FORMULA E: Jaguar on the road relevance of a race programme – p76

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BAJA GOES HYDROGEN
OFF-ROAD ODYSSEY JUST GOT HARDER AS NEW FUEL IS TRIALLED

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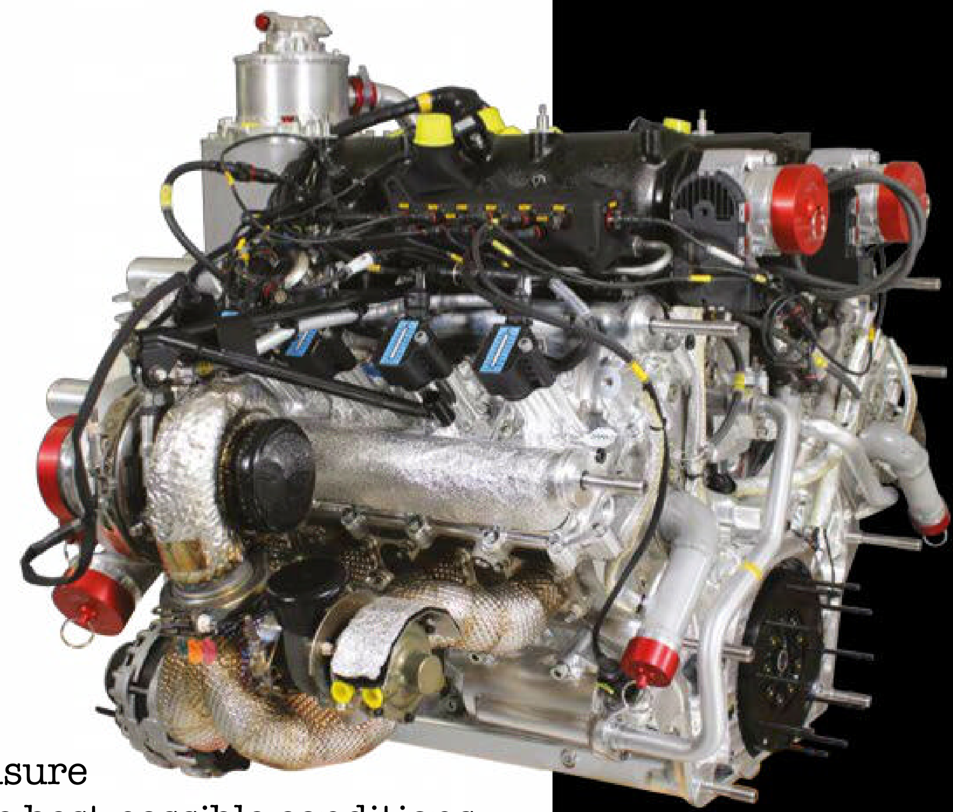
Photo credit Patrick Hecq

The BMW M4 GT3, as featured in *Racecar* issue V31N7, raced at Barcelona in the GT World Challenge Endurance final



Getting a grip

Questions of trust, throttle application and Americanisation

Trust between driver and team is often quoted as one of the key elements for success in motor racing. This, to me, seems to be entirely logical. Strange, therefore, that in two recent F1 races in particular, Lando Norris and Lewis Hamilton both ignored their engineers' calls to pit for tyres – and almost certainly lost out big time as a result.

Norris' performance in Sochi, pulling away from *regenmeister* Hamilton in the wet on similarly worn slick tyres, was phenomenal, but his refusal to follow initial instructions from the pit wall cost him and the team dear, even a probable first race win for the young Englishman.

Hamilton, meanwhile, has a deserved reputation for his 'gut instinct' proving correct, much of this due to his mastery of tyre preservation and seat-of-the-pants feel. But, according to the post-Turkish GP analysis of his discarded tyres, and of those who ran lights-to-flag without stopping, at best he would have lost even more places and crucial points by staying out. At worst they would not have lasted the distance.

In both cases it seems there was confusion. In Russia, with McLaren, regarding the anticipated rainfall. And in Turkey, with Mercedes by a lack of explanation to Hamilton concerning the overall situation, with his increasingly worn tyres' lap times allowing cars behind to rapidly close him down.

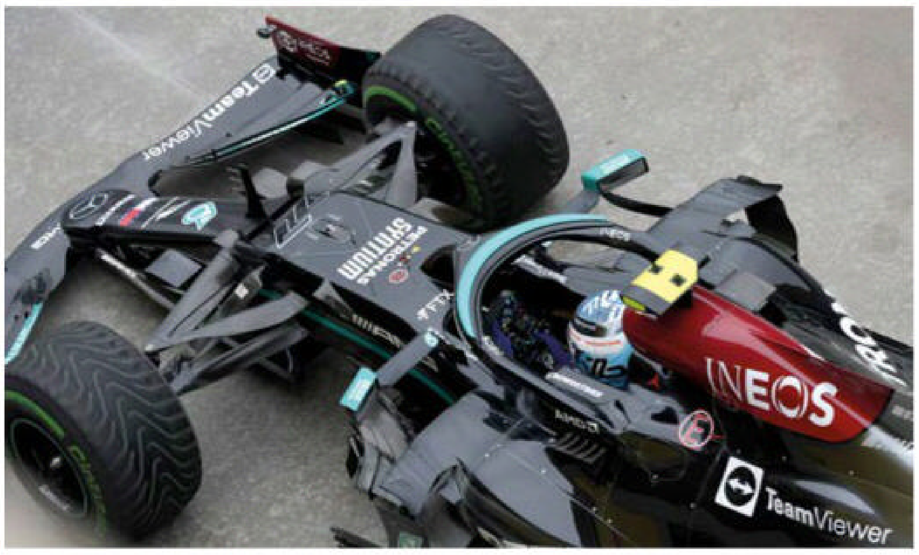
Like most people, I'm not privy to exchanges between Mercedes' drivers and their engineers, other than those broadcast, but Hamilton's agitation on blasting back onto the track following his too-late stop made it clear he had received no such clarification. Why not is puzzling, given how long Hamilton and Bonnington have worked together.

Less so in Norris' case, which appeared to be due to meteorological finger trouble. I've little doubt that radio communication has since been the subject of intense examination within both teams (McLaren and Norris having apparently run through every aspect of the Russian event at least twice on the simulator trying to find out why they got it wrong). This is essential because the aforementioned trust is vital, especially in such a close championship battle as this year's.

Sometimes the impression is given that, apart from gushing plaudits after the chequered flag has fallen on a good result, drivers are otherwise prone to be treated as robots, to do as bidden, regardless. Nonetheless, exhaustively analysed strategic and tactical plans fall apart if dissension and argument occur at critical moments in a race.

Off-throttle moments

I found video clips I have watched of overtakes in the Turkish race particularly interesting. They exaggerated, due to the slippery track conditions, something I have noticed before – the amount of time in slow corners that drivers of today's machinery are almost completely off the throttle. Following turning in, there seems to be an age before the drivers can get back on the gas. One would normally expect to be balancing the car on the throttle after braking and through the apex, to exit as fast as possible.



XPB

Are the days of total trust between driver and engineer in motor racing numbered?

I can only assume the torque the PUs produce requires the car to be virtually straight, without any steering lock on at all, to avoid sudden traction loss. Pussyfoot, point and (gently) squirt!

It's quite different in medium and fast corners, of course, when the giant hand of downforce comes into play, although caution still has to be exercised as rear-end breakaway on current F1 cars always looks abrupt and non-progressive, even on a dry surface. A combination of aerodynamic sensitivity, radial tyre characteristics and weight, I assume.

It's strange to realise that today's F1 cars are heavier than IndyCars and even pre-WW2 Mercedes and Auto-Union monsters. Although electronics come into play to try and mimic banned traction control, it's great that they aren't as effective because these handling traits allow the best drivers, with a sensitive right foot and quick but smooth steering inputs, to stand out.

Norris has described from simulator experience that the new regulations 2022 McLaren, 'isn't as nice to drive as the current car.' From the above, I wouldn't call 2021 cars 'nice', but it's very early days and I'm sure ongoing work will improve on this, because a non-flat-bottom car should fundamentally be less pitch sensitive – surely still a major aero balancing factor.

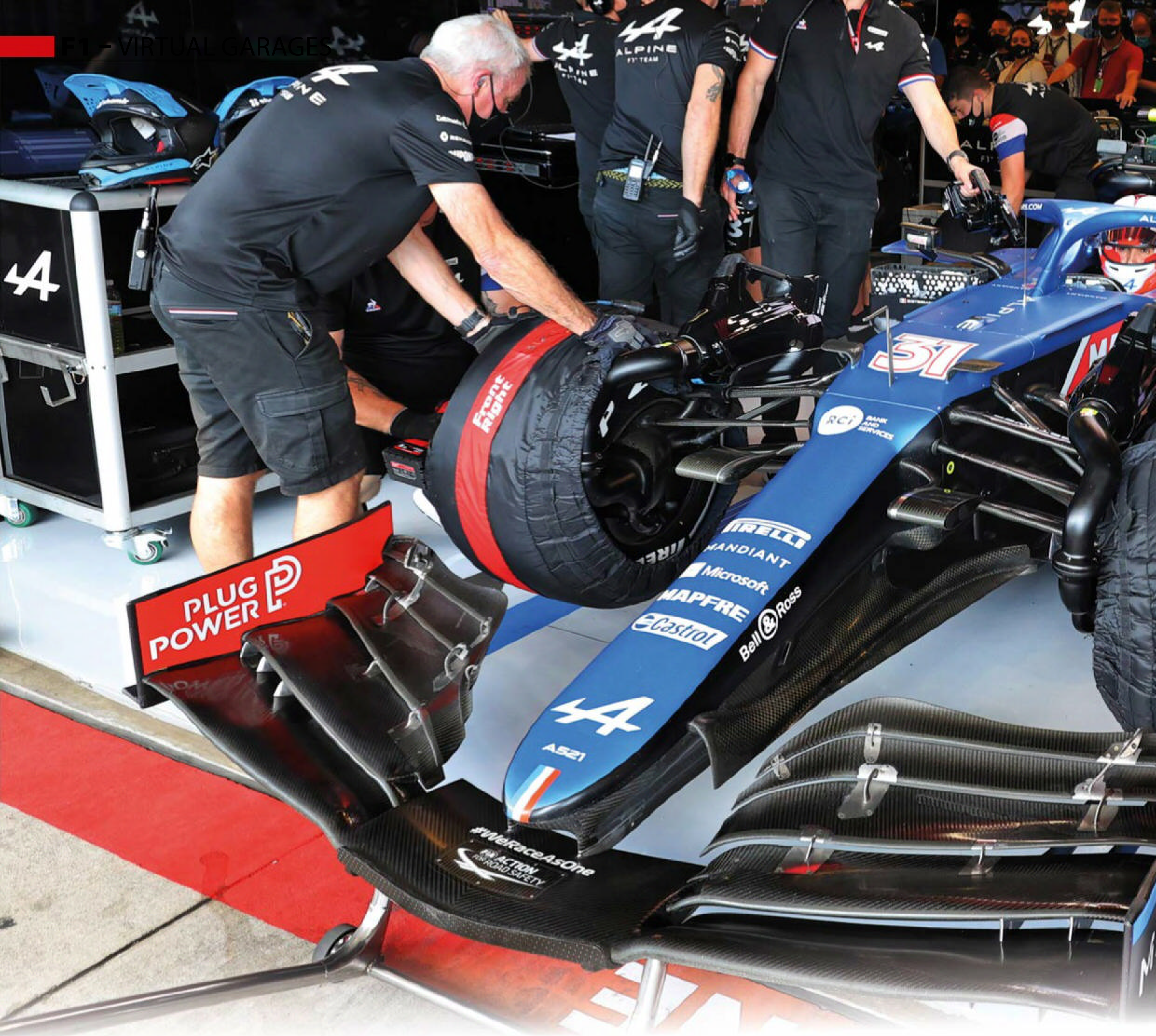
Elsewhere, the probability of Andretti Autosport buying a majority of the Alfa-Romeo Racing (Sauber) F1 operation is intriguing. Alongside Haas, this would make two American-owned GP teams. There's no reason for F1 to be dominated by European outfits is there? Especially not given its World Championship status, and with US corporation, Liberty, in charge of the show, anxious to gain more exposure in the USA.

This new potential acquisition, bringing more funding and publicity for the team *could*, together with Fred Vasseur's stewardship and the Hinwil facilities, allow the team to move up the grid. What a boost for Valtteri Bottas if that happens. Departing Mercedes for Alfa, he must have accepted that any more race wins, let alone his World Champion dream, will disappear. The Finn, freed of his obsession to beat Hamilton, and no longer being regularly dumped on, may be able spread his wings. His classy victory in the Turkish GP underlined this, with Hamilton penalised for an ICE change.

The number of such penalties proves that the regulation concerning allocation of PU components needs serious review, never having allowed for crash damage or the desire to encourage new PU suppliers into F1, with the inevitable learning curve failures involved.

Plus, with budgets reducing each year, I simply cannot understand the perverseness of holding yet more sprint races next season, other than a refusal by those who enthusiastically advocated it to back down. There is little or no evidence available to support their continuation. A case of throwing the dart and drawing the dartboard around it? Daft.

There's no reason for F1 to be dominated by European outfits, is there?



Remote control

Called variously 'virtual garages', 'mission control' or 'race support rooms' is the future of race engineering sitting in the warm back at HQ?

By DIETER RENCKEN

Once Formula 1 took the decision to resume action in July 2020 after a Covid-induced three-month break, one of the crucial criteria was the number of travelling staff per team permitted paddock access via tightly controlled 'bubbles'. The decision largely hinged on restrictions imposed by authorities in the region the sport targeted for its return, namely Austria's Styrian province, home to the Red Bull Ring.

A limit of 80 staff per team was imposed, half the number a well-heeled team would usually take to grands prix, of which around 60 are required to directly operate two cars, with the balance providing engineering, logistics, media, marketing and hospitality services. Although the last three activities were downsized considerably, it soon became clear some of the performance-related functions would need to be executed remotely.

The remote garages … have their roots not in foresight but in circumstance

Alpine F1 operates a mix of proprietary and in-house software in its remote garage, but also regularly checks social media channels like Twitter and Instagram

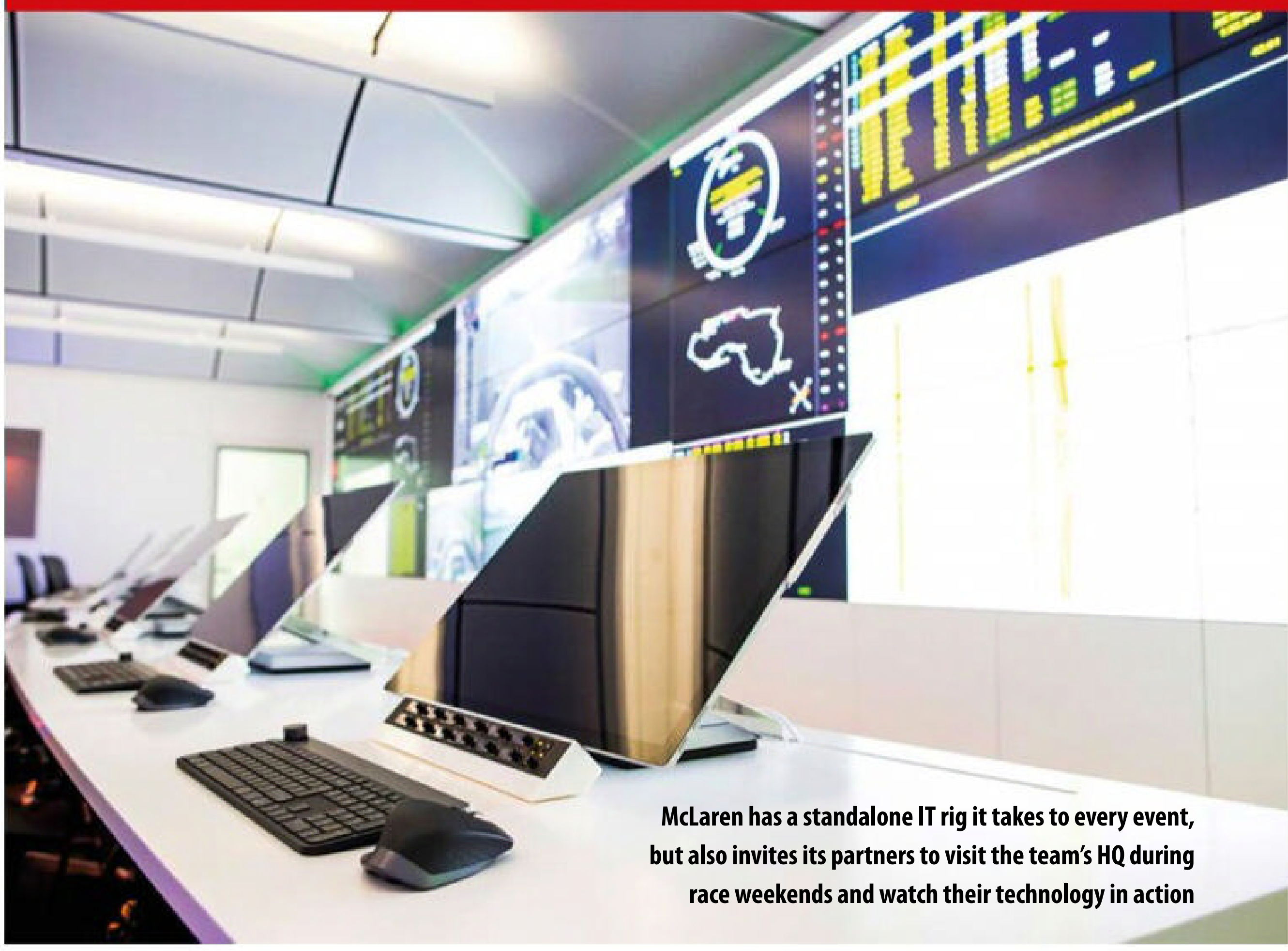
Fortunately, Formula 1 had form in this area, having developed hi-tech data transfer channels over the past two decades. This enabled it to be the first global sport to return to action once restrictions were lifted, initially by way of 'ghost' races staged behind locked gates.

Without remote technologies, those first races would have been considerably more complex to stage, let alone so soon.

As is so often the case in Formula 1, though, the remote garages, which directly connect trackside teams to their factories via data links, have their roots not in foresight but in circumstance, in this case the enforced absence of Ross Brawn from the 2002 Japanese Grand Prix – reportedly due to a slipped disc – during his Ferrari technical directorship. Brawn, now managing director of F1, mandated Ferrari's IT department provide access to trackside data to enable him to direct the weekend's proceedings from a 'virtual pit wall perch' in his home in Surrey, UK. Significantly, the team noticed little difference.

'When he talks to us, it's so clear it sounds as if he's here at the circuit,' said Ferrari driver, Rubens Barrichello, of 'Virtual Ross' during that weekend's press call. '[Brawn] was also not at Monza on the

McLaren's IT crowd


McLaren has a standalone IT rig it takes to every event, but also invites its partners to visit the team's HQ during race weekends and watch their technology in action

Teams have leveraged their commercial partners in the quest for the best in virtual garages, with HP, Pure Storage, AMD and Tata Communications partnering Mercedes, Cognizant title partner to Aston Martin and AWS inking a deal with Ferrari. Kapersky and Acronis represent two of the data security companies currently in F1.

McLaren, which recently added more partners than any other, boasts Dell Technologies, conference platform Webex and cyber surveillance company Darktrace, developed in conjunction with British intelligence agencies. These provide the bulk of the team's virtual garage kit.

'We have an IT rig that we take with us,' says Ed Green, McLaren's head of commercial technology. 'We have only one set, and it travels to every race. It's full of computers and storage and servers, which come from Dell. Should the worst happen and the

The need for growth is that there is an ever-increasing amount of data available, and there are ever more eyes available for it

Dominique Riefstahl, race support team leader, Mercedes F1

Friday of [that year's] Italian Grand Prix, but it was as if he was there. He talked to us and we could hear him just as normal.'

That slipped disc sowed the seed for the logical next step. And when F1 restricted the number of passes per team and imposed curfews, it just provided further impetus for remote garages, variously known as 'virtual garages', 'mission control' or 'race support rooms'. However, there was also another trigger.

'When we had constraints from regulations that limited how many engineers we could take to the race track, we started to think about what we could do to not lose [data] we had in terms of analysis on reliability and on performance,' explains Laurent Mekies, Ferrari's racing director. 'That's how the ideas of remote garages were born.'

Size matters

As is usually the case in F1, successful implementation of any new concept, combined with personnel migration between teams soon sees copycat editions up and down the pit lane. Within a year, all major teams had their own versions in place, albeit to varying effects and of differing sizes. That said, the more funding teams had, the more sophisticated their technologies, and the greater their virtual head counts.

'We're now in our fifth iteration of the race support room [RSR],' explains Dominique Riefstahl, Mercedes F1 race support team leader. 'It started off with a tiny cupboard behind one of the meeting rooms, where literally you had two people sat in there, primarily trying to run simulations and doing analysis on both cars.

'Over the years it's grown in size, from two people to about 10 people, then 20. These days, there's 30 of us in there. Obviously, the need for growth is that there is an ever-increasing amount of data available, and there are ever more eyes available for it. At the same time, the numbers of people at the track reduced. As a result, you tend to find some roles are now happening in the RSR as opposed to the track.'

However, in an ironic twist, remote garages came close to extinction in 2018 after Brawn proposed they be banned on cost grounds and to level the playing field under F1's incoming 'new era' regulations, due for introduction in 2022 after being pushed out a year as a result of Covid. Team bosses pushed back robustly.

'What cost?' Otmar Szafnauer of Racing Point (now Aston Martin) questioned. 'We have the virtual garage already, and so does everyone else. That cost is sunk. Getting rid of it is only going to cost everyone.

'We also have sponsorship for it. We'd lose that, too. So you've got to ask yourself if there is no cost benefit in getting rid of the virtual garage, are they asking us to get rid of it because we compete with [F1] on sponsorship?'

Mercedes F1 CEO, Toto Wolff, was equally critical: 'I think it's a very bad idea because we've invested in virtual garages,' the Austrian argued. 'It's a great selling proposition for partners and sponsors. There's not only engineers in our virtual garage back at Brackley. We have sponsors there, we're trying to have cooperations with hi-tech companies and this is the part they are most interested in.

'As far as I know, many teams have managed to commercialise the race support structures back in the factories and, of course, it gives you an advantage if you've got more brains working on solutions and problems. For us it's become a point of sale.'

Informed decisions

Ultimately, sense prevailed, with F1's return to action under Covid later vindicating the decision. Team bosses had fought long and hard for the reprieve for good reason though. Apart from the obvious cost and performance benefits, there are real safety aspects in the data from incidents that can be immediately analysed back at base and informed decisions taken. From that perspective alone, it is critical links do not drop out.

According to Juan Rodriguez, head of the race operations room for Sauber (racing as Alfa Romeo F1), most teams prefer land or submarine optic cables, which are routed through switchable nodes rather than satellite connections.

Riefstahl reckons the last full outage Mercedes suffered occurred in 2013, but says 'the most dangerous bit' – in terms of reliability – is the last kilometre.

Mid-size team, Alfa Romeo, boasts an impressive inventory of trackside garage kit, namely 60 virtual machines running bespoke software and 55 PCs supported by 40 notebooks and eight tablets, all hooked up to team HQ in Hinwil, Switzerland via a MPLS (multi-protocol

internet pipe all the way to our mission control in McLaren Technology Centre go down, we can run the race on its own with those Dell servers.'

For cyber security, McLaren relies heavily on Darktrace, rather than humans, as the artificial intelligence system is on guard 24/7, including race weekends. Green recalls an incident during last year's (ultimately cancelled) Australian Grand Prix when McLaren was protected from sophisticated attacks after the algorithms picked up unusual flurries of emails.

A senior F1 figure's computer had been hacked, sending emails containing 'links' to McLaren staff, some of whom would not regularly receive emails from the individual. Darktrace intercepted the emails and quarantined them. Had just one link been clicked, the team's systems, and potentially the race, could have been compromised.

The artificial intelligence system is on guard 24/7, including race weekends

Webex has become the standard platform for McLaren meetings, whether internal, external or track to HQ, while Splunk, another McLaren partner, provides software for pre- and post-race analysis.

In common with other teams, McLaren activates its partner links by inviting sponsors and guests to the McLaren Technology Centre during race weekends, providing real-time demonstrations of mission control in action. Guests become part of the team for the race by following the data flow via headsets and giant screens erected in the boulevard area, where historic McLarens are on display.

'We have a viewing gallery adjacent to our mission control behind privacy glass, which we can turn on and off, so people can watch mission control in action,' confirms Green.

Juan Rodriguez, heads the race operations room at Alfa Romeo F1, with 60 machines running bespoke software

label switching) system that directs data along the shortest, most stable route in real time with minimal latency (delay).

During the Azerbaijan Grand Prix weekend, around 10,000 files comprising mainly telemetry, voice and video data totaling 500Gb were transferred. These numbers largely tally with those provided by the other teams interviewed for this feature, although McLaren professes to transfer three times that amount.

'From the radios, videos, cameras from the pit stops, cameras from the garage and all the software needed to run the car, as well as the telemetry and the delivery channels, we are able to have a normal communication with the track [garage from the operations room],' Rodriguez explains.

'There's about 400 channels of sensors on the car,' says Riefstahl. 'If you take a load cell in the suspension and a displacement sensing in the suspension, that's only two channels coming off the car but, by the time you resolve those in terms of forces, and you've done that everywhere around the car, we augment that to about 40,000 channels.'

Teams don't, of course, monitor all 40,000 channels, as he explains: 'With a lot of the channels, especially when they are compound channels, you don't need all of the steps that are in between, you look at the final numbers. If something goes wrong with the final number, then you start going back down through the chain, but we do have mechanisms that monitor certain channels and flags them immediately [if there is a massive offset].'

Live telemetry

Live timing telemetry for all teams is provided by the standard Atlas software, which is part and parcel of the compulsory McLaren-supplied electronic control units mandated by the FIA. Teams have developed their own add-ons to these for simplified processing, lap averaging and bespoke requirements, while the engineering software suites are usually team specific and developed in house.

For strategic simulations, the majority of teams rely on the RaceWatch package from SBG Sports Software, which provides the full suite endorsed by FIA F1 race director, Michael Masi.

Bernadette Collins, head of race strategy for Aston Martin F1 team, says a number of teams, including her own, 'developed their own versions off the back of that. But it gets to a point where the cost of developing software – the resource required vs off-the-shelf software – is key.

'For that sort of software, a lot of it is the parameters you put in, rather than the information you get out. The video analysis, for example, which F1 developed, what they call 'Pit Wall', provides all the onboard videos from other drivers. That's pretty robust and we pay them for licences on that.'

According to Chris Dyer, head of vehicle performance at Alpine F1, the team operates a mix of proprietary and in-house software: 'We are using SBG for timing information, then, like all teams, we use Atlas for telemetry data. We have our bespoke systems and software that sit on top of those common building blocks.'

Bernadette Collins, head of race strategy at Aston Martin F1, emphasises the open communication between track and mission control

Laptops, notebooks and tablets are all linked into teams' data strategy, with robust cyber security and surveillance software in place

It gets to a point where the cost of developing software – the resource required vs off-the-shelf software – is key

Bernadette Collins, head of race strategy, Aston Martin F1

Staffing strategy

Mission control staff numbers during race weekends typically run to 35 heads, although individual faces may change depending upon track programmes. Strategy staff may not be required during free practices, while there can be less aero group attendance during a race, for example. That is a major benefit of remote garages: staff can be swapped, or called in, as required, whereas once they're trackside there is no flexibility.

'We have a mix of people in the remote garage. We have people from vehicle performance, from the aero group, race strategy and a person who belongs to the race team and doesn't travel,' says Dyer.

'Then we have a couple of support people – one or two from the design office following reliability issues. The breakdown of the operation changes through the weekend, with less performance people in the group after parc ferme and more from strategy,' the Australian says, adding that under Covid rules some mission control staff members worked from home provided their connections were up to it.

Depending on a team's relationship with (and distance to) its power unit supplier, a

Virtual working

Working virtually is not the sole preserve of F1 teams, with the FIA and brake supplier, Brembo, embracing virtual reality solutions under Covid.

The governing body has long operated connected systems for back-up purposes, but as Chris Bentley, the FIA's head of information systems, explains, these came into their own once F1 returned to action as a number of stewards on the traditional F1 roster were not permitted by their governments to travel internationally.

'When you have an international panel of stewards and the direction of what we're trying to achieve, [then] you've got someone with the level of experience as, say, [chairman of the F1 stewards] Gary Connelly based in Australia, or Tim Mayer in America, we had to look at things in a different way.

'That's where we started to build on top of the remote services we had. We doubled our bandwidth for the track to cover not only the stewarding but also software engineers for extra service provision that would normally be at the track.'

The acid test

The system was put to the test for the 2020 Le Mans 24 Hours event when Mayer was stuck in Georgia, USA, and the FIA connected him to the French circuit via 'a box of goodies', which Bentley says allowed him to connect to race control and the stewards group.

'The quality of this was quite strange because it was as though he was next door, which is very eerie when you've got someone on the other side of the Atlantic,' says Bentley. 'There was minimal latency because when we plug these things in our technical partner, Riedel, manages the connections end to end for him, from the point in his house right into the track.'

The system again proved its worth when F2 / 3 steward, Dennis Dean, was unable to travel to Sochi from Washington DC in September due to a passport issue. Again, the system worked flawlessly.

Due to restrictions on media at grands prix, the FIA introduced video conferencing and, while the FIA accepts that personal interface between journalists and interview subjects is crucial in certain circumstances, the platform will be used increasingly for more casual media calls. 'We swapped the whole emphasis of our network connectivity to sending data to people coming in remotely, and sending [back-up] data overnight or later in the day,' concludes Bentley. 'That is something that will continue because we've been able to do quite a lot of things successfully this way.'

As for a supplier like Brembo, which supplies 90 per cent of the F1 teams with brake componentry, it traditionally sent two engineers to the track who would consult with individual teams on an as-needed basis. Unlike Pirelli, which provides a dedicated tyre engineer to each team, and could therefore incorporate them into their 'bubbles', the Brembo engineers could not do similar as they needed to move between teams.

Andrea Algeri, Brembo Racing's F1 customer manager, says the company adapted processes developed with Ferrari, who in 2017 requested a dedicated engineer during race weekends who worked remotely. So, between last year's (cancelled) Australian Grand Prix in March 2020 and the recent US GP in October 2021, attended by Algeri, Brembo had no physical trackside presence. It worked, under the circumstances, but he concedes personal contact is vital and so Brembo will in future rotate its engineers, with one travelling to events and the other operating remotely. The best of both worlds, if you will.

Dennis Dean

Since Covid, home working has become reality for many people, and the technology available to implement it has accelerated dramatically

PU support engineer could physically be in mission control, or hooked up from wherever. Then, as the sophistication of driver-in-loop simulators improves, so teams increasingly experiment with set-ups, and then feed results to the team, often before sessions end.

Equally, requests can go the other way, with trackside engineers asking those back at base for specific simulator set-ups.

Data flow

Collins, who recently featured on the Forbes list of 30 Under 30s for contributions to manufacturing and industry, says that within Aston Martin there are totally open data flows between mission control and trackside garages: 'There's nothing hidden between the trackside environment and the people who are plugging laptops into mission control,' she says. 'Everything comes back via IT link. Additionally, everything on the intercom feed comes back to mission control, all the videos come back and any live stream images from garage cameras.

'A few years ago, when the FIA tried to tie down what teams were allowed to tell drivers on the radio, tried to ban coded messages, they got to the point of saying, "We're not going to police this any more, but everyone else is going to get your intercom." All of that gets fed back to mission control and processed [for strategic] reasons there rather than at the track.'

However, not all track intelligence comes via normal channels: 'We'll also go and look at certain websites for a competitor, or see what information we might gather from Twitter and Instagram and Reddit, because team actually give away quite a bit of information over those channels,' smiles Dyer.

Therein lies the key to the concept: gathering information and intelligence in a relatively calm and methodical environment, one well away from the direct stresses of the trackside garage, and then supplying crucial support to those in the midst of battle.

Apart from undoubtedly easing F1's return to action, the acid test for virtual garages is how realistic they actually are, particularly as they increasingly rely on artificial intelligence and augmented reality scenarios. Riefstahl relates an anecdote

The key to the concept: gathering information and intelligence in a relatively calm and methodical environment… and then supplying crucial support to those in the midst of battle

which underscores their realism: 'We had a case where Lewis [Hamilton] was discussing his steering wheel with his control engineer and at some point he said, "I just want you to come down and do it." To which the engineer said, "I can't, I'm in Brackley…"

'It shows how transparent communication can be, and how much people rely on us providing information, analysis and support, without realising at times that we're not actually physically there at the track.'

