moved the goalposts with its definition of survival cell. Our ERS system lived outside, ahead of the cockpit / survival cell. It was then decreed the ERS must live inside the survival cell, and the survival cell must not be made of bolted components (as with our ERS housing).

See Article 1, illustration of the car construction. We still don't know where this all came from but, after futile argument, we were forced to cut the front bulkhead off the survival cell and bond the ERS housing to the front with a removable panel separating the driver from the flywheels. This cost us valuable manpower, resources and money to comply with an illogical ruling that also forced us to fit the ERS system into the chassis through the windscreen. Good job it never came out once it went in.

On March 9, 2014, we had our FIA-witnessed crash test. The FIA had added the 713kg RH door / head load test requirement by this time, which was a surprise that we had not prepared for, so we tested what we had and naturally didn't pass the test, but at least it gave us valuable data for the re-designed door and latch system.

Via: Zack Eakin?????

The mechanics and design engineers team (left to right): Pascal Houtin, Tom Jacobs, James Nero, Bob Jansen, Ben Bowlby (crouching), Justin Gurney, Peter Kosev (Alias CAD) and Zack Eakin

After a futile argument, we were forced to cut the front bulkhead off the survival cell and bond the ERS housing to the front

The front roll hoop failed again in the same manner. I had relied too much on the glue joint under the load conditions, which worked in theory (!) but clearly wasn't good enough in practice. This was one of the most stressful periods of my working life.

We (that is Jason, Randy and our composites department) fixed this quickly by laminating the new front hoop into the outer shell and within a couple of weeks the chassis was sent back for the next FIA-witnessed test.

No chassis were lost in crash testing, 'just' (sorry, composites department) a couple of bond-in front roll hoops. The rest 'buffed out'.

At this point in the programme, chassis nos. 1 and 2 were still testing in the USA. On March 23, 2015 we achieved success with the second FIA test.

The front and rear impact tests aren't usually a surprise, as we had previously run the crash boxes into the wall with the appropriate speed and sled weight early in the programme, but they're still coronary inspiring. Our average deceleration was 25.0*g* of the allowed maximum 25.0*g*.

It was speculated at the time that the crash test programme delayed the racing prospects of the car. The truth is the two test cars, even some time after this successful FIA test, were struggling to run consecutive laps at Bowling Green, Kentucky in early May 2015 when I took the car no.3 race engineer mantle, with Yoshida Masanoba from Nismo. The April 12 Silverstone race and May 2 Spa race were never on the cards for GT-R LM.

Next stop, bodywork stiffness testing, which commenced in the Indy Nissan team facility in April 2015.

Bodywork

At this point, we were working with 11 different composite shops, including the primary AAR facility, to make between three and six sets of the 220 composite parts used on the car. There were 380 machined male masters (patterns / mould blocks), and then approximately 220 moulds required to make all the necessary parts.

Brian Oeters

The Nissan off to crash testing in Zack's Toyota pick-up, though the 70kg tub also fitted in the back of Ben's Toyota Sequoia with the hatch closed, showing how small an LMP tub really is


SSM

The dummy driver is given a different criteria based on the FIA's learnings over many years. We have to keep the sensors in the chest below 60*g* for a cumulative time of more than 3ms during the impact. The average in this case isn't as important as the duration of the peaks, but it's all tied together by the car's construction


Brian Oeters

To pass revised crash tests, the right-hand door was re-made as a beefier 1kg part, and resisted the 713kg load, together with the custom latch mechanism designed by my colleague, Brian Oeters

Success! You can only go for the full car impact test when the other 17 static and dynamic tests have been passed successively using the same parts

The last sets of composite spares were ready on the day before the Le Mans race

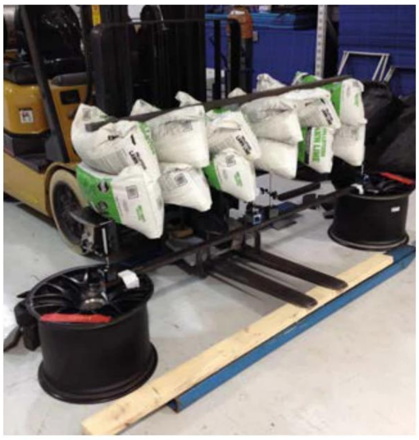

SSM

The first composite piece out of the gate was the panel sitting over the fuel cell. There's plenty of space for fuel in the designated area, so we had to keep it as low as possible. The patterns went out for machining in late March 2014, but the mould making for this single part proved to be laborious and over complex due to its shape. I immediately wished I had designed the part differently. I should have compromised design for manufacture as we were wasting valuable manpower on an insignificant part.

In April 2014, we were still deciding how to best split the bodywork, but the final body shape wouldn't be released until August, which meant the main bodywork and rear structure patterns were sent for machining between September and December 2014. Hence the reason the November 20 test car ran without any bodywork fitted. Bodywork shaping by CAD was done by Peter Kosev using Alias from Ben's CFD directions and, when the split lines were decided, it was over to SolidWorks for part design and tooling.

The composites part count at this point was at about 1000 pieces (for the three cars, including spares), all of which had to be moulded, prepared and fitted or bonded to sub-assemblies. The last sets of composite spares were ready the day before the Le Mans race. The moulds were shipped to GTR in the UK in early March 2015. They also invaluable provided composites track support to help out our composite team.

In the third and final article, we'll conclude with the 2014 / '15 testing schedule, as well as racing the GT-R LM at Le Mans and detail the developments that were made for the 2016 season although were never used.


Brian Oeters

That's a rear wing under 245kg (539lb) of lime. Note the dial indicators at the wing tips


Zack Eakin

Yep, I think I can see the apex! 220 individual composite parts went into the construction of each GT-R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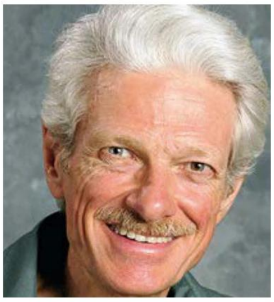
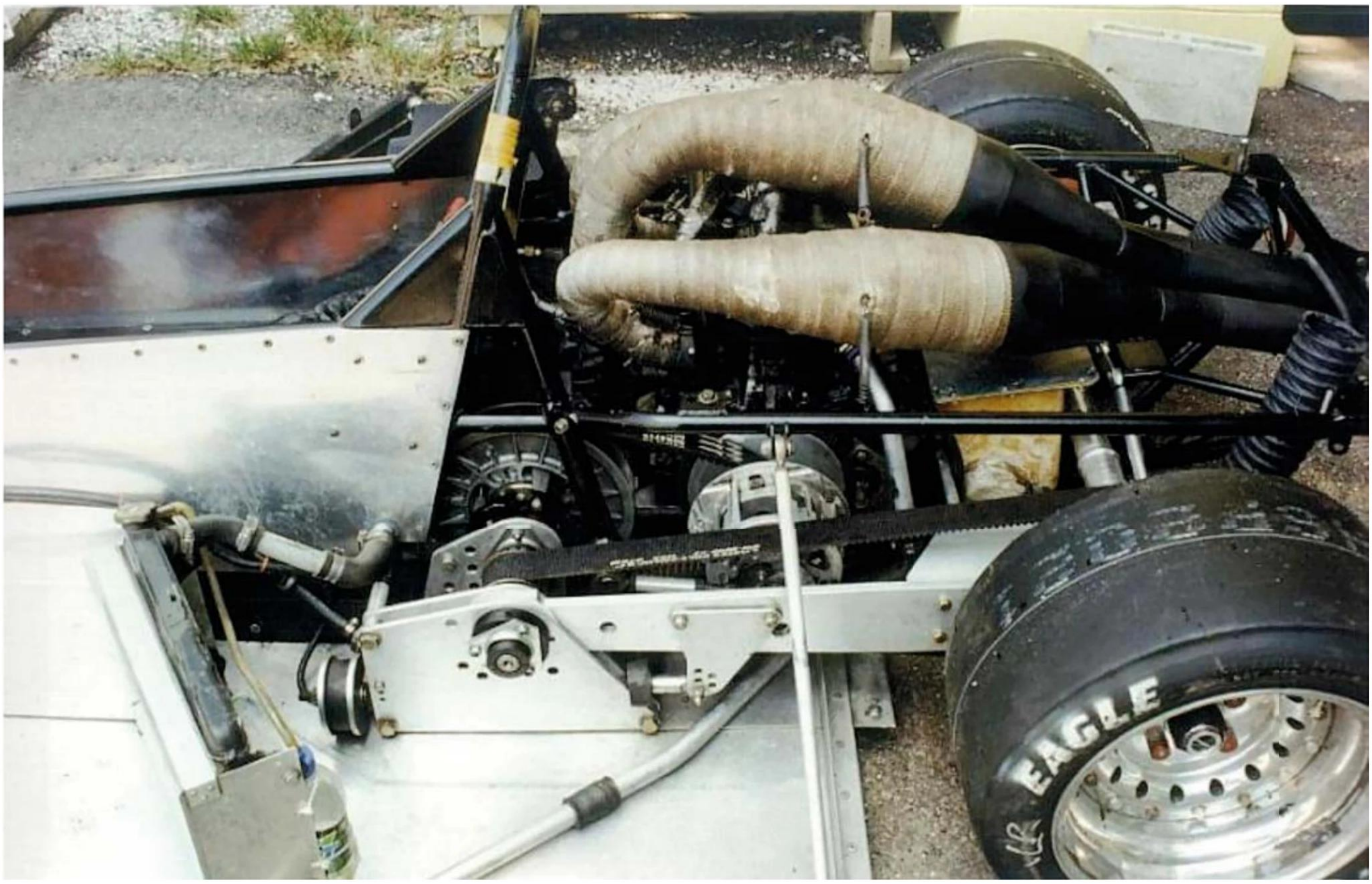


High tension

Belt drive vs cog drive in a live axle application

By **MARK ORTIZ**



Belt drive is more efficient than chain drive, but requires high belt tension to stay engaged, and trailing arm or trailing link suspension to maintain tension during suspension deflection

Q I was looking at the pic of the DSR racer in your column in the February 2020 issue of *Racecar Engineering* and one thing about it struck me – they were using a cog belt drive. Cog belt drives are seven to 10 per cent more efficient than a chain drive, so at first this appears to be a pretty good way to improve power without adding engine stress.

However, when I contacted Gates Application Engineering with my specifications for the small lakester my son and I race at Bonneville that uses a motorcycle engine with chain drive, they recommended a belt tension of over 700lbs to ensure it stays engaged!

That level of tension almost surely requires some sort of swing arm suspension be used at least on the drive side of the engine, as seen in the photo of the DSR suspension, or some way that ensures the belt is maintained under constant tension (and alignment) regardless of suspension travel.

I think the belt drive is probably the main reason the illustrated DSR is using trailing arm suspension, and not a more sophisticated suspension design.

The thing I was concerned about with using, say, a pair of equal length trailing links is their length has to be exactly the same length as the belt pulley centres as even a slight difference could change the belt tension considerably. A very substantial idler pulley would be an absolute requirement to compensate for any possible change due to suspension travel, and also some sort of lateral location control to keep the pulleys vertically in line to keep the belt flat across them.

THE CONSULTANT

A Actually, the same thing can be accomplished with four trailing links. Each pair just need to be the same length as the pulley centre-to-centre distance, and either parallel to each other and parallel to a line connecting the pulley centres, or non-parallel, with an instant centre somewhere on that line.

It can be used for any kind of belt or chain, provided we don't need to maintain precise timing

In response on differentials

The German idealist philosophers were right when they said anything is possible. You just have to say the magic words, 'Nobody would ever do that.'

Look what Doug Milliken sent me in response to my recent articles on differentials.

In Jan-Feb 2020 you wrote:

'And theoretically at least, we could make a bevel gear diff with unequal torque split, too. This would involve having different size side gears, and pinion gears at an oblique angle. This is not a very attractive approach and I don't expect to see anybody do it, but it's theoretically possible.'

Well, please see the attached photos, taken in the lobby of the Segrave truck plant in Clintonville, WI (formerly the Four Wheel Drive Company). There was no signage, and no one I met there could give details, but it looks to me like a heavy duty transfer case with fixed ratio torque split and a clutch pack limited slip. I didn't try turning the crank as I don't think our guide would have appreciated that.

THE CONSULTANT

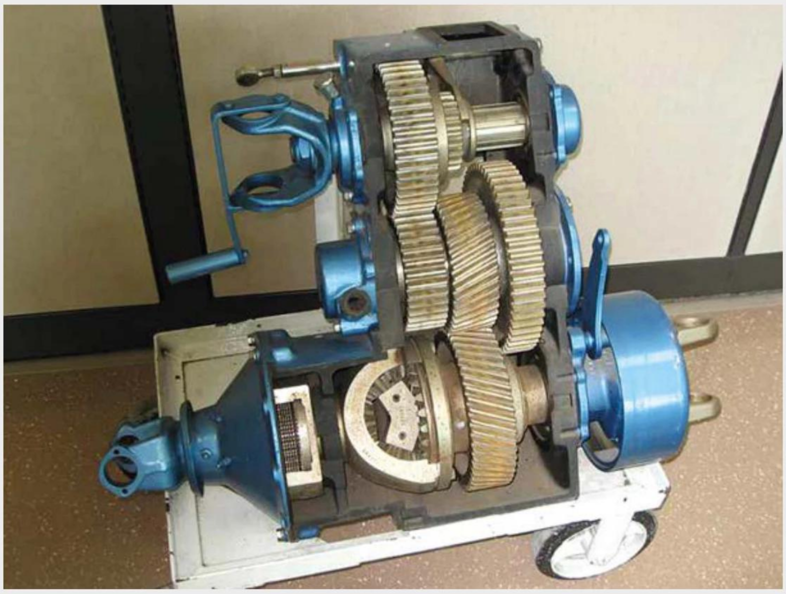
It definitely is a transfer case, for a heavy, all-wheel-drive vehicle. The u-joint yoke at the top with the crank is the input, presumably from a front engine and transmission, and the smaller yoke at the lower left is to drive the front axle. Looking at the close-up shot of the diff', it looks like the smaller side gear has about half the pitch diameter of the larger one. That would mean the front driveshaft would get about a third of the torque, or about half as much as the rear driveshaft.

I expect that for this application, the idea is not to facilitate throttle steering, or allow for rearward load transfer. More likely, the vehicle will have two rear axles and the idea is to transmit similar torque to each of the three axles (generally, the front axle of a truck's rear tandem will have an inter-axle diff' and its own diff', often with a driver-controlled lock for the inter-axle diff'). This vehicle would have five differentials!

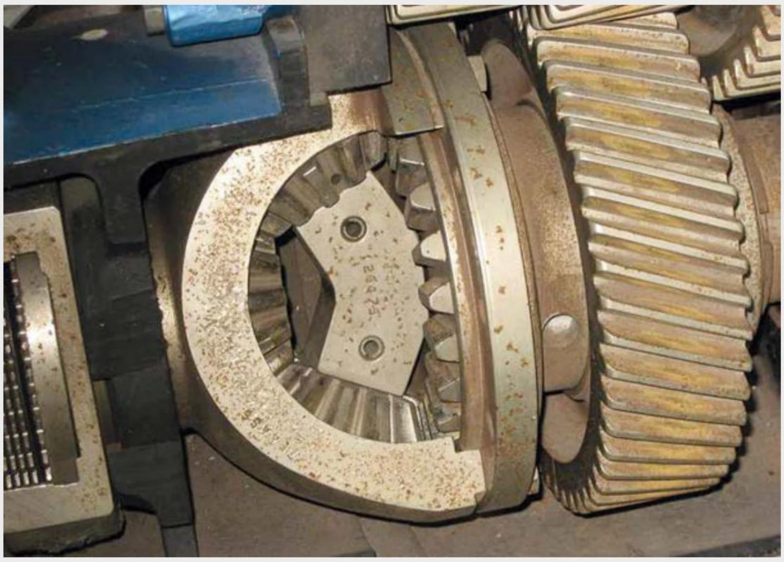
This is a two-speed transfer case, and in the picture it's positioned in high range. The shaft at the top with the rod end on it works the range selector shifter fork.

Interestingly, the teeth of the low range input gear are used as engagement dogs to select high range. I take it this is not intended as a shift-on-the-fly system.

Thanks for sharing the pictures, interesting stuff.



This vehicle would have five differentials!



