LE MANS: First interview with ORECA's new tech boss Remi Taffin – p76

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Red Bull RB16B

We trace the incredible development of 2021's most successful Formula 1 car

Champions!

This year's worldwide motorsport winners

Formula Ford

The continued success of Britain's entry level single-seater series

PIKES PEAK HILLCLIMB
Anglo-American outright record challenger

SWINDON POWERTRAIN
BTCC engine supplier ends its unique deal

WRC AERODYNAMICS
Tracing the history of rally aero development

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Old meets new: Fernando Alonso tests the new 18in wheels and tyres at Abu Dhabi as Formula 1 gears up for an all-new future in 2022

XPB Images

Moving on

Abu Dhabi is behind us, but there are still vital lessons to be learnt

It seems the Qatar and Saudi Arabia GP shenanigans were simply precursors to the Abu Dhabi 'you couldn't have written it' championship finale. I have to say, regardless of everything else, this race provided one hell of a last lap, edge-of-the-seat drama. Could Netflix have dreamed for better?

Mercedes is being sensible in not pursuing legal action concerning the controversial outcome. If not Toto Wolff, then the Mercedes hierarchy have realised that, apart from little likelihood of winning – especially as there is no obvious redress that could be sought – the German automotive giant's reputation risked the inevitable accusations of sour grapes and being bad losers. After all, the company is not in F1 to generate bad publicity.

However, the failure of team principal and driver to attend the annual prizegiving ceremony is poor as this is a mandatory commitment that's part of competing in F1.

So, on one hand Wolff complains about rules not being followed, and on then immediately breaks one!

Knight and day

The reality is that Mercedes and Sir Lewis (whose deserved knighthood should surely have been awarded long ago) have had a real challenger for the title for the first time in this PU era, and it's not a coincidence that it has occurred without the team's past, pre-budget cap financial and resource advantages.

The 'We will crush them' motivational address to the team by Wolff of a couple of years back never sounded to me as reflecting the sporting attitude he endorses. So, suck it up Toto and move on, you've had good fortune, as well as superb performances for eight years. Winning the Constructors' Championship *again* is not to be sneezed at, and reflects well on Mercedes and the team as a whole.

Ultimately, though, despite (unlike Hamilton) losing many points due to DNFs, which have been no fault of driver or team, Verstappen won more races than Lewis. Which surely should ideally be the mark of the champion each year?

If I have a gripe, it is that Red Bull and the Sky commentary team made virtually no mention of Honda's vital contribution to the result (although Max did). I have to admit to some personal interest here as I work with a Honda-related company, but Red Bull has form as it seldom gave credit to Renault when using the French engines to win four previous World Championships.

Quite possibly, by the time this column is read, a lot of this hoo-hah will have died down, the issues involved referred to an FIA commission. Unfortunately, this reflects a common problem: important issues can quickly become diluted when they are no longer filling the headlines.

The Spa race fiasco was supposed to be debated by the FIA and F1 in October, but I have heard only vague notions about examining the aero wake of other types of racecars in very wet conditions. Nothing I'm aware of has happened so far concerning ways of making a race happen in these circumstances with acceptable safety, nor the farce of points being awarded for just trailing around behind the safety car. Enough time has elapsed for positive action to be taken.

XPB

Verstappen was a worthy winner, but what mention of the Honda PU that powered him?

Standard response

Not adhering to one common track-limit regulation for *all* corners and *all* circuits by F1 race director, Michael Masi, reflects the same lack of decisiveness employed concerning the back markers wave-past u-turn in the final laps of Abu Dhabi. Even more worrying, his response to the issue of crashing cars being bounced off the barriers back on to the track at the top of Eau Rouge at Spa has been 'It meets F1 standards.' Yet again, with regards to the Jeddah track, without significant changes there is a virtual guarantee that a similarly hazardous, stop / start, red flagged and safety car-beset grand prix will occur again next year, and every year after.

Yet Masi openly states 'Only fine tuning is required.' No firm action has been taken to prevent cars being deliberately driven slowly anywhere on track, not just in one section, at *all* circuits in practice *and* qualifying.

This head-in-the-sand attitude is simply not good enough, and nothing to do with 'putting the racing first.' That said, responsibility for this is not solely confined to Masi who, after all, is appointed *by* the FIA. It is the FIA who need to instruct Masi that he should not have free reign of these fundamental decisions, but should operate under overall parameters and not make it up as he goes along. Otherwise, he should go.

It reminds me of a FFord event I attended at Mondello Park in Ireland aeons ago, when the commentator announced 'Sure, and the boys are having a great race so we'll give then another couple of laps.' I loved the sentiment but it was a bit unfortunate for those without enough fuel in their tanks!

Delegation game

I do agree with a comment by Martin Brundle that part of Masi's role – track safety, including reinstatement of barriers after damage, for instance – should be delegated to someone with relevant knowledge and experience, reporting directly to him. This would leave Masi free to concentrate on matters affecting the race itself.

Charlie Whiting developed vast experience during his tenure as F1 race director and was able to expand his knowledge and abilities as the role grew over time, whereas Masi has had to learn rapidly, if not completely from scratch. But I am minded of Eduardo Freitas, FIA race director of the Le Mans 24 Hours. His job, lasting twice around the clock and covering a circuit of almost 14kms with 50+ cars running in all weather and track conditions, might make directing an F1 race seem easy. He has an authoritative voice that deters argument, vital in the heat of battle. There's no hint of indecision with him.

Winning the Constructors' Championship *again*… reflects well on Mercedes

Bull ring fever

Red Bull Racing's chief engineer of car engineering, Paul Monaghan, takes us through the 2021 development of the RB16B chassis

By STEWART MITCHELL

The 2021 FIA Formula 1 World Championship was the most competitive of any since the birth of the hybrid era in 2014. A battle from the outset between Red Bull Racing and Mercedes AMG Formula 1 teams saw the fight to decide the victor rage on until the last few corners of the last lap of the last race of the championship. Two powerhouse cars of the sport, with arguably the biggest difference in Formula 1 car design philosophy throughout the paddock, battling it out at every circuit made 2021 a season to remember.

Here, we look at the Red Bull Racing RB16B and unpick its technical accolades with Red Bull Racing's chief engineer of car engineering, Paul Monaghan.

Before the gantry lights went out for the first race of the season in 2021, there had been a very short winter development period. After the huge concept changes for the 2022 season chassis were postponed, the FIA implemented a series of rule changes ahead of the 2021 season to reduce cost of development before the 'new era' arrives, and as calming measures in response to the ever-increasing downforce the cars deliver.

Photos: XPB

Max Verstappen drove the Honda-powered RB16B to the drivers' Formula 1 World Championship title having won more races than anyone else in 2021

The cost reduction exercise saw a token system introduced whereby teams could opt to use two tokens to fundamentally change the design of particular elements on the car in certain areas.

As for the performance calming measures, the FIA feared that if development continued with the 2020-spec regulations, it would push car pace beyond safe limits of both the tyres and some tracks, certainly those that have remained unchanged as pace has steadily increased over recent years. The target was to reduce downforce by 10 per cent.

The most significant contributor to the desired aerodynamic load reduction saw a diagonal cut in the cars' floor ahead of the rear tyres, reducing the floor width at the trailing edge by 100mm on each side, and the banning of any fully enclosed holes in the floor through which airflow could be manipulated, be they slots, holes or aerodynamically-shaped furniture.

These changes decreased the floor's working area used to generate downforce from under the car, and reduced the ability to seal the floor to work the diffuser as effectively as possible. This made it harder to control the influence rear tyre wake had on the diffuser stream, and the aerodynamic consequences of varying sidewall bulge and rear tyre contact patch squirt (the loss ejected by the tyre as it contacts the ground).

Rear diffuser and brake duct development was key throughout the year, often seeing design iterations on a race-by-race basis

Bargeboard regulations changed, and then changed back again, leading to a diversion of resource that was not anticipated

Philosophy of change

Red Bull Racing's RB16B stuck with the designer's long standing short-wheelbase, high-rake philosophy. Despite reports that its design would suffer less from the regulation changes than its long-wheelbase, low-rake rivals – as the rake of the car was a primary contributor to the pressure delta at the diffuser, and therefore downforce at the rear, rather than floor area – that didn't mean the RB16B was immune to these changes, as Monaghan explains.

'As we went through the machinations of trying to not carve up too much of the RB16, knowing the effect [of the new regulations] was big on us, we put forward proposals on what to change and what not to change.

'We not only had structural work to do, but a new engine to install and a new sidepod, front floor edge, rear brake ducts and diffuser to re-design, not only to comply with legality requirements, but also to try and recover some of the downforce that had been eroded by the regulations.

'In addition to all this work, the vehicle dynamics crew also had to deal with new tyres and how to integrate these into the rapidly evolving car. So, if you consider that this was supposed to be a sort of carryover car, we had the structures group busy, aerodynamics group busy, vehicle dynamics group busy and that, inevitably, must flow through the design group, all to be realised in a full-size car that we had three days of running with before race one.

'When you look at the effort that went in to produce a competitive car, it was a huge team effort. The car that came out of it was immediately quick, won a lot of races and was reliable. I shouldn't omit Honda from all of this as they pulled out all the stops to give us a revised engine that worked brilliantly.