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Toyota regards the 2021 victory as the greatest team effort at the race

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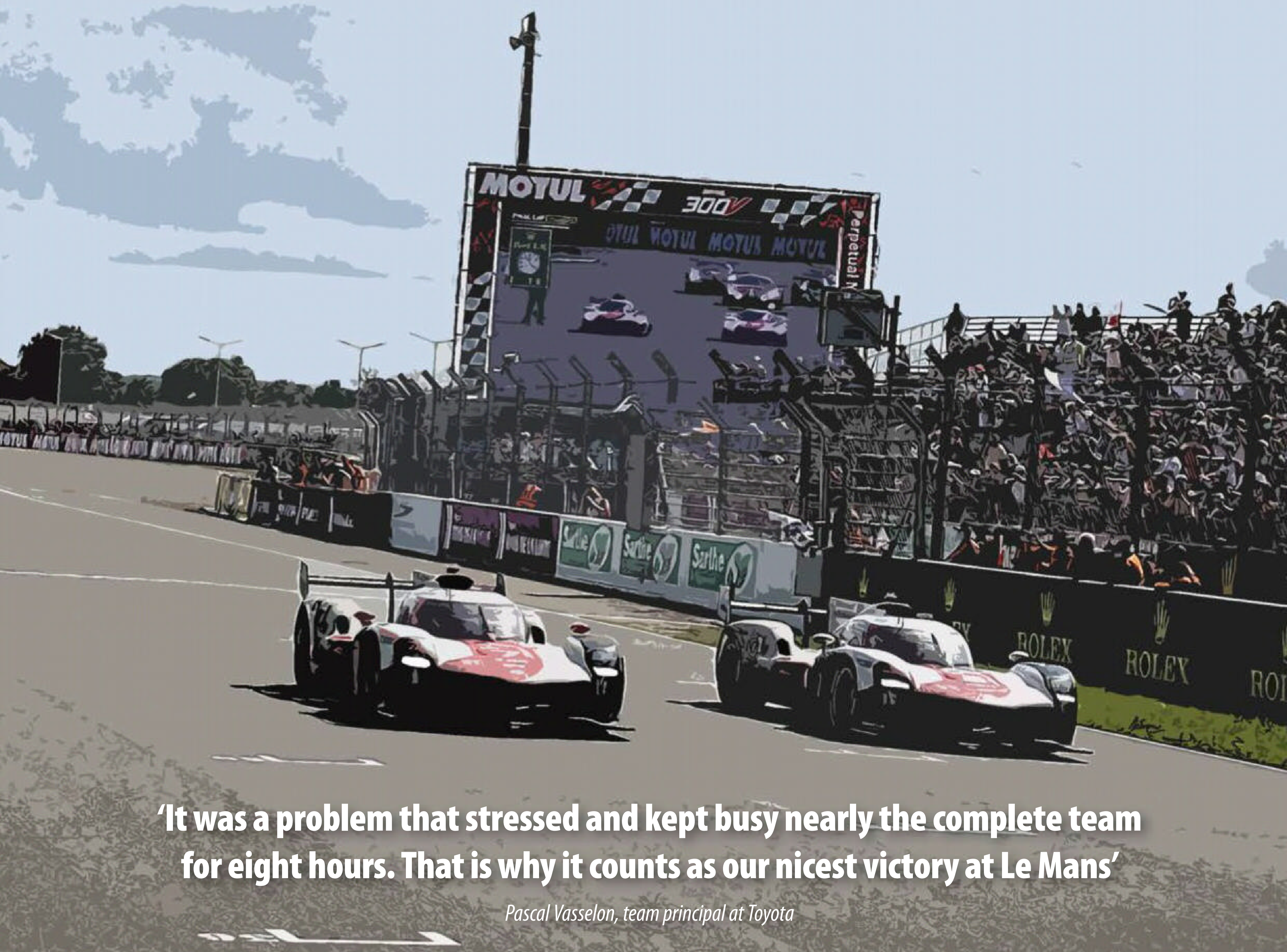
Under pressure

Toyota may have finished first and second at Le Mans this year, but the effort required to overcome a fuel delivery problem and finish with both cars was Herculean

By ANDREW COTTON



'It was a problem that stressed and kept busy nearly the complete team for eight hours. That is why it counts as our nicest victory at Le Mans'

Pascal Vasselon, team principal at Toyota

The history books will show Toyota dominated the 2021 running of Le Mans, with opposition coming from a year-old Alpine that was hamstrung by regulations, and two Glickenhaus LMH cars that were in their first year of competition.

The GR010s finished four laps clear of the Alpine in third position, but after the race the Toyota team members were exhausted, both mentally and physically. The effort it took to bring both cars to the flag was little short of miraculous, as both cars suffered blocked fuel filters that threatened to retire them at any point in the last eight hours of the 24-hour race.

From the outside, it was clear the cars were nursing a problem as they were not running full length stints on the fuel. At times, the cars were pitting every three laps, which put incredible strain on the team in the pit, and also lost valuable track time.

Onboard cameras also showed the drivers were pressing a set sequence of buttons at various points around the lap. At their most vulnerable point they were switching to 'DD7.3', a setting on the steering wheel that was broadcast to the outside world, in every one of the six major braking zones around the lap. What they were in fact doing was switching off the fuel pump when it was not loaded under braking, and then re-activating it when acceleration was required from corner exit in a bid to maintain engine performance.

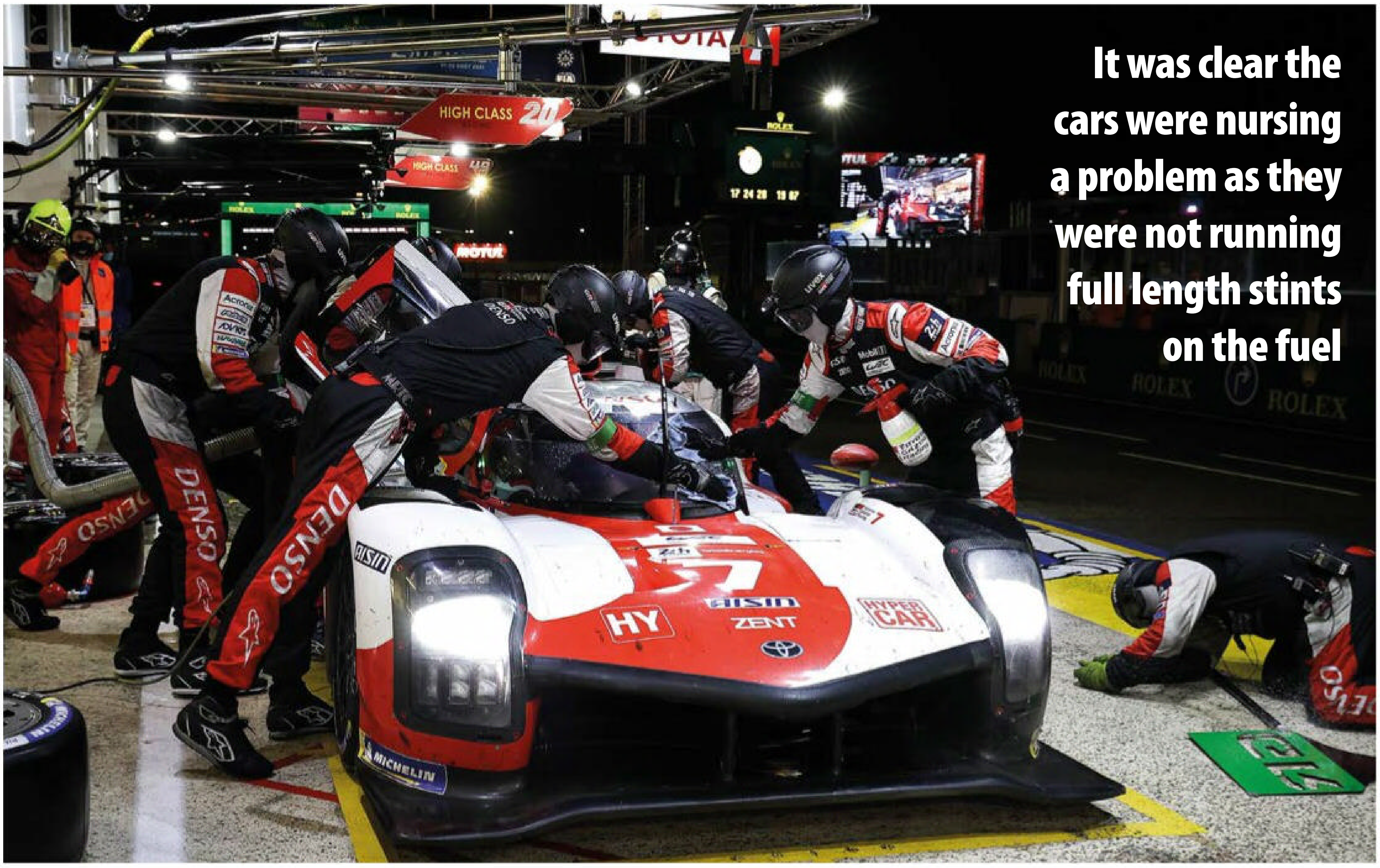
'At 8am on Sunday, there was no one who knew about the problem who would have bet that we would be there at the end,' admitted team principal, Pascal Vasselon, after the race.

The entire team was involved in either brainstorming to find a solution, or running

Underlying the whole final third of the race was the fear they would lose one or both cars through a fuel starvation misfire

XPB

Toyota first hit problems at Monza (shown) when the fuel filter was blocked by debris collected in grease around the fuel connector



It was clear the cars were nursing a problem as they were not running full length stints on the fuel

XPB

The fuel filter issue hit the number seven car just after 7am on Sunday morning, trailing the same issue in the number eight car by an hour while fixes were hypothesised and then put into action

the cars, but underlying the whole final third of the race was the fear they would lose one or both cars through a fuel starvation misfire.

This is the story of the race, Toyota's mission to analyse the problem whilst running at race pace, find a workaround for an unstable issue and, ultimately, bring its two cars to the flag.

The problem

The opening round of the FIA World Endurance Championship at Spa in May was the race debut for the Toyota GR010s, and they were not without problems. One of the two cars had only just been shaken down prior to arriving in time for the pre-season test, and the team spent much of the weekend working around various electrical and hydraulic issues. The other had completed much of the pre-season testing so had been largely de-bugged.

After bringing both cars to the flag there, in first and third places, the team worked hard to improve them for the second race at Portimao. The cars ran well in Portugal and so it was with a little more confidence that the team arrived for the third race in Monza.

However, the Italian race provided an indication that the cars were still vulnerable. The number seven car had stopped for a system re-set on its way to victory, but there were far more issues for the number eight car, which suffered from a clogged fuel filter, which was at times starving the engine of fuel, leading to a misfire.

Brendon Hartley was at the wheel when the problem became so great the team had to pit the car and change the collector at the bottom of the fuel tank. The fix took 45 minutes, but a mistake in the pits meant the front left wheel was not properly re-attached, and in braking for the first corner the car went off, Hartley again the innocent passenger.

Toyota took a close look at the fuel system of the number eight car to work out *why* the filter had become blocked, and almost immediately hit on a reason.

'The blockage of the filter came from two things,' explains Vasselon. 'The first, and most critical, one was a grease that was present in excess in the refuelling connector on the car where the nozzle connects. This is serviced every year at the supplier, and the connectors came back with a lot of grease. This grease did not dissolve in the fuel and was going around [the tank]. But this grease alone was not enough [to cause the blockage]. The grease was able to go through the filter.

'What happened in Monza was that this grease collected aluminium oxide particles that were present in the fuel machines. We had new fuel machines in Monza that were not completely clean inside, and were generating aluminium oxide particles. This is how we concluded we were certain to have found the problem.'

Toyota

Technical director, Pascal Vasselon, was central to the decision making process and led the team to first and second at Le Mans

The fuel storage tanks were new at the start of the season and had not presented this problem in testing, or at the opening race, so it was with some surprise that the team found the issue post-Monza.

'We never found this issue in testing,' confirms Vasselon. 'It takes time to clog the filter, it doesn't happen in three laps. You need the grease to collect the particles, and the particles came from the machines we don't always use. We got these ones for the Prologue in Spa, so there was not so much mileage on them.'

Confident arrival

The team therefore arrived at Le Mans convinced it had identified and solved the fuel issue by cleaning the machines properly, and senior management was robust in its defence when questioned prior to the race. Privately, however, there were members of the team that were not convinced the problem was completely resolved.

The race started cleanly for the first few hundred metres before the number eight car was hit by one of the Glickenhaus machines.

This was the car that appeared to be suffering more than the other throughout the race, and some put this down to that first contact. However, that was not the problem. At around 4am, the stint lengths of the number eight car started to reduce dramatically, and then became highly erratic in terms of the number of laps per stint the car could complete.

From regularly posting 13-lap stints during the night, the number eight car dropped to nine, seven, five, four and then three-lap stints in succession. Lap time also increased slightly.

It was clear something was wrong, but just as the car suddenly returned to a 13-lap stint on Sunday morning, exactly the same issue was noted on the leading car.

'A decision to change the collector was in fact a decision to lose the race'

Pascal Vasselon, team principal at Toyota

'The first indication came to me at 7.19am, and the first person who spotted an issue was an electronic system engineer. The reason he could spot it was because we had a similar issue at Monza,' explains Vasselon of the issues with the team's leading car. 'He was familiar with the pressure trace and how it looked when this problem happened before. Already at that time we understood that car eight was more advanced than car seven with the problem.

'We knew from Monza that this kind of problem never improves because it is a filter getting progressively clogged by debris. At that moment in time, we knew what was happening, but we didn't know why because we were convinced we had solved the problem from Monza.

'We were very surprised. We thought it could not happen again, but it was clear a similar problem was developing.'

45-minute solution

The team needed to think and work fast, to find a solution that would keep them competitive. That meant leaving the cars out on track racing, and finding a workaround. The Alpine was too close to allow them to stop and change the collector. To stop would have been to surrender the race. The team also felt it did not need to stop to identify the cause because the electronic signature told them what was wrong. They just didn't know why.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'Obviously, the more we were waiting to change the collector, the more risk we had to suffer misfire and lose performance and lap time, so there was a pragmatic view to say change the collectors as soon as possible, get rid of the problem,' says Vasselon.

'The problem was this option would, in the best case, take 45 minutes. It meant a decision to change the collector was in fact a decision to lose the race.

'Considering we were not at Le Mans to finish in the top 10, we were there only to win, it was quite an easy decision to say we don't do that, we try to run as long as we can.'

The team was split into those that needed to run the cars, and those that had the knowledge and expertise to consider other possible solutions. Those that were tasked with running the cars kept an eye on the fuel pressures, and the moment they started to show a drop, the car would pit to fill up with fuel. Hence the erratic stint lengths.

'The first observation was that every time we stopped in the pits it was getting better,' says Vasselon. 'That was the first counter measure we put in place to keep running. As soon as the pressure dropped too much, we pitted the car. The problem was we quickly finished up in a situation with car eight that we were pitting every three laps. If you have one hour to go you can keep going like that, but with seven hours to go you understand it would not work.'

The team therefore had to use the time in the pit to try and understand what was happening in the pit that was causing the problem to alleviate. One option was the fuel pump was being switched off during refuelling. With no draw through the filter, like a pea on the end of a straw, the pressure was reduced briefly and the debris shifted. The team then considered how they could try this workaround out on track.

Manual override

They identified a point on the circuit that would not require the pump to draw into the engine, which was the braking area into the first chicane on the Mulsanne Straight. Driver of car eight at the time, Sebastien Buemi, was given a sequence of instructions to manually override the systems and switch off the fuel pump

'You have a lot of driver defaults to handle different problems. I think we have around 200 of them,' explains Vasselon. 'There was a driver default, DD7.3, that was able to stop the pump and re-activate it, but it was not an easy manipulation. The driver had to activate the page on the display, select the driver default, and then, after starting braking, activate it to stop the pump, and then re-start it again for acceleration. Seb understood, he did it, and the first time he did it, it was perfect.'

Toyota

The connectors were serviced ahead of the race at Monza, and came back with excess grease around the openings, which leaked into the fuel tank. The grease itself could pass through the filter, but it collected additional debris from the fuel storage containers

A new programme [for the fuel pumps] was written, sent to the team's base in Cologne to be de-bugged, and then implemented on both cars

It quickly became apparent this was not enough though. The problem was not stable and was getting progressively worse so, at 09.35am, the team asked Buemi to activate the sequence at more points around the circuit.

'They said, "It is going to be a bit complicated," recalls Buemi. 'They told me we either lose the race or we try the complicated thing, so we chose the complicated thing and it started to work.

'The first time they told me to do it in turn eight, and it worked. Then they said I had to do it again the next lap. That was okay. Then they said more corners… the second chicane, Mulsanne… Can you do it in Indianapolis please? And Ford Chicane, and turn one?'

The attendant drop in lap time wasn't due to the complexity of operation, more because the team had asked its drivers to elongate braking distances to increase the amount of time the fuel pump was switched off.

Driver changes were made at 10am on Sunday morning as it was easier to brief the driver in the pit and then install him in the car than to explain the protocol on the radio to a driver who was already busy on track.

Extreme measures

Though complicated for the drivers, the solution seemed to be working, and the problem stabilised for around four and a half hours. It was not, however, rectified and when the situation started to deteriorate once again, the team needed to take more extreme measures to keep the cars running.

The lead electrical engineer, who had spent Saturday afternoon in hospital with blood pressure issues, had discharged himself and returned to the track. He came up with a radical solution.

The cars are fitted with four lift pumps, two of which work at any one time. The other two are redundant, but there in case of failure. In order to increase the pressure applied to the fuel through the filter, and to create a disturbance that could shift the debris, a new

XPB

Sebastien Buemi was instrumental in the cars reaching the line, implementing a complex series of running procedures whilst driving through Sunday morning

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The fuel bladder itself was collapsing as the fuel load lightened, and the inner linings of the bladder were rubbing against each other


Toyota

The fuel filter post Le Mans. At 10microns filtration, it took analysis with a microscope to work out what the debris was, while an endoscopy back at HQ in Cologne identified a collapsing and degrading fuel tank due to an insufficiently sized breather pipe

programme was written, sent to the team's base in Cologne to be de-bugged, and then implemented on both cars. The new software activated all four lift pumps at the same time.

'This happened at 2pm in car eight and, after refuelling, we plugged the umbilical to download the software,' explains Vasselon. 'That is something you would never normally do during a race. We saw immediately that the situation was improving [and] it was again restoring some pressure.

'Seeing that it was working on car eight, we implemented it just a little while after on car seven. We were coming closer to the race end at that point.

'With car seven, we went to the end [of the race] with this configuration, but with car eight the situation was still degrading and so we had to apply another measure. We asked Kazuki [Nakajima] to do partial acceleration. The pressure drop was higher when you were asking for more fuel, especially after the Karting corner.'

The team stopped car eight in the pits, not to bring it out for a photo finish, but to reduce the need for it to do any more laps than absolutely necessary. The rules at Le Mans state that the car must complete the last lap in a minimum time, as Toyota had found to its cost so painfully in 2016. The strategy worked.

Ongoing problem

The team had just two weeks with the cars at Cologne to establish the cause of the issue at Le Mans before they were due to be loaded onto the ship bound for the final two races of the season in Bahrain. While the engineers were aware the grease was an issue, they were equally sure the fuel machines were spotlessly clean, so there must therefore be another foreign object that had been picked up within the grease and blocked the filter.

There was no obvious solution from the outside, but a fuel tank endoscopy quickly established what was going on, and the team was at last able to work out why. The fuel bladder itself was collapsing as the fuel load lightened, and the inner linings of the bladder were rubbing against each other, shedding debris that was then left to float around the fuel system.

Why the fuel bladder was collapsing was the next issue to solve, and here the problem directly related to the system employed by the team's LMP1 car, the TS050.

'For the LMP1, the breather line was optimised because it had an effect on the refuelling time,' says Vasselon. 'So we kept this feature. With the LMH car, though, the fuel flow is much higher. The pumps are sucking fuel much faster, and a larger amount than in LMP1, for two reasons: first, the engine power is much higher, and second, the engine efficiency is lower.'

Heavy breathing

'The speed at which the fuel leaves the tank is therefore higher, and then the breather line became too small to cope. This is now the understanding we have of the problem.

'So, one of the counter measures for Bahrain is to have a bigger breather line. It was not easy to see that the bladder was collapsing. It was a combination of things that led to the problem, it was not just one cause. At Monza, there was one obvious cause. We did not see the other ones, and after Le Mans we understood the full picture.'

There was a further change to the regulations with the Hypercar, and that was the shift to a new FT5 fuel cell. This is a Kevlar shell with a bladder held within.

'The old fuel bladder was degrading,' explains Vasselon. 'The inner surface was degrading with mileage. The fuel is quite aggressive, and it was one of the reasons car eight was more affected [due to the higher mileage at the start of the season at Spa]. The fuel cell [in car eight] was older and had more mileage than the one in car seven.

'At the beginning of the season with the new fuel cell, they were not generating as many particles as at Le Mans. It was a complex problem that needed several combinations of circumstance. Normally, we don't change the fuel bladder so often. We have new ones for Bahrain. It is a new regulation to use FT5 fuel bladders, and it is new territory for everyone.'

Conclusion

The team has now implemented a raft of changes to the fuel system to ensure the cars don't suffer the same fate at future races of the WEC but, while this year's Le Mans was stressful for the entire team, the 1-2 finish was also one the team ranks among its very best performances.

Vasselon: 'We had some leaders doing the brainstorming, we had system and performance engineers monitoring the fuel pressure to decide quickly to pit the car, because if they were not quick enough then the car could stop on track.

'Then we had the race engineers managing the information to the drivers, the drivers – you have seen the incredible activities they had to do in the car – and for the pit stop crews, their life was terrible. At one point we were pitting the cars every three laps, so for the pit stop crew to get everything ready to refuel the tower, prepare the tyres, it was terrible for them. It was a problem that stressed and kept busy nearly the complete team for eight hours. That is why it counts as our nicest victory at Le Mans.'

007 LMH: designed, developed and built for Glickenhaus Racing
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Das Boot

A curious Twitter exchange fired up a unique, hydrogen-powered, cross-country project that will contest the Baja 1000 in November 2022

By ANDREW COTTON

The rivalry is unlikely to become a reality, but Elon Musk's tweet that his Cybertruck was better than a hydrogen fuel cell option sparked Jim Glickenhaus to propose a challenge. 'You have said that hydrogen technology is "mind-bogglingly stupid,"' wrote Glickenhaus in response to Musk. 'You've also mentioned that the Baja 1000 would be a great test for your Cybertruck. We say bring it.'

It is a classic, old school racing challenge, laid down by one who could afford to back it up to another. Even though Musk went quiet, Glickenhaus pushed ahead with its programme under a new company, Glickenhaus SCG Zero.

This is a project designed to look at carbon zero technologies, including electric, but also other alternatives. It is run by Jesse Glickenhaus, Jim's son, whose life, he says, has been affected by the plight of the population of Bikini Atoll. That's the series of islands used by the Americans to test nuclear weapons after the second world war, and whose inhbitants' attempt to return has now been thwarted by the threat of global warming.

As such, Jesse, who wrote to the first General Assembly Resolution for the UN to say that climate change was an issue of international peace and security, decided the future of mobility had to be more friendly to the environment. He has since been given free reign within Scuderia Cameron Glickenhaus (SCG) to pursue options.

Initial target

The Glickenhaus Boot, which has already competed in the Baja 1000 with some success, will form the base car for the programme, with heavy modification for the hydrogen fuel cell that will provide the power needed to compete. It is not expected that the car will be able to *win* the event, as there are a number of obstacles that need to be overcome, but the target for year one is to finish reliably, and to set a benchmark that will put the technology onto the radar of governments around the world.

Creating a hydrogen fuel cell car is not easy, and it may seem unlikely that a cross country machine with excessive weight being driven through the desert is the perfect vehicle to demonstrate green credentials, but this is where the Glickenhaus team started.

'In November, we were racing the Baja for the second year, and a person down there asked me what it would take to run a zero emissions Baja 1000,' recalls Glickenhaus. 'That was the question that set it all off. I did research, started with the laws of physics and chemistry, and what's currently known about them, and those are my limits.

'I researched using medical waste that's radioactive in the US, and tiny nuclear reactors, which are used in satellites, spaceships and in the US military on aircraft carriers. I looked at batteries. I looked at capacitors. I looked at burning hydrogen, which is not quite zero emissions because it creates NO_x, and it creates CO_2.

'The answer I came up with, using existing technology, is hydrogen fuel cells.'

Tweet tweet

That was the tail end of 2020, but then came the tweet from Musk.

'First, he tweeted that the new size Cybertruck suspension would be great for the Baja 1000, and the second thing he tweeted was that fuel cells are stupid,' remembers Glickenhaus. Actually, he tweeted that these were 'fool cells' and it sparked a rivalry.

'My dad, being my dad, tweeted back and said, "Great, you bring the Cybertruck. We'll bring a fuel cell Boot, and we'll race you in the Baja in 2022."'

A Le Mans refuelling time of around 15 seconds would be the target for the Boot

The goal of this project is to set a benchmark that will put hydrogen technology onto the radar of governments around the world

Computer renderings of the proposed hydrogen fuel cell-powered racecar version of the Glickenhaus Boot

There were a few issues to overcome before this could even be considered a possibility, but both Jim and Jesse Glickenhaus had the bit between their teeth.

SCORE, which runs the Baja series, did not have a regulation set for a hydrogen fuel cell vehicle, so had to come up with something quickly. Refuelling was also an issue, particularly in the desert, and in light of Toyota's performance at the 24-hour race at Fuji earlier in 2021 where it required multiple trucks and minutes to refuel at a circuit.

Glickenhaus decided that a Le Mans refuelling time of around 15 seconds would be the target for the Boot, and set its engineers the task of achieving that.

Refuel for thought

The refuelling solution has been identified as the most important part of the programme as, aside from other advantages over electric in terms of efficiency, this is the part that currently lets down the electric solution.

'SoCalGas reached out to us completely unsolicited,' recalls Glickenhaus. 'They asked if we could build them a pick-up truck. They have a fleet of 5000 vehicles and are based in California. By law in California by 2035, they need to be zero emissions. Their trucks drive 350 miles a day, need to be permanently ready and cannot afford to have downtime charging, or cope with blackouts, so they know the solution cannot be battery electric.'

Increasingly commonly, such companies are turning to racing outfits due to their prototype experience and tight turnaround times. For that reason, SoCalGas, and others, have approached Glickenhaus. Not that they are funding the programme. The company is self-funding the design, build and development of the project, and says it may do some crowd funding closer to the event in order to generate some additional audience participation in the project.

Once the issue with SCORE's rule making was overcome, the company could then turn towards the technology. SCG partnered with First Mode, a team of engineers that by chance were in the process of designing a hydrogen-cell electric earth moving vehicle, and which had monitored the Glickenhaus Twitter conversation with Musk.

Engineering phase

'First Mode did a feasibility study over several months. We gave them all of our Baja data and they built a Baja course,' says Glickenhaus. 'We ran combinations of fuel cells, batteries, hydrogen storage solutions and came up with our design. Then we moved to phase two, which is the engineering.' Podium Technologies, which was the design partner for the Glickenhaus road and racecars, has vast experience with batteries and electric technologies, and so was employed to do the packaging, cooling and heating of the hydrogen, as well as take the lead on chassis design.

'One of the things we learned in the simulation is, at some points, we are power limited,' explains Glickenhaus. 'At some points we're torque limited, but the biggest factor with how we will do in the race is the rolling resistance of the sand. If the rolling resistance is 30 per cent, we can finish in 25-26 hours. If the rolling resistance is 40 per cent, we barely don't time out. We'd finish in 33-34 hours.

'The difference in rolling resistance because we're power and torque limited makes a giant difference in our outcome.

'You can affect the rolling resistance a little bit by managing tyre pressure, but you can't affect the terrain. So, what we decided to do is work with a company called BWI. They are doing our ESC [electronic stability control] system for our road car and track-based car traction control. We've tasked them with making basically an ESC traction control system not for safety, but for efficiency, so as little wheel slip as possible to get the forward momentum we want is being used.'

The refuelling issue still had to be sorted, though, and Glickenhaus now believes they

A fuel cell lasts 30,000 hours driving at 35mph – that's a million miles

A road version of the Boot is in development, and could be an option for companies looking for an alternative to battery electric

have a solution that will work. It has moved away from the idea of compressed hydrogen as that leads to long refuelling times, and instead focussed on cryogenic tanks.

Mass factor

'From the technology side, the limiting factor [in compressed hydrogen] is the starting temperature,' says Glickenhaus. 'As you fill, the gas heats up, and you can't heat it up too quickly, so you have to pre-cool it to at least -70degC. The problem compounds when you carry a lot of fuel.'

Which brings up another problem – the size of the fuel tank, and its storage capacity.

'The best existing tanks have a mass fraction of about 10, maybe 12, per cent. Some of them are as bad as two per cent, meaning a tank to hold 10kg of hydrogen at a mass fraction of 10 per cent weighs 100kg. We were trying to carry 30-40kg of hydrogen, so the tank mass would be gigantic, and in the Baja weight is very important.

'We studied two different ideas. The first was using compressed tanks and, instead of refuelling, swapping out the tanks like a propane cylinder. Then you could refuel in 15 seconds, theoretically, because you just thread one tank out and thread another tank in, but you're still left with the mass fraction of the tank issue.

'The other push I did is to say look into cryogenic. When the engineers started crunching all the numbers, they realised for an extreme race application, and for anything where you have significant weight to carry, cryogenic makes more sense. So, from a technology point of view, we found a type five aerospace tank.'

This has the capacity to solve the mass fraction issue, while First Mode is busy working on a mobile solution around the 800-mile loop to conduct the refuelling at speed. The refuelling does not need to occur in 15 seconds as the pit stops are far longer than that in Baja racing, but it is a target that has been set by Glickenhaus and will be met.

Vented fury

Finally, there is the thorny question of where the hydrogen comes from. Building a refinery and producing it is not at all friendly to the environment so, much like TotalEnergies and its use of waste ethanol from the production of alcohol for the WEC, Glickenhaus is proposing to use the hydrogen that is a by-product from another process.

'It is hydrogen that has been produced from fossil fuels but, depending on the process, it's hydrogen that otherwise would have been vented from refineries, and instead is being captured and used productively.'

Transporting it over the US / Mexico border would also be an issue but, strangely, there is an existing solution that ticks all the boxes, as Glickenhaus explains: 'We found a company in Ensenada, which is where the race starts, that sells 600 gallons of cryogenic hydrogen bi-weekly. It's an industrial supply gas that is everywhere. It's a welding supply gas in the US, and you can get it virtually anywhere in the country.'

Percentage game

The final issue is a longer term one, and that is the cost of the fuel cell. In small quantities, the cells come in at around $80,000 (approx. £57,850 / €67,700). That makes it unaffordable in a low volume production car application. If the overall car has to be sold at $100,000, the fuel cell needs to account for just 30 per cent of the cost, not 80 per cent. Volume may bring that number down somewhat, but by not nearly enough at this stage.

'There's a lot of money riding on keeping the internal combustion engine alive. Not just in the fossil fuel industry, but the automobile industry, all the auto suppliers and so on,' concludes Glickenhaus. 'The fuel cell core is a much simpler concept, and there's no maintenance on it. A fuel cell lasts 30,000

Glickenhaus moved away from the idea of compressed hydrogen… and instead focussed on cryogenic tanks

hours driving at 35mph – that's a million miles. The repair bills are less through the repair shops too, but that impacts on the whole auxiliary supply chain for the automotive industry.

'So, the reason ICE hydrogen might be a bridge is not necessarily because it's a good idea, and not because it's environmentally clean, but because there's *so* much pressure from *so* many people to keep the ICE alive.

'It may make sense in places like China, India and Mexico, where a $100,000 pick-up truck is not going to be sold for 30 years, but a $5000 car would be. The primary problem in that case, though, is that ICE or hydrogen cars are up against battery cars in the consumer marketplace. Those are relatively cheap now, and the range is comparable.'

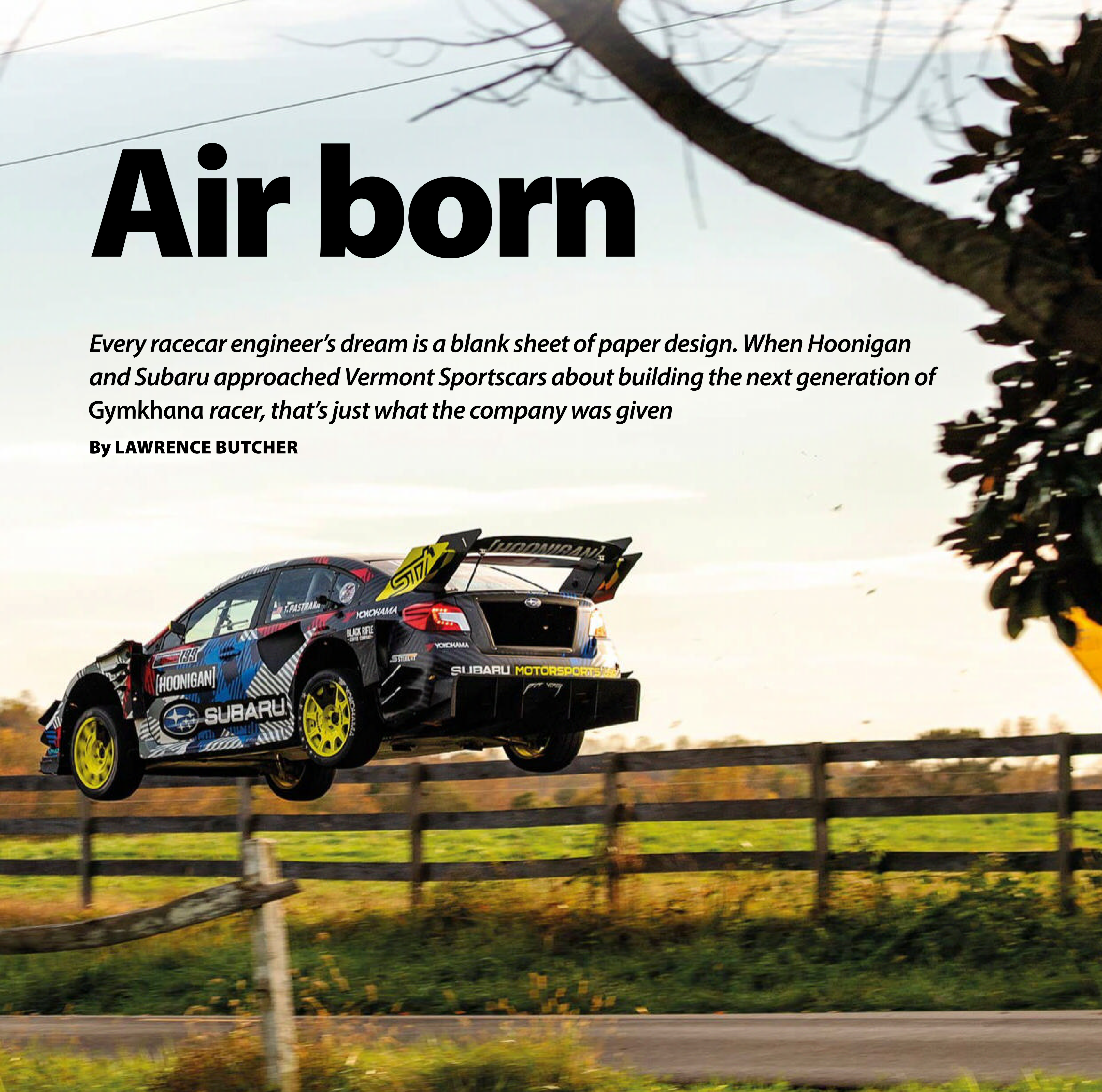
At time of writing, the hydrogen-powered Boot is still at the concept and design stage, but building and testing will take place in time to take the car to Baja to compete in 2022. There's just the small matter of this year's competition with the traditionally-powered Boot to get through first.