Photos courtesy of Doug Milliken

A heavy duty, two-speed transfer case with clutch pack limited slip differential

To create no wedge change in braking with a single brake, the links need to be parallel, but not necessarily horizontal. To create zero bump steer, they need to be horizontal. So, there may be a conflict between belt drive geometry and rear steer properties, but it is possible to completely eliminate wedge change in braking with a single brake.

Regarding the tensioner, it is possible to use one, albeit at some penalty in weight, cost and complexity. One appealing design is used for the belt drives in wheel balancers. It can be used for any kind of belt or chain, provided we don't need to maintain precise timing, as with a cam drive. The system has two idlers, one on the top run of the belt (or chain) and one on the bottom run, each mounted to the frame on its own arm. The arms are free to swing with respect to the frame, but are connected to each other with a tensioning spring.

When no torque is being transmitted, both runs are pinched toward each other. When torque is applied, the tension run straightens and the slack run bends more. The geometry is such that this stretches the tensioning spring and tension increases with torque, especially on the tension run. This effect can be tuned with the geometry and spring rate.

The mechanism described also cushions any abrupt variations in torque, and works equally well on deceleration. It is common with toothed belts to provide guide flanges on just the drive pulley and make all the other pulleys wider than the belt to allow some lateral (axial) float.

CONTACT

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

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Multi-talented

How motor racing has enhanced Multimatic's already successful engineering organisation

By GEMMA HATTON

You're probably familiar with the name Multimatic, and I bet you it's for several different reasons. That's because Multimatic is a company who have been involved in almost every aspect of racecar development for the last 28 years. In that time, the Canadian-based outfit has designed and manufactured high volume parts as a supplier, built and optimised numerous chassis as a constructor and raced cars as both a manufacturer and race team.

In each of these guises, Multimatic has won races and championships, developing a comprehensive suite of engineering facilities and innovative technologies along the way.

Originally, however, Multimatic had nothing to do with racing. When the company began its engineering journey in 1984, its primary business was the manufacture of high-volume automotive products for the global road car industry, which is still the case today. It was only when Larry Holt, Multimatic's now executive vice president, joined did racing come on to the agenda.

Competitive advantage

'In the '80s, the automotive parts business changed quite radically,' remembers Holt. 'Previously, the customer would design everything, and suppliers would bid on that job. Whoever had the best quality for the best price won the job. But that all changed and automotive companies started asking the suppliers if they could engineer the product. That's when I made my move into the automotive industry to support Multimatic.

'In the end, the better business is to develop your own product with novel technology and then go to the customers and say, 'nobody else has this.' That gives you a competitive advantage.'

This prompted Multimatic to add an engineering arm to its business in which

Alongside its trackside activities as a constructor, manufacturer and race team, Multimatic has also developed an impressive suite of engineering tools, such as four-post rigs (pictured below), seven-post rigs, K&C rigs and advanced driver-in-the-loop full motion simulators

'The better business is to develop your own product with novel technology and then go to the customers and say, "nobody else has this"'

Larry Holt, executive vice president at Multimatic it could develop its own products and technologies. That, in turn, gave Holt the opportunity to run an engineering business, which supported the manufacturing side but could also involve other types of work.

'This is where the opportunity for getting involved in motor racing was, because as long as my business looked after the manufacturing side of Multimatic, I could also take on other work,' says Holt. 'So in 1992 we partnered with aluminium company, Alcoa, and went racing in the Firestone Firehawk showroom stock series with a Ford Taurus SHO, a high-performance four-door sedan.

'At that time in Canada, the Formula 2000 open-wheel series closed down and I managed to convince Scott Maxwell to climb into a family sedan with a rollcage, modified suspension and a warmed over engine.

'We dominated that championship by 570 points, and for me that was the first year of racing as Multimatic. We made money out of that, so I went, 'hey this is easy, make money and win championships in racing."

In 1994, Multimatic worked with Ford to develop the Mustang to replace the Taurus, and in 1995 designed, built and developed its first chassis in-house for the IMSA GTS-1 car.

Turning point

A big turning point came in 1999 when Lola hired Multimatic to develop an aluminium honeycomb chassis for the B2K/40 SR2 prototype after carbon chassis were banned in that class. After selling 18 cars, Holt took one to Le Mans in 2000, competing in the LMP675 class as Multimatic Motorsports.

'It was the first time the Canadians rocked up in Europe and we were wide eyed,' he remembers. 'We were there as a race team on an incredibly thin budget and we won it. That is the biggest win for me, still to this day, because we were only eight years into our racing journey and that was the first class win by any Canadian motorsports organisation in the 68-year history of the race.'

By this point, racing had become a major part of Multimatic's business. The product engineering activity had transformed into a full racecar constructor, with all the development hardware and simulation tools.

'The motor racing side helped enhance the whole culture of the engineering business because, in motorsport, any problem has to be solved in two weeks because there's another race,' highlights Holt. 'You have to be innovative and agile.

'Although there was not a lot of direct technology transfer, that [racing] culture trickled down into the mainstream business, which differentiated Multimatic from its competitors because we could solve problems faster. I can honestly say motor racing really did enhance our entire engineering organisation.'

In 2003, Multimatic made history again as the first constructor to win the new Daytona Prototype class with the Multimatic-Ford DP1, which was the first entirely purpose built Multimatic racer.

In 2005, Multimatic partnered with Ford to develop the Ford Mustang FR500C, selling 50 and winning the driver, manufacturer and team Grand Am Cup championships.

The addition of [a] UK-based engineering team to the Canadian motorsport operation, along with the IP from Lola, allowed Multimatic to then support LMP projects

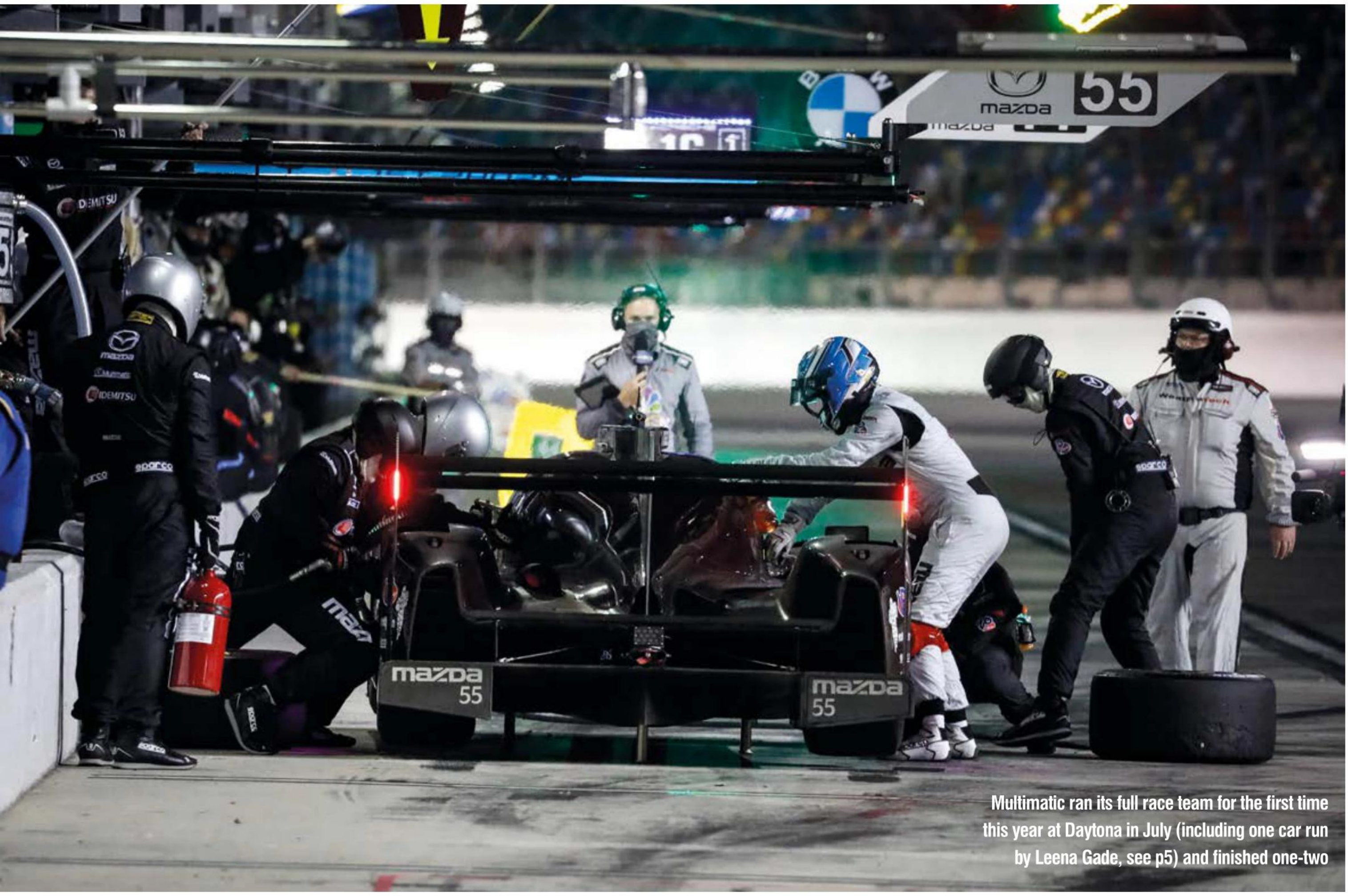
Multimatic continued to run versions of the Mustang for the next 10 years, winning the 2008 and 2016 championships.

Asset management

To boost its motorsports engineering capabilities further, Multimatic purchased assets from Lola when the company went bankrupt in 2012. An office was set up in Huntingdon, England near Lola's 40 per cent scale wind tunnel, and Holt filled it with the engineers from Lola. The addition of this UK-based engineering team to the Canadian motorsport operation, along with the IP from Lola, allowed Multimatic to then support LMP projects.

In 2014, Multimatic then partnered with Mazda, putting a four-cylinder diesel engine in the back of the Lola B08/80. 'We had two years of absolute hell with that engine. The torque of that diesel engine just destroyed transmissions but, on

Multimatic has over 450 patents worldwide and has achieved many industry firsts, including the famous DSSV (Dynamic Suspension Spool Valve) damper that helped Red Bull Racing win its four F1 championships. Pictured is the rear GT version



Multimatic ran its full race team for the first time this year at Daytona in July (including one car run by Leena Gade, see p5) and finished one-two

the other hand, it wouldn't rev high enough to actually go anywhere, so it wasn't fast and it damaged everything around it,' remembers Holt grimly. More success was achieved with the petrol version of the car in 2016/17.

Three-humped camel

The next major venture was the partnership between Riley Technologies and Multimatic Motorsport, which secured one of four licences to build the new 2017 LMP2 cars.

'That's a case study in itself,' says Holt. 'How two companies in two countries with two teams *can't* develop one racecar, because you end up with a three-humped camel. Everyone has their own ideas of how things are done, and no one is really wrong. But a car needs to be designed by one team, it just has to be.'

'We've come from running a four-door sedan in 1992 to showing the world we can be a successful race team at the highest level'

By mid-season, Multimatic and Team Joest took the lead role of the LMP2 programme, investing in further vehicle development work to solve a number of engineering issues that had hampered the car's performance. Multimatic was also responsible for the performance engineering work, while Team Joest remained in charge of race engineering.

'That became the Mazda summer, where we won three races, starting at Watkins Glen, and it finally all came good because we eventually had the right combination of everything,' concludes Holt.

Earlier this year it was announced that Mazda and Joest had ended its contract and so Multimatic took over the running of the race team as well. The IMSA WeatherTech 240 at Daytona in July marked the first time that the Canadian team was in charge of the entire operation, and the Mazdas finished one-two.

'We've come from running a four-door sedan in 1992 to showing the world we can be a successful race team at the highest level,' says Holt. 'I think as a constructor we have proved ourselves two or three times against the likes of Oreca, Ligier and Dallara. But what makes us unique is we are a race team, too.'

A lot of the successes Multimatic has enjoyed in motorsport are largely down to the company's engineering approach, which is supported by a whole host of advanced engineering tools. Alongside the office in Huntingdon, Multimatic also has a base in Norfolk where *Racecar Engineering* columnist, Leena Gade, manages a simulator, four-post rig and K&C rig in between race engineering weekends. Meanwhile in Toronto, Multimatic has another simulator and four-post rig.

Crossover tool

The latest addition to this plethora of engineering toys is the recently opened SimCenter in Detroit.

This vehicle dynamics development centre will see the installation of VI-grade's largest nine degrees of freedom driver-in-the-loop simulator, the DiM250, along with another static simulator. One of the few available outside OEMs, the patented design of the DiM250 enables it to generate both low and high-frequency inputs, allowing it to effectively model vehicle dynamics, as well as the more subtle ride and handling characteristics within the same system. This tool can therefore be used to develop automotive advanced driver-assistance systems (ADAS) and suspension development, as well as race set-up work.

In fact, the drivers for the Mazda programme will have completed their first pre-race work on the new SimCenter simulator by the time you read this.

‘I think we’re heading into another golden age of Sportscar racing, like back in Group C days, and… we’re totally committed’

‘Our simulators are very much a crossover tool that we can use to develop products for our OEM customers, as well as for racecar development,’ says Holt. ‘One day, we’ll be evaluating the front suspension of a road car, the next we’ll be doing pre-race work for Sebring. I think this is unique within the industry, and the crossover knowledge is invaluable and enhances both sides.

‘That business model hasn’t changed in the 28 years we’ve been involved in racing.’

The next challenge

The next big challenge heading Multimatic’s way is LMDh, and its advanced simulator platforms will prove invaluable when going hybrid. The four LMP2 constructors, Multimatic, Ligier, Dallara and Oreca are currently working together, along with the ACO and IMSA, to define the rule set that will govern the next era of Le Mans Prototypes.

‘In the technical working groups there are about 18 manufacturers. Will all of them come racing? No, but with that ratio you’re probably going to get eight or so,’ reveals Holt. ‘To me it makes sense because you’re going to be able to race for the outright win at Daytona, you’re going to be able to race for the outright win at Le Mans, and you’ll probably be able to do it on the same budget as running a GTE. Who wouldn’t want to do that?

‘The progress and cooperation between the ACO and IMSA has been very impressive. Throughout my whole career that hasn’t been the way, but now it’s really happening and it’s positive. IMSA and the ACO are working like they were brothers, American and French brothers, but brothers nonetheless.

‘I think we’re heading into another golden age of Sportscar racing, like back in Group C days, and that is pretty exciting, so we’re totally committed.’

Of course, going hybrid presents a whole host of different engineering challenges, particularly with regards to software and harvesting strategies. Yet advanced motion platforms, with hardware-in-the-loop capabilities, can be the key to unlocking reliability and performance.

‘The [Ford] GT road and racecar were both developed on the simulator,’ explains Holt. ‘I got Bosch to do all the ABS and ESC calibration on the sim. Normally that has to be done during endless laps at the racetrack, constantly tweaking the calibration. But by utilising the simulator to tune the software, the car was about 85 per cent there in terms of ABS and ESC when we hit the track. That was software-in-the-loop but now, with the bigger simulator in Detroit, we’ll have hardware-in-the-loop capabilities.’

Hardware-in-the-loop effectively means that instead of the simulator modelling components such as the ECU, the actual ECU from the racecar can be integrated. This not only allows teams to test and validate the software running on the real ECU, giving them confidence in its functionality before heading to the track, it also allows teams to experiment with different energy management strategies. This is particularly important when trying to optimise the harvesting of energy from the brakes and deployment of energy from the battery, all whilst achieving a level of driveability that satisfies the driver.

Hard-real-time

However, to effectively integrate hardware such as this into the simulator, the vehicle models need to run on a hard-real-time system. These are advanced computers that guarantee certain processes will be completed within a time step of precisely one millisecond, or at 1kHz.

In the case of the ECU, which is used to dealing with real inputs from sensor signals in real time, the simulated inputs from the vehicle model also need to be in real time.

Divide and conquer

Multimatic has seen huge business growth over the last 30+ years so, to manage this growth, the Canadian-based company’s approach has been to split the business into smaller and more agile operations. Following this business model, earlier this year, Multimatic created a new division called Special Vehicle Operations group (MSVO), the fifth group within the Multimatic structure.