'I think all said and done, a team effort was rewarded with a quick car in 2021.'

The flow conditioning areas of the car that influence downforce at the rear were a huge development area for the team in 2021. Although the 2020 'Venetian blind' concept continued from the RB16, during pre-season testing in Bahrain the car sported a basic concept for airflow control around the bargeboard. However, by Portugal a more advanced version was fitted to both RB16Bs.

The updates included longer longitudinal slats to manage and condition the flow around the central body of the car and towards the rear. This design was expected

'If you consider this was supposed to be a sort of carryover car, we had the structures group busy, aerodynamics group busy, vehicle dynamics group busy and that, inevitably, must flow through the design group'

The controversial rear wing introduced at the Spanish Grand Prix, which appeared to change shape under high downforce load

The wing's single pillar design was initially a weight saving exercise, but revisions made to appease the FIA ended up adding weight

to claw back some of the FIA-implemented downforce reduction by feeding high energy air to the back of the car.

On floor and wing

The short fences that protrude from the edges around the middle of the floor have also seen several iterations throughout 2021. The z-shaped cut out in the side of the floor that many teams on the grid adopted in early 2021 never surfaced on the RB16B. Instead, Red Bull started the season with a relatively plain floor design and only later developed a stepped floor concept.

The RB16B features detailed elements in the central segment of the floor that were adjusted to suit the tracks on the calendar at the time. The floor furniture is then designed to manage the airflow around the inner face of the rear tyres and seal the edge of the diffuser.

Red Bull introduced several iterations of rear wing throughout 2021, though the one introduced to the RB16B at the Spanish GP was by far the most famous. The design was noticeably different from the outgoing one, moving away from a flat edge on the lower element to one with a dished central section in the middle of the profile that swept up towards the wing end fences.

The change in profile offered preferable performance characteristics for the high-speed Barcelona circuit, as well as better stability at the rear. However, the new wing was the subject of some debate during the practice sessions as it was observed from the rearward-facing camera onboard the RB16B that, as car accelerated down the straight and load on the rear wing increased, it started to deform, levering down and away from its static position, returning only when the aerodynamic load was shed under braking.

The rulebook allows for some deflection of this sort but, as the wing was twisting backwards at such a high displacement, it was put under close scrutiny, given it could provide an aerodynamic advantage by reducing drag on the wing.

The amount the wing was tipped back in this condition equates to potentially a couple of degrees of angle of attack, which reduces rear axle downforce – unnecessary on the straights after a certain speed where mechanical grip is high enough. So having the rear wing rotate backwards slightly is a way of being able to still have a relatively stiff set-up, but gain some potential advantage on the straights.

The FIA has a template for the rear wing and addressed the movement with the team using cameras and datum points mounted to the wing surface, all the while acknowledging it cannot be entirely stiff.

'The regulations as we began 2021 allowed an amount of angular rotation in side view of the car, and explained the FIA tests that were in place to guide you on whether your elasticity was excessive or not,' says Monaghan. 'In seeking a lighter pylon solution at the back of the car, we went to single pillar. That gave us the ability to save just over 1kg, compared with the previous dual pillar version, and exploited some, not all, of the deflection permitted by the FIA tests at that stage.

'It's fair to say that in Portugal we could see a lot of movement in the rear wing end plates, and we questioned whether that was helpful or not. We didn't have a thorough answer to that before the wing assembly was revised going into Baku, and then again into the French Grand Prix.

'We were looking for a stiffness-to-weight trade and felt we were within the regulations, but the goalposts shifted a little bit. We then had to find a different trade and we went to Baku with a 1.2kg deficit, so it wasn't our favourite moment, shall we say.

'And then there were further minor revisions going into the French GP, where the new tests were introduced, so we enjoyed the weight penalty to the end of the season.'

Diffuser development

The RB16B's diffuser saw significant development throughout 2021, seeing it sport serrations on the trailing edges of each diffuser element. Although only slight changes in lift coefficient could be observed from these serrations, each serration results in an upwards displacement of the dip position of the root flow, due to the movement of the flow through the serration's valley and vortices arise from the serrated edge tips. This flow and the vortices influence the turbulent energy decay at the wake region, bringing down the turbulence level significantly compared to a straight-edged diffuser element. Consequently, as there is less turbulent flow working the diffuser elements, it produces more downforce in this region. These were combined with Gurney flaps atop the diffuser to energise these vortices more effectively.

'The serrations were on the last 25mm of the diffuser tops, because to keep that Gurney attached is quite challenging,' says Monaghan. 'We had looked at two and three-element versions of it and, if you think about the scale in which we're working, and the fact that the flow must roll around the corner of the diffuser, it's quite impressive that you can get three elements in that space. But we did.

'The quality of the onset flow can give you quite different circumstances and challenges. Our research into the serrated edges, which gives you a little bit more mixing between the elements, saw us settle on this design being slightly better than the straight trailing edge versions we had before.

'Initially, it was a metallic item, which put a little bit of weight on the car. Once we knew the idea was sound, we went to the additional complexity of carbon and recovered most of the weight penalty.'

The Red Bull design team spent significant further development effort on changes around the front brake ducts throughout 2021. The car arrived at the start of the season with a completely new shape to the front ducting when compared to its RB16, and the subsequent iterations had a significant aerodynamic influence on what's behind them – particularly the bargeboards and the front sections of the floor.

Red Bull made numerous front brake duct design changes, sometimes between consecutive races, trialling different sculpting for the inlets, size and severity of ducting, and overall duct shape. The various versions were designed primarily to influence different

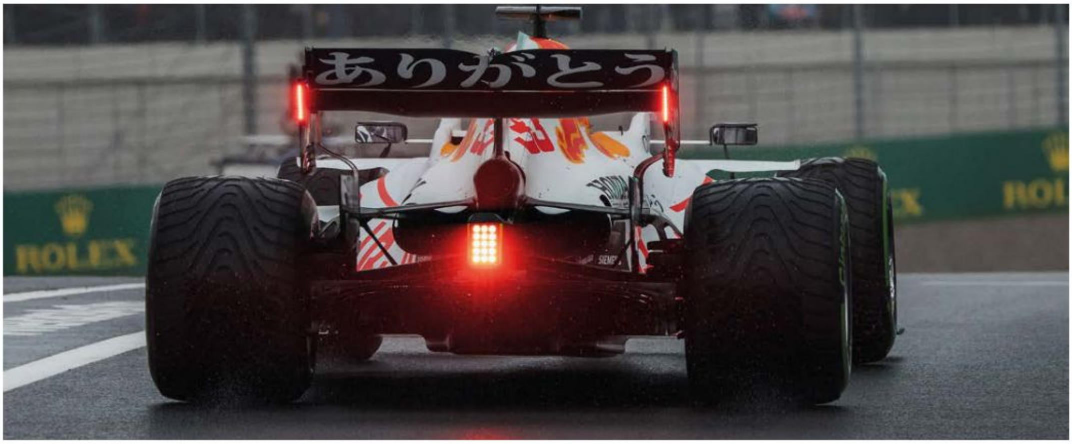
downforce demands as a function of the onset conditions of the flow to the elements behind the front wheels, not just brake cooling.

Handling the airflow around the front tyres and providing the desired interaction with the bargeboards for a given circuit is extremely valuable to car handling, and therefore has a knock-on effect on lap time.

Swept back suspension

Red Bull chose to spend its two development tokens on a new gearbox casing. This was to facilitate a totally revised, and dramatically swept back rear suspension to improve rear end stability, traction and increase the volume between the rear wheels and diffuser in a bid to claw back aero performance in this area.

Red Bull chose to spend its two development tokens on a new gearbox casing… to facilitate a totally revised, and dramatically swept back, rear suspension to improve rear end stability [and] traction



Saw tooth rear diffuser was marginally more efficient than straight edge version. Honda tribute on wing was fitting, having brought a new engine, despite installation headaches for the team

High rake angle has been a philosophy of the Red Bull cars since the V8 days

Elasticity of aerodynamic elements on the RB16B was a talking point for much of the mid-season

Aerodynamically, this is extremely productive real estate and the more high-speed air that can be directed through here, the harder the diffuser will pull on the underfloor airflow, increasing the car's rear downforce.

In spending the two tokens on a new gearbox casing, the inboard rear suspension pick-up points were able to be changed. The bottom wishbone was reversed to sweep rearwards rather than forwards, with the forward leg picking up (at the inboard end) on what had previously been the rear leg mounting. The rear leg now picked up what had previously been used for the toe link, which moved from ahead of the driveshaft to behind it, using what had previously been the mounting point for the forward leg.

'We'd seen what Mercedes had done [in 2020] with their rear suspension geometry. In particular, their lower wishbone and track rods were quite different to ours,' says Monaghan. 'We looked at that, though couldn't make the same package work for us. But we did still find some improvements in other areas.

'We decided to capitalise upon those and looked at some structural stiffness work with a gearbox case revision as well. We had perceptions that we were struggling a little bit in stiffness and, whilst our finite element analysis models would say we should be fine, it wasn't as good as some cars we had done before. The new case design supported rear-end stability and aerodynamic efficiency.

