F1 ENGINES: Future powertrain ramifications under discussion – p8

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Switch craft

Why Former F1 drivers often thrive when they move to IndyCar

In the interest of fairness and accuracy I want to correct a comment I expressed in last month's column. This referred to F1 race director Michael Masi having considerable influence on penalty decisions awarded by the race stewards. A chat with my extremely knowledgeable colleague, Dieter Rencken, has assured me that the stewards do operate fully independently. I am grateful that he could assure me of this. My other comments stand, however!

Having watched a couple of entertaining NTT IndyCar Series races recently (12 different race leaders during the Indianapolis Road Course event) I was interested to see how drivers recently departed from F1 have been able to race for podiums and wins in IndyCar, something largely denied them since their junior racing careers due to the far-from-level F1 playing field.

After slogging away frustratingly for years with uncompetitive GP machinery, it's clear that, like Takuma Sato and Sebastien Bourdais before them, Marcus Ericsson and Romain Grosjean are thoroughly relishing the opportunity to race for outright honours, rather than relying on the misfortunes of others to, at best, scrape a point or two all-season. While Ericsson took a while plus a move to Chip Ganassi Racing to become a race winner (twice so far), Grosjean has been on it right from the outset with Dale Coyne Racing and surely a victory is on the cards soon. But then there was never a doubt about his speed in Formula 1, just his judgement and over-emotional red-mist moments.

Foreign exchange

At the other end of the experience scale, is F1 potentially missing out on young future stars? Alex Palou, Patricio O'Ward and Rinus VeeKay spring to mind, let alone the IndyCar home-grown talent epitomised by Colton Herta and Conor Daly. To this list might be added F2 racer Christian Lundgaard, who qualified a sensational fourth for his first IndyCar race, although as part of the Alpine Academy his future career might be directed back to F1, when the timing is right.

Inevitably, this might also raise questions as to the quality of driver skills between the world's two premier single-seater disciplines. Such conjecture is bound to be skewed, however, as it's not often that IndyCar drivers migrate to F1. Why endure the political and financial barriers to attaining a seat in a front-running car, let alone the exhausting travel schedule, coping with a different culture and learning new circuits when a good living and chances of success on a variety of challenging tracks are all available within the confines of the USA? Understandable, even though F1's earnings and global status might, potentially, be considerably higher.

However, it is also undeniably true that those few who have made the switch have not been conspicuously successful since the long-ago days of Mario Andretti. His son Michael's foray into F1 alongside Ayrton Senna was not without promise but lacked commitment. IndyCar stars Alex Zanardi and the aforementioned Bourdais never hacked it, surprisingly. Others, like Scott Dixon, have toyed with the idea but never moved beyond testing a Formula 1 car – often because the terms of any contract on offer were demeaning to an established well-paid winner, already a star in his own firmament.

Chris Owen/IndyCar

Romain Grosjean adapted to IndyCar very quickly and looks set to score his first win soon, but does that mean the US series is easier than Formula 1?

The quality of racing in IndyCar is among the best. Being less hi-tech than F1, it places more emphasis on driver and team, is much less expensive, has good TV and media exposure and thus encourages different winners. Hence the proliferation of sponsors throughout the grid compared to F1, albeit at less cash value.

But it must be recognised that F1 and IndyCar are different animals. While there *are* crossovers, IndyCar is more about entertainment. It's less elitist, more relaxed and open to fans and it presents greater opportunities for young drivers. In other words, it's typically all-American.

Formula 1, despite its worldwide remit, remains European in its roots and philosophy; in not becoming a single-chassis formula (thankfully and essentially) it attracts far more interest at a technical level. Apart from a reflection of this in the fan base, it stirs the participation of manufacturers and – increasingly now – from ultra-high technology companies. Both championships present great motor racing in their own way and have their own personalities and style; long may this remain so.

Changing vrooms

Interestingly, the way in which drivers fresh to IndyCars seem to adapt very easily contrasts markedly with the difficulties that some drivers are experiencing in Formula 1. Until recently it was accepted that an experienced driver could get on top of his/her equipment without much bother. But in swift succession we have seen Sebastian Vettel and Daniel Ricciardo struggling to do this initially with their new teams and cars – and even Fernando Alonso, with his proven versatility, took a while to get up to speed. Ricciardo is still not delivering in his McLaren, while his young team-mate Lando Norris is.

Meanwhile, George Russell stepped into a Mercedes at last year's Sakhir Grand Prix and looked set to win the race, while Carlos Sainz appears to have had little trouble with his move to Ferrari. Perhaps a certain style of driving can become too ingrained over time with some F1 drivers?

The current, heavy, Formula 1 machines are not easy to drive at their limits, due to the combination of peaky aerodynamics, high torque power units and the unprogressive tyre characteristics. Similar to fly-by-wire fighter planes, their maximum performance potential appears to be found when close to neutral stability, a control state that only a handful of race drivers can fully exploit.

It boils down to the fact that we are all individuals. Some drivers have an instant feel for a car regardless of extraneous factors, others have to get every detail of seat fitting, brake and throttle response, steering feedback and chassis balance etc perfect before having the confidence to push to the absolute limit.

Being less hi-tech than F1, IndyCar places more emphasis on the driver and team

Power politics

Time is running out for Formula 1 to choose a clear path for its future powerplants, but with a wide array of possible fuel and PU solutions, each with its own supporters amongst teams and manufacturers, the ultimate decision is proving to be a tricky one. **Racecar** ***investigates***

By DIETER RENCKEN

Consider the plight of the FIA when formulating future power unit regulations for its various international series. Where once power units were restricted to internal combustion engines powered by fossil fuels and the only options apart from ignition – spark (petrol) or compression (diesel) – were reciprocating or rotary pistons, configuration and two or four strokes, the choices have of late multiplied exponentially.

Indeed, the FIA's secretary general for sport, Peter Bayer, runs out of fingers as he lists the number of potential options: fossil- or synthetic-fuelled spark, compression or rotary internal combustion engines (ICE); ditto with hybrid elements and/or powered by hydrogen or CNG (compressed natural gas); and purely electric motors, in turn energised by one of three variants, namely battery, hydrogen fuel cell or range-extended battery charged by any of the ICE types listed above.

That potentially makes for 10 basic power unit alternatives, each with at least one sub-option. It is, as Bayer freely admitted during the FIA's recent annual member club conference in Monte Carlo, something of a power unit jungle out there, with none of the options providing a universal solution, whether for sporting, transportation or commuter applications.

Road relevance

Thus the FIA, which holds global responsibility for both motorsport and mobility disciplines, elevated road relevance at the top of its agenda and plans to formulate motorsport regulations that ultimately benefit global four-wheeled mobility in all its forms. The electric vehicle (EV) boxes are, of course, ticked by Formula E and various battery-powered tin-top series, while next year's Dakar sees Audi enter a range-extender concept.

That said, it became abundantly clear during the FIA conference that electricity is not the only alternative for future mobility and that the internal combustion engine will be around for decades to come – regardless of what ecologists and politicians preach – if for no other reason than the world simply cannot generate sufficient affordable electricity and deliver it in sufficient quantities to charging points across the globe. In addition to this, Motorsport Industry Association (MIA) CEO Chris Aylett believes that, although consumers are dictated to by governments to switch to electric, 'Too many nations can't adapt; can't afford it. Electric won't work everywhere.

'The internal combustion engine is a very efficient mode of mobility and has been so

It became abundantly clear during the FIA conference that electricity is not the only alternative for future mobility, and that the internal combustion engine will be around for decades to come

Formula 1 has to make a change to its power units in 2026 but agreement has been hard to find due to the different priorities of those involved: from drinks manufacturers to private teams, and mass production car companies to specialists such as Ferrari

for 100 years,' Aylett adds. 'There is plenty of potential there if we were not in such a hurry to go electric. With regard to using sustainable fuels, I am quite sure we will go forward into the future with an urban electric solution and a non-urban solution.'

There is another factor: 95 per cent of the global vehicle park is ICE-powered, and these cars cannot be scrapped overnight, something over-zealous politicians – typically elected for five-year spells, and therefore with no need to play long games – conveniently overlook in their determination to shade themselves green. Crucially, 90 per cent of the 85 million cars that will be added to roads this year will be fuel-powered to some degree.

Disciples of electric vehicles predict enormous strides in battery technology over the next few years, often citing mass/power density advances which will reduce weight, cut costs and extend the range of EVs. However, they seldom acknowledge that such technologies apply equally to plug-in hybrid vehicles and many deny that PHEVs could play a pivotal role in accelerating development of batteries, thus serving hybrids and electric vehicles equally.

Yet both Renault and Alfa Romeo are currently committed to F1 despite corporate plans to go the all-electric route for their future product ranges, with the latter's CEO, Jean-Phillipe Imparato, telling *Racecar Engineering* that spin-offs from F1's hybrid electrification provided the basis for the brand's recent extension of its contract with Sauber. 'The answer came naturally when I met [Sauber MD] Frederic Vasseur some months before: to bet on Formula 1 as a next step in terms of technological content to fit my product, because Formula 1 is electrified since 2010. For me, in terms of rationale, it feeds the [brand's] storytelling,' Imparato says.

However, the entire auto industry, including Formula 1, needs to dump fossil fuels and become carbon zero. Yet said public officials cannot even agree on the emission standards needed, let alone provide road maps for the future. Compounding the matter is the fact that motorsport does not carry the highest political priority, yet it could, rather ironically, provide the technologies required for low- or zero-carbon mobility solutions via synthetic fuels.

Poles apart

With F1 being both the most technological and visible of all FIA championships it is the obvious series to pioneer sustainable fuels, and therefore this element lies at the heart of the sport's plans for its future power unit regulations, due to come into force at end-2024. However, these may be delayed a year to provide a longer formulation window – but only if all parties agree.

The key, though, lies in that phrase, 'agree', for agreement in Formula 1 is an extremely scarce commodity given all the players have contrasting agendas. On the one hand Renault uses Formula 1 (largely) as a flagship for its range of mass-produced econo-boxes, on the other Red Bull enters two teams to sell energy drinks via Formula 1's popularity, yet aims to be totally self-sufficient – hence its decision to acquire the rights to Honda's designs as the basis for its own PUs.

Sitting between these two extremes are Mercedes and Ferrari, premium automotive brands both with a determination to spend what it takes to prove their technical superiority to the world, particularly on the power unit front. Try slotting an incoming engine supplier (or two) into that lot, be that an independent or another car maker. Yet to secure its future F1 desperately needs to attract at least one additional PU supplier.

An example of the conflict reigning between the factions was aired by Red Bull's Christian Horner and Mercedes motorsport boss Toto Wolff during the British Grand Prix weekend. Asked his preferences for future PUs, the former said: 'I think the combustion engine does have a future, so why not introduce high revving engines that sound fantastic, and that do it in an environmentally-friendly manner? I think that biofuels and sustainable fuels enable you to do that. F1 could play a key role with the fuels and with the fuel partners that we have on sustainability and zero emissions, with a high performance, high revving emotive engine. I'm sure every grand prix will be packed.'


The FIA's Peter Bayer admits there are many PU options

'I think the combustion engine does have a future, so why not introduce high revving power units that sound fantastic, and do it in an environmentally-friendly manner?'

Christian Horner, team principal Red Bull Racing

Wolff, though, immediately disagreed: 'Because it's what we [the older generation] think, but we are not the most relevant generation. When you ask an 18-year-old or 22-year-old what relevance noise has, most of them consume [F1] via different screens where noise has little or no relevance.

'I personally like it too, and I would like to have a 12-cylinder that screams down the road,' Wolff continued. 'But we are a sport and we are also a business. I think we would lose complete relevance with our partners, sponsors and major stakeholders if we weren't looking at the environment and the impact that we make.'

See the conflict? One represents an edgy energy drink, the other a premium auto brand – yet between them they have dominated the sport since 2010 and are currently neck-and-neck in both championships.

To set the ball rolling ahead of 2025 the FIA and Formula 1 convened an engine summit during the Austrian Grand Prix weekend. In addition to F1 and FIA executives and senior officials, only CEOs of currently committed and potential engine suppliers were present at the meeting, held in the nearby five-star Hotel Steirerschlossl, a mini castle-like establishment owned by Red Bull proprietor Dietrich Mateschitz.

The invitation list – Ferrari president John Elkann, Mercedes/Renault CEOs Ola Kallenius and Luca de Meo, Horner representing Mateschitz plus Porsche/Audi CEOs Oliver Blume and Markus Duesmann – suggests


Next year Audi will use a range extender on its RS Q e-Tron for the Dakar Rally. Could a similar sort of technology be utilised in F1?

Toto Wolff (left) and Christian Horner have found themselves in disagreement over the direction Formula 1 should take with its PUs

the purpose was not to discuss engine configuration or hybrid elements (these were broadly discussed) but to formulate a top-down strategy and determine what the current suppliers are prepared to invest. The FIA and F1 also hoped to gauge the terms under which Porsche or Audi would be prepared to join Formula 1.

This approach differs markedly from what went before when ambitious engineers – mostly with little grasp of marketing or economics – trotted out wish-lists which they submitted to the governing body. These were combined into a set of regulations that delivered the most complex (but efficient) engines in automotive history – at eye-watering costs said to average close to $2m per unit when measured across a season.

The summit agreed the new engines should deliver similar power levels to current units, so 1000bhp overall; at lower costs (annual budgets of $100m, so around $30m per supplied team as opposed to thrice that); run on zero-carbon fuels and provide substantially increased hybridisation (potentially a 50/50 split). On the surface it is a simple enough list, yet fundamentally all the desired characteristics are mutually exclusive.

Various options were discussed in broad terms, including a switch from V6 to downsized 4-cylinder inline units as per road car trends, and scrapping the horrifically complex and expensive MGU-H units


Ferrari boss John Elkann attended the Austrian summit

Various options were discussed in broad terms, including a switch from V6 to downsized 4-cylinder inline units as per road car trends, and scrapping the horrifically complex and expensive MGU-H units which sap engine noise. Energy thus lost would be compensated for by front-wheel motor-generators, creating intriguing potential for all-wheel drive – as revealed by *Racecar Engineering* in May's issue (V31N5)

The main sticking points, though, appear to be configuration and hybrid component: four cylinders or six, and the level of ICE/hybrid mix. As potential newcomers, Audi and Porsche are pushing for a clean-sheet approach to provide a reset across the grid. Ferrari is said to be open to a turbocharged inline-four engine powered by e-fuels, which it considers as being crucial to market acceptance of its future product range.

Ironically, Mercedes and Renault – both of whom market ultra-high performance 4-cylinder road-going cars – are believed to favour sticking largely to the current architecture and power split on cost grounds, but they no doubt hope to benefit from their hard-earned (and expensive) experience under the current PU formula.

In addition, Renault believes AWD will be a costly, heavy and complicated add-on and questions why F1 risks alienating existing teams as it panders to two (potential) incomers, both from the VW Group. Unsaid is that de Meo is a former VW Group executive, having joined Renault from his Seat CEO role.

'The discussion was "what are we doing in the future in terms of engine", because we want to save costs, so we don't want to reinvent the wheel,' Wolff, who did not attend the Austria summit as he is not a director of Mercedes High Performance Powertrains, told the FIA conference.

'We also want to have an engine that is relevant from 2025 to 2030, and we can't be old petrolheads with screaming engines when everybody expects us to be going electric. So these engines are still going to be fuelled [by zero-carbon fuels]. We are staying with the current V6 format, but the electric component is going to massively increase,' Wolff added, clearly pushing the Mercedes corporate line.

However, Horner does not believe retaining the current engines will reduce costs. 'Such engines will still cost $2m. We need to reduce that by half,' he says, having in May pushed for powertrain budget caps, with an annual $50m R&D limit.

Audi and Porsche

What, though, is the position of VW Group and either or both of its premium performance brands? 'Audi and the Volkswagen Group are quite a big organisation,' said Audi Formula E team boss and its former factory sportscar driver Alan McNish during the recent London FE round. 'We've got very good relationships through a lot of motorsport and we sit in a lot of discussions. That doesn't mean to say they will all come to fruition, but you need to be in the discussions to understand.

'Audi has sat in Formula 1 discussions in the past. [And so has the] Volkswagen Group, and that's part of evaluating where


Ola Kallenius represented Mercedes at the PU summit

'We are staying with the current V6 format, but the electric component is going to massively increase'

Toto Wolff, team principal and CEO Mercedes

The powers that be

There are already quite a few alternative energy solutions at play in the wider motorsport world, including of course Formula E. Scepticism abounded when in 2011 the FIA conceived of this, its first alternative energy championship. Yet the series has gone from strength to strength, this year holding world championship status and boasting seven manufacturers – three more than Formula 1 although Audi, BMW and Mercedes have all cancelled their FE programmes recently. There's even Extreme E, a rally series for electric vehicles.

Meanwhile, from this year F1's support Porsche Supercup series and the European Truck Racing Championship have switched to petrol and diesel biofuels respectively, with Porsche reporting the former required only software updates to co-optimise engine and fuel performance, with output of the GT3 remaining unaffected.

The 2022 World Rally Championship goes a step further by integrating biofuels and hybridisation, while WRX's switch to full electric was delayed by the Covid pandemic.

Next year also sees Audi debut its RS Q e-Tron on the Dakar Rally using a 600bhp ex-DTM ICE to power an FE-derived motor-generator, which in turn charges 52kWh batteries that power two 335bhp FE electric motors. Thus the car can complete stages without regular charging, although the plan is for overnight charging via auxiliary generators. Range extenders could also see use at Le Mans, with a project combining a Mazda rotary running at constant speed to charge batteries rumoured as a Garage 56 entry.

However, ACO president Pierre Fillon, whose club promotes the 24 hour race, believes that 'Hydrogen is one of the best energies for future mobility and will play a key role in Le Mans in 10 years. We will have zero CO2 emissions, with hydrogen as the top class and e-fuels in the lower classes, and we will stage an exemplary event in terms of social responsibility.'

In May Toyota chairman Akio Toyoda completed the 24 Hours of Fuji in a Corolla powered by a turbocharged inline 3-cylinder engine fuelled by compressed hydrogen, an exercise that Bayer labels as 'super interesting, something we are analysing and studying'.

'The goal is to become carbon-neutral,' Toyoda said of the project. 'If all cars become battery-electric one million jobs will be lost in Japan. I want to tell the world there is also this option to become carbon-neutral.'

Motorsport now merely needs to introduce a series for hydrogen fuel cell technologies to cover the full spectrum of alternative energies …

motorsport is,' McNish continued. 'It's not a matter of regulatory tourism, it's about guidance of where motorsport needs to go to stay relevant, because the car industry is clear where it's going.'

There is, though, a caveat to all these positions. Unless Porsche and/or Audi (or any other incoming brand) commits wholeheartedly to a new power unit formula there is little rationale in dumping the current formula for the sake of change, as that makes little economic sense, unless Formula 1 as a whole benefits via increased participation from motor manufacturers.

In that case it is not inconceivable that Formula 1 sticks to its current V6 1600cc format by converting its tried and tested engines to run on e-fuels or 'drop-in' fuels that require little modification. The MGU-H tech will, after all, have been amortised over 12 years while reliability is no longer a major concern. Such a decision will be by far the cheapest, but ticks fewer boxes and is highly unlikely to attract incoming brands.

The FIA is, though, determined to prevent such a scenario and made that clear during two subsequent meetings held since the Austrian summit during the British and Hungarian GPs respectively. The regulator is believed to have given engine suppliers until the Italian Grand Prix in mid-September to reach agreement or it will impose whatever formula it sees fit from 2026.

Power switch

FIA president Jean Todt retires this year, and the Frenchman aims to hand over safe, sustainable sport to his successor, whoever that may be. Elections are scheduled for mid-December, with two candidates – current FIA deputy president for sport Graham Stoker and the UAE's Mohammed bin Sulayem – having announced their candidacies.

Contractually, the FIA has every right to act unilaterally. The Concorde Agreement expires at the end of 2025 and the FIA is thus under no legal obligation to agree 2026-onwards regulations with teams or engine suppliers. Indeed, it followed this policy for 2022's regulations – having granted teams various opportunities for input, it took decisions in conjunction with Liberty Media, Formula 1's commercial rights holder. Thus, precedent exists.

That Formula 1 needs to change its ways is clear, that the internal combustion engine is far from dead equally so. The trick facing the FIA, Formula 1 and all engine suppliers – present and potential – is to manage the switch-over in such a way that the final direction finds lasting favour amongst fans, sponsors, promoters, broadcasters, all of whom will base their medium- to long-term decisions upon a sustainable, bio-fuelled hybrid engine formula.

The ultimate irony is, though, that after years of criticism of the current engine formula this season it is delivering the best racing for many a year in Formula 1, and yet its demise is being widely debated due to external factors, not all of which are within the sport's direct control.

It remains unclear what PU regulations F1 will race to from 2026, but a decision needs to be made by mid-September

Hyper tension

Toyota won its fourth successive Le Mans in August, which was the first for the new Hypercar era, but it was much more stressful for the team than it appeared and it took an inspired fix to coax both GR010s over the line. Racecar *watched the drama unfold*

By ANDREW COTTON

Rolex/Jad Sherif

For much of Sunday, August 22, the Toyota team in the pit was worried that its two cars could stop at any moment, denying them of the chance to secure the overall win at Le Mans, its fourth in a row. A problem with picking up fuel from the collector threatened to eliminate the two GR010s from the 24 hour race and hand the win to a grandfathered LMP1 car run by a private team. But that team, Signatech Alpine, was under pressure itself, from the Glickenhaus 007Cs, both of which made it to the chequered flag, defying pre-race predictions that they would not be reliable enough. It was then, for various reasons, quite a dramatic Le Mans 24 hours.

There were some clear signs that all was not well with the Toyotas. For instance, they dropped their stint lengths from 13 laps to sometimes as little as three. They also had a slight drop in lap time after the problems started to emerge early on the Sunday morning, but by then they were so far ahead of the Alpine and Glickenhaus entries that they could manage their pace.

Staying out on track was the only option that they had anyway. As a similar fuel issue had hit the two GR010 Hypercars at Monza in July, and then it took nearly an hour to fix it.

The cars did have the pace to stay ahead, but the risk was that one of them coughed terminally out on track. So while it looked serene from the outside, inside the cockpit the drivers were working harder than ever to put into place the 'fix' that the engineers in the garage had helped to figure out.

Sebastien Buemi was the first to have the fuel pick up problem in the number 8 Toyota, and he spent much of Sunday morning trying to find a solution with his race engineers. The car was regularly to be seen out on track somewhere, seemingly struggling, slowing to do a power recycle and generally losing ground to the sister Toyota. At that stage the race win was gone for them, and it was a matter of survival. Ultimately, it also turned out that, when the 'fix' was found, it could be applied to the race leader.

'We were faster than car 7 at the beginning and then we lost pace with a loss of grip at the front end [which was changed], and then after that we had the technical issue, explained Buemi. 'It was stronger on our car than theirs, and it happened to us before it happened to them, so we had the fix prepared for them! I could do a stint of three laps, and when we had the issue we [found the solution by pressing] a lot of buttons. Every braking we had to press three buttons, for five hours we drove like this.

'What the engineers found saved us,' Buemi added. 'Without them we would have lost the race. They said "it is going to be a bit complicated". Then 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 "you do it in Turn 8" and it worked. Then they said I had to do it again the next lap. That was okay. Then they said some more corners, like at the second chicane, Mulsanne, can you do it in Indianapolis please? And then the Ford Chicane, and then Turn 1.'

Pressing the buttons during every braking event for five hours was what was affecting the number 8 car's lap time, but the team also had to refuel more often with both cars, cutting stint lengths to less than 10 laps, four short of their night-time running.

Brake point

The GR010 was already tricky on the brakes, too. For while the old LMP1 car had hybrid regen on both axles, which took care of the majority of braking force, the Hypercar has a brake by wire system at the front only, with an MGU system, while the rear is purely mechanical. The BBW system still takes care of the feel on the pedal for the driver, but the heavier car is more difficult than its predecessor when it comes to stopping.

However, one thing that the Toyota team had addressed, quite brilliantly, was the robustness of the racecar. On the opening lap under green flag conditions (after two laps behind the safety car following a rain shower before the start left the track wet) Glickenhaus driver Olivier Pla arrived at the first corner with cold tyres and cold brakes on a slippery track, and smashed into the rear wheel of Buemi's number 8 Toyota. Pla admitted responsibility over the radio, and when he got back to the pits. But the Toyota suffered nothing more than a slight bruise on the wheel, and a drop to 58th position overall.

The fact that the car was now more robust than the fragile TS050 was highlighted once more when Buemi, once again, was the innocent victim shortly afterwards as he was hit by an LMP2 car, this time on the other side of the Toyota, which broke a wheel rim and forced an extra stop. Yet still the car was fast enough to keep its sister car, number 7, honest, before the fuel issue struck.

Fuel issue

Toyota expected to lose the one car, but then the leader hit the same problem. This was a total mystery to the team, which had effectively carried over the fuel system from the old TS050 and never experienced this problem before Monza. Something to note here is that one other major change to the GR010 is the reduction in data channels to

Average best 50 lap times: Hypercar and LMP2

Pos	No.	Team	Car	Laps	Best Lap	Percent	Ave Best 50 Laps	Percent	No of Pit Stops	Total Time in Pit
1	7	Toyota Gazoo Racing	Toyota GR010 HYBRID	371	03:27.734	0.06%	03:29.659	0.00%	33	44:18.298
2	8	Toyota Gazoo Racing	Toyota GR010 HYBRID	369	03:27.607	0.00%	03:29.688	0.01%	37	48:06.107
3	36	Alpine Elf Matmut	Alpine A480 - Gibson	367	03:28.994	0.67%	03:30.592	0.45%	31	44:10.085
4	708	Glickenhaus Racing	Glickenhaus 007 LMH	367	03:30.102	1.20%	03:31.655	0.95%	28	40:23.403
5	709	Glickenhaus Racing	Glickenhaus 007 LMH	364	03:29.427	0.88%	03:31.600	0.93%	29	43:19.361
1	31	Team WRT	Oreca 07 - Gibson	363	03:33.494	1.14%	03:34.128	0.77%	33	41:40.960
2	28	JOTA	Oreca 07 - Gibson	363	03:31.703	0.29%	03:32.496	0.00%	35	49:00.945
3	65	Panis Racing	Oreca 07 - Gibson	362	03:31.096	0.00%	03:34.301	0.85%	34	44:26.155
4	23	United Autosports	Oreca 07 - Gibson	361	03:33.013	0.91%	03:34.613	1.00%	33	53:16.888
7	26	G-Drive Racing	Aurus 01 - Gibson	358	03:31.435	0.16%	03:33.440	0.44%	34	1:14:17.764
NC	41	Team WRT	Oreca 07 - Gibson	362	03:31.887	0.37%	03:32.570	0.03%	34	46:12.155

In the top class the 3m30s target was met pretty successfully by the Toyota GR010s, the Alpine is a half-second below par, while the Glickenhaus 007s have room for improvement

feed information from the car to the pit. The team has eyes on some parameters, but not nearly the same amount of detail as it had before, which was hardly helping.