Gymkhana cars are the ultimate expression of a road car based racer

What they wanted from the car in terms of jumping, power, sliding and driveability was very similar to the requirements for Rallycross

Bertrand Vallat, technical director at Vermont Sportscars

Air born



Every racecar engineer's dream is a blank sheet of paper design. When Hoonigan and Subaru approached Vermont Sportscars about building the next generation of **Gymkhana** ***racer, that's just what the company was given***

By LAWRENCE BUTCHER

Racecars are defined by regulations. From the entry level kart to F1, the rulebook dictates what can and can't be done, rather than what an engineer may think is the ideal approach. The skill in designing and building a winning racecar is finding every ounce of performance within the rules, but not breaking them.

Throw that rulebook in the bin, though, and things get a whole lot more fun. The result? Cars like this, built by Subaru's works team in the US, Vermont Sportscars (VSC).

The company has a long history of constructing cars to the 'rules', fielding a variety of machines in Rally and Rallycross, but this project was very different.

Initially built for the *Gymkhana* video franchise (for those not familiar, these were essentially a showcase for driver, Ken Block, sliding around like the 'Hoonigan' he is in various high-profile locations), the franchise is now known as Airslayer, and encompasses more than just videos, while former FMX star, Travis Pastrana, has taken over as wheel man.

Setting the stage

The VT20G is based on a 2020 Subaru WRX STi that VSC uses for its Rally and Rallycross programmes. 'Given the initial request from Hoonigan (Block's brand) and Subaru, it was obvious to start from a Rallycross car,' explains technical director, Bertrand Vallat, who was chief designer at Hyundai Motorsport prior to his move to Vermont in 2019. 'What they wanted from the car in terms of jumping, power, sliding and driveability was very similar to the requirements for Rallycross.'

However, while this car is *similar* to a Rallycross version in its underpinnings, it moves the performance to another level. Its turbocharged boxer four engine displaces 2.3-litres (compared to 2.0-litres in RX) and puts out over 850bhp, 200bhp more than even the most potent RX machines.

Likewise, the aero package goes far beyond that allowed in Rallycross, not least thanks to the addition of a driver-adjustable rear wing. More on that later.

The car started life as a body in white Subaru WRX, the majority of which was then either removed or modified in one form or another. Underneath, the transmission tunnel was opened up to accept the Sadev-supplied, six-speed transmission, from the same family as the company's Rallycross unit, but heavier duty thanks to the use of 24mm rather than 20mm gears to withstand the power hike.

'It was a compromise on weight, because when you have a wider gear, you have a bigger gearbox, which means you have a heavier gearbox in the end,' admits Vallat.

The upgrade was considered necessary, though, and did not unduly compromise the overall car package.

Mounting positions

The engine sits approximately 200mm further back in the chassis than the production car, which in turn means the transmission is almost centrally mounted, using a torque tube connection from the engine and propshafts driving the front and rear differentials. With the engine mounted so far back in the chassis, the front differential, produced by VSC (the rear is a Sadev unit), actually sits under the engine block in order to place the driveshafts in the correct location relative to the hubs.

Steering is provided via a hydraulically-assisted rack with an 11:1 ratio, and notably, the wheelbase is close to stock, a hangover from the Rallycross base design.

Though not built to any particular rulebook, the bodyshell was outfitted with a full FIA-compliant rollcage, braced into the front and rear shock towers. All trace of the factory subframes was removed, with bespoke units fabricated from tubular steel to support the MacPherson struts front and rear. The suspension gives all the adjustment one would expect in terms of camber, caster etc, as do the Reiger dampers.


Photo: © David Trumpore, subaru.com/motorsports 2021

Six-speed sequential gearbox is based on Sadev's Rallycross unit, but beefed up with 24mm gears to withstand some serious abuse

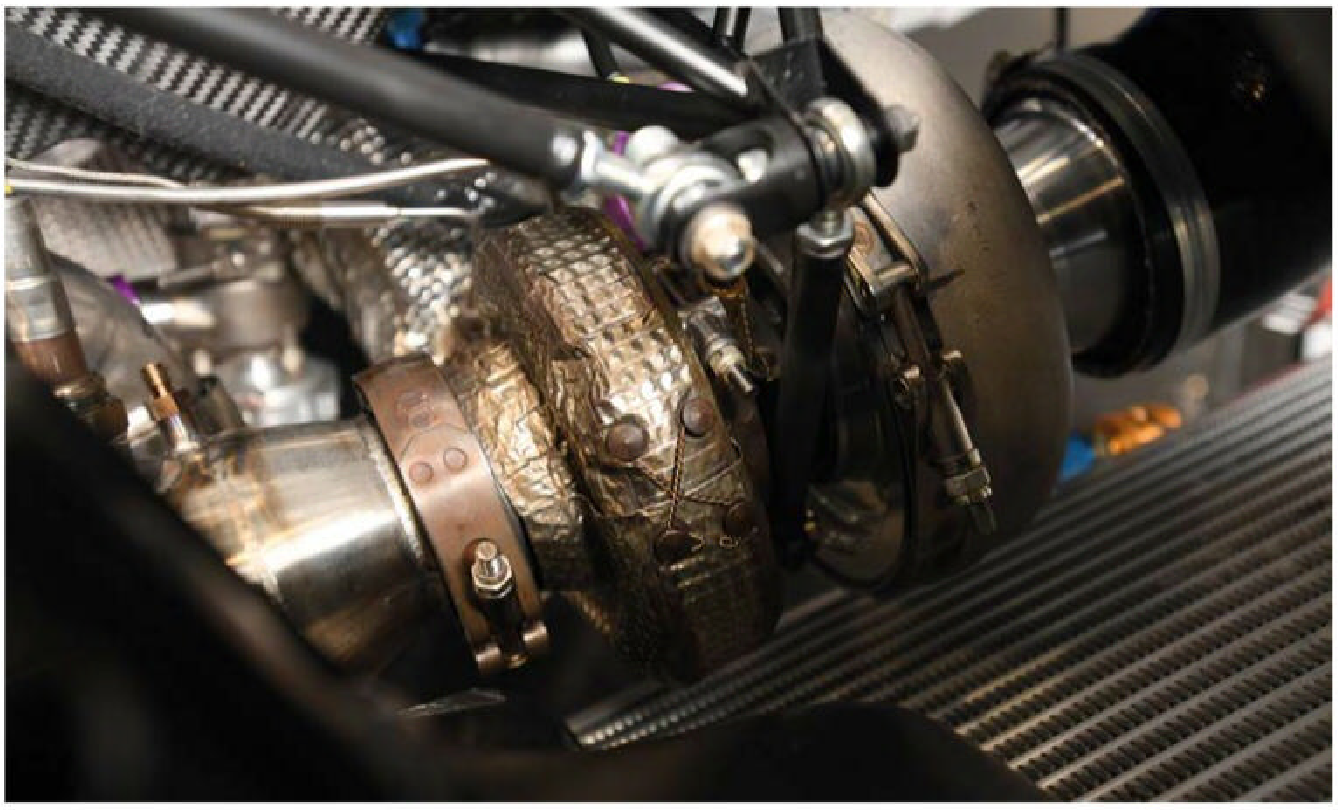
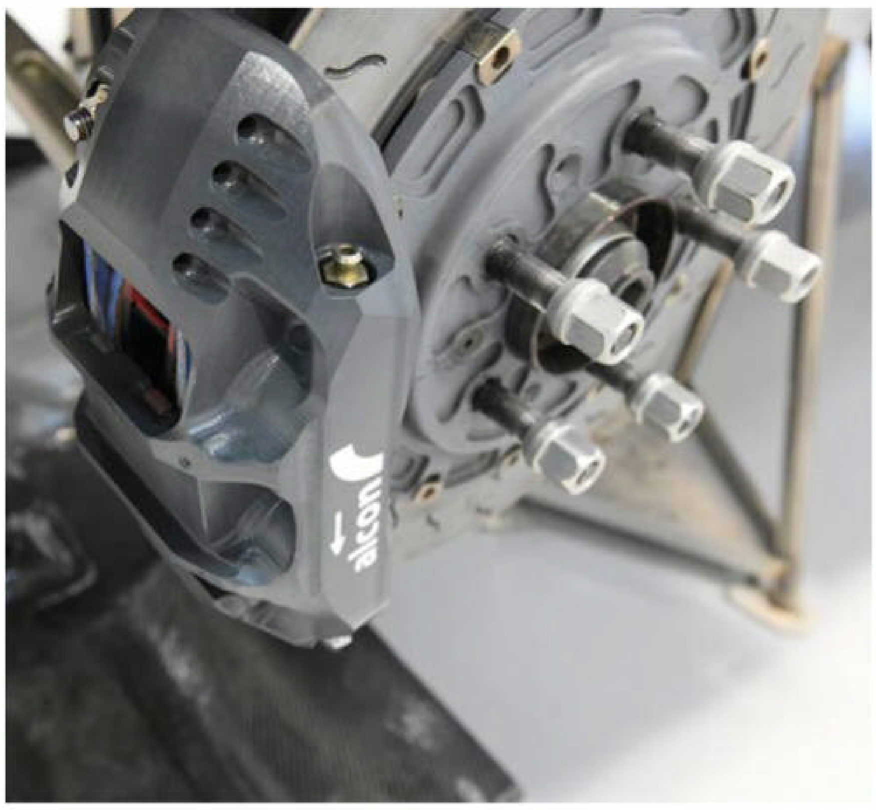


Photo: © David Seaver, subaru.com/motorsports 2021

As well as enlarging capacity, adding a bigger turbo helped the Vermont engineers easily reach the 850bhp power target


Photo: © David Seaver, subaru.com/motorsports 2021

MacPherson strut suspension is mounted to custom built tubular structures front and rear



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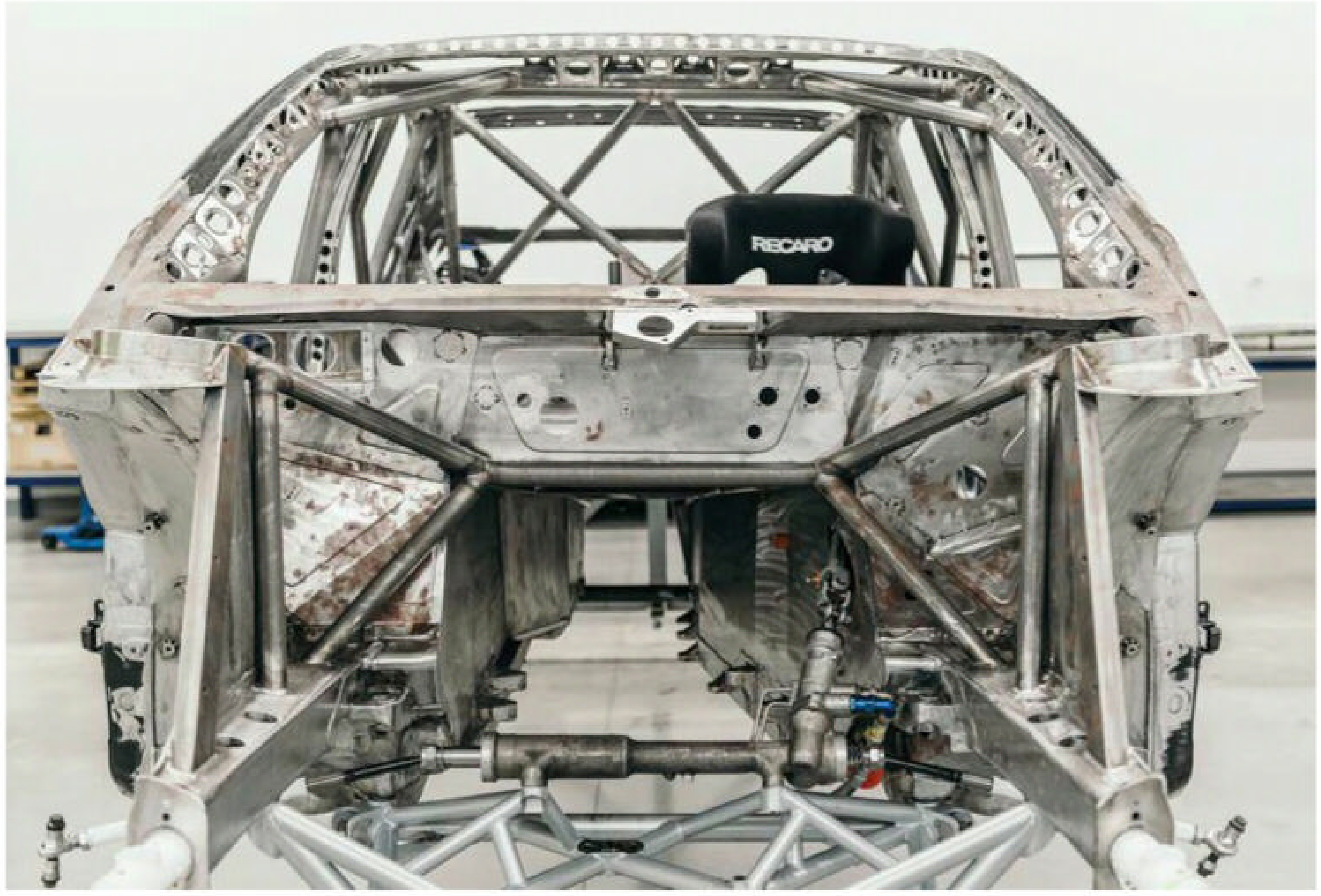
Where economically viable, Rallycross-spec parts were used for familiarity

Photo: © David Trumpore, subaru.com/motorsports 2021



Rollcage structure is FIA-spec, but the front and rear subframes are bespoke to the car, and engine and gearbox position were free

Photo: © David Trumpore, subaru.com/motorsports 2021

After assessing the requirements of the client, Vermont Sportscars concluded the best fit for much of the technology was Rallycross

Photo: © David Trumpore, subaru.com/motorsports 2021

Multi-adjustable dampers are by Reiger, specially built for the car to instill predictability and confidence in the drivers

It's not the kind of car where you will be optimising to the last hundredth of a second to beat a competitor. What's more important is the spectacle

The suspension is the one area of the car that is closest to being built to a regulation set, as many of VSC's existing Rallycross components were used.

'That was an economically sensible approach,' reveals Vallat. 'Even if we didn't already have those parts, we would have designed it like a Rallycross car. Maybe there were a few things we could have done differently, given the lack of regulations, but as we already had the parts, we didn't feel the need to. There were some adaptations to suit the aero, and some for the tyres, because we are not using the Rallycross tyre, but the base set-up was there.'

Flexible friend

The name of the game – much like Rallycross, but to an even greater extent – was flexibility. To this end, Vallat and his team were able to hone the chassis to provide exactly the confidence and predictability the drivers required, even if this came at the expense of ultimate performance.

'It's not the kind of car where you will be optimising to the last hundredth of a second to beat a competitor. What's more important is the spectacle,' he points out.

Despite the overarching demand for sliding sideways and doing doughnuts, control was still an important consideration.

'We needed that precision on the front axle,' confirms Vallat. Clearly, given the car's performance at events such as the Mount Washington hillclimb and the Goodwood Festival of Speed, when needed the car can do accurate as well as lairy in equal measure.

However, there are certain demands placed on the car that required the set-up to be weighted towards its airborne antics.

'You need to find compromises. Okay, you need to jump, but you need also to find the best grip everywhere. However, we did want a little extra safety on the jumps, which we ensured,' explains Vallat.

Though essentially built for entertainment, he admits that some findings during the car's development were fed back into VSC's competition programmes: 'That was interesting, because we focused on the performance on the jumps, we did have some other findings that were useful for the Rallycross. Sometimes you may want to move the compromises on a [Rallycross] car in a certain direction to your advantage.'

Aerodynamic presence

While not quite on the scale of the machines found at the Pike's Peak hillclimb, the VT20G certainly has aerodynamic presence, along the lines of a Rallycross car that has hit the protein shakes. One of the standout features is its driver-adjustable rear wing. The upper wing element is attached to a pair of rams that change its angle of attack when the driver presses a button on the steering wheel.

The function of this adjustability is twofold. Firstly, it allows the driver to trim out the car during high-speed running, much like Formula 1 DRS, while retaining downforce when needed. Secondly, it is a vital tool when the car is airborne.

Rally and Rallycross drivers are well used to using the throttle and handbrake to adjust the attitude of their cars when in the air. The inertia of the spinning wheels is considerable, so a dab of handbrake, for example, can be used to bring the nose of the car down. The adjustable rear wing can be used in a similar fashion, bringing the nose up if necessary, much like the elevators on an aircraft.

As Vallatt remarks, it is a good example of a lack of rules allowing VSC to stretch its imagination. 'This is a show car, and we wanted to demonstrate that we have the capacity to do things like active aero, giving us the possibility to play with the attitude of the car when flying,' he says. 'It also helps to run high top speeds, as we are able to reduce the drag, but also get the downforce and high cornering speeds we want.'

The rest of the aero package follows many of the trends seen in current WRC and Rallycross machinery, and its basis is VSC's current Rallycross package with, as Vallat puts it, 'some extensions.

'We wanted to ensure stability in all conditions – corners, straights and jumps – so the aerodynamics were developed from that perspective. It also had to look spectacular.'

To ensure these goals were met, the car was subject to an extensive CFD analysis and a wind tunnel test programme using a 40 per cent scale model. However, as with any car running over irregular surfaces and across a wide range of ride heights, yaw angles and attitudes, only real-world testing could prove the effectiveness of the design.

Many of the appendages on the car would not be allowed in World Rallycross or the WRC (though engineers in those disciplines would likely appreciate their addition). For example, the rear wing features a pair of additional winglets extending beyond the sides of the car, placing them in (relatively) clean airflow, where Vallat says they produce very efficient downforce. Given the amount of time the car spends in yaw, elements such as the extra winglets adorning the trailing edges of the front wheelarches also provide useful downforce as the car is sliding.

We wanted to ensure stability in all conditions – corners, straights and jumps – so the aerodynamics were developed from that perspective

Photo: Vermont Subaru Motorsport

Fans of the *Gymkhana* series will know there's a lot of creative licence, but the cars and drivers still have to be at the top of their game

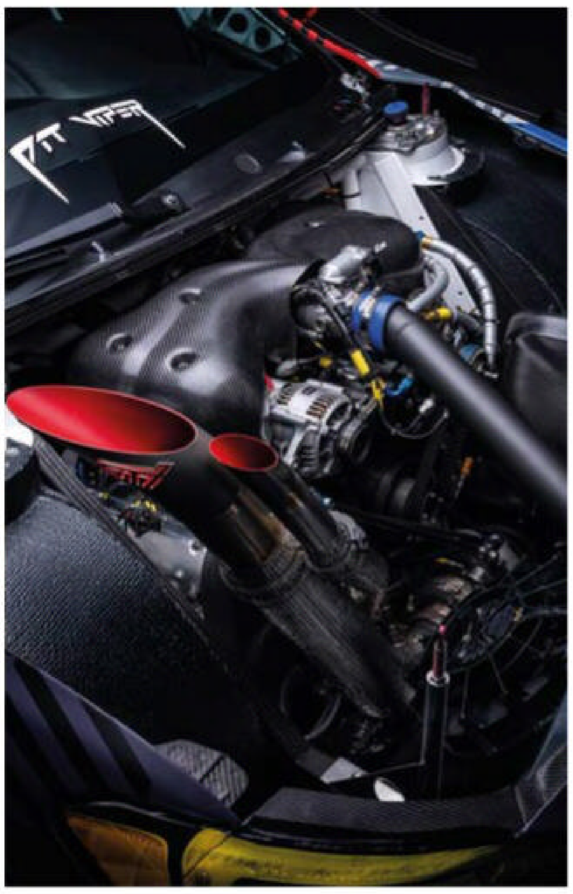


Photo: Vermont Subaru Motorsport

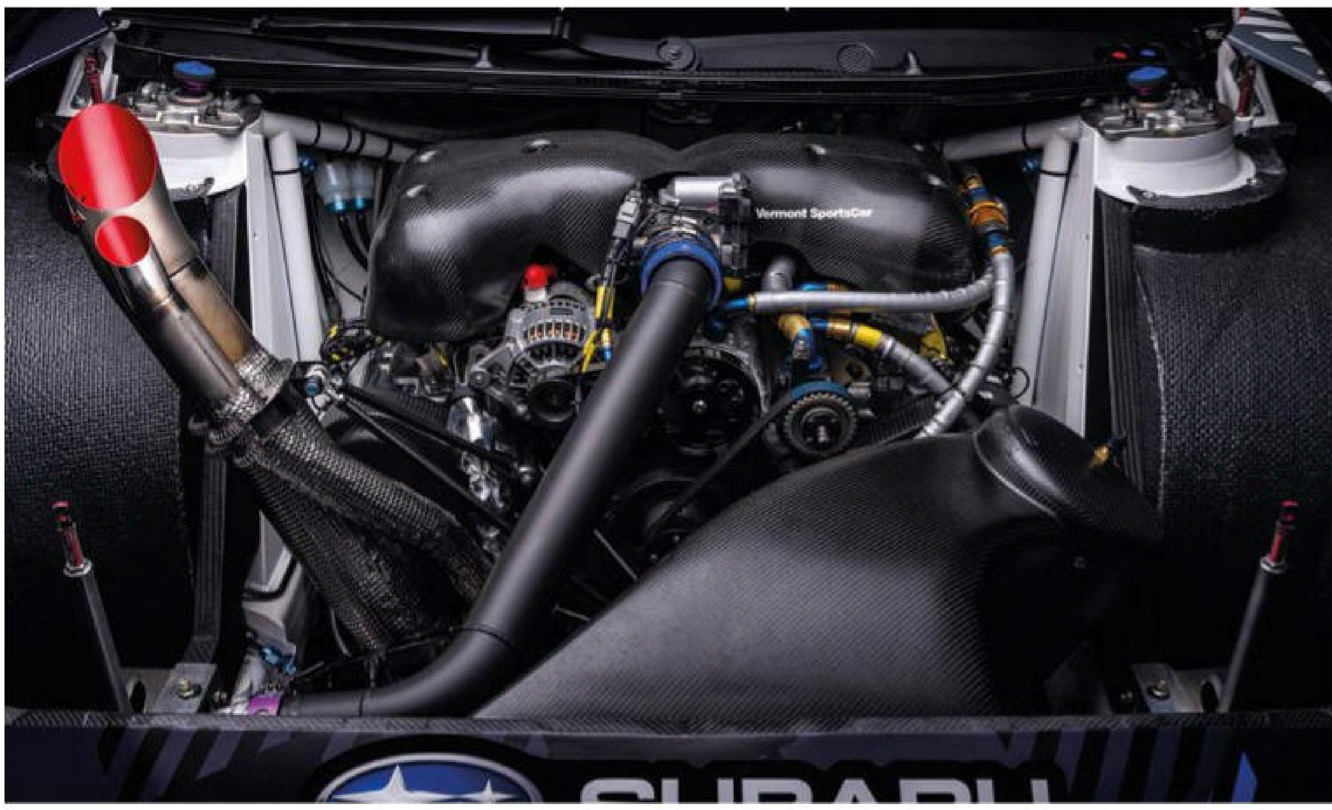


Photo: Vermont Subaru Motorsport

Engine may look outwardly like a tuned Subaru EJ-series, but it's based on a billet block, with a 75mm crank and 99.5mm bores taking the four-cylinder boxer to 2.3-litres. Vermont Sportscars says it didn't take a lot of optimising to reach the 850bhp required

From the team's perspective, development of the car presented a unique opportunity to research approaches that would not normally be given a second thought.

'On the engineering side that is really interesting because we could say, okay, this is not authorised, but what does it gain? That's why this aerodynamic development was useful, because we now know not only what can be done at the limit of the regulations but also what can be done beyond them,' says Vallat. 'Sometimes you have an idea in WRC or WRX, but you don't even test it because you're not allowed. Now we have tested some of those ideas and that's super interesting.'

Power parameters

Vallat says the engine specification is very close to that used in the company's RX machine, but not hamstrung by the mandated 45mm restrictor. 'We changed some parameters, such as the bore, which allowed for an easy power increase. The idea was to use all of our knowledge from RX, but without the limitations we have there.'

The boxer uses the same architecture as Subaru's EJ engine series but is a completely bespoke production. The billet aluminium block houses a 75mm stroke crankshaft, related but not identical to the one found in the RX cars, mated to 99.5mm bore liners. Vermont Sportscars remains tight lipped about the fine detail of its engine packages, particularly the proprietary method it uses to ensure sealing integrity between the billet heads and block, which apparently bypasses the need for a head gasket.

'When you remove the restrictions in RX – increase the capacity, use a larger turbo… the gains are immediate. We didn't have to spend a lot of time optimising it, the level of power we needed came quite easily.'

Photo: © David Trumpore, subaru.com/motorsports 2021

The car started life as a body in white, built up with an FIA-spec 'cage, but there the similarities to standard Rally and RX cars ended

The capabilities of the VT20G are phenomenal. For example, during the filming of the *Gymkhana 2020* video, there was a shot that called for a jump on a quiet country lane, where a shallow ramp would propel Travis Pastrana several hundred feet down the road.

Of course, jumps are the bread and butter of Rallycross competition, but not on this scale. In order to clear the distance, he would have to hit the take off at around 130mph, not to mention negotiating a landing on a bend, hemmed in by fences, trees and telegraph poles. Pastrana launched the jump multiple times, taking the car close to its maximum speed, yet still could not clear it, coming up short and landing on a flat section of road. The data logger recorded a vertical impact force of 19*g*.

The idea was to use all of our knowledge from RX, but without the limitations we have there

Ultimately, Pastrana had to call time on the attempt, stating the car could take the repeated pounding, but his body could not.

At the other end of the spectrum, in formal competition Pastrana smashed the Mount Washington hillclimb record at the 2021 running of the event, proving without doubt the VT20G is no simple stunt pony, it is a truly versatile racing machine.

Photo: © Matthew Stryker, subaru.com/motorsports 2021

It may be all about the show, but the development of the VT20G has also been about performance, with technological advances feeding back into the worlds of both Rally and Rallycross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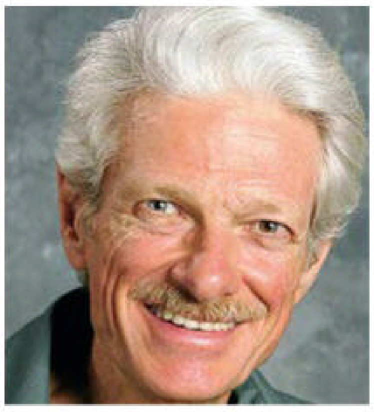

Talk the torque

More thoughts on in-wheel motors and their effects on twisting force

By MARK ORTIZ

Q Regarding the question about in-wheel motors in *Racecar Engineering* issue V31N11, I was surprised not to see any mention of torque vectoring with hub motors. Or was this in the catch all about making vehicles go directions other than where they are pointed?

When you mix performance vehicle dynamics and hub motors, independent control of the motors is the first thing that crosses my mind. This may be as simple as using software to link the speed of two wheels together, rather than a set of clutch discs. Once you do it in software, it can be cognisant of the yaw rate of the vehicle. Obviously, this is more of a challenge with a conventional limited slip.

Porsche AG

Further proof in-wheel motors are old. The Lohner Porsche was developed in 1898, with hub-mounted electric motors

THE CONSULTANT

A That was a significant oversight on my part. Yes, having a separate motor for each wheel *does* open up interesting possibilities for generating yaw moments by applying unequal power to the right and left wheels, in addition to steering them individually. Of course, it is not necessary for this to occur that the motors be hub motors. They could be sprung. There just has to be one motor for each wheel, or at least one for each side of the car.

The control strategy for such a feature, or combination of features, really poses some puzzles. It's more complex than thrust vectoring for an aircraft, for example. Near the limit of adhesion, the relationship between torque applied and ground plane force produced is complex and non-linear, and longitudinal force capability plays off against lateral force capability.

If you are directing the exhaust gases of a jet or rocket engine, you can be pretty sure that more fuel to the engine will result in more reactive propulsion opposite the direction of the discharge. The relationship may be somewhat non-linear, but it doesn't reverse.

With tyres on a road surface, however, applying more power only gets you more thrust up to a point, beyond which you break traction and lose force in all directions.

Same applies to steer or slip angle. Up to a point, steering a tyre more, or running it at a greater slip angle, adds lateral force, but beyond that point lateral force diminishes.

With reactive propulsion, there is a trade off between thrust in the direction of travel and thrust perpendicular to that, but there is no point at which more nozzle angularity gets you less perpendicular force.

Performance envelope

With a road vehicle, accelerations change tyre loading, and the entire performance envelope of the tyre grows and shrinks with that. It also varies with temperature, inflation pressure, nature of the road surface and ageing of the tyre, which can occur very rapidly in racing rubber.

It is *theoretically* possible to improve performance of racecars teetering on the limit by controlling the torque distribution and steer angles of the wheels individually, but it is going to be a truly ferocious challenge to do this optimally in the face of all the aforementioned variables, without unintended adverse consequences. It will require a closed-loop control system vastly more powerful than the human brain.

It's hard enough to drive a car at the limit with just a steering wheel mechanically controlling the front wheels, a throttle, a brake system and suspension designed to hold all else as constant as possible.

It is going to be immensely hard even just to engineer the driver / vehicle interface with all the complex new possibilities. If we can individually steer all four wheels, and individually control what their four motors do, how does the driver (or robotic controller) tell the system to *just* turn the front wheels right, as opposed to turn the left front right, the right front left, the right rear right, and the left rear left, as well as drive the left wheels forward and the right wheels rearward *and* pivot the vehicle to the right in place?

With such vastly enhanced vehicle behaviour possibilities then comes the problem of deciding and communicating to the system which of these, or what combination, we want it to execute.

Just as an interesting aside, the idea of individually powering and controlling electric wheel motors is by no means new. Check out this video about an effort to pursue this concept with the ill-fated Antarctic Snow Cruiser in the 1930s: **https://www.youtube.com/watch?v=pW0eZRoQ86g**

It will require a closed-loop control system vastly more powerful than the human brain

Q Last month you suggested vertically mounting four electric motors to the frame with telescoping vertical driveshafts down to 90-degree gearboxes at each wheel. I like this idea in that it allows more suspension and steering travel than conventional CV joints (and requires zero CV joints).

But would it add torque steer if one wheel is loaded more than another? Could this be cancelled out by the correct amount of scrub radius?

THE CONSULTANT

A Usually, if a vehicle is going to have individually controlled motors for each wheel, with computer control of power distribution, *and* take advantage of the various modal steering possibilities, it will probably steer-by-wire as well.

In that case, any torque about the steering axis is not felt by the driver. It may impose loads on the steering actuator, and it may create compliance steer, but it is most likely possible to correct for compliance steer with closed loop control.

If the motor is sprung and does *not* steer with the wheel, driveshaft torque would create a steering torque, for the same reason as driveshaft torque with a live axle creates torque roll and torque wedge. This would act in opposite directions on the right and left wheels of a front or rear pair and, if the two moments were unequal in magnitude, a pull would be felt at the steering wheel if the vehicle has mechanical steering.

To eliminate the steering moment due to driveshaft torque, the system would have to be arranged so the motor steers *with* the wheel, despite not going up and down with it. This should not be particularly difficult to achieve in practice.

Even if we eliminate steering moment due to driveshaft torque, any wheel that is both driven *and* steered generates a torque about the steering axis when the propulsion thrust has a line of action offset from the steering axis.

With a typical driven front wheel, driven through a jointed shaft, the offset that matters is the front view steering offset at hub height, that is the difference between the y coordinate of the wheel plane and the y coordinate of the steering axis one tyre loaded radius above the ground.

Lots of people think it's steering offset or scrub radius at the ground that matters instead. For braking, that is correct, assuming outboard brakes. But with hub motors, the otherwise slightly erroneous understanding turns out to be exactly right. It *is* steering offset at the ground that matters here. What makes the difference is whether drive torque reacts through the suspension linkage.

Audi AG

Audi's Skysphere concept features steer-by-wire technology on the front and rear wheels developed from racing

The processing and actuation will need to be *extremely* quick to effectively replicate the instantaneous feedback a driver receives through a good mechanical steering system

It's somewhat analogous to longitudinal jacking coefficients: when measuring dx / dz with an outboard brake locked, if drive torque is applied through a jointed shaft, it's the dx / dz at hub height that matters for anti-squat on a rear-driven wheel, or anti-lift on a front-driven wheel. If drive torque acts through the linkage, it's dx / dz at the ground that matters.

Tactile feedback

This also brings us to one of the inherent disadvantages of steer-by-wire systems: lack of (or artificiality of) tactile feedback through the steering. In traditional performance cars, the steering is not merely a means of aiming the wheels, it's a way for the driver to *feel* the road surface, to judge the location of the front contact patches (which are most likely out of sight) and to know how much grip the tyres have at any instant.

It is surely possible to create a steer-by-wire system that senses forces at the wheels and communicates to the control module, which could then control actuators that apply forces to the steering wheel. But the processing and actuation will need to be *extremely* quick to effectively replicate the instantaneous feedback a driver receives through a good mechanical steering system.

And it is exactly the instantaneous character of this feedback that makes it so useful to the driver. If you watch in-car video of good drivers running on the ragged edge, the steering wheel is in constant motion, partly on its own in response to the road, partly due to the driver making continual small corrections. Yet the car itself maintains a smooth trajectory. The driver is looking where they want to go, and manipulating the steering wheel reflexively, based in considerable measure on tactile input received through both the steering and the seat. The smoothness of the car's trajectory depends on any adjustments made being small and prompt, and their smallness depends on their promptness.

The steering system's tactile feedback is uniquely important for this process because it communicates changes in grip to the driver *before* the car responds to them.