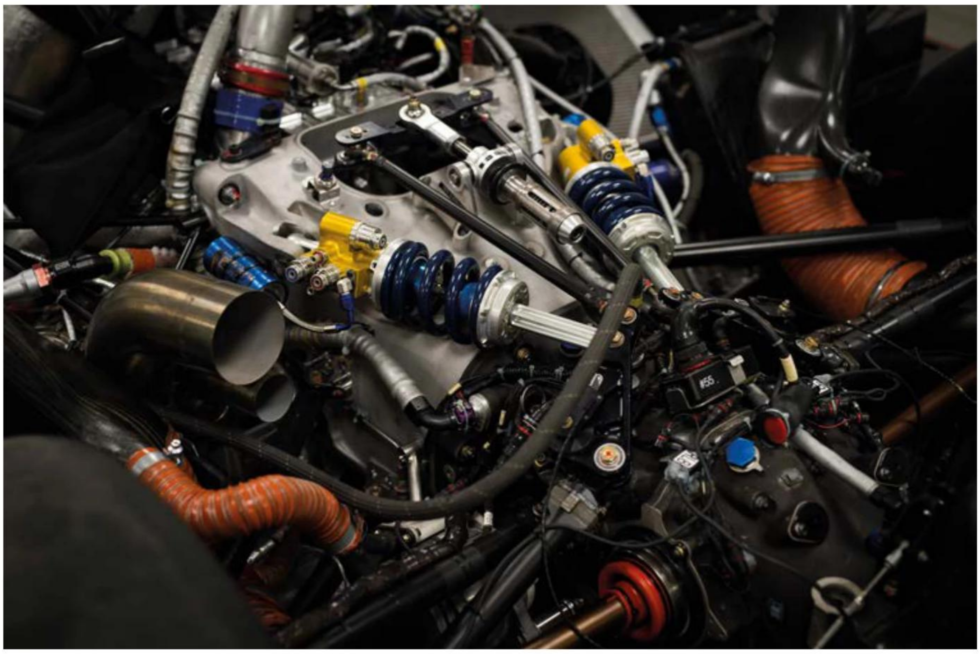
Led by Larry Holt, MSVO is responsible for all of the company’s motorsport engineering projects, such as the Mazda DPi programme, as well as all race team operations. Also falling under the MSVO umbrella is low volume chassis manufacture, carbon fibre part production and the various niche vehicle engineering development programmes. The mainstream engineering business, Multimatic Engineering, headed up by Jim Holland, will focus on high volume manufacturing.

‘It’s just got so big we had to split it to make it sustainable for the future’

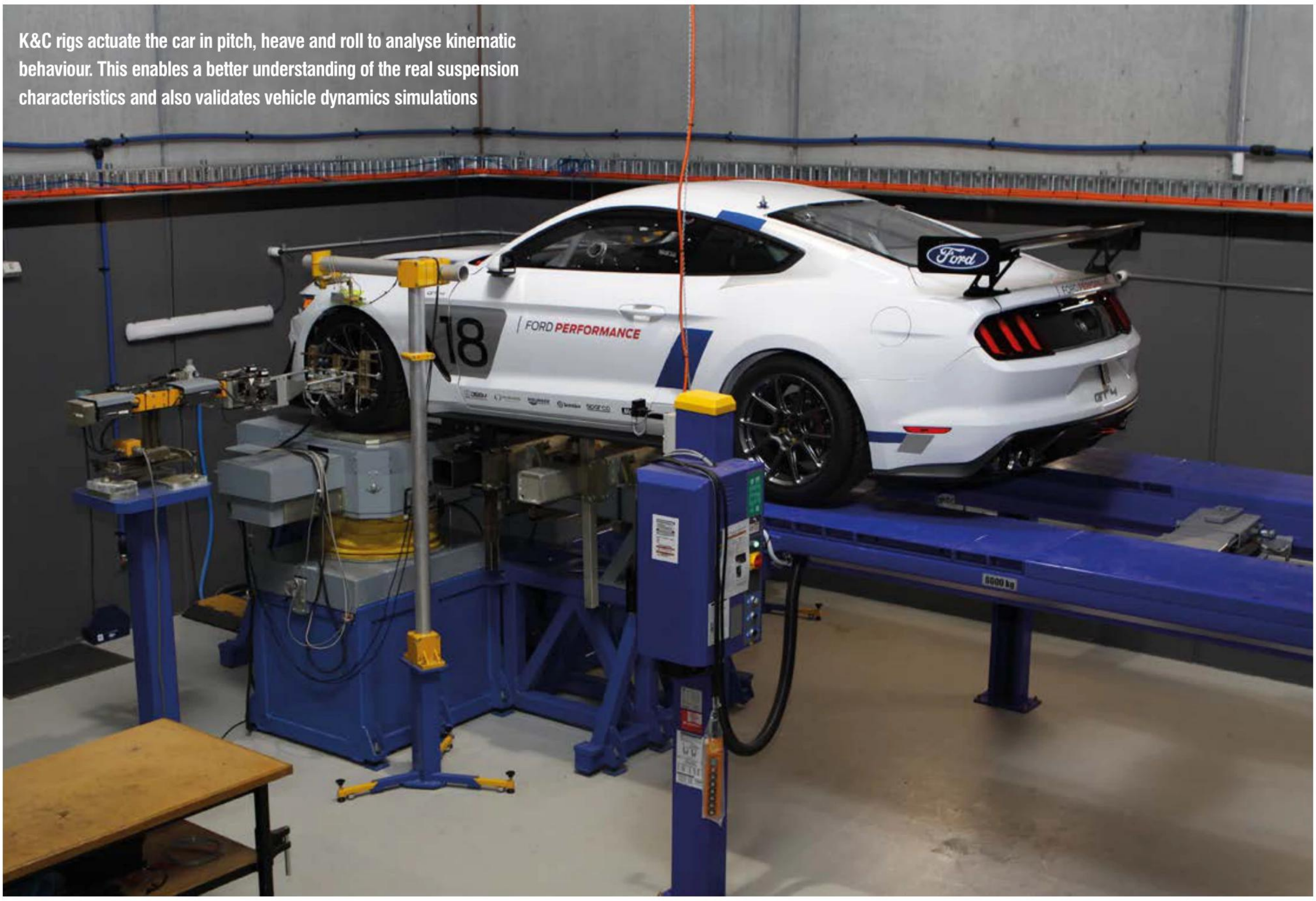
‘Alongside our racing activities, we are also involved in the engineering of many road car projects with the likes of Ford, Aston Martin and AMG. So, it’s just got so big we had to split it to make it sustainable for the future,’ says Holt.

‘High volume component and systems engineering requires a different approach to the development of an entire low volume vehicle, so the management of those types of projects has now been split. But the relationship between the two groups will be very close.

‘It makes no sense to try and duplicate functions like the best predictive methods organisation in the industry. Simulation will stay with the engineering group and continue to grow in size and capability. So Multimatic Engineering and MSVO will continue to learn from each other.’



Suspension detail on the Mazda RT24-P DPi



K&C rigs actuate the car in pitch, heave and roll to analyse kinematic behaviour. This enables a better understanding of the real suspension characteristics and also validates vehicle dynamics simulations


Multimatic opened a new SimCenter earlier this year, which includes a VI-grade nine degree of freedom DiM250 simulator that the Mazda drivers will now use for race preparation

Multimatic is working with Ontario Technical University to upgrade a climatic wind tunnel into a full-scale aerodynamic wind tunnel. A moving ground plane, along with a restraint system and a set of measurement devices will all be incorporated

If information arrives a time step later than expected, the ECU can interpret this as lost information and, when the ECU then tries to compensate for that, it can lead to errors.

Hardware-in-the-loop has been a key part of the development of the AMG Project One Hypercar, which Multimatic is also involved with, particularly with regard to hybrid strategies.

'We know from our work on Project One that developing the brake-by-wire systems to get a smooth transition from regenerative braking to hydraulic braking, whilst not impinging on brake feel for the driver, is really challenging,' explains Holt. 'It's a degree of freedom that we've never had to deal with before, and the best way to experiment with that is on the simulator.

'You may think that with all this engineering capability the thought of going hybrid doesn't scare me, but actually it does. In fact, I may be more scared of hybrids now I have experience with them.'

Reverse feedback

Currently, IMSA and the ACO are leaning heavily on the constructors to conduct this development work, and right now they're focussing purely on offline simulations. However, it won't be long until it's time to utilise hardware-in-the-loop simulators. So interestingly, the knowledge transfer has reversed and the experience gained from these niche automotive projects is now feeding directly back into the motorsport side of the business.

Another project in the works is the development of a full-scale wind tunnel. Partnering with Ontario Technical University, Multimatic is involved in transforming a full-scale climatic tunnel into a full-scale aerodynamic tunnel. The plan is to integrate a moving ground plane to accurately replicate aerodynamic forces, along with a restraint system and a set of measurement devices. When opened, it will become the home tunnel for Multimatic and only the second full-scale moving ground wind tunnel in North America, Windshear being the first.

Spectacular facility

'It really will be a spectacular facility,' confirms Holt excitedly. 'I would say probably *better* than Windshear because the test section is so much bigger.'

As the restraint system has been designed to cater for a 40 or 50 per cent scale model as well, scale model wind tunnel tests will also be able to run there. And because the test section is so large, the blockage factor will be minimal, leading to more reliable results (see the article on p62).

Despite this advanced facility, Multimatic will continue to utilise the Lola wind tunnel in the UK for aerodynamic testing because, as Holt explains, 'Every tunnel has its own

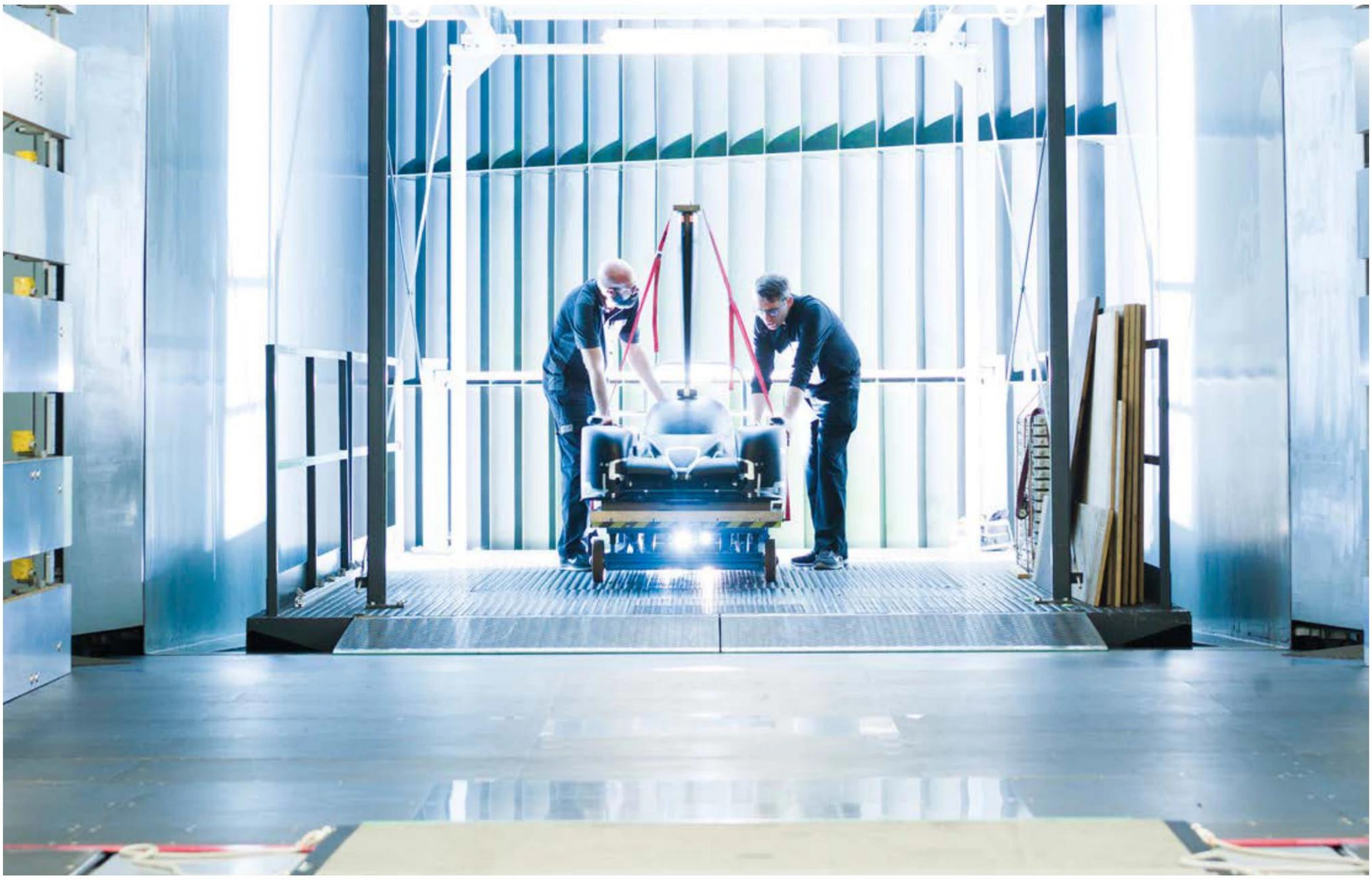
With the addition of this new full-scale tunnel, Multimatic will now have access to the full suite of aerodynamic capabilities in-house

character and nuances, and our aero team know that tunnel so well that there's a comfort level to using it.'

With the addition of this new full-scale tunnel, Multimatic will now have access to the full suite of aerodynamic capabilities in-house, from advanced CFD tools through to scale and full-scale wind tunnels.

Arguably, the only aero tool left in the armoury is the Catesby tunnel in the UK, which is 2740m long with a 40m^2 working section. This will become the UK's first indoor coast down facility and was covered in detail in *Racecar Engineering* V24N11.

'We've built up all our aerodynamic facilities and we've got fantastic vehicle dynamics capabilities now. We have all the pieces of the puzzle,' concludes Holt.



TGR

Model behaviour

Understanding the benefits and limitations of scale model wind tunnel programmes

By JAHEE CAMPBELL-BRENNAN

Wind tunnel testing has a fascinating history, beginning in the aerospace industry. As testing methods became more sophisticated and laboratory testing evolved, a need was identified to provide a method of validating design concepts. The Wright brothers were the first to achieve controlled flight as they built a tunnel to calibrate the characteristics of wing profiles and showed that the accepted characteristics were wrong.

However, few tunnels existed that would be capable of managing a 1:1 scale prototype. Aerospace engineers quickly figured out there were many advantages to preparing scale models. Namely, it enabled testing to take place at all, but furthermore cost, materials use and build times were slashed when compared to full-size prototypes.

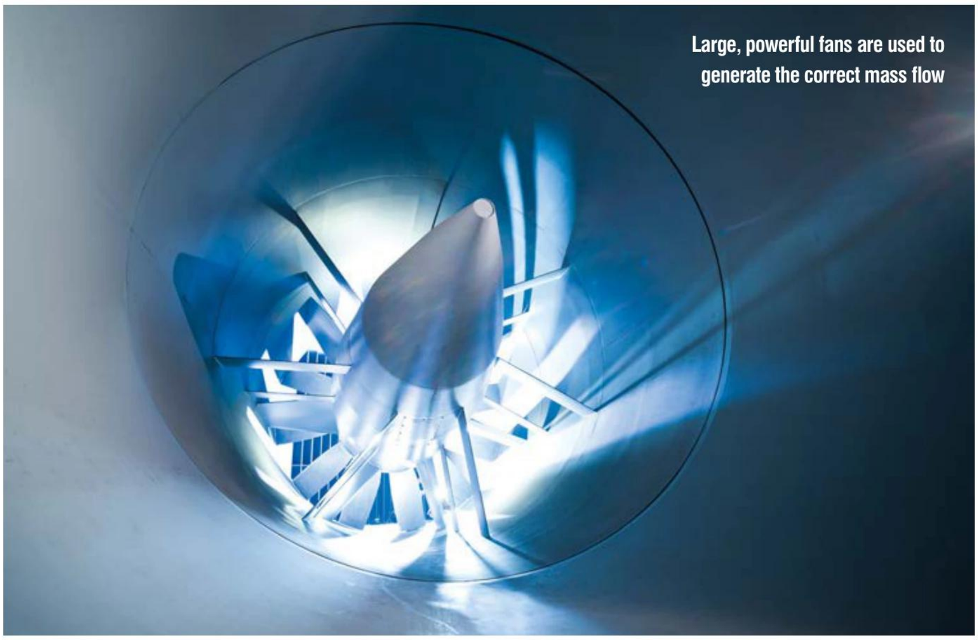
Cars by their very nature operate close to, and in contact with, the ground, so automotive wind tunnels differ substantially in design to aerospace ones. A moving ground plane and effective boundary layer control are critical features but, in the early days of automotive wind tunnel testing, these weren't available to full-size models. The concept of scale models within automotive and motorsport testing was therefore born out of similar necessity to aerospace.