'Because the diffuser and floor were in for a heavy re-design, we incorporated these changes to the case with the potential to influence behaviour in the whole back end of the car. We had this sequence of iterative steps by which we looked at the rear suspension alongside the revised floor, rear brake duct and diffuser. It was important to note that the suspension members play a big part in the rear brake duct cascade that runs up the inside face of the brake duct.

'We didn't move the suspension to deliberately influence the diffuser. Once the casing was settled, and we had the pick-up points, you can work with the shape of the suspension members, observing the 100mm cord, 3.5:1 aspect ratio and angle limitations perpendicular to the member itself.

'It's not as if everything is frozen immediately so, once we set the pick-up points, we'd done a large amount of the work. It was then a sequence of iterative steps by the aero team, then back to the structures team to see how we could exploit it as we approached each release date, and best address the losses and changes that have been brought by regulation 2021.'

Honda engine

The power unit regulation revisions brought in by the FIA at the start of the 2020 season meant only one specification change was permitted to the internal combustion engine, turbocharger, MGU-H, fuel and oil, MGU-K, control electronics package and energy store until the end of 2021. Honda took advantage of this for its 2021 power unit, the RA621, as it was in essence an all-new design, within the framework of what is allowed by the power unit regulations of course.

The RA621 saw architecture changes to major elements such as the block and cylinder head, resulting in a smaller and more powerful power unit than the 2020-spec RA620 it replaced.

The RA621's block used a new material, its bore spacing (the gap between the cylinders) was reduced, shortening both overall engine size and crankshaft length, as well as improving the relative stiffness of the base construction of the driveline.

With each opposing pair of cylinders sharing the same crank pin, one bank is slightly offset from the other. Honda swapped the offset from one side to the other from the RA620 to the RA621 to aid packaging in the chassis. This enabled induction system and heat exchanger ducting to be further optimised, despite the positioning of systems on the front of the engine remaining the same as the RA620.

The RA621's small stature allowed the rear of the car to be packaged even more tightly for aerodynamic gain. It also needed less cooling capacity, allowing the Red Bull aero team to reduce the radiator inlet and outlet sizes through the bodywork.

The reduced dimensions and cooling needs of the RA621 PU allowed even tighter packaging under the bodywork and engine cover

Improved efficiency

A re-assessment of priorities between combustion chamber efficiency and energy captured from the exhaust gas led to a new cylinder head design. Revised valve angles allowed the cylinder head to be shorter and for the camshafts to be smaller in diameter – a feature of the cylinder heads that benefits both the engine and the chassis. In the RA620, Honda's double overhead camshafts were quite high and wide apart and the valve angle made for a pent-shaped ceiling to the combustion chamber. Bringing the valves lower and closer together yielded a flatter combustion chamber, improving gas exchange and energy from the combustion process, in conjunction with the pre-chamber ignition system.

The improved combustion in the RA621 combustion chambers also reduces exhaust gas enthalpy (the amount of internal energy contained in a compound) fed to the turbine which, in turn, reduces the peak energy recovery potential of the MGU-H. However, the effect on the whole power unit system means this is a better solution overall for Honda and Red Bull Racing.

Although the engine mountings are in a set position, as per the regulations, from the chassis perspective, the shorter block, narrower engine and lower cylinder head height means the engineers can bring the bodywork around the power unit more tightly, aiding overall aerodynamic efficiency.

Honda engineers at the factory in Sakura, Japan also developed a new coating to deal with more heat and different levels of friction inside the engine that was a key enabler to the RA621's revision.

Honda still favoured air-to-air intercooling for the RA621, evident by the large inlet area in the Red Bull roll hoop, feeding both intake air to the compressor and compressed air to the air-to-air cooler mounted over the power unit. Air-to-air charge cooling can be considered more efficient, as the charge air's temperature delta across the cooler core is typically higher than the water-to-air solutions used by the team's closest rival, Mercedes. On the other hand, the temperature can be more inconsistent across the range of car speeds because the cooling is primarily defined by the air mass flow passing through the cooler, rather than a fluid flow rate through the cooling core defined by the coolant pump's speed.

Air-to-air is also inherently a lighter solution since air-to-fluid relies on an ancillary fluid-to-air cooler and demands more plumbing, though it does require more volume for a given amount of work, so arguably air-to-fluid offers an advantage there, which can be significant in terms of the overall aerodynamic package.

Mobil oil

Red Bull Racing's fluid partner, Mobil 1, was also instrumental in the improvement of the RB16B's performance. A new engine oil with a unique molecular composition was produced specifically for the RA621. The primary improvement metrics for the new oil formulation are delta in thermal conductivity and heat capacity per molecule of lubricant. Both are critical to getting heat out and releasing the heat as the oil passes through a heat exchanger quickly and efficiently without increasing the volume of oil in the engine. Mobil 1's new formulation could withstand significantly higher temperatures than its predecessor, providing substantial advantages for designing other parts of the car, helping improve the car's packaging volume and aerodynamics.

The [Honda] RA621 saw architecture changes to major elements such as the block and cylinder head, resulting in a smaller and more powerful power unit than the 2020-spec RA620 it replaced

The oil also helped push the performance limit of the engine higher as it contained more stable compounds that reduced the risk of low-speed pre-ignition.

In performance, the RB16B was competitive with Mercedes on power during 2021 and, in contrast to 2020, could often deploy for longer on the straight, though the difference was small. It also suffered less performance degradation at high mileages than the Mercedes, with team boss, Christian Horner, noting the delta between a brand new and end-of-life power unit was in the order of 0.1s of lap time. Indeed, Verstappen needed to take just one extra engine over the seasonal allocation of three, and that was only because one suffered a cracked block after his Silverstone crash.

Champions!

Celebrating the best of international motor racing in 2021

By ANDREW COTTON

FIA World Endurance Championship

Drivers
Mike Conway, Kamui Kobayashi, Jose Maria Lopez
Team
Toyota
Car
Toyota GR010

Mike Conway, Kamui Kobayashi and Jose Maria Lopez took victory in the FIA World Endurance Championship, opening the Hypercar era of endurance racing with their second title together.

Driving the Toyota GR010, which also dominated the overall results from the start, the trio started the season third at Spa after Kobayashi went off, finished second at Portimao in June, and then won at Monza as their team mates Brendon Hartley, Kazuki Nakajima and Sebastien Buemi hit problems with debris blocking a fuel filter. They then followed that with a further win at Le Mans despite a similar fuel filter system problem. The trio powered to victory in the first of two races in Bahrain and finished five points clear of their team mates.

The Hypercar regulations mean the car is larger in all dimensions than the old LMP1 cars. The GR010 is also162kg heavier than the LMP1 and has 32 per cent less power, so lap times were slower this year. The 2021 car was powered by a 3.5-litre, 24-valve, turbocharged V6 petrol engine with direct fuel injection that produced 500kW of power from a combination of ICE and a hybrid drive system that, on its own, was capable of making 200kW. The delivery of electrical power was free around the lap, the only stipulation being that total maximum output could not exceed 500kW. The GR010's four-wheel drive was disabled up to a certain speed in the wet to help balance it against its two-wheel drive opposition. The car had a seven-speed gearbox, ran on Rays wheels and used Akebono brakes.

XPB

FIA Formula E World Championship

No fewer than 13 drivers entered the final race of the 2020 / '21 season with a chance of becoming champion, but Nyck de Vries came through to take the coveted crown in Berlin.

Two of the protagonists were taken out at the start when Mitch Evans failed to get off the line and was hit by Edoardo Mortara. Jake Dennis then contacted the wall before the red flag came out for the start line crash. As others crashed out, De Vries came through to take eighth place, enough to be crowned champion driver, while Mercedes won the teams' title. However, during the year the German manufacturer confirmed it would withdraw from the series in order to focus on its Formula 1 activities.

The Generation 2 car was introduced in 2018, and was a step change in performance, allowing teams to compete for a full race without the need to swap cars in order to complete the distance. The new cars were faster, with power rising to 250kW and top speed increasing to 174mph, used a Brembo braking system and a chassis by Spark Racing Technology, the sole supplier.

The Generation 3 car was unveiled towards the end of the calendar year, after the 2020 / '21 racing season, with power further increased to 350kW in qualifying, and 300kW in the race, while regen' will increase to 600kW from front and rear axles. The battery will be designed to handle flash charging, meaning in-race charging will be available for the first time.

Spark Racing Technology will continue to supply the chassis and front-axle MGU, while Williams Advanced Engineering will provide the battery and Hankook will take over tyre supply from Michelin.

Driver
Nyck de Vries
Team
Mercedes-EQ
Car
Spark SRT05e

Andrew Ferraro

NASCAR

Getty Images

Drivers
Kyle Larson
Team
Hendrick Motorsports
Car
Chevrolet
Camaro
ZL1 1LE

Kyle Larson made the most of his one-year deal with Hendrick Motorsports to take the title, but it was a slow start to the season. A top-10 finish at the Daytona 500 was followed by some awful races, including overheating at Talladega three laps in, due to the team leaving in some transport packaging.

Larson and the team rebounded after that, though, with a series of second-place finishes until the Coca-Cola 600 when he won for the first time this season. That was to be the first of 10 wins this year, a season in which he finished with a total of 20 top five finishes, 26 top 10s and the drivers' title.