CONTACT

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Rolling about

An explanation of the limitations of a previous load transfer article, bringing jacking forces into the mix

BY CLAUDE ROUELLE

First things first. The suspended mass does *not* rotate around the kinematic roll axis. After reviewing the previous simplified explanation of how load transfer works, this month we'll explain why it first had to be presented this way, and give a more correct perspective.

In earlier articles we decomposed lateral load transfer into suspended and non-suspended situations. We also broke down the suspended mass load transfer due to lateral acceleration acting on the suspended mass c of g in a geometric and elastic load transfer, the repartition of which depends on the geometric roll centre altitude vs the ground.

We did this by assuming the suspended mass rotates about the roll centre in 2D or roll axis in 3D. **Figure 1** is a quick reminder.

What is wrong with this picture? The equilibrium of the moments is respected. No matter how we decompose it, the roll moment resulting for the centrifugal acceleration acting on the suspended and non-suspended mass cs of g is balanced by the variation of tyre vertical load.

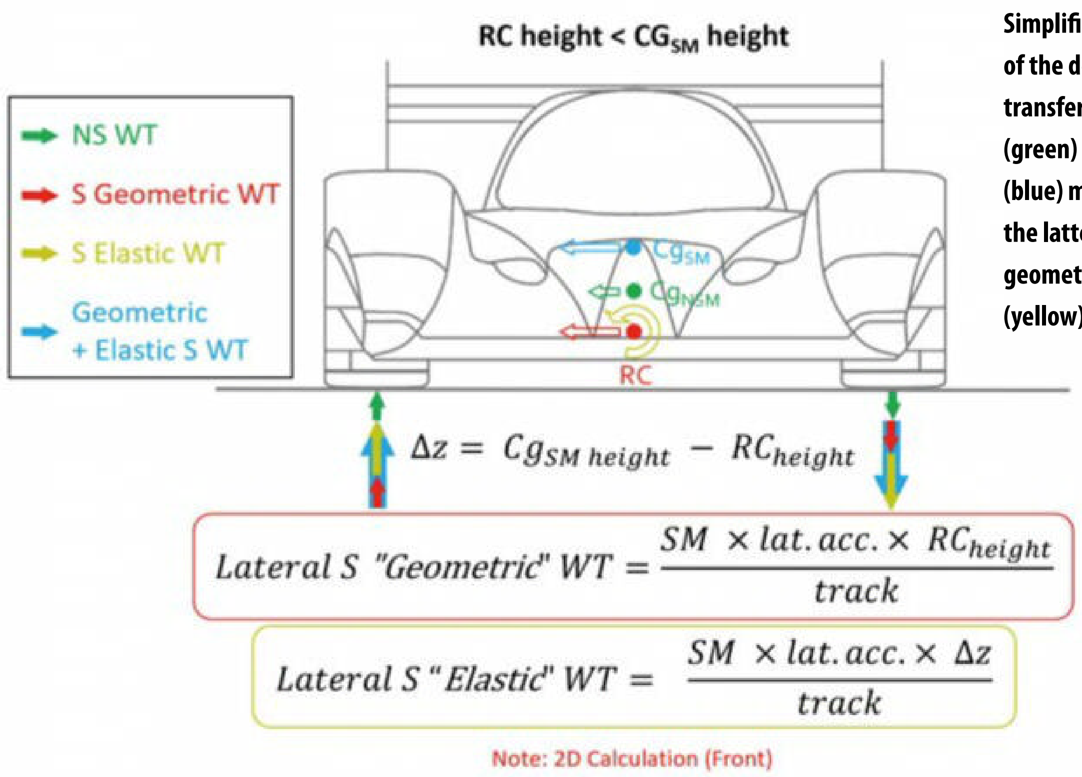
But wait, there aren't any horizontal opposite lateral forces to the ones acting on the two cs of g.

In **figure 2**, we only look at the decomposition of the suspended mass centrifugal applied at the kinematic roll centre and the geometric load transfer (red) of the suspended mass. The non-suspended mass load transfer (shown in green in **figure 1**) and the elastic part of the suspended mass load transfer (yellow in **figure 1**) are not represented here.

At least there is an equilibrium of the centrifugal force: *F =M* V2/R* and the reaction at the outside and inside tyres. Still two things are fundamentally wrong in this sketch though. Firstly, there is little chance the kinematic roll centre would stay in the same position once the car gets some tyre and suspension deflection and, secondly, the tyres' lateral forces cannot be equal as the outside tyre is more loaded than the inside one.

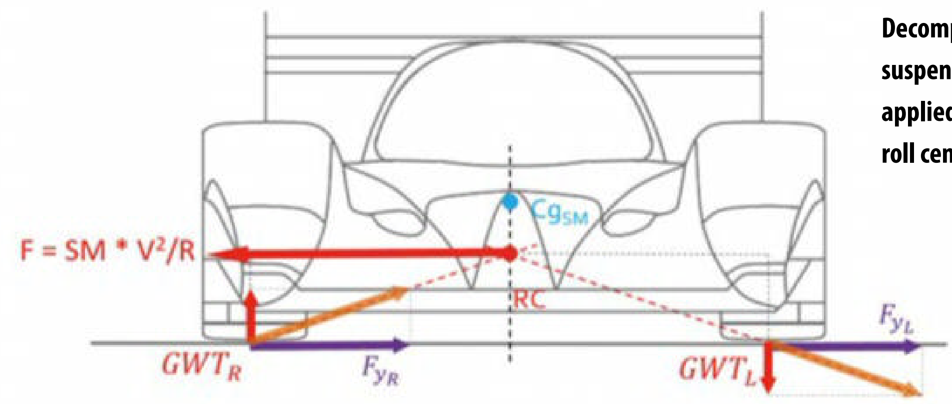
Figure 3 therefore represents a more realistic perspective, with a more pragmatic roll centre position and distribution of lateral forces between the tyres.

Figure 1



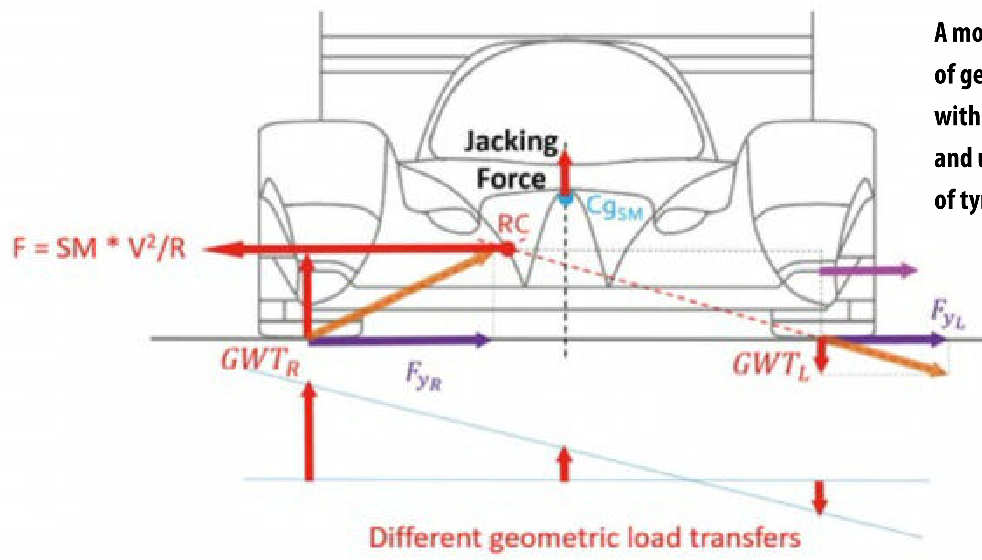
Simplified 2D view equations of the decomposition of load transfer in a non-suspended (green) and suspended (blue) mass load transfer, the latter decomposed into geometric (red) and elastic (yellow) load transfer

Figure 2



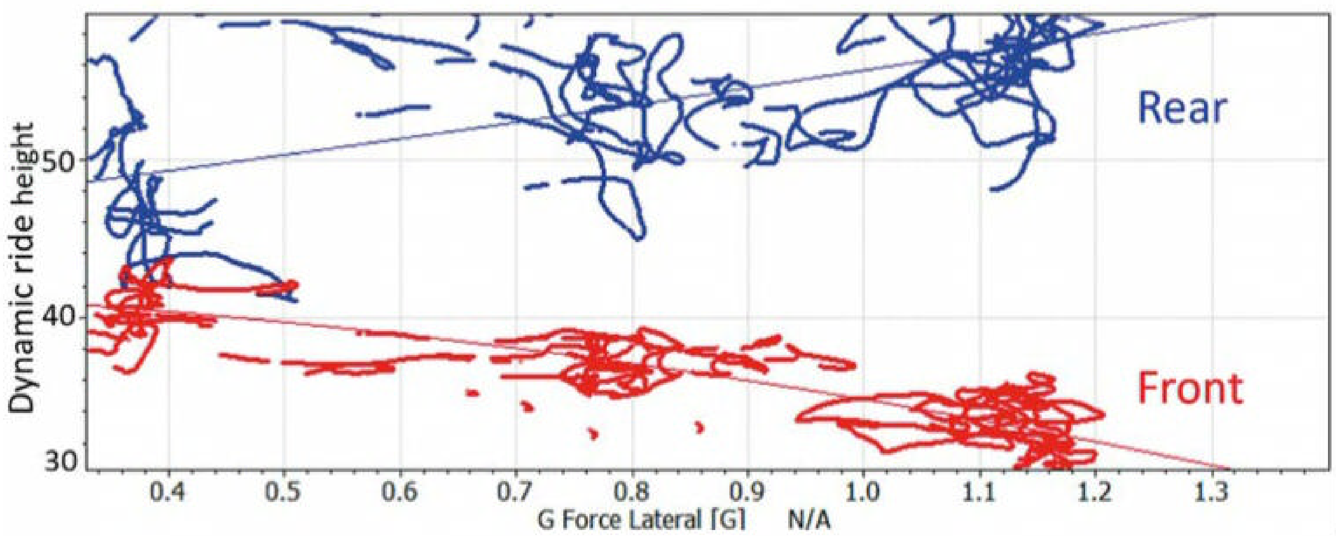
Decomposition of the suspended mass centrifugal applied at the kinematic roll centre

Figure 3



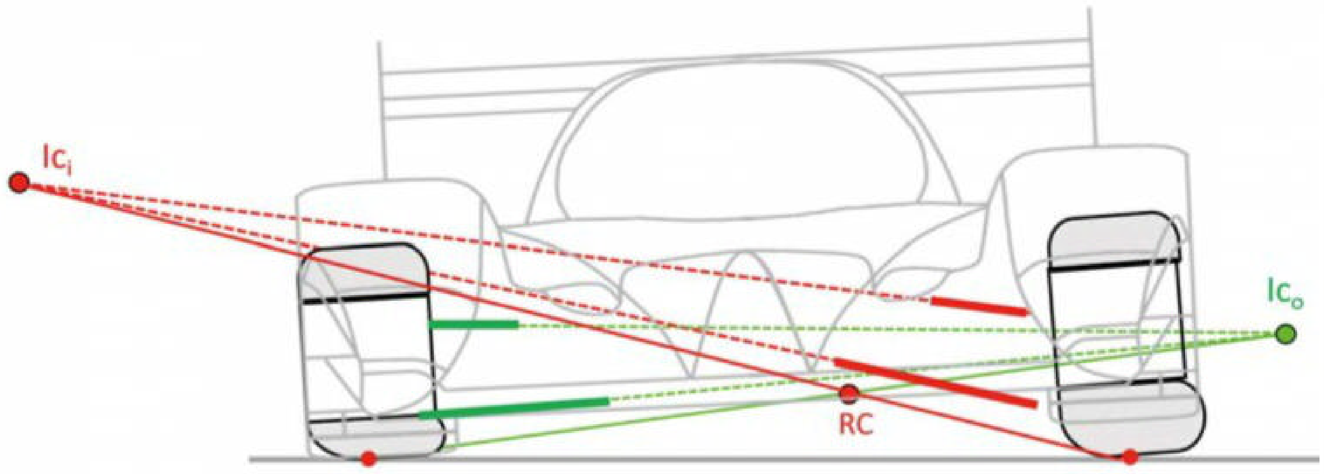
A more realistic decomposition of geometric load transfer with an off-centre roll centre and unequal distribution of tyre lateral forces

Figure 4



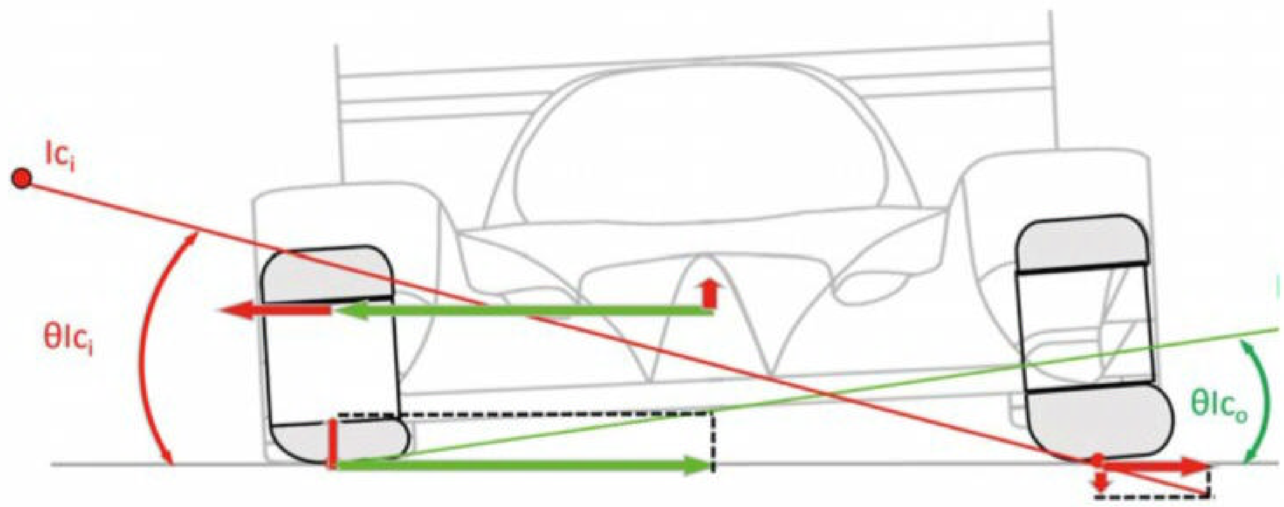
Front and rear ride height variations vs lateral acceleration observed in a variable velocity skid pad test

Figure 5



Traditional definition of kinematic roll centre. The inside wheel instant centre of rotation (red) and the outside wheel instant centre of rotation (green) about the suspended mass are determined by the suspension kinematics

Figure 6



For each tyre, the angle between the ground line and the instant centre to contact patch line, and the side force applied at the tyre, determines the amount of geometric load transfer (red vectors). These forces are pointing in opposite directions but, if they have unequal absolute value, a jacking force is created

We can now observe that the outside and inside geometric load transfers are unequal. This is what imposes jacking force and subsequent ride height variation. Depending on the positive or negative difference between the outside and inside geometric load transfers, the car suspended mass could be dynamically lifted or pushed down.

The suspension stiffness and kinematics, the distribution of inside and outside lateral forces (that depends on so many factors: slip angle; vertical load; camber; pressure; temperature…), and the amount of lateral acceleration will dictate the ride height variation. It could be in the order of 1mm with stiff suspension or as much as 10mm with soft suspension.

It is interesting to note that the jacking forces and resultant ride height variations could have a significant influence on the aerodynamic downforce and downforce distribution, both of which are front and rear ride height sensitive.

Skid pad testing

Figure 4 shows the front and rear ride height variation observed on a skid pad with a car driven on a constant radius at increasing speed (it is worth mentioning the test was conducted on a car with moderate aerodynamic downforce). We can observe an increasing rear ride height and a decreasing front ride height, most probably due to a rear roll centre above the ground and a front roll centre below the ground.

This type of test can be used to find jacking at different lateral accelerations. Then, using damper potentiometers and knowledge of suspension motion ratios, the suspended mass vertical movement from jacking can also be found.

The main reason why the simplified explanation on load transfers without jacking forces was not developed in previous articles is that knowledge of the front and rear side forces and their distribution depends on the tyre model, and not everybody has access to that.

Elaborating further, **figure 5** shows the classical way kinematic roil centre is found.

In **figure 6**, we apply a side force on the outside tyre (green) and an inside tyre force (red), the total of which are logically equal to the suspended mass multiplied by the lateral acceleration. The angles θIc_i and θIc_o are determined by the ground line and the line going from each tyre contact patch to its

No matter how we decompose it, the roll moment resulting from the centrifugal acceleration acting on the suspended and non-suspended mass cs of g is balanced by the variation of tyre vertical load

A force acting on the line tyre contact patch to its instant centre would not create any wheel movement vs the suspended mass

respective instant centre. These angles will determine the amount of the jacking forces.

We realise that with an unchanged suspension kinematic (and therefore the same θIc_i and θIc_o angles), if we had a different tyre lateral forces distribution, we would have had a different jacking force.

In **figure 7**, we have the same kinematics, the same instant centres position, the same kinematic roll centre but a different distribution of inside and outside forces (that could come, for example, from different tyre temperatures). Despite that, their total is unchanged and still equal to the product of suspended mass by the lateral acceleration. It is the different tyre side force distribution that affects the jacking force.

The same consideration could be made by keeping the same tyre side force distribution and modifying the kinematics.

The validation

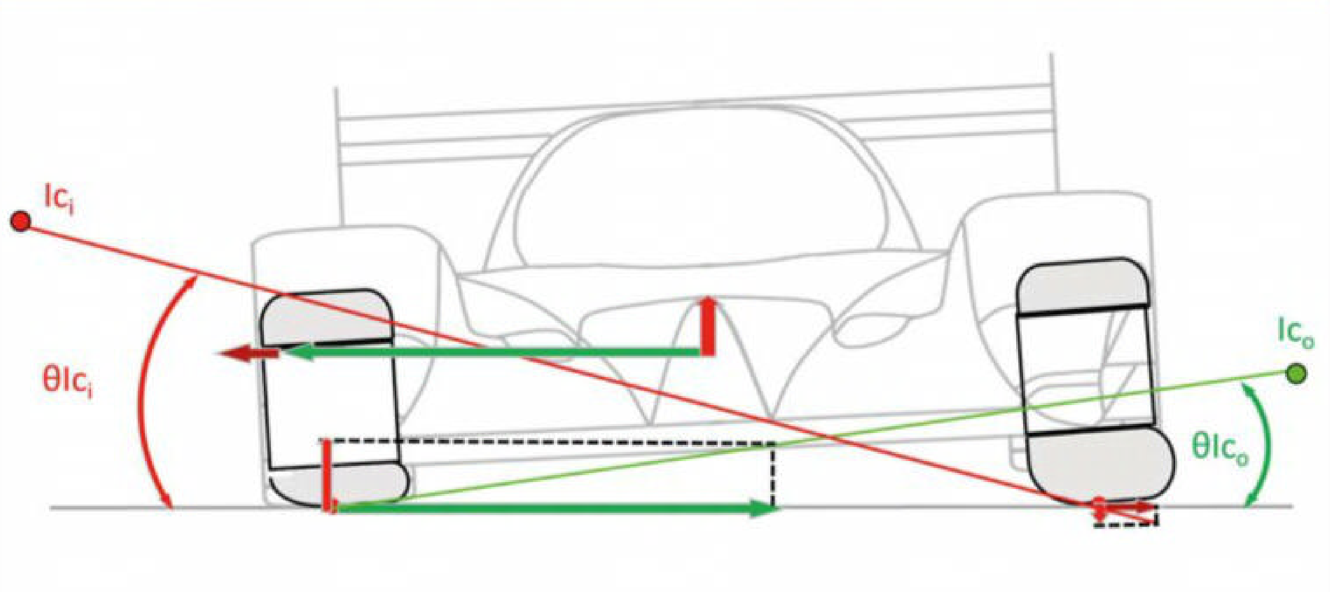
In fact, more than the kinematic roll centre, it is the angles θIc_i and θIc_o that determine the jacking forces. The proof is that a force acting on the line tyre contact patch to its instant centre would not create any wheel movement vs the suspended mass. This validates the definition of geometric load transfer that only produces forces in the suspension linkages with no spring, damper or anti-roll bar movements.

The last thing to note is that if the kinematics and / or the tyre side force distribution affects the geometric load transfer, jacking forces and ride height, it also affects the elastic part of the suspended mass load transfer, as seen in **figure 8**.

No matter what, load transfer is *only* a function of mass, lateral acceleration, track width and c of g height. The total of the non-suspended mass load transfer (green) and the suspended mass load transfer (red and yellow) remains the same.

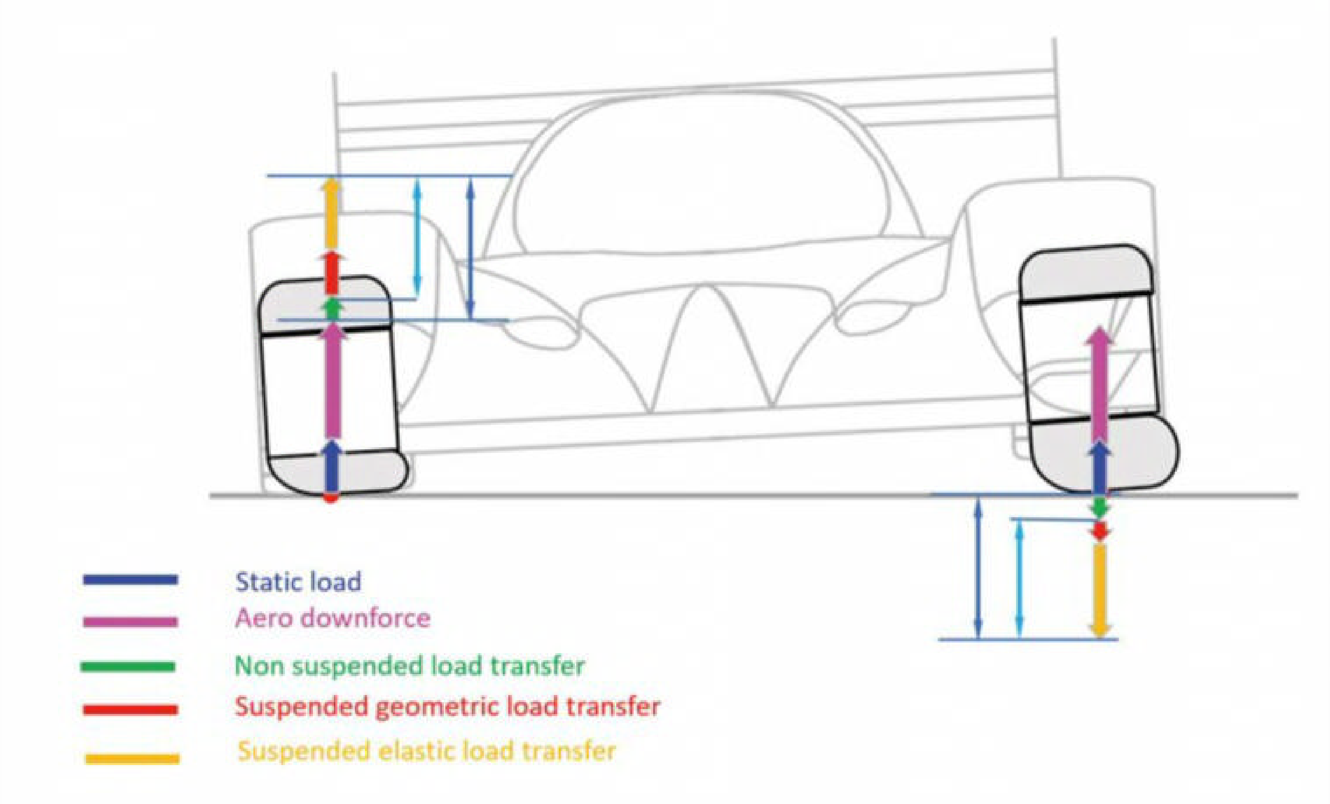
What could change is the *distribution* of the geometric (red) and elastic (yellow) parts of the suspended load transfer. However, as their *total* do not change, if we have more geometric, we will get less elastic and *vice versa*.

Figure 7



Same kinematics as in figure 6 but with a different side force distribution results in a different jacking force

Figure 8



Analysis of all vertical load and load variation on the tyres in a 2D simplified view

No matter what, load transfer is *only* a function of mass, lateral acceleration, track width and c of g height

As the elastic load transfer affects the forces and movements of springs, dampers and anti-roll bars, we understand that kinematics and tyre side force distribution will also affect roll angle and car attitude vs the ground. These are all different perspectives of the same load transfer and its consequences.

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

Public, on site, and online OptimumG seminars are held worldwide throughout the year. The Advanced Vehicle Dynamics and the Data Driven Performance Engineering seminars present several theories and best practices that can be used by engineers when making decisions on how to improve vehicle performance. OptimumG engineers can also be found around the world working as consultants for top level teams.

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Chasing percentages

Developing the Spire GT-3 for Sports1000 and Bike Sport: a case study for CFD, wind tunnel and track correlation

By JAMES KMIECIAK

Simon McBeath

The 2014 Spire Sports Cars GT-3 undergoing testing in the full-scale wind tunnel at MIRA, UK which turned into an Aerobytes feature in 2016

In 2012, Paul Nightingale of Spire Sports Cars and Tim Gray of Tim Gray Motorsport, both based in the UK, started to look at the aerodynamic development of their successful GT-3 racer for the 750 Motor Club Road Going Bike Engined (RGB) Championship, now known as Sports1000 (see **figure 1**).

They had already enjoyed significant success with its predecessor, the GT-R, and the GT-3 evolution, with new chassis, suspension, transmission and bodywork raised the bar again for the class, but the competition was closing the gap rapidly and so the duo turned to CFD, tunnel and track correlation to ensure they stayed ahead.

Not only did they require a step change in aero performance for the tightly regulated RGB-specification cars, they also wanted to create a version of the car using the same chassis and main bodywork panels that would be capable of competing in the 750 Motor Club Bike Sports Championship, too.

The Bike Sports class has less restrictive regulations and allows the use of bigger engines, slick tyres and almost unrestricted

A reduction in drag on the straights and more predictable handling through the corners were key to the car's performance

Table 1: 2012 Spire GT-3 – MIRA vs CFD data

Configuration	Front DF (N)	Rear DF (N)	Total DF (N)	Drag (N)	L/D	% Front	% Rear
MIRA	68	573	641	784	0.82	10.58%	89.42%
CFD	98	447	545	633	0.86	17.93%	82.07%

Table 2: 2012 GT-3 – MIRA vs CFD rake change

Rake	2012 GT-3 MIRA		2012 GT-3 CFD		Deviation	
	MIRA DF	*MIRA Drag*	*CFD DF*	*CFD Drag*	*ΔDF*	*ΔDrag*
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.2	3.66%	0.34%	4.72%	1.82%	-1.06%	-1.48%
0.3	7.51%	2.14%	9.71%	3.19%	-2.20%	-1.05%
0.5	11.92%	3.27%	16.14%	5.22%	-4.22%	-1.95%

Anything that was not seen as a critical aero surface was reduced in definition to save on modelling and analysis cost

aerodynamic development, provided it adheres to the MSA Blue Book.

Critically for this development, Spire Sports Cars wanted costs kept under control to give new GT-3 owners the ability to upgrade from the 'limited aero' RGB car to a 'full aero' Bike Sports car in the future.

When the new generation GT-3 bodywork and chassis took over from the soon to be retired GT-R model, Spire Sports Cars took the car to the MIRA wind tunnel in the UK to run through ride height and rake changes, and get a feel for what the car's aero performance would be. This is where our correlation story starts.

The first tunnel test

Table 1 shows the original 2012 GT-3 car at a set ride height and rake in the MIRA wind tunnel. The car produced 641N of downforce against 784N of drag at a wind speed of 100mph. This gave an -L/D (-ve lift, aka downforce, over drag) of 0.82:1. Meaning that for every 0.82N of downforce generated, we see 1N of drag.

Of more interest, the balance of the car as originally presented showed a significant rear aero bias, with only 10.58 per cent of available downforce acting on the front axle of a car with near perfect 50 / 50 weight distribution. To rectify this imbalance, rake was added to the car to move the balance forward and modifications were made to the rear bodywork to reduce its effectiveness and return a more useable balance.

With balance achieved, the car was given a rake sweep, starting with the chassis parallel to the ground at equal ride heights front and rear, and gradually increasing rear ride height until a maximum rake of 0.5 degrees was achieved. Changes to downforce, drag and balance were recorded at each phase. These changes are shown as a percentage increase against the baseline, zero rake configuration, in **table 2**.

This wind tunnel data provided enough information for the race engineer to set a baseline spring and damper arrangement that could be used at the next track test session. With driver feedback and data logging all being monitored, adjustments were then made to these baseline settings throughout the day, until the car was running consistently quicker over a lap than had previously been recorded.

The twin benefits of a reduction in drag on the straights and more predictable handling through the corners were key to the car's performance.

Significantly for the 2013 development phase, the wind tunnel and track information collected now gave enough data points to allow comparison with the

All images: J A Kmieciak unless otherwise stated

Fig 1: The 2013 Spire GT-3 Road Going Bike Engined (RGB) car was a significant upgrade on its predecessor with a new chassis, suspension, transmission and bodywork that needed analysis

CFD results that were to follow. This provided the beginning of the correlation feedback loop for the project.

CFD first pass

Using original drawings, measurements and photos, a CAD model was created that captured the critical design features of the 2012 Spire GT-3, as shown in **figures 2** and **3**. As the CFD analysis was to focus on the external body shape and radiator ducting, anything that was not seen as a critical aero surface was reduced in definition to save on modelling and analysis cost.

It was decided the CFD analysis would be set up to represent the MIRA wind tunnel, as this would ensure repeatability of the tests. Repeatability is probably the biggest hurdle when attempting to correlate with on-track testing, due to the many uncontrollable variables experienced.

In the wind tunnel, the car is located on a set of pressure pad-style load cells on a static floor with a vortex-generating boundary trip ahead of the vehicle. This is there to reduce the boundary layer thickness under the car, while a controlled airflow around 80mph is passed over it.

Humidity, temperature and atmospheric pressure are recorded to ensure deviation between runs of only around one per cent are achievable when values are corrected for 100mph wind speed.

Where MIRA, and the many other wind tunnels around the world, provide controlled laboratory conditions for testing, the same cannot be said on track, as the following anecdote serves to explain. Many years ago, an aero track test session was undertaken for aerodynamically-enhanced sports cars that had already been run in MIRA. The cars were wired up with suspension pots front and rear, flow visualisation and data logging but, due to issues with undulations, gradients and camber changes over the test section, occasional strong gusts of wind and stoppages due to heavy rain, the full-day test ended with barely four data sets that could be used for correlation. Compare that to the 50+ data sets that can be collected in a steady day in the wind tunnel, and the difference in the 'dollar-to-data' rate is blindingly obvious.