A modern automotive wind tunnel's principal function is to accurately recreate the motion of a car driving on a road surface. The key difference experimentally, however, is that you are moving the air over the vehicle, rather than moving the vehicle through the air. At a minimum this requires the presence of a relative air velocity over the car body, and a moving ground plane to simulate the asphalt passing beneath.

Matched relationship

The relationship between tunnel and model is a valuable point of learning as they must be matched in order to create a suitable test environment. So, from an engineering point of view, the particular tunnel facilities available for a project tend to decide the maximum scale of model used. Let's explore what that means in practice.

When testing in any wind tunnel you have a fixed cross-sectional area. Naturally, the presence of a test model introduces a flow


Large, powerful fans are used to generate the correct mass flow

TGR

The scale of the model ultimately dictates the air speed, and for this reason it's usually a case of 'the bigger the better'

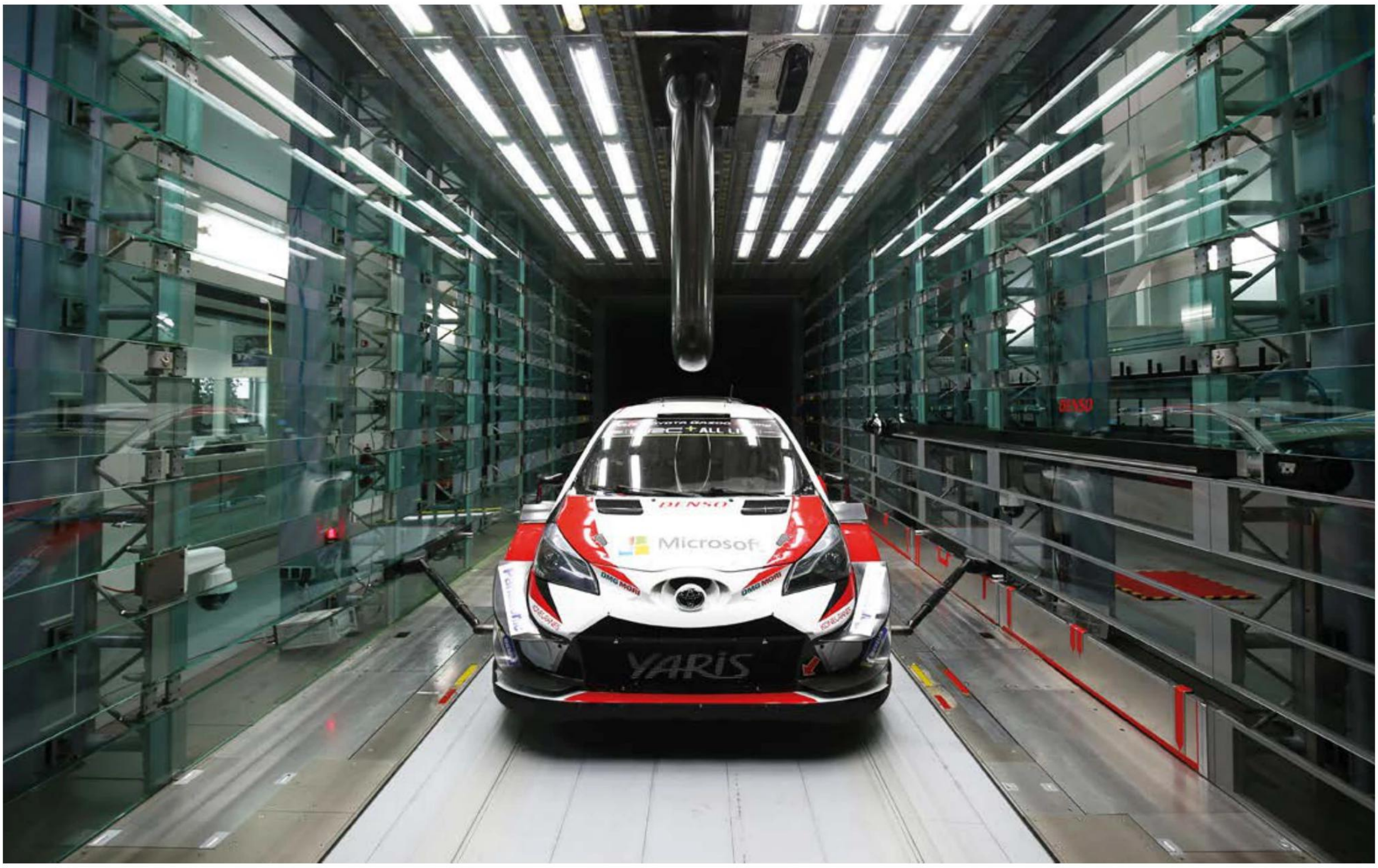
constriction into the tunnel. The presence of the flow constriction can manifest in two ways – either as a solid blockage, attributed to the frontal area of the vehicle, or wake blockage, which occurs when the dispersion of turbulent wake from the body is impinged by the roof and side walls of the tunnel. The design of the tunnel does have influence into how significant these effects are, but they are inescapable.

Solid blockage is problematic as it causes local increases in velocity around the vehicle body. Due to the principles of continuity (Bernoulli), flow travelling through a constriction must increase in velocity to preserve mass flow. The static pressure around the car body therefore lowers and the measured forces around the body become skewed. The result are therefore invalid.

Wake blockage is a little different as it's not directly a result of the model's area but, due to its geometry, will generate a turbulent wake in the tunnel. Interfering with the wake flow affects the pressure distribution across the whole body. The rear wing and diffuser can be particularly sensitive to this as pressure distribution and mass flow are impacted, which means the point of flow separation can be altered.

'Wake blockage can be an issue with larger test models. When the wake is very large, the flow can affect the breather, where tunnel pressure equilibrium is maintained. If the wake is too big it can also affect your pressure distribution across the test section,' says René Hilhorst, chief of aerodynamics at Toyota Gazoo Racing. 'Depending on the design and whether the splitter, rear wing or diffuser are strong in generating downforce, it can affect those to a greater degree, but it really does affect the whole car.'

The section, or blockage ratio (tunnel cross section vs test piece frontal area) is usually maintained at below 10 per cent. Although a blockage as low as is practically possible is desired, it's always necessary to



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Toyota Gazoo Racing's custom wind tunnel facility was built with a slotted test section and optimised for 60 per cent scale models, though will also fit full-size vehicles

Scale models for high-level motorsport are highly refined and feature all the dynamic complexities of the full vehicle

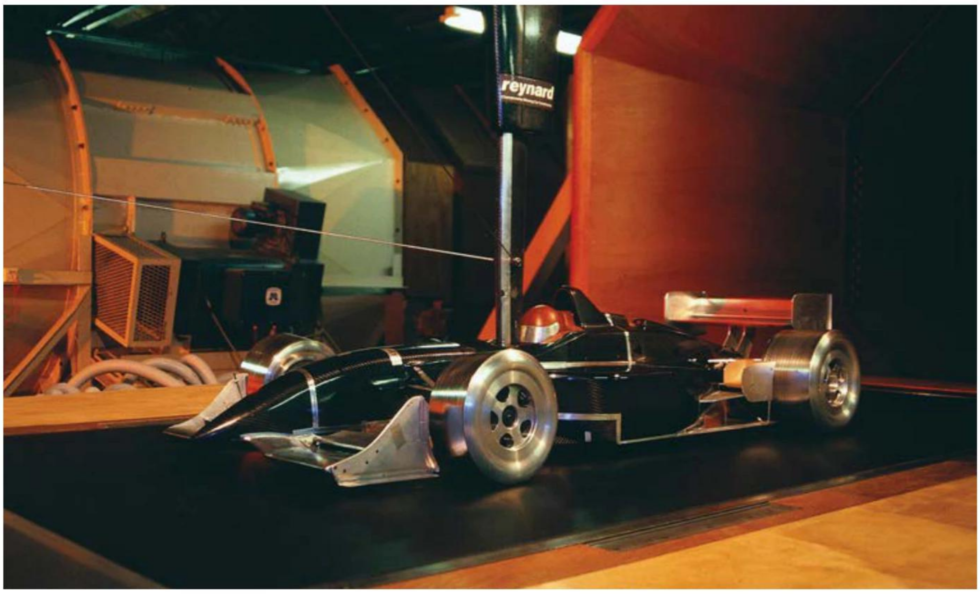
‘[Scale models are] generally now a mixture of polymer, sintered metallic parts and metal reinforced polymers’

René Hilhorst, chief of aerodynamics at Toyota Gazoo Racing

incorporate blockage corrections into any measured lift and drag coefficients to adjust for local velocity and pressure gradient influences. The actual correction arithmetic can be fairly complex and proprietary to a particular tunnel, but it’s important to remember this is not a problem specific to scale model testing.

As we’ll discover a little further into the article, the scale of the model ultimately dictates the air speed around it, and for this reason it’s usually a case of ‘the bigger the better’ when referring to scale.

‘The tunnel at Toyota Gazoo Racing [TGR] was built for F1,’ adds Hilhorst. ‘The main target was to have exceptional conditions for scale model testing up to 60 per cent, and capability to do very good full-scale testing, but we don’t do this so often.’



Models can also be relatively simple and static, but still reveal meaningful data

Levels of complexity

So now we understand some of the elementary concerns of wind tunnel testing, let’s take a look into the detail of the scale model and what’s required from it to produce meaningful data for the aerodynamicist.

The model itself is a pretty elaborate component as it must be intricate to be representative. In all but the simplest test cases, the model must incorporate all the degrees of freedom [DoF] a real car has – wheel rotation, steering, body and suspension movement (with accurate kinematics), ride heights, chassis pitch, roll and so on. And that doesn’t even touch on secondary effects such as aeroelasticity and tyre squish due to aero load. It can quickly become an extremely complex item.

Of course, the actual racecar is the perfect instrument in this sense, so how do you incorporate these features of a real car into a model? And more importantly, what determines the level of complexity required of a model for a particular project?

‘There are clear differences in model complexity as you get to more high profile championship levels, and therefore bigger budgets. The more basic models will not have any kind of ride height actuation or steering capability, and will likely have solid tyres,’ comments Dominic Harlow, a motorsport engineer director of engineering consultancy, Dominic Harlow Consulting. ‘When you get to Formula 1 territory, however, you’ve got pneumatic tyres, full DoF of suspension movement and ride height actuation, right down to the pre-loading of tyres to represent the effect of aero load. Prices then can go from £50k [approx. $63,425 / €55,425] for something like a 30-40 per cent [scale] F3-style model up to around £500k [approx. $634,250 / €554,250] for an F1 model.’

Hilhorst adds: ‘When we were competing with Audi and Porsche in the WEC, the level of detail required was close to F1 level. We had to go into very refined models with lots of data acquisition and sensing to find the maximum information possible. When you are doing development for a project with less intense competition, you might focus more on styling, where the model detail might be less important, so it’s chosen accordingly.’

Added detail

Features requiring actuation, such as steering and ride height adjustment, are usually achieved using linear actuators and motors. By extending or collapsing the length of a push rod, the ride height or pitch and roll of the model can be adjusted. Likewise, a steering rack can be represented to actuate the steering arms of the model. Tyres add another level of detail to the picture.

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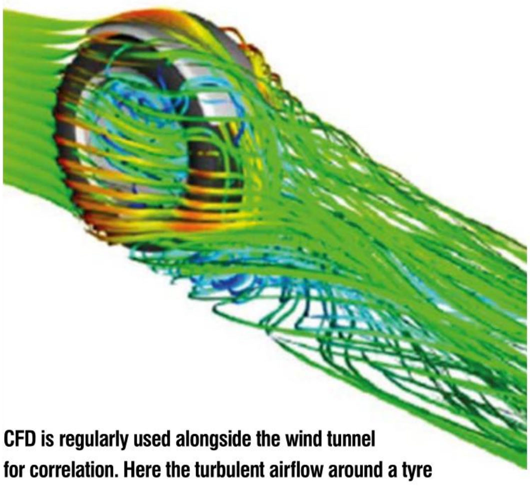
Pre-load can be added to scaled tyres to imitate squish due to aerodynamic loads. In some cases, tyre manufacturers will make scale models of their products for wind tunnel testing



CFD is regularly used alongside the wind tunnel for correlation. Here the turbulent airflow around a tyre

As a pneumatic device with its own spring rate, the shape of the tyre varies dynamically with air speed and the subsequent aerodynamic loads that result

As a pneumatic device with its own spring rate, the shape of the tyre varies dynamically with air speed and the subsequent aerodynamic loads that result. In certain applications, this has a huge influence on aerodynamic behaviour, particularly at the contact patch where air is 'squished' outwards as the wheel advances forward. Tyres, especially with open wheelers, generate quite considerable lift and drag forces too, which are of interest to aerodynamicists.

Let's add some context to this and imagine the airflow over an open wheeler. Turbulent flow structures coming off pitching and rolling front wings, deforming tyres and turning wheels have a huge potential to interact with downstream performance parts such as bargeboards, underfloor and rear wings. Closed-wheel cars are affected due to the tyres influence on underbody flow, although not to the same degree.

To provide an accurate means of modelling this on a scale model, tyre manufacturers, at least at higher levels of motorsport, actually make scale versions of tyres with matched physical properties to their real counterparts (see *RE* V23N11).

'We like to understand the contribution of the tyres to overall forces. As the tyres are attached to the model and we are running rubber tyres, we must measure the lift and drag contributions from those also. As you get into more detail around aerodynamic behaviour, you see that the deformation of the tyre patch is important to overall aerodynamic behaviour, and is very dynamic, so we try to be as accurate with this as possible,' adds Hilhorst.

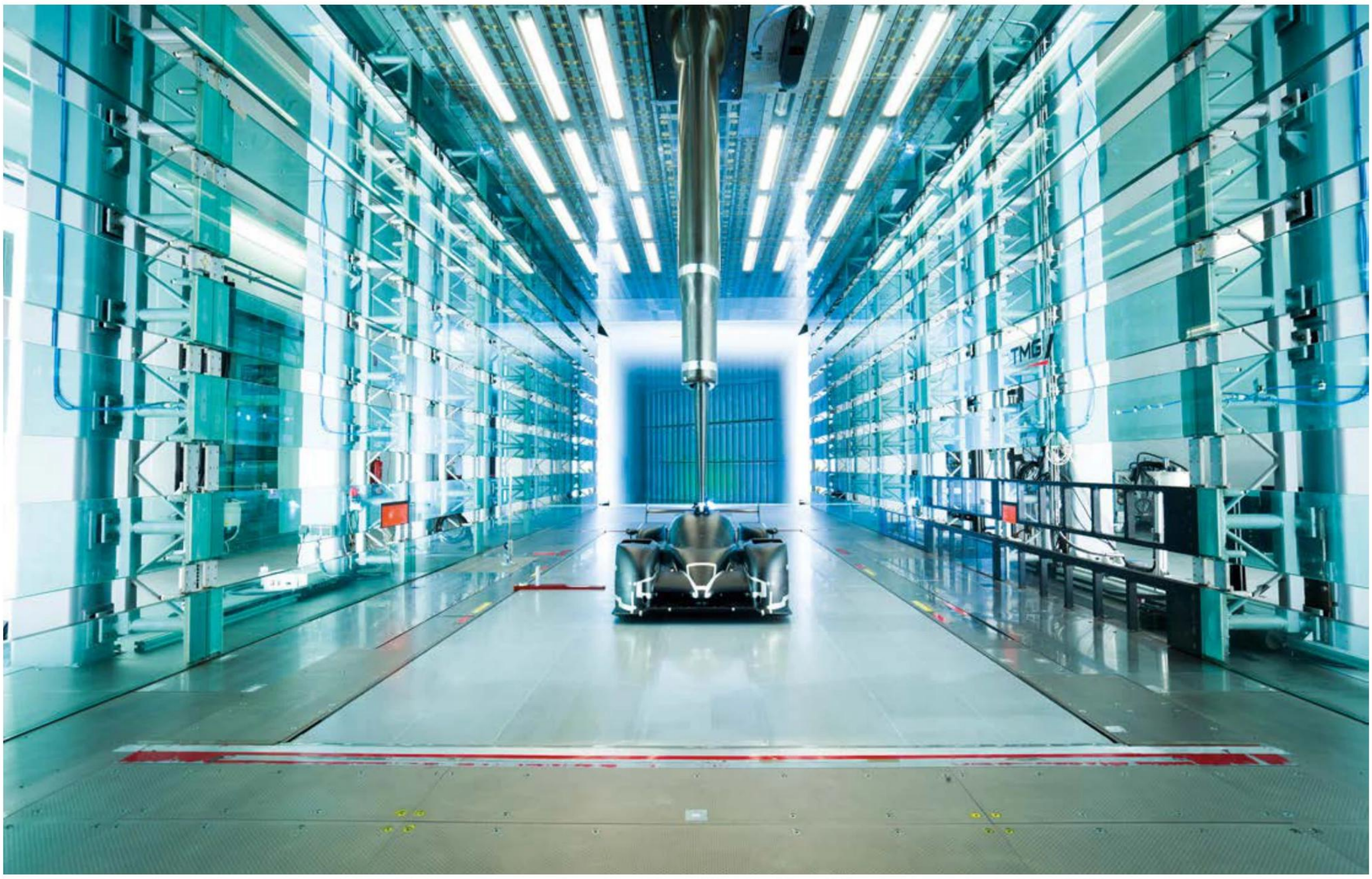
A GT platform, for example, simply wouldn't require the same level of detail.