Towards the end of the year, the series confirmed its Gen 7 cars that will take to the track in February 2022 at the Daytona 500. The new cars will replace the Gen 6 cars that have competed since 2013, and feature all-new aerodynamics, gearboxes and wheels. Testing is continuing throughout January for the Chevrolet, Ford and Toyota teams.

WRC

Driver
Sebastien Ogier
Team
Toyota Gazoo Racing
Car
Toyota
Yaris-WRC

Five wins from 12 rallies ensured that Sebastien Ogier won the World Rally Championship for Toyota, defeating Elfyn Evans, who won twice and finished on the podium a further five times.

Making a perfect start to his season, Ogier won the opening rally in Monte Carlo, but a non-points finish in Finland brought other drivers into the mix. Three wins in the next four rallies, coupled with a third place in Portugal, put him back on track, while a further win at the final round in Italy secured Ogier his eighth title in nine seasons. It was a fantastic end to a career in full-time rallying, and Ogier celebrated by testing Toyota's Le Mans Hypercar at the end of the season.

Toyota also secured the manufacturers' honours for the first time since 2018, having won nine of the 12 rounds.

WRC technical regulations stipulate 1.6-litre, direct injection, turbocharged power units and all cars, including the title-winning Yaris WRC, make use of inline, four-cylinder, transverse engines limited by 36mm air restrictors. Six-speed gearboxes deliver around 380bhp and 425Nm of torque to the four-wheel drive system, and the cars run 15-inch tyres on gravel, 18-inch tyres on tarmac. All use Pirelli tyres.

The winning Yaris WRC was based on the 2020 configuration car, but featured significant upgrades, including aero developments through the year.

IMSA

Drivers
Felipe Nasr,
Pipo Derani
Team
Action Express
Car
Cadillac DPi-V-R

Felipe Nasr and Pipo Derani emerged from a hard-fought season to take the drivers' title in the IMSA WeatherTech Sportscar series, inching ahead of the Acura of Ricky Taylor and Felipe Albuquerque in the final race, the Petit Le Mans in November.

For Cadillac, it was its first manufacturers' title, finishing 113 points ahead of Acura, which has won the previous two seasons.

The Whelen Cadillac that powered Derani and Nasr to the title is based on the carbon fibre Dallara chassis, fitted with Xylon panels to increase side protection. The car was introduced in 2017, and has performed better as a Cadillac in IMSA racing than as an LMP2 car.

Dallara, ORECA, Multimatic and Ligier were all selected to provide LMP2 cars, and IMSA allowed its manufacturers to base their DPi cars on these, fitting their own engines and creating bodywork that carried brand styling cues. The final designs were run in the Windshear full-scale wind tunnel to complete the performance balancing from an aero perspective, while engines were dyno tested to ensure parity.

Dallara was not allowed to cure the handling imbalance the LMP2 version of the car suffered when manufacturers were allowed to introduce a joker package mid-way through the homologation process, a decision that was seen as a contributory factor to the LMP2 arena being largely being dominated by ORECA chassis. However, the Cadillac has proved itself a force to be reckoned with in DPi ever since its introduction.

The Cadillac is powered by a 5.5-litre engine that was first introduced in 2018, built by ECR. The power unit replaced the 6.2-litre version GM debuted in 2017, but which series organisers struggled to control using Balance of Performance.

Like all the DPi cars that raced this season, the Cadillac features Xtrac's 1159 six-speed gearbox and carries Brembo brakes.

Michelin has extended its contract to supply control tyres to the series for a further five years, locking out any chance of opening up the competition. That's needed, however, as the new Prototypes, which will be called LMDh, will be introduced at the Daytona 24 Hours in January 2023, and performance balancing will need to take place with entirely new machinery.

Peter Burke

BTCC

Jakob Ebrey

Driver
Ash Sutton
Team
Laser Tools
Racing
Car
Infiniti Q50

Ash Sutton claimed his third championship title in the British Touring Car Championship, having defended a 32-point advantage heading into the final race meeting of the season. A top-six finish in the first two races were enough for him to claim the title, and he went on to finish his season with a victory, also retaining his Independent Drivers' crown behind the wheel of his Infiniti Q50.

Sutton's season saw him take five wins, four podium finishes, one pole position and 29 point-scoring finishes from 30 races.

The cars are all built to the Next Generation Touring Car (NGTC) regulations that allow independent teams to compete on a level playing field with manufacturers. Common parts include the turbo, wastegate, intercoolers, ECU, instrumentation and dash, power management system, six-speed sequential gearbox from Xtrac, fuel tanks from ATL, differential, subframe from RML, steering, AP Racing brakes, clutch, Rimstock wheels and SPA Penske dampers and suspension.

The Infiniti was powered by the 2.0-litre, turbocharged, TOCA engine, supplied by Swindon Powertrain, and produces 350bhp with fly-by-wire throttle.

Australian Supercars

Driver
Shane van Gisbergen
Team
Red Bull Ampol
Car
Holden Commadore ZB

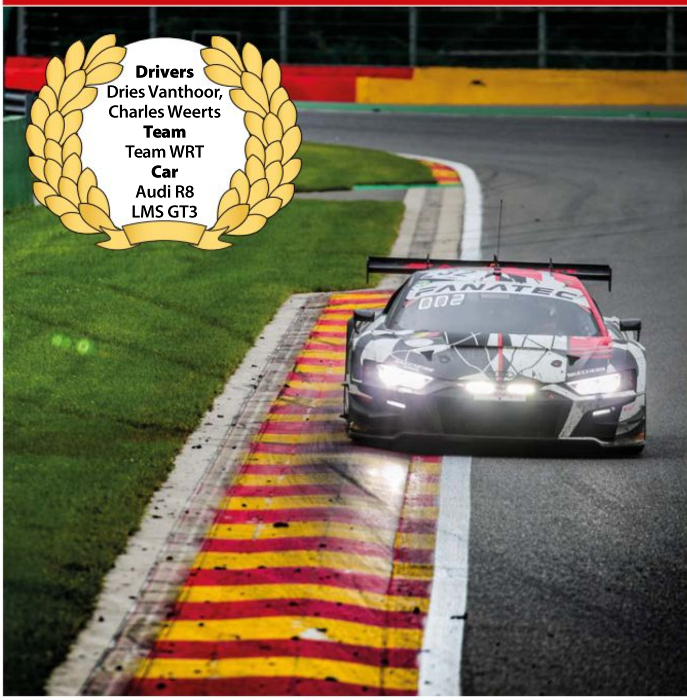
Shane van Gisbergen took the 2021 Repco Supercars Championship, having won 14 races from 30 starts to wrap up the title before the end of the season. Driving for the Red Bull Ampol Racing team, van Gisbergen finished the year 211 points clear of his retiring team mate, Jamie Whincup. He only missed out on the top 10 three times in the 30 races in which he competed, including a puncture at Bathurst, a slow pit stop in Darwin and a pit stop infringement in Sydney. However, he had won the first six races of the season and used that solid platform to build his second title-winning season.

Powered by a twin-turbo V6, the car was developed by Triple Eight Engineering in Brisbane. The Supercars are all based on a common spaceframe and have a 2822mm wheelbase, defined engine location, suspension points, front undertray position and rollcage. Pedal box, brakes, rear suspension and Albins transaxle are also identical throughout the field. The biggest area of technical design freedom is in the double wishbone front suspension set-up. With wind tunnel testing banned in the series, Holden worked with Wirth Research in the United Kingdom to develop the aerodynamic package for the car.

Towards the end of the year, the Supercars' organisers released details of its Gen 3 cars that will debut in 2023. These will feature Chevrolet, with the Camaro ZL1 that will replace the Commodore ZB, and Ford with the Mustang.

Mark Horsburgh/Red Bull

GT World Challenge



Drivers
Dries Vanthoor, Charles Weerts
Team
Team WRT
Car
Audi R8 LMS GT3

SRO/Jules Benichou

Team WRT won the Fanatec GT World Challenge powered by AWS, having scored consistently across the Sprint and Endurance elements of the season.

Audi drivers, Dries Vanthoor and Charles Weerts, didn't win at the Spa 24-hours when Vanthoor's wet-weather tyres lost their edge on a dry track before a storm hit, and that allowed Alessandro Pier Guidi to win for Ferrari, but they did win Sprint races at Magny Cours, Misano and Brands Hatch. In the endurance series, they won at Paul Ricard, sharing with Kelvin van der Linde, then came second at Spa and scored a podium at Barcelona, which was enough to comfortably take the overall drivers' and teams' titles.

The Audi R8 LMS GT3 has been the mainstay of the German manufacturer's customer racing programme for years now, and this evolution was introduced in 2019. The aluminium-chassised car shares its platform with the Lamborghini Huracan that also competes in the GT World Challenge, and is powered by a 5.2-litre V10 engine. It weighs 1225kg in basic trim, but is performance balanced and so race weight changes according to series' requirements. Suspension is double wishbone, with Öhlins dampers. Mid-year, Audi unveiled a mild upgrade to the car for introduction in 2022, including a newly hung rear wing and upgraded suspension package.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Super Formula

Driver
Tomoki Nojiri
Team
Team Mugen
Car
Dallara SF19
Honda M-Tec
HR-417E

Tomoki Nojiri secured the drivers' championship title with a round to spare, the first driver to achieve the feat since Loic Duval in 2009. The Japanese driver won three races in 2021, and picked up points in a further three races. Fifth place in the penultimate race was enough for him to claim the title behind the wheel of his Mugen-powered Dallara.