Humidity, temperature and atmospheric pressure are recorded to ensure deviation between runs of only around one per cent are achievable when values are corrected for 100mph wind speed

Track testing depends on precise recording of the day's test conditions, how accurate your tyre and suspension models are, and what you are trying to achieve from the tests. Consequently, for the aero

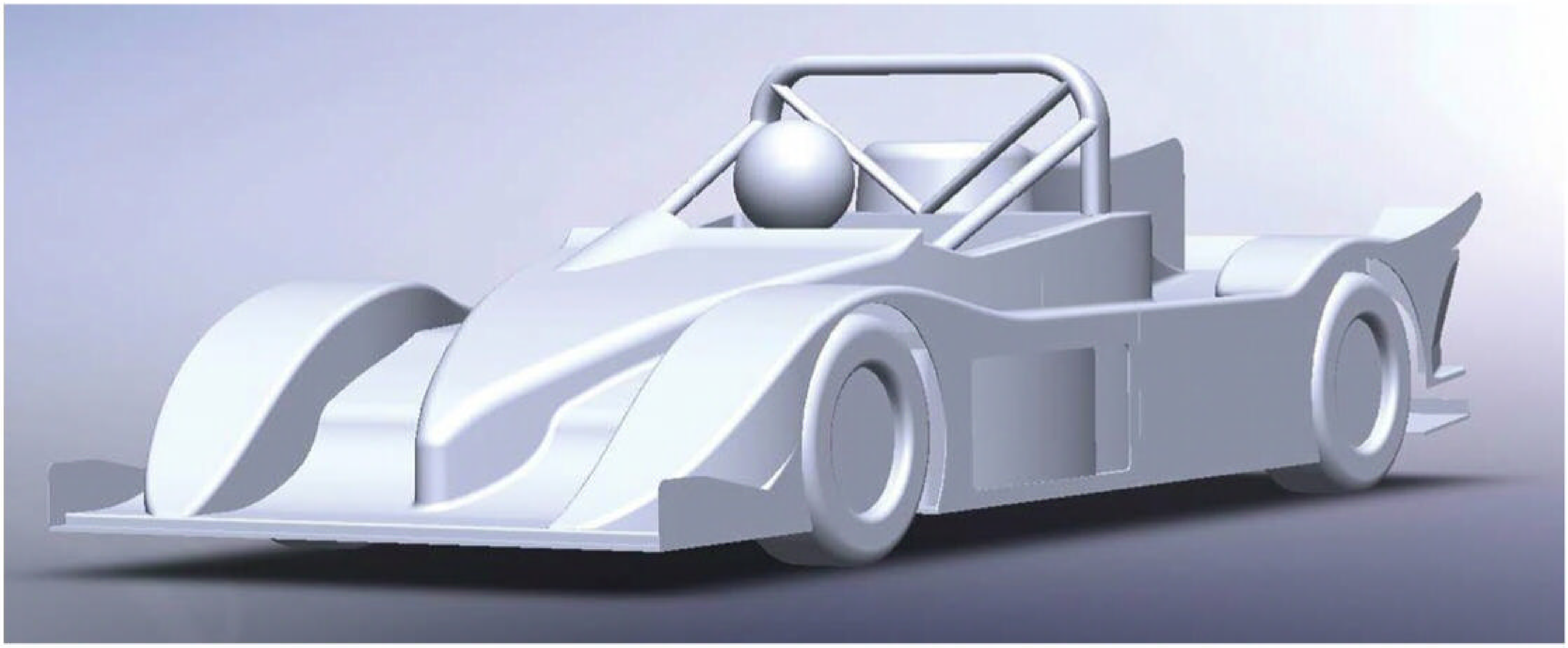


Fig 2: 2013 Spire GT-3 RGB CFD model (front)

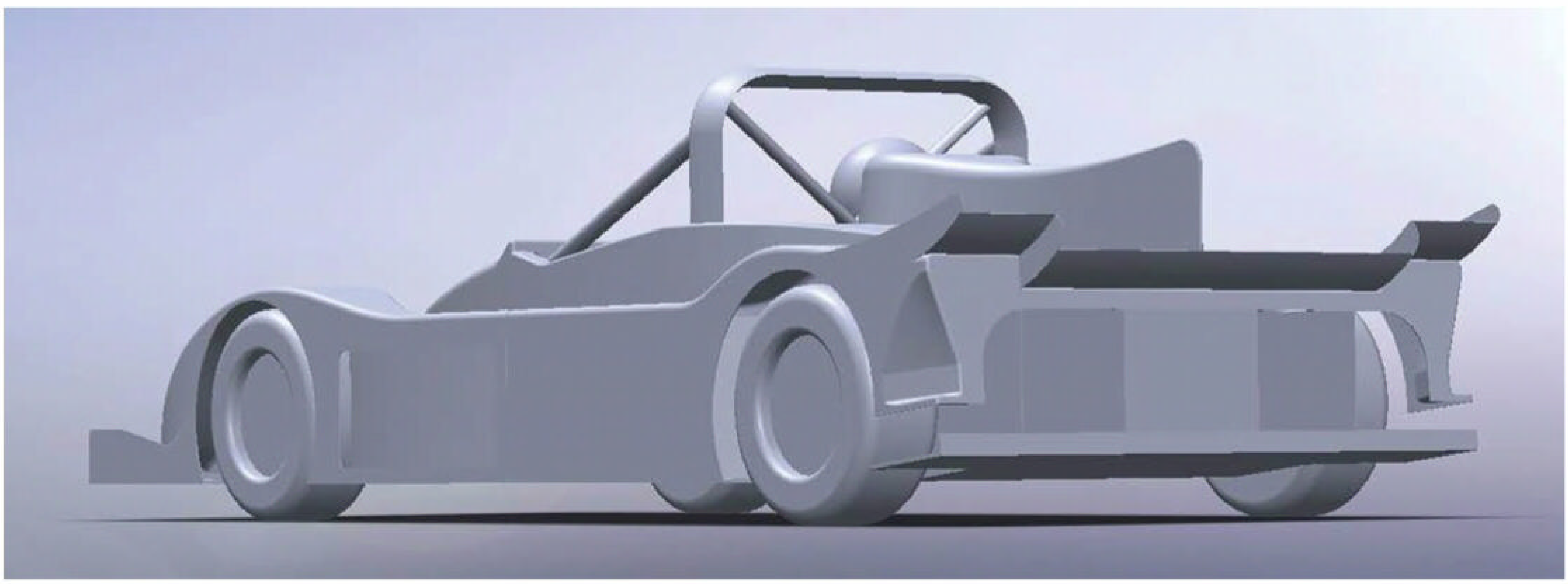


Fig 3: 2013 Spire GT-3 RGB CFD model (rear)

development phase of a project, these uncontrollable external variables are the reason why wind tunnel and / or correlated CFD analysis are used to design and test new components or configurations. The reliable, repeatable, back-to-back results achieved can then be referenced against an existing baseline data set before being used to generate a new set-up and taking it to the track for testing.

The 2012 GT-3 CAD model was run with matching boundary conditions to the wind tunnel before systematic adjustments were made to both these and the mesh settings to achieve a suitable correlation between the CFD results and existing MIRA data.

Data comparison

As can be seen in **table 1**, the predicted CFD values for downforce and drag at the same 100mph corrected speed as used in MIRA were out by a factor of around +15 per cent for downforce and -19 per cent for drag. Unlike the 10.58 per cent front / 89.42 per cent rear aero bias mentioned earlier, balance was being shown as 17.93 / 82.07 per cent in the CFD. If we were looking for an idealised 100 per cent correlation between results, these results were not it.

At first glance they look useless, so we start asking questions of our model accuracy, mesh density and the solver's robustness, along with all the possible issues we may have overlooked.

But before we follow Alice the aerodynamicist down the rabbit hole of ever-increasing possibilities, we need to look at the bigger picture. Our second set of data showed the rake analysis for the 2012 GT-3 in MIRA. The same rake analysis procedure was tested in CFD, and the results compared in **table 2** and **graph 1**. The latter shows our CFD analysis is following the same trend line for downforce and drag change as the results recorded in MIRA. The deviation between downforce sits within a boundary of 1.06 per cent minimum and 4.22 per cent maximum. The deviation for drag sits within a boundary of 1.05 per cent minimum and 1.95 per cent maximum. So, our worst case deviation for change to recorded forces is now a maximum of 4.22 per cent of the downforce figure and 1.95 per cent of drag.

That tells us that, although our original baseline values were out by factors of around 15 and 19 per cent, they consistently followed a trend of deviation within a range of between one and four per cent.

Graph 1: 2012 GT-3 MIRA vs CFD rake change

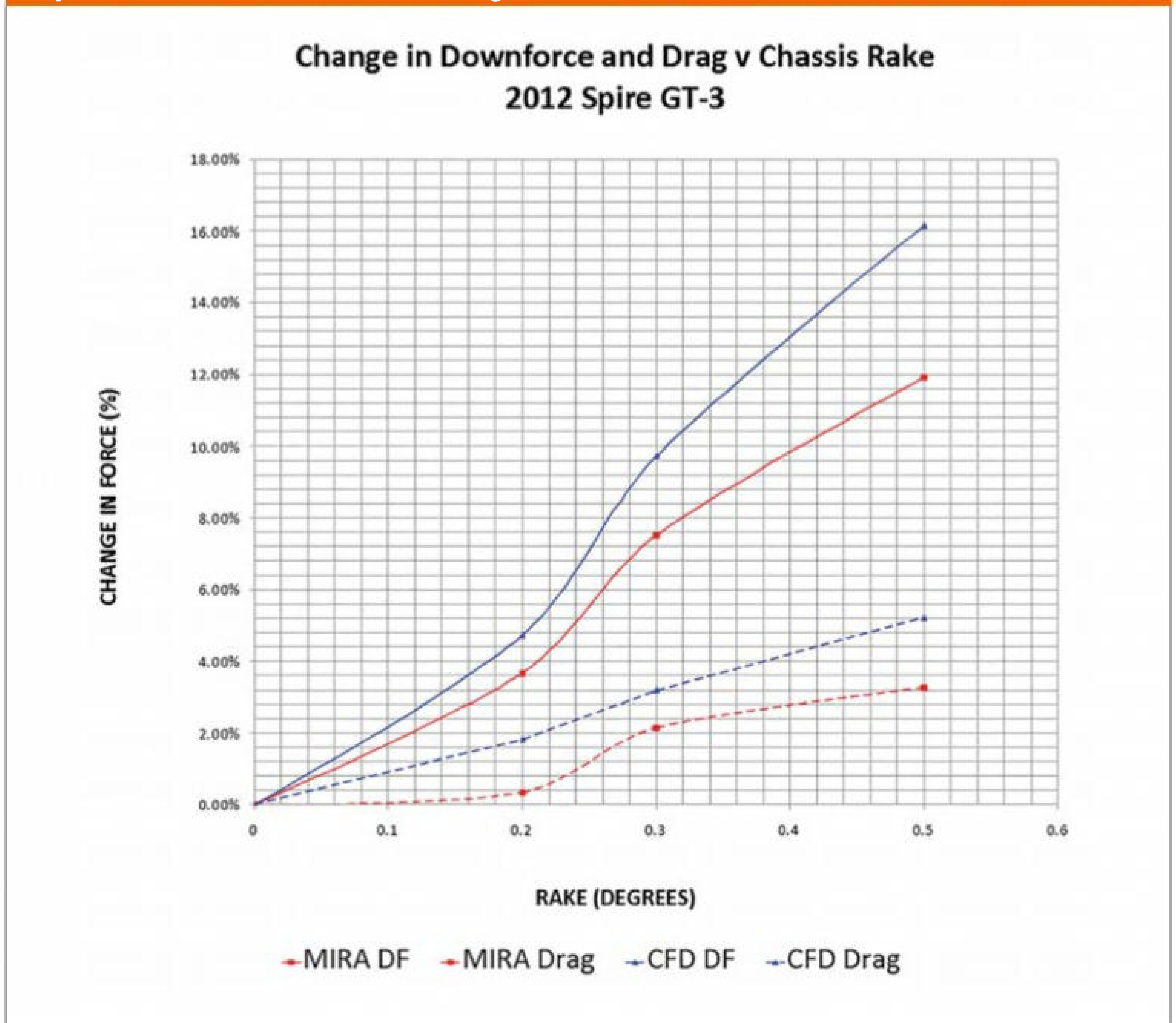


Table 3: 2013 Spire GT-3 – Corrected CFD vs MIRA results

Configuration	Front DF (N)	Rear DF (N)	Total DF (N)	Drag (N)	L/D	% Front	% Rear
MIRA	408	478	886	733	1.21	46.05%	53.95%
CFD	509	452	961	751	1.28	52.95%	47.05%

Further analysis was then undertaken to find the reason behind the seven per cent deviation in front aero balance, prior to checking whether significant changes to bodywork by adding and removing sections in CAD (as had been tested in the tunnel) also created the same percentage change to downforce and drag as seen in the wind tunnel.

With all this data compiled, and ever wary of the old programmers' adage, 'garbage in, garbage out', the deviations were fed back into the loop for the design stage and the limitations of what could and could not be relied upon within the CFD analysis were established.

Data comparison v2.0

Jumping forward several months, after analysing a multitude of CAD configurations in CFD, a new bodywork was created that showed improvements in all three key areas. Downforce was up, drag was down and balance was where it needed to be to create a stable and predictable aero platform for the driver. Using the deviations collected from the initial model analysis, corrected CFD values were then produced that would hopefully predict what to expect from the wind tunnel results when the 2013 GT-3 prototype bodywork was fitted and tested (as shown in **table 3**).

The 2013 GT-3 bodywork was manufactured by hand in glass fibre from model renders and technical drawings that captured the design intent for each panel. From that, a buck was produced. Yes, machining from tooling block on a five-axis mill using a detailed 3D model would be better, but in the less well-funded world of clubman motorsport this isn't usually financially viable. So, old school manual methods are still very much in use, which can cause even more correlation problems, as we are about to discover.

The new GT-3 was taken back into MIRA and run at the same ride heights and rakes as its predecessor to generate initial back-to-back data. The results are shown in **table 3**.

A comparison with the original 2012 configuration confirmed significant increases in downforce, a notable reduction in drag and a major shift forward in aero balance from 10.58 per cent front to 52.95 per cent. That was a surprise, as the corrected CFD results predicted front balance to be around 46 per cent.

Front downforce was also some 25 per cent higher than the corrected CFD had predicted. Checking the rest of the results, we see rear downforce was down around five per cent, overall downforce was up by around 8.5 per cent, and drag was up 2.5 per cent. Balance had shifted almost seven per cent further forward than predicted, too.

To add even more intrigue to the situation, when the rake analysis data sets were overlayed with the MIRA results (see **table 2** and **graph 2**) the rate of change for downforce and drag was now *higher* in MIRA than predicted in the CFD.

The only upside came from a considerable tightening of the deviations between results. The previous range was around one to four per cent, while we were now seeing deviations of 0.6 to less than three per cent, as seen in **table 4** and **graph 2**.

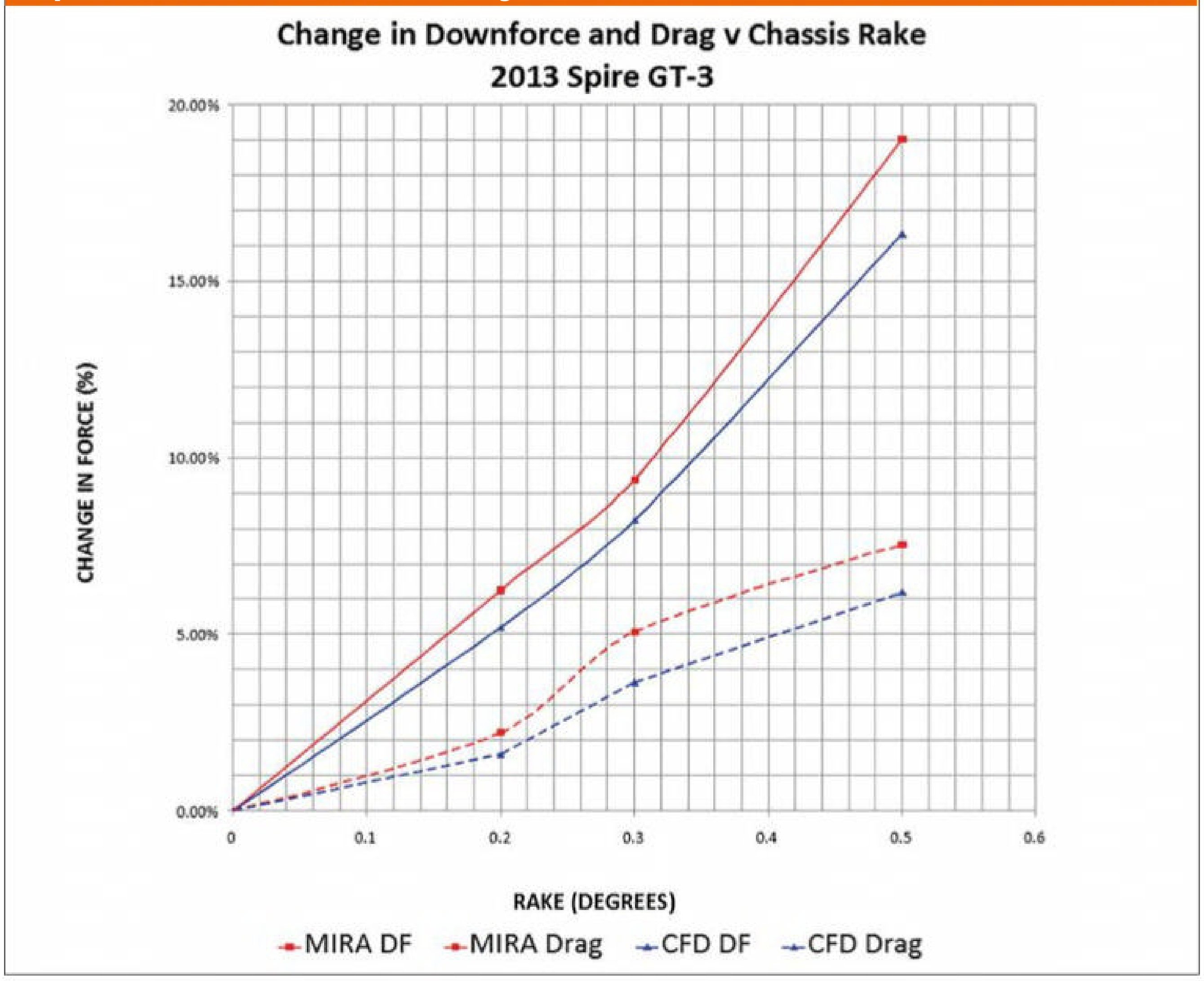
When the MIRA test was completed, the car went back to the workshop and measurements were taken off the new bodywork and compared to the CAD model. This would best be done with a laser scanner capable of measuring down to hundredths of a millimetre, if necessary, but we used templates, tapes and drop gauges and worked to the nearest few millimetres, only to find the new nose had been modified for clearance over the new safety structure that lies beneath it.

The resulting change to the final part was recreated in CAD and further CFD analysis undertaken. Sure enough, this was where the significant jump in downforce had occurred, where the extra drag had come from and where the increase in front aero bias arose. It also explained why the more effective front end was causing a larger increase in downforce and drag on the MIRA data compared to the original test model when rake was being added.

Table 4: 2013 GT-3 MIRA vs CFD rake change

Rake	2013 GT-3 MIRA		2013 GT-3 CFD		Deviation	
	MIRA DF	*MIRA Drag*	*CFD DF*	*CFD Drag*	*ΔDF*	*ΔDrag*
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0.2	6.25%	2.22%	5.21%	1.60%	1.04%	0.62%
0.3	9.38%	5.07%	8.23%	3.65%	1.15%	1.42%
0.5	19.01%	7.53%	16.33%	6.20%	2.68%	1.33%

Graph 2: 2013 GT-3 MIRA vs CFD rake change



Feedback loop

Believing the problem solved, corrections were made to the correlated data and passed on to the race engineer to make suitable reductions in rake, several tweaks to the rear bodywork and apply a new base suspension setting prior to the next track session.

Armed with the combined data sets from MIRA and the CFD analysis, the car could now easily be balanced and trimmed to the drivers', and stop watches', preference. With this new data plugged back into the design loop, the Bike Sport version could now be modelled in CAD and developed in CFD (see **figure 4**). Unlike the flat floor RGB version, this was permitted the luxury of a front splitter, rear diffuser, wings and a range of additional bodywork appendages. The only restriction was cost, and the need for it to use the RGB chassis and bodywork.

Referencing track and tunnel data from similar cars, downforce and drag targets were identified at the expected ride heights.

[The Bike Sport version] was permitted the luxury of a front splitter, rear diffuser, wing and a range of additional bodywork appendages

Fig 4: The modified Bike Sport version of the car was modelled in CAD and then developed in CFD

Fig 5: The modified car had produced some alarming results, but they could be traced to different bodywork at the front built around a new safety structure that had skewed expected figures

As ride heights were to be lowered to improve chassis dynamics, it meant the aero platform would have to be assessed more critically for pitch and ride height sensitivity to prevent any nasty surprises at the increased cornering speeds expected.

Using the updated CAD model of the 2013 GT-3 RGB car and adding suitable aero components, the CFD showed downforce to be around 2206N and drag to be at 997N, giving an -L/D of 2.21 and an almost 50 / 50 aero balance from the start. Similar rake and ride height analysis was undertaken to see what limitations the CFD highlighted.

Constant evolution

A while later, we were back at MIRA again to review the constantly evolving, corrected, CFD results against the actual car's figures, the car shown in **Figure 5**.

Table 5 shows the predicted CFD values showed around 10 per cent less overall downforce, almost six per cent more drag and a four per cent difference in front aero balance. The deviation had not directly carried over from the original RGB car, but was still in the same ballpark. Of more importance was the improvement over the standard car, and the later ride height and rake sweeps that closely followed the expected trends shown in the CFD.

Again, with this data in hand, the car had a baseline set-up applied to it and was wired for data logging on track. A good day of running came back with some pleasantly surprising figures for the engineers at Spire, but even more questions for the correlation between the CFD, MIRA and track test data for the rest of us!

Table 5: 2013 Bike Sports – MIRA vs CFD vs track data

Configuration	Front DF (N)	Rear DF (N)	Total DF (N)	Drag (N)	L/D	% Front	% Rear
MIRA	1058	1148	2206	997	2.21	47.98%	52.02%
CFD	900	1152	2052	940	2.18	43.86%	56.14%
Track	1253	1436	2689	959	2.80	46.60%	53.40%

With the car at the specified ride heights and speed, we were seeing a significant jump in downforce of nearly 31 per cent over the CFD results, while drag increased by four per cent. Happily for the driver, this had only changed the balance by just over two per cent from the combined data sheet predictions we were working to.

Searching through previous track data confirmed suspicions that these increases were predominantly due to the presence of an actual 'moving floor' on track that was not fully replicated in the tunnel. It was noted this had significantly less effect on the RGB car, which was likely due to its increased ride height and relatively simple flat floor.

So, another column was added to the ever-increasing spreadsheet and the quest for direct correlation continued.

Conclusion

Looking over the finished Bike Sport car and comparing it with the simplified CAD model, it could be seen where certain areas were contributing to the differences in CFD and MIRA values. But to correct these to find those last few per cent would have pushed the cost of aero development out of the available budget for this project.

As most final year degree and MSc-level aerodynamic students will attest, generating correlation between two controlled methods of analysis is a long-winded, expensive and time-consuming process. Add in the moving floors, rotating and deflecting tyres, pitch, roll and fluctuating ride heights associated with the real world and the task becomes ever more complex and demands more resources. This is especially true when chasing the one per cent margins expected in F1.

A while later, we were back at MIRA to review the constantly evolving, corrected, CFD results against the actual car's figures

What can be shown from this case study, though, is that even with a limited budget, the correct approach to data collection, analysis, post processing and a constantly evolving feedback loop can still generate suitable correlation data to improve the aerodynamic performance of a racecar.

Racecar's *thanks to Paul Nightingale of Spire Sports Cars, Tim Gray of Tim Gray Motorsports and Black Art Customs Ltd for their valuable time and information.*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Diff'rent strokes

Racecar *looks at the different types of mechanical differential, their benefits and limitations*

By JAHEE CAMPBELL-BRENNAN

Whatever the axle configuration, or number of axles, between any driven wheels of an automotive powertrain (with a caveat for some EVs and hybrids) you will find a differential gear set.

The technology was conceived as a solution to two problems of the early, combustion-engined automobile associated with transmission of power from the engine to the road and manoeuvrability.

As a combustion engine has one rotational output and the requirement to power two driven wheels, the differential firstly serves as a mechanism of splitting the rotation of the crankshaft to drive the left and right wheels of an axle. The second, and more interesting, function it serves us as motorsport engineers is to provide a method of introducing a speed differential between opposing wheels.

To understand the requirement for this speed differential, we need to look to the foundations of vehicle dynamics.

As a vehicle travels around a corner at a given cornering speed, the inside and outside wheels are logically travelling on different radii due to their distances from the vehicle's centre of rotation. The inside wheel is closer to the centre of rotation than the outside wheel and therefore must have a relatively lower forward velocity to maintain a free rolling condition, without slip.

In the early days of automobiles featuring rudimentary solid axle configurations, the physics that enable these free rolling conditions are blocked by the fact the wheels are mechanically coupled to each other. This mismatch of speeds stimulates the inside and outside tyres to generate longitudinal forces in opposition of the yawing moment requested by the driver's steering inputs.

The result is a dynamically limited vehicle – a significant portion of the total yawing moment generated by the chassis is absorbed in the process of overcoming these longitudinal forces and *not* yawing the vehicle. In the automotive world, this leads to a poor handling car with a laboured turn in and excessive tyre wear. In motorsport, it means poor tyre management, slow lap times and frustrated drivers.

Open differentials

As we explore the science of differentials, we will explore an interesting variation of the technology in a form of a limited slip differential (LSD), but we must start with some focus on the original implementation of the automotive differential. What we call 'open'.

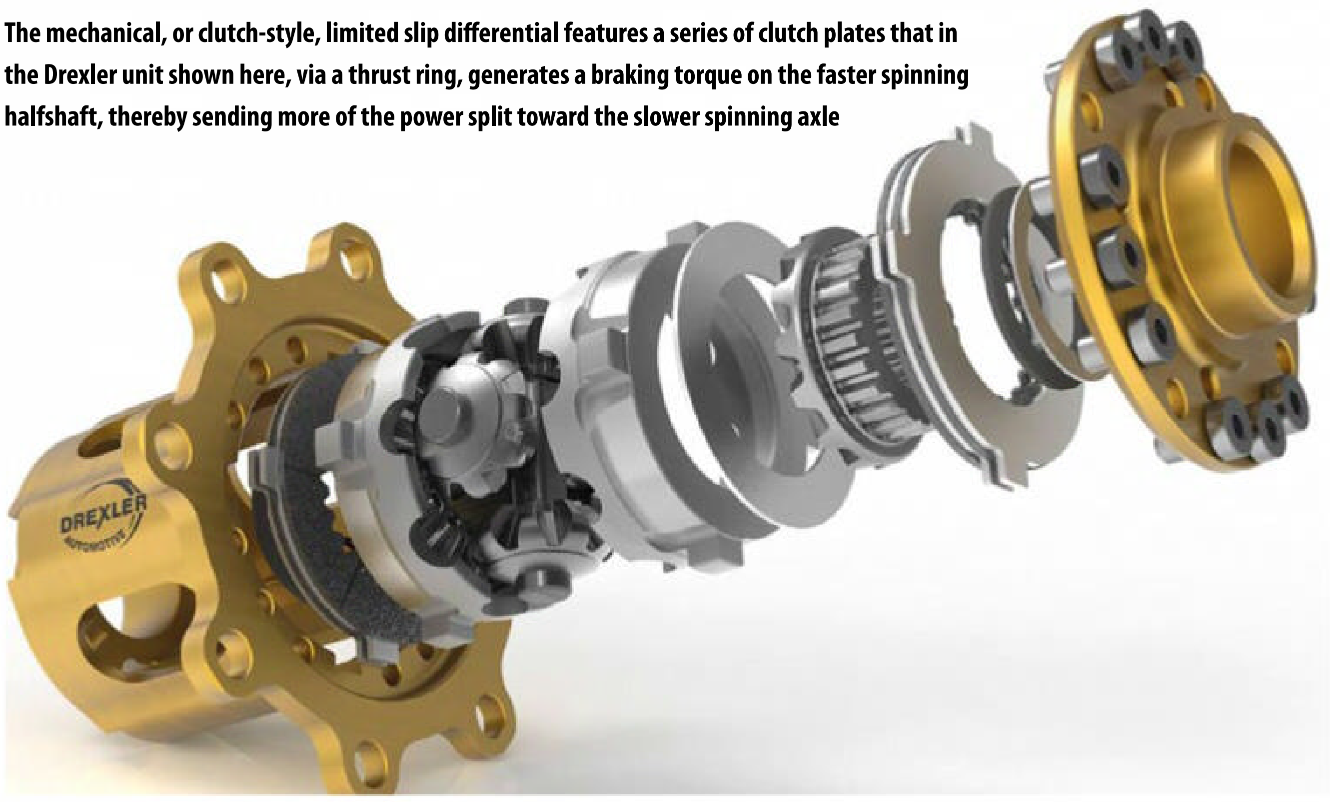
The open differential is a relatively simple mechanism consisting of a number

XPB

The differential serves two functions – it splits the energy from the rotation of the crank to the driven wheels, and also introduces a means of creating a speed differential between those wheels

Drexler

The mechanical, or clutch-style, limited slip differential features a series of clutch plates that in the Drexler unit shown here, via a thrust ring, generates a braking torque on the faster spinning halfshaft, thereby sending more of the power split toward the slower spinning axle



Drexler

of intermeshed bevel gears with input from the driveshaft and two outputs to each axle halfshaft. The driveshaft supplies torque to the differential housing, which carries two pinion gears meshed with side gears located at the end of each halfshaft.

Under normal conditions, such as straight line driving, these pinion gears do not rotate on their shafts as the housing rotates, driving the halfshafts via the side gears with equal velocity as the housing.

But, under conditions where one wheel needs to rotate faster than the other, the slower halfshaft reduces velocity relative to the housing, while the faster shaft speeds up.

The inside wheel is closer to the centre of rotation than the outside wheel and therefore must have a relatively lower forward velocity to maintain a free rolling condition, without slip

The fundamental kinematic relationship within a differential is described as follows:

$$\omega_F + \omega_S = 2\omega_h$$

With open differentials, the inside and outside wheels can spin completely independently of each other through the induced rotation of the pinion gears. This allows free rotation, which solves the cornering issues, but introduces a new problem in the context of vehicle dynamics that can be equally as damaging to performance as operating with a fully coupled, solid axle.

With an open differential, one could hold a single wheel of the axle static while the entirety of the engine's power travels to the unrestricted wheel. If this scenario rings any bells, this is analogous to an on-limit cornering situation in which lateral weight transfer has an outside wheel heavily loaded and the inside wheel very lightly loaded.

Once power is applied on the exit of a corner in this scenario, due to its reduced vertical load, the inside wheel will break traction first and quickly receive close to 100 per cent of the engine's power. The result is a spinning inside wheel and greatly reduced acceleration.

The solution to this was realised in the implementation of a new style of differential that blurred the lines of an open and solid axle by introducing a coupling action dependent on external factors, maintaining the independence of the wheels, but in a controlled way.

And so, the limited slip differential was conceived. Various references point the introduction of the LSD to a collaboration between Porsche and ZF in the 1930s, but safe to say the technology has been around for a long time. In motorsport today, the LSD presents itself in two main forms – mechanical and geared.

Mechanical LSD

The first and most common type is the mechanical, or clutch-style LSD. These use the basic architecture of an open differential, but with the addition of a series of clutch plates constrained to the differential housing and pressure plates splined to each axle halfshaft.

These clutch packs work in a similar action as the clutch and flywheel of an engine. In normal conditions, where each wheel is rotating with the same velocity, an amount of pressure is exerted on the clutch pack through engine torque from the driveshaft, clamping the clutch and pressure plates together and creating a partial couple between the wheels.

As a speed differential occurs across the axle due to a loss of traction on one wheel, the mechanics of the differential exert a greater pressure on the clutch pack of the faster spinning axle, which generates a braking torque, shifting the distribution of the engine's power towards the slower axle.

'In our mechanical differentials, we have a device called the thrust ring,' explains Harald Hinterwallner, director of design and engineering at Drexler. 'As soon as there is a driving torque on the differential, this thrust ring experiences an axial force, compressing the clutch pack and locks the differential. In this condition, the torque from the driveshaft is distributed in a greater proportion to the wheel with more traction.'

Due to the nature of meshed bevel gears, the resultant force at the gear teeth has an axial component as well as a radial component. In practice, this means the faster halfshaft will generate a larger clamping pressure in the clutch packs, braking the shaft and biasing torque towards the inside wheel.

'With a clutch-type LSD, this clamping force generates a friction between the output shaft and the differential housing via the clutches that allows some locking between both wheels, allowing some torque to be distributed to a single driveshaft.

'It's important to note, however, that it can never distribute 100 per cent,' continues Hinterwallner.

The mechanical LSD uses a pre-load spring to provide a constant loading to the clutches and couple the axle. With this, the wheels are coupled until a 'breakaway' torque sufficient to overcome friction is reached.

The clutches themselves are coated with molybdenum, which is a metal useful for its effect in stabilising the frictional coefficient across the working range of the differential and it's positive influence on wear rates.

Geared LSD

Geared LSDs predominantly follow the Torsen layout. This uses side gears in a similar fashion to the clutched LSD, but the major difference here is the replacement of the bevelled pinions with pairs of intermeshed and counter rotating worm gears on parallel axes.

On this style of differential, both the side gears and worm gears are helically cut – an important distinction.

In a similar way as bevel gears, helical gears produce a resultant force with components in both the axial and radial direction so, like the clutch LSD, as the halfshafts and housing rotate together with the same rotational velocity, there are balanced axial forces within the differential.

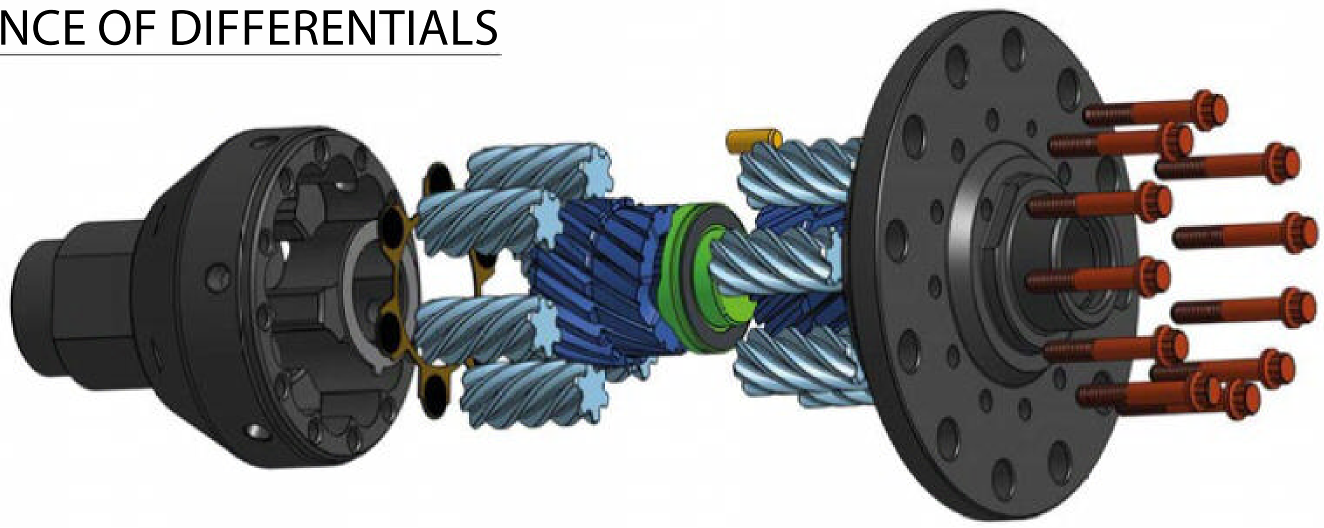
In conditions where one wheel loses traction and spins, the greater torque experienced by the side gear of the faster halfshaft generates a thrust force, which causes the side gears and differential housing to come into contact.

There are machined contact faces on the housing and the rear face of the side gear so, as the axial force causes these faces to contact each other, a braking torque is generated through the speed differential between them and torque is sent to the slower wheel.

'By controlling the surface preparation of these faces, we can modulate the frictional force,' comments Dana Clark, technical operations manager at Autotech Driveline. 'The surfaces are metal-to-metal contact, and usually a hardened steel. We can also use special inserts between the frictional faces to offer further control over the friction force generated here in very high power or heavy duty-cycle applications.'

The geared-style LSD is inherently flawed in the sense that when there is no load on the faster rotating wheel, the differential offers no braking torque, but there are multiple ways to provide solutions to this problem. One of them is patented by Wavetrac, a subsidiary of Autotech, which uses a device between the two side gears of an otherwise Torsen-style layout.