Rapid modelling

In their construction, scale models have taken huge leaps forward in terms of technology in recent years, particularly with the advancement of rapid prototyping technology. In the past, model aerodynamic surfaces were constructed from carbon fibre with an aluminium inner skeleton to provide structure, but now it's a different world.

'Since the explosion of rapid prototype manufacturing, in terms of printing techniques and quality, we are now enabled to use this technology in our model construction,' explains Hilhorst. 'It depends on the specific load requirements of the structure, but is generally now a mixture of polymer, sintered metallic parts and metal reinforced polymers. There's just so much development that has happened over the last few years, it's fantastic.'

The ability to rapid prototype engineering solutions has unlocked an entirely different approach to prototype production and revolutionised testing. 'We can go straight from CAD to the machines, which means we can have a model completed in a very short time. Typically, a few days, but if there is a real emergency and all our machines are free, we can make this happen overnight.



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With similitude, boundary layer control and a moving ground plane, TGR has seen accurate correlation between wind tunnel models and the full-size car

'This capacity and capability exists as a carry-on from our time in F1,' says Hilhorst.

That is in sharp contrast to the several months it can take to construct a model using the more traditional techniques.

It's interesting here to note the relationship between model size and material usage. As volume is a cubic function, it follows that a part made at 50 per cent scale is using 12.5 percent the quantity of material. Likewise, 6.4 percent for a 40 percent model and 21.6 per cent for a 60 percent scale model. Mass follows the same trend, and this is an important consideration for material usage and the associated costs of machining, which can be factored into the scale one might choose for a project.

Dynamic similitude

Earlier, we touched on the fact that flow speed has to change with scale. Assuming you want to maintain the same relative flow speed over the model surfaces, when you halve the scale, you might think you halve the speed. In fact, the opposite is true.

The engineering behind this is focussed around a concept called dynamic similitude. In this context, similitude demonstrates that the flow conditions between the model and the real application are analogous but, in an absolute sense, they are different. Again, this is a concept the aerospace industry had to tackle long before automotive. Since in motorsport we are dealing with low flow velocities that we can consider them to be incompressible, it means we can ignore the effects of Mach number and need only look at the Reynolds number.

The Reynolds number of a flow defines its regime – either laminar or turbulent. It relates the inertial forces generated by the fluid molecules as they collide and alter direction to the viscous forces generated by shear stresses generated during internal friction. In principle, this is an indication of the point at which a flow can be expected to transition from laminar to turbulent.

Its relationship with flow speed is perhaps easier to see via this equation:

$$Re = \rho u L / \mu$$

Since fluid density (ρ) and dynamic fluid viscosity (μ) are constant in cases within automotive wind tunnel and L, the reference length section, is determined by the model scale, the equation shows us that any reduction in scale can only be balanced by an increase in flow velocity (u). A simple mathematical problem ultimately.

The Reynolds number becomes really useful in understanding flow over items such as wings, underbodies and diffusers. When the ratio of inertial and viscous forces reaches a certain threshold, and the momentum possessed by the fluid exceeds the effects of the viscosity in keeping the flow laminar, it indicates the flow is turbulent. This is crucial when ensuring flow separations and vortices are happening on both the scale model and at full size in the same manner. This relationship is what must be maintained in achieving similitude. In short, what this tells us is that a 50 per cent scale model requires double the air speed to achieve similitude.

In a real sense, this means a 'real life' 70m/s airflow becomes a wind tunnel air speed of 140m/s (313mph / 504kph). You might not only struggle to find a wind tunnel with the power to generate that level of flow and ground plane speed, but with even smaller models you also start to enter a realm where the Mach number is large enough that air

'We can go straight from CAD to the machines, which means we can have a model completed in a very short time. Typically, a few days'

René Hilhorst

cannot be considered incompressible any longer. At this point it all starts to unravel.

On paper, you can get around this issue by pressurising the tunnel, or using a 'heavy' gas, but I'm not aware of any automotive tunnels that do anything like that.

Despite efforts to match the Reynolds number in a particular test, there are other factors that need to be considered in order to effectively correlate wind tunnel tests to a scale model, as Harlow explains:

'There can be times where you're especially sensitive to Reynolds number. For example, front wing ride height sensitivity. You can get into a situation where your wind tunnel data looks very favourable in a particular scenario, but which would ultimately lead to separation and stall at the track, so is therefore not representative.

'Sometimes subjectivity and experience come into play there. Reynolds number is all about the transition from laminar to turbulent, and then separation, and ultimately how close that is to reality.'

TGR's experience also reflects this reality. 'With scale models, by definition you are not at the same Reynolds number as the real car at the same speed, so you always have to accept a slight difference in Reynolds number. Through correlation you must make sure the flow structure is not affected by this difference. Even then, sometimes a model will follow a slightly different flow pattern and give you a different result. Because of this, some parts that work in the wind tunnel don't perform as suggested in real life,' notes Hilhorst. 'This can be due to things such as surface finish, model quality and detail, aeroelasticity… It can be a number of reasons. When we discover this, we go back and change the model, but sometimes it will still never truly match.'

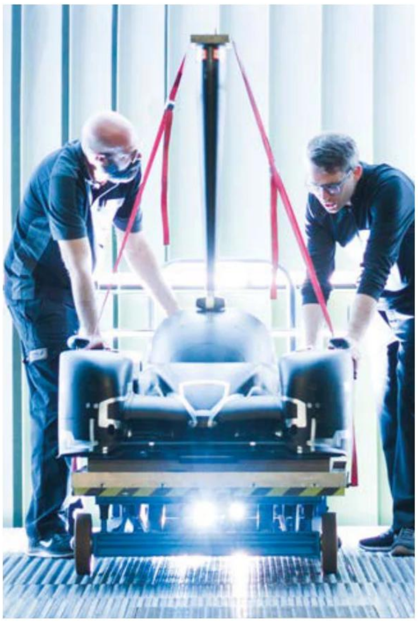
Surface finish

One particularly interesting concept is the effect the surface finish of a model can have on the measured drag, and the way in which a part generates lift. In this case, the finish of an aerodynamic surface has influence on the boundary layer of flow over the part. A rougher surface can induce flow separation earlier than a smooth part would, although a rougher surface can also trip the boundary layer flow from laminar to turbulent, which is more robust and can *prevent* separation.

'If you take a part straight from rapid prototyping and measure its performance without performing any finishing, then polish or paint the part, you will always measure something different. This effect can be significant, not only affecting skin friction but also lift,' confirms Hilhorst.

For practical reasons, wind tunnels operate at a fixed speed / Reynolds number

A scale model must be constructed in such a manner that there are representative levels of flex at peak loads



60 per cent models can look more like 30 per cent scale to the naked eye due to the way we view area

during any set test. The actual test speed is generally chosen to give the largest benefit for a particular driving scenario, usually determined statistically.

'A car drives at an enormous range of speeds at any track, so you have to find a way to determine what speed and attitude you'd like to represent in the tunnel. Usually this is determined with an element of subjectivity, but there's also an element of data using statistical analysis ie at what speed does the car spend the most time, correlated with where you generate the most lap time. Where those two things are at maximum is where you tend to focus development,' says Harlow.

This data can be taken from lap time simulations or measured data.

The science of aeroelasticity is also an important consideration with scale models, which gives consideration to the interaction of aerodynamic forces on structures. As a generalisation, it's not a design feature to have aerodynamic surfaces flexing (unless you were in F1 circa 2012). Jokes aside, a scale model must be constructed in such a manner that there are representative levels of flex at peak loads. A rear wing that flexes can alter its angle of attack, an underfloor that bows towards the ground can stall the diffuser. It's an important thing to get right if you're to rely on the wind tunnel results.

'Aeroelasticity, in the context of ensuring the scale model has representative physical properties to the real car in terms of stiffness, becomes trickier as you go up in scale and test speed as you're generally not using the same materials,' says Harlow. 'This is why a lot of F1 teams use metal-coated, rapid-prototyped parts, especially when they're very small and intricate.'

It's common process to match the stiffnesses between the scale model and real car at your chosen design speed. With this methodology, you enable the deflections at particular Reynolds numbers to be identical. Small steps like this are really necessary when you're trying to realise a strong correlation between the two cases.

Aerodynamic loading

On the subject of aerodynamic loads, how do they compare between scale model and full size? To understand this, it's important to remember that the peak loading of an aerodynamic structure is dependent on the area of surface the pressure is working on. As we know, area is a squared quantity, so it's quite a simple move to 'scale up' (or down, depending) the forces to suit.

This information is useful on two fronts. In the design and build of the model you need to understand the magnitude of forces it's likely to encounter for precisely these concerns of strength and aeroelasticity. Then, when you've completed testing, you need to understand how the values recorded in the tunnel compare to the full-size vehicle.

To explain this with a little mathematics again: take any given speed, say 40m/s. The forces on a 50 per cent model are 25 per cent (0.25) of the full-size model, a 60 per cent scale model gives 36 per cent of the forces, and so on. To work the other way and relate model forces to the full-size car, use the inverse. At similitude, the forces are the same on both scale and full size.

Area 36

This relationship of areas is interesting. If you've ever seen a scale model in person, they can look really quite small in a way that initially doesn't make sense. When we view objects, any object, we're actually looking at the area, which explains why a 60 per cent model looks more like a 30 per cent model because we're only viewing 36 per cent of the full-size area.

The actual testing methods of scale models don't differ substantially to their full-size counterparts. It starts with understanding the operating envelope of the car and each

Go with the flow

How aerodynamicists combine CFD with scale model testing to obtain fast, accurate results

Watching a racecar travelling 230mph is exciting, but watching two cars side by side trying to outmanoeuvre each other for the lead at 230mph is heart pounding! At these speeds drivers need to have the utmost confidence in their car's performance. However, the wake of air behind the leading car creates a turbulent flow that makes its handling tricky at best. This is a very challenging problem to solve for both driver and aerodynamicist.

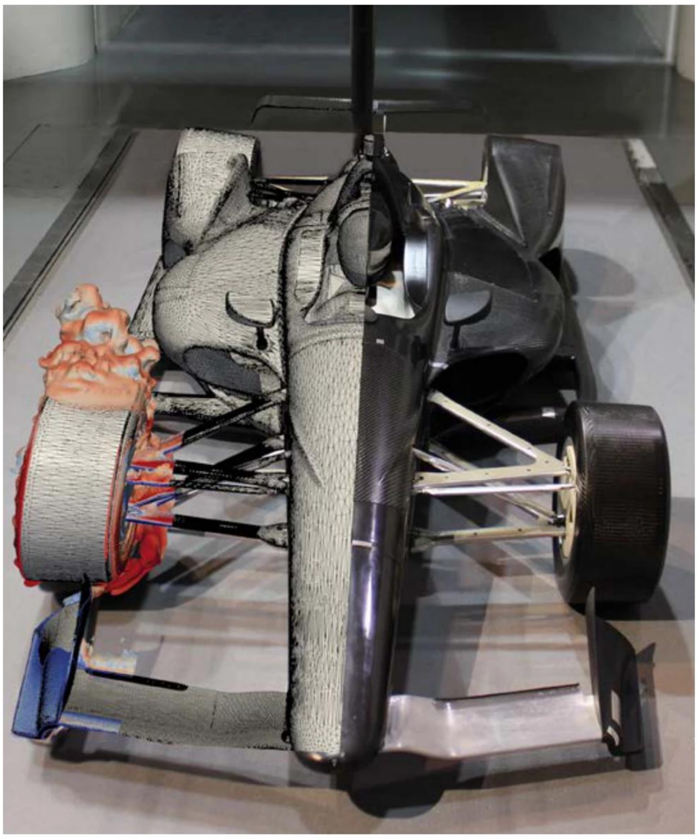
In order to tackle this, Auto Research Center (ARC) personnel used a combination of tools to come up with possible solutions. Our aerodynamicists used a blend of computational fluid dynamics (CFD) and scale model wind tunnel testing to study the flows and resulting aerodynamic forces and to develop an optimal solution.

Scale model wind tunnel testing is a well-established method of developing racecars. At scales of 40 to 50 per cent, our models have the resolution to capture even the smallest details found on the real car. Our rolling road system replicates the complex aerodynamic conditions that ground effect vehicles experience giving results that mirror the real world.

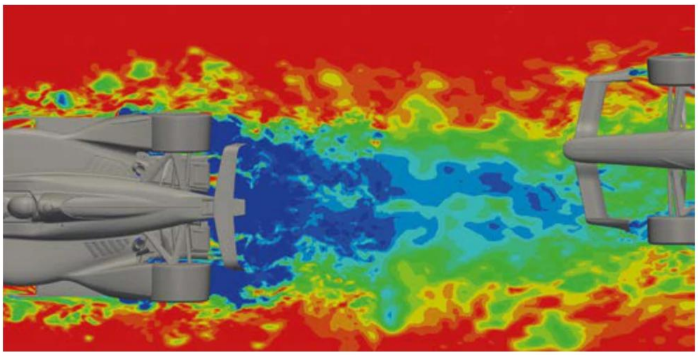
Master craftsmen

Our scale models are built by master craftsmen using manufacturing methods and materials from advanced composite construction, CNC machining to rapid prototyping. With in-house manufacturing, an idea in the morning can become reality by the end of day.

Our automated model motion system runs through various ride heights and roll, pitch and yaw angles in a single run. An automated steering system may be used as well to study the interactions of the tyres and front wings. The data acquisition system logs the aerodynamic forces on the model, wings and wheels, as well as hundreds of pressure taps.



At ARC aerodynamicists use both CFD and scale model wind tunnel testing to get results



CFD data is backed up and refined using physical data obtained from the scale model

Modern data analysis methods then help the aerodynamicist process the comprehensive data sets in order to effectively apply what is learned in the tunnel to the track, the true test of performance.

CFD, when used in conjunction with a wind tunnel programme, can lead to even further understanding of the physics of the problem and the correlation between the two quickly blends into a symbiotic tool for further development and tuning of the vehicle.

Quick turnaround

Just as scale model testing opens up new options in planning physical testing, CFD encompasses a range of solutions allowing you to go from highly resolved and detailed studies to quick turnaround optimisation that can run from concept to results in less than an hour, even for a full vehicle. Leveraging scalable cloud computing to provide hundreds of thousands of core processor hours, combined with efficient and accurate transient turbulence modelling and mesh design, it is possible to create terabytes of data very quickly. Streamlining the process and creating custom scripts to handle data transfer and analysis is a key part of accessing the potential of modern CFD practices.

Design of experiments was used to create a passing map, which charts the positions of two cars during the passing manoeuvre. This map gives sufficient data to understand the interactions of the airflow between the two cars and helps the aerodynamicist identify critical areas. CFD evaluations showed the resulting wakes and let us design wing changes that removed the undesirable balance shift and downforce losses the passing car experienced. We were able to quickly offer solutions for better passing and more exciting racing by using two of our technologies in concert with each other.

Today's customers demand accurate results quickly. Combining both the virtual and physical worlds results in more accurate, faster and cost-effective results. ARC has been a leader in this blend of technologies for 22 years. Find out how our expert staff can help ensure your success.

Contact us at solutions@arcindy.com or +1-317-291-8600 or visit our website at www.arcindy.com for more information.