The Super Formula racecar is a Dallara SF19, powered by a 2.0-litre, turbocharged, inline four cylinder with direct fuel injection, supplied by either Toyota or Honda. Turbos are provided by Garrett, while power limitation comes from a fuel restrictor.

The six-speed gearbox is from Ricardo, brakes are by Brembo and KYB provides the cars' electric power steering system. Yokohama has been tyre supplier for the series since 2016 through its ADVAN brand.

Mid-season, the series launched a new initiative, Super Formula 50, which will look to build a sustainable motorsport industry from 2022. The new Super Formula series will, it says, be a 'mobility and entertainment testing ground' and will run test cars equipped with technology that is still undergoing development, using the series as a testing ground for its support.

Honda and Toyota will test new powertrains, chassis, tyres, materials and fuel solutions in a bid to become more carbon neutral. The series has so far targeted e-fuel, biofuel and a bio-composite chassis derived from plants and other natural minerals, all of which will be seen on track from the 2022 season onwards.

'As further technical developments are made for other items, and tests are conducted, we will look to be able to include them in the next generation of formula cars,' says the series' press release.

IndyCar

Driver
Alex Palou
Team
Chip Ganassi Racing
Car
Dallara DW12
Honda

Gavin Baker

Alex Palou became the first Spanish champion of the American IndyCar series when he finished fourth in the final round of the 2021 season, scoring enough points to see off Josef Newgarden and claim the title for the Chip Ganassi Racing team.

Palou won three races this season and went into the final race needing only to finish 12th or better to claim the title, regardless of what his competitors achieved. However, when his nearest rival, Pato O'Ward, stopped with damage to his car, the title was well within his grasp.

IndyCar has yet to confirm the specifications of the next chassis to replace the now-aged DW12. Built by Dallara, using PFC brakes, an Xtrac gearbox and Firestone Firehawk tyres. The 2021 cars were powered by 2.2-litre, V6, twin-turbo engines from Honda and Chevrolet, but these will soon change to include a hybrid system.


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WORLD CHAMPIONSHIP TITLES, AND COUNTING

FIA World Rallycross Championship

Johann Kristofferson took his fourth FIA World Rallycross Championship title at the end of a sensational season, claiming the crown on count-back having tied on points with rival, Timmy Hansen. The Audi S1 driver went into the final round 17 points behind Hansen, but a third win of the year in the opening race was accentuated by Hansen being disqualified, which reduced the gap to just four points. By the time they lined up for the finale, they were separated by a single point, and, despite help from his brother, Kevin Hansen, up front, Timmy was unable to take the title from his rival.

At the FIA World Council in December, it was decided to introduce a number of key regulation changes for the WRX series. In the future the weekends will start with a SuperPole shootout after free practice, which will require all competitors to complete a timed lap from a standing start. This will decide the grid for heat one, replacing a draw. Single-header events will comprise three heats, double headers will be two heats and finishing order will determine the grid for the following heat.

All drivers will then enter a Progression race, in which the highest-ranked driver will choose their grid slot first. The top 10 will then advance to the semis, the top five to the finals.

Driver
Johann Kristofferson
Team
KYB EKS JC
Car
Audi S1

Michael Jurtin

FIA Formula 3 Championship

Driver
Dennis Hauger
Team
Trident
Car
Dallara F3 2019


XPB

DTM

XPB

Driver
Maximilian Goetz
Team
Haupt Racing Team
Car
Mercedes AMG GT3

W-Series


XPB

Driver
Jamie Chadwick
Team
Veloce
Car
Tatuus F3 T-318

WEC GTE Pro


XPB

Drivers
James Calado, Alessandro Pier Guidi
Team
AF Corse
Car
Ferrari 488 GTE

Formula 2

Driver
Oscar Piastri
Team
Prema Racing
Car
Dallara F2 2018


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Two mile high club

Developing a Pikes Peak winner

By JAMES KMIECIAK

Figure 1: 2021 Pikes Peak Winner

The Sendy Club

In June 2019, Robin Shute became the first British driver to win outright at Pikes Peak, Colorado, the gruelling, 12.42-mile mountain course that winds its way up through over 150 corners from a start line at 9390ft above sea level to a finish line above the clouds at 14,115ft.

As a quick reality check on those heights, that means it starts at a point twice as tall as the UK's highest mountain, Ben Nevis, and finishes at a point just below Base Camp on Mount Everest.

Pikes Peak International Hillclimb is a far cry from the venues we find in the hotly contested British Hillclimb Championship, where competitors regularly see a finish line below the 2400ft mark and have significantly less corners to contend with on the way there. If we go one step further and look at Robin's home county of Norfolk, its highest peak being Beacon Hill, all of 344ft above sea level, it becomes an even greater example of how far removed competing at Pikes Peak is to anything racers can expect to find in the UK.

Prior to 2011, the last section of the road was loose gravel, and consequently favoured cars that resembled heavily modified rally cars with all-wheel drive, longer suspension travel and significant upper surface aero appendages to maximise cornering speed and aid traction under hard braking and acceleration, while coping with wildly varying ride heights. Since then, though, the course has become one continuous tarmac ribbon all the way to the top, and cars have become more akin to those found on a circuit, with lower ride heights, shorter suspension travel and more emphasis on controlling the aero platform nearer the ground.

As the road still follows the original trail, it isn't like the billiard table smooth circuits of most FIA events. Some of the hairpins have significant camber and gradient changes that can destroy overhanging aero devices and floors, while the upper sections have bumps that make it look like they have draped a thin tarmac blanket over a motocross track. Look at the YouTube video of Shute bouncing across the finish line in 2019 if you need proof.

Into thin air

On top of the difficult road surface, cars have to deal with the altitude. The air is thin there, and it keeps getting thinner. As a reference, with a car at sea level we can expect air density to be around 1.2kg/m^3. At the start line in Colorado, when temperature, humidity and altitude are taken into account, we are likely to see air density already depleted to 0.85kg/m^3. So, before the attempt on the peak has even started, we have lost around 30 per cent of the oxygen required for the engine to create power, and have 30 per cent fewer air molecules to push the wings into the track and create meaningful downforce.

The Sendy Club

The team's Wolf GB08 CN car has been heavily modified by The Sendy Club for hillclimb use, and so is now known as the Wolf-TSC

As a reference, with a car at sea level you can expect air density to be around 1.2kg/m^3

Table.1: Times comparison and average speeds

Year	Driver	Car	OA Time	Avg MPH	ΔOA Time	Δ per Mile
2019	Robin Shute	Wolf TSC	9m12.476s	80.92	-	-
*2019**	*Robin Shute*	*Wolf TSC*	*8m35s*	*86.82*	*37.48s*	*3.02s*
2013	Sebastien Loeb	Peugeot 208 T16	8m13.9s	90.53	21.096s	1.69s
2018	Romain Dumas	VW-IDR	7m57.148s	93.72	37.848s	3.045s

As the car crosses the finish line, we can expect to see air density drop again to something near 0.72kg/m^3. This is 15 per cent lower than when we started our climb and almost 40 per cent less than at sea level.

The only upside of this drop in air density is drag reduces rapidly too, meaning we are pushing less air out of the way to go fast. This also means that, like climbing Everest, drivers use personal oxygen supplies to keep them from losing focus and falling off a cliff, both metaphorically regards performance, and physically because of the precipitous edges along parts of the track.

Even with the reduction in downforce and horsepower, cars will regularly see speeds in excess of 140mph up the mountain, and average speeds of over 80mph for the whole course. Shutes' average speed in 2019 came in at 80.92mph over the full course, which produced a winning time of 9m12.476. To put that into context, the outright Pikes Peak record came in 2018, courtesy of Romain Dumas, driving the factory-supported, all-wheel-drive, all-electric, heavily aero-dependent Volkswagen-I.D. R to a reality warping time of 7m57.148, with an average speed of 93.72mph.

It can be argued the majority of this time came from the car's electric drivetrain that suffers significantly less than an ICE at altitude, but the car was still monstrously fast.

One factor that did have to be taken into consideration for our calculations were engine issues during that 2019 run that meant Shute was expecting to cross the line around the 8m30 mark, as per his combined practice times, giving a more realistic average speed of 86.82mph.

So, the next logical step is to look at the fastest ICE record for comparison. This came from WRC driver, Sebastien Loeb, in 2013, who took a bi-turbocharged, all-wheel-drive, ground-effect Peugeot 208 T16 up the mountain in a time of 8m13.9, with an average speed of 90.53mph. Putting this into context, **Table 1** shows the overall comparisons between the three cars, with Shutes' Wolf-TSC (corrected time) being 37.84 seconds slower over the 12.42-mile course than the VW and 21.096 seconds slower than the Peugeot. Breaking this down to bite size chunks, Shute was losing ground at a rate of 3.04 and 1.69 seconds per mile respectively.