'The technology we use in our differentials uses a cam-style device to generate a load in the differential under zero axle load. In normal conditions, two cam profiles on the side gear and the pre-load hub between the gears are interfaced with each other,' explains Clark.



Wavetrac

The innovative Wavetrac geared LSD uses a cam-style device to generate a load in the differential under zero axle load

Wavetrac

Under light load, the Wave Gears rotate and push each other apart, forcing the side gears into the housing to maintain a torque bias

'With a light axle load and differential wheel speed, those cam profiles rotate on each other and begin to push each other apart. This action then forces the side gear into the housing where a friction face begins to generate a load, initiating a torque bias.'

Viscous LSD

The final type of differential is the viscous LSD. These aren't seen so much in motorsport as they present disadvantages relative to the other types, but follow a similar principle.

Instead of generating braking torque through mechanical friction, they use a highly viscous fluid to replace the action of the clutch packs in a similar manner to automatic transmissions. The locking torque is generated within the fluid by a speed differential between the housing and a series of plates splined to the driveshaft.

In conditions where both wheels are rotating at the same speed, the housing containing the fluid and plates are spinning at the same rate but, when one wheel is spinning faster, the speed difference between them is subsequently resisted by the viscosity of the fluid.

The drawbacks of viscous LSDs are that they introduce lag in their response and offer a locking performance very sensitive to the speed differential between the housing and halfshafts. The viscosity of the fluid also changes with temperature and age, giving inconsistent performance.

In a similar way as bevel gears, helical gears produce a resultant force with components in both the axial and radial direction

Torque biasing

All LSDs work with a torque bias ratio (TBR). This is an indication of the amount by which the torque received at the faster wheel (the wheel without grip) is multiplied at the slower wheel.

Ignoring any frictional losses, the power into the differential is equal to the power out. Power is a product of torque (M) and angular velocity (ω), so the following description of the differential power balance applies:

$$MH\,\omega H + MF\,\omega F + MS\,\omega S = 0$$

Here, MH ωH represents the power into the differential housing, while MF ωF and MS ωS represent the power of the faster axle and the slower axle respectively.

This is an important point to be clear on: the power into the differential is equal to the power out, *whatever* the driving conditions.

In reality, the LSD is a frictional device, so there will always be a small amount of power lost in the gear sets and the frictional faces but, for this discussion, that isn't important.

The TBR is defined as the ratio of torque distribution across the differential, and with positive torque from the engine, is represented as follows:

TBR = MS / MF

In simple terms, this means that at an operating point generating a TBR of two, the slower wheel will receive 66 per cent of the engine's torque.

'Typically, in motorsport, we're designing our differentials to offer up to 70 per cent locking torque under drive,' adds Hinterwallner, which corresponds to a TBR approaching three.

Clutch-type differentials are most common within motorsport, and so far we've discussed them in the context of on-throttle behaviour, but the benefit of an LSD would also be felt within braking zones where, as the vertical force on the tyre fluctuates through road imperfections and lateral load transfers, it would help prevent individual wheels from slipping.

There are three common configurations of the LSD that broaden its effectiveness and capitalise on the benefits over a wider spectrum of operating conditions.

1-way: This application of an LSD only provides braking torque to halfshafts under positive driveshaft torque ie on throttle.

2-way: Provides a braking torque equal in magnitude under both positive and negative torque, acceleration and braking.

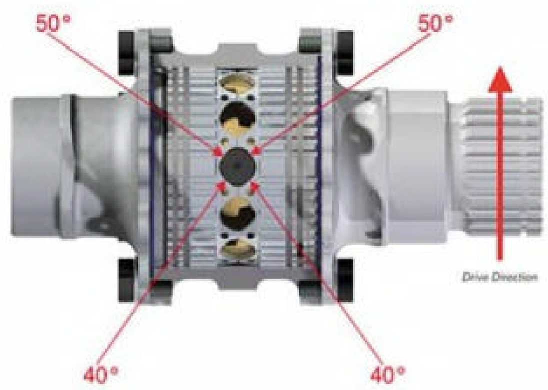
1.5-way: Provides braking torque of unequal magnitude under positive and negative driveshaft torque conditions.

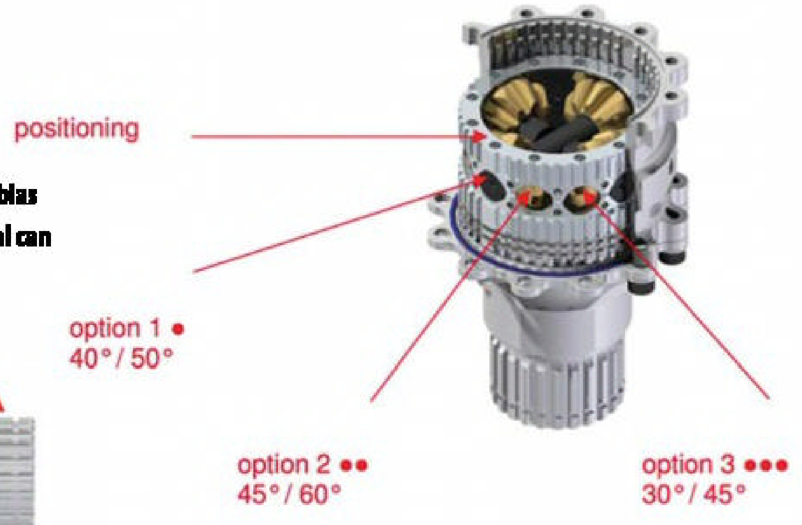
Under negative torque, or deceleration, 1-way differentials act as an open system, which means the wheels are free to rotate as the forces generated at the road dictate. This is great for turn in, where there are no forces opposing the yawing moment generated by the driver's steering input, but bad for braking stability.

The 2-way differential is a solution to the issue in braking zones but, as the braking torque it generates is relatively strong to effectively meet the requirements of on-throttle traction, it is prohibitive in allowing the appropriate wheel speeds from the point of corner entry to point at which the throttle is applied at the apex.

The compromise between these two conditions is the 1.5-way differential. Like the 2-way set up, this configuration provides braking torque under both positive and negative acceleration, but the important distinction is that different braking torques can be specified in each condition.

In this way, the braking torque under negative acceleration can be carefully balanced to the requirements of the braking phase of the corner and the tendency to understeer at turn in.





The ramps in a clutch LSD, such as this Drexler example, offer a mechanism through which torque bias can be accurately adjusted. In this way, a differential can be tuned to suit a particular race track

Ramp it up

Clutched LSDs achieve this through accurate specification of 'ramps', on which the pinion axles are located. The presence of these ramps is effectively the mechanism through which torque bias is adjusted within mechanical LSDs.

Rather than a circular journal as one might expect, the pinion axles sit within a quadrilateral kite, or diamond-style journal. As the pinion gear rotates with the housing, there is both a radial and an axial force component generated by this ramp.

'Depending on the angle of this chamfer, you change the axial forces,' explains Hinterwallner. 'This allows a set up that develops a thrust on the clutch pack based on the angle present in this journal. The lower the angle, the higher the thrust force.'

In geared LSDs, the approach is slightly different and relies on the fact that a negative torque input brings opposite faces of the helical gear teeth in contact, which reverses the direction of the thrust on the side gears.

'In reality, the frictional area of our differentials is different on either side of the side gears,' notes Clark. 'In coast conditions, the helical gears are loaded in the opposite direction, which draws them into the centre of the differential to engage the opposite friction face. 'As this generates a different torque bias in drive and coast, this effectively means our differentials are closer to the 1.5-way concept normally associated with clutch diffs.'

Different circuits, and even corners within the same track, will favour different torque biasing to balance the advantages of increased traction under braking and deceleration with the best cornering response. A tighter, slower corner will require less torque biasing than a fast, open corner so, depending on the composition of the track, it would be advantageous for a particular differential to offer some adjustability.

Machining processes have improved over the last decade which means components can be smaller and lighter while handling higher load

The power into the differential is equal to the power out, *whatever* the driving conditions

Adjustability

Both geared and clutch differentials offer flexibility in the set up of the differential for different conditions, and common to both styles is that different locking torques can be set by adjusting the strength of the pre-load springs, but clutch-style differentials offer another dimension of adjustability.

The number of clutch plates can be tuned to suit the application and, furthermore, the design of the thrust rings can also be adjusted to alter the relative performance under drive and coast conditions.

'The largest effect on the behaviour of the differential is defined by the locking torque defined by the geometry of the ramps on the thrust rings that the pinion gear axles sit within,' notes Hinterwallner. 'We can therefore supply our customers with different thrust rings graded by ramp angles.'

The thrust rings can typically be altered trackside by mechanics within an hour, which makes them particularly advantageous in this respect.

With all this friction happening within the differentials comes heat, so they can become fairly hot during operation, which brings the potential for very high wear in the friction faces and some interesting effects in geared differentials where there is direct metal contact.

With correct design specification to ensure the contact areas are large enough, temperatures are generally manageable, but extreme cases do present issues. 'The friction faces on gear diffs can burn up and burnish, which causes a loss in frictional coefficient with time,' says Clark. 'Higher loads, extreme differential speeds and inadequate lubrication make this worse so in our designs we use a woven carbon fibre plate in between the pinions and housing to eliminate the metal-to-metal contact. This provides a much more reliable and durable frictional performance.'

The type of oil used in these applications is, of course, an important consideration in their operation too, and heavy, synthetic oils are widely used in these applications.

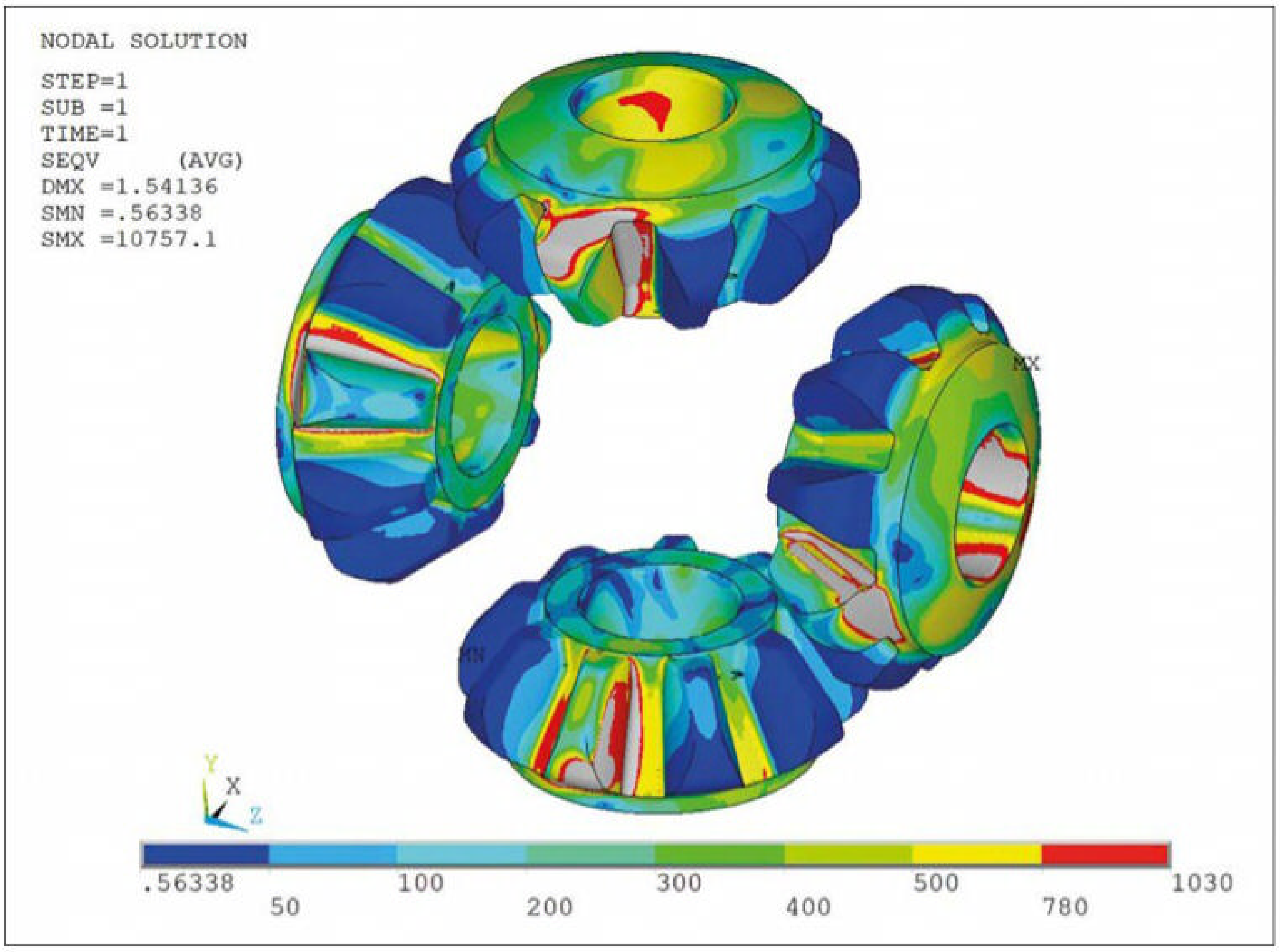
In wet applications, where the differential is located within the gearbox housing and submerged in gearbox oil, such as with transaxles, clutched differentials use carbon frictional surfaces on the clutch faces as they generate less oil contaminating particulates. Gearbox oil is also generally cooled, which helps with heat management.

Historically, predicting the load cases differentials are subjected to has been a difficult task, which resulted in high safety factors designed into particular applications. Today, with mounting pressure to design gear sets within increasingly constrained packaging spaces, this approach has required some improvement.

Simulation

Parts are getting smaller, while loads are getting higher, so components are operating much closer to their limit in terms of strength. Friction materials and machining processes have improved over the decades, but the largest steps forward in differential technology have come through a better understanding of the stresses occurring within the units using simulation methods.

'The biggest change is we use FEA a lot today. We are able to simulate the oil flow around the differential and have a much better understanding of fatigue loads to accurately calculate lifetimes. The size of a differential for a car dealing with 800-900Nm of torque is really quite small with today's technology compared to maybe even 10 years ago,' says Hinterwallner.



FEA is used to simulate load cases and stresses within a differential to better understand fatigue loads and component lifespans

Implementations of electronic control to replace traditionally mechanical systems are appearing everywhere. The limited slip differential isn't exempt

Electronic control

In today's era of electronics and mechatronics, implementations of electronic control to replace traditionally mechanical systems are appearing everywhere. The limited slip differential isn't exempt.

Operationally, from a vehicle dynamics perspective, having the capability to dynamically adjust the torque biasing generated across an axle is attractive. Being able to continuously modulate the torque distribution across a rear axle to your specific requirements throughout a lap, or based on driver request, would certainly provide performance and driveability benefits.

Indeed, high-profile championships such as F1 have used hybrid-style, electro-hydraulic clutch differentials for a long time. Having the functionality to develop software to use the differential to achieve torque vectoring for optimised performance in various vehicle states is a big win for any vehicle dynamicist, but the issue with electrical systems in this application is primarily around the issue of latency.

Purely mechanical differentials offer instantaneous reaction to the conditions experienced by the wheels, providing a very reliable and predictable character. Electrical systems firstly have to detect the state of a particular wheel, and then react with a control output to be effected by the hardware, whilst at the same time accounting for a level of backlash in the gearing. The response is always out of phase and, in motorsport, this is not an acceptable condition.

Nonetheless, innovation continues, so there are a range of hybrid, clutched differentials currently under development for the wider market that operate mechanically, but have an element of electronic control to expand the operational envelope of the technology.

With the additional of this electronic control to actively broaden the range of torque biasing available, while maintaining the instant mechanical response, something of the best of both worlds can be realised. Sure, there is additional expense and complexity but, if there's lap time in it, we can expect to see it on a racetrack soon, FIA permitting.

Gone with the wind

If you enjoy complex mathematics, expecting the unexpected and getting your hands dirty, this could be the job for you

By MIKE BRESLIN

Katlynn Bringhurst Lucas is an aerodynamicist who worked at Honda R&D before becoming a test engineer at the Windshear full-scale wind tunnel

Dallara IR05 IndyCar in the Windshear test section. Once the car is securely in place the runs, which can take up to two hours for a detailed aero map, are fully automated

There's a story that in the early 2000s, when full-scale wind tunnel testing was still allowed in Formula 1, a team failed to properly secure its car before subjecting it to a test and it was destroyed. It was simply taken by the airflow, like a plastic chair in a cyclone, and thrown against the tunnel's diffuser. It was an expensive mistake, one the team concerned never owned up to, but what this incident illustrates is the importance of having skilled and thorough technicians operating these amazing facilities.

Katlynn Bringhurst Lucas is a test engineer at Windshear, the well known, full-scale, rolling-road, single-belt wind tunnel that can produce top speeds of 180mph (both wind and road), and is one of the few facilities of this kind available to hire in the world.

It is owned by Gene Haas – also owner of the Formula 1 team that bears his name, and co-owner of the Stewart-Haas NASCAR operation – and it was completed in 2008. The original intention had been to offer a facility for F1 teams, but full-scale testing was banned in Formula 1 soon after it opened.

A NASCAR Cup car is wheeled into the tunnel. The team at Windshear need to perform a multitude of tasks to prepare a racecar before it's tested. This can include removing brakes and driveshafts where necessary

There is still plenty of other motorsport work for the tunnel, though, and as it's conveniently located in Concord, North Carolina, at the heart of the US motorsport industry, much of this is right on its doorstep.

First love

Bringhurst Lucas trained as an aerodynamicist and initially worked for a time in the production automotive industry, as she explains: 'I graduated from Georgia Tech [Georgia Institute of Technology] with my bachelor's in aerospace engineering in 2014. My first job out of college was at Honda Research and Development. I'm a motorcyclist, so I really fell in love with Hondas, and wanted to work for the company.

'I was an aerodynamicist with Honda production cars out in Columbus, Ohio, and while I was employed there I used to come down to Windshear as a customer [many road car manufacturers use the facility]. We would bring our cars here, perform aerodynamic testing on them, and then feedback that into development.'

Having found working in the road car world a little restrictive, a move to Windshear and the company that operates the facility, Jacobs Technology, proved hard to resist, and Bringhurst Lucas has been there for over four years now. It's a role she relishes too, not least because of the diversity of work it offers.

'On paper, I'm 50 per cent engineer, 50 per cent operations,' she says. 'The operations

On paper, I'm 50 per cent engineer, 50 per cent operations… that comes down to making sure whatever needs to get done gets done

The main fan at Windshear is 22ft (6.7m) in diameter and is capable of producing air speeds of up to 180mph

side of things is easy to describe, because essentially that comes down to making sure whatever needs to get done gets done. Whether I'm picking up a broom, or a wrench and working on the car [to ready it for testing], or I'm out in the test section operating the tunnel, or I'm doing maintenance activities on the facility, so be it. Whatever is required for operating the facility, it gets done.'

Customer service

On the engineering side, on the other hand, it's mostly about customer interaction.

'It's making sure the customer is getting the data they intend to get, and learning the things they intend to learn.' Bringhurst Lucas continues. 'The speciality I provide here with my aero background is data quality. So, all the mathematics and the physics that go on at a facility like this, making sure that a, it's repeatable, b, it's accurate and c, that we understand it, and what's physically going on.

'And lastly, how we explain all that to the customer. Because, at the end of the day, it's a simulation. It's just like a computer simulation, but this is a physical simulation. You can only understand your results as well as you understand your model. The role I play here is making sure we *really* understand the model, so our customers are able to truly understand the results.'

A typical day for Bringhurst Lucas begins with a walk through the facility, starting at the test section and checking on the status of vehicles that are in the process of being tested, and what is lined up for testing that day. It's worth remembering Windshear is a 24-hour facility, so there is also a night shift.

The impressive Windshear facility is situated in Concord, North Carolina, at the very heart of the American motorsport industry

While much of her time after this might then be taken up with engineering projects, such as uncertainty analysis, or going through quality data or calibrations, the tunnel test work always remains a priority. It's hands-on work, and to prep a car to free wheel on the rolling road the brakes need to be removed, as do the driveshafts on many vehicles. Fluids are also taken out, unless it's an actual running car and then it will likely be just the fuel that's removed.

'And then, of course, there's cleanliness,' notes Bringhurst Lucas. 'You're making sure there's no debris that could come off the car.

The role I play here is making sure we really understand the model, so our customers are able to truly understand the results

We really get involved and get our hands dirty preparing the cars for testing.'

Other things that might need setting up include hydraulic or electric actuators, if the car is running a ride height control system,

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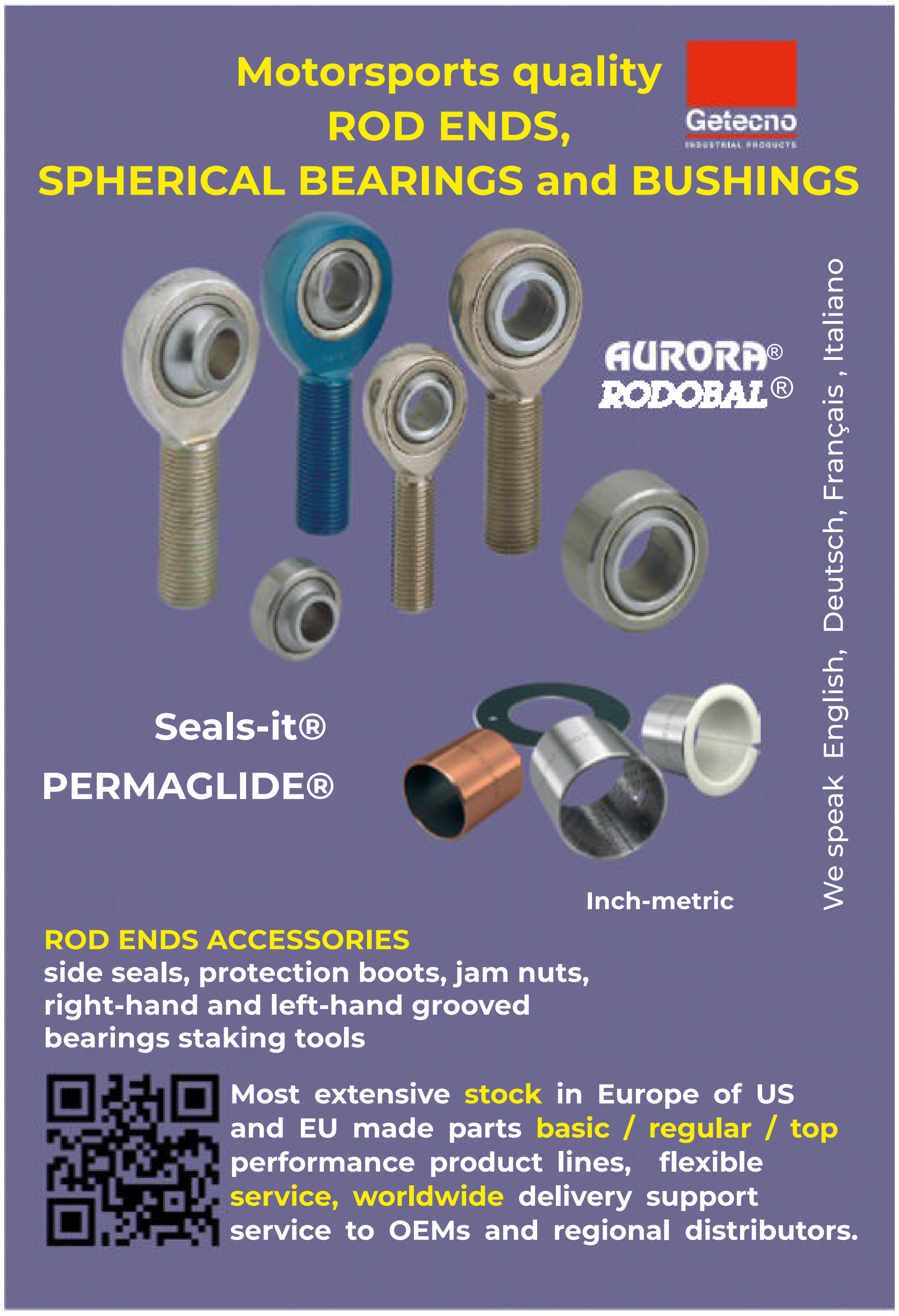

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plus anemometers, flow measurement devices and pressure measurement systems. The car also needs to be kept securely in place, which is achieved with struts that connect to the hubs.

In all, it takes around 30 minutes to install a car in the tunnel, says Bringhurst Lucas, but that's just the start of the process.

'We also need to know what sequences they're running, what ride height numbers they want, what speeds they're working at, what yaw points they require [the belt swivels horizontally to simulate yaw], and we have to get all that programmed because, when you're operating the tunnel, 90 per cent of it is automated. The human operator is there predominantly for facility health checks. Their primary aim is safety.'

With that in mind, and while Windshear has not had a catastrophe to match that described in the opening to this piece, it's always prepared for the worst, especially when testing single seaters such as IndyCars.

'Because the cars run so low to the ground, if they actually touch the belt – and this happens, because it gets unstable and it will tap down onto the belt – we have a system that will automatically 'E stop' the facility and bring the belt to a complete stop in less than 10 seconds. That minimises damage to the car, and to the facility.

The E stop can also be applied if the operator needs to abort a test for any reason.

The long game

It's not surprising to learn that Katlynn Bringhurst Lucas believes there should still be a place for full-scale wind tunnels in motorsport. She works at one after all. But she also presents a compelling case for them: 'Studying classical aerodynamics, you learn that everything is scalable. Well, in classic aerospace, for the most part that is true, because you're dealing with very stiff metals and pressurised vessels, and things don't really deform all that much. Even if they do, there's air elasticity that's well defined, and the structures are relatively simple.

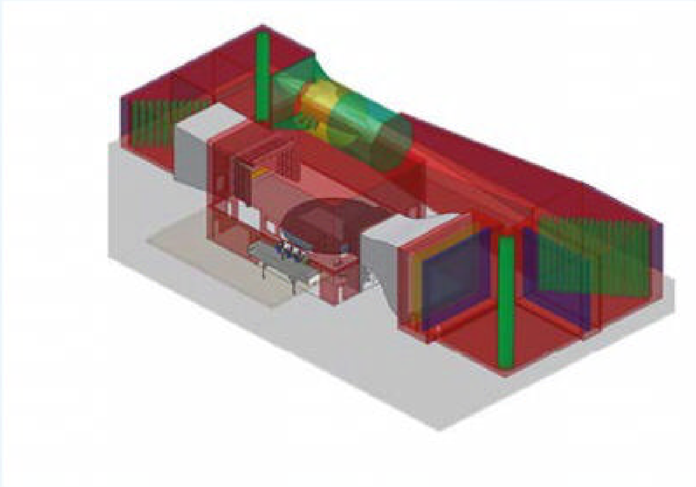
'But none of that really applies to automotive. There is a lot of very complex phenomena in automotive aerodynamics that simply isn't scalable.

'And these are things I've learned with experience. Automotive is way harder than aerospace because there are so many more things going on. The structures and shapes are so much more complex that the simple equations you learn at college just break down.

'What I have learned is you use scale model testing to develop large scale changes – overall shape, overall dimensions and roughly what your streamlines are going to look like.

'But once you get into the real detail, you really need a full-scale facility. And motorsport, especially, needs a wide belt system because the cars we're testing are so low to the ground that having the air flow around the entire underbody and around all the wheels, and having all that accurate, is super important.'

Bringhurst Lucas also believes that motorsport will probably never be able to do its aero development with CFD alone: 'In my opinion, there will never be a time when CFD completely replaces wind tunnel testing. Because even the best CFD analysts in the world will base their fundamental understanding on some sort of full-scale testing. Whether it's track testing or wind tunnel testing, or some combination thereof, they *have* to get some kind of real-world data.'



Schematic of the Windshear facility, showing the test section at the front and the huge fan to the rear

Data runs

With the car in place and secure, the wind and road speed is then increased to the desired test velocity, some further checks are made, and then the data is collected.

'Data runs can be anywhere from two minutes to two hours,' notes Bringhurst Lucas. 'It really depends on what the customer is looking for. But if they are trying to do a full envelope ride height sweep, to *really* understand the detail and the dynamic changes between a brake entry into a corner to a full acceleration coming out of the corner, they may run an aero map, and those could be two hours long.

'Aero mapping is so important, and a lot of the customers early on in the season will spend a lot of time understanding the full envelope of a car, so they have some sort of baseline to apply to all the tracks they go to.'

Motorsport clients will tend to use the wind tunnel as part of a holistic development process that also includes track testing and computer simulations, as Bringhurst Lucas explains: 'Some of them will take changes made at the track and say, this worked. Then ask why did it work? To find out, they'll run a computer simulation and say, well, that makes sense, but how do we *know* this is right? So then they try it in the wind tunnel and really get an idea of what's going on.

'Other customers will go the other way around. They'll say, we need more downforce in this section of the track. We already have track data to know what that looks like, so let's throw a bunch of random things at the car and do a computer simulation, pick the top 20 performers, and then take those same things, put them on the car in the wind tunnel and see what they do.'

Practically speaking, there is, of course, a big difference between doing CFD simulations and wind tunnel tests, and working with such a huge and complex piece of machinery does present its own problems.

'Any test engineer will tell you the hardest part about the role is planning for the unplannable,' says Bringhurst Lucas. 'How do you make sure your tests will run smoothly, and that you collect the data you had intended to get when everything goes wrong – your car is not ready, things are falling off the car, the facility's not ready?'

Winning team

It's this unpredictability, Bringhurst Lucas believes, that also makes the job so enjoyable.

'I get bored really easily, so I love that every day is different. I love being able to come here every day and just constantly learn something new. And I really like the team environment that exists. Here at Windshear, we either work together as a team, or we fail. We don't have a choice.'

Here at Windshear, we either work together as a team, or we fail. We don't have a choice

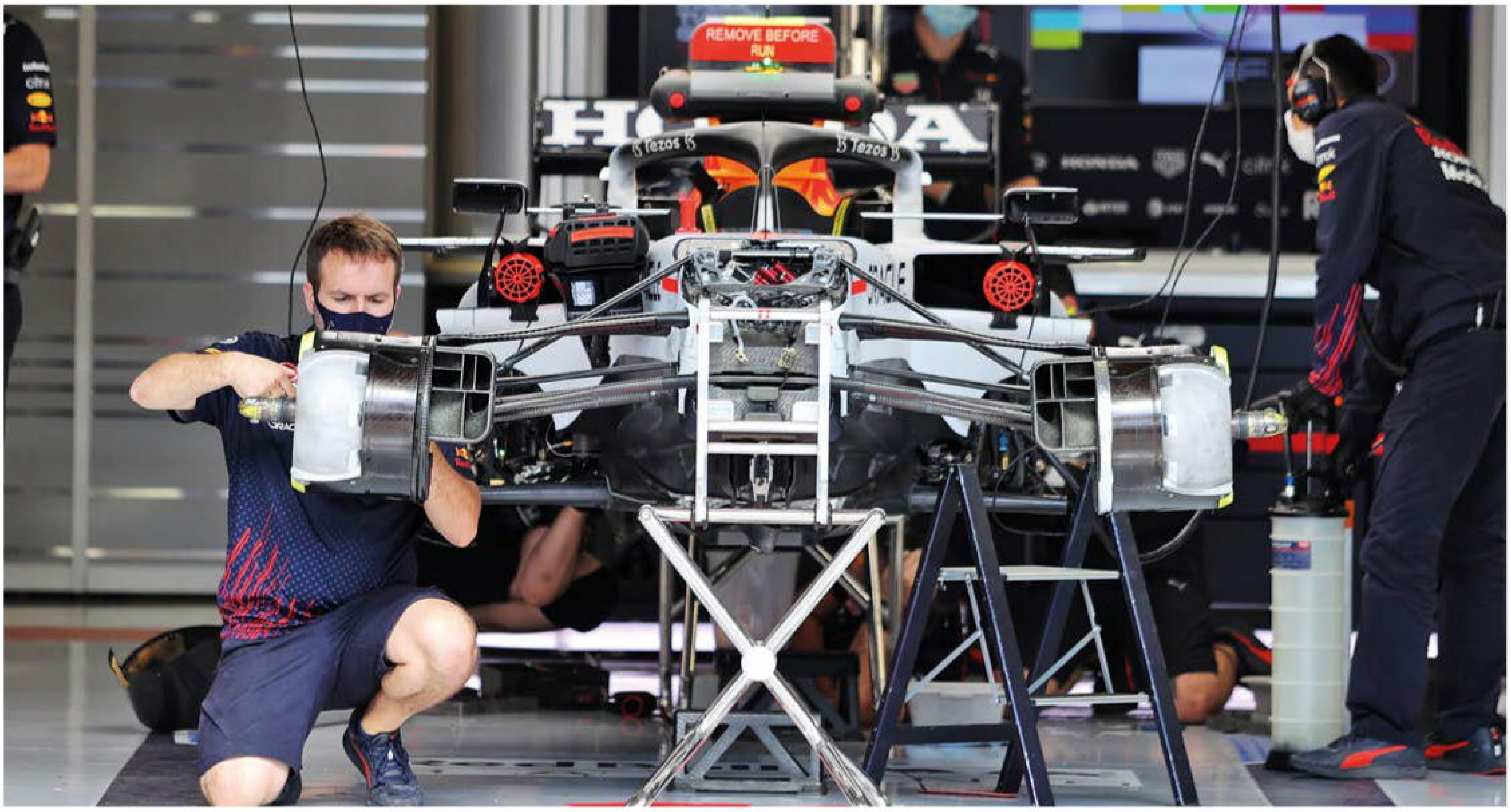
For those wanting to become involved with such a team, Bringhurst Lucas has no firm advice, pointing out that people at Windshear come from a wide range of backgrounds. There is one constant though: 'Everyone here has some sort of racing background, whether they were a technician at a race shop, or they used to race themselves, or they're just enthusiasts. Everyone is into racing.'

That said, to work in a wind tunnel at an engineering level, like Bringhurst Lucas, would require the relevant experience and qualifications in aerodynamics, or a similar discipline. Oh, and if you do find employment in a full-scale wind tunnel, don't forget to make sure the car you are working on is secure before you turn the fan on…

I'm alright jack

Understanding where jacking forces come from and how they are applied to the subject of suspension geometry

By DANNY NOWLAN



XPB

Racing formulae that have high levels of downforce, like Formula 1, use anti-dive geometry to control jacking forces

If there is one thing guaranteed to start a bar room brawl with racecar performance engineers, it's the subject of suspension geometry. Particularly when you mention force application points vs kinematic roll centre.