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Track correlation is still a must have for any wind tunnel programme

Porsche

'A wind tunnel is a different picture of the truth and needs a lot of energy to ensure good correlation'

David Floury, technical director at ORECA

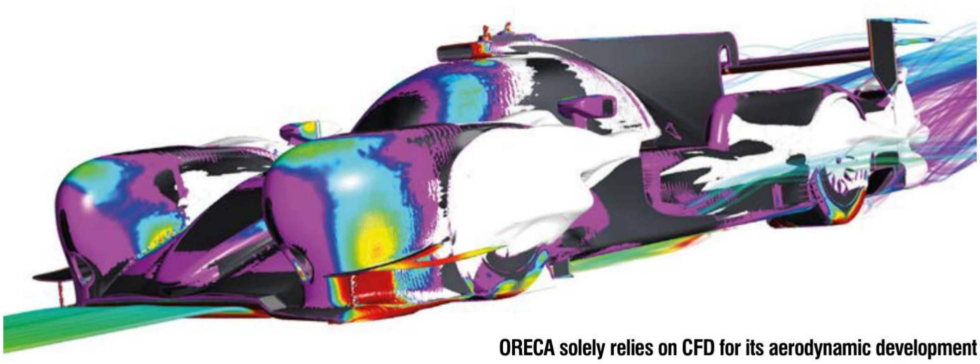
feature of the model that is adjustable. Then we look at the range of attitudes that are likely to be seen on the track, and any specific areas which demand particular focus. For example, aside from forces and moments, is there interest in cooling or brakes or some other specific elements? The test then proceeds as per the agreed plan.

As with any laboratory test, correlation is crucial and results should always be verified via some form of real-life track testing. It's usual for a wind tunnel correlation loop to have the following flow: scale model in tunnel –> full-size car in tunnel. Full-size car in tunnel –> full-size car on track.

This is often why you see F1 teams during pre-season testing with elaborate aerodynamic rake assemblies featuring Kiel probes and other such devices. They don't have the luxury of full-size wind tunnel testing, so must go straight from scale model (usually 60 per cent) to track verification.

Artes Max

As often seen in Barcelona, all manner of measurement apparatus appear in efforts to correlate lab and CFD methods



ORECA

ORECA solely relies on CFD for its aerodynamic development

CFD advances

CFD methods have advanced so much in recent years that one may wonder if there will be a point at which wind tunnel testing becomes obsolete. ORECA is an example of a motorsport organisation that abandoned wind tunnel testing just over a decade ago, and has found success in the approach and methodology they developed to replace it.

'We are among [a limited number of] organisations, if not maybe even the only one, to operate at this level using only CFD. As technology develops and cost is squeezed more and more, complex wind tunnel test programmes look less attractive and cost efficient,' David Floury, technical director at ORECA says as he reflects on the choice.

'It is an endless process to improve the methodology and correlation with the track, but a wind tunnel is also a different picture of the truth and needs a lot of energy to ensure good correlation. We have reached a level we are happy with, but we keep on improving.'

Many teams don't have their own wind tunnel facilities and are therefore forced to outsource their requirements to test suppliers. Aside from the cost, this can sometimes bring issues with test slot availability, and sometimes having quite rigid gateways in the timeline doesn't work for programmes where more flexibility is required. Combined with regulations strictly limiting their use in some of the more high-profile championships, perhaps we can expect more teams to follow ORECA's lead in the future?

This CFD-only approach requires quite a substantial modification to the usual design structure and overall project timeline, but clearly has benefits if it can be made a legitimate alternative.

'We decided a number of years ago to develop and invest in our in-house CFD resource, developing our own methodology and correlation processes. It proved to work quite well so we continued to develop it, and we've also been able to use this in different areas of business, which is nice,' adds Floury.

It's still swings and roundabouts as CFD solutions still do take significant processing time, though that is speeding up all the time. The benefit of having an accurate model motion system controlled in real time is it allows a huge amount of data to be gathered in a short run of 10-15 minutes in a way that CFD can't quite match. Yet, with the ability to also take measurements during the transient phase of any model movement, physical testing provides a great advantage in terms of time and information gathering.

Operations such as TGR, who have the privilege of custom built, dedicated facilities and a full in-house operation from blank design to race day certainly stand by wind tunnels for the immediate future.

Measuring with high accuracy

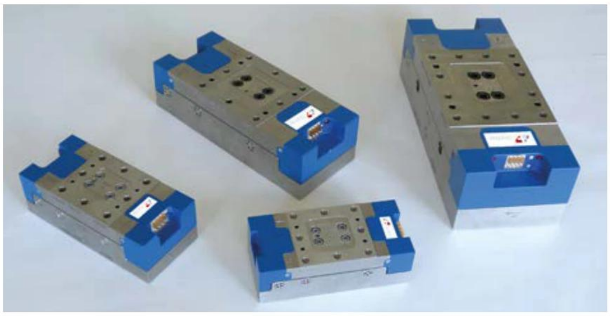
How RUAG has developed quality strain gauges fit for modern wind tunnels

The best performance requires the best preparation. Technology plays a very important role in this. In motorsport especially, characteristics such as resistance, downforce and load distribution are essential when it comes to validating and enhancing the aerodynamic performance of racecars. Only when the highest quality standards are met can the best results be achieved. Therefore, wind tunnels catering to motorsport require compact scale designs with high accuracy, stiffness, precision and repeatability.

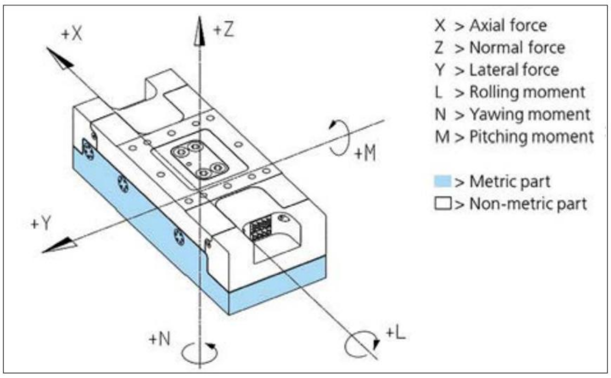
Precision counts. The strain gauges are applied in a controlled environment at exactly defined locations to provide great accuracy in measurement

Experience counts

RUAG designs, manufactures and operates precise scaled and instrumented models for maximum data accuracy. They allow the evaluation of real-world effects within a controlled environment. RUAG's most prominent instrumentation product is the block-type family 7xx, a 6-component strain gauge scale, which is characterized by its robustness against overloading, as well as its high precision, repeatability and long-term stability. With its roots back in the 1950s, the company can look back on many decades of experience of designing, manufacturing and operating strain gauge scales. Continuous evolutionary improvements and adaptations to new geometrical constraints and load requirements have led to a family of scales that are today very well received in the wind tunnel and Formula 1 community, among others.



6-component strain gauge block balance



Geometrical schematics and axis orientation of the 7xx block balance family

Strain gauges at carefully selected and designed locations on the scale measure the six force and moment components induced by aerodynamic loads and the model weight on the metric side of the scale. The gauges are arranged in seven Wheatstone bridges with integrated temperature compensation. Extensive theoretical, computational and experimental analyses have led to design features which reduce the interferences between the singular load components, diminish local and overall deformations, and increase the safety factor by limiting local stress concentrations in the critical areas.

To calibrate the unit, around 400 precisely defined and distributed load combinations are applied to the scale. The signals of the gauges are measured with HBM's DMP40 high precision data acquisition system. During the testing operation in the wind tunnel, RUAG partners with Cosworth, using their ESG16 precision data acquisition modules. The ESG16 EtherCAT Strain Gauge module digitizes the analogue signals generated by our balances, thus representing the perfect counterpart to our block-type family 7xx strain gauge scale.

The calibration and years of testing experience in RUAG's as well as customers' wind tunnels confirm the excellent combination, resulting in small interferences, high linearity and an accuracy in the order of less than 0.05% for combined load cases. The highly linear characteristic of the scale allows the use of a linear calibration matrix which simplifies data processing and improves test performance. A nonlinear second order matrix is complementary delivered with each scale, allowing an increase in accuracy up to 0.03%.

Claus Zimmermann, Teamleader Measurement & Computing at RUAG, notes: 'While RUAG and Cosworth provide best in-class solutions for customers, it is clear to all of us that it is not only the sensor itself but the entire measurement chain which must be optimized in order to achieve the best result. That is why RUAG and Cosworth have been working together for all these years.'

Positive feedback from many customers and partners is our motivation to contribute to making vehicles safer and faster. We support you in both with standard scales and with the revision or design of your scale – optimized for your needs and at an absolutely reasonable cost. Visit our website and let our component experts assist you.

Further reading material

Cosworth Case Study:
https://www.cosworth.com/electronics/case-study-ruag/
HBM Wind Tunnel Testing:
https://www.hbm.com/en/9242/wind-tunnel-testing-at-ruag/

Contact us at
aerodynamics@ruag.ch
https://www.ruag.ch/en

RUAG

Survival strategy

Why data and simulation are motorsport's best friends

By DANNY NOWLAN

DJR Team Penske

Downloading chassis data during a race has now been banned in Australian Supercars, something that our simulation expert is far from happy about

To say motor racing has a Jekyll and Hyde relationship with technology is an understatement. When things get tough, the technology that exists is always the first scapegoat for why things have gone awry. A recent example of this has been the banning of chassis data downloading during the races as V8 Supercars came out of Covid-19 hibernation.

However, this attitude has zero basis in fact and, as we shall see, not only is data acquisition and simulation motorsport's best friend, it is critical to a level playing field.

First though, we need to call out the elephant in the room that inspired this article in the first place. I recoiled in horror when I learnt that when V8 Supercars resumed at Eastern Creek on June 25-26, chassis downloading for the races would not be permitted. Due to cost cutting and 'making the show more interesting', they said.

Scarier was the glee some commentators showed at this. One, who shall remain nameless, said the fans don't care about 500 maths channels. All this does is showcase motor racing's resident technophobia that, left unchecked, will lead us to our end.

The nail here is that while race fans may *not* care about 500 maths channels, they do care about their teams competing on a level playing field, and nothing delivers this better than data and simulation.

To illustrate this, let me draw on a correlation example I present at the ChassisSim bootcamp. This is actual vs simulated data for a Supercar category of vehicle, and is presented in **Figure 1**.

In this example, the first trace is speed, the second is throttle, the third is steering, the fourth and fifth are front and rear dampers respectively, the sixth is acceleration and the last trace is front pitch. The correlation at this point is very good, except for the front dampers, where the simulated pitch under braking does not match up. At this point most people throw their hands in the air and say it doesn't work.

What this is actually telling you is that something in the car is not right, and this is where hand calculations and simulation come in. The great thing about simulation is it returns a truck load of channels like this for you to investigate. To resolve the pitch conundrum in this example, we need to sanity check the simulation. To do this, some representative figures are given in **Table 1**.

With this information to hand, calculating the simulated pitches is straightforward, and illustrated in **Equation 1**. **Equation 2** then shows what happens when you crunch the numbers on the damper movement.

When this was applied to **Figure 1**, it was found the simulation was working as advertised, which means there is either a data acquisition issue, a broken component or something has not been measured properly on the racecar. Either way, using common sense, you have ascertained something very important about the car. To

Table 1: Suspension geometry parameters

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

Figure 1: Touring car actual (coloured) vs simulated (black) data

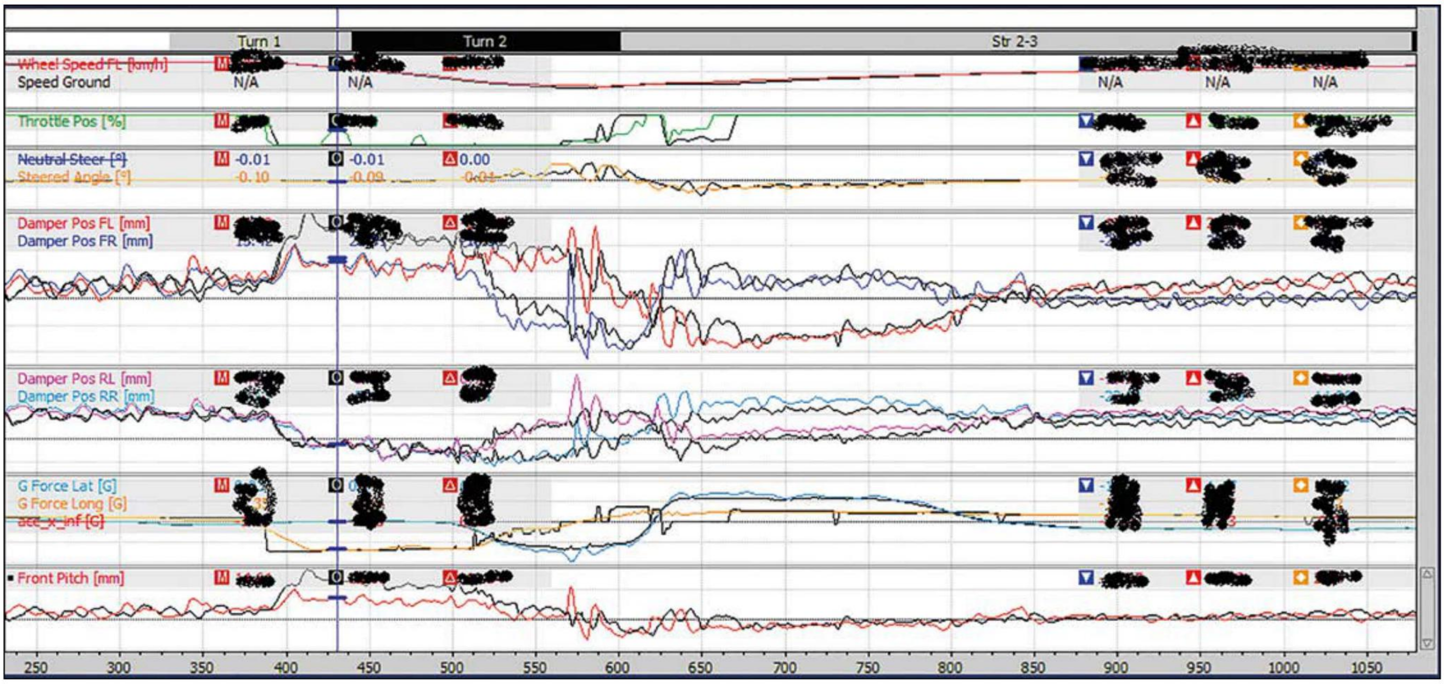
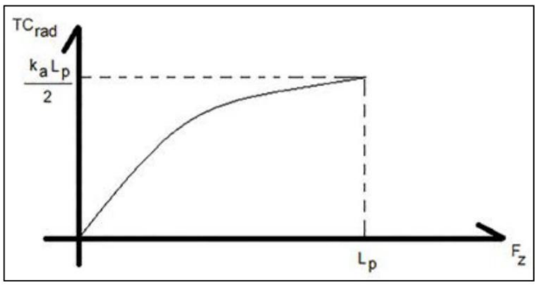


Figure 2: Tyre model visualisation



EQUATIONS

EQUATION 1

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

EQUATION 2

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

EQUATION 3

$$TC_{RAD} = k_a(1-k_b\cdot F_z)\cdot F_z$$

Where:

TC_{RAD} = traction circle radius of the tyre (N)
k_a = initial coefficient of friction
k_b = normalised friction coefficient with load (1/N)
F_z = normal load

the techno sceptics reading this, I ask: how does this spoil the show?

Critical insight

The next reason for using data and simulation is they give you a critical insight into what the tyres are doing. The basic building block of any tyre model is the second order traction circle radius vs load equation, which can be expressed mathematically as **Equation 3**.

The neat thing with **Equation 3** is that any tyre can be approximated by **Figure 2**.

When you combine this tyre model visualisation graph with data and simulation, you have the tools to fill in the gaps of what **Figure 2** looks like. A case in point here is the World Time Attack tyre reverse engineered from data shown in **Figure 3**. The data here came courtesy of the ChassisSim tyre force modelling toolbox, which works by running a number of track replays to minimise the difference between actual and simulated data by changing the tyre model.

The reason for going to all this trouble is that it gives you the ability to numerically quantify what a set-up is doing. The bulk

Race fans may *not* care about 500 maths channels [but] they do care about their teams competing on a level playing field

of what we do as race and performance engineers is balancing what I call the racecar grip and balance equation. This can be illustrated graphically in **Figures 4** and **5**.

What we as race engineers do is try to arrive at a lateral load transfer distribution that gives us good grip but ensures the car is driveable. The power of using data and simulation together is that it gives you a tremendous short cut.