'We did not know if we could manage it or not,' admitted a relieved Kamui Kobayashi, who shared the winning car with Conway and Jose Maria Lopez. 'The most important thing is to finish 1-2 in Hypercar. We were limited to the test day, and in testing too, [and] you cannot modify your car by homologation.'

Alpine's peaks

The Alpine had the solid race that was expected, spoiled only by driver error – with Nicolas Lapierre spinning in the wet first hour and Matthieu Vaxiviere having an accident with a GT car that lost three minutes during the night. 'We expected this result, and just to finish Le Mans is a glory,' said team owner Philippe Sinault. 'To finish on the podium is a good sign. We had a little bit of trouble with the setting [up] of the car in the wet because we have never tested the car in the wet.

'The gap between us and the Toyota was huge, and imagine if they had no trouble!' Sinault added. 'But we know at the start of the story [that we have had] to make a compromise … We did the job and to finish in this position, P3, is a great result.'

The Alpine had a helping hand before the race, receiving a larger fuel tank that would allow it to complete the 12 lap stints it needed to compete with the Toyota and Glickenhaus. In the race, however, both of its rivals stretched their fuel limit to 13 laps, and that brought the French car under attack from Glickenhaus. 'We had a lot of work from Gibson [engines], and with my power management team,' confirmed Sinault. 'We did increase the size of the fuel tank for the race as well.' By how much was not revealed.

For Glickenhaus, reaching the finish was a huge achievement, in no small part thanks to the work of the Joest mechanics and engineers who have helped the programme

Rolex/Jad Sherif

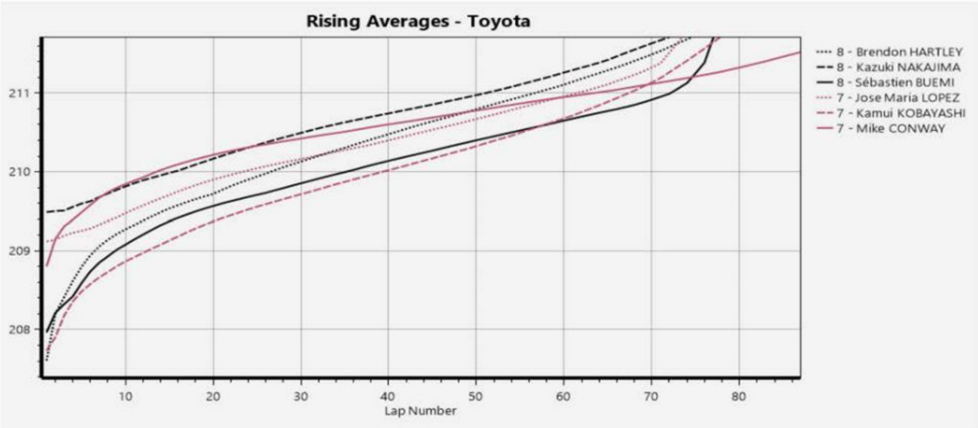
Alpine had a solid race but fell victim to costly driver errors, while it also struggled in the rain due to a lack of wet-weather running

XPB

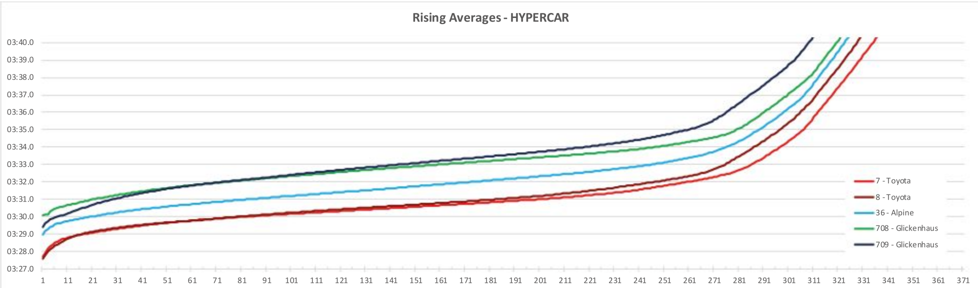
The 708 Glickenhaus finished fourth, just 2m34s behind the Alpine. The car proved reliable and its aero was well suited to Le Mans

For Glickenhaus reaching the finish was a huge achievement, in no small part thanks to the work of Joest mechanics and engineers

Rising averages: Hypercar



Toyota driver comparison shows that Kobayashi and Buemi were the star turns for their respective crews. That said, while a little slower, Conway was by far the most consistent



Rising averages for the top class, which were also the top five finishers: note that No.709 seems to have been the quicker of the Glickenhaus pair, but No.708 was more consistent

make incredible leaps in performance since the start of the season. Few expected them to go through the race without a mechanical issue, but other than Pla's accident and a small issue with the gearshift system on the 709 car that finished fifth in class, both racecars were reliable and made the finish – though a water leak on the 709 car had to be managed for much of Sunday and the engine temperatures rocketed in the final two laps.

Disc-o- tech

Glickenhaus had increased the width of the brake disc at Monza in the hope that that would be enough to fix the brake wear drama it had been experiencing, while it had also changed the airflow through the nose of the car to further help with cooling of the outer rim of the disc. However, in the first practice session this proved ineffective, and the brakes continued to wear at an alarming rate.

The team then introduced some blanking, which helped the front brakes, and used protective coating around the rear brake ducts to protect them from the hot exhaust. These measures ensured that the issue would not strike again, and the cars completed the race without even a planned brake change at 18 hours, as it chased the Alpine for the third spot on the Le Mans podium.

Meanwhile, a traction control issue was addressed by Bosch at the Le Mans test day, a week before the race. One car was developed with the new traction control settings in the morning, the other adopted them in the afternoon, and the rear tyre wear improved immediately as wheelspin was limited.

Previous aero stability problems were not an issue at Le Mans, the car having been designed for the famous race track rather than for the shorter circuits of the FIA World Endurance Championship.

However, the Glickenhaus team was caught out in strategy calls, particularly with tyre selection when the weather was changeable on Saturday night, and it opted for a full stint on wet tyres rather than stopping to change. That lost it time to the Alpine, which might have proven to be valuable at the end, as Pla, Luis Felipe Derani and Franck Mailleux finished just 2m34s behind Andre Negrao, Lapierre and Vaxiviere's Alpine, while Ryan Briscoe, Richard Westbrook and Romain Dumas finished fifth in 709.

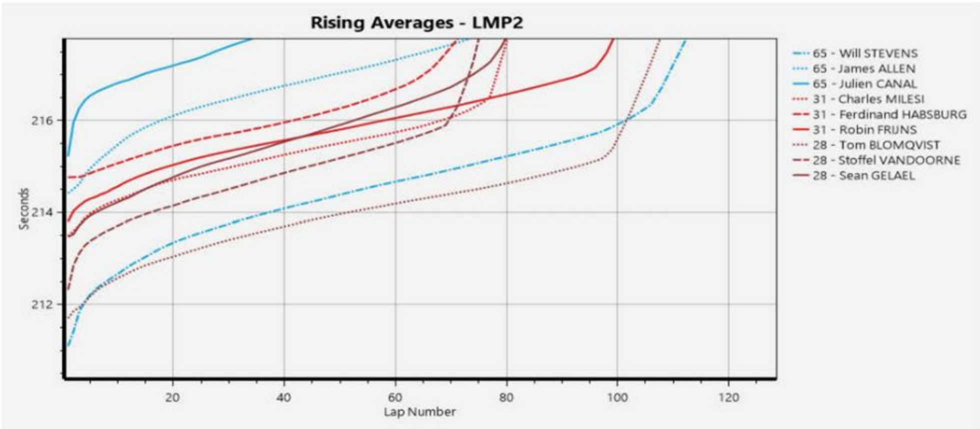
'Everyone did such a fantastic job and to finish the way that we did after Monza, where we had the problems with the brakes, to do a full 24 hours without even a brake change was fantastic,' said Derani. 'It is not easy to come to such a race, but we finished, which is an achievement. There were moments in the race when we were competitive. It was hard to compete against the Hybrid but we were able to challenge the Alpine … Race incidents caused us to lose laps, and at the end to finish four laps from the leader is a fantastic effort. It gives us a good starting point for next year.'

Next year should see the Peugeot arrive at Le Mans. Crash testing for the chassis is planned for October, and on-track testing after that, while the Porsche LMDh cars are due to start testing before December 31.

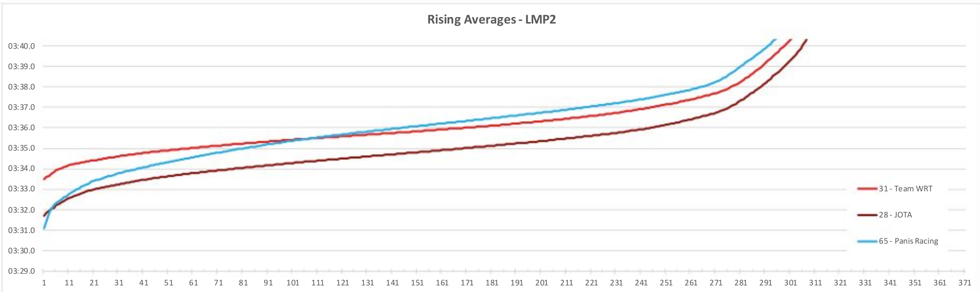
LMP2

Success at Le Mans was bitter sweet for the Belgian WRT team, for while their long-time leading car – driven by Ferdinand Habsburg, Charles Milesi and Robin Frijns – took the

Rising averages: LMP2



Tom Blomqvist (JOTA) and Will Stevens (Panis) were consistently quick in LMP2. The pace of both was reflected in the final result, as they finished second and third respectively



This shows the top three finishers in LMP2. Note that it is the JOTA car which put the best and most consistent performance in during the race, but it also lost more time in the pits

chequered flag by an amazing 0.7s over the team JOTA car to record an historic debut win for the team, its other entry, driven by Robert Kubica, Louis Deletraz and Yifei Ye, which was set to take the win, stopped on the last lap due to a broken throttle sensor.

Much was made before the race of the potential for the LMP2 cars to compete for the overall win, and given the drama that affected the Hypercars perhaps this conjecture was not misplaced. However, the LMP2 teams themselves were all focused on getting the most out of their packages in what was a highly competitive 24-car field.

Teams were particularly interested in their engines and making sure they had the best that Gibson could offer. United Autosport and Dragonspeed both requested engine changes before the race, the former awarded the decision, the latter not.

The race turned on its head a few times, not least when the leading United Autosport car of Paul di Resta, Wayne Boyd and Alex Lynn was hit by the sister car, driven by Manuel Maldonado. That accounted for two of its three cars, the other was delayed by an

Much was made before the race of the potential of the LMP2 cars to compete for the overall win

SRO/Brecht_Decancq_Photography

The number 31 WRT had a very dramatic race, limping to the chequered flag and then claiming the LMP2 spoils by a scant 0.7s

THANKS TO ALL TEAMS RACING IN 24H LE MANS

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SET UP PADS
WITH LOAD CELLS

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BASED ON THE CAR MODEL

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TOUCH SCREEN

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SPECIAL AT WHEEL

AIR JACKS
CE CERTIFIED

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alternator failure that lost it several laps to the leaders while under repair.

Anthony Davidson crashed his JOTA car, which he shared with Roberto Gonzalez and Antonio Felix de Costa, on a damp part of the track on Saturday evening. Gravel in the floor eventually punctured the oil tank, leading to a long pit stop, and they then had a long race ahead of them with little reward.

Last lap drama

The two WRT cars had lapped the circuit consistently through the night, completing their 11 lap stints without fault. As others fell by the wayside they were metronomic in their pace and were able to take the lead and then maintain it through Sunday morning.

Frijns, Habsburg and Milesi led the sister car and looked comfortable but then on Sunday afternoon things started to take a turn for the worse for them. On board for his final stint, Frijns was compromised by a failure of the lifting equipment to change tyres. The team had to come up with a pneumatic solution as it could not be a manual lift, as seen in F1. The team inflated a cushion under the car, and opted to change the front tyres at one pit stop, the rears at another but, in between, he crashed with a GT car.

'The moment that I jumped in for my final four stints the air jack broke,' said the Dutchman. 'I had new front tyres and five-stint old tyres at the rear. The balance was nowhere, struggling big time, and the sister car was chasing me down because we lost a minute in the pit stop. Then a Porsche hit me, and I lost downforce. After the Porsche hit me I had a rear left tyre construction failure, I had it in the DTM with Hankook so I know how that feels. I could not load the rear left at all, so I drove 10 laps like that and lost a lot of time. We had to change the rears, so we lost another 20s, and then I found out that the rear structure was broken. Then I asked when I left how was the tyre, and they said it was [gone], so I thought it was the tyre, but after two laps the rear died again.'

Nursing a mechanically broken car to the line was hard enough, but when the sister car had taken the lead Frijns was set for second, but on the final lap he re-passed the stricken other WRT car by the side of the road, and inherited the lead. It was heartbreaking for the driving crew. But the WRT team's new golden hope was hobbled, and was being chased down by the second JOTA car of Tom Blomqvist, Stoffel Vandoorne and Sean Galeal.

'That last stint, I was 15s behind at the last stop and I came out 28 behind,' said Blomqvist whose car had been earlier delayed by a late pit call, which meant it missed the official pit entry and cut across the Ford chicane to get to the pit, which earned it a penalty, and then he passed a green light to get back on track, but did not wait for the next safety car, which earned a stop and go of 90s. 'To lose the race by seven tenths of a second is hard but everything went their way,' he said. 'We weren't meant to win it. We had a super fast car, and when I knew that the gap was 5-6s on the last lap, getting to the last sector behind him there was nowhere to pass, everyone was slowing down for the finish and we were still racing, it was crazy.' French team Panis racing took third, with Julien Canal, Will Stevens and James Allen a lap down.

Artificial intelligence at Le Mans

The LMP2 class at Le Mans has taken huge strides in the last two years as the top teams seek a lucrative LMDh project. At Le Mans this year the category had pretty much sole chassis supply with the ORECA, the engines are all prepared by Gibson, gearboxes by Xtrac and tyres from Goodyear. The difference is the drivers, and the teams, and with the latter it has turned into a spending war.

And teams are making extra efforts to find an edge. For instance, this year the JOTA team arrived with a new AI software partnership with Monolith, designed to increase the speed of data analysis for their two cars. It signed up with Monolith at the start of the year, and is continuing to evolve how to use its product most effectively.

At Le Mans, JOTA used Monolith AI to aid car set-up in terms of vehicle dynamics, aerodynamics and tyres. 'The AI side, we only rolled it out this year,' says JOTA's technical director Tomoki Takahashi. 'Monolith is a relatively new company which just received massive investment and is working for some OEMs. The AI can work for CFD, FEA and for us it works for lap time analysis and data analysis. When we look at data, a human can only do so much. Understanding trends is hard for a human being, because they are only looking at single data points, while AI can look at much more than that.

'We don't have endless budget and hundreds of people, and classically Excel is the best thing in the world' Takahashi adds. 'Getting end of lap data at Le Mans is the most important thing because you get an average of what has happened over the lap, but if you have an average and something has interpreted it already, it is way better.'

The problem with such computer systems is, firstly, trusting the data to deliver what you need it to, but also to realise when it is leading you down the garden path. 'Simulation and AI, classically you have very intelligent people who will tell you that it is always fantastic, and will always work, but you have to apply common sense to it,' says Takahashi. 'This is an ideas factory, you get all the ideas, and you have to apply it to real life with some logic behind it.'

'Everyone was slowing down for the finish and we were still racing, it was crazy'

Tom Blomqvist, driver JOTA LMP2

GTE

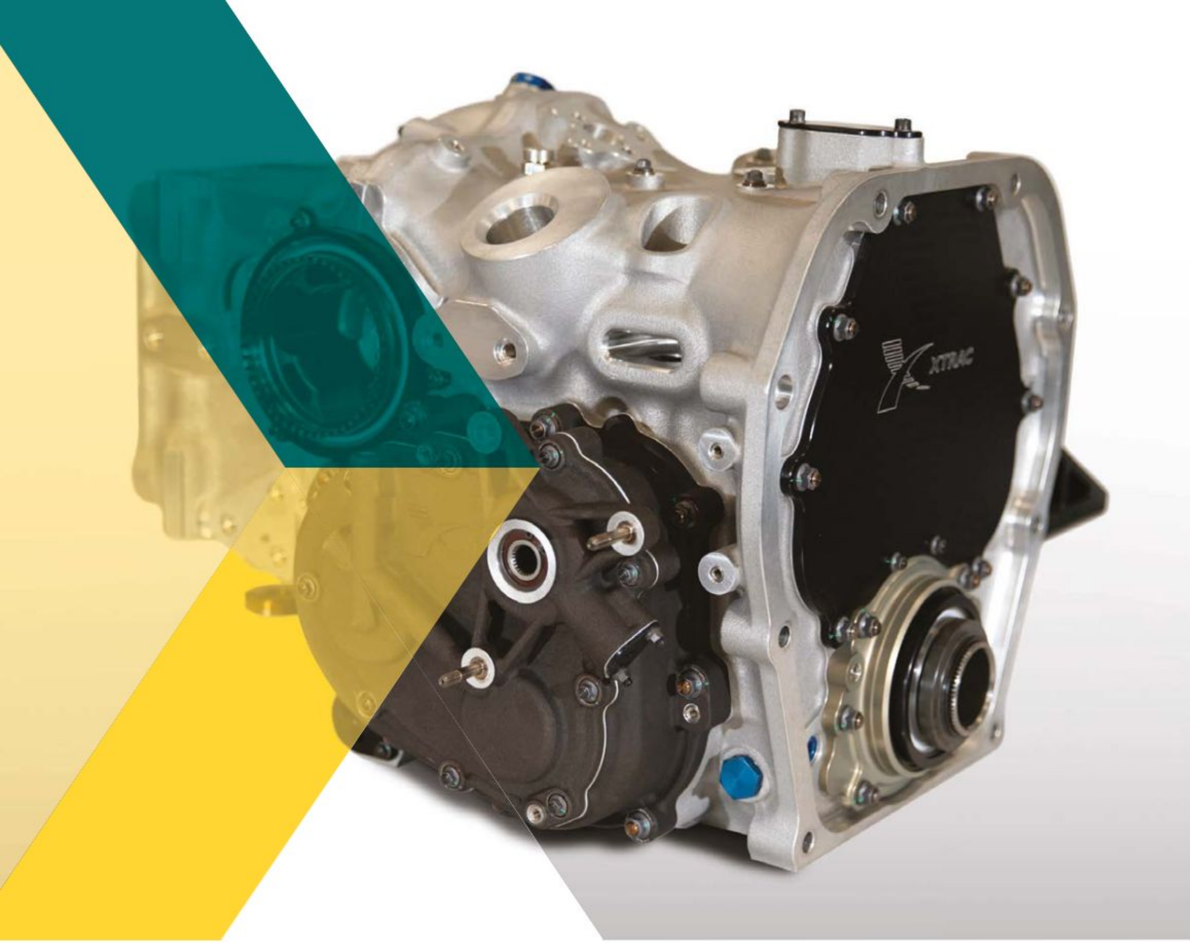
With the GTE category now confirmed to be ending by the end of 2022 as factory racing and 2023 in private hands, the FIA and ACO says that its replacement will be GT3-based cars. There was no word about whether or not there would be a place for factory-run cars, as Corvette wants, or if they will put the cars solely into the hands of privateers, the preference of Porsche and Ferrari. A decision will be reached in the next few months.

However, while the political shenanigans were on-going regarding the future of GT

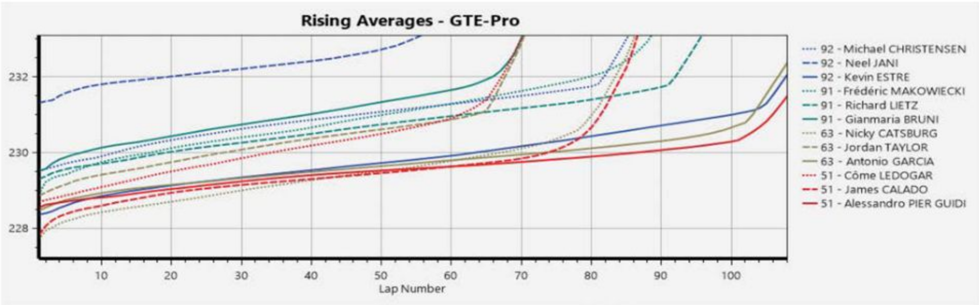
Average best 50 lap times: GTE

Pos	No.	Team	Car	Laps	Best Lap	Percent	Ave Best 50 Laps	Percent	No of Pit Stops	Total Time in Pit
1	51	AF Corse	Ferrari	345	03:47.818	0.04%	03:49.010	0.00%	23	33:27.914
2	63	Corvette Racing	Chevrolet	345	03:47.716	0.00%	03:48.999	0.00%	23	32:33.977
3	92	Porsche GT Team	Porsche	344	03:48.366	0.29%	03:49.610	0.27%	24	33:54.453
4	91	Porsche GT Team	Porsche	343	03:48.895	0.52%	03:50.068	0.47%	23	36:04.692
		GTE-Am								
1	83	AF Corse	Ferrari	340	03:50.943	1.42%	03:51.846	1.24%	25	37:32.360

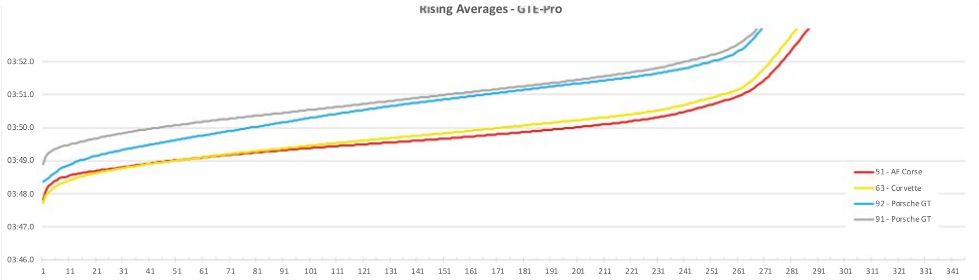
Note that there is absolutely nothing to choose between Ferrari and Corvette, so those last-minute balance of performance tweaks were pretty much on the money after all


XTRAC

Rising averages: GTE



Driver comparison: as always the competition in the GTE Pro class was pretty fierce, but honourable mentions should go to Nicky Catsburg (Corvette) and Kevin Estre (Porsche)



This shows the difference between Corvette and Ferrari; the latter more consistent in the dry, better in the wet, but the Corvette was still quick. Porsche struggled in comparison

There was much consternation before the start as Ferrari received two balance of performance changes

Even though Ferrari was hit with a BoP-inspired reduction in fuel allowance and turbo boost the AF Corse 488s dominated GTE

racing, there was much consternation before the start as Ferrari received two balance of performance changes that were designed to slow its car. The first was on Thursday, just before practice began, and that cost Italian cars one litre of fuel in overall tank size, plus a reduction in turbo boost pressure. The second came on Friday morning with a further reduction of fuel allowance, this time an extraordinary three litres.

Balancing act

The BoP for Le Mans is not part of the automatic system that rules the rest of the WEC. Due to the nature of the track and the race, it is manually adjusted according to what the technical team see at the test day, which therefore becomes unrepresentative, in practice and in qualifying. To add insult to Ferrari's injury, Corvette may have had its fuel allowance dropped by a litre for the race, but it also had its minimum weight reduced by 7kg. This was rather less extraordinary as this was the first time that this racecar, the Corvette C8.R, had raced at Le Mans, and the only data that the technical team had on it came from one race at Spa in May.

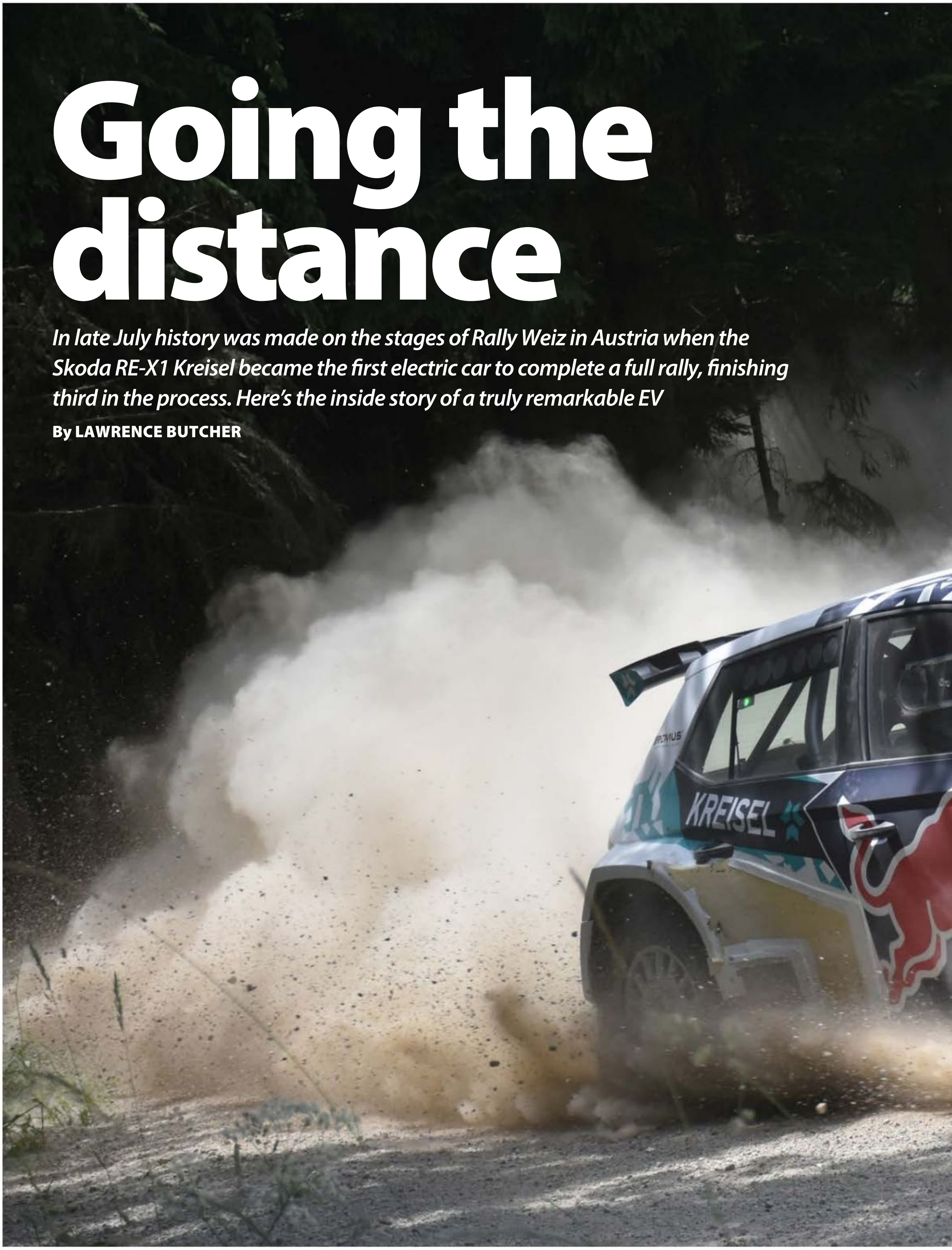
However, the data shows that Ferrari clearly had the faster of the three cars, compared to Corvette and to Porsche. The two AF Corse Ferraris led for the majority of the race, and although one was delayed by a suspension failure and a puncture, the sister car took victory by 41 seconds over Corvette. The factory Porsche scraped a third place, a lap down on the winning Ferraris.