Of all the articles I have written for *Racecar Engineering*, by far and away the ones that have generated the most interest are those concerning suspension geometry. However, if there is one big blind spot on the subject, it is jacking forces. You see the term thrown about, but there is a lot of mystery about what it actually is. That is what I will be discussing in this article.

To kick things off, I want to start by way of an apology. I really didn't take this subject seriously until about 2013 or so, when I was starting to deal with formulae that had outrageous levels of downforce and used utterly silly values of anti-dive to control it.

Once the penny dropped, it forced me to reconsider a few things. However, as we are about to see, things on paper don't become that clear cut once the rubber hits the road.

Jacking forces come from the vertical component of the suspension geometry linkages that are applied to the sprung mass, as shown in **figure 1**.

What this illustration shows is a traditional double wishbone suspension. To keep things simple, I've put the lower control arm parallel to the ground (in my book, *The Dynamics Of The Race Car*, I go to great lengths to explain that the 2D case is actually a subset of the 3D case) and the jacking force is the vertical component of the force in the linkage 3-4. This is what drives the force to the tyre, but is also applied directly under the sprung mass.

The reason we can state this is explained in chapter three of my book, where we have already taken into account the moments, which is what drives the force application points.

The great news is we can readily relate the roll centre to the jacking force, using the simple formula shown in **equation 1**.

$$F_{JACK\_Y} = \frac{F_y \cdot rc}{0.5 \cdot t} \qquad (1)$$

Where,

F_{JACK_Y}	= lateral jacking force
F_y	= applied lateral force
rc	= force-based roll centre location
t	= track width

The only thing I will add here to what I have written in my book is the reason we have the *0.5t* term is because I am assuming the c of g is located symmetrically.

Where things get interesting with the lateral jacking forces is in how they are

Jacking forces come from the vertical component of the suspension geometry linkages that are applied to the sprung mass

applied to the sprung mass. They are actually applied *per axle*, as illustrated in **figure 2**.

The reason they are applied in this way is because if we review **figure 1** to see where these forces come from, we see they happen at *each* axle, which is why we have the formulation shown in **figure 2**. **Equation 2** then shows what these numbers look like.

$$F_{JACK\_Y\_F} = \frac{F_{y1}\cdot rc_1}{0.5\cdot tf} - \frac{F_{y2}\cdot rc_2}{0.5\cdot tf} = 2\cdot\frac{(F_{y1}-F_{y2})}{tf}\cdot rc_f$$
$$F_{JACK\_Y\_R} = \frac{F_{y3}\cdot rc_3}{0.5\cdot tr} - \frac{F_{y4}\cdot rc_4}{0.5\cdot tr} = 2\cdot\frac{(F_{y3}-F_{y4})}{tr}\cdot rc_r \qquad (2)$$

Where,

$F_{JACK\_Y\_F}$ = front lateral jacking force
$F_{JACK\_Y\_R}$ = rear lateral jacking force
F_{y1} = lateral force, front left (positive to the right)
F_{y2} = lateral force, front right (positive to the right)
F_{y3} = lateral force, rear left (positive to the right)
F_{y4} = lateral force, rear right (positive to the right)
rc_1 = force-based roll centre, front left
rc_2 = force-based roll centre, front right
rc_3 = force-based roll centre, rear left
rc_4 = force-based roll centre, rear right
rc_f = effective front-based roll centre
rc_r = effective rear-based roll centre
tf = front track
tr = rear track

Some notable things come out of **equation 2**. Firstly, when the forces are equally distributed left to right, the lateral jacking forces are bystanders since the terms cancel out.

Fig 1: The mechanism that drives jacking forces – laterally

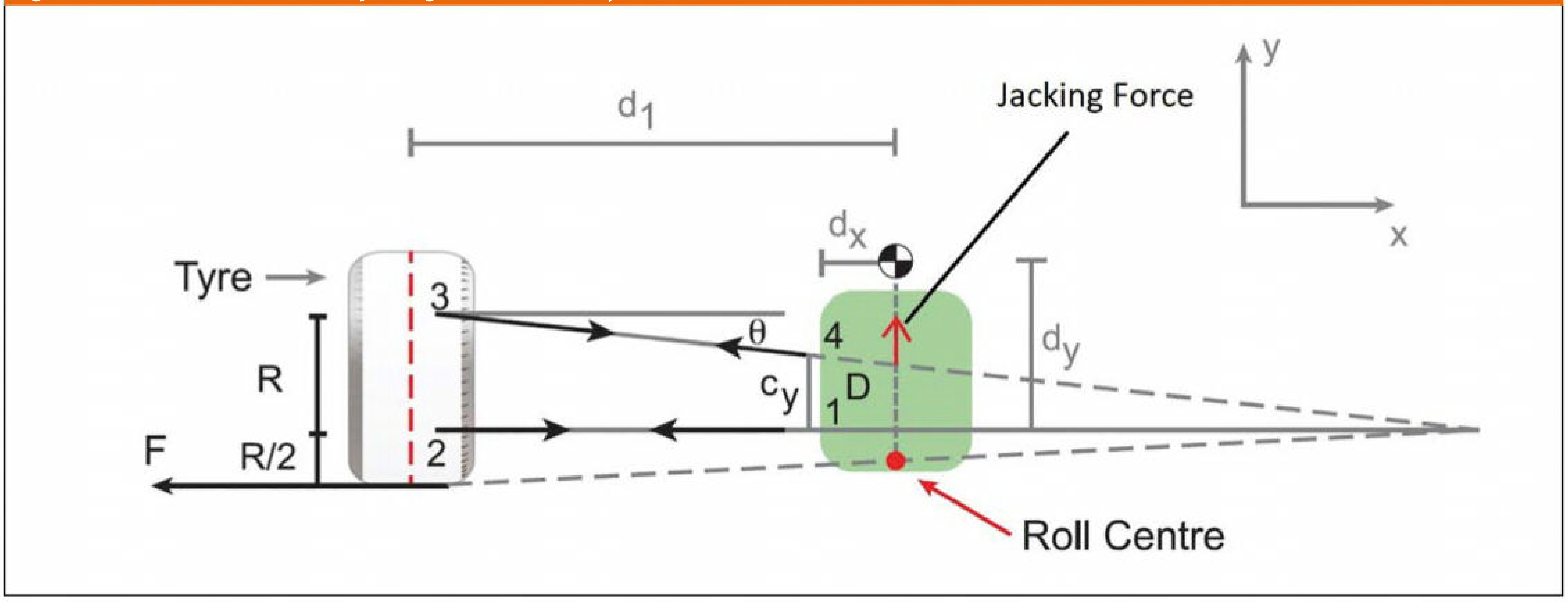
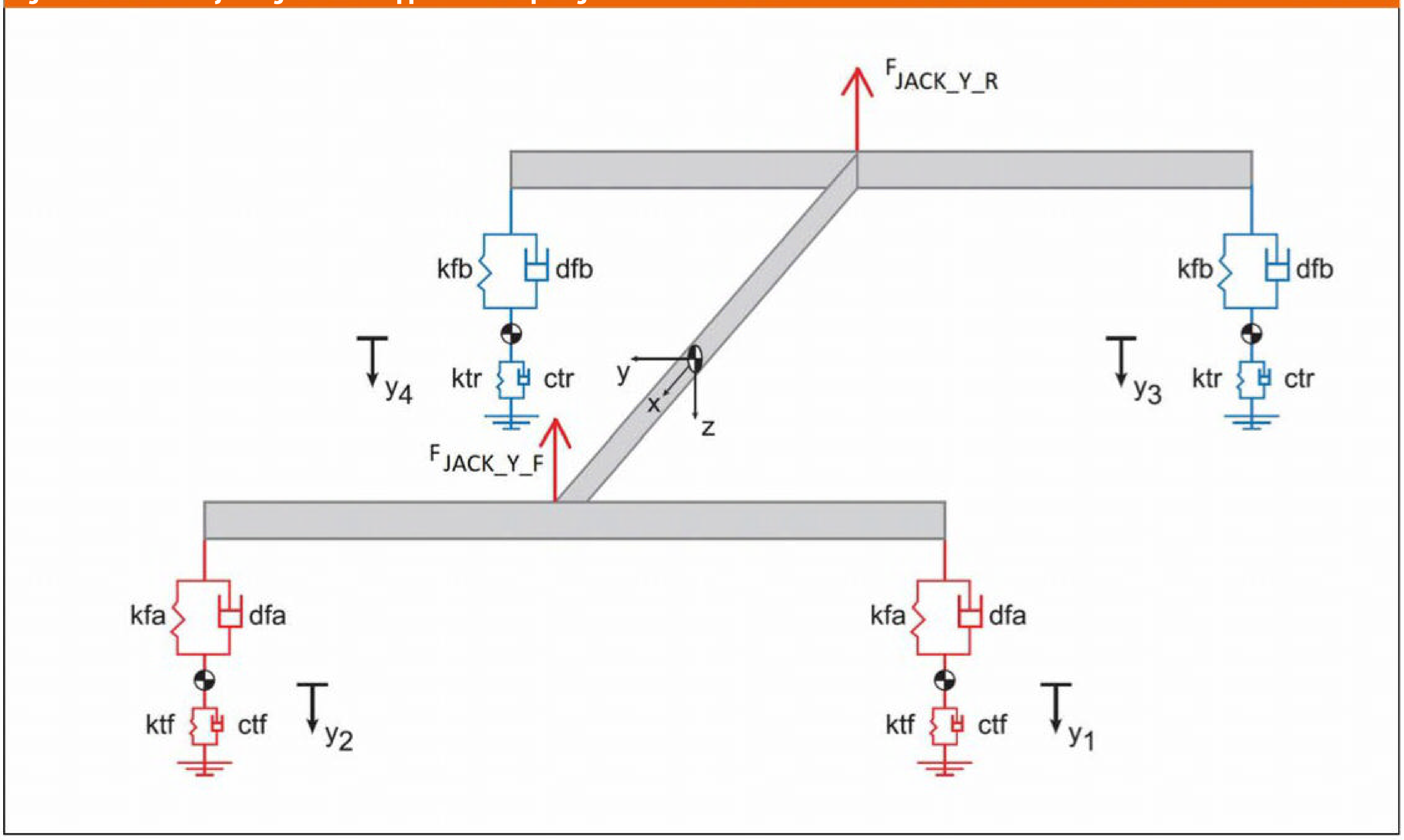


Fig 2: How the lateral jacking forces are applied to the sprung mass



Where they make their presence felt is at the middle of the corner with large load transfers or asymmetric set-ups. That said, there is a curve ball here, but we'll come to that shortly.

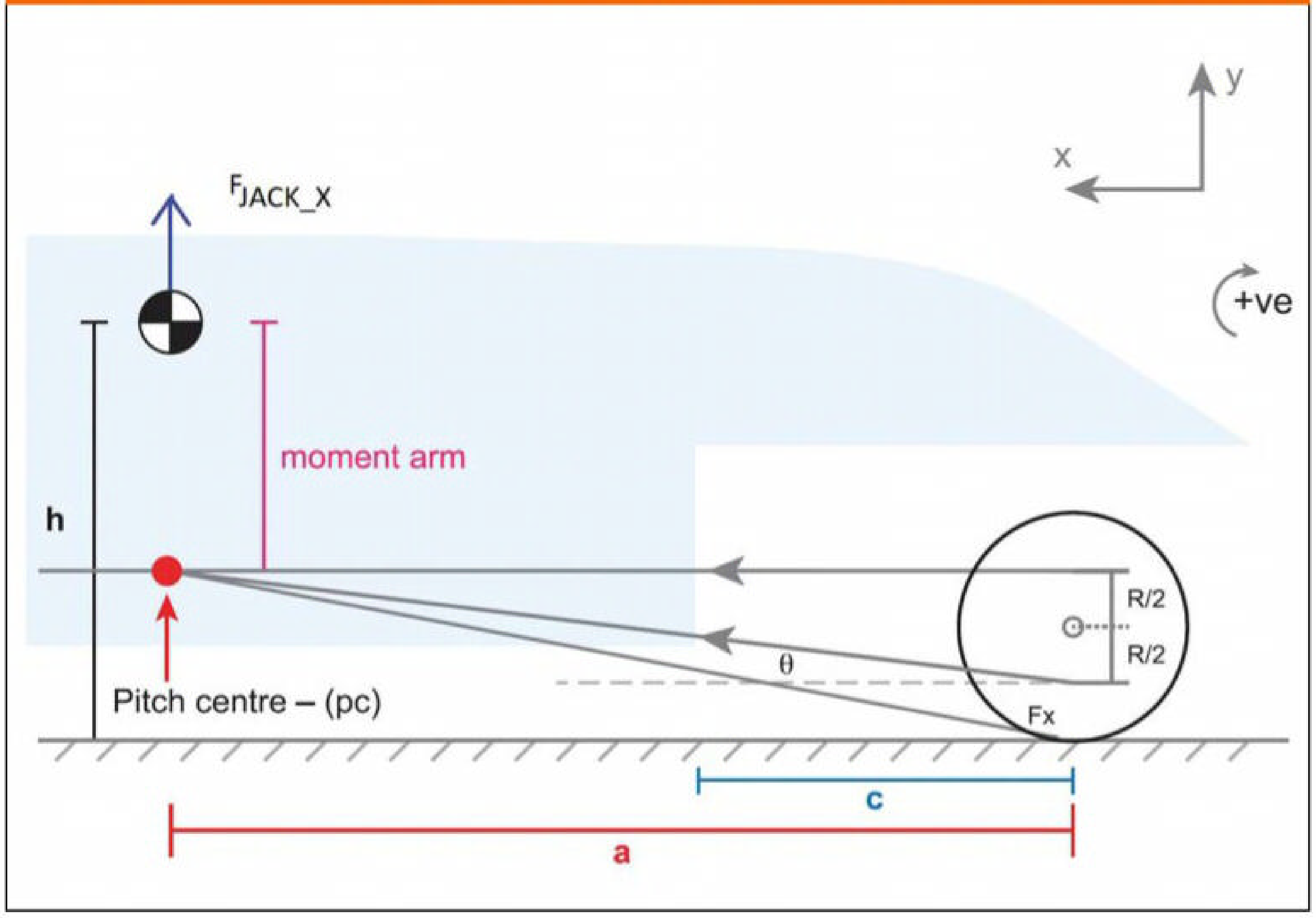
Longitudinal forces

The longitudinal jacking forces are driven by exactly the same mechanism as the lateral case, as illustrated in **figure 3**.

As with the lateral jacking forces, for ease of illustration we have assumed a simple 2D visualisation that can be a four link or double wishbone suspension. As with the lateral case, what drives the longitudinal jacking force is the vertical components of forces in the longitudinal suspension linkages. Again, we only need to add this to the c of g since we have already taken into account the pitch centre of longitudinal force application point by resolving the moments.

Also, as per the lateral case, we can readily relate the pitch centre location to the longitudinal forces. Your guiding principle here is **equation 3**.

Fig 3: Longitudinal jacking forces origin



$$F_{JACK\_X} = \frac{F_x \cdot pc}{t} \tag{3}$$

Where,

F_{JACK_X} = longitudinal jacking force
pc = pitch centre location
t = moment arm from the axle to the c of g
Fx = applied longitudinal force

Where things deviate is with the longitudinal jacking forces, provided they are symmetric. Unlike with the lateral case, they are applied straight to the c of g and not per axle. It's a very important distinction and a trap for young players. What drives this is we have already taken into account the moments thanks to the pitch centres.

Now, in terms of an overall formulation for the longitudinal jacking forces, we have **equation 4**.

$$F_{JACK\_X} = \frac{-F_{xf} \cdot pc_f}{a} + \frac{F_{xr} \cdot pc_r}{b} \tag{4}$$

Where,

F_{xf} = front applied longitudinal force (positive forward)
F_{xr} = rear applied longitudinal force (positive forward)
pc_f = front pitch centre
pc_r = rear pitch centre
a = distance from front axle to c of g
b = distance from rear axle to c of g

$$F_{JACK\_X} = \frac{\left(-F_{x1} \cdot pc_1 + F_{x2} \cdot pc_2\right)}{a} + \frac{\left(F_{x3} \cdot pc_3 + F_{x4} \cdot pc_4\right)}{b}$$
$$M_{JACK\_X\_ROLL} = \frac{\left(-F_{x1} \cdot pc_1 + F_{x2} \cdot pc_2\right) \cdot tf}{2 \cdot a} + \frac{\left(F_{x3} \cdot pc_3 - F_{x4} \cdot pc_4\right) \cdot tr}{2 \cdot b} \tag{5}$$

One thing we do need to discuss here is the case where the longitudinal forces are asymmetric, either through badly conditioned suspension geometry or asymmetric running. In this case, **equation 4** becomes as shown in **equation 5**.

Where,

$M_{JACK\_X\_ROLL}$ = rolling moment due to the jacking force (positive to the right)
$pc1$ = pitch centre, front left
$pc2$ = pitch centre, front right
$pc3$ = pitch centre, rear left
$pc4$ = pitch centre, rear right
$Fx1$ = longitudinal force, front left
$Fx2$ = longitudinal force, front right
$Fx3$ = longitudinal force, rear left
$Fx4$ = longitudinal force, rear right

In all cases, longitudinal forces are positive forward. To keep the maths simple, I've assumed the c of g is in the middle of the car. I should also add the reason we have a rolling moment due to the asymmetric effects of pitch centres is the same reason we needed to take into account the front and rear lateral jacking forces' effects on the sprung mass. The mechanisms are identical.

What this shows is that for asymmetric set-ups, such as Sprint Cars and Dirt Late Models, this is something you can manipulate to get a result you want.

Load transfer

So, the next question to be asked is what roles do jacking forces play in load transfer? The answer is they bridge the gap between what is going on with the sprung mass and unsprung mass so the load transfer equations we know and love all work out.

The lateral case is very straightforward. The moments we resolve in the unsprung mass to sprung mass work out quickly.

What is more surprising is the longitudinal case, particularly if you have load transfer happening on just one axle. For example, in acceleration for rear-wheel drive. At the rear, the load transfer equation is the reaction of the moment of the sprung mass combined with the jacking force applied at the rear tyre. But what happens at the front is that jacking force applied at the c of g going vertically up tidies up the load we see on the front axle. Here, the jacking forces ensure all the numbers add up nicely.

When the forces are equally distributed left to right, the lateral jacking forces are bystanders since the terms cancel out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ARP
CP
Drenth
tilton
ARROW
SCHRICK
ATI PERFORMANCE PRODUCTS
CAT CAMS
COMETIC
QUAIFE
VAC
Billet Engine Blocks
• High Strength 6061-T6 Aluminium Block
• Extreme Weight Savings over Factory Iron Block
• Can Stand 1500+ Horse Power
• S14 | S38 | M50 | M52 | S50 | S52 | S54 Applications
VAC
Stroker Kits
• Rally | Drag | Hill Climb | Road Racing | Drifting
• S14 | S38 | M50 | M52 | S50 | S52 | S50B30 | S50B32 | S54 | S65 | S85 Applications
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When we resolve the forces and moments about the hub for the lateral case, this system becomes statically indeterminate

Now that we have discussed what drives this principle, we need to talk about the wild cards in the pack. For jacking forces, where these wild cards come in is how the spring / damper unit is mounted. To kick off this discussion, let's talk about the longitudinal case, as illustrated in **figure 4**.

Damper mounting

What we see here is the spring damper unit mounted vertically. In this case, we have zero cross pollination with what is going on between the sprung mass and the jacking forces. The jacking forces here then are a slam dunk and correlation is straightforward.

However, things are not so clear cut in the lateral case because achieving that vertical mounting is very difficult. Let's consider this for a pushrod-mounted suspension, as illustrated in **figure 5**.

What happens in this case is that when we resolve the forces and moments about the hub for the lateral case, this system becomes statically indeterminate. That doesn't mean the jacking forces go away. On the contrary, they are always there, but what it shows is that it's not going to work out completely as advertised.

I should add here, though, that in the case of a lower control arm mounting, the lateral jacking forces will behave much closer to the ideal case.

XPB

Jacking forces must be considered during suspension design, as they not only impact tyre performance, but also the sprung mass loads

Fig 4: Spring mounting, longitudinal case

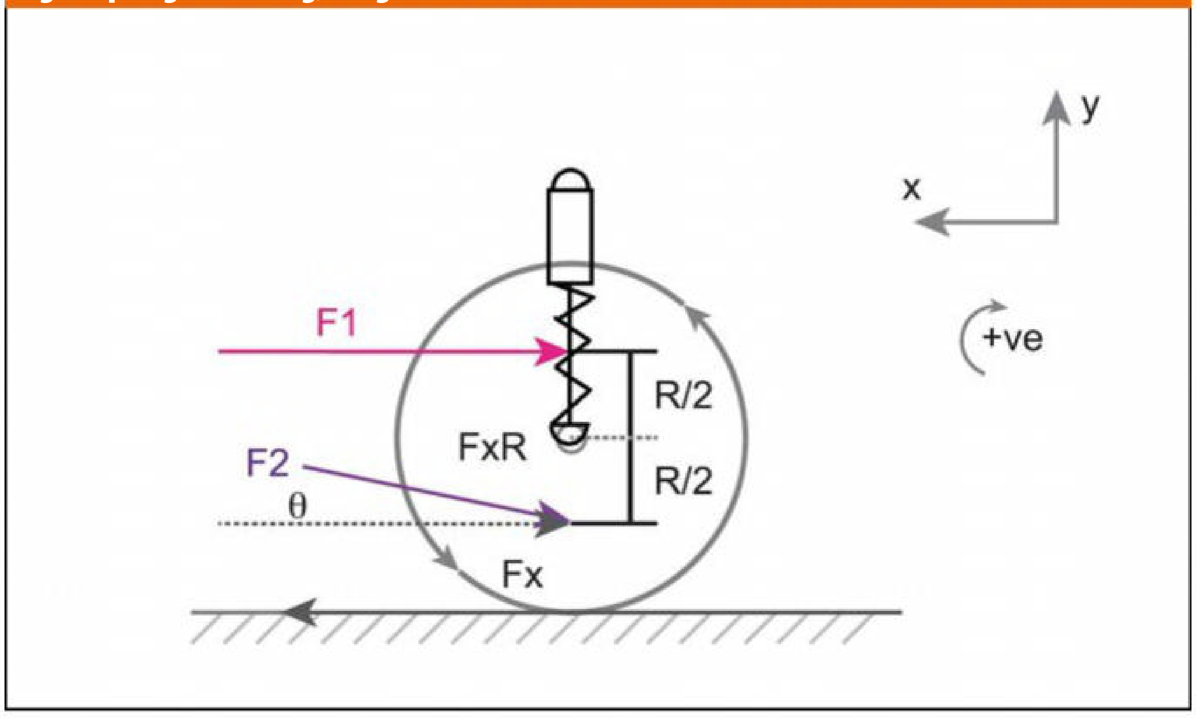
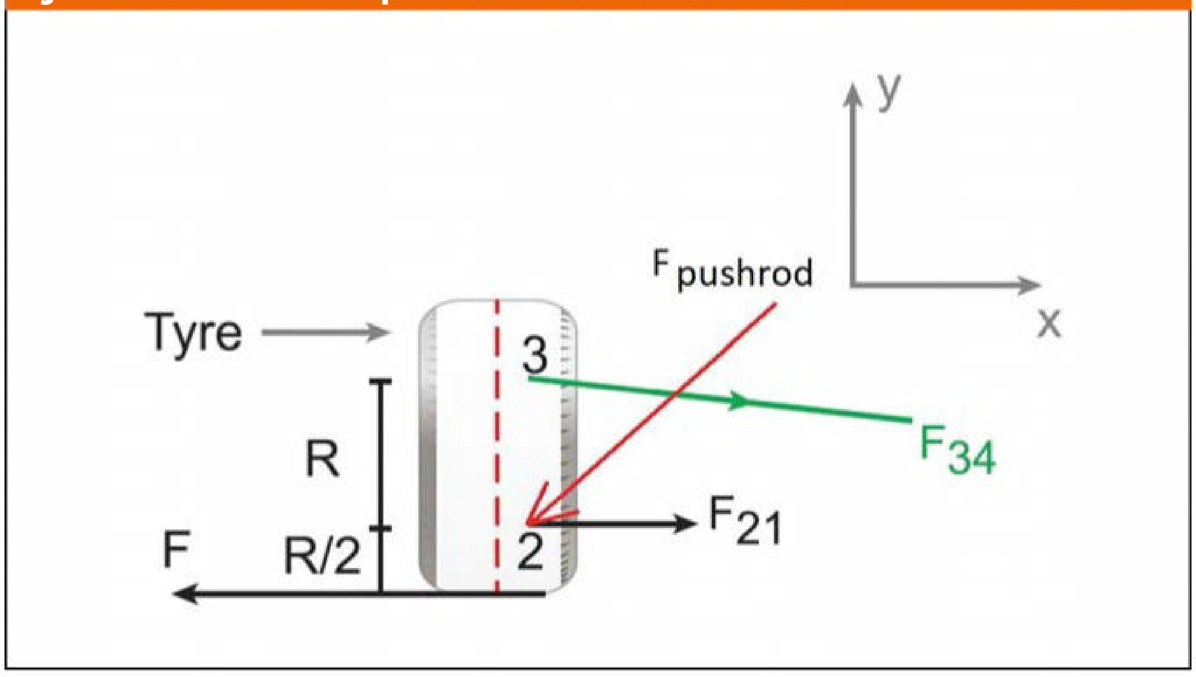


Fig 5: Pushrod-mounted suspension



Conclusion

So, to wrap this month's discussion up, here are some rough rules of thumb for when jacking forces make their presence felt. In the lateral case, with anything less than about 25 per cent of the c of g height for the lateral roll centre, you can pretty much get away with not taking jacking forces into account. While this is far from perfect, it allows you to do quick and dirty approximations to get into the ballpark.

In terms of anti-squat / dive, if you are over 50 per cent, jacking forces well and truly make their presence felt.

Jacking forces are therefore a very important part of the suspension geometry kaleidoscope. Not only do they impact on the tyres, but also on the sprung mass. There are a few things to watch out for, but what jacking forces do is tidy up the load transfer numbers we see. If you are clever about it, there are quite a few things you can do to exploit this, but remember the final arbiter in your correlation is *always* the data. Ignore it at your peril, and don't end up in the ditch over a textbook.

Physics at work

Dutch company, Intrax, offers *Racecar Engineering* an insight into the technologies it employs to optimise its suspension products

By Stewart Mitchell

In the realm of vehicle dynamics, the spring and damper system plays a significant role in compliance on track. It controls the relative motion between the sprung and unsprung masses, and is arguably the most critical influence on tyre performance.

However, not all spring and damper systems are created equal, and in this domain of racecar engineering, there is a margin for applying philosophy to the science of suspension.

Enter Intrax, a Dutch manufacturer of high-performance suspension technology with over 40 years' experience at the highest level of motorsport. Intrax designs and manufactures suspension products for everything from Formula 1 to road car applications in its purpose-built factory.

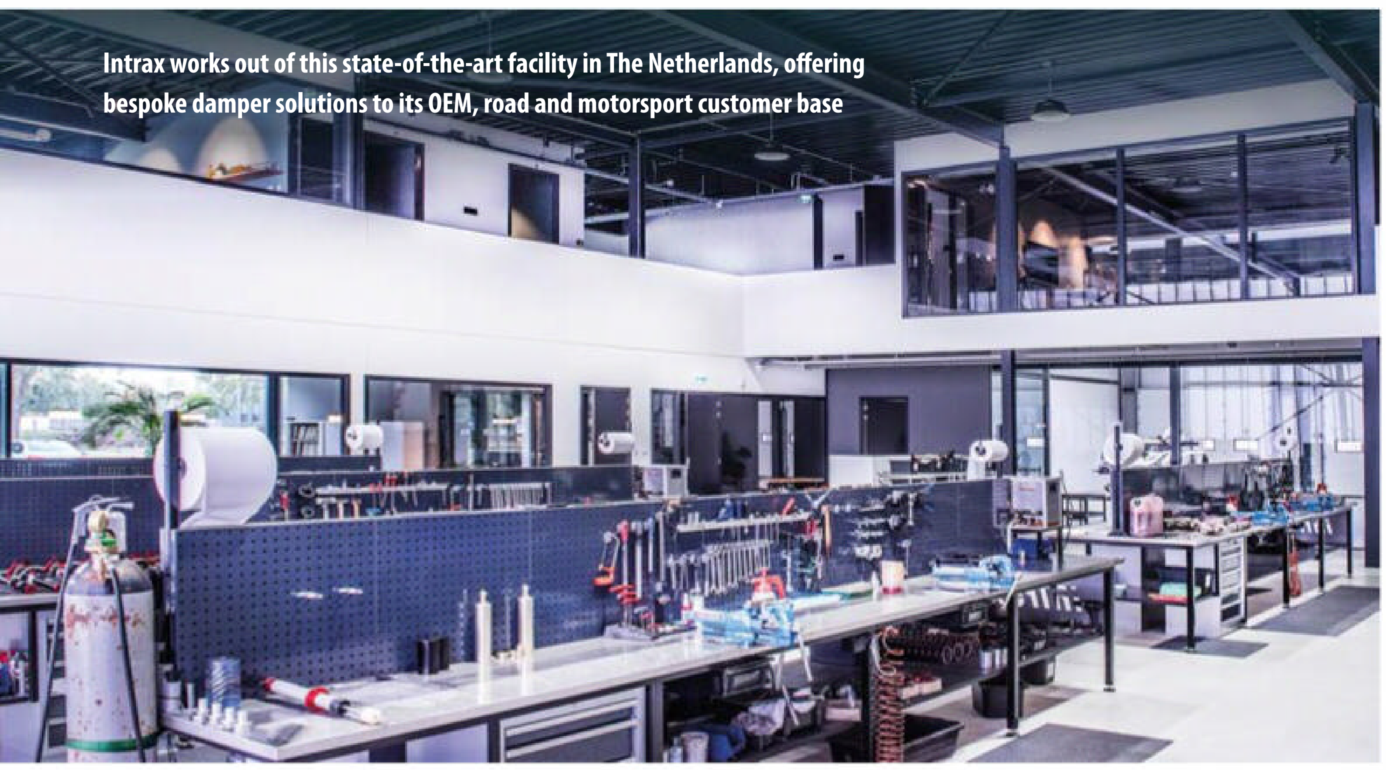
'Intrax's policy is to design, manufacture and race engineer the suspension system bespoke for each customer and application, because the challenges of controlling the relative movement between the wheels and the car cannot be considered standard for a given vehicle, or a given situation,' explains Niek van Sambeek, co-owner and suspension engineer at Intrax.

'By doing that, Intrax can significantly reduce the number and severity of the compromises involved in implementing racing suspension systems. Custom tailoring the suspension to the application vastly improves performance over standardised components and installations.'

Design philosophy

Intrax's design philosophy revolves around using the softest possible spring to maintain grip and compliance between the tyre and the road, and then engineering the damper to reduce body roll as much as possible. For this, it combines calculations for wheel frequency, damping ratio and weight transfer, and optimises all of this into construction before manufacture.

Technologies include developing gas pressurised monotube dampers and



Intrax works out of this state-of-the-art facility in The Netherlands, offering bespoke damper solutions to its OEM, road and motorsport customer base

Intrax was founded by racer, Henk Thuis, and many of its employees are racing drivers. He feels that experience on track puts it in a unique position to understand the needs of its motorsport customers

BMW E90 WTCC four-way adjustable damper with the company's Black Titan coating

Our methodology looks to run the spring and anti-roll bar as soft as possible, so less energy is transferred into the tyre, improving its longevity

unique, in house-designed pistons, valves and low friction coatings for each build.

Intrax also employs a research model to continuously evolve its knowledge of physics at play in its suspension systems, the company's engineers visiting its racing clients and race series it supports as often as possible.

'We are at the track, listening to our customers and race engineering the cars with them to improve the performance and collect vital information for our development,' notes Donald Molenaar, chief sales officer, successful racing driver and co-owner of Intrax Suspension.

'Our company is not just engineers that work on computers to provide set-up data, because this does not achieve optimum results. Mathematics may give as much as 90 per cent of the optimal solution, but the last 10 per cent is done through track testing, using experience and implementing the right driver feel for them to get the most out of the car.

'With all this first-hand experience, we can predict how Michelin, Dunlop, Hankook or other tyres behave in a given condition, at a certain track, and therefore how the suspension should be set up.

'Additionally, we understand the trade off between getting the peak performance of the tyre and ensuring a target average performance throughout a stint. These are solutions a computer-based technique cannot easily produce. It requires an acute understanding of the relationship between the spring, damping and anti-roll control and, therefore, the roll timing.

'While the spring oversees the ride height of the car and its vertical displacement, the anti-roll control manages the rate of displacement in pitch and roll. Understanding the suspension nuances and its effect on the tyre helps guide the set up of these elements to extract the best performance.

'Our methodology looks to run the spring and anti-roll bar as soft as possible, so less energy is transferred into the tyre, improving its longevity. Instead, the energy transfers to the shock absorber, which will not degrade like a tyre over a stint.'

Secondary valves

Intrax also uses a dual valve system on its dampers, which acts to control the car's roll rate in transition from bump to rebound. The secondary valve generates additional compression force when there is a change in the rate of load transfer in compression.

'The transition from bump to rebound is arguably the most important aspect of a suspension system as it is where the car can easily lose traction,' explains van Sambeek. 'To make the transition smooth, the valves must accurately manage the change of direction of the oil flow to make it as smooth and responsive as possible. To improve this transition, we use a second valve to manage the deceleration of the damper displacement post-peak load in compression. This control allows the oil direction change to happen quickly, keeping the tyre in contact with the road on route back to ride height position.'

The secondary valve solution also allows Intrax to run a lower gas pressure than would typically be seen in performance suspension systems, reducing the friction in the damper. The design of the oil flows in the valves and the damping rate additionally reduces the risk of cavitation. The pressurised shock absorber with an internal piston is shimmed for the correct position for the car and application.