The reason for this is that in the past, the shapes of **Figures 4** and **5** were unknown, and you had to get there with a lot of track time, or spending thousands of dollars in tyre testing. Even then, in most cases the results are dubious. Data and simulation give you the ability to nail this down accurately at a fraction of the cost. Again, I ask someone to give a logical explanation of how banning chassis data acquisition on the altar of cost cutting spoils the show? Or increases cost?

The other thing both data and simulation give you is the ability to reverse engineer aeromaps from data. The most acute example I can give is the aeromap for the first generation A1GP car, shown in **Figure 6**.

One thing that made this car unique was its aeromap, and one critical key to unlocking its performance, as you can see in **Figure 6**, was the very narrow band of ride height in which the car worked.

If you ever want a case study of just what a leveller simulation and data acquisition is, look no further. **Figure 6** was a key reason why Team China in the 2007-'08 season was able to punch well above its weight. There was no CFD here, this was all reverse engineered from data by myself and the tools I had set up with ChassisSim. Again, how does this spoil the show and add cost?

Ultimate proof

Yet the ultimate proof of all this is in the pudding, and this was graphically illustrated at World Time Attack Challenge 2016. That weekend I was looking after the NA Autosport Evo 6 entry in the open class. I outlined exactly what we did in a previous *Racecar Engineering* article, but the foundation of the results of that weekend were laid using data and simulation to reverse engineer the tyres and aero properties. **Figure 3** is a very good case in point. This was the key to making one of the critical calls of the weekend, which was applying front dive planes to the front splitter. This is illustrated in **Figure 7**.

The end result was going from P17 in 2015 to P3 in 2016. Without the good work done in combining data and simulation we would have been flying blind, and that improved result (which shocked quite a few of the punters at the time) would have been impossible. This illustrates just what a dramatic leveller data and simulation can be.

Figure 3: World Time Attack tyre TC radius vs load characteristic

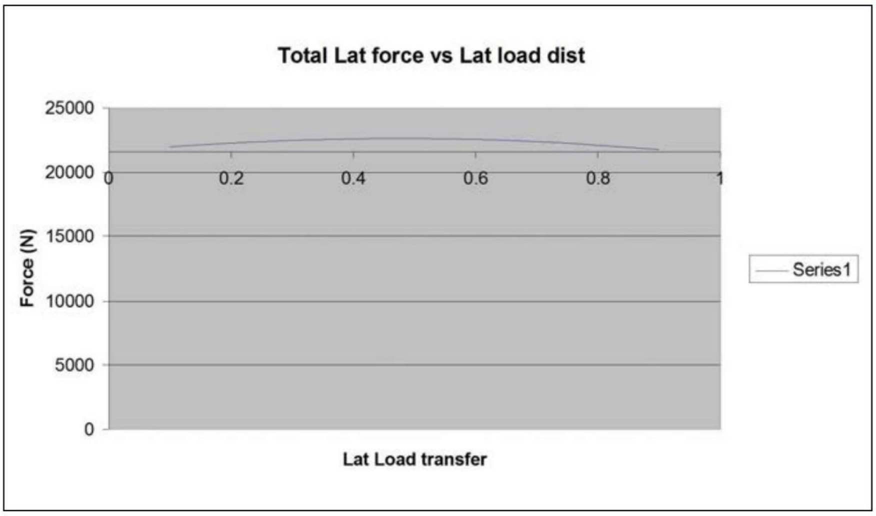


Figure 4: Total grip vs lateral load transfer distribution at the front

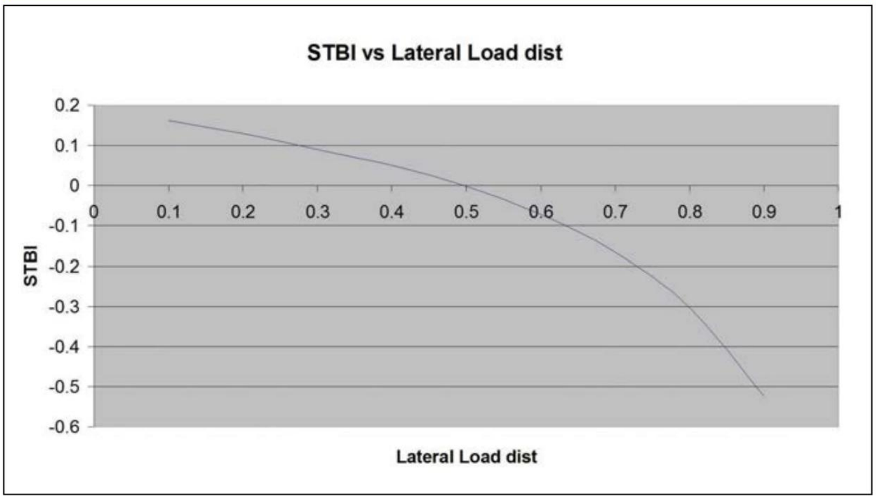
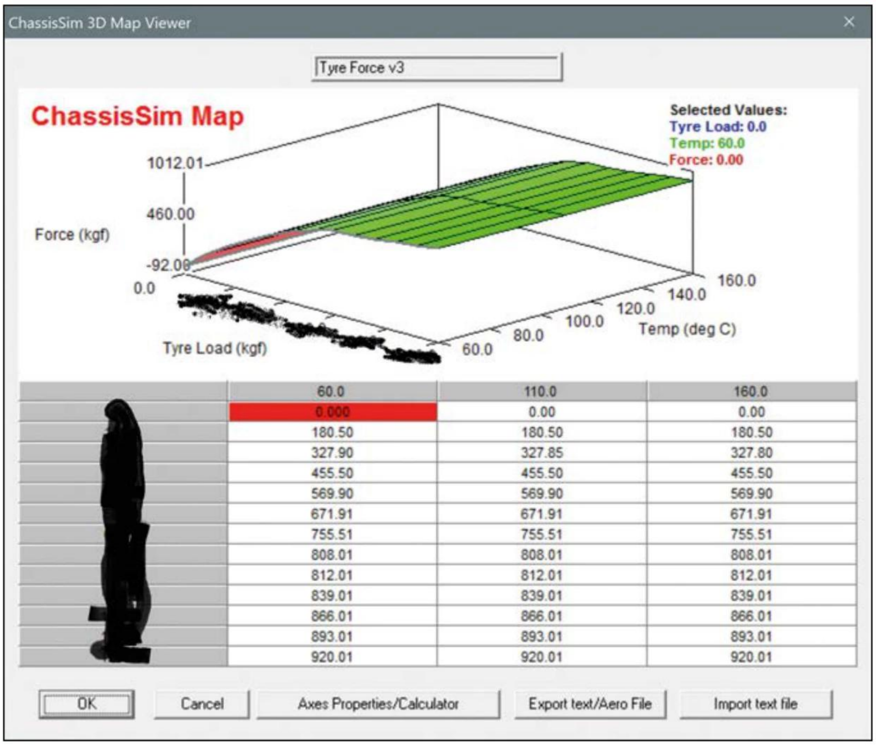


Figure 5: Stability index vs lateral load transfer distribution at the front



	60.0	110.0	160.0
	0.000	0.00	0.00
	180.50	180.50	180.50
	327.90	327.85	327.80
	455.50	455.50	455.50
	569.90	569.90	569.90
	671.91	671.91	671.91
	755.51	755.51	755.51
	808.01	808.01	808.01
	812.01	812.01	812.01
	839.01	839.01	839.01
	866.01	866.01	866.01
	893.01	893.01	893.01
	920.01	920.01	920.01

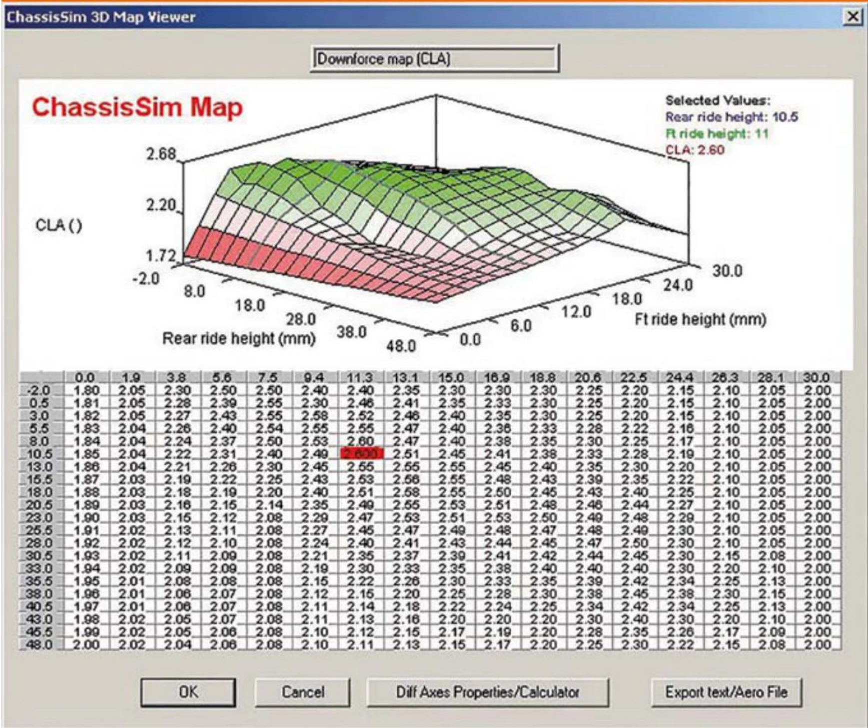
One key question to ask, however, is what channels you need to make all this happen. A common criticism levelled at data acquisition, and one of the biggest misconceptions, is that in order to achieve results like those we have discussed here you need to be running $30K of data acquisition. I'm here to tell you that is total nonsense. The results we have just discussed were achieved with just the following common or garden variety data channels:

- Four damper position sensors
- Wheel speed
- Lateral and longitudinal *g*
- Steering and throttle sensors
- RPM

Also, it's worth noting these channels were all exported at 50Hz, although in most cases the logging frequencies were 200Hz.

What I have just described is all the channels needed for the ChassisSim monster file. And given this is used on a daily basis in the ChassisSim community, it speaks highly of the veracity of this approach, and its economic sustainability.

Figure 6: First generation CLA map for the A1GP car



	0.0	1.9	3.8	5.6	7.5	9.4	11.3	13.1	15.0	16.9	18.8	20.6	22.5	24.4	26.3	28.1	30.0
-2.0	1.80	2.05	2.30	2.50	2.50	2.40	2.40	2.35	2.30	2.30	2.30	2.25	2.20	2.15	2.10	2.05	2.00
0.5	1.81	2.05	2.28	2.39	2.55	2.30	2.46	2.41	2.35	2.33	2.30	2.25	2.20	2.15	2.10	2.05	2.00
3.0	1.82	2.05	2.27	2.43	2.55	2.58	2.52	2.46	2.40	2.35	2.30	2.25	2.20	2.15	2.10	2.05	2.00
5.5	1.83	2.04	2.26	2.40	2.54	2.55	2.55	2.47	2.40	2.36	2.33	2.28	2.22	2.16	2.10	2.05	2.00
8.0	1.84	2.04	2.24	2.37	2.50	2.53	2.60	2.47	2.40	2.38	2.35	2.30	2.25	2.17	2.10	2.05	2.00
10.5	1.85	2.04	2.22	2.31	2.40	2.49	2.600	2.51	2.45	2.41	2.38	2.33	2.28	2.19	2.10	2.05	2.00
13.0	1.86	2.04	2.21	2.26	2.30	2.45	2.55	2.55	2.55	2.45	2.40	2.35	2.30	2.20	2.10	2.05	2.00
15.5	1.87	2.03	2.19	2.22	2.25	2.43	2.53	2.56	2.55	2.48	2.43	2.39	2.35	2.22	2.10	2.05	2.00
18.0	1.88	2.03	2.18	2.19	2.20	2.40	2.51	2.58	2.55	2.50	2.45	2.43	2.40	2.25	2.10	2.05	2.00
20.5	1.89	2.03	2.16	2.15	2.14	2.35	2.49	2.55	2.53	2.51	2.48	2.46	2.44	2.27	2.10	2.05	2.00
23.0	1.90	2.03	2.15	2.12	2.08	2.29	2.47	2.53	2.51	2.53	2.50	2.49	2.48	2.29	2.10	2.05	2.00
25.5	1.91	2.02	2.13	2.11	2.08	2.27	2.45	2.47	2.49	2.48	2.47	2.48	2.49	2.30	2.10	2.05	2.00
28.0	1.92	2.02	2.12	2.10	2.08	2.24	2.40	2.41	2.43	2.44	2.45	2.47	2.50	2.30	2.10	2.05	2.00
30.5	1.93	2.02	2.11	2.09	2.08	2.21	2.35	2.37	2.39	2.41	2.42	2.44	2.45	2.30	2.15	2.08	2.00
33.0	1.94	2.02	2.09	2.09	2.08	2.19	2.30	2.33	2.35	2.38	2.40	2.40	2.40	2.30	2.20	2.10	2.00
35.5	1.95	2.01	2.08	2.08	2.08	2.15	2.22	2.26	2.30	2.33	2.35	2.39	2.42	2.34	2.25	2.13	2.00
38.0	1.96	2.01	2.06	2.07	2.08	2.12	2.15	2.20	2.25	2.28	2.30	2.38	2.45	2.38	2.30	2.15	2.00
40.5	1.97	2.01	2.06	2.07	2.08	2.11	2.14	2.18	2.22	2.24	2.25	2.34	2.42	2.34	2.25	2.13	2.00
43.0	1.98	2.02	2.05	2.07	2.08	2.11	2.13	2.16	2.20	2.20	2.20	2.30	2.40	2.30	2.20	2.10	2.00
45.5	1.99	2.02	2.05	2.06	2.08	2.10	2.12	2.15	2.17	2.19	2.20	2.28	2.35	2.26	2.17	2.09	2.00
48.0	2.00	2.02	2.04	2.06	2.08	2.10	2.11	2.13	2.15	2.17	2.20	2.25	2.30	2.22	2.15	2.08	2.00

Long-term future

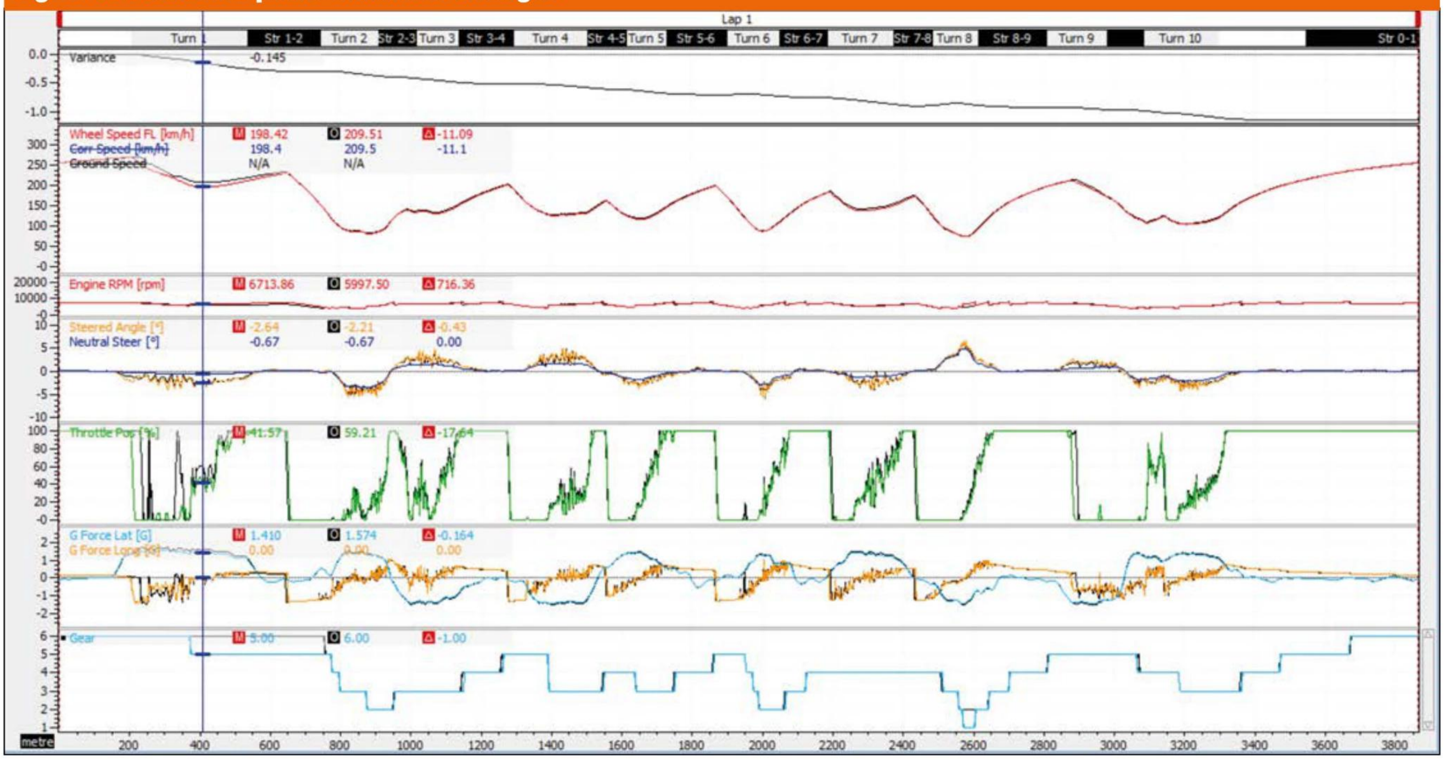
Finally, to illustrate the difficult state we find ourselves in today, it came to light recently that one of the younger, less enlightened actors in the 2019 movie *Ford vs Ferrari* actually had to Google what the 24 hours of Le Mans was! This would have been unthinkable in the 1950s and '60s.