This meant looking at the aerodynamics of the car and trying to find where the team could find those missing three seconds per mile to go for the outright hill record. So let's introduce the car and team.

The Sendy Club

The car is developed and run by joint owners, Robin Shute and Matt Sampson. Both are automotive engineers based in California, USA working for Arrival. They run the car with an independent team of professional engineers, friends and technical partners who predominantly volunteer each year to prepare the car in readiness to run on the mountain. Collectively, they call themselves The Sendy Club.

The car itself started life as an early Wolf GB08 in FIA CN specification, powered by a naturally aspirated, 2.0-litre, Honda K20a four-cylinder petrol engine producing around 250bhp and 240Nm of torque. Mated to a six-speed sequential gearbox, this potent combination gives the car a top speed of around 160mph with the CN-specification aero package.

However, as the car has been heavily modified for hillclimbing by The Sendy Club, it has evolved into the Wolf-TSC. And for 2019, it had already undergone a significant amount of development for its attempt on Pikes Peak. Gone was the original enclosed front bodywork in exchange for a custom made, triple-element front wing manufactured by DJ Racecars in the UK.

The rear bodywork was cut away to provide space for a horizontally-mounted intercooler and ducting that was plumbed into the Borg Warner EFR 8474 turbocharger and over bored (now 2.1-litre) K20a powerplant, tuned to produce 600bhp and 550Nm of torque on VP Racing Fuels' Q16.

With an all-carbon tub, floor and bodywork, the car weighed in around the 600kg mark, meaning it also hit the magical 1:1 ratio of bhp per kg.

The original rear wing swan neck mounts were retained, but now hung a substantial dual-element wing with SM203 main plane and SM170 flap, capped off with significantly larger end plates.

Finally, a heavily braced front and rear hooped rollcage had to be mounted over the cockpit as per regulations. This climbing frame-style structure puts a notable piece of steel high above the c of g and directly in the rear wing's airflow, which is bad for chassis dynamics and worse for aerodynamics, when compared with the integrated factory part, though it would pay its dues in the event of a 'minor' off-mountain excursion. The whole package ran on Pirelli rubber.

Tuned by Mountune

After the 2019 event, the team further developed the 2.1-litre engine with Mountune USA, and a custom turbo courtesy of Borg Warner improved the torque curve. The existing intercooler was to be re-housed in a more conventional manner within the sidepods and a smaller and more efficient core design implemented by PWR. A larger inlet filter was also installed as the restrictive nature of running an air filter designed for 14.7psi inlet pressure at sea level when having to deal with an operating inlet pressure between 8-10psi at altitude was hurting engine performance in every sector.

With all these modifications, the engine was now producing 650bhp and 550Nm torque, and development focused primarily on creating a broader torque curve to improve driveability and acceleration out of tight corners, in a similar way to that seen in rally car engine development, further demonstrating the hybrid nature of a hillclimber.

2020 aero development

As the world plunged into the global Covid pandemic, the 2020 Pikes Peak Hillclimb was delayed and eventually ran behind closed doors in late September. With transportation and travel restrictions in place, and the car 4500 miles away from Colorado in its Norfolk, UK workshop, the team decided to focus on preparing for the 2021 event, which allowed time to take a deep dive into the car's aero package, with the help of Black Art Customs.

The Sendy Club

Car's carbon rear bodywork has been cut away to make space for extensive intercooler and turbo plumbing

After the 2019 attempt, the Honda K20a engine was further developed by Mountune USA and fitted with a custom Borg Warner turbo

The first stage was to correlate and evaluate the existing 2019 aero package, so a representative CAD model (**Figure 4**) was created from numerous laser scans, as well as photos, sketches, hand measurements and existing CAD data (**Figure 6**). Suitable ride heights and rakes were then applied and the car run several times at 100mph in CFD to generate reliable baseline values for downforce, drag and balance.

As can be seen in **Table 2**, the baseline figures showed the car had around 5738N of downforce and 2010N of drag at sea level, giving it an estimated top speed of 162mph. With the corrections for altitude applied to engine power and drag force, the data was overlayed with that recorded from Shutes' 2019 run. We could immediately see that these values lined up pretty well with what had been recorded.

With an all-carbon tub, floor and bodywork, the car came in around the 600kg mark, meaning it also hit the magical 1:1 ratio of bhp per kg

Looking at suspension plots and confirming with the driver's well-calibrated 'seat sensor', it was confirmed the CFD predicted balance of 40.9 per cent front, 59.1 per cent rear was very close. This gave the

Table 2: CFD comparison of downforce and drag vs 2019 car

Modification	Downforce (N)	Drag (N)	-L/D	% Front	% Rear	VMax (mph)
2019 Baseline	5,738	2,010	2.855	40.90%	59.10%	162.14
Conventional IC Position	5,730	1,951	2.937	37.20%	62.80%	163.74
Remove Front Wheel Mount Pods	5,800	2,022	2.868	40.20%	59.80%	161.83
Enclosed Rear End	6,691	2,127	3.146	36.00%	64.00%	159.11
2021 Interim Car	9,291	2,674	3.475	38.80%	61.20%	152.69

All images: Black Art Customs unless otherwise stated

Figure 4: CFD CAD model developed during 2020 to prepare for running in the 2021 event

Figure 5: Scan data from existing bodywork panels in the 2019 aero configuration

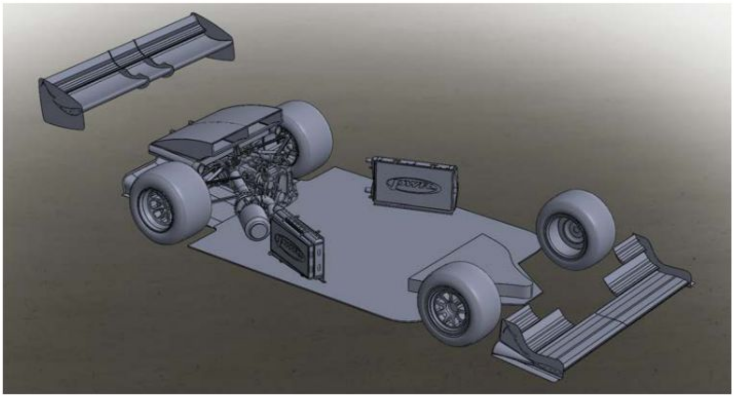

Figure 6: Existing CAD model of floor and main aero elements

2019 winning car a very reasonable lift-to-drag (-L/D) ratio of 2.85:1.

For reference, when we take into account the estimated corrections for altitude, the 5738N downforce seen at sea level rapidly reduces to 4064N at the start line around 9000ft, and drops further to 3443N as the car crosses the finish line around 14,000ft. That means the car loses over 100kg (220lbsf) of downforce in its run to the top.

Looking at figures floating around of the VW I.D. R producing upwards of 10,000N at altitude ('over 2,200lbsf' quoted by VW), we could assume this is taken at its average speed of 93.72mph and then averaged over the entire run between 9390ft and 14,115ft. This suggests that at sea level it is producing around 13,500N of downforce against our 5738N. So, at the start line it has 9562N vs our 4046N, and across the finish line, where we are also likely to have less horsepower as our engine struggles to ingest enough oxygen, we are down to 3443N against the VW's 8100N (see **Table 3**).

As neither Volkswagen or Peugeot will publish their aero figures, further estimations using available data on similar ground effect cars are used to figure Loeb's 208 T16 aero numbers and find a sensible value for the VW's drag. From the associated data, it could be safe to estimate the VW's -L/D ratio would be around 5.5:1, giving it a reasonable value for drag of 2455N at sea level. Using the same information, we could assume the Peugeot has a similar ballpark figure of 2500N for drag, as what it lacks in rear wing frontal area it makes up in overall frontal area thanks to its hatchback-style bodywork. This road car-derived body would normally be an inefficient shape compared to that of a Sports Prototype associated with the Wolf-TSC and VW I.D. R, but with its sculpted underfloor and huge front splitter it's safe to assume it is producing significant downforce at 100mph, and likely has an -L/D ratio of around 3:1. That gives it around 30 per cent more downforce than the Wolf-TSC and 45 per cent less than the VW I.D. R.

Target 2021

After that segue into the wonderful world of reverse engineering, the potential downforce figures of our competitors – based on limited information from dubious sources – means we could now calculate suitable values for improving the 2019 car, and set a target for the 2021 car's aerodynamic platform to be capable of competing for the outright record.

Table 3: Comparison of downforce and drag vs altitude

Year	Driver	Car	-L/D	Sea Level		Start Line c.9390ft		Finish Line c.14,115ft	
				Downforce (N)	Drag (N)	Downforce (N)	Drag (N)	Downforce (N)	Drag (N)
2019	Robin Shute	Wolf TSC	2.85	5,738	2,010	4,064	1,424	3,443	1,206
2013	Sebastien Loeb	Peugeot 208 T16	3	7,500	2,500	5,312	1,771	4,500	1,500
2018	Romain Dumas	VW-IDR	5.5	13,500	2,455	9,562	1,739	8,100	1,473

As the car is a lot more than just the aerodynamic platform, Shute ran numerous scenarios of chassis, engine, tyre and aero configurations through his own lap time simulation software to confirm we needed at least 40 per cent more downforce at an -L/D ratio around 3.5:1 to be in with a shot at the title. This equates to 8033N downforce and 2295N of drag at sea level, which meant finding over 200kg of downforce at a rate of 10:1 to achieve less than 20kg of drag over the current package.