Intrax specifies its dampers with any combination of adjustability up to four-way adjustable (high and low-speed compression, rebound and displacement operating window adjustment). Dampers with bleed adjustments, pre-load and a pop-up / blow-off valve control the forces and the relative movement of each.

'It's not only one technique or parts you use to make high-performance suspension components,' says van Sambeek. 'The combination from all high precision parts, unique technics and settings working together makes the suspension the best it can be and offers optimum performance.'

Coating technology

Intrax has also developed a coating it calls Black Titan that, van Sambeek says, 'provides consistent suspension dynamics across a range of damping scenarios, contributes to uniform suspension performance and extends the lifetime of parts.

'We use it on the piston rod and the inner tubes, reducing the friction and stiction, which is very important, especially with McPherson strut-type suspension. Going through a corner with a high *g*-force causes a sizeable bending force on this type of suspension, affecting its performance.

'The Black Titan coating allows for smooth damper motion during cornering, providing a better steering feel, more grip, better tyre life and tyre performance.

'With this coating, Intrax can produce Macpherson strut-type suspension with up to a 57mm internal diameter of the piston rod, significantly larger than most damper units due to the friction the surface area would produce. This additional diameter capability adds significant stiffness to the damper units, further improving suspension performance.'

Intrax Suspension, Kantsingel 34 5349AJ Oss, Netherlands
Tel: +31(0)413 272997 Email: info@intrax.nl Website: www.intrax.nl

F1 breaks schedule records

The FIA has confirmed no fewer than 23 races on the 2022 Formula 1 World Championship schedule, the highest number of grands prix ever to be held in a single season, and that has led to criticism from some teams that will be on the road for eight months.

The race schedule, not including pre-season testing, runs from 20 March in Bahrain to 20 November in Abu Dhabi, and includes a return of the Australian Grand Prix on 10 April and Japan on 9 October, as well as races in Singapore and Montreal. Each were forced to postpone in 2021 due to travel restrictions surrounding the Covid pandemic.

Confirmed by the FIA World Motorsport Council in October, the schedule does not include the Portuguese Autodromo do Algarve, or the Istanbul Park in Turkey, which were both temporary, if popular, stop gaps for the series as it battled to host races during the global crisis.

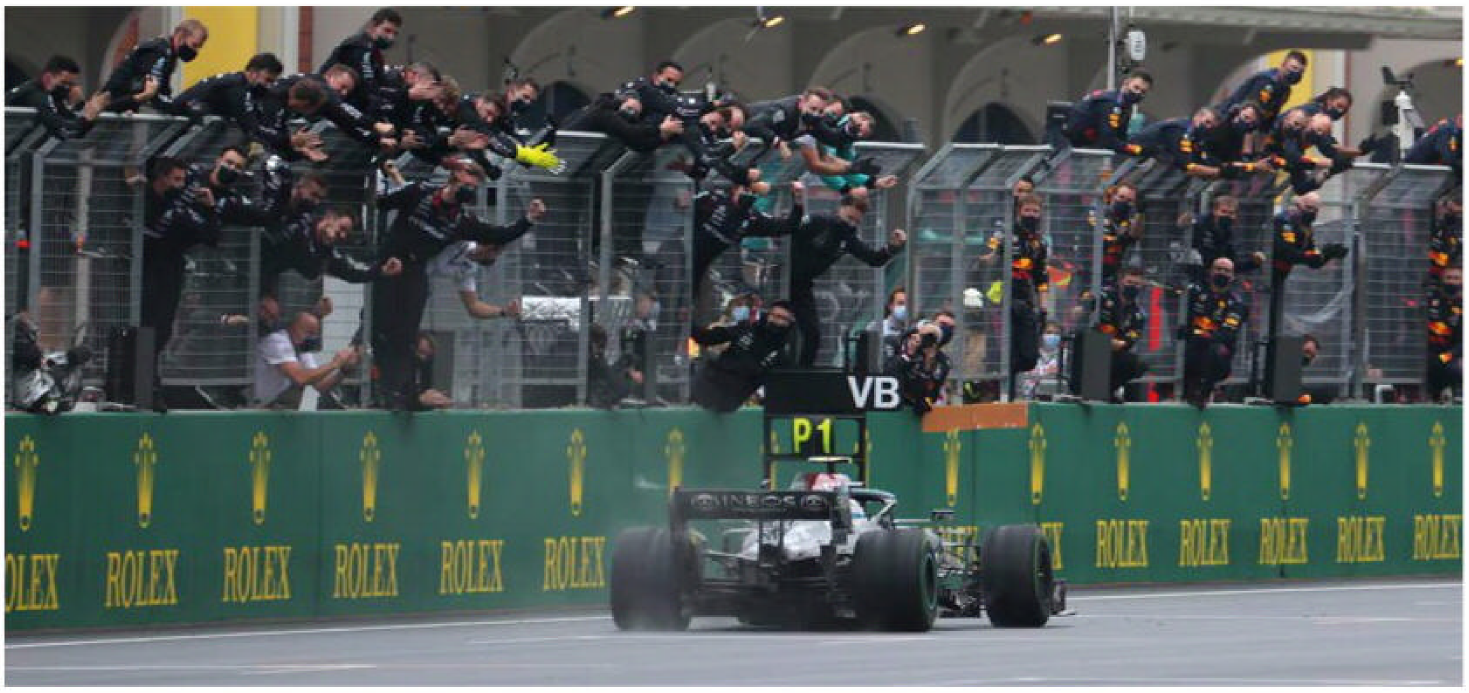
China will not hold a race next year due to its continued travel restrictions, which leaves the door open for Imola to host a round once again.

The schedule is too short for teams to invest in second teams to alleviate the travel burden on race-based personnel but, while some team owners raised concerns, others were more robust in their defence.

'Of course, we take care of the people,' said AlphaTauri's team principal, Farnz Tost, who was one of 10 team principals to sign the Concorde Agreement that can extend the season to a maximum of 24 races in a single season.

'For example, mechanics after a race weekend have three or four days off where they can stay at home. For engineers, it's a bit more difficult, but also if I remember back in former times they had to go to tests after a race weekend and work there.

'I think we should be happy that we are in a position to be in Formula 1 and to have 23 races. If someone doesn't like it, then they should go.'



XPB

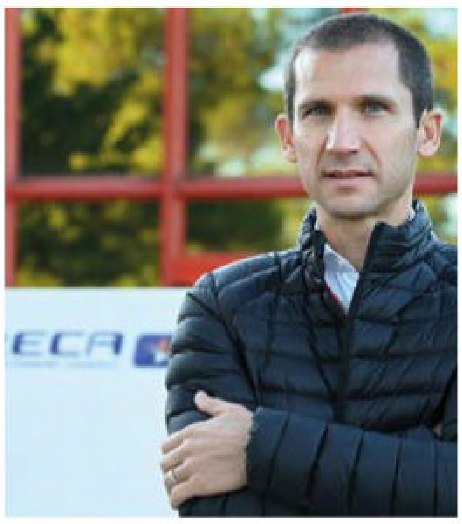
F1's 23-race schedule for 2022 will put pressure on track personnel, but some teams see the new, extended schedule as beneficial to the series

ORECA welcomes Taffin into the fold

Remi Taffin, former director of operations and engine director at Renault Formula 1, has taken a role as technical director at Signes-based ORECA, replacing David Floury who has moved to Toyota on a full-time contract as chief race engineer.

ORECA provides operational support for the Toyota World Endurance Championship team and Floury, technology and technical director at ORECA since 2004, and who has been the chief race engineer on Toyota's LMP1 and Hypercar programmes since 2012, has now made the switch between companies permanent.

Taffin will be responsible for ensuring the continuity of the structuring of ORECA's technical departments at a time when ORECA Technology is carrying out sports and technical projects with numerous partners. 'His technical skills, mastery of new technologies, high level of experience and customer philosophy will all serve the company at a time when it is experiencing an important stage in its development as one of the world leaders in the construction of racecars,' said ORECA group president, Hugues de Chaunac.



Remi Taffin will continue to push technological boundaries for the French racecar constructor

'He will succeed David Floury, a key player in our success in endurance racing, who helped ORECA achieve a significant number of sporting, technical and commercial successes.'

ORECA is one of four manufacturers that will provide chassis to LMDh manufacturers, including Renault and Honda Performance Development, and also won the contract to design, develop and then supply the next generation of Ferrari GT3 cars, having won the contract over long-time partner, Michelotto.

IN BRIEF

French car company, **Alpine**, has finally confirmed it will compete at Le Mans in the LMDh category in 2024 with a car supplied by **ORECA**. The announcement, shortly before Remi Taffin was confirmed at ORECA, was expected at Le Mans in August. The company says that it will share technical knowledge with the F1 team.

Hybrid World Rally Championship cars will be fitted with the FIA Artificial Intelligence Safety Camera from 2022 that will scan the road on special stages and monitor spectator activity. The cameras will help the FIA safety delegate address potentially unsafe situations. Zones where the cars must run in electric mode will be identified in the road book.

Technical regulations for the **FIA World Rally Raid Championship** have been modified to allow for alternative fuels to power the T1 Ultimate category vehicles. The class will now accommodate electric motors and an ICE engine powered by hydrogen or hybrid.

McLaren Applied has appointed **Nick Fry**, former CEO at Mercedes F1, as non-executive chairman. Fry's appointment is the first at board level since Greybull Capital acquired McLaren Applied in August 2021. Fry's previous roles include managing director of both Aston Martin and Prodrive, as well as several leadership roles across the Ford Motor Company.

AP Racing has become technical partner to **Bahrain Raid Xtreme** and will supply the Prodrive Hunter to meet FIA T1+ cross country regulations to compete in Saudi Arabia in January 2022.

Nick Fry moves to McLaren Automotive

Williams' 2030 ambition

Grove, UK-based racecar constructor sets out its five-pillar approach to achieving sustainability and creating technical solutions to global challenges

Williams Racing has committed to becoming climate positive by 2030 as part of an all-new sustainability strategy.

To achieve this, the company has developed a series of technological and data initiatives across five pillars: Climate Action will cover the strategy and targets for the team to reduce carbon emissions for travel and at its Grove headquarters; Biodiversity Stewardship aims to protect the 60-acre HQ campus; Sustainable Innovation will look to tackle challenges inside and outside Formula 1; Industry Access For All has the aim of encouraging a workforce that reflects the local community through academy programmes; and lastly, Purpose Driven Leadership, which aims to encourage sustainability in motorsport as a whole.

'As a team we wanted to push the envelope and be the pace setter for sustainability in global motorsport and the wider automotive industry,' said Williams CEO, Jost Capito.

'We are making the commitment to be climate positive by 2030 and we will be using our knowledge to nurture and develop advanced technology to meet this goal.

'As a huge global sporting platform, Formula 1 has the power to inspire millions of people all across the world and, as the pinnacle of so many advanced technologies, Formula 1 has the ability to create technical solutions and innovations to help tackle the global challenges we all face as a planet.'

Future composite options

Retrac Group, one of the UK's leading composites and metallics manufacturing specialists, has launched its bio-composite range with five sustainable or recycled composite material options.

The product of an extensive R&D programme by the Group's Retrac Composites division, the Retrac Future range showcases an array of recycled carbon fibre and natural fibre products for multiple applications

With five new products, Retrac Group aims to be at the forefront of the 'lightweighting revolution'

across various lightweight structures. 'The world is on the cusp of a lightweighting revolution, and Retrac Group is positioning itself at the forefront of knowledge and techniques to maximise the successful applications of natural fibres and recycled composites,' says Retrac Group CEO, Dan Walmsley.

'The meny of material options in the Retrac Future range serves to demonstrate to customers the breadth of what is possible with our various processes using sustainable and recycled materials.'

Retrac Group has forged alliances in the supply chain with leading flax natural fibre specialist, Bcomp, and also with Composites Evolution, the UK-based pre-preg manufacturer and supplier that earlier this year launched its Evopreg ampliTex pre-preg range.

IN BRIEF

The Indy Lights series has appointed former champion driver, **Levi Jones**, as director. Jones will oversee all operations and competition of Indy Lights, which is the final stepping stone on the 'Road to Indy' ladder that brings young talent into IndyCar racing. Aged 39, Jones comes to his new role after working in competition and executive positions with the USAC organisation since 2015.

Bosch has extended its partnership with Formula E for a further three years that will now see it through the end of season 10. The company will work with Formula E to provide more powerful, lighter racecars for the all-electric series.

TOCA, organiser of the British Touring Car Championship, has announced its cars will carry an onboard visual signalling system next season. This will alert drivers via their dashboards of yellow flag zones, red flag stoppages, Safety Car periods, black flags and other important safety messages. It is expected support races will add a similar system.

Tyre manufacturer, **Pirelli**, has outlined a sustainability strategy that will enable its factories be powered by 100 per cent renewable electricity by 2025, and be carbon neutral by 2030. The company has already reduced the specification and mix of its GT3 tyre range from 10 to four sizes, and its GT4 offerings from 18 to 12. Its GT programme will aim to use 30 per cent more renewable material by 2025, and create 20 percent fewer prototypes in 2022, due to a greater reliance on virtual development.

Stephane Ratel's organisation has warned teams competing in the GT World Challenge races that a newly-formed committee will have the power to upgrade or downgrade drivers outside of the FIA's system of Platinum, Gold, Silver or Bronze.

'At the moment we have two categories, Platinum and Gold, covering the same drivers,' explained Ratel. 'Then there is a huge Silver class that runs from young professionals to accomplished amateurs. They are two different kinds of driver so that doesn't make sense.'

Interview – Craig Wilson

Electric storm

Racecar *talks to the race director at Jaguar Racing about the demands and challenges of Formula E*

BY STEWART MITCHELL

With the race for electrification in mobility in full swing, there is no more poignant time in history for motorsport's speed of innovation and rapid product-to-market cycle times to be employed.

There's a real rationale for electrified powertrain firms' involvement in motor racing as it provides a fast track for high-performance driveline systems and a proving ground for the technology. Formula E has been the innovation centre for many OEMs since its inception and today, the evolution of the powertrain hardware and software is faster than ever.

Craig Wilson, race director at Jaguar Racing Formula E team, has been working in the automotive and motorsport arenas for decades, and has seen the targets of the sport mature in that time. The constructors he has worked with have changed their powertrain focus from internal combustion engines through to hybrids and full electric.

While electrification has been around for a long time, the recent drive for efficiency, forced in part by motorsport regulations, has brought about a massive acceleration in development operations to improve systems efficiency and performance.

Wilson believes there has never before been a time when there is as much relevance between race and road technical environments as there is today: 'The motorsport environment is fantastic for extracting performance from every system element, as there is nothing unnecessary in the car,' he notes.

'In Formula E, powertrains are limited to two per car per season, and each is a sealed unit. If a team needs a third, it's a 20 grid place penalty. So, along with performance, reliability is a hugely important factor.'

In the last few years, powertrain technology has begun to converge, as teams home in on the best ways to exploit technical regulations, developing techniques and technologies to find that nth degree in performance. Cooling, software and material development have all become vital as teams try to extract more power within ever decreasing weight and packaging envelopes. With that optimisation, minimal changes can mean a lot.

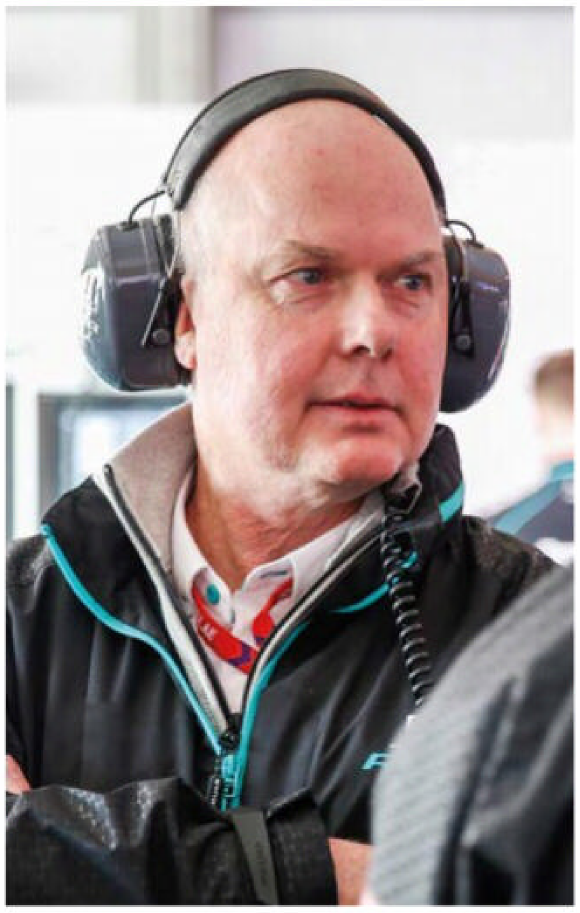
Powertrain overview

Despite many Formula E teams having practical experience with the sport, there are still several different powertrain architectures visible on the grid. Both longitudinal and transverse motor-to-transmission orientations are in use, though all teams run a single speed ratio transmission.

'Many teams learnt early on that losses in transmission efficiency and gear change time weren't conducive to the fastest overall car,' says Wilson. 'So nobody's running a geared transmission.

'Then it's a matter of optimising motor speeds and transmission reduction speed, and there is a variety of those in the formula. There are also different approaches to parts like the inverters and controllers. That's where there are some differences, and there will continue to be some differences.'

In the ongoing search for efficiency and control improvements, teams look at the minutiae of motor control, and how accurately the control modes manage the car. The nth degree is where software and architecture come into play together.



Jaguar Racing

Craig Wilson, race director, Jaguar Racing Formula E team

The challenge is to optimise at the limits, but not over them, and optimise them for every second you're on track

Formula E

Jaguar Racing driver, Sam Bird, taking victory at the 2021 New York E-Prix

'The software is critical because teams can get penalised for things like overpowering,' explains Wilson. 'These could be little spikes for a millisecond of too much power consumed by the motor, and FIA sensors will pick it up and alert the stewards. The challenge is to optimise at the limits, but not over them, and optimise them for every second you're on track. If you're giving yourself headroom, that is unexploited performance.'

Motor architecture

Internal permanent magnet synchronous motors with radial flux operation and peak speeds of around 30-40,000rpm with the single reduction gear is current the most popular choice throughout the Formula E paddock.

Formula E

The challenge for powertrain supplier to Jaguar Racing, GKN, is to transfer the developments made in Formula E directly into the

Formula E

Electrical safety and ingress protection is critical in Formula E as the cars must work optimally in all conditions and environments the series travels to

wider engineering environment. GKN's road car e-motors, for example, take advantage of the Formula E e-motor innovations in cooling efficiency.

Recycled materials

One part of the package that is becoming ever more critical is sustainability in the powertrain systems, as well as other elements of future production cars. For example, when using recycled material in motor construction, teams can find magnets from more sustainable supply chains.

'In some cases, this strategy will yield a compromise in performance, but how we best protect adequate performance for the market, and push that to its limit, and still protect sustainability, and the cost / benefit equation is GKN's task,' says Wilson. 'GKN takes elements of the sport going to the edge of the technology and applies them to a sustainable EV powertrain model.'

Some of the cost in Formula E motor technology is the use of exotic materials for high performance. But there are other things that Formula E competition teaches, such as efficiency in assembly and design techniques. These include how the engineers arrange the e-motor windings. Teams can find significant production efficiencies using these methods that could allow them to use a lower cost, lower grade wire, aiding the development and transfer to road car technology.

OEMs associated with Formula E have the advantage of taking what is being learnt in motor design optimisation and applying some of that into mainstream automotive, but without the same exotic material usage.

'Formula E e-motors operate at high 90 per cent efficiencies, and with single speed transmissions can yield extremely high energy exchange,' remarks Wilson. 'In an automotive application, with different materials, the outcome might be two or three per cent less, not a huge margin, and it's a very different cost level. There's also a weight factor with the housing and other elements of the powertrain, being significantly lighter than a road car version. The weight-to-cost equation is still essential for automotive applications, but not in the same way as in Formula E. Both are weight sensitive, but not on the same level, so compromising where needed is vital.'

Thermal management

The cooling system targets of a racecar are never static. Engineers must size and design cooling systems to coincide with the extremes of the locations where races take place. At an event such as Mexico City, there are capacity challenges from a cooling perspective due to the elevation of the circuit and the thinner air reducing cooling capability.

'The ambient conditions of places like Mexico must be baked into the system architecture so the car can always perform at its highest potential,' says Wilson. 'There needs to be some wriggle room for if, in the second homologation year, Formula E ends up with a new addition on the calendar that gives us another extreme to deal with. Teams set about their car design considering the operation framework in on-track conditions where the race calendar visits.'

Jaguar Racing has competed since season four and believes that the pace of development is in keeping with government targets for electric cars

'Teams like Jaguar Racing, who have been in Formula E for a while, have a lot of data in their Formula E careers and can anticipate the conditions at previously visited circuits quite well. Jaguar Racing is therefore confident in its concept design requirements for the spectrum of locations the championship visits.

'Teams are allowed to change radiators and other ancillaries, but can't change the e-motor, inverter, gearbox or another powertrain-related hardware, restraining development that way. However, we have confidence in our development strategy here.'

As Wilson explains, improper thermal management of e-motors doesn't have to last long before an unrecoverable event can occur:

'Most of the Formula E electrical components are highly stressed and thermal management critical so, if a thermal event is triggered, that part is going to fail quickly.

'Jaguar, like many teams, has battled issues with component failures, and it's been as a result of inadequate thermal management. Component temperatures must be optimised, rather than simply taking as much of the temperature away as possible.

'With the strive for efficiency, Formula E cars are energy limited. How much of that is consumed by the cooling system is vital to overall car efficiency. Formula E cars don't want the cooling system to be costing a lot of energy, as consuming more energy to power cooling systems means less energy for drivers to deploy on the track.'

GKN and Jaguar Racing

Formula E

Jaguar Racing's powertrain partner, GKN, has been with the team since it joined Formula E in 2017

GKN's partnership and technical collaboration with Jaguar Racing started in 2017, season four, and has focused primarily on driveline efficiency. GKN is engaged in a few core areas of the e-drive system's development. One of those is cooling where, alongside the race team, GKN engineers test, analyse and simulate advanced cooling developments at a full system level, particularly validating it at the test bench.

The modelling work carried out in this partnership is considered critical to arriving at the most effective compromise in a complex mechatronic development programme designed to achieve optimal efficiency.

Additionally, the two firms work together on software development for e-drive driveline control, each recognising how key this component is to an integrated e-propulsion system and, to a large extent, its overall performance. It's an area that both partners are set to benefit from in terms of product development and championship competitiveness.

In the future, GKN will continue to work together with Jaguar Racing on advanced electronics research, new architectures and e-drive applications with the hardware and software developed in the Jaguar Racing Formula E partnership.

Component temperatures must be optimised, rather than simply taking as much of the temperature away as possible

Vibration and interference

Robustness is a crucial consideration for the performance of any racecar because you can't win a race if you don't finish. The e-motor in a Formula E car is relatively safe, contained well within the crash structure. Transmissions, on the other hand, are mounted right at the back of the car and are more vulnerable.

Vibration is another significant issue to manage with so many delicate electrical components. 'E-motors tend to be the source of vibration, not its recipient, so it's more critical in some of the other electrical areas like inverters and control units,' explains Wilson 'Bench testing and validation, including vibration, temperature and humidity testing cover thousands of miles before a season to address reliability.'

With year-on-year improvements in current density, power density and packaging of all the electrical systems onboard Formula E cars, teams must consider the issue of electromagnetic interference. Electromagnetic phenomena can be modelled and simulated through the rigorous test programme that is required to validate them. Electromagnetism is a bit of a black art, though teams are now beginning to understand more about it, and can mitigate some of it with hardware developments. Other factors, such as signal interference, can be controlled through software. GKN can model whole life cycles, and identify ways to extend life far more accurately today than even just a few years ago.

Gen 3 rules are applicable from the beginning of season 8 (2022-'23). The FIA is taking weight out of the cars, adding power and rapid charging, which will bring a new dimension to Formula E. However, Europe is legislating toward only all-electric new cars on sale within a decade. So, are the four-year cycle changes to Formula E architecture too long for the series to stay ahead, and will road car manufacturers surpass Formula E technology in that time? Wilson is confident that Formula E will remain relevant.

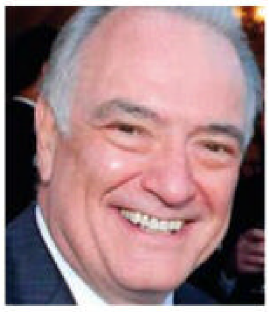
Arms race

'Software development is an arms race continually through a season,' he says. 'Software at a system level can unleash serious performance, which is directly relevant for road cars.

'Each of the technical partners has got its own area of expertise to contribute. Dow materials, Castrol fluids, and GKN with powertrain design and testing, support all the powertrain elements. Developing together on analysis and simulation tools at the vehicle level, particularly the testing and validation of that, GKN has a unique methodology and capability.'

As the targets for performance and reliability evolve, Gen 3 of Formula E will see new technical challenges. The two-year hardware homologation period remains, aimed at trying to contain costs, so for the teams the challenge will be optimising a package that will provide the performance and reliability needed for the duration of that period. Teams can change some parts at the end of the first season of the homologation period, but the main elements will still have the same design.

As such, if a problem arises, a team may be stuck with it for two years. Improving performance outside of the hardware will therefore still be the primary driver of the in-season technical exercise. Software will become an ever more significant component as teams rely on it more and more for optimising their cars and powertrains.



Welcome back!

As the motorsport world opens up once more, change is in the air

Hundreds of high-performance motorsport engineers and dozens of companies met face to face at the MIA Conference and Technology Showcase (CTS) at the Silverstone Wing in October. The pleasure and relief on the faces of all delegates was heartening to see. Their energy and enthusiasm gave a clear indication that we are on our way back – still a little cautious perhaps, but keen to re-engage with friends, old and new, and get on with business.

The timely theme was collaboration, and new partnerships linked to new technologies demanded by change.

A glance across the motorsport landscape, not even thinking of automotive, marine and aerospace, reveals the speed of change in technology. You only have to consider F1, most UK and European championships and the USA, where NASCAR and IMSA are embracing substantial technical changes.

So much so that Pat Symonds, CTO of Formula 1, has described this as the most exciting decade for innovation motorsport has ever seen.

Prodrive

The BRX Hunter Dakar contender from Prodrive is typical of the rapid development and production capability of the motorsport industry

Innovation on show

Adding to the upbeat, positive atmosphere at this new MIA event, novel and unusual innovations were on show, and spotlighted in the Conference which ran alongside. There, Symonds joined up with Xtrac's Peter Digby and Andy Damerum from Red Bull Applied Technologies (RBAT). Digby outlined Xtrac's critical collaborations, which support new technologies required in the USA:

'No one can be the world's leader in all technologies,' he said. 'Xtrac choose to work with the best suppliers, we then add our own world-class capabilities to satisfy our customers.'

Their dominance each year at the 24 Hours of Le Mans demonstrates that in practice.

Damerum enthusiastically encouraged those with new, relevant technology, which may benefit from the resources of RBAT to fully develop, to make contact. Although Symond's immediate focus is on the new Formula 1 engine, he made it clear he and his team are also looking further forward to secure new technologies:

'No one can afford to stand still in this decade of rapid change,' he said.

The 'electric motorcycle collaboration' between Williams Advanced Engineering (WAE), Triumph Motorcycles and WMG (part of the University of Warwick, UK) is fascinating. The high-performance battery heritage of WAE, linked with the specialised motorcycle battery systems knowledge of Triumph, WMG's extensive knowledge of testing electrification and Integral Powertrain for the motor and inverter help secure Innovate UK and APC funding for the project.

This group faces very different challenges with a motorbike than a car. The 'bike must be extremely robust, able to handle exposure to the elements, and has entirely different aerodynamics and c of g affecting its road holding. As they strive to overcome these challenges, future new technologies will be born.

With the exciting launch of its new sustainable fuel, Coryton confirmed Prodrive will use Sustain in the next Dakar rally, having now extensively tested and validated it. Coryton has worked with M-Sport and others who agree that, other than minor calibration changes in the engine, Sustain is a perfect 'drop-in' fuel to replace existing fossil fuels, and offer an 80 per cent reduction in greenhouse gas emissions in the process.

Coryton says motorsport is uniquely placed to show to the wider world the benefits of sustainable fuels. The volumes required are low in comparison to fossil fuels, as the details on Coryton's website show. This new product looks to be a great solution for competition series who can now improve their green credentials with minimal changes to current engines.

Now Nick Fry, former Head of Honda F1, has become chairman of McLaren Applied, we can expect this to become one of our fastest growing innovative companies. You could feel change is in the air when its director of motorsport, Matthias Dank, made it clear collaboration with new suppliers and partners is vital, and that they want to hear from those with an innovative project with whom they can work. He also introduced three of the company's technology partners: D30 Technology's world famous 'Orange Goo' has simply endless safety properties, with many applications in motorsport; torque sensors from Transense Technologies, using surface acoustic wave (SAW), is a world-class technology; and DC Electronics, a highly specialised electronics company with both UK and US production facilities.

McLaren Applied explained how working with collaborative partners benefit all involved – from access to markets, brand connections and a continuing source of new projects.

The first CTS event was so successful, the MIA announced a two-day event on 19-20 October next year in the Silverstone Wing.

Accelerate ahead

My lasting impression, from meeting so many of those involved in the industry, was that the UK's motorsport community is confidently planning to accelerate its business growth. And fast. It will enthusiastically embrace the decade ahead, no matter what technology challenges appear. It felt good that by working together, the unique Motorsport Valley community will gain strength.

The MIA is working hard to secure increased government funding as its aim is to push forward in making the UK a powerful, global R&D leader for the future. We can all help them achieve this.

PS The MIA's EEMS Conference and Technology Showcase is on 12 January at the NEC, Birmingham, UK, the day before Autosport International commences. I hope to see you there.

For more information on the MIA, look up www.the-mia.com, or contact info@the-mia.com

Collaboration with new suppliers and partners is vital, and [UK motorsport companies] want to hear from those with an innovative project with whom they can work

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Future vision

Two candidates, two very different manifestos. Only one can win

December this year will see the *Fédération Internationale de l'Automobile* (FIA) announce a new president after12 years under the leadership of Frenchman Jean Todt.

Since 2009, the motoring world has moved on and the sporting world has struggled to keep up. As governments have applied pressure to accept electric and hybrid cars, so racing has responded by following the trend. The lack of certainty around what will be the power source of the future has left the sport pursuing ever more expensive goals, and the reduction in the number of SMEs involved in the process has been alarming, as the FIA has increasingly relied on manufacturer guidance. Those same manufacturers who have been pressurised by European governments to produce a particular kind of powertrain.

In a bid to encourage more technology into the sport, long homologation periods, preferred suppliers to individual series and a lack of diversity of companies has led to a strangulation of the traditional motor racing world. As a result, companies are increasingly turning to other forms of motorsport, which partly explains the rapid increase in interest in historic racing.

Since 2009, the rise of electric motorsport has been extraordinary. Hybrids have become normal in Formula 1 and at Le Mans, so much so that conversations about the incredible efficiency of these power units has now pretty much stopped. Indeed, people are now talking about bio and synthetic fuels instead.

World domination

Hybrid technology has been increasingly introduced to motor racing series around the world, including the WRC, and soon we will see the British Touring Car Championship, IndyCar, NASCAR and IMSA all adopting hybrid powertrains. Full electric racing series are also on a steep rise, first with Formula E, and now Extreme E, soon to be joined by the DTM according to current plans.

The cost for this expensive technology is that technology competition has waned alarmingly. No longer do we have such a diverse set of chassis or engine manufacturers as we had at the start of Todt's stint as president. No longer do we have so many small engineering companies developing young talent. Sport has followed the automotive world in either shutting down such companies, or they are swallowed up by larger ones. History has shown this never ends well.

Two candidates are up for the presidency. One it seems will continue Todt's work, the other it appears will not.

Graham Stoker's manifesto, with nine-time Le Mans winner Tom Kristensen at his side, suggests this pursuit of technology will continue: 'The FIA must be proactive in leading the development of potentially vital solutions such as EVs, advanced ICE / Hybrids, e-fuels and hydrogen,' it says. 'The requirement to encourage pioneering development also applies to the digital and esports sectors, which are key to engagement with new generations and will play an increasingly significant role in achieving diversity and true accessibility for all in motorsport.'

Affordable and accessible

The other candidate is Mohammed Ben Sulayem, whose tone is strikingly different. As well as introducing grant-aided, lower cost entry to motorsport and local production of entry-level cross cars and karts, his plan is to 'double global motorsport participation by improving affordability and accessibility.' He also promises to 'work with manufacturers, suppliers, teams [and] clubs to improve sustainability.'

It's hard to imagine they are looking for high cost, hard-to-manage hybrid or electric systems to achieve this.

It's shaping up to be a fascinating battle, one that will have repercussions throughout the sport

Running alongside Ben Sulayem as the candidate for deputy president motorsport is former World Rally Champion, Robert Reid, while his candidates for vice president include one Fabiana Ecclestone, wife of the Formula 1 ring master, Bernie.

It's shaping up to be a fascinating battle, one that will have repercussions throughout the sport.

From the outside it appears the manufacturers' commission has become stronger than ever. The FIA has given even more power to the OEMs, and SMEs are consequently pushed to the outer rooms, if they are lucky.

This relentless pursuit of standardised technology and manufacturer money has left the sport in a precarious position, at the mercy of companies who can at any time pull the plug if it suits their marketing policy. And when they do, the teams, manufacturers and suppliers, whose livelihoods depend on the sport, are left in their wake.

Whoever is confirmed as the next president, with a vote on December 17, they have the future of the sport in their hands. We now wait to see what fate brings.

ANDREW COTTON Editor

Energy is life.
We all need it
and it's a source of progress.
So today, to contribute to
the sustainable development of the planet
facing the climate challenge,
we are moving forward, together,
towards new energies.

Energy is reinventing itself,

and this energy journey is ours.
Our ambition is to be a world-class player
in the energy transition.
That is why

Total is transforming and becoming TotalEnergies.

TotalEnergies