Ferrari also dominated GTE Am, winning the class by more than a lap from the Aston Martin run by TF Sport, while Iron Lynx continued its recent run of good results with a third place in class to back up its win at the Spa 24 hours earlier in August.

Going the distance

In late July history was made on the stages of Rally Weiz in Austria when the Skoda RE-X1 Kreisel became the first electric car to complete a full rally, finishing third in the process. Here's the inside story of a truly remarkable EV

By LAWRENCE BUTCHER



Harald Illmer

In place of the usual 1600cc turbocharged engine are a pair of electric motors, one front, one rear, powered by a 52.6kWh battery pack

Kreisel has created a portable charging pack called Chimero, which can be easily transported to remote services where it can provide the RE-X1 with an 80 per cent charge in just 15 minutes

Currently, much of the conversation around electric motorsport focuses on short sprint events such as rallycross, which can work within the limitations of current battery technology. For longer events, hybrid is still seen as the next logical step from pure IC engine propulsion, as will be demonstrated next year in the WRC. It therefore may come as a shock that an EV recently completed a full-length national event – Rally Weiz in Austria – and even secured a podium finish. Even more surprising is the fact this wasn't a no-holds barred special, but a conventional looking car that had been performance-balanced to match existing Rally2 equipment.

The car in question is the culmination of a two-year collaboration between electric powertrain specialist Kreisel, Skoda Motorsport and the Austrian Baumschlager Rallye and Racing outfit (BRR), and is called the Skoda RE-X1 Kreisel. The Kreisel name will be familiar to many as the supplier of battery systems to the electric World Rallycross field, but the company also felt confident its technology was sufficiently developed to take on a true, stage rally car application.

'Initially, it was just a feeling we had, but we did many investigations and lots of real-world tests and simulations, at a battery cell level,' says Daniel Foissner, who headed up the project. 'We got some figures and some values, where we felt that it would be worth taking a step forward.'

Confident it could, theoretically, field a car that was capable of full rally distances, Kreisel then approached a number of potential partners for the project, eventually settling on a collaboration with BRR and Skoda, as both saw the appeal of an involvement in such a ground-breaking endeavour.

Solid base

The car is based around Skoda's latest Fabia Rally2 Evo, which has had great success on both the WRC and in national competition. However, in place of the usual 1600cc turbocharged engine, sequential transmission and mechanical four-wheel-drive system are a pair of electric motors, one front, one rear, powered by a 52.6kWh battery pack. The development and implementation of the battery is where Kreisel has concentrated most of its efforts, as this is the key component in enabling the car to run full stages, back to back, at a competitive pace.

The pack makes use of off the shelf, cylindrical cells, and is liquid cooled via an immersion cooling process. 'We are able to surround each cell with a cooling fluid we have developed in conjunction with Shell which allows us to pull a lot of temperature from the battery, that is at the core of our battery technology and it makes it much easier to handle high performance applications,' Foissner says.

This isn't a no-holds barred special, but a conventional looking car that has been performance-balanced to match existing Rally2 equipment

The most interesting aspect of Kreisel's design is that only the sides of the cell are immersed in coolant, and this allows it to keep overall pack mass and volume down when compared to other cooling techniques. 'We have a patented cooling chamber, and the top and the bottom of each battery cell sits outside that,' Foissner explains. 'That means we are not flooding the whole battery system, and the approach is much more efficient in terms of weight.'

The battery weighs 330kg, which is far from light, but when judged against other motorsport batteries of a similar capacity it compares well – Formula E's Gen 2 battery is 54kWh and weighs in at 380kg, for instance.

Thanks to the cooling system's ability to remove heat from the cells, the car is able to complete stages up to 35km in length at racing speed, then still receive charge at a rate of 200kW. Even more astoundingly, without needing any special cooling treatment post charge, it is ready to complete another stage. Impressively, Foissner states that throughout all the running it has completed with the car, including in ambient temperatures of around 30degC, the battery temperature has not exceeded 45degC.

The fast-charging system is another area where Kreisel has looked to address some of the shortcomings of EVs operating in remote areas, which is where rally stages tend to be. Rather than having to drag generators around the countryside, it has created a portable charging pack dubbed the Chimero, utilising second life batteries from its other projects, which can be easily transported out to remote services to provide the car with an 80 per cent charge in 15 minutes.

'We are really only in the second half of the first stage of testing the car under racing conditions, but I think we have a very good basis already'

Daniel Foissner, project leader at Kreisel

Peak performance

Kreisel's key expertise is in battery technology, rather than designing and manufacturing electric motors and control systems, and so it sought an outside supplier for these elements, settling on UK-based Integral Powertrain. The company has provided motor and inverter technology for a host of high-profile motorsport projects, including Volkswagen's ID-R Pikes Peak machine, and its high power density, radial flux motors were the ideal choice for the RE-X1.

Each motor has its own dedicated control electronics, which use silicon carbide power semiconductors, and the combined output of the powertrain is 260kW, compared to the 214kW an internal combustion engine Rally2 car produces. Cooling for both the motors and inverters is achieved using a traditional water-glycol coolant mix.

Drive is transmitted through a reduction gearbox mounted to each motor, supplied by Xtrac, which also handles the Rally2 car's transmission, and the single speed transmission features the same plate type limited slip differentials used in the IC application. According to Foissner, the ramp angles on the differentials have been subject to some tuning to better suit the torque delivery of the electric motors, but beyond that they are very close to the standard units.

However, the technical challenge of electric rallying is not simply in making batteries, motors and inverters that are up to the task, they must also be integrated in such a way that their performance is usable, as rally drivers, probably more than any other racers, rely on having a consistent feeling car under acceleration, braking and turn-in. On the standard Rally2 Fabia, this consistency is achieved thanks to Skoda's extensive experience with engine mapping, differentials and set-up. But when it comes to using an electric drive, there is no mechanical link between the front and rear wheels, meaning the balance is purely a function of software and throttle mapping. According to Foissner, synchronising the power delivery front to rear was one of the more challenging aspects. 'It was very tough, we do all of the software development in house and we had to make sure there was proper communication between the two axles,' he says.

Foissner readily admits that, even after 4000km of testing, this aspect of the RE-X1 is still a work in progress. 'We are really only in the second half of the first stage of testing the car under racing conditions, but I think we have a very good basis already,' he says.

There's been much work on the RE-X1's driveabilty and synchronising the power delivery between the front and the rear has proved to be one of the more challenging aspects of the project

The same considerations apply under braking, and a degree of regenerative braking is deployed, without which it would be far harder to achieve the necessary battery range to run full stages. 'As an initial step, we are doing some regen on the braking but not when the driver lifts off throttle,' Foissner says. 'The regen can be adjusted via a paddle on the steering wheel so the driver can choose the mapping of the regeneration.'

As with the rest of the package, regen braking development is at an early stage, but Kreisel has been working with an established brake-by-wire supplier on the development of a system to provide variable mechanical braking assistance on all four wheels, which would greatly increase the level of regeneration available. However, with braking consistency being such a vital aspect of a rally car's overall performance, refining a system that will operate reliably on low grip surfaces will be a prolonged process.

Czech mate

With Kreisel handling the powertrain side of the project, it was up to Skoda to integrate this within the Fabia Rally2 and ensure the relevant FIA mandated safety standards were maintained. Where possible, the existing Rally2 components have been retained, including the majority of the suspension and braking system, though the power steering system needed replacing because the original utilised an engine-driven hydraulic pump.

One area that remains entirely unaltered is the outer bodyshell and roll cage, which simplified the homologation process for competition. However, the floorpan of the car came in for extensive revision in order to accommodate the battery pack.

Where there was once a central transmission tunnel and fuel tank, there is now a T-shaped battery pack, which is contained entirely within the roll cage. Kreisel designed the layout of the pack (which is closely related to its rallycross unit) to optimise the weight distribution of the car, which sits at 53:47 front to rear, exactly mimicking the standard Rally2 Fabia.

Foissner notes that while there was plenty of spare space at the front of the car, with the motor and inverter occupying far less volume than the battery, a location outside of the cage structure would have presented considerable safety challenges. The battery modules are encased within a carbon-fibre composite shell, which has passed the same crash tests as the company's rallycross units.

According to Ales Rada, technical director at Skoda Motosport, even though the RE-X1 is more than 100kg heavier than the Rally2, the extra torque of the motors can mitigate the impact of this weight under acceleration. However dynamically, such as under braking and cornering, the added weight is a

The battery pack sits in the floorpan within the footprint of the cage, its modules safely encased in a carbon fibre composite shell

ŠKODA FABIA Rally2 evo vs. ŠKODA RE-X1 Kreisel

	ŠKODA FABIA Rally2 evo	ŠKODA RE-X1 Kreisel
	Chasis	
Base model	ŠKODA FABIA 3rd generation	
Bodyshell	FIA Rally2 category homologated	Modified for battery and drivetrain implementation
Length	3,994 mm	
Width	1,820 mm	
Suspension	Front and rear McPherson	
Brake discs	Alcon, Asphalt Ø 355 mm, Gravel Ø 300 mm	
Weight	1,230 kg	1,330 kg (inc. 330kg battery)
	Powertrain	
Engine/drive	Turbocharged 1620 cm^3 ICE	Two e-motors, silicon carbide inverter
Max. power	214 kW	260 kW (Reduced for Rally2 cat.)
Max. torque	425 Nm	600 Nm
Consumption	0.6l / 1km of special stage	1.2 kWh / 1km of special stage
Fuel/battery capacity	82.5 l	52.6 kWh
Transmission	5 speed sequentional Xtrac	High Performance Xtrac

ŠKODA Storyboard

The combined output of the powertrain is 260kW, compared to 214kW from an IC engine Rally2 car

ELECTRONIC THROTTLE BODIES

MOTORSPORT ABS

POWER BOX PBX90

CAS M ANTI-COLLISION RADAR

MOTORSPORT MOBILE WHEEL ALIGNMENT

MOTORSPORT IGNITION COILS

MOTORSPORT FUEL PUMPS

MOTORSPORT SENSORS

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Stage debut

The Skoda RE-X1 Kreisel's debut was impressive given it was competing against some of the most potent rally machines short of full Rally1/WRC cars. While it took some adaptation, for driver Raimund Baumschlager, his experience of the electric Skoda was, overall, a positive one. 'For a car we drove for the first time in February, [the result] is great,' he said after the rally. 'I have to change my driving style a little bit, because the car is about 100kg heavier than the classic Fabia Rally2 Evo. There's also no clutch or gearbox, so it's a completely different way of judging speed when cornering. Otherwise, though, the RE-X1's handling is getting closer and closer to a petrol-engined Rally2.'

With most of Rally Weiz's stages taking place on wet tarmac, the Skoda was already sitting in third place in the Rally2 class by the second day of the Austrian event, Baunschlager remarking that he was able to press on as confidence improved. 'I seem to be quite good in the wet with the Skoda RE-X1 Kreisel. I made a great tyre choice and we gradually increased the pace. Third place is a brilliant result for us, especially since this was the world premiere of an electrically powered competition car that completed the full length of the race [rally]. We now have a lot of data needed for further development and we can't wait for the next race.'

For Skoda, the rally was a resounding success, with one of its Fabia Rally2 Evos also claiming the win. 'For the Skoda Motorsport team, the project to implement electric drive in rallying has been an exciting challenge from the very beginning,' David Jares, Skoda Motorsport's customer programme coordinator said. 'Having two cars with completely different powertrains on the podium shows that the Skoda Motorsport team is well prepared for the future of rallying.'

The RE-X1 impressed on its debut on Rally Weiz in Austria, coming home third against strong opposition and performing very well on the wet asphalt stages that were a feature of the event

hindrance, though not an insurmountable issue. The main hurdle his team faced, Rada says, was integrating the battery within the shell. 'We had to decide how to fix a 330kg battery within the bodyshell and floor. At least the batteries are built to standards already defined by the FIA, so there were some guidelines to work to.'

Leading the charge

That a pure EV has managed to complete a traditional stage rally without any issues is an impressive achievement. Currently, the RE-X1 is only homologated in Austria by the national ASN, with Skoda supporting the homologation process for the roll cage, but there is no reason why, technically, it could not compete in other European rallies. But, as Rada points out, the problem remains that while the technology may now be approaching a level of maturity where EV rallying becomes achievable, regulations continue to lag behind. Beyond one-off prototypes such as this, there is currently no unified drive towards an all-electric rally class.

Rada says: 'The future is not only the techniques, not only the development, but how the regulations and the FIA and manufacturers will look after this new technology globally, not just in the WRC category, but in categories one and two steps lower. We are following the situation for an indication from a rules point of view in which direction to go and which technology to support, then we will integrate that into our development activities.'

While the WRC is locked into its next rule cycle for at least five years, and there seems to be little appetite among manufacturers to pursue full electric, ensuring there is scope for EVs to compete in FIA sanctioned classes would seem a wise move. Provided the performance can be balanced against traditional machinery, or dedicated classes created, it could do a lot to improve rallying's image among those sectors of society who are currently offended by flame spitting monsters tearing up forest tracks.

While the technology may now be approaching a level of maturity where EV rallying becomes achievable, regulations continue to lag behind


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Formula Student

Scots' speed

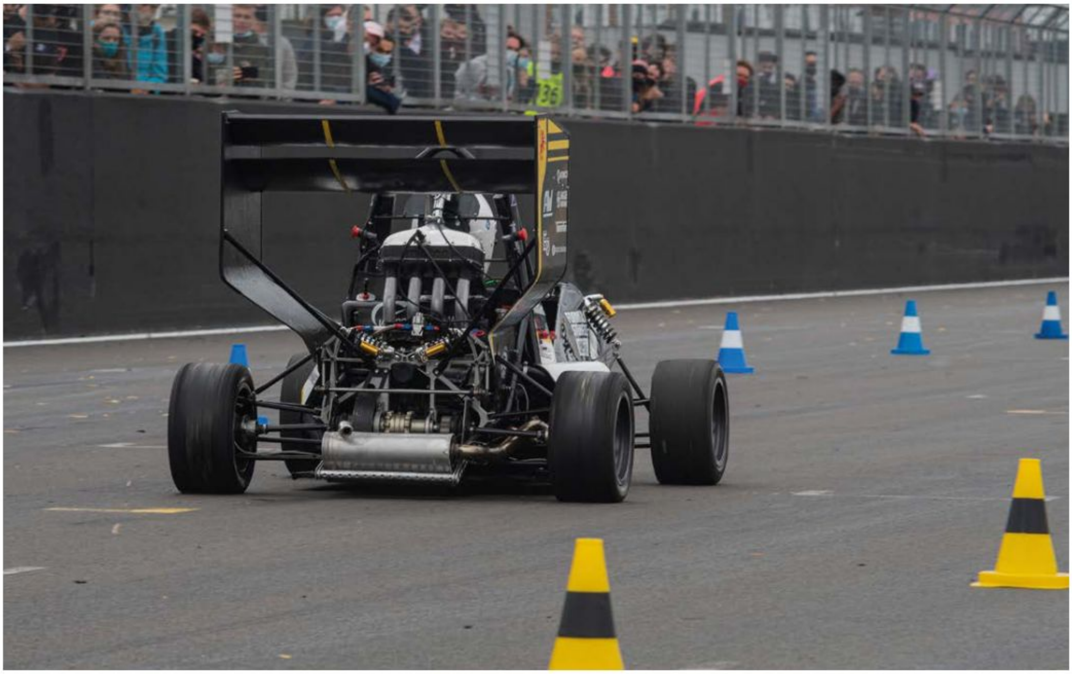
Formula Student returned to Silverstone this year, where the University of Glasgow's UGRacing team scooped the coveted Racecar Engineering *Engagement, Outreach and Communications Award, earning its cleverly designed UGR20 entry a technical profile in these very pages*

By STEWART MITCHELL

Formula Student is Europe's most established educational engineering competition, arguably producing the most well-rounded engineers for the motorsport industry with a format that inspires the students involved to innovate in their fight to reach the top step of the podium.

Due to the coronavirus pandemic and the associated travel restrictions, the 2020 live event at Silverstone, scheduled to take place 22-26 July, was cancelled. Instead, teams competed in a virtual event held online, showcasing their Formula Student project efforts in a digital format. The acceleration and skid-pad events were replaced by lap-time simulations using a multi-body dynamics model and recreations of the courses used at Silverstone. Secondly, online multiplayer competitive simulation races in Assetto Corsa tested the skills of the drivers. With restrictions lifted this year, 21-25 July saw 31 Formula Student teams return to Silverstone to once again put their efforts to the test in real competition.

For the first time in its Formula Student history UGRacing's car featured a rear wing, which offered significant downforce at low speed



Formula Student

The inline 4-cylinder CBR 600 engine saw significant development to deliver more driveable torque in the optimum rev range, while the first gear was lengthened to help with the corner exits

This year, the University of Glasgow team, UGRacing, posted its best ever result with an eighth-place overall finish, while it also retook the Scottish Formula Student crown. It also won the Engineering Design event for 1st Year Vehicles and the *Racecar Engineering* Engagement, Outreach and Communications Award. In recognition of the latter achievement UGRacing's 2021 entry, the UGR20, is reviewed in these pages.

Evolution

The 2019 Formula Student competition was pivotal for the University of Glasgow Racing team (UGRacing). It finished eighth in the design event with its UGR19 entry, a massive leap up the tables compared to previous events. 'Finishing eighth in the design event gave us a real confidence boost going into the design phase of our next car, UGR20,' explains Fraser Cowie, team principal of UGRacing. 'We started designing our 2020 car at the tail end of 2019, and we went about it with quite a holistic approach. We went right back to a blank page.'

With the pandemic effecting the 2020 event, the deployment of UGR20 was put on hold until the 2021 live event at Silverstone. UGR20 is a vast departure from its predecessor in almost every respect. 'The aerodynamics, engine development, suspension and packaging all play a role in the increased performance of UGR20,' Cowie says. 'We had so many performance gains on

'The aero, engine development, suspension and packaging all play a role in the increased performance'

Fraser Cowie, team principal UG Racing

UGRacing

Formula Student

UGR20 performed well in the dynamic events at Silverstone. It features a forward-braced chassis design and a new machined aluminium rear bulkhead, which helped to increase the stiffness

As with all forms of motorsport, Formula Student is very much a team effort

paper from the design we completed at the tail end of 2019 that we were confident that, if we could get our correlation right, we would have a very high performing car when we turned up to compete.'

Chassis

The primary driver for redesigning the chassis was improving the car's handling, which meant increasing stiffness. 'We designed a machined aluminium rear bulkhead, replacing steel members at the back of the car,' Cowie says. 'The new design is much nicer to package. The differential sits off it, and the rear suspension elements mount directly off it as well. Rather than having clunky, inefficient steel members, we have this aluminium profile that you can bolt on to, saving weight back there.'

The UGR20 chassis is forward braced, meaning the stiffest part, and where the chassis warp is controlled, is ahead of the centreline. This produces less twisting going in to and coming out of corners and it should also give the driver a lot more confidence in the car, while providing more positive feedback. But this change to the chassis concept didn't come for free. Several compromises were associated with moving to a front brace chassis regarding powertrain installation, suspension geometries, and ergonomics. 'The chassis is so integral to every system and subsystem, and each design team wants to put their two cents into the chassis design compromises,' says Cowie. 'Concerning ergonomics, the driver must be able to operate the car safely from within the confines of the chassis and evacuate the car within five seconds in an emergency. Getting out of the car is a bit more challenging when you've got forward chassis bracing coming around outside of the driver where it usually wouldn't have been. However, we were able to design it within the regulations with no issue with driver extraction.'

There are some freedoms within the Formula Student regulations regarding the car's overall geometry. However, because of the nature of the competition the teams tend to design the wheelbase to the minimum possible dimension. On the other hand, the track width is entirely dominated by the suspension geometry and vehicle dynamics, ensuring the car achieves the desired weight transfer load distribution. New for this year, UGR20 has anti-roll bars to control the load transfer during cornering, and each corner has anti-geometry in the suspension design to maintain a stable platform in dynamic situations. 'Since we don't have a coupled suspension system, we used the suspension geometry to reduce the car's pitch, particularly for the braking events,' says Cowie. 'Having a slightly higher anti-dive percentage so that the ride height stays as constant as possible is key to fast lap times.'

Aerodynamics

UGR20 is the first winged car produced by Glasgow for the competition. 'We haven't had the resources to do an aerodynamic study on the car in previous years; we didn't have the team members with that knowledge or [who were] willing to design and advance the car's aerodynamic performance,' says Cowie. 'Understanding simulation tools for the aerodynamic development has been a learning curve and quite intensive design-wise and in terms of resources. Although carbon fibre is getting cheaper, it is not cheap. However, thanks to some of our sponsors, we have been able to pick up carbon fibre for the aerodynamic elements within budget.'

Despite Formula Student being relatively low speed, there are some significant advantages in vehicle dynamics which are gained with aero. Teams in the competition design wing packages that produce substantial amounts of downforce at low speeds. 'Our rear wing provides 80N of load on the rear axle with airspeed of just 20mph,' Cowie says. 'The driver can feel and use the added grip that this correlates to in the low-speed corners, making for a more confident drive and a faster lap time. As aerodynamic load is exponential at speed, this translates to a more compliant car with higher level handling in the medium and high-speed sections of the course as well.'

Formula Student

Due to the UGR20's chassis being all-new for the 2021 Formula Student competition, the scrutineering process was quite intensive

The team simulated the aerodynamic package using a nominal airspeed of 10m/s (~20mph) and optimised around that speed. Miguel Cuni Municio, vehicle dynamics team leader, built the simulation in a multi-paradigm programming language and numeric computing environment called MATLAB. 'Effectively, we hard code all different parameters of the car so we can change them and then change the coefficient of drag and lift to see how that will affect cornering performance and top speed,' explains Cuni Municio. 'We were able to calculate the best compromise in drag/lift ratio that was most effective for fast lap times in the Formula Student application.'

The simulation considers all the data from the car, including the powertrain, creating a thermal model and ensuring that the car will not overheat with the aero package onboard. Where possible, the team was able to refer to the simulation to reduce the size of the cooling system, reducing the heat capacity, reducing weight and aerodynamic losses.

Tyre models were also used in the simulation to yield accurate vehicle dynamic modelling, taking into consideration the tyre forces, mass, and inertia of the car to get the linear and angular accelerations of the vehicle at all points on the circuit. The UGR20's vector combined with track parameters also highlight the throttle, steering, and braking inputs.

'With the digital environment for the car designed as effectively as possible, we ran many different simulations to find the best set-up,' says Cuni Municio. 'It was surprising how negligible drag can be for a Formula Student car. Due to the low average speed and highly technical nature of the Formula Student circuit, the yield from cornering faster is huge. The drag penalty for carrying big wings is minimal compared to the gain they provide in cornering performance.'

> **The drag penalty with big wings is minimal compared to the gain they provide in cornering performance**
>
> *Miguel Cuni Municio, vehicle dynamics leader UGRacing*

Powertrain

A naturally aspirated inline 4-cylinder Honda CBR 600 powers the UGR20. UGRacing selected the engine because of its high-power density and has heavily modified it. For parity across the field, Formula Student mandates the use of air restrictors on internal combustion engine powered cars. With this, the characteristics of the powertrain must be explored and exploited to the best resulting output for the application.

'The base engine has a notable dip in the torque curve in the middle of the rpm range (4000-8000rpm) with the restrictor we have to run, which is where we spend over 80 per cent of the time in the Formula Student event,' explains Neil Dawson, powertrain manager at UGRacing. 'Reviewing data from the engine in operation, and driver feedback, along with characterising the performance window for Formula Student, we highlighted several areas that we could significantly improve.'

The primary influencer of the torque curve is the breathability of the engine as a function of camshaft profiles and timing. This is the

first area the team addressed. 'We started off measuring the stock cams, looked at fuel mapping and spark timing to see what effect each was having on the torque dip,' Dawson says. 'We did a 1D simulation of the intakes to see if we were getting reverse flow through the valvetrain timing, and it was here that we saw that during valve overlap there was reverse flow coming from the exhaust side, through the combustion chamber and into the intake port. When we analysed it against dyno data we could see that we had a very lean mixture because the reverse flow gasses were diluting the intake charge mixture.'

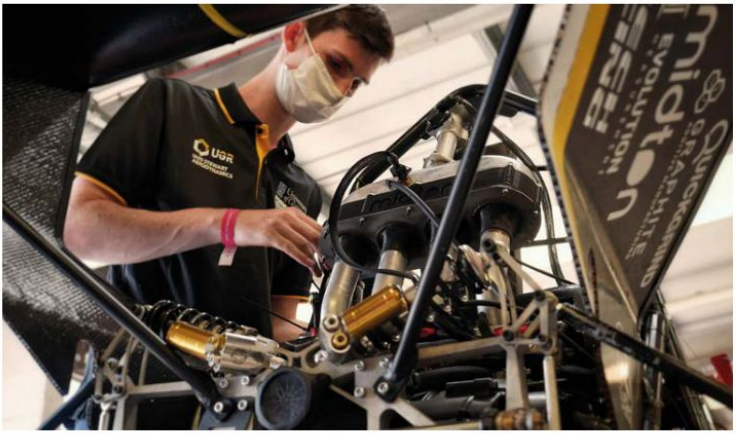
Camshaft profiles

The big job for the camshafts was to reduce the valve overlap to prevent the reverse flow. To do this, UGRacing set up simulation sweeps using optimisation software to generate a series of camshaft profiles that would provide maximum area under the torque curve in the desired operating range. 'The optimisation went through around 480 different camshaft profile designs to get the maximum area underneath the torque curve,' Dawson says. 'From there, we were able to select the best profiles for the application based on simulated engine data.'