First item to be modified, then, was the intercooler. Removing the large rear cowl (**Figure 7**) and repositioning the intercooler more conventionally in the sidepods (**Figure 8**) saw the drag drop by 2.9 per cent and a 3.7 per cent reduction in rear lift due to the high curvature of the cowl's upper surface and cleaner flow reaching the rear wing. Unfortunately, it had no overall change in downforce as it lost the same percentage off the front floor and wing due to the base pressure behind the car now being higher, which reduced the velocity of the air being drawn under these surfaces.

To reduce mass, and hopefully remove another apparent area of lift, the wheel pods from the original Wolf front end were removed. This opened up a large flat surface behind the wheels and saw a 1.1 per cent increase in downforce to 5800N at the sacrifice of more drag, evidenced by the yellow leading edge of the radiator intake shown in **Figure 9**.

The modifications so far had made negligible impact on our 40 per cent target for downforce, but did have significant impacts on c of g position and mass reduction, with over 10kg of excess weight shed that was inconveniently sat above the engine crank centre line. At least the chassis guys were having a good day. Time to bring the performance bias back towards the aero department and ruin it for them.

The original Wolf had a fully enclosed rear end, as per CN regulations, and in line with most Sports Prototype, closed-wheel categories. With this re-fitted (**Figure 10**) the downforce jumped up 16.6 per cent over our 2019 baseline, while drag took a step up by 5.8 per cent to give us a healthy 6691N of downforce and 2127N of drag at an -L/D of 3.146:1 and a rearward balance of 33.8 per cent front and 66.2 per cent rear. Admittedly, this came at the expense of adding the 10kg+ back that we had just taken off, thus returning the car to its original weight.

An interim solution

Over the next 60 iterations we trialled a vast range of modifications including end plates, rear deck Gurney flaps, front wing Gurney flaps, triple-element wings, biplane wings, various diffusers, various strakes, semi-enclosed front ends and a modified version of the original, fully enclosed front end that worked well but was quickly discarded due to weight concerns over the front axle.

Removing the large rear cowl and repositioning the intercooler more conventionally in the sidepods saw the drag drop by 2.9 per cent and a 3.7 per cent reduction in rear lift

One thing was clear from the analysis: we really needed to go full ground effect. The issue we faced with this was more logistical than technical. It was now early 2021 and the car was still in the UK. It had to be shipped to the US so the team could fit the updated aero and chassis modifications, along with installing the new engine, turbo and cooling package. Optimising a new ground effect floor was not on the cards if it was to be fitted and tested prior to the June 2021 deadline, meaning the car had to run with existing, off-the-shelf, or easy to manufacture parts. As such, an interim car was born.

Dubbed the TSC-Long Tail, or LT, the 2021 car arrived late at Pikes Peak having sat for two weeks outside Zeebrugge in Belgium, before having to be hauled across America from New York to Colorado by truck, and then

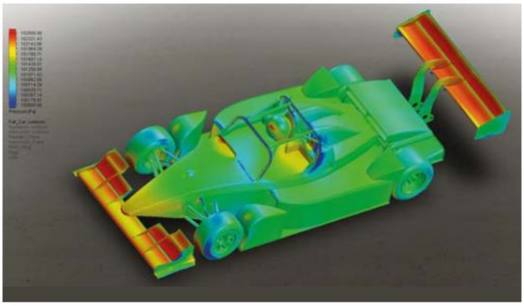

Figure 7: Pressure plots of 2019 car with horizontal, rear-mounted intercooler

Figure 8: Pressure plots with conventional intercooler siting in the sidepods

Figure 9: Pressure plots with front wheel pods removed

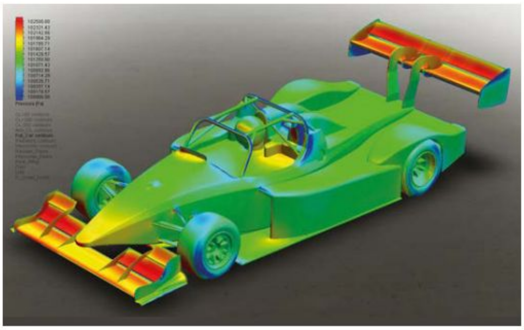

Figure 10: Pressure plots with enclosed rear bodywork fitted


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Figure 11: The 2021 interim aero package gave rise to the name TSC-Long Tail

OMNI41 Designs

The total combined improvements of engine, turbo, chassis and aero had gained us around 1.6s per mile, meaning we were now in the hunt for that record

completed and dyno run at the workshop. The team worked 24/7 for the week prior to the event, the car only turning a wheel at 6pm the evening before first qualifying.

The interim aero package, as shown in **Figure 11**, consisted of a modified front wing set up with optimised angles, heavy use of Gurney flaps (**Figure 12**) and modified end plates to boost front downforce while keeping mass down. It ran a modified flat floor with increased rake and tweaked profiling coupled to a lower beam wing, *à la* Jaguar XJ-14/16, to help drive the whole floor harder and increase overall downforce (**Figure 13**).

With the interim modifications applied, we saw a 64.6 per cent improvement in aero performance from our initial 5738N of downforce to 9291N. This did, however, come at a 32.3 per cent increase in drag from 2010N to 2674N, giving a final -L/D of 3.475:1.

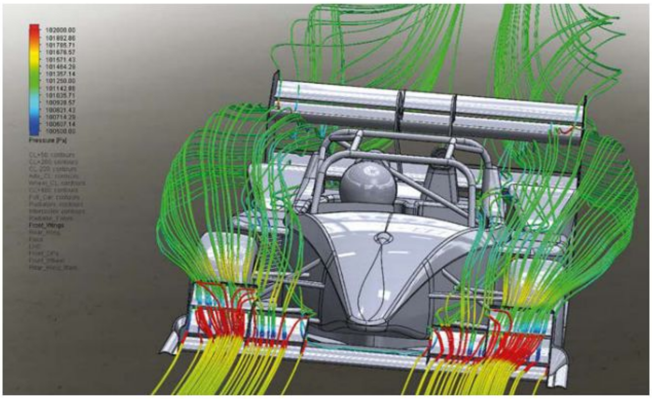

Figure 12: 2021 interim aero package streamlines, showing extensive use of Gurney flaps and modified end plates

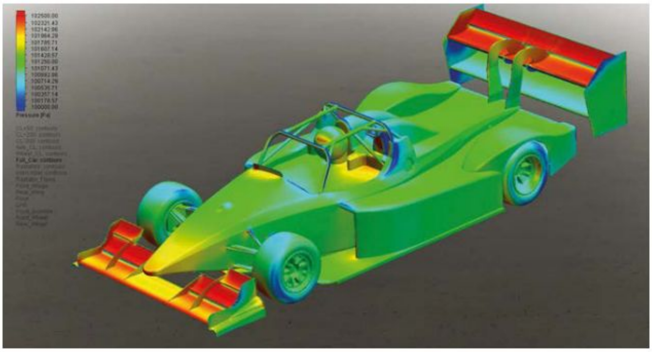

Figure 13: 2021 interim aero package pressure plots showing increased overall downforce

One thing was clear from the analysis: we really needed to go full ground effect

So, we had piled on the 'down pounds' a a rate of 5.35:1 against drag, and that meant we had smashed our downforce target, finding over 360kg of downforce, but exceeded our drag target by 38kg. It was a good job we now had that extra 50bhp!

Road closed

In the event, the 99th running of the Broadmoor Pikes Peak International Hillclimb saw the top section of the mountain closed, meaning there was no chance of anyone going for a hill record. In truth, this came as something of a blessing as a lack of testing and set-up time showed the car would squat down heavily and over accentuate the rearward aero balance, giving it significant understeer up the shortened course.

This, combined with the minor issue of Shutes' oxygen supply not functioning as it should meant he could still breath at the nine-mile finishing mark, some 12,000ft up, in a time of 5m55.246 at an average speed of 94.143mph – the fastest average speed ever recorded up 'America's Mountain'.

However, what all this showed us was the total combined improvements of engine, turbocharger, chassis and aerodynamics had gained us around 1.6s per mile, meaning we were now in the hunt for that record. After the brief but heavy celebrations of a job thoroughly well done, The Sendy Club went back to the drawing board, with the aim of improving the chassis and powertrain in readiness for the next attempt in 2022, while we started reviewing the run data and began developing the full ground effect challenger with enough downforce that, to partially quote Guy Martin, 'would suck Marmots out of hedge bottoms as we pass.'

Racecar's *thanks to Robin Shute and The Sendy Club for their time, and Black Art Customs Ltd for all the data*

Unbranded awareness

Swindon Powertrain provided a unique service to the British Touring Car Championship for 12 years, supplying an unbranded engine

By ANDREW COTTON

All images: Jakob Ebrey Photography courtesy of the BTCC

Ash Sutton (left) won the BTCC for a second consecutive year behind the wheel of his Laser Tools Infiniti, powered by the TOCA unbranded engine supplied by Swindon Powertrain

The final round of the British Touring Car Championship at Brands Hatch in October 2021 marked the end of an extraordinary era. For 12 years, Swindon Powertrain has serviced a contract that is unique in top-flight racing, providing an unbranded engine to any team or manufacturer that wanted to use it in the championship, and at a cost that was affordable to all.