If motor racing is going to have a viable long-term future, it is not going to be by turning the technical clock back to some prejudiced, romanticised version of a low-tech 1950-'60's era that didn't actually exist. It is going to be by future racecars capturing the general public's imagination, and pre-empting the immense technical challenges automotive and general society faces.

In this endeavour, technology and engineering analysis is our greatest ally because, after all, in order to survive you must first be worthy of being saved.

In closing then, contrary to popular perception, data and simulation is one of motor racing's greatest equalisers. As we have seen with all the case studies we have discussed, its appropriate use offers valuable insight into what a car is doing in finer detail that directly translates to improved results on track, and it does so in a very cost-effective manner. So much so that motorsport's very survival could well depend upon it.

Figure 7: Front dive plane simulated changes



Last chance saloon

The DTM series is at a crossroads and needs to make decisions quickly to save the series. *Racecar* looks at the options available

By ANDREW COTTON

In 2012, the DTM series introduced a new base car developed in conjunction with its three competing manufacturers, Audi, Mercedes and BMW. The latter joined the series on the proviso that this car become a global platform, available to be used in multiple race series, but that plan was only a partial success. Eventually, the series did reach an agreement with the Japanese Super GT series to also use their components, and it seems they will continue to use the German-developed chassis in future.

However, while that model appears to be working in Japan, in Germany things have taken a turn for the worse. Mercedes withdrew from the series before the 2.0-litre, four-cylinder engine regulations were introduced and, at the end of this year, Audi departs, leaving BMW the sole manufacturer. For many, this signals the end of a once-great series after a flawed rules-set was introduced.

The cars that were introduced in 2012 featured components designed by the three manufacturers, and then shared around the competing teams. Mercedes developed the rollcage and monocoque, Audi the driveshaft and gearbox, BMW the electronics.

Each had a specific set of safety parameters to hit, and each an aggressive budget limit, so the engineering challenge was high. What was produced was a two-door car (previous cars were all four-door), that could withstand much greater impact than their predecessors. So the cars were safer, but they were also heavier. Too heavy, in fact; as much as 150-200kg overweight, depending on who you spoke to.

Rising costs

A massive weight saving exercise was therefore undertaken, with the cost per unit rising accordingly. But at Hockenheim in 2012, the new cars were ready to race, having been tested and developed prior to the first meeting. The DTM hailed the plan a success, while others sat in the background and waited for the axe to fall.

The issue was the obsoletion costs. While manufacturers could enter and run cars, private teams were always the backbone of the series, but none of them were really able to compete without factory support. The model was built on marketing rather than on pure racing, and the results always

DTM has been pioneering natural fibre technology using dry ampliTex powerRibs and flax

Bcomp-stemutz.com

Audi Sport

Here the DTM Bcomp natural fibre 'shoebox' being tested by Audi Sport

For many, this signals the end of a once-great series

looked suspicious. A driver with a birthday would normally finish up on pole position, for example. Drivers who retired from the series spoke privately about how their cars received less race preparation compared to favoured drivers, and were shocked that they would not be able to compete.

The chosen ones

It was the same for all drivers. If you were chosen, you had everything at your disposal. If not, you had to fight for whatever you could get. Some even suggested that, if they looked good in the early part of a race meeting, they would be pegged back by the manufacturer themselves. There were a limited number of drivers going for the title, while the others just played a supporting role. This was team orders taken to a new level.

Worse still, the cars could not be sold on after competition into national series. There was nothing to do with them once their active life was over but to scrap them.

The Class 1 regulations that were designed to allow the Japanese and German series to compete with eachother made no sense. The Japanese like open-tyre competition, for example, while the Germans have developed DRS for their 2020 cars.

The model was built on marketing rather than on pure racing, and the results always looked suspicious

Even the concept of Class 1 and a World Cup makes very little sense. The Japanese market share in Germany is low, as is the market share of the Germans in Japan. What is to be gained then from hosting a World Cup between the two, other than prestige?

Even to get the series to run alongside each other, each need to compromise their domestic settings to align them.

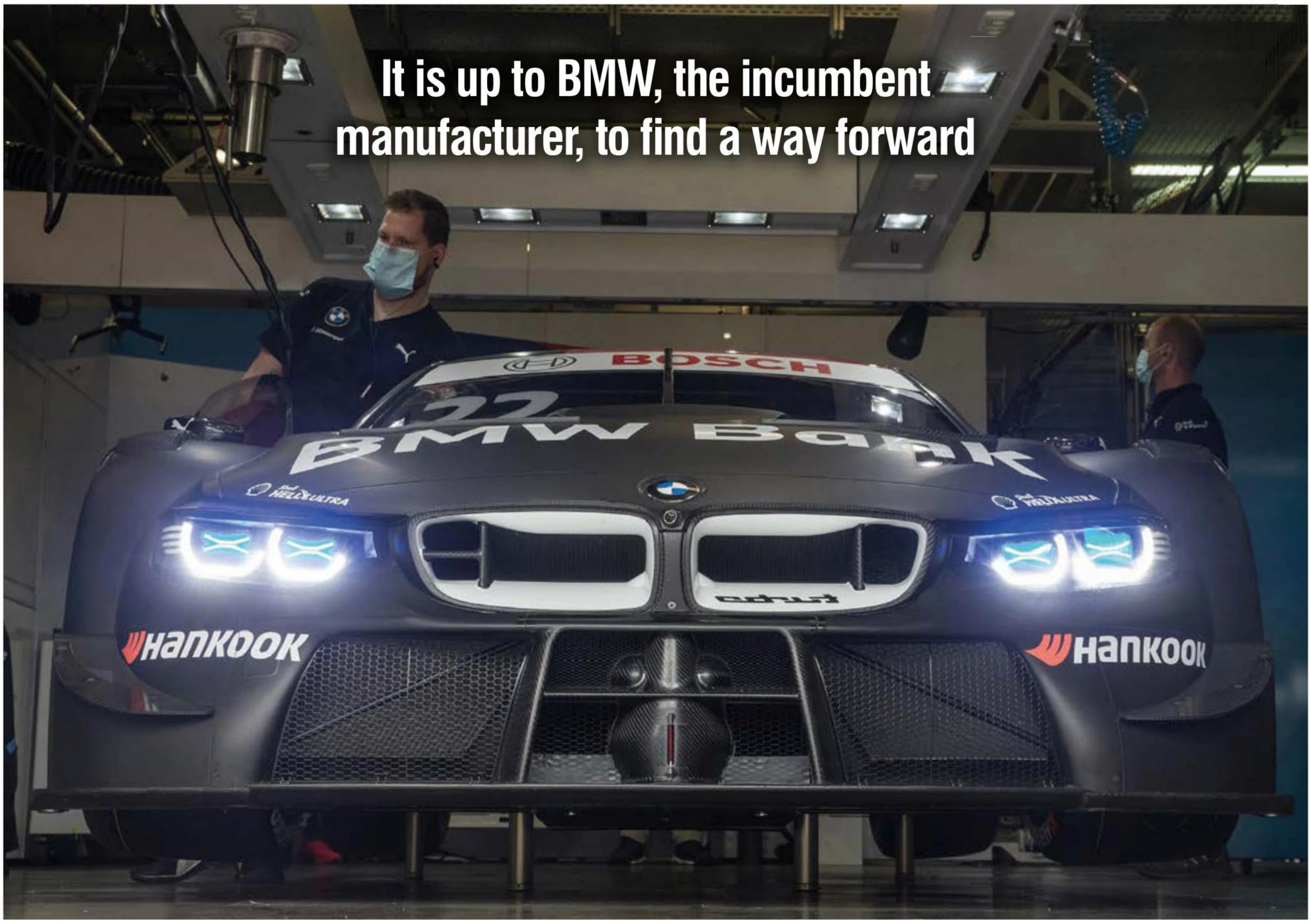
With Audi and Mercedes gone, it is now left to BMW and private teams to uphold the series and push ahead with future plans. Aston Martin's brief foray into the DTM was privately funded and contentious, with the cars needing a redesign aerodynamically as rumour has it Aston Martin didn't like the scaled model of its Vantage.

Now the series has to stand up and be counted. There are some that hope it will die, but this would be a mistake as the series has built up a strong calendar and a stable fan base. The race weekends are well organised and well attended and there is a strong feeling in Germany that these weekends should be protected. So what are the options? Essentially, there are three.

One is the current cars are bought and run by private teams, and the DTM steps off the global stage until the financial situation recovers. Following that, a new set of regulations could be introduced that again reduces the cost of competition.

Could the DTM look at going back to production car racing rather than these silhouette cars? Would that be cheaper than the current cars, given the amount of development work that needs to go into preparing any production car for racing?

The current DTM silhouette racercars are impressive, but when Audi leaves at the end of this season, BMW will be the sole manufacturer on the grid. The series needs to change dramatically to make it accessible to private teams once again



One of the big problems is the current cars have no home outside of DTM or Super GT and so cannot be sold on to other series. So is a return to production-based cars the answer?

Should this option be on the table, private teams would have the option of decorating the 2020 cars as Toyota, Nissan or Honda, as per the Super GT series. They might even receive manufacturer support for this concept from the Japanese that would be represented in what amounts to a minor market for a relatively small investment.

The second option is the DTM adopts another set of regulations, either from another Touring Car series or GT racing, and here the options are plentiful. That is not to say they are necessarily a good idea, but at least they already exist.

The most likely is the adoption of GT3 regulations, but there are issues with this. There is already a strong GT3 series in Germany and to promote these GT cars, rather than Touring Cars, would be difficult. However, Audi, BMW, Mercedes and Porsche all have GT3 cars in existence and they are cheap to buy and relatively cheap to run.

The series could also take regulations from the British Touring Car Championship (BTCC), which will introduce hybrid technology in its next set of regulations, and which also features inexpensive cars to purchase and run. But would the BTCC hand over its regulations to the DMSB, which is the organising body of racing in Germany?

The third option is to allow the series to die, and to sell its coveted race dates to another series to help it flourish. That would benefit some parts of German motorsport and the supporting industry that surrounds it, but would mean the end of the DTM era.

Global reputation

The DTM was founded in 1984 and, since then, has established a global reputation. To allow it to die would also damage the racing aspirations of some of the most prolific and successful motor manufacturers in the world. The decision for Mercedes and Audi to stop their DTM programmes was significant as they knew that by doing so, they risked the failure of the series, and therefore would have limited options to come back in.

It is probable that the series will design a whole new rule set based on production cars

The big issue facing all manufacturers is that cost reduction is easy on paper, but very difficult to achieve in reality. On paper, cost cutting in Formula 1 is simple: use Formula 2 machinery, resource and teams, but that would defeat the very object of what Formula 1 is. The same argument can be made for GT3 cars. Use them in a series for which they were never intended, such as manufacturer sprint racing rather than customer motorsport, and the costs again rise out of control, killing the golden goose that laid the egg in the first place. The only proviso to this is that the GT3 manufacturers are currently working on a new rule set and could bear the DTM requirements in mind.

It is probable that the series will design a new rule set based on production cars that will allow the tuners to race once again. This is undoubtedly the backbone to motorsport in the coming years and the DTM is no different. Some organisations have already accepted it, along with the reduced money that comes without manufacturer involvement, others still fight for it as they have built businesses that cannot cope without it. As one organiser put it, the Covid pandemic has meant the fat series have got thinner and the thin series are in trouble. The DTM needs to come up with a way of feeding itself or it will die.

Racecar engineering
The International Journal of Motorsport Technology

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Subscription rates
UK (12 issues) £89
ROW (12 issues) £100
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News distribution
Seymour International Ltd, 2 East Poultry Avenue, London EC1A 9PT
Tel +44 (0) 20 7429 4000
Fax +44 (0) 20 7429 4001
Email info@seymour.co.uk

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

THE CHELSEA MAGAZINE COMPANY LTD

www.racecar-engineering.com

Positive steps

Focussing on a positive future in these extraordinary times

There is something refreshing about the Formula 1 scene at the moment. Stripped of all the paraphernalia surrounding the race series, suddenly it has become a lot more attractive. Gone are the motorhomes, the hospitality units filled with beautiful people and hangers on, gone are the multiple trucks that ferry all the kit around. Instead, front and centre, are the racecars and the race teams, while on track the racing is no less intense.

It may be a bit strange to see the drivers getting out of their cars to the applause only of their teams, and they don't seem to know how to celebrate, but that's okay. I have been to enough British Formula 3 races in the 1990s to understand the crowd isn't everything. At Pembrey, the sheep in the neighbouring fields didn't care if Christiano da Matta or Juan Pablo Montoya had won, as long as the grass was good. And preferably it wasn't raining.

The announcement of circuits hosting F1 races this year has increased my interest as the list includes Imola, one of my favourite tracks, and Portimao. These are circuits on which Formula 1 belongs. One has a long history with the sport, the other will debut in competition, although the layout and undulation are excellent.

Facilities may not be up to scratch – there was nearly a riot in the press room when the charges for the internet were revealed for a GT race at Portimao a few years ago – but never mind that. It's about the racing, after all.

Front and centre are the racecars and the race teams, while on track the racing is no less intense

Positive step

As noted by Leena Gade this month, teams in all walks of the sport have been faced with a new challenge: to reduce the number of personnel working on the cars at the track. This is a positive step. There is no need to take so many around the world. It is expensive, and tough on the body.

While the drivers are kept in top shape to avoid them getting ill and having to miss a race, the mechanics and engineers put in long hours and do not necessarily have those same benefits. Memories of Ricardo Divila stretching out his knackered back on the front of a racecar, or over a chair on the truck, are enough to convince me of that.

Hosting races in such close proximity is also tough, not only on the race teams, but also the development teams back at base who have to work particularly quickly.

Communication back to base is critical to success, particularly with shortened schedules. The gap between practice and qualifying, and qualifying to the race now places an increased emphasis on the relationship between driver and race engineer. Debriefs have consequently become shorter and more focussed. The quality of that relationship will now have a far greater effect on the result of the weekend than ever before.

On the mend

Other news that is filtering out is that of Alex Zanardi, the extraordinary man who has overcome so much, and last month was presented with a new challenge. Having been involved in an accident on his hand bike, he suffered head injuries and was placed in an induced coma. Thankfully, it seems he is on the mend, but the road ahead of him is long, tough and painful. He has recovered from so much with positivity that defies human comprehension, and a sense of humour that is second to none, and we wish him well with his recovery this time around.

The other hot topic in Formula 1 is, of course, ethnic diversity. Raised as an issue by Lewis Hamilton on the back of the Black Lives Matter movement, it has caused intense media interest and an array of responses online and in print. Our writer, Jahee Campbell-Brennan, felt inspired by Hamilton's position to write about his experience as a black man working in a predominantly white environment, and I felt compelled to offer a platform on which he should air his views.

One thing I have learned over the past month or so since the start of the BLM movement is that I know absolutely nothing about how it feels to be so out of place in such an environment. It is important to listen to the stories and the experiences before we can become part of the solution. As a middle-aged white man working in motor racing, how could I offer a considered opinion when I have never experienced what Jahee and Lewis have? Or, for that matter, the countless others who have been somehow dropped between becoming highly qualified before they hit professional sport.

There is a lot we can do collectively to rectify that, but first we need to understand. And, above all, listen.

ANDREW COTTON Editor


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