The resulting exhaust camshaft features a reduced valve overlap, reduced lift, and delayed timing. For the inlet camshaft, the duration remains the same. Despite the software producing a thermodynamically optimised gas exchange, it did not consider the mechanical limitations. This meant that the simulation produced profiles which would have seen the valves occupy the same space in the combustion chamber as the piston at TDC. Because of this the camshafts needed further optimisation to ensure safe clearance for the valvetrain in operation.

Valve lift, acceleration and jerk were also analysed to ensure the camshaft/tappet interface could survive. 'Because we are trying to achieve the same lift in a shorter duration, the stress on the valvetrain was going to increase,' Dawson says. 'However, we were able to minimise it with harshness development to prevent any camshaft failure. The final profiles saw the valves accelerate faster than the stock camshafts permit, and with the harshness analysis carried out, we had the confidence to run the new profiles.'

Changing the camshafts had some knock-on effects with regards to engine control, as Dawson explains: 'We originally wanted to advance the exhaust, but the ECU, which relies on camshaft and crankshaft position sensors to run the engine, wasn't happy with the delta in the position of the exhaust camshaft so wouldn't run the engine. However, the mechanical changes we made to the camshaft profiles were sufficient to yield the performance we needed.'


UGRacing

The engine package features a bespoke 3D printed plenum designed to coincide with the mandated restrictor and the pulse tuning within the rpm range in which it spends most of its time. Inside the unit there is a set of upgraded, higher-compression pistons

The engine also features an upgraded, higher-compression piston package, taking it from the base 12.2:1 compression ratio to 13.5:1. The upgraded pistons are slightly lighter than the original pistons. However, the biggest gain was in balancing the engine – the new pistons were each within 0.5 grams of each other, making for a much smoother running engine that could maintain better lubrication in dynamic situations.

The original crankshaft from the CBR 600 engine remains, though it has been through a significant weight saving regime. 'We shaved a total of 793 grams out of the counterweights on the crankshaft,' says Dawson. 'We also sculpted the counterweights to a knife-edge design to aid its flow through the air in the crankcase.'

'We shaved a total of 793 grams out of the counterweights on the crankshaft'

Neil Dawson, powertrain manager UGRacing

Exhaust and intake

Tuning the exhaust and intake was another significant part of developing the CBR 600 engine. Dawson notes that the intake volume and runner lengths are calculated for drivable torque in the racecar's 4000-8000rpm operating range with the prescribed restrictor, a significant departure from the original motorcycle engine set-up. 'We have designed the intake volume and shape to tune the wave reflections within it to provide high torque in the race operating rpm range and constructed the plenum from 3D printed material to allow for a more complex volume,' he says. The exhaust design coincides with the engine's intake side, providing sufficient flow and pulse tuned backpressure for adequate torque in the desired rpm range.

The team super finished the gears to reduce the frictional losses and it also lengthened the first gear. 'Because the original first gear was too short, coming out of hairpins and the tight turns in the Formula Student competition, the driver was shifting just on the corner exit, which was not optimum for the fastest lap times,' Dawson says. 'We lengthened the first gear ratio and left all the others the same as they were sufficient for the application.'

Dawson used an NTU method to calculate the heat output from the radiator and correlate that with the amount of heat the engine needed to reject during the event. Calculations were associated with simulated models of previous Formula Student tracks to produce a load case for the engine linked to the thermal energy produced throughout the lap. The radiators and coolant flow are sized appropriately. The team replaced the stock mechanical CBR 600 water pump with an electric pump running on an independent module. It is programmed to operate at a higher flow rate than stock to extract more heat at lower engine speeds. The maximum simulated engine temperature in 25degC ambient was 103degC. During the event, the car ran at 105degC, proving the simulations were very close to real-world conditions.

While the UGR20 is now the most successful car in Glasgow's Formula Student history, it was the 2021 UGRacing team's effort in producing professional and entertaining content for consumer and partner consumption which clinched the *Racecar Engineering* Engagement, Outreach and Communications Award.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The much-missed Ricardo Divila (left of picture), a *Racecar* regular for many years, was a great believer in the radical philosophy behind the GT-R LM and a key member of Nissan's race team

'Nissan had stipulated that we had to have three cars at Le Mans, and we could not let them down'

End game

In the final part of our series on the ground-breaking but ultimately flawed Nissan GT-R LM, one of the team's engineers recalls its first and only race, at Le Mans, and the shock termination of the LMP1 project at the end of 2015

By SIMON MARSHALL

By mid-May of 2015 time had pretty much run out on the test and development programme for the Nissan GT-R LM, and the team moved from Indianapolis to a temporary home at the Silverstone circuit in the UK to complete its preparations for Le Mans.

Then, late in May, all three cars were taken to Le Mans. The first garage on the north end of the pit straight gave us an extra external working area to keep the tyres, plus a trailer given over to the machining and fabrication shop for essential maintenance. We knew we were in for a busy month.

Our driver line-up had been confirmed by now. Car 21 was to be driven by Lucas Ordonez, Tsugio Matsuda and Mark Shulzhitskiy; car 22 by Michael Krumm, Harry Tincknell and Alex Buncombe; car 23 by Max Chilton, Jann Mardenborough and Olivier Pla.

By this stage we were also still modifying parts, drawing them on CAD in the garage at Le Mans and getting them made. The ACO insisted that we move the mirrors outboard by 100mm and so mountings were modelled and emailed to CRP in Italy, who rapid prototyped them using their Windform material. One of our engineers then flew to Italy, received them at the airport and flew straight back again. By now, Brian Oeters (design and composites engineer) and I were knee deep in Jabroc (wood laminate) shavings from having to re-profile the chamfers on the underbody skids to pass scrutineering. Three cars, three sets of skids, equalled plenty of dust.

Testing times

There are two schools of thought when it comes to preparation; *just in case* and *just in time*. We were the latter, and even that was stretching it a bit. But once we had settled into our new home at Le Mans we elected to take part in a private test day on May 31. Interested parties shared the cost of the Bugatti circuit for a shakedown before the full circuit was opened. It was the first time that the opposition had seen 'Godzilla' in the flesh, but it was also a big deal for the team.

The Bugatti circuit does not have long straights and big braking events, so for the hybrid systems, brakes, gearing and car set-up for any team it is not ideal. Still, our brakes overheated quite quickly due to a quick succession of braking areas linked by very short straights, and there was no ERS braking.

For the official test day and the race, Nissan had stipulated that we had to have three cars and we could not let them down. On the orders of Nissan, and the insistence of Darren Cox (the former motorsport boss) and the drive of chief designer Ben Bowlby, coupled with the determination of the race team, on the offical test day at 9am we lined up first, second and third in the pit lane waiting for the session to start. From a distance we looked prepared, but we were like swans on the water, serene on top while paddling frantically beneath the surface.

We noticed that the other P1 cars weren't trying to complete full laps at high speed, as it wouldn't wouldn't prove anything at this stage. However, we had a test programme and throughout the day we executed it. Each driver got a run, and a long job list was penned for the race week practice. The team then went out in the city's old town for a raucous evening in preparation for what was about to be our longest ever month.

Tradition at Le Mans is everything. Come the week of the race the cars are taken one-by-one on flat beds from the track to the old town for scruntineering, and the razzmatazz that goes with it. This is the only race where scrutineering is a day-long carnival, at least it was pre-Covid. For 2015 there was a little extra spice to the proceedings, as we awaited the verdict of the ACO on the technical discussions that we had been having with the FIA. How would our execution of the letter of the regulations go down with them, we wondered? They hadn't necessarily been involved in our discussions with the FIA.

Not all the tests are completed in town. Indeed, the hybrids had their tests undertaken at the track for various safety reasons. We, too, had some of our tests at the circuit. The FIA-witnessed bodywork load/deflection tests were conducted in the scrutineering garage on June 9, adjacent to garage number 1. That involved a 30-metre push for our car, which was easier than the trip into town. However, it was still a nerve-wracking event as it was the first time that these tests had actually been performed on the car. All went well, much to our relief. But there was much hard work to come.


The team moved from its base in Indianapolis to a temporary home at Silverstone in May for some last minute Le Mans preparation


Scrutineering. Note that the radiators are part of the front splitter assembly; this caused big problems in the pits during the race

Sleepless nights

There was a mantra for our Le Mans programme which was repeated often in the media output from the team: *Eat. Sleep. Race. Repeat*. But this was totally wrong. There was no sleep for us, and often we hardly had time to eat, either. *Work. Eat. Sleep*, sometimes. *Work. Eat*, at others. Then: *Work. Eat. Work. Work. Work* for much of the race prep week.

It wasn't only us in the garage that were racing to be ready. Brandon Fry, the race engineer for the number 22 car, had set the target for the first practice session for Buncombe, Chilton and Matsuda to each get in 10 laps, as they had no previous experience at the track, other than on a simulator.

'We also needed to understand the tyre situation at Le Mans,' says Fry. 'As a new manufacturer we were allowed 14 sets for the race and existing manufacturers were allowed 12. Our plan was to run the front tyres for four stints, the rears for eight or nine.'

In practice our GT-R LM was the fastest thing on the Mulsanne Straight, breaking the speed trap beam at between 330 to 350km/h (205 to 217mph). We knew that it would be quick, and that this was possibly its strongest point, but it caused the raising of some eyebrows among the other teams, which in turn caused some remonstrations at the rules committee's door. As always, in politics it is cheap to have an argument, which is why people are so happy to complain.

The 2015 regulation weight was 880kg without driver or fuel. This was a 10kg increase compared to the year previously due to rule changes which increased safety by adding driver support load testing to ensure they were as protected as possible. My recollection is that our racecars were significantly overweight. Le Mans cars normally come in above the required minimum weight as various bits have been beefed up ready for the 24-hour battering that the racecars get, but we were something like 30kg over the minimum weight!

The ERS was homologated from the latest heavy flywheel iteration we had, and even though we were only using it as ballast it still had to be the correct weight. The engine was also marginally overweight and the gearbox much heavier than we had planned. The cooling system used Mezzo stainless steel tube cores which were also extremely heavy. These have become more popular recently for their rugged nature, but you have to save weight elsewhere in the car if you want to use them without any penalty.

We had underestimated the real weight of the 'must-have' items on the car and each missed weight target was logged ready for a rather complex planned diet for 2016.

'Part of the difficulty was that the design of the GT-R LM was so interdependent, as were all of the LMP1 cars of that era, that the failure of the hybrid system had significant knock-on impacts for other parts of the vehicle, which ultimately created the situation that compromised the running more than possibly would occur with a normal car,' says

It might sound as if it's like the rear end of other cars, but the nature of a front splitter diffuser is much more aggressive than even a powerful rear wing

Fry. 'Most significantly the brake system was woefully under capacity for running without the hybrid system working.'

For that first practice session, the conditions were changeable and so having the right tyres mounted on the rims, set at the right pressures, warmed and ready to go in our tyre cabinets, was imperative. However, I was reacting to my drivers' comments (I was engineering the number 21 car of Ordonez, Shulzhitskiy and Matsuda) and the rain that I could see coming, while our team managers were watching what the other teams were doing. The information was coming too fast and we hadn't got our game together to have a solid enough session plan.

Qualifying

Come June 11 it was time for qualifying. By now a driver size issue had become apparent in our cockpit, with the front-mounted ERS space taking cockpit length away. Knees and the steering wheel were fighting for the same real estate and with the short/tall combo of nine drivers sharing six steering wheels with all sorts of mounting spacers it was not ideal. Sometimes the driver got the wrong wheel.

Our simulation of the Audi lap was a 3m23s time, which we estimated would increase to 3m26 with the extra weight for 2015. Our GT-R LM simulated lap time hinted that we would be in the region of 3m29s at Le Mans, without the ERS and with the 2MJ fuel allowance (see box out). Three seconds off meant that we would still be within reach of the rest of the field. However, simulation is one thing, reality is – and certainly was in our case – a totally different matter.

We achieved a 3m37s lap time in qualifying, eight seconds slower than our simulated time. Why? Sims are at the mercy of data input, while the track surface, conditions, real tyre characteristics and team orders to avoid the kerbs (see below), all clouded the waters. There is simply no substitute for making a sim, running the lap, and then setting a baseline before tuning the sim.

Then there was the power. 'The Cosworth engine was felt to be reasonable in terms of power and efficiency, but without the hybrid system it did not look very spectacular,' said Fry. 'To stay within the allocated fuel per lap, measured by the FIA fuel flow meter, we required significantly more lift and coast than our competitors. An LAC [lift and coast] system was developed which would optimise the lifts around the track for the best lap time based on simulation and would continuously recalculate based on position on track, driver over-ride, and so on. However, without the hybrid system we were in a different league compared to the others.'

The qualifying lap times of rivals was also significantly quicker than we had anticipated. Porsche was on pole with a 3m16.8s lap, and in the race its fastest lap was a 3m18.6. The fastest Audi was 3m19.8s in qualifying, 3m17.5s in race conditions, while Toyota qualified in 3m23.5s and its best race lap was a 3m22.6s. We qualified in a 3m36.9 and our fastest race lap was 3m35.9s …

Rate expectations

One of our main problems was that our car was easily disturbed by the kerbs due to high front spring rates. The front springs would be ideally soft for front-wheel drive traction, but the conflicting interest of maintaining front (aero) ride height with the sensitive splitter soundly won the day. Rear-wheel drive cars can have pro-tractive soft springs on the drive wheels, which makes more sense dynamically with low-speed high rear ride height and high speed low rear ride height (less drag). It was a hard problem to solve. We needed maximum compliance at the same end as the max weight and max downforce. It might sound like the rear end of most racecars, but the nature of a front splitter diffuser is much more aggressive than even a powerful rear wing.

In testing, the drivers did not have cause to clatter the kerbs, but at Le Mans in competition they had to deliver the lap times and taking kerbs was the fastest way around the race track. We had also noticed that the spherical bearings in the end of the steering rack were being plucked out due to binding and bending of the tie rod.

'One other issue that was a constant problem in testing was the power steering system,' says Fry. 'It was not consistent or reliable and had a dead-spot in the middle of the range which the drivers struggled with.'

The Michelin 18in tyres did not seem to be performing well on our car, too. They were the older spec (due to the supply issues that we had imposed on Michelin with our change from 16in rims) and they didn't have the load capacity or tractive capability that we needed.

The number 21 car shown before it embarked on a shakedown test on the airstrip at Le Mans. The GT-R LM was actually pretty quick in a straight line, even though it was massively overweight

Our initial strategy for the slow corners was to use the rear tyres in the most efficient way, with a maximum brief acceleration with no rear tyre slip, and without the need for lateral grip at that time. The faster corners, with the aid of more downforce, wouldn't involve rear ERS power anyway.

The new front tyres (even with their shorter sidewalls) were quite bouncy and didn't help us with our porpoising issues under braking. The tyre pressures set by Michelin were unusually high for a sports prototype searching for grip, in the region of 30psi (2.07bar), but we weren't able to lower the pressures due to the problems with our front aero ride height control.

The race

By the time we had arrived at the track on Saturday, race day, the crew of the number 23 car had been up for 32 hours having discovered an issue with the fit of the underbody. It was not an ideal start for them.

During the race, all cars had problems with high front brake wear and brake cooling. Our regular pit stop routine included front splitter off, gearbox internals check, new clutch, new brakes, new rear suspension, refill the radiators (because they were mounted on the splitter), bleed the system and warm up the engine. This took around 1.5 hours and wore out the mechanics.

The second and third gear ratios were prone to failure when prompted by kerb strikes while these gears were engaged. This was a function of our narrow gear design. Our gearbox man, Jerry Brushard, and Nismo experts, performed nine gearbox ratio cluster changes for the three cars during the race. This was planned for, based on testing failures, and so they had the clusters built, and used aluminium shafts bristling with magnets to insert into the case and draw out the broken steel parts as quickly as possible.

Each of the GT-R LMs had rear suspension failures during the race. The rear aluminium suspension rocker had some fatigue issues which had been improved with a titanium version, but not eradicated. But as the racecar was light enough to drag itself around on three wheels when this happened, none of the failures was race-ending.

My car (number 21) was the first to retire, with a loose wheel nut. The brake caliper wore through the loose wheel and we lost tyre pressure. Matsuda tried to get the car home from Arnage with only one driving wheel. The differential speed was therefore very high and the small electric-hydraulic motor controlling the torque vectoring diff, with its own watch-like gearbox, was over-run and eventually exploded, essentially freezing everything. The heavily-laden front was the Achilles heel of the racecar; when one front wheel was lost it was all over.

The rocker failure locked the unloaded wheel, which spun the troublesome diff motor up to 30,000rpm, at which point it exploded and caused a gearbox oil fire

Car 23 then had a front rocker failure under braking for Mulsanne corner after approximately 16 hours. That was a new one for us. This locked the unloaded wheel, which spun the troublesome diff motor up to 30,000rpm, at which point it exploded and caused a gearbox oil fire.

Our hopes rested on the number 22 car, and the drivers were doing a solid job in it before Tincknell hit a tyre in the road on the Mulsanne Straight at full speed. He got the car back, missing its bonnet and dragging its sparking underside, forcing major repairs. He tried to continue, but was held in the garage for further repairs before finishing the last lap of the race as a gesture to the Nissan fans – they were with us all the way, and this was were very much appreciated by the team.

The winning Porsche completed 395 laps, an average of 3m24.6s lap time (3m24.6 multiplied by 395 laps is 22.5 hours, with 1.5 hours for 30 scheduled stops). Our number 22 spent nine and a quarter hours in the pits.

Picking up the pieces

So that was Le Mans. The first and only race for the GT-R LM, but not quite the end of the story. We continued testing in July and September of 2015, the latter immediately after the WEC race at COTA, and we used the lap times from this as a baseline against which we could measure ourselves. 'The brake package was completely overhauled for cooling, durability and performance,' says Fry. '[But] this compromised the aero performance, which was a strength of the car.'

Through CFD studies Bowlby, together with Total Sim CFD, had deduced where the porpoising was originating. The low-pressure vortex that was formed by the front diffuser and the outboard fences was, at low front ride

The 21 car was the first GT-R LM to retire, falling victim to a chain of mechanical catastrophes that began with a loose wheel nut

The Cosworth engine was good in terms of power and efficiency, but without a hybrid system the car was always going to struggle


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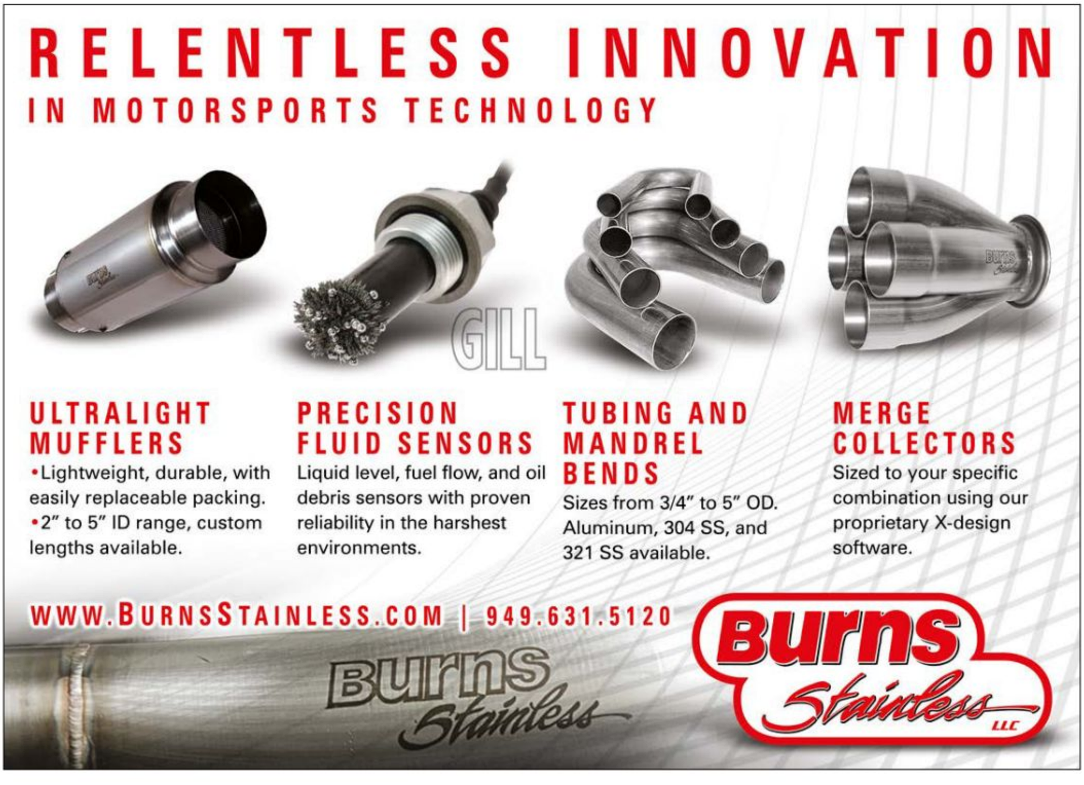
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heights, very sensitive to the front tyre wake coming from the squish ahead of the contact patch. The wake would destroy the forming vortex, turning the front downforce off and on, sending a mess down the through ducts. The trick we had to learn (with TotalSim) was how to model this flow instability in CFD, rather than just guessing about the origin and the cure, which is where we were before.

With development aimed at 2016, Bowlby increased the expansion of the front diffuser ahead of the front tyre, which changed the flow structure enough to rid us of the tyre wake/vortex problem.

FRIC show

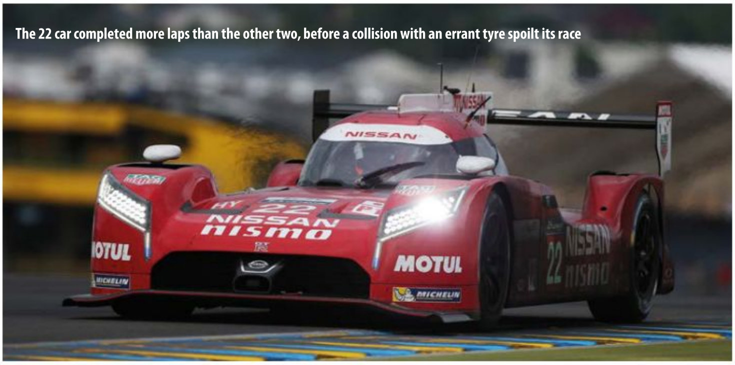
We also had our new 'Front and Rear Interconnected Suspension' (FRIC) to hone. This was based on the existing rear hydraulic ARB arrangement. The powerful leverage of the soft rear motion ratio would lift the front of the car up as the rear came down at high speed. If the rear squatted down 20mm, the front would raise up about 8mm, a good drag reduction, and upon initial braking we could keep the front splitter from hitting the road, and so have a generally lower corner ride height than otherwise. In July the car went to the shaker rig at ARC Indy. The FRIC was tested there, but there was still a lot of damper work to do to stop the racecar bouncing on its tyres.

But in terms of racing, the 2015 season was over for us. The car wasn't fit to carry on with the season, so we set our sights on a new beginning in 2016. Our redesign objectives were: new electric ERS plan; front brake cooling; aero balance and front splitter sensitivity; manage weight distribution effects of the ERS strategy; serviceability; overall weight; rear structure; re-design for rear electric motors; the suspension geometry; and sort FRIC.

The 2016 weight saving plan (mentioned earlier) required losing 53kg ideally, or 40kg at minimum. This would come from: 25kg gearbox (!); 7kg tub; 10kg rear structure; 3kg engine; and 3kg from dampers and springs.

The initial projection for the 2015 GT-R LM flywheel system was 126kg for 8MJ (15.8kg/MJ) which in hindsight was very optimistic. When we tested the Flybrid ERS system at Palm Beach (March 2015) with only one flywheel and 2MJ capability deploying through the front wheels only, it weighed in at 104kg, which was 52kg/MJ (without the driveshaft, rear diff, halfshafts, stub shafts, which would have added another 40kg).

There were a few options open to us with electric, battery, capacitive or kinetic electric ERS systems for 2016 that were available and that had on-track history. The correct range for such a system in 2015 was 21kg/MJ. McLaren's Formula E system produced 8MJ, 155kg which is 19.4kg/MJ, the most



The 22 car completed more laps than the other two, before a collision with an errant tyre spoilt its race

powerful option but one that would put the car overweight. An air-cooled capacitor type system allowed 6MJ at 140kg, 23.3kg/MJ. An electric flywheel was 2MJ at 60kg, 29.5kg/MJ. We aimed for a 78kg 4MJ Formula E type system that came in at 19.5kg/MJ.

Andy Palmer had by now left his position at Nissan, having headed for Aston Martin in 2014 when we were in the throes of the 2015 car design process. With his departure we had lost our head corporate supporter. By mid-2015, after the Le Mans race, Nismo and Nissan were insisting on more involvement and oversight of the project.

Nismo design engineers were now flown in from Japan, to integrate with the team in Indy for the 2016 redesign. They introduced complex design submitting and engineering change management via Nissan HQ in Japan, which slowed down the previous rapid response from our small team.

Nismo's engineers (who were a friendly and energetic bunch, and we all got on very well together) were designing in metric and we (being an American race team) were designing in imperial, which led to further complications and delays. The gearbox was redrawn and the supplier was changed from Xtrac to Emco for 2016.

Then, while I was enjoying the Christmas holiday in England on December 22, 2015, Nissan announced that the story had ended. This happens from time to time in a motorsport career. But for a few weeks

Nismo's engineers were designing in metric and we were using imperial, which led to further complications and delays

afterwards we were receiving brand new composite, ERS, gearbox parts etc., unpacking them and putting them in sorted recycling bins. This was soul destroying.

It was a sorry end to the GT-R LM. Car number 23 was sent to the Nismo museum in Japan. The other cars, together with all spares, were crushed with the requisite certificates of destruction required by the new Nissan management.

Fuelling fantasy

When the FIA allowed us to slip from the 8MJ category to the 2MJ category (we had to run in a hybrid class as a manufacturer per regulation, even though we weren't actually using a hybrid system at all other than as ballast), the fuel allocation went up slightly as did the power from the engine. In the 8MJ class we had 89kg/h petrol, which meant our engine produced 550bhp (410kW) with this fuel flow. For the 2MJ class, that increased to 94kg/h, 580bhp (433kW), an increase of 30bhp, or a 5.6 per cent increase in power, although we would then have the penalty of shorter stints if we used all that power.

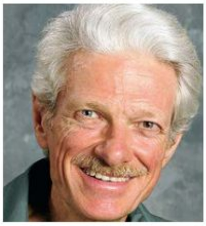
There were seven specific zones for ERS harvesting. Each zone started about 50 metres before the corner, giving the parameters for the design of the ERS harvesting mechanism.

As power = Energy/Time: 8MJ(energy) harvesting per lap equates to 2.2kWh (the energy of 2.2kW of power over one hour) and divided by seven = 0.314 kWh per zone. The extra accelerative power that was available can be found by:

$$\text{Power (W)} = \frac{1000 \times \text{Energy (kWh)}}{\text{Time (hours)}}$$

Assuming a five second burst of ERS deployment: 1000x.314/.0014= 224kW (300hp).

The 2MJ class calculation would only give a 75bhp boost. You can see the allure of the higher MJ classes versus the extra petrol power available, but horsepower from petrol is quite straightforward, whereas horsepower from ERS deployment is heavy, expensive and complicated.



Rig for victory

How do suspension testing rigs function and can a cheap pull-down example do the same work as high-end machines?

By MARK ORTIZ

Q What is your opinion of pull-down rigs? And how do they compare with K&C and seven-post rigs?

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A Pull-down rigs are mainly to be seen in oval racing. They were first used in lower division pavement classes where ground clearance and body template rules required the car to sit higher statically than people wanted it to run on the track. Where legal, people work these rules by running soft springs and hold-down shocks, while they try to have the car run on bump rubbers or small bump springs, at least at the front and sometimes at the rear as well, once it gets up to speed. This makes it desirable to have a way to set up the car in the shop that replicates those running ride heights, and to measure camber, caster, toe, and static wheel loads in that condition. More recently, dirt track racers have also started using pull-down rigs and measuring set-ups at some of the extreme roll displacements produced by rear suspensions that hike up the left rear of the car.

The advantage of a K&C rig over the pull-down type is that it can apply ground plane forces at the contact patches

Budget option

Pull-down rigs are a reduced-cost way of doing a bit of what you can do with a K&C (kinematics and compliance) rig and they are cheap enough to be fairly common in race shops. Various designs exist, but they all incorporate some way of moving the sprung structure in any desired combination of roll, pitch, and heave with the suspension fully assembled as run, including having the springs and shocks installed. Wheel scales are positioned under the wheels, on slip plates. Measurements are taken statically once the vehicle is positioned as desired.

Camber, caster, and toe can all then be measured using any means with the car just sitting on the shop floor; or on wheel scales, and we can read the wheel scales. I have seen claims that this lets you see the wheel loads the car experiences when running. That is definitely not so. When the car has independent front suspension and live axle rear suspension, it's not even close to being true. The problem is that, unlike a K&C rig, the pull-down rig cannot apply any ground plane forces at the contact patches. This means it cannot capture the geometrically induced forces and load transfers.

With live axle rear suspension and independent front, the geometric roll resistance and load transfer when cornering are much greater at the rear of a racecar than at the front, and the elastic component is larger at the front. Consequently, if we try to simulate cornering by measuring the racecar on a pull-down rig in an attitude similar to what it assumes when cornering on the race track, the loads shown on the wheel scales will not remotely resemble what the tyres see when the racecar is cornering on the track, with respect to both the total load shown and the load distribution.

Set-up comparisons

This does not mean it's useless to look at the car in such a condition using a pull-down rig. The camber and toe readings will be pretty accurate, and even the scale readings are at least somewhat meaningful for comparing one set-up to another, especially when the set-ups do not differ geometrically. It's just important to be mindful of its limitations, and what it actually does and does not show you.

A K&C rig is a much more expensive device, and beyond the budgets of most race teams. Most people who use K&C rigs buy time on one owned by a business specialising in this service, or in some cases can use one provided by a major car manufacturer which the team is associated with. The K&C rig can do a reasonably good job of statically simulating any constant-acceleration condition, and can perform many other tests as well.

The K&C rig can hold the sprung structure in any position, just like a pull-down rig, and it can apply longitudinal and lateral ground plane forces to the contact patches and measure the wheel load changes that result from those. This can be used to determine the jacking coefficients and geometric roll moments. I have used a K&C rig to verify that when right and left wheel jacking coefficients are unequal, the geometric roll resistance moment per unit of ground plane *y* force (i.e. the roll centre height) varies depending on right/left distribution of the ground plane force – and also that when the right and left jacking coefficients are equal, there is no such effect.

Pull-down rigs are a reduced-cost way of doing some of the things you can do with a K&C rig, and they are cheap enough to be fairly common

When you are simulating cornering the outside wheels need to see more ground plane forces than the inners

But to simulate cornering, braking, forward acceleration, or a combination of all of these, and take a look at what the car does in response and what wheel loads result, we don't hold the car in a predetermined position. We input an estimated or measured c.g. location and desired ground plane forces at each of the four wheels, and then let the racecar roll, pitch, and heave freely in response. The sprung structure is not actually constrained at the input c.g. It is clamped at points on its underside and the computer that controls the rig forces it to roll and pitch about the selected point. The wheel pads can move a bit laterally and longitudinally.

On a high-end rig the posts, which can be hydraulic or sometimes electronic rams, sit directly under the wheels of the test vehicle

Figuring the rigging

To get reasonably accurate results when doing this, firstly the ground plane forces need to be properly distributed. When simulating cornering, the outside wheels need to see more ground plane force than the inners, preferably apportioned according to pre-test calculations, and then tweaked according to test results. For braking, the ground plane forces need to be apportioned according to brake force distribution. In oval track cars, this may be unequal side to side.

Secondly, if we are simulating a condition that includes power application, the driving wheels must be rotationally constrained through the driveshaft(s), not with the brakes, unless the brakes act through the driveshafts. This point is especially important in live axle suspensions, where the driveshaft torque will produce significant roll displacement and wheel load changes.

How significant? Suppose we have a 3000lb (1360kg) car, 500lb/ft of torque at the driveshaft, and a 5ft (60in, 1.5m) track width. The driveshaft is trying to roll the car to the right with respect to the rear axle. This is resisted by both the front and rear suspensions, in proportion to their respective elastic roll resistance rates, but only the portion reacted at the front creates a change in diagonal (LR + RF) percentage. This may seem odd, but imagine what would happen if the front suspension had no elastic roll resistance, like some Formula Vee rear suspensions. The car would roll to the right, but the roll resistance would all be at the rear and there would be no load transfer at the front. Since weight jacking can only change diagonal percentage, not front, rear, left, or right, that also means there would be no load transfer at the rear. Same if the rear can't roll at all, as was once common in drag cars. This explains why muscle cars launch better with the front anti-roll bar disconnected.

Generally, when the front suspension is independent, the front will have at least three quarters of the elastic roll resistance and will therefore absorb at least three quarters of the moment. That would be 375lb/ft, reacted over a 5ft track width, resulting in a 75lb (43kg) load transfer from the left front to right front.

Since this effect cannot change the front, rear, left, or right weights, we also have 75lb of load transfer in the other direction at the rear. This means our diagonal weight increases by 150lb, or five per cent of the car weight.

The 500lb/ft might represent straightline forward acceleration on a level surface, assuming no downforce. If the rear tyres are using about half their grip for cornering, because we're powering out of a turn, we might see 350lb/ft and 3.5 points of diagonal percentage change due to driveshaft torque. This is still significant. It definitely matters if our simulation on the rig misses this.

There are some other inescapable inaccuracies, such as the inability of the rig test to separate unsprung load transfer from the total, and the inability to replicate transient effects, including those coming from the dampers. However, the test is still far better than we can get on a rig that doesn't apply ground plane forces.

Post modern

Seven-post rigs are a completely different sort of animal. They are used to test the car's response to road irregularities. They subject the wheels to *z* axis forces and accelerations (normal forces, perpendicular to the ground plane). They originated as modifications of four-post shaker rigs used by passenger car manufacturers to test a car's responses to excitations at the wheels.

These permitted durability testing, exposed vulnerability of components and mounts to particular frequencies, and allowed better tuning of elastic mountings for engines and other large masses to achieve inertial damping of ride motions.

In a four-post rig, the posts, which are generally hydraulic rams but can also be electronic, are under the wheels, and the car is allowed to respond freely to the excitations. The seven-post rig adds three posts attached to the sprung structure. This permits a degree of simulation of aerodynamic downforce, roll and pitch. The posts at the wheels can be run at particular frequencies, or they can be used to play back (albeit usually imperfectly) the wheel motions from an actual race or track test, recorded with data acquisition.

The object then is to tune the suspension to minimise load variation at the tyres. The loads recorded are post-processed through an algorithm that outputs a value called 'grip'. Here this does not mean the frictional force at the contact patch, but rather the consistency of the normal force. This affects the amount of friction force realistically obtainable, since this is to some degree limited by the minimum value the normal force reaches.

I should probably mention the existence of a fourth kind of rig, made by MTS, that combines all the functions and has belts under the wheels. These are accordingly the most expensive variety of rig and I have not had experience with one yet, but I expect I'll get comments if I ignore them entirely.

CONTACT

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Entry requirements

How load transfer plays out at the start of a corner and why it's vital to understand exactly what a car's doing during these first few metres

BY CLAUDE ROUELLE

I remember doing a few laps of a track with a race driver instructor who showed me something: 'Look, I can make the car understeer or oversteer, it's just about where in the corner entry I start to turn the steering wheel, and by how much.' The demonstration was convincing, but not surprising. After all, without being too metaphysical, so many things in our life are decided by education and parenting, those early 'inputs'. Why should vehicle dynamics be any different?

If it is true that a big part of car's performance is defined by the reaction to the driver's steering (and if required, braking) inputs at the corner entry, then we must carefully understand transient load transfers in the first metres of a corner.

Cutting corners

In last month's article (V31N9) we showed the decomposition of the load transfer on one axle in a geometric load transfer (depending on the roll centre altitude, and passing from one tyre to another via the suspension linkages) and an elastic load transfer (that is a function of the vertical distance between suspended mass c.g and the roll centre) that also passes from one tyre to the other through the springs, anti-roll bars and dampers, as shown in **Figure 1**.

With the lateral acceleration starting at 0.50 seconds, if we zoom in (**Figure 2**), 0.05 seconds later (0.05 seconds at 180km/h corresponds to 2.5m), we have about 65 per cent of the suspended mass load transfer that is geometric and about 35 per cent that is elastic, most of it (32 per cent) controlled by the dampers. After 0.10 seconds (five metres at 180km/h) 52.5 per cent of the suspended mass load transfer is geometric and 47.5 per cent is elastic, most of it (41.2 per cent) being, again, controlled by the dampers.

Before we draw some conclusions here, let us look at similar graphs with **Figures 3** and **4**. In **Figure 3**, with a roll centre below the ground, we can see that the geometric load transfer is negative, with a bigger elastic load transfer (peak at about 750N compared to 500N with a roll centre 75mm above the ground as seen in **Figure 1**).

If we zoom in (**Figure 4**), at 0.55 seconds we have about 52 per cent of the suspended

Figure 1: Roll centre 75mm above ground – lateral acceleration and load transfer components

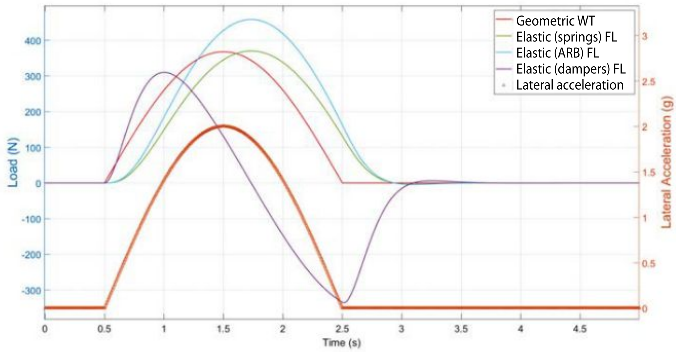
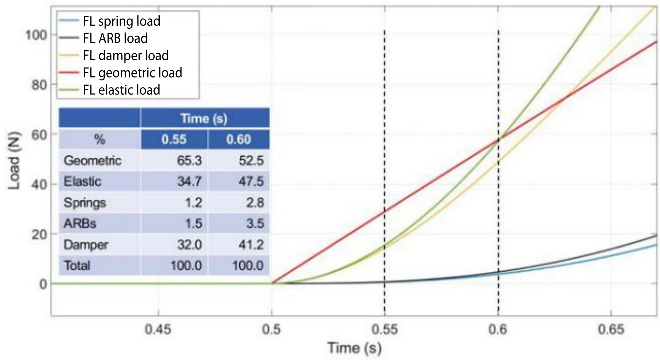


Figure 1: The diagram above shows decomposition in a simplified open loop simulation with a lateral acceleration input of the geometric load transfer (which is shown with the red trace) and the different parts of the suspended mass elastic load transfers due to: springs (green), anti-roll bar (blue) and the dampers (purple), versus time with a fixed roll centre 75mm *above* the ground. Note that the non-suspended mass load transfer is not represented here

Figure 2: Roll centre 75mm above ground – percentage load transfer



%	Time (s) 0.55	0.60
Geometric	65.3	52.5
Elastic	34.7	47.5
Springs	1.2	2.8
ARBs	1.5	3.5
Damper	32.0	41.2
Total	100.0	100.0

Figure 2: At the beginning of the corner (0.55 seconds) most of the suspended mass load transfer is geometric (65.3 per cent) and controlled by the dampers (32 per cent). After 0.10 seconds these percentages become 52.5 per cent and 41.2 per cent

Put simply, at the entry of a left-hand corner the rear-right negative camber and toe-in are the back end of the car's friends

Figure 3: Roll centre 75mm below ground – lateral acceleration and load transfer components

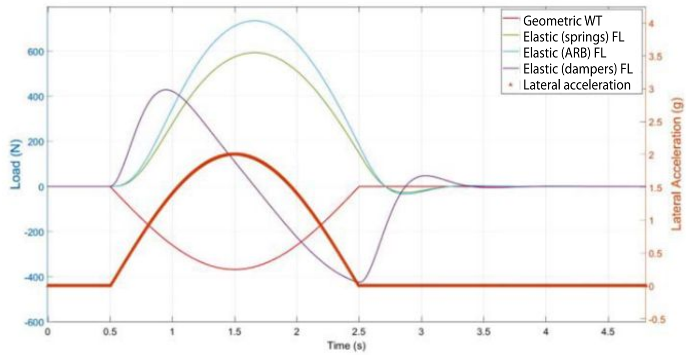
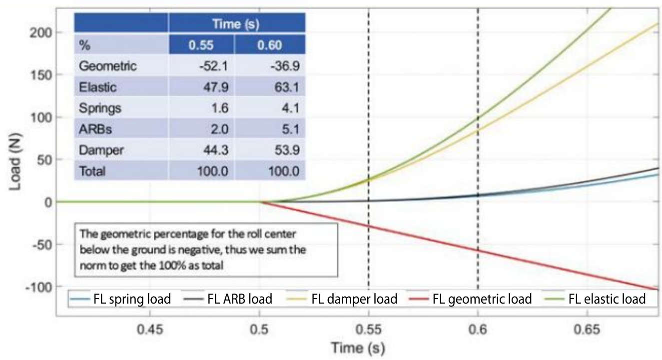


Figure 3: Decomposition of the geometric load transfer (red) and the different parts of the suspended mass elastic load transfers due to: springs (green), ARB (blue) and dampers (purple) versus time with a fixed roll centre 75mm *below* the ground and a simplified open loop lateral acceleration input (brown). The non-suspended mass load transfer is not represented here

Figure 4: Roll centre 75mm below ground – percentage load transfer



	Time (s)	
%	0.55	0.60
Geometric	-52.1	-36.9
Elastic	47.9	63.1
Springs	1.6	4.1
ARBs	2.0	5.1
Damper	44.3	53.9
Total	100.0	100.0

Figure 4: At the beginning of the corner (0.55 seconds) most of the suspended mass load transfer is geometric (52.1 per cent) and controlled by the dampers (44.3 per cent). After 0.10 seconds these percentages become 36.9 per cent and 53.9 per cent

Figure 5: Tyre forces sequence in a corner

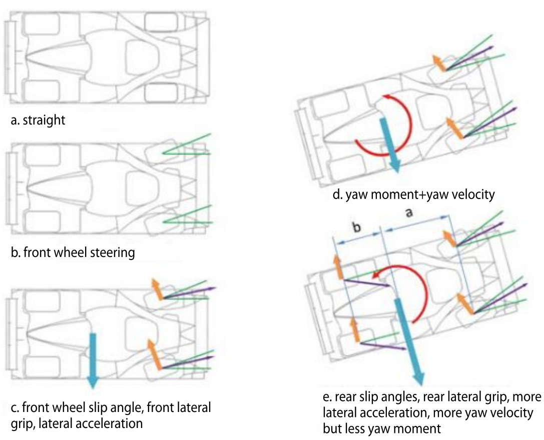


Figure 5. Evolution of the tyre slip angle, lateral forces, and the car yaw moment. Note that in this simplified explanation only the lateral forces on the four tyres are considered. The longitudinal forces and self-alignment moments are ignored

mass load transfer that is geometric and about 48 per cent elastic, most of it (about 44 per cent) controlled by the dampers. After 0.10 seconds (five metres at 180km/h) about 37 per cent of the suspended mass load transfer is geometric (red) and about 63 per cent is elastic (blue), most of it (about 54 per cent) being, again, controlled by the dampers.

What is the main conclusion then? If it is true that the first metres of a corner determines most of the car behaviour for the rest of it and, if because of a driver's comments, you want to change the car handing at the very first part of the corner entrance, whether you want to increase or decrease the load transfer (and we will discuss this in the next paragraphs), it seems that the kinematics and the dampers are the first things you want to play with.

High tail

Another thing I want to look at here is the often asked question: why does the rear roll centre need to be higher than the front? First, a quick reminder of the sequence of the force occurrence of the tyres in a corner is shown in **Figure 5**. From **5a** to **5b** the driver turns the steering wheel and creates a LF and RF steering angle. Things are not necessarily that immediate, depending on the steering system compliance, but that's another story.

Due to the tyre's relaxation length, it takes a few hundredths of second for the front tyre centripetal lateral forces to build as is seen in **5c**; action = reaction; the sum of front tyres' centripetal lateral force creates a centrifugal force acting on the car centre of gravity ($F = Ma$). You can do the sum of the moments around any point you want, and a yaw moment will be created. Depending on the yaw inertia you will create a yaw acceleration. A high yaw inertia will result in a low yaw acceleration and vice versa.

Now, in **5d** the rear end of the car is moving sideways, rear tyre slip angles are created, and rear tyre lateral centripetal forces are created too. That will go on like this until the corner apex region (**5e**), where the sum of the front tyres' lateral forces multiplied by the distance between the front axle and the c.g (distance **a**) will be equal to the sum of the rear tyres' lateral forces multiplied by the distance between the c.g and the rear axle (distance **b**) and the yaw moment will be zero. Note that in this simplified explanation, we only consider four out of the twelve causes of the yaw moment, the four tyres' lateral forces, Fy, and we ignore the four tyres' longitudinal lateral forces, Fx, and self-alignments, Mz.

Importantly, no matter what, the rear tyres' forces will always start later than the fronts. In some cases, we will want the rear tyres' forces to 'catch up' with the fronts quicker. And that has something to do with the geometric load transfer, as we will soon see.

Now, let us have a look at a specific corner, a left-hander. In **Figure 6** you can find the steering, speed, lateral and longitudinal acceleration inputs and speed input.

Knowing all the necessary car design and set-up information, the five essential parts of the data that are steering, speed, lateral and longitudinal accelerations (and vertical acceleration if the track has slopes and banking which is not the case here), and using the reverse engineering Track Replay from OptimumDynamics software, we can find the slip angles, slip ratios, vertical load, cambers forces and moments on each tyre.

Lateral thinking

Let us now draw attention to the lateral forces at the beginning of the corner, shown in **Figure 7**. Ultimately all the lateral forces on the tyres will end up positive as we can see at the apex. The interesting part comes from the analysis of the lateral forces at the corner entry. If you revisit **Figure 6** you can see that the lateral acceleration and steering only start at about 30 metres. Before that we only have braking. The lateral force on the LF (red) is positive before we even enter that left-hand corner. That is due to the front toe-out that is 'preloading' the LF tyre with a 'good' slip angle before we even need that lateral force. The side load due to the LF negative camber is not helping (that force pushes the car towards the corner outside) but, as the force generated by 0.1-degree of slip angle is usually much bigger than the one created by 0.1-degree of camber, the negative contribution of the LF negative camber is small compared to the positive effect of the LF toe-out.

On the RF (green), the toe-out is a 'bad' slip angle that generates a tyre lateral force that pushes the car towards the outside of the corner and its 'good' effect is smaller than the 'bad' effect of the negative RF camber thrust.

The lateral force on the RR (orange) is positive before we even enter the corner. That is due to the rear negative camber and the rear toe 'preloading' the RR tyre before we even need that lateral force. Put simply, at the entry of a left-hand corner the RR negative camber and toe-in are the rear end of the car's friends. On the other hand, on the LR tyre (blue) the negative camber and toe-in (a 'bad' slip angle) are creating LR tyre lateral forces pushing the car towards the outside.

If you look carefully, you can see that from 30 metres (the beginning of the steering and lateral acceleration) until about 80 metres, the RF is not helping. The force is still negative. On the contrary, it helps the car to be pushed to the outside the corner. It's the same for the LR until about 90 metres. On the RR, though, the lateral force is always pointing in the right direction (towards the corner inside).

If you want to increase the rear grip at a left-hand corner entry, then, or you want the rear grip to occur quicker, you need to capitalise on your friend (the RR) and also disinvest on your enemy (the LR). And how do you do that? By *increasing* the rear load transfer. And then how do you do that? By increasing the rear roll centre altitude because at the corner entry the biggest component of the load transfer is geometric.

Usually load transfer has a negative consequence on the car grip because, put simply, you lose more on the inside than you gain in the outside. But that is not always the case, as it depends on what the initial conditions of slip angle and camber are.

Here's a practical application. The driver complains about turn-in oversteer, but is happy with the car for the rest of the corner. Whenever possible raise the rear roll centre to create more and/or quicker load transfer, to temporarily increase the rear grip where needed, and soften the rear ARB to get the same 'magic number' (total lateral load transfer distribution) at the apex.

Figure 6: Dynamic corner entry to exit – inputs

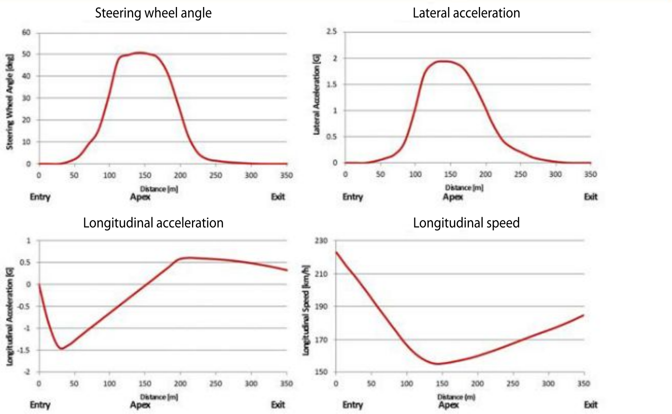


Figure 6. The steering wheel, lateral and longitudinal accelerations and speed inputs in a medium speed left-hand corner

Figure 7: Dynamic lateral force

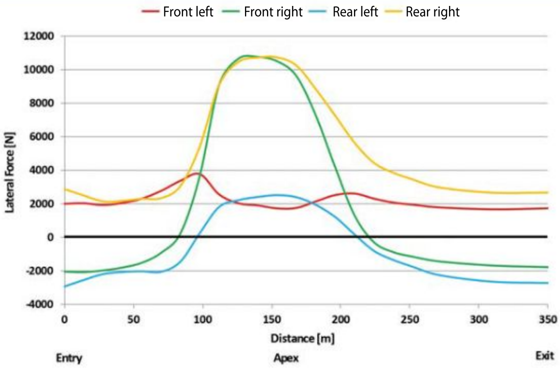


Figure 7. Tyre lateral forces evolution in a corner based on the inputs shown in Figure 6, using the Track Replay function of OptimumDynamics and the acquired data of speed, steering, lateral and longitudinal accelerations. Note that the RF (shown in green) and LR (blue) remain negative for quite a way in to the corner entry

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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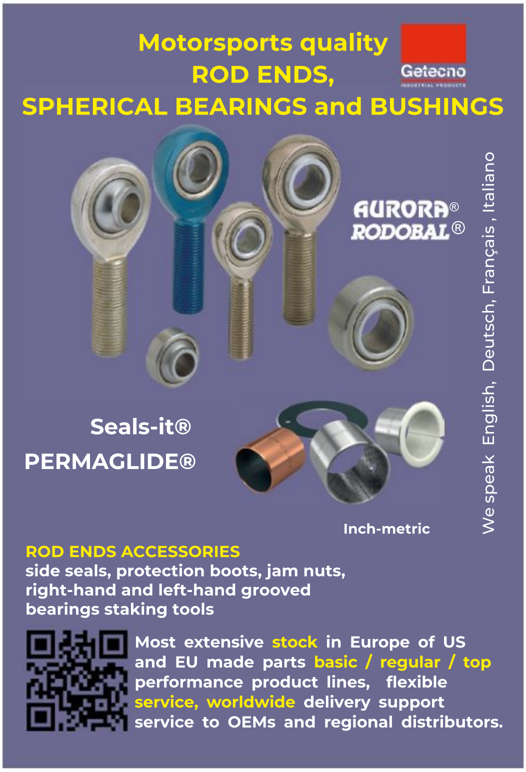
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Hard and fast

Hardware in the loop (HIL) testing involves integrating racecar systems into driving simulators and running them in what's called 'hard real time'. We spoke to those in the know to get to grips with this fascinating technology

By GEMMA HATTON

In the mid 2000s, some Formula 1 teams were testing up to 250 days per year. Today, they are restricted to just eight on track days: three days pre-season, three in-season and a two-day tyre test. It's no surprise, then, that teams turned their attention to simulators which then resulted in a huge surge of development in motion platforms, vehicle models and graphics technology. It is now sim sessions that overwhelm a race engineer's calendar.

Meanwhile, the continued adoption of hybrid and electric powertrains in motorsport has forced teams to focus their development on energy management and control strategies. This involves complex software running on devices such as ECUs (Electronic Control Unit) which can be difficult to model accurately. To enable teams to test these software strategies, simulators have had to take another technological step. Modern Formula 1 and Formula E driver in the loop (DIL) simulators can now fully integrate hardware in the loop (HIL), which allows teams to test the real ECU hardware and associated control systems from the car in a simulated environment, with the driver.

'On-car software in Formula E is what aerodynamics is to Formula 1, it's where you can make your competitive advantage,' says Juan Pablo Ramirez, head of simulation at Mahindra Formula E team. 'Hardware in the loop allows you to run many automated tests on the hardware as well as validate software. By integrating HIL into a driver in the loop simulator, you can then simulate race conditions such as full course yellows, safety cars and the battery's state of charge whilst testing the real hardware and it's interaction with a real driver.'

As a concept, hardware in the loop is not new. Indeed, the first example of a HIL system was a flight simulator developed in 1901, although it took until the mid-1990s before HIL rigs became commercially available in the automotive industry.

HIL is essentially a testing technique where a piece of hardware is connected to an electronic unit containing a software model which simulates the relevant outputs to trick the hardware into thinking that it is on the real racecar. In this way, the functionality and performance of the hardware can be extensively tested without it having to be on the real car.

All in good time

On the car, the inputs to an ECU or controller are from sensors which operate in what's called 'hard real time'. Therefore, in an HIL system, the simulated inputs from the vehicle model to the ECU also need to be delivered in hard real time. If information arrives to the ECU a timestep later, the ECU can interpret this as lost information. The resulting extrapolation the ECU does to compensate for this can be incorrect, ultimately leading to wrong decision making. To avoid these issues, vehicle models are run on a hard real time system.

A hard real time system is essentially a computer which guarantees that certain processes will be completed within a particular timestep, usually one millisecond, or 1kHz. This PC consists of processor boards equipped with I/O (input/output) cards which process analogue and digital inputs and outputs to interface with the ECU.

Hard real time is not to be confused with soft real time, though. In a hard real time system tasks have to be completed to meet

‘On-car software in Formula E is what aerodynamics is to Formula 1, it’s where you can find a competitive advantage’

Juan Pablo Ramirez, head of simulation at Mahindra Formula E

The steering wheel on Mahindra’s Cruden Formula E simulator. The most advanced HIL set-ups link to driver in the loop sims

HIL simulation allows Formula E teams to test hardware and software, and also how it interacts with a race driver, in an ultra-accurate temporal state known as hard real time

strict deadlines and the failure to do so could lead to the entire system failing. Whereas in soft real time, the time requirement is not as crucial. Tasks should still be performed within the deadline, but if this is missed, as long as the required output is still provided, then this is not considered a failure, just a degradation of performance.

'Soft real time is typically used for systems running on Windows, where you try to create a scheduler to give a fixed timestep,' explains Adrian Simms, business director of AB Dynamics, which supplies simulators to several F1 teams. 'But soft real time performance is only as good as the processing power of the computer itself and is reliant on other processes not interfering with or interrupting code execution. For hard real time you need hardware that is specifically intended to deliver that exact frequency at every timestep.

'So if you're running a relatively simple model and you're not after absolute performance, you can get away with running in soft real time,' Simms continues. 'From a simulation point of view the de facto standard for hard real time seems to be one millisecond, but that's not an official thing. If you run at less than a millisecond, you can still be running in hard real time.'

In motorsport, hardware in the loop can be used in a variety of ways. A typical HIL rig will test a piece of hardware such as an ECU in isolation. This set-up will consist of a vehicle model running on a hard real time system, the ECU to be tested and a model of whatever the ECU is trying to control. Let's take the example of a motor controller. The vehicle model provides inputs to the ECU in hard real time, mimicking signals from on-car sensors. The motor controller software on the ECU performs the necessary calculations and feeds information back into the motor model contained within the vehicle model. This then simulates the response of the actual vehicle and the process repeats.

Test match

HIL rigs can be programmed to run complex test sequences automatically, allowing the functionality of the ECU to be rigorously tested in a variety of conditions thousands of times. 'You can also test the failure behaviour of the ECU,' says Dr Klaus Lamberg, senior product manager HIL Testing at dSPACE GmbH. 'By inserting simulated electrical failures such as electrical shorts into the vehicle model, you can assess whether the ECU is monitoring and detecting these types of issues correctly as well.'

The next step up from a simple HIL rig is to incorporate basic human inputs. This is required when testing the functionality of the steering wheel controls, for example. 'These

> **'For hard real time you need hardware that is specifically intended to deliver that exact frequency at every timestep'**
>
> *Adrian Simms, business director AB Dynamics*

are sometimes called engineer workstations where the set-up allows you to 'drive' and do certain manoeuvres but you don't need to be on a track or use a real race driver,' says Ramirez. 'This allows you to test all the functions on the steering wheel, for example, and ensure the controls do what they're supposed to do under various conditions.'

The most advanced HIL set-ups require inputs from the real race driver and so have to incorporate the driver in the loop. 'In Formula E the ECU that controls the energy management is also the ECU that communicates with the driver through the dashboard,' explains Dennis Marcus, commercial manager at Cruden, which provides simulator solutions to Formula 1 and Formula E teams. 'So, when the driver needs

HIL also allows a team to assess how a piece of hardware or software will perform during unplanned events such as a safety car period

to regen, for example, they will receive a beep in their ear or a light sequence on their dash. How that system interacts with the driver is essential to test, because if it does not inform the driver accurately then it could ruin the race strategy. Also, the tuning of these energy management strategies has to be done in close co-operation with the driver to ensure they can still drive on the limit. These all have to be tested with the driver in the loop because it's the driver and the systems working together.'

Successfully merging an HIL system into a simulator requires a lot more integration. Firstly, the virtual environment including track models and tyre models has to feed into the vehicle model. 'Although the vehicle model drives the simulator, the virtual environment is what drives the vehicle model and therefore the whole simulation,' says Marcus. 'The software behind the virtual environment is not in hard real time as it's running on a Windows computer, so this requires some conversion to work with the vehicle model and can often be a challenge.'

As before, the vehicle model has to provide inputs in hard real time to the ECU, but now also has to send the necessary information to the actuators of a hexapod type simulator. This includes position, velocity and acceleration data in six degrees of freedom for the chassis and wheels as well as steering torque. The race driver outputs are fed into the simulator and ECU, with their response fed back to the vehicle model and the virtual environment.

> **'The tuning of energy management strategies has to be done in close co-operation with the driver to ensure they are still able to drive on the limit'**
>
> *Dennis Marcus, commercial manager at Cruden*

Time difference

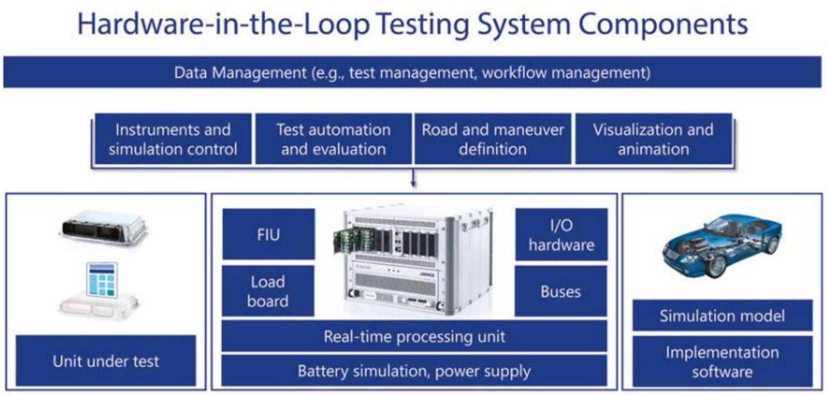
You may be wondering why simulators are not already operating in hard real time as the marketing for any simulator is usually quick to promote 'real time performance'. This is where the terminology of real time gets confused with latency. Latency is defined as the time delay between an input and an output, whereas real time refers to the timestep itself.

'Humans cannot perceive if timesteps are precisely one millisecond,' says Marcus. 'What is important for driver perception is to minimise the latency which is in the order of 30 milliseconds, due to modern projector technology. It is only the hard real time requirement of the hardware in the loop that pushes you into using a hard real time operating system in the simulator.'

However, latencies within the system can still affect its ability to deliver and receive information in hard real time. 'You can have a very good real time simulation, but if the I/O is too slow and latencies mean the signals to the ECU are delayed then you miss the real time requirement,' Lamberg says. 'That's why, particularly in motorsport applications, it is critical to have very low I/O latencies and jitters, but at the same time high bandwidth. If the I/O performance is not high enough, your real time simulation is of no value.'

To match the demand for hard real time, processing technology has progressed significantly since it was first introduced into the automotive world and into motorsport. Around 30 years ago, most hard real time systems consisted of digital signal processors (DSPs) or RISC (reduced instruction set computer). The most common technology these days is x86 PC with many cores and multiple processor systems.

However, these types of processor technologies could not cope with the particular demands of hybrid and electric applications, which is why companies such as dSPACE introduced FPGA (Field



Hard real time systems guarantee processes will be completed within a particular timestep. The schematic above (*dSPACE*) shows the components involved. Image on right gives an idea of the computer power needed

Programmable Gate Array). This is a low level multi-purpose hardware that is highly configurable and allows for high speed execution and turnaround times.

'There are two main approaches to achieving the desired processing power for accurate HIL simulations which depends on the size and dynamics of the vehicle model,' Lamberg says. 'You can have processors with high core performance which have fewer cores but with a high clock rate. Although the clock rate can impose some physical limitations. Or you can have processors with up to 16 or more cores which allows you to run operations in parallel.'

Core values

In the past, most models were run on single cores as single threaded processes. This is essentially where the instructions are executed in a single sequence, in other words one command is processed at a time. Whereas with multithread processes, as the name suggests, there are multiple threads of execution. This means it can execute multiple parts of a program at the same time. These threads share the resources of a single core or multiple cores.

'What you often find when you are running models on one core is that if you don't optimise it sufficiently, you essentially end up with something that runs slower than if you were to run it on a soft real time PC,' highlights Simms. 'This is because you are not making the very most of the actual capabilities of the hardware. A lot of the work we do is getting software suppliers to modify or open up their systems to allow customers to run multithread processing and make the most of the real time systems. That is a trend we are seeing at the moment across a variety of applications.'

This increased flexibility, along with a boost in processing power, will allow teams to run more complex models in hard real time. 'In the past some models, such as tyre models for instance, had to be simplified to run in real time on a commercially available hard real time system,' explains Ramirez. 'Now, the computing capacity is increasing which allows us to run more complex models. We're also seeing more flexibility and modularity of the various components of HIL. So we can interface more easily with different types of software, making the system as a whole more versatile in terms of what we can do with it.'

The move towards electric mobility and autonomous vehicles has also had an impact on development in the area of networking technologies. Consequently, HIL rigs have had to develop to allow testing of such systems. 'The increased automation of modern vehicles means that there will be more high performance computers on board,' Lamberg says. 'These computers run AI algorithms on GPUs [Graphic Processing Unit], while being connected to the rest of the vehicle using network technology like Ethernet. So the HIL set-ups to test these types of systems will likely have a handful of discrete I/O and power supply, but many Ethernet ports and CAN connectors. This is very different to HIL rigs for testing engine ECUs, for example, that usually have more than 250 discrete pins.'

Hard-wired

Overall, hardware in the loop technology has provided a lifeline for many top level race teams to extract the maximum performance out of both hardware and software in a time of heavily restricted testing. Whether it's a basic HIL rig testing an ECU in isolation, a set-up which includes human interaction, or fully integrated into a DIL simulator, each tool helps teams to validate their software and optimise their strategies.

Increased flexibility, along with a boost in processing power, will allow race teams to run more complex models in hard real time

'The instrumentation that's allowed in Formula E is also heavily restricted, unlike Formula 1,' says Ramirez. 'The list of allowable sensors is really small, so the software has to work around a very limited amount of information. So it's even more important to use HIL to validate software and test the functionality of hardware.

'But ultimately you want to run HIL in the simulator with driver interaction to make sure you didn't miss anything a driver would see,' Ramirez adds. 'This is particularly crucial as the current regulations in Formula E allow for one software release per event so you can't update software during a race weekend. That's why it's now even more important to get the driver's feedback on the system before getting to the racetrack. It's like F1 teams bringing a new aero package to a race. Instead, we release a new version of software and that needs to be tested.'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Stabilising influence

Why incorporating the stability index into your lap time simulations is critical if you're searching for a set-up that's both fast *and* driveable

By DANNY NOWLAN

One of the biggest criticisms levelled at lap time simulation packages is that handling is a total afterthought, and that they can even come up with set-ups that are undriveable. I will admit that I have fallen into this trap on many occasions, and about two years ago I wrote an article that discussed this in depth. Then, upon re-reading it recently, I saw there were a couple of key themes that should not only be reviewed, but also explored in greater depth.

The reason this situation exists is that we in the business have done an appalling job of defining racecar stability, primarily because what drives it is very poorly understood. But the good news is, once we address this, then a lot of things fall into place.

So, to kick off this discussion, while refreshing everyone's memory, the stability index (stbi) is the primary driver for understeer and oversteer. It has its origins in aircraft longitudinal dynamics and it's a measure of the moment arm between the centre of gravity and the centre of the tyre forces, as shown in **Figure 1**.

The neutral point is the location of the sum of the lateral forces. With the stability index what we are measuring is the moment arm between the centre of the lateral forces and the centre of gravity. We then non-dimensionalise by dividing it by the wheelbase.

The stability index is such an important measure because of how it varies with the lateral load transfer distribution at the front. Here it is worth reviewing an earlier analysis I did when I discussed the significance of the magic number. This is shown in **Table 1**.

To say these figures are fascinating is an understatement. As we can see, the peak lateral force occurs at a front lateral load transfer of 0.5. Not surprisingly the stability index is very marginal at -0.00291. What is interesting is when we go to a lateral load transfer factor of 0.6 we drop only 80N of force, but the stability index drops to -0.072. This is a big change in handling. What is even more interesting, though, is that the spread of forces is only about 1000N, or about four per cent. However, we see large fluctuations of the stability index. To fully appreciate this it's worth looking at it graphically, and a plot of lateral load transfer *vs* available force is shown in **Figure 2**.

For effect I've put the maximum number of this plot at 25,000N and the minimum at 0N. Note the small variation. But plotting the stability index shows a completely different story (**Figure 3**).

Incidentally, a colleague of mine plotted this out once then immediately phoned me and said 'you are on to something here and if you don't pursue this you are nuts'. He was right, as **Figure 3** is crucial when it comes to driver feedback.

Inherent instability

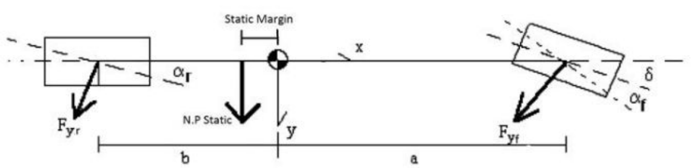
But before we get on to why the stability index is such a good measure of quantifying drivability changes, we should first discuss why lap time simulation will sometimes favour an unstable response. The simple answer is that at times this is where the grip is. For instance, you might remember previous articles on the magic number where we have discussed why the ideal lateral load transfer for a rear-wheel drive car was 0.473.

Also, remember that one of the biggest advances in fighter aircraft design came when the performance potential of making aircraft unstable was recognised. This trend was kicked off by the F-16 and has

Table 1: Results of lateral load transfer *vs* the stability index for an F3 car

Front lateral load transfer	Total lateral force (N)	Projected front slip angle (deg)	Stability index
0.1	21952.64	4.24	0.162
0.2	22264.4	4.42	0.13
0.3	22479.4	4.6	0.09
0.4	22597.6	4.80	0.05
0.5	22619.05	5.01	-0.00291
0.6	22543	5.24	-0.072
0.7	22371	5.51	-0.166
0.8	22102.6	5.8	-0.303
0.9	21736.9	6.14	-0.524

Figure 1: The stability index



Where:

F_{yf} = total lateral force at the front
F_{yr} = total lateral force at the rear
δ = steer angle
α_f = front slip angle
α_r = rear slip angle
a = moment arm between the front axle and the centre of gravity
b = moment arm between the rear axle and centre of gravity
NP = neutral point

One of the biggest advances in fighter aircraft design came when the performance potential of making aircraft unstable was recognised

Figure 2: Total lateral force *vs* front lateral load transfer distribution

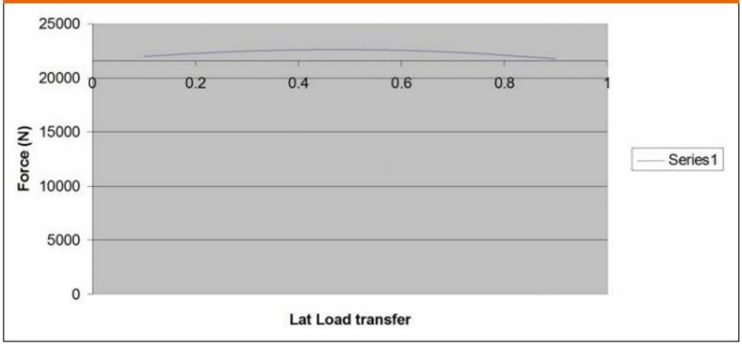


Figure 3: Stability index *vs* front lateral load transfer distribution

come to full maturity in the extremely agile designs you see with the Russian Sukhoi Su-35S and the Su-57. They are unstable because that is where the performance is, and it is no different to what we have seen with the magic number before.

Stability ability

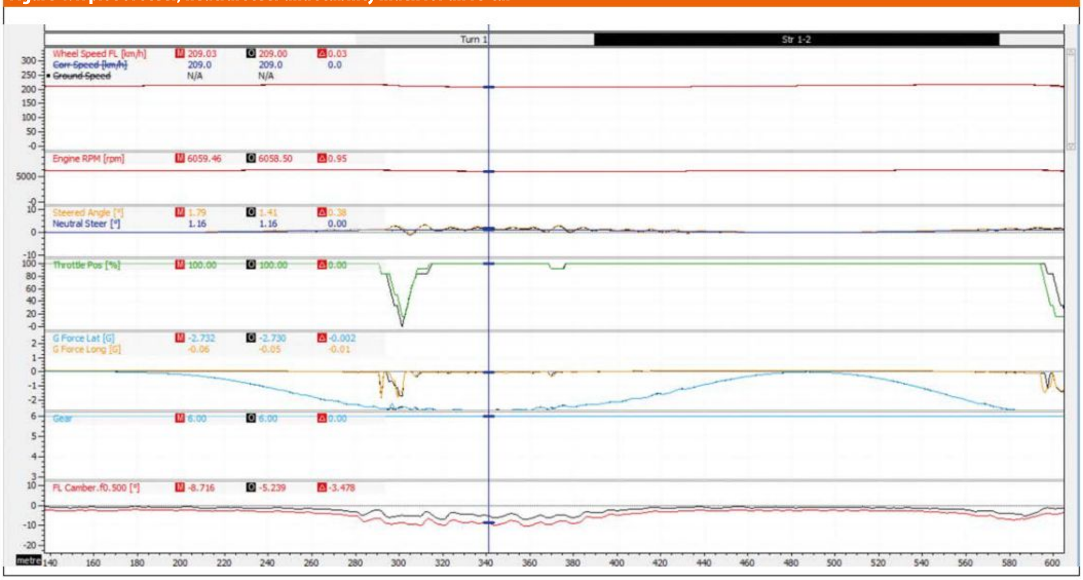
The next question that needs to be addressed is why the stability index is such a good measure of drivability. To answer this let's compare the simulated results of an F3 car with an aero balance at stock, and then with the aero balance of plus five per cent towards the front axle. This is illustrated in **Figure 4**.

If we take a look at the mid-corner condition there isn't a lot of change in speed and the steering has reduced by 1.8 degrees to 1.4 degrees. However, where things really change is with the stability index which is the bottom plot (ignore the 'FL Camber' title). The stability index is shown as a percentage. The baseline has a stability index of -8.76% and the change shows a stability index of -5.3% (I should add that the reason this is filtered is because the circuit is bumpy, and ChassisSim can respond at 400Hz. As a rough rule of thumb a filter of 5Hz works really well). Anyone who has spent more than five minutes in F3 will know that this is a change even the most inexperienced driver will feel.

The reason why this is such a clear measure of drivability change lies

Anyone who has spent more than five minutes in F3 will know that this is a change even the most inexperienced driver will feel

Figure 4: A plot of steer, neutral steer and stability index for an F3 car



in the mathematics. The formula for the stability index is shown in the neat sum below (**Equation 1**).

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\bigg|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2})$$
$$C_r = \frac{\partial C_r}{\partial \alpha_r}\bigg|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4}) \qquad (1)$$
$$C_T = C_f + C_r$$
$$stbi \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb}$$

Here we have:

$\delta C_f/\delta\alpha(\alpha_f)$ = Slope of normalised slip angle function for the front tyre
$\delta C_r/\delta\alpha(\alpha_r)$ = Slope of normalised slip angle function for the rear tyre
$F_m(L_1)$ = Traction circle radius for the left front (N)
$F_m(L_2)$ = Traction circle radius for the right front (N)
$F_m(L_3)$ = Traction circle radius for the left rear (N)
$F_m(L_4)$ = Traction circle radius for the right rear (N)
C_f = Front lateral force gradient (N/rad)
C_r = Rear lateral force gradient (N/rad)
C_t = Total lateral force gradient (N/rad)

However, where things get really interesting is when we look at the numbers under the hood that drives all this, and the normalised ChassisSim slip curve is shown in **Table 2**.

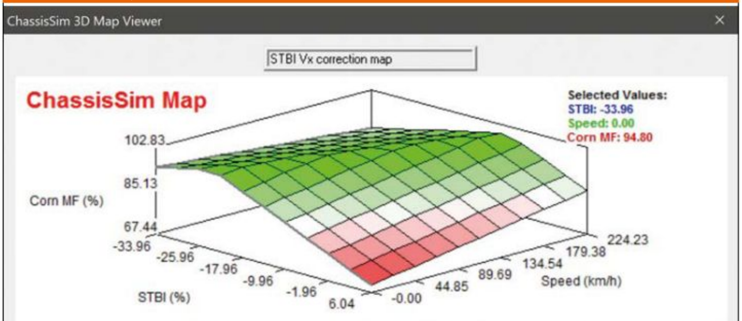
The key reason we are getting such big variations in the stability index is the gradient of the normalised slip curve. As we get closer to maximum force you will see this is dropping off quite markedly. However, from a slip angle of four to six degrees the normalised force is only changing by 15 per cent. Given that these are the slip angles we will spend the most time in when the car is at peak *g*, cross referencing the above with **Equation 1** shows why the stability index variation is so large.

Stable door

So, the key question to be asked is how do we roll this out and implement it in a lap time simulation package? **Figure 5** will go a long way to answering this.

This map multiplies the final corner speed by the look-up table. Because racecar stability is strongly affected by the aerodynamics, to get an accurate output you need to have speed as well as stability index in the picture. So, in this case ChassisSim will calculate mid-corner and turn-in speeds and will then modify these values by cross referencing the mid-corner speeds to this map.

Figure 5: Stability index corner multiplier map



	0.00	22.42	44.85	67.27	89.69	112.11	134.54	156.96	179.38	201.80	224.23
-33.96	94.804	94.06	93.32	92.58	91.84	91.09	90.35	89.61	88.87	88.12	87.38
-29.96	96.80	96.06	95.32	94.58	93.84	93.09	92.35	91.61	90.87	90.12	89.38
-25.96	98.80	98.06	97.32	96.58	95.84	95.09	94.35	93.61	92.87	92.12	91.38
-21.96	98.39	99.88	99.32	98.58	97.84	97.09	96.35	95.61	94.87	94.12	93.38
-17.96	94.39	95.88	97.36	98.85	99.84	99.09	98.35	97.61	96.87	96.12	95.38
-13.96	90.39	91.88	93.36	94.85	96.33	97.81	99.30	99.61	98.87	98.12	97.38
-9.96	86.39	87.88	89.36	90.85	92.33	93.81	95.30	96.78	98.27	99.75	99.38
-5.96	82.39	83.88	85.36	86.85	88.33	89.81	91.30	92.78	94.27	95.75	97.24
-1.96	78.39	79.88	81.36	82.85	84.33	85.81	87.30	88.78	90.27	91.75	93.24
2.04	74.39	75.88	77.36	78.85	80.33	81.81	83.30	84.78	86.27	87.75	89.24
6.04	70.39	71.88	73.36	74.85	76.33	77.81	79.30	80.78	82.27	83.75	85.24

OK | Cancel | Axes Properties/Calculator | Export text/Aero File | Import text file

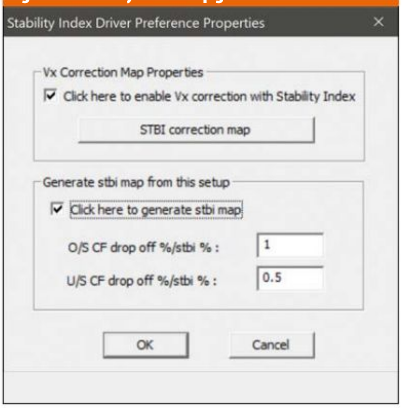
Table 2: Plot of normalised ChassisSim slip angle derivatives

Slip angle (deg)	Slip angle (rad)	F_{NORM}	δC/dα
0	0	0	14.323
1	0.0175	0.25	13.925
2	0.0349	0.5	12.731
3	0.0524	0.69	10.742
4	0.0698	0.85	7.9567
5	0.0872	0.96	4.375
6	0.1047	1	0

The first part of this process is how to define this map. The key method is to run a simulation on a set-up that your driver is comfortable with, or rather a set-up they feel comfortable pushing the car in. This will give you the stbi *vs* speed characteristic they feel comfortable driving to. All you need to do then is to specify a map as the basis of this. This can be done manually or by using the map generator in ChassisSim – **Figure 6** shows this.

Here you simply have a slope of corner multiplication % *vs* stability index as a percentage. In this case the oversteer slope is 1, so if the car oversteers for every stability index increase of one per cent the corner speed will be penalised by one per cent. In the understeer case, for every decrease of one per cent of stability index

Figure 6: Stability index map generator in ChassisSim



Because racecar stability is strongly affected by aerodynamics, to get an accurate output you need to have speed in the picture as well

the corner speed will be penalised by 0.5%. These are default numbers, but they can be increased or decreased depending on the skill and/or sensitivity level of the driver.

To quantify all this we ran two tests at the Willowbank circuit in Queensland, Australia, with a live axle V8 Supercar and a twin shock F3 car. The reason Willowbank was used is that it's a notoriously bumpy circuit, so consequently it offered the perfect torture test. The F3 results are presented in **Table 3**.

The F3 results present an interesting set of numbers. The smallest change here was the rear spring change of 900lbf/in. Since the rear bar rate is 1200N/mm not surprisingly there aren't big changes in the base corner speed, so the effect here was minimal. The next change was halving the rear bar rate. On standard the delta was 0.305s, while the stability index change was 0.32s. It's starting to make its presence felt, but due to the fact the bar rates are still saturating the tyre spring rates the effect wasn't large.

Stable manners

It's with the aero changes that things got interesting for the F3 car. When we reduced the aero balance by five per cent the delta in the standard lap time calculation was 0.44s. For the stability index calculation the delta was 0.538s, so this effect was starting to show. But things really started to happen with the forward aero balance change. The delta for the standard lap time calculation was a gain of 0.12s. The stability index calculation was a loss of 0.218s. This is where the stability index correction is making its presence felt because car stability, as opposed to corner grip, is now taking precedence in the corner speed calculation.

There is a key reason behind the lap time discrepancy between the standard and stability index correction. Given this is an F3 car, stability index will be varying with speed. Here we used only a 10 by 10 matrix and had just five corners to reference. If you increased the size of the map and you had more corners this discrepancy would be reduced.

The V8 Supercar numbers were even more enlightening, and the results are presented in **Table 4**. In this particular case the stability index correction now dominates the corner speed calculation. For the spring and bar changes the standard lap time calculation was in the order of 0.1s. With the stability index calculation it is now 0.3s. The large rear roll centre was even more pronounced with a change from 0.284s to 0.86s. Again, the differential between standard and the stability index correction comes down to a coarse correction map.

As can be seen, the stability index correction has definitely made its presence felt. In the F3 car it prevented something that can all too often happen with lap time simulation, that is that the more aero balance you apply the faster you get, where in reality you wind up with a car that is quick but undrivable. Meanwhile, in the V8 Supercar case it accentuated the characteristics that were already there. This is quite significant. Where it didn't have an effect is where the chassis changes were too small to affect a change in the stability index. This does show that we aren't making it all up, though, and that's a good thing.

The other question that needs to be addressed is whether we can define the handling we want from scratch. The answer is most definitely *yes*. All you need to do is to define the map you want. A case in point is shown in **Figure 7**.

As far as correction maps go **Figure 7** is as simple as they come. What I've done here is come up with a set-up that states that if we keep the stability index mid-corner between -6 to -14 per cent then this will be where the maximum grip will occur. Also, this map heavily penalises any excursions from this. Now a key thing here is that this map will vary depending on the driver. The thing that separates the Lewis Hamiltons and Max Verstappens from lesser drivers is that these superstars have an innate feel for what the contact patch is doing and they can tolerate stability indexes that are very close to zero.

In closing, not only is the stability index a viable way of quantifying drivability changes, but, as can be seen in both the F3 and V8 Supercar examples, the stability index correction methodology produces results that enhance and add to the base lap time calculation.

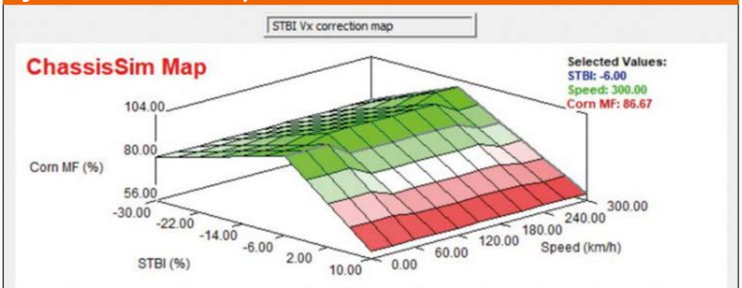
Table 3: Stability index correction results for an F3 car at Willowbank

Change	Standard	STBI correction
Baseline	61.96s	62.262s
Aero balance + 5%	61.84s	62.48s
Aero balance - 5%	62.4s	62.8s
Rear bar 600N/mm (std bar 1200N/mm)	62.265	62.58s
Rear spring 900lbf/in (std spring 800lbf/in)	62.0s	62.3s

Table 4: Stability index correction results for a V8 Supercar at Willowbank

Change	Standard	STBI correction
Baseline	69.5s	69.69s
Rear spring 70N/mm (standard 60N/mm)	69.584s	69.99s
Rear spring 50N/mm	69.464s	69.62s
Rear bar 25N/mm (standard 15N/mm)	69.564s	69.9s
Rear roll centre 300mm (standard 230mm)	69.784s	70.55s

Figure 7: Desired racecar stability index



	0.00	30.00	60.00	90.00	120.00	150.00	180.00	210.00	240.00	270.00	300.00
-30.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
-26.00	83.33	83.33	83.33	84.00	84.00	84.00	84.00	84.00	84.00	85.00	85.00
-22.00	86.67	86.67	86.67	88.00	88.00	88.00	88.00	88.00	88.00	90.00	90.00
-18.00	90.00	90.00	90.00	92.00	92.00	92.00	92.00	92.00	92.00	95.00	95.00
-14.00	93.33	93.33	93.33	96.00	96.00	96.00	96.00	96.00	96.00	100.00	100.00
-10.00	96.67	96.67	96.67	100.00	100.00	100.00	100.00	100.00	100.00	93.33	93.33
-6.00	100.00	100.00	100.00	92.00	92.00	92.00	92.00	92.00	92.00	86.67	86.667
-2.00	90.00	90.00	90.00	84.00	84.00	84.00	84.00	84.00	84.00	80.00	80.00
2.00	80.00	80.00	80.00	76.00	76.00	76.00	76.00	76.00	76.00	73.33	73.33
6.00	70.00	70.00	70.00	68.00	68.00	68.00	68.00	68.00	68.00	66.67	66.67
10.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00

Stress management

Stress analysis is all about that delicate balance of maximising component performance while ensuring safety and reliability. Rob Hansen, McLaren's head of Structural Design, gave* Racecar *an insight into this most challenging of F1 engineering roles

By MIKE BRESLIN

Formula 1 racing at its finest is about a car on the very limit, brushing the barriers at Monaco or lifting a plume of gravel dust elsewhere. It's this tightrope walk between triumph and disaster that partly defines the sport. But pushing things close to the edge is not solely the preserve of the drivers. In a business where performance is everything, almost every part of an F1 car needs to be designed so it is as light as possible. Yet this also needs to be balanced against a requirement that a component is strong enough and durable enough to last a race. Finding the fine line between these often conflicting demands is the work of the stress engineer.

'Our job is to essentially maximise the performance of structures, while also ensuring they are safe and reliable,' says Rob Hansen, head of Structural Design at McLaren Racing, who joined the team as a stress engineer back in 2007. Before that he worked in the same role at the Rolls Royce aero engine plant in Bristol, on behalf of engineering giant Atkins, having gained his first-class degree in mechanical engineering at Imperial College London in 2005. He now heads up what he describes as a compact team of 'really capable and highly experienced specialists' at the McLaren Technology Centre in Woking, though he stresses – no pun intended – that these days the title of 'stress engineer' does not quite do justice to the work they're involved in.

'We have moved away from the title stress engineer as the roles have expanded to include other disciplines, such as prediction of loads, data analysis, and more multiphysics type simulations,' Hansen says, the latter basically meaning covering a broad area of physics and engineering. 'Within the team we have a mix of structures engineers and structural dynamics engineers, and the structures engineers are more focussed on the largely composite chassis and suspension assemblies, whilst the structural dynamics engineers split their time between stress analysis and investigating vibration and dynamic behaviour, to allow us to maximise our understanding of both the performance and reliability side of those areas.'

Lando Norris pushes his McLaren to the limit at Silverstone, secure in the knowledge that each and every part in the MCL35M has been stress tested

XPB

It's a high-pressure role, that's for sure, as the danger of miscalculating the trade-off between a component performing to its maximum or failing is always hanging over the Structural Design team, like a carbon sword of Damocles. 'I think managing risk and uncertainty is what I find the most challenging,' says Hansen. 'We're always looking to push the designs to the limit, whether it's to minimise mass, achieve stiffness requirements, or maximise the opportunity for the aerodynamicist. But it is really paramount that designs are reliable and safe, and that we're also able to deliver them in a timely and cost-effective manner. But there are always unknowns, whether it's the confidence in the material properties, loads, environmental conditions, manufacturing variation or even just limitations in our methodology, or the capability of the tools.'

Judgement calls

Because of these 'unknowns', there is no single, easy, way to conduct stress analysis. 'In practical terms we can't take a single approach across the board,' Hansen says. 'Our methodology and safety factors, our approach to a particular problem, is based on our knowledge, experience, confidence

Rob Hansen joined McLaren as a stress engineer back in 2007. He now heads up the Structural Design team

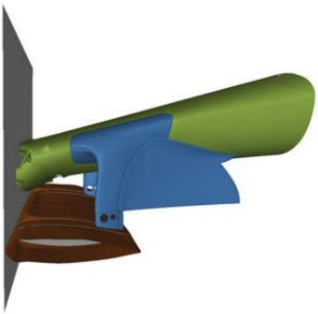
level; and part of the challenge of this work is deciding what level of analysis and physical testing needs to be performed, and also what level of rigour is required to sign off the designs. These days our tools allow us to model more structures and loading scenarios with an amazing level of complexity and sophistication, but time and resources are finite, and we need to strike a balance by identifying the areas where there's the most opportunity, or greatest risk.

'With all this in mind there isn't really a day that goes by where I'm not thinking whether we've played it too safe on a part or not safe enough,' Hansen adds. 'You do keep awake at night sometimes wondering whether we've pushed things too far.'

Sometimes parts do fail, though very rarely, and then it's a matter of learning the lessons. 'Obviously, over the years many things have gone wrong,' Hansen says. 'I think what is important is how you recover from the situation. When something goes wrong everything is going through your mind, you're wondering: "okay, how did this happen, did we make a mistake, did we miss something", and really you need to take a step back and go through the process in a structured and methodical way, to understand what happened and then put the measures in place to prevent it from happening again. This has to be an open and collaborative process but for that to happen it is critical not to jump to conclusions or apportion blame.

'We had a catastrophic suspension failure a few years ago,' Hansen adds. 'It

Below: Before expensive destructive testing an F1 car is subjected to the same in the FEA realm. This shows a virtual impact on the nose of a McLaren MP4-30A



McLaren Racing

'There isn't really a day that goes by where I'm not thinking whether we've played it too safe on a part or not safe enough'

was a part that had been operating reliably for some time. The investigation process was very thorough, and it involved several of our colleagues in Design, Quality and Materials, and as a result we were able to fully understand the chain of events that led to the failure, and then respond for the next event to make sure that the part was reliable. As is often the case, there was no single causal factor, but it took a failure triggered by a perfect storm of events to highlight opportunities to improve in multiple areas.'

Job satisfaction

But it's not all about worrying and losing sleep, and Hansen says that the positives to be taken from this work far outweigh the negatives. 'It's a great feeling to see the parts you've designed out there, especially when they're working well and really making a difference to the performance of the car. Even more so when they've been particularly challenging or ground-breaking to design. There aren't many industries which have as quick a turnaround as Formula 1, and to see the fruits of our work only weeks after we've undertaken it is quite satisfying.

'We're also very lucky to be able to collaborate with lots of other departments, whether it's Design, Manufacturing, Aerodynamics or Vehicle Performance, and that makes you feel like you're really making a good contribution,' Hansen adds.

XPB

Formula 1 is a very tough environment for components – kerb strikes are just one of the hazards a stress engineer has to consider

But to make that contribution the Structural Design team needs the very best tools available, the most important of which is FEA. 'The primary tools we use are Finite Element Analysis, FEA, based software, and these packages can be used to simulate a wide range of structural and multiphysics problems in quite a lot of detail,' Hansen says.

Very basically, FEA is the applying of a mesh of blocks to the CAD rendition of a part, each of which is to a finite size and hence equates to a mathematical property. Forces and failure parameters can be added, based on things like track data, FIA regulations and the limits for the materials, and then the part can be examined in a number of conditions, for instance, bending or vibrating.

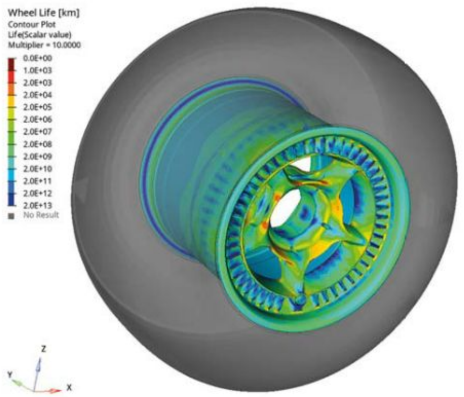
But while FEA remains the most powerful weapon in the Structural Design team's armoury, it is far from the only one. 'We're fortunate enough to have access to a variety of tools ranging from in-house spreadsheets, MATLAB tools, analytical and empirical methods, right up to more sophisticated tools for geometry and laminate optimisation and advanced durability analysis,' Hansen says. 'There are also subroutines for simulating failure evolution in things like composite structures. We use multi-body simulation, MBS, to simulate dynamic behaviour and predict loads, and we also make extensive use of data acquisition and analytic systems to collect and monitor data. So, we are using a lot of different tools and packages in our day-to-day work.'

Getting physical

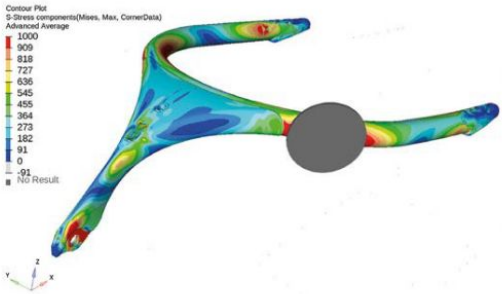
Not all of the work is virtual, of course, for when safety and reliability is involved parts will often need to be tested physically, too. 'Most of the work we do will be underpinned by physical testing in some shape or form, whether it's to sign off the components in the lab before they are run on the car, testing R&D parts to failure, or defining the inputs, such as material properties that we need to use for our analysis work,' Hansen says. 'But the main issue with physical testing is that it's really expensive, [which is] increasingly a factor with the cost constraints coming into Formula 1.'

Over the past few years the power of the tools the team uses has increased significantly, says Hansen. 'The advancements in the software and hardware technology over the last few years have meant that capability that was previously the preserve of R&D departments has become a lot more accessible, and we can really use this to help drive the design of large complex structures, allowing us to optimise the designs and have a higher success rate. It's really helping us with our 'first time right' goal, and '100 per cent reliability' ambition.'

The technology used can only continue to improve, too. 'In terms of the future, I think it



A fatigue life plot on the front wheel of a McLaren MP4-31A



Safety devices are a prime focus for the Formula 1 stress engineer. This is a von Mises stress plot, which is used to determine whether a material will yield or fracture, of the Halo

McLaren Racing

will become a lot easier to integrate complex structural simulations into design workflows to help drive the designs and allow them to be iterated and optimised even more quickly,' Hansen says. 'Additive manufacturing is also a hot topic, and as this becomes more established as a production technique then the simulation tools will also progress to allow us to better exploit it.'

Wide variety

A Formula 1 car contains around 5000 different components, so variety is very much the order of the day for the stress engineer. 'There isn't really a typical part,' says Hansen. 'During the development of a Formula 1 car we evaluate hundreds of parts, and they can vary from something that takes us an hour or less, or up to several weeks to fully evaluate and iterate to a final solution, collaborating closely with the designers.'

Unsurprisingly, the element of the racecar which takes up most time and resources is the biggest, the tub. 'The chassis/monocoque is the single most time-consuming part and that's simply due to the complexity of the composite structure,' Hansen says. 'The laminate has over 400 unique plies, and on top of that there are over 70 load cases.

'Many of these load cases require bespoke models which allow us to capture the critical detail that we are really interested in,' Hansen adds. 'We have a mixture of static load cases and dynamic running cases. However, these days the monocoque structure is dictated by the immense safety tests that are prescribed by the FIA regulations.'

For example, one of the survival cell tests for the new 2022 Formula 1 car consists of a 380kN load applied directly to the side of the cockpit. To put this into perspective, that equates to around 38 tonnes – or a fully loaded cement truck.

As mentioned above, this work is very diverse, and Hansen confirms that every day is different. Yet there is still a certain structure to a day in the office. 'Most commonly we would start the day by loading and reviewing the results from any FEA analyses that have run overnight on our HPC [High Performance Computer],' Hansen says. 'And then the first meeting of the morning will be a catchup with the team where we might discuss the day's, or the week's, priorities, discuss latest car concept developments, reliability issues from the previous race, if anything broke that needs investigating, and also things like the results of recent physical testing. Sometimes [we use this] as an opportunity to share technical knowledge on various techniques and capabilities we have.

'The rest of day usually consists of meetings with design engineers, aerodynamicists, and materials engineers,' Hansen adds. 'We will also often visit the workshops to review component repairs or manufacturing concessions. We also attend the R&D labs to oversee rig tests. And then, of course, the bulk of the job will be building and updating FEA models.'

It's clear then that this is the sort of role many a wannabe F1 engineer would be happy to fill, but what sort of person makes a good stress engineer? 'To start with, they need to have a solid foundation of engineering principles, and then they need to know how to apply these to different scenarios,' Hansen says. 'Every design starts at the concept stage, and then to turn this into the final design you need to fully understand the problem at hand in terms of the design constraints, so things like packaging, space, loads, stiffness requirements, costs, to name a few. Understanding the foundation of the design is really important, and then taking the next steps in terms of modelling and design complexity, but you need to have that foundation to choose a successful final design. I think by applying these principles to an engineering problem, you will be taking the first steps to becoming a stress engineer.'

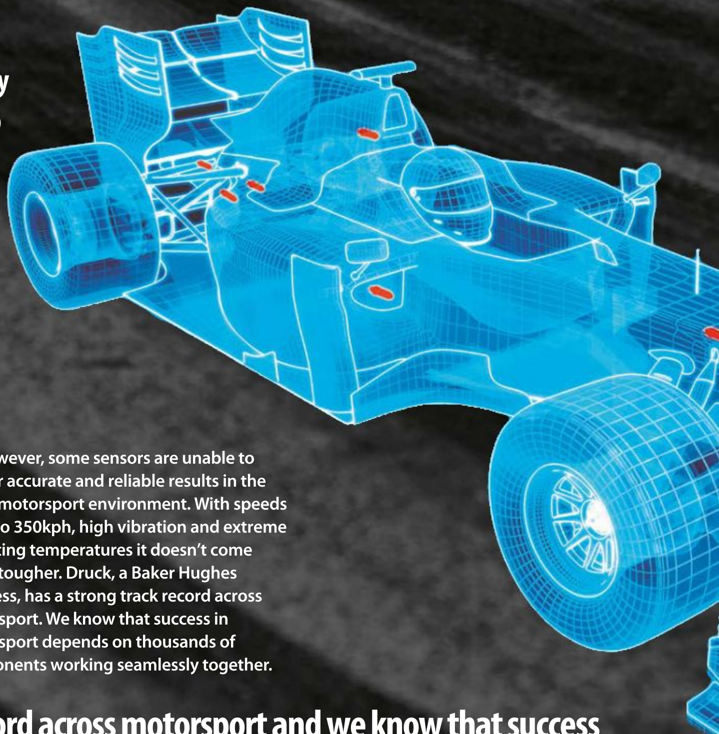
'A stress engineer needs to have good attention to detail, because if you miss something the consequences can be quite extreme'

A good degree in mechanical, aeronautical or automotive engineering (or similar) would normally be a prerequisite if someone was applying for a position as a stress engineer, but Hansen says that he would be looking for more than just qualifications. 'More importantly, they would need to demonstrate great technical aptitude and a good understanding of the principles of stress analysis,' he says. 'We also look for someone with a practical and pragmatic mindset. At the same time, they need to have good attention to detail, because if you miss something the consequences can be quite extreme. Needless to say, being enthusiastic and self-motivated is important, as well as having high levels of initiative and teamwork skills, as often you need to be quite autonomous in the work that you're doing and be able to collaborate with multiple departments.'

And let's not forget the key word in the job title. 'You do need to be quite resilient in terms of dealing with setbacks, and with things that don't go to plan,' Hansen says. Or, to put it another way, you need to be able to cope with the stress.

Two in one

Druck's 4400T, a combined pressure and temperature sensor, is specifically designed for the motorsport sector to provide unrivalled levels of accuracy and reliability. By combining two sensors into one, race engineers don't have to accommodate extra sensors into complex engine designs, and they will also benefit from simple and quick verification



In all levels of motorsport teams are looking for fine margins of performance that can help attain a podium finish. Pressure and temperature sensors are critical components for all fluid and air pressure applications. By adopting the right measurement technology, manufacturers can better optimise vehicle performance, safety and reliability, which can make the difference between first and second place.

However, some sensors are unable to deliver accurate and reliable results in the harsh motorsport environment. With speeds of up to 350kph, high vibration and extreme operating temperatures it doesn't come much tougher. Druck, a Baker Hughes business, has a strong track record across motorsport. We know that success in motorsport depends on thousands of components working seamlessly together.

'Druck has a strong track record across motorsport and we know that success depends on thousands of components working seamlessly together'

Innovation

We're excited about our latest innovation, the 4400T, a combined pressure and temperature sensor, developed specifically for motorsport and designed to suit all chassis and engine pressure measurement applications. The 4400T is the next evolution of our highly successful 4400 series, which has been used widely for many years throughout the motorsport sector.

Added benefits

The 4400T offers all the benefits of a small, highly accurate pressure sensor with the added benefit of a Pt1000 temperature sensor. Combining pressure and temperature measurements provides race engineers with a number of key benefits:

- Firstly, 4400T provides unrivalled levels of accuracy and reliability across pressure and temperature measurement.
- The 4400T mass is less than that of two independent sensors and consumes less real estate, which simplifies installation.
- Wiring looms are also simplified, further reducing mass and complexity.
- In addition, the measurement of pressure and temperature is taken in the same location resulting in more consistent data.

As per the existing 4400 range, the new 4400T has a maximum operating temperature of 175degC and is available across a range of pressures from 1.6bar to 600bar. With excellent thermal compensation, the sensor provides unrivalled levels of accuracy and reliability across the full temperature range.

The 4400T has been tested to the same high levels of shock and vibration demanded of high-end motorsport sensors and validated using a rigorous HALT (Highly Accelerated Life Test) process in our dedicated engineering testing facilities at our global headquarters in Leicester, UK.

Druck has a history of providing quality sensors for test applications and we have a range of other products that excel in vehicle test beds, dyno, or wind tunnel applications. In addition, we have an expanded range of performance pressure controllers and handheld indicators and calibrators for in-house or track side testing and diagnostic use.

4400T Summary

•	Available pressure ranges:-	1.6 to 600bar
•	Pressure output:-	Amplified
•	Temperature output:-	Pt1000 Class B
•	Operating temperature:-	-40degC to 175degC

Industry leader

Druck's industry leading technology reflects the experience and expertise of the Druck team – we've been developing sensors for more than 50 years and continue to be a market leader. It also reflects our investment in state-of-the-art R&D and manufacturing facilities. For example, Druck is one of just a few companies across the globe with the capability of turning raw silicon into finished pressure sensing products, utilising our advanced and comprehensive in-house silicon processing capabilities. This enables us to produce pioneering products that provide customers with the accuracy and reliability they need to optimise their operations.

Elite partnership

Determined to build upon our strong track record in the motorsport sector, expand our footprint and develop new technologies, Druck has recently partnered with Elite Sensors Ltd. Specialists in the design and manufacture of sensors for the motorsport sector, Elite Sensors has become Druck's route to market, which enables the rapid introduction of a new range of pressure sensors that will push the boundaries of innovation for the motorsport industry.

Entrenched in motorsport, the Elite Sensors team have worked with the highest performing teams across the sector, developing, adapting and fine-tuning sensing technology to enhance vehicle performance. Adding Druck's pressure and measurement sensors will complement its extensive portfolio of engine and chassis sensors. Our partnership will also enable customers to access a range of supporting instrumentation and interface equipment helping provide the critical edge in competition.

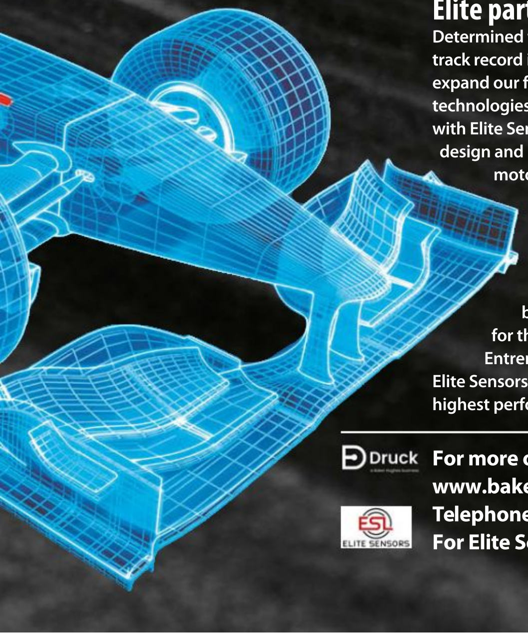
'Druck is one of just a few companies across the globe with the capability of turning raw silicon into finished pressure sensing products'

Multi-channel interface

Elite Sensors also specialises in the provision of technology to capture and interface with the sensor signal and can supply miniaturised amplified output conversion PCBs for probes and multi-channel interface units to capture results from an array of sensors.

'I'm proud that Druck technology is established across a wide range of sectors often in very harsh environments,' says Michael Thomas, project manager, Druck. 'From the bottom of our oceans, to the highest mountains. From the latest military aircraft to missions to outer space. From helping to provide clean water to even saving lives in hospitals, our accurate, reliable robust technology is making a difference right across the globe.

'I'm excited too that we're on the cusp of expanding an already strong track record in motorsport, where there is no room for error in the toughest of environments,' Thomas adds, going on to observe: 'I would want Druck technology in my engine on the starting grid for a race!'



Druck

ESL ELITE SENSORS

For more on Druck Motorsport go to www.bakerhughesds.com/druck-high-performance-sensors-motorsport
Telephone: +44 8000 260864 (UK), +1 8 44 9910 494 (USA)
For Elite Sensors go to elitesensors.co.uk

Mercedes bids farewell to Formula E after winning title

Newly-crowned Formula E Champions Mercedes has confirmed that next season will be its last in the series before it leaves to focus its attention on Formula 1.

It is the third manufacturer to confirm its departure from the all-electric single seater series, following Audi and BMW, who also announced they were quitting in August 2021.

However, in a statement Mercedes says that it is exploring ways to allow customer teams to continue with its cars into the new Gen 3 era. The HWA Racelab team has been involved in Formula E since Season 5 and may continue to run cars, as well as provide them to customer teams.

'In motorsport, Formula E has been a good driver for proving our expertise and establishing our Mercedes-EQ brand, but in future we will keep pushing technological progress – especially on the electric drive side – focusing on Formula 1,' said Markus Schafer, member of the board of management of Daimler AG and Mercedes-Benz AG. 'It is the arena where we constantly test our technology in the most intense competition the automotive world has to offer.'

Toto Wolff, head of Mercedes-Benz Motorsport and CEO of Mercedes-EQ Formula E Team was clear that the double title, for Mercedes and driver Nyck de Vries, was a milestone achievement for the brand. 'We entered Formula E with an open mind about the series and its innovative approach to motorsport,' he said. 'A lot of hard work went into building the team and making it competitive – and we have seen an incredible group of talented women and men deliver at the highest level.'

The FIA is continuing to develop its Electric GT series, which may be more relevant to Mercedes' future racing activities. In the statement the company says that it will use F1 to develop its technology that will 'be brought to life through future product architectures like the AMG.EA platform, the dedicated performance vehicle electric platform that will be launched in 2025, and projects such as the Vision EQXX.'

Alastair Staley

Mercedes has decided to leave Formula E at the end of next season, joining BMW and Audi in a recent exodus from the electric championship

Wine-based fuel for Le Mans from 2022

French company TotalEnergies has announced that it will bring a new fuel to the grid of the Le Mans 24 hours next year, which will be based on wine residues from the French agricultural industry.

The fuel, which will also be introduced into truck racing, is 100 per cent renewable and offers an immediate reduction of at least 65 per cent of the racing cars' CO2 emissions. Excellium Racing 100, as the product is known, will be produced on a bio-ethanol basis, and will power the entire grid. 'Our ambition is to be a major player in the energy transition and to get to net zero carbon emissions by 2050,' says Patrick Pouyanne, chairman and CEO of TotalEnergies. 'TotalEnergies is supporting its customers and partners in their evolutions by thus applying its strategy to motorsport: sustainable fuels, electricity, batteries, hybridisation and hydrogen. Advanced bio-fuels have an undeniable part to play in helping the transport sector to reduce its CO_2 emissions immediately.'

While the fuel will be available to the racing community next year, it remains to be seen whether or not it can be produced in the bulk needed for mass transport. The ACO also confirmed its commitment to hydrogen for 2025.

IN BRIEF

Brabham Automotive has confirmed that it will build a GT2 car to compete in the **Fanatec GT2 European** series in 2022, and will debut the GT63 model at the Paul Ricard circuit on October 3 this year. Brabham joins Audi, Porsche, Lamborghini and KTM in producing a car for the category. Homologation has yet to be confirmed.

The **ACO** and **IMSA** have renewed their agreement to work together, binding the two organisations for the next 10 years.

IMSA has launched a new **Diverse Driver Development** annual scholarship programme worth more than a quarter of a million dollars each year to promote and empower drivers from a variety of backgrounds to participate in IMSA-sanctioned events. To be eligible, candidates from diverse lifestyles or backgrounds must have a strong desire to compete in IMSA races, have proven on-track potential in junior racing categories, while they must also build a compelling business plan for securing the remaining funding needed to compete.

IMSA has revised its strategy for **GTD Pro** next year and announced that the Pro and Am classes will have the same sporting regulations except for the driver pairing requirements. It means that GTD Am teams will be more easily able to challenge the Pro cars, using the same tyres, same safety car procedures and same balance of performance.

Cadillac cancelled its announcement scheduled for the Le Mans 24 hours weekend and instead announced its plans to run in the prototype category in IMSA and the FIA WEC. The future of **Corvette** in GT racing remains uncertain with no confirmed programme, but GM says that the shift in regulations (see above) caused it to re-evaluate its plans.

Acura updates its NSX GT3

Sportscar manufacturer Acura has launched the next evolution of its NSX GT3 car, which is homologated through 2024 and will hit the track next season.

The car features upgraded intercoolers to ensure consistency in engine performance in a wider range of conditions, revised spring rates and suspension geometry adjustments, increased fluid tank sizes for endurance racing, wheel revision for faster pit stops and a new FIA-mandated rain light.

As this is an evolution rather than a new car Honda is not obliged to meet the minimum sales requirements stipulated by the FIA, but the company will seek to sell the upgraded car, named the NSX GT3 Evo 22, for competition around the world.

The chassis is produced in Ohio and prepared for competition by JAS Motorsport in Milan, which will continue to provide parts and technical support in Europe.

The updated NSX GT3 features a revised wheel design to help speed up pit stops

IN BRIEF

Porsche has produced a 700bhp 911 GT2 RS Clubsport to celebrate its 25 years of racing with Olaf Manthey's team. Just 30 of these cars will be made.

Best Water Technology (BWT) has expanded its strategic partnership with F1 to become the Official Water Technology partner for the series. The plan is to eliminate single use plastic in the Formula 1 paddock.

Extreme E has confirmed that it will hold a round of its off-road series in Sardinia in October, 2021. The move follows the series' decision to postpone its originally planned events in Brazil and Argentina.

McLaren Applied, the electronics and data arm of the company, has announced that it is to provide technical support to leading Formula Student teams Joanneum Racing and TU Graz.

Extreme E reveals first scientific project for support ship

Extreme E, the electric motorsport series designed to raise climate change awareness, and Enel Foundation, the energy transition think tank, have confirmed their first joint science research project to take place in the purpose-built science laboratory onboard the series' floating HQ, the St Helena.

Extreme E has been working with the Enel Foundation since its inception, and last year the two organisations collaborated to launch the championship's open call for research named 'Racing for the Planet.' The call invited international scientific researchers to apply to join the ship to conduct research to advance the knowledge of the consequences of climate change and/or adaptation and mitigation strategies on the world's oceans and the planet.

This project, led by 24-year-old Belgian Alexander Vanhaelen, is centred around investigating changes to marine life due to climate change. Vanhaelen will join the St Helena's championship journey as it departs from Greenland – where the series will hold its Arctic X Prix – at the beginning of September.

He will be supported onboard by Adam Pantelis Galatoulas. Both scientists are currently studying Marine Biology at the University of the Algarve, Portugal. The pair will filter seawater during St Helena's latest voyage to obtain DNA shed from marine organisms, and by sequencing this DNA will look to determine how marine life has changed across various parts of the ocean that experience different conditions, with the aim of creating a global inventory of vertebrate species supporting existing data banks.

There are a variety of reasons for these potential changes which both scientists are investigating, including human impact and climate change, which lead to a loss of biodiversity and impact the make-up of marine environments and the species that live there. With rates of extinction and the introduction of invasive species at an all-time high, this type of research and the knowledge it will provide are critical to understanding the behaviour of marine communities to inform effective ecological management and conservation biology, we're told.

The team's findings will be published in an international scientific journal and are planned to be orally communicated at scientific meetings dedicated to marine biodiversity.

Lead scientist Vanhaelen, said: 'I've been a fan of both motorsport and nature for as long as I can remember, so this call to research was the perfect opportunity to combine my passions to help the Earth – it really is bucket list material.

'Sadly, nature is suffering, and we are determined to see what we can do to make it better. I believe Extreme E is a very useful platform to show the world how to interpret the signs nature has been giving to us and how to act upon them.

'I hope our research will contribute to the race against global climate change by confirming which species occur in which regions, and how they have been moving or even disappearing. My ultimate goal is to provide this knowledge to improve sustainable fisheries, conservation and management. I know this project will provide vital information for this which I am incredibly motivated by.'

Alejandro Agag, CEO and Founder of Extreme E, said: 'A big welcome to our first scientific project team – Alexander and Adam. I'm fascinated by this project, and looking forward to hearing more about our oceans and how its inhabitants are suffering at the hands of the climate crisis, but also how we can make change.'

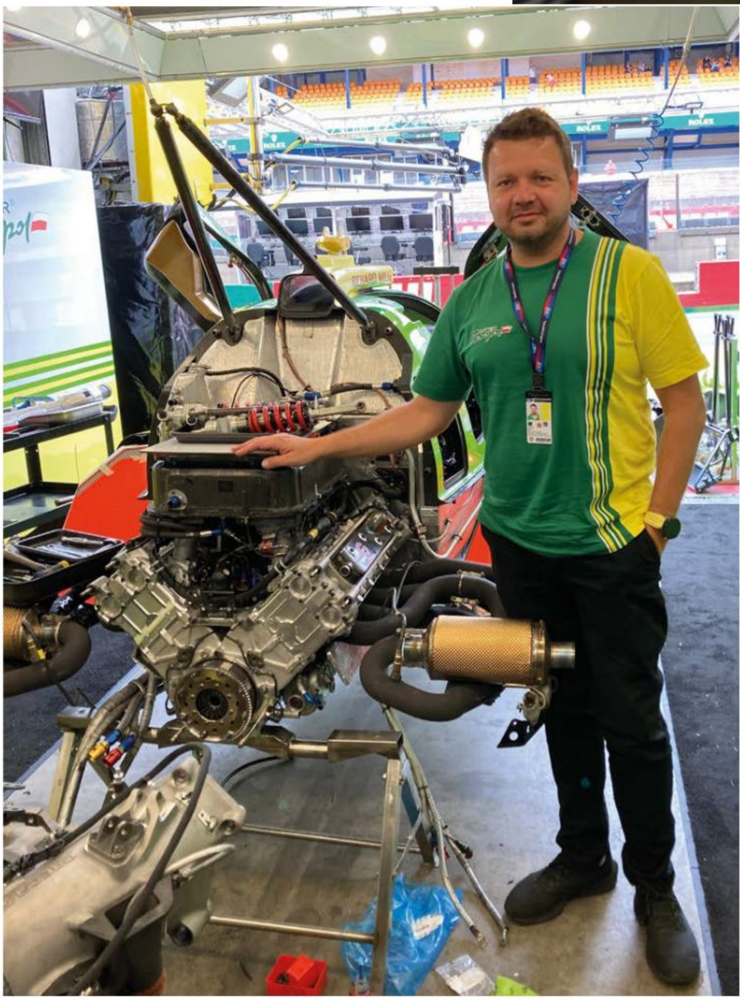
Louisa Tholstrup, Extreme E's science and legacy manager, said: 'Alexander's research is part of a growing trend in the scientific community working on the synergies and trade-offs between climate and biodiversity. It contributes to research urgently needed to take action to protect biodiversity that simultaneously contributes to the mitigation of climate change, and [helps us] understand the capacity of marine species and ecosystems to adapt to those climate changes that cannot be avoided.'

Interview – Rafal Pokora

Pole's position

Former Toyota race engineer Rafal Pokora explains why he is relishing his new role as technical director at ambitious LMP2 outfit Inter Europol Competition

BY ANDREW COTTON



Polish engineer Rafal Pokora has hooked up with LMP2 team Inter Europol, which has a long term plan to move up into LMDh

'Everyone wants to win Le Mans but it took me time to do it, and when you do win you realise how special it is'

Inter Europol Competition had a pretty successful Le Mans 24 hours this year, its car running like clockwork throughout the race before coming home in a creditable fifth in class and tenth overall

The LMP2 field at Le Mans in 2021 was one of the most competitive in recent years. With 25 cars lining up at the start of the event, all of them bar one an ORECA chassis, on the same Goodyear tyres and with highly professional drivers, this was a category to watch. And one of the stand-out teams in LMP2 is Inter Europol, which perhaps has more to do with a lairy colour scheme than results to date, though its ORECA did show well at Le Mans, coming home fifth in class and 10th overall.

This result might partly be attributed to the arrival of Rafal Pokora as technical director. The Pole has a long history in racing, starting in British F3 with Hitech, then moving to South Africa to engineer a car in the A1 feeder series, A3, before returning to the UK, to work with RML and then JRM, engineering the GT1 Nissan alongside Nigel Stepney.

Making his Marc

From JRM, the chassis and brake specialist went to Marc VDS in GT racing, before heading to Toyota to eventually became the race engineer on the number 8 car, which has a famous history at Le Mans. It won three races with Pokora on the pit wall, in 2018, 2019 and 2020. However, Pokora had a hard ride to that Le Mans win as it was his number 5 car that stopped on the last lap in 2016, while leading the race.

'Everyone wants to win, but it took me time to win [Le Mans] and when you do so, you realise how special it is,' says Pokora. 'You also realise how much it takes from you. In 2016, when we had that last lap failure, the entire team was down, and to bring it back to where it was in 2018 was a big job. It was just crazy.'

Reflecting on that 2016 race it was hard to focus on the positives, but there were actually plenty to be found, Pokora believes. 'From a strategy point of view, that was the best I ever did at Le Mans. It is peculiar, but that is exactly what it was.'

Long road to victory

The team ran three cars in 2017, but despite introducing a new engine and making what Pokora calls 'the biggest technological step that I ever saw from the electronic protection point of view', through a succession of mishaps, self-inflicted as well as external factors, Toyota didn't win once again. It wasn't until 2018 that the manufacturer got its coveted victory, with Pokora on the pitwall as the race engineer.

'There are lots of things that were happening, but I thought "how much is this costing me"', says Pokora. 'It was a very technical role, there was a vast amount of information with the jobs and roles that you have to fulfil. It was massive, and it was good, but I had been in motorsport for 17 years and I had achieved what I wanted. It would have been great to stay there, but I was not enjoying life as it should be overall because we are completely detached from reality.

'From one perspective it is very good, fantastic to be there and [in that] environment, making use of the tools, understanding the things that you can do, and you know that you are pushing engineering forwards,' Pokora adds. 'But at the end there is a life around that and it is passing you by without you interacting with it anymore.'

With all that in mind Pokora left Toyota and it wasn't long until the Polish Inter Europol outfit contacted him to join the team. He had tested out the Polish racing scene nearly a decade earlier but was told that there was nothing at his level, but now the team was ready, competing in the FIA World Endurance Championship and wanting to make the move to the big league.

Pole to Pole

Inter Europol started racing in 2010 in the Formula Renault 2.0 series in the Northern European Cup, and other single seater championships. In 2016, the team turned its attention to prototype racing with an LMP3 car, winning the VdeV championships in both 2016 and 2017. It then stepped up to the European Le Mans Series in 2017 and 2018 and then entered an LMP2 car alongside its LMP3s in 2019.

East to Ouest

However, Le Mans was always the goal for the team, and so in 2018 and 2019 it also took the strategic decision to contest the Asian Le Mans Series. The champion there would get an automatic entry at Le Mans, and this goal was achieved. Driver Kuba Smiechowski and Martin Hippe won the LMP3 class and the team first went to Le Mans in 2019 – for the 2021 race Smiechowski was joined by Dutchman Renger van der Zande and Brit Alex Brundle.

However, against teams such as United Autosport, Jota and the Belgian WRT team it was clear that if they wanted to take the next step it would have to improve. If a team wants to be ready to win Le Mans overall, which is its ultimate ambition, it

'My time at Toyota was good, but I had been working in motorsport for 17 years and I had now achieved what I wanted'

Pokora suffered heartbreak at Le Mans in 2016 when the number 5 Toyota he was engineering ground to a halt on the last lap. He did win the race with number 8 in 2018, 2019 and 2020, though

'The guys need to have courage, they need to be aware, they need to rely on each other, because only as a team can you succeed'

has to get the fundamentals right, and Inter Europol decided that Pokora was the man to help it to do this. For his part, he was happy to take on this new challenge, to help bring a Polish team to the top step of the podium.

Inter Europol started racing in Formula Renault 2.0 in 2010 and switched to sportscars in 2016. It's been running an LMP2 since 2019

Team building

'The first objective is to make good the race team that will operate the car at a high technical level to give you the result,' says Pokora. 'That requires a lot, from the infrastructure that is being built, and the team operation. The operation itself is growing. We are looking to LMDh and this is part of the long-term objective but it won't be available in 2022 [the rule set only starts in 2023].

'In four years, you need to be on it, it will be very busy,' Pokora adds. 'It should be enough time to grow the team technically that we can swallow [cope with] LMDh, not that we get a car and then think "what do we do at this?" We need to get the car and operate it at an appropriate level.'

This is the right time for the team to be building, and it believes this is the right environment in which it can work. At Le Mans, the FIA and ACO confirmed that it would honour its commitment to LMP2 in the long-term future, rejecting manufacturer plans to flood the field with LMDh cars and instead offering assurance to smaller teams such as Inter Europol that they would continue to have a place in which to race.

'The team is reasonably small, we don't want to grow too fast,' says Pokora, who has taken on pretty much the entire engineering responsibility for the team's ORECA 07. 'We want to have a good background, the basic jobs need to be done and we have to grow on this one. This is a long-term plan from a technical point of view, and operational, it is a long-term project, and we have to push.'

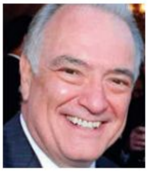
Winning mentality

While Pokora brings a manufacturer level of expertise to the team, he also brings a wealth of racing experience. That extends beyond his knowledge of how to operate a car, or how a team should manage itself, as it also means mentally preparing yourself for success and, just as importantly, failure.

'What I always say is that if we win, we win as a team, but if you lose, you lose as an individual,' Pokora says. 'If you win, everyone cheers, but if you lose, everyone hurts. I am pretty emotional on this because I went through it. This is a very tough race both technically and mentally because you have to prepare for it. You think you cannot do something, but you have to do it, better than anyone else, and there is a lot of mental energy that you have to put into the team.

'On the pit wall, you have to energise the team where it is needed,' Pokora adds. 'You are the eyes and ears to make sure the drivers are aware of what is happening on the race track, you have to energise the mechanics to make sure they also know what is going on. You have to orchestrate everything, and the guys need to have courage, they need to be aware, they need to rely on each other, that everyone has the back of the others, because only as a team can you succeed. There is no one guy who is Superman. This is piece by piece systematic preparation.

'You can only find out at the end of the race during the debrief what has happened,' Pokora adds. 'And then the very next day you can start the preparation for [the next] Le Mans.'



Going for gold

The MIA's CEO notes some similarities between the Olympics and motorsport

The government has freed us to get on with our working lives across Motorsport Valley UK, at last. It's been a long time coming. The negative effect on businesses during the pandemic is hard to estimate, but is certainly substantial.

Now we urgently need to re-engage and again meet face-to-face with our customers, suppliers and potential new business partners. Zoom, whilst being a life-saver, is no substitute for personal interaction in business.

On October 13 at Silverstone, the MIA is hosting a new, free-to attend event to help that vital re-engagement to take place. The MIA's Conference and Technology Showcase 2021 is the ideal opportunity for you to meet and talk with old friends and new.

On the same day, alongside the Showcase, you can drop in, at no extra cost, and enjoy a valuable Technology Conference, the title and theme of which is 'Competition driving Innovation'.

World-class speakers from high-performance engineering and motorsport will bring you up to speed with the latest products, challenges, solutions and opportunities. This is the perfect time to reintroduce yourself and your company to the wider engineering marketplace. October is the ideal month for our industry, as its early enough to capture new business for next year's motorsport activities and initiate ideas for 2023.

Positive business news is the exceptional number of technical regulation changes that are coming up in the next few years. Not just Formula 1 but also IndyCar, LMDh and junior formulae. The collaboration between US and European endurance sportscar racing is long overdue. It's full of potential new business for many suppliers which will be highlighted at the MIA's Silverstone Showcase and Conference in October.

Olympic flame

Motorsport operates in a never-ending world of competition demanding innovative engineering and technology solutions, fast. The recent Olympics reminded me that competition has always driven innovation.

Human fitness can be improved marginally by novel diets and new training techniques, but changes to equipment, between each Olympic Games, is phenomenal and helps set new records and win gold medals. Look closely at the canoe, sailing and cycling events to see what I mean; even the Nike running shoes used new technology featuring a lightweight, full-length articulated carbon fibre plate.

Increasing innovation is a current goal of the UK government, it being determined to increase the level of R&D spend in the next decade. It plans to help fund UK-based companies, which are active in R&D, from many sectors. The prime minister also recently announced a new Science and Technology Council, led by senior scientists and hi-tech business leaders.

Lotus Cars

The push for excellence in the Olympics mirrors the attitude of the motorsport business sector, while some of the bikes have F1 DNA running right through them

The global success of the science-led, government-supported, UK vaccination business solution, has encouraged the UK government to invest further in innovative companies which can react quickly to challenges. Project Pitlane, the COVID-response led by seven Formula 1 teams and their suppliers, has brought the potential of our industry to influential eyes.

Another thing to look out for is that soon the UK will have a new, independent £800m Advanced Research and Invention Agency (ARIA) modelled on the USA's successful DARPA. It aims to 'identify and fund transformational science and technology at speed', leaving the solutions open to innovative companies.

It will have a much higher tolerance for failure than is normal, mirroring the established motorsport approach, which recognises the freedom to fail is often the freedom to succeed.

We are entering an exciting period when the intensively competitive experience of hugely talented people across Motorsport Valley could secure R&D funding to help them deliver solutions to a variety of challenges.

Climate for change

Many R&D opportunities for motorsport companies are likely to arise from the COP26 conference in Glasgow in November. Major world leaders will discuss the challenge of climate change and agree on plans to respond to this as a collective group.

As I speak with many business executives, it seems recovery from this tough pandemic environment is well underway across the world of motorsport and high-performance engineering. One commented that 'whenever there is a world crisis, banking, financial or such like, motorsport has always been the last in but first out'. We pride ourselves on being rapid solution providers, our attitude of just get on with it and push forward with confidence, is helping our community to recover faster than others.

Finally, keep your eyes on changes in the marine world, not the offshore maritime sector, but inshore coastal and inland waterways. This huge sector recently made decarbonisation commitments and needs to make progress quickly. The MIA, which has close links with UK marine from which our members now benefit, is hosting a visit to the Southampton Boat Show on 16 September with a two-hour workshop for members to meet marine engineers, specifiers, and buyers. We are determined to find new business so maybe this is the time for you to join the MIA and come with us and let us help in your recovery plans face-to-face.

The immediate value of the MIA's community, focusing on motorsport and high-performance engineering, is a real asset to speed up recovery. Membership is increasing every week, the faster we can collaborate and work together to rebuild our community the better. In the meantime, keep up the Olympic spirit, and please feel free to contact me directly (chris.aylett@the-mia.com).

Nike's running shoes used new technology featuring a lightweight, full-length articulated carbon fibre plate

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Hard lines

The future of endurance racing is clearer, but not all are happy

Clear red lines were drawn throughout the endurance racing paddock at Le Mans, and the reaction was actually one of surprise. Big companies used whatever influence they had to create a favourable position for themselves, while the ACO and FIA sat in the middle forced into making decisions. They had a choice to cave in to manufacturer pressure, of which there was plenty, or to stand firm. They stood firm.

The first issue was that Cadillac cancelled its planned press conference on Thursday night. At the conference, it was expected to confirm a prototype programme for a GM brand, and a Corvette GT3 programme that would race at Le Mans. However, IMSA in the US decided to make the only difference in class separation between pro and am through the driver grading system. That meant that should Corvette come with a factory team, and factory drivers, it would have to race the very customers it was trying to sell to. And they have to sell 20 cars within the first two years. They were not an island in looking for pro teams in GT, they said, and had support from other manufacturers, likely BMW and Lexus.

Porsche and Ferrari, meanwhile, were pushing for an amateur-only category in the hope that they would avoid having to invest in a full factory GT team when in fact their resource was pitched at prototypes. They found allegiance from governing bodies, particularly the likes of Stephane Ratel, who hoped to protect his philosophy for the category; customer racing. The ACO and FIA appear to agree with him, at least for now. Cadillac subsequently confirmed its prototype programme on the Tuesday post-race, but there was no confirmation of the Corvette decision.

> **Big companies used whatever influence they had to create a favourable position for themselves**

LMP2 commitment

The second red line was drawn by the FIA and ACO in terms of LMP2. They made a firm commitment to Goodyear, sole supplier to the category in the FIA WEC, that it would have significant market share of the grid to justify its involvement in the series. That rather hurt the business case of the LMDh manufacturers, who were hoping to flood the series with their cars, plus take over the top class of the European and Asian Le Mans Series.

The FIA and ACO looked at the future sales figures of the LMDh cars, the price, and the teams that were competing in LMP2, and re-affirmed its commitment to the privateer category. From the point of view of Dallara and ORECA, this was the only sensible solution, as when the manufacturers do leave, and they surely will, teams do not need to have been under such financial pressure that they collapsed. The LMP2 teams are not on the same level financially, some struggle to meet the cost of running an LMP2 team, guessed to be around the €2-3m, and asking them to step up to double that would be too big a step.

With the Cadillac, Goodyear and LMP2 conundrums all sorted the only other big question was: what happened to Alpine? A decision was expected pre-summer break that the company would enter LMDh and the lap of the Le Mans circuit by Fernando Alonso pre-race rather served to confirm this. It didn't happen, and strangely the PR team stated that it was never intended to either. That one we had to park while the race went ahead, as clearly there was no one to verify the state of affairs.

Formula E refugees

We then chased up the loose ends; the less likely stories. With Mercedes confirming its departure from Formula E, would any others depart? A persistent rumour that Jaguar is looking into the WEC is another tough one to nail down. Jaguar, Nissan and Porsche have all committed to the next generation of Formula E cars as OEMs, but will they all follow through with full race programmes?

It seems unlikely that there will be too many more manufacturers looking to join the top class at Le Mans. Porsche, Audi, BMW, Cadillac and Acura are all confirmed to do LMDh; Toyota, Peugeot and Ferrari confirmed to do Hypercar, while Alpine and Lamborghini wait in the wings ready to leap onto the stage at any moment. If I were Jaguar, Mercedes or Nissan, I'd probably listen to Marcello Lotti, organiser of the TCR rule set, who stated clearly 'I need only three manufacturers as there are only three spots on the podium.'

So, the future has at least got its red lines and hopefully that will lead to some stability. The VW Group will not flood the grid with customer cars, that will still be the role of LMP2, in whatever form that takes. Toyota, Peugeot and Ferrari will not, therefore, face an armada of Porsches, Audis and Lamborghinis. GT3 looks as though it will stay in customer hands, while Michelin and Goodyear have a market share that they are comfortable with. Other than the racing, the appearance of Captain Sensible was the most surprising thing about Le Mans 2021.

ANDREW COTTON Editor

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