During the 12-year cycle of the engine it has undergone two major upgrades due to regulation and contract changes, been re-branded as the TOCA race engine, and has achieved every goal that the championship organisers set for it.

During the lifetime of the contract, Swindon's engines have covered nearly 600,000kms, won 119 races, scored 49 pole positions, and powered more than 100 drivers in the championship. There have been title successes too, in the Independents' Trophy in 2012 with James Nash, Independent titles most years, Manufacturer's title with MG in 2014 and overall Drivers' title in 2020 and 2021 in the hands of Ash Sutton.

The company has built and supplied 305 engines to a total of 21 teams, and there is no doubt that the engine concept has played an instrumental role in securing the strength of the series overall.

Next season the BTCC will field 32 cars as TOCA released its three licences in order to meet with demand, making this one of the strongest Touring Car series anywhere in the world.

The initial tender was for a 2.0-litre, turbocharged, four-cylinder engine that was based on a production car unit, to be supplied to any team that wanted to run it. Direct Injection was used as it was common in production cars at the time, and also because it helped the racing series present itself with a more modern image.

Early days

The initial engine ran on KKK turbochargers and produced around 300bhp at a maximum 7000rpm, tested on a TOCA-nominated dyno. Components such as camshafts, pistons, dry sump, inlet and exhaust system were free to develop, and the engine was housed in the New Generation Touring Car (NGTC). Key to the success of the concept was the focus on cost control, and here Swindon Powertrain, which won the tender to supply the engine, had to meet strict criteria. The engine had to be available priced at £23,900 (approx. $31,900) at the time on a year lease with full at-event support.

Swindon Powertrain started its engine programme in 2010 powering just two cars in the BTCC, but that quickly escalated and, by 2015, the company supplied engines to more than half the grid

It was a tall order, and Swindon realised early on that it needed to supply at least seven cars in the series just to break even. For year one, however, its engines only ran in two ex-Triple 8 Vauxhall Vectras, falling far short of the hoped-for target, but that was to be expected as the first season was just the start of a long programme.

'2010 was an interesting period, a difficult period for many businesses,' says Raphaël Caillé, the then newly installed MD of Swindon Racing Engines who had just moved over from Triple Eight. 'Everyone was recovering from the 2008 crisis. I left Triple Eight Race Engineering at the end of 2009 when the business from GM was drying up for them as a result of the financial crisis. At the same time, I took over the business that was with Swindon Powertrain, which was also struggling to recover from the crisis.

'The BTCC was not in a great shape – just 15-18 cars on the grid, and costs were too high. One aspect that was of use to me was that there could not be more entrants at that time because they would have to invest in an engine development programme, which was both very expensive, and high risk.

'There were huge discrepancies in performance and reliability between engines then too, and it seemed as if it was a bit of a lottery, whether your engine package would be a success or failure.

'That was the situation in 2009-2010, and it created an opportunity.'

So, Swindon took the base engine and swallowed the cost of the development, making its powerplant an attractive offer to any team that was interested in competing. The belief at the time was that teams would prefer to take a readily-developed engine over one that came with a development budget attached. But still that was only a medium-term goal for Swindon.

'Our engine had to be extremely cost effective,' says Caillé. 'We were on the back of engine regulations where investment on the engine alone was £250-500,000 and each engine cost £30-40,000.

'The aim of the unbranded engine was to say we have absorbed the development costs, so the teams would not hear about them, and we would slash the cost per mile by 50 per cent. It was an ambitious target, but it was a necessary one to provide to the championship, and it's a target we reached and maintained to the end of 2021.'

Comfort blanket

There was another selling point for the engine. Not only was Swindon to swallow the development costs, it also offered a comfort blanket to those who leased the engine: 'If you look at any championship 20 years ago, you could change the engine after every race and nobody would blink an eye, apart from those paying the bills,' reveals Caillé. 'It was fine, it was allowed, it was what everyone was doing, and as engineers we were not pushed into doing durable solutions. Ultimate performance was all that mattered.

'Now, in the BTCC and many others, you are limited on the number of engines and that means we have to develop a solution that as best possible meets the performance point of view and has durability in it. That changed the way we validate things.

'That allowed us also – a first in motorsport, and still present in 2021 – to introduce a proper warranty. Any team buying or leasing an engine from us is under warranty and, if there is a technical problem with it, the cost is fully covered by Swindon Powertrain. It is a big risk for us, but we took it on, and made it a feature of the product and the programme. It is an incredible asset to the product.'

The aim of the unbranded engine was to say we have absorbed the development costs, so the teams would not hear about them, and we would slash the cost per mile by 50 per cent

Raphaël Caillé, MD at Swindon Powertrain


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Although there was a level of secrecy around the identity of the base engine when it was first released, Swindon says it was a brand new concept, based on a production engine, developed to meet the stringent cost target, while also providing the reliability it would need to service the grid.

'2010 was loss making, but it wasn't supposed to be [for profit],' admits Caillé. 'We were investing in the programme. We also invented a programme that had never existed before, and to this day doesn't exist in any other championship.

'There is not another championship that has an unbranded engine that you can choose to use, or not, as another competitor. So, there was a real novelty.

'By year two, 2011, we reached that seven-car target, and so we were on our way to having a piece of business that started to make sense. We also started to have serious programmes associated with our engine, and so customers who were having good results with our engine.'

Engine development has been ongoing throughout the contract as the unbranded engine had to keep up with the manufacturer engines that were constantly improving. Two significant regulation changes also meant further redesigns were required

Versatile performer

That wasn't an easy task. This was a far more complex engine programme than providing a manufacturer with a straight engine partnership programme. In that case, the engine is bespoke to the car, and the performance targets are slightly easier to reach. The TOCA engine had to service *all* cars in *all* conditions, be they front, rear or four-wheel drive. It also had to accommodate the different cooling layouts each chassis offered, and so it needed to have some wiggle room to fit each of the different cars.

'If, as an engine supplier, you work for one team and then you deal with a budget negotiated with the customer, you work so the benefit to the team is worth the money they are spending,' says Caillé. 'The added difficulty with the TOCA engine is that your product goes into many different cars, which have different engine installations, so cooling and car side of the powertrain. Nevertheless, you cannot adapt to that because the TOCA engine must be the same for every car. That really is an added difficulty.

'If you think about working with one team, working with one car, optimising everything to get the best installed performance is a very straightforward principle and line of work. But keeping that ultimate performance while being able to cope with different types of vehicles adds difficulty.'

In 2011, the BTCC threw another curve ball into the mix when it introduced a spec turbocharger, provided by UK company Owen Developments, which has just had its contract extended to 2026. The introduction of a new turbo charger meant that the new and unbranded engine had to be recalibrated to suit.

That allowed us also – a first in motorsport, and still present in 2021 – to introduce a proper [engine] warranty

Raphaël Caillé, MD at Swindon Powertrain

'A turbocharger has a particular compressor map, so how the turbocharger performs depends on how you use it,' says Caillé. 'The rpm of the compressor wheel [is one aspect], and it depends on the delta pressure in and out of the turbo. This is a crucial aspect that needs to be looked at so the rest of the engine uses the turbo in the best area for efficiency.

'It is all to do with raising efficiency work, so cam profiles, pressure drops… it is a real engineering piece of work.'

Despite this added difficulty, a Swindon powerplant claimed its first BTCC title in the Triple Eight Racing with Collins Contractors Vauxhall Vectra, driven by James Nash, that claimed that year's Independents' Trophy.

The Manufacturers' title in 2014 was secured by MG, powered by a Swindon Powertrain TOCA engine

The 2017 diet

The next change came in 2017 when the engine was put on a diet. More than 5kg was removed from the engine, 420g from the camshafts alone when Swindon opted to use hollow ones for the first time, having designed the original engine with a rather more conservative approach.

The diet also helped revise the c of g downwards, so that made it even more attractive to competitors in the series.

Support for the teams running the cars was also provided by Swindon Powertrain as their engines won multiple titles in various cars

Raphaël Caillé moved from Triple Eight to Swindon Powertrain and spearheaded the TOCA engine programme from the start

'You can't do commercial success without success on the track,' says Caillé. 'We had to develop the engine further year on year in order to remain competitive to increase our customer base. This has been the game that we develop, which is to never sit back.

'We had a contract with the organiser, and we never sat back. We maintained a competitive edge to our work. It is different to the type of work where you supply to a single-make series where your goal is to supply the same to everyone and there is no competitive edge. For Swindon, and supplying TOCA, it was more about [producing] the best technical work to allow our customers to win.'

One other complexity is that engine development is allowed in the BTCC year on year, and so each season Swindon had to improve its product, but was not able to pass on the development cost to the teams. The only way it could raise the money for development was to sell more engines, so it was a fine balancing act from the start.

'Every engine is allowed to develop,' says Caillé. 'There is a set of technical regulations and you can work and develop your engine, be it unbranded or not. We were more or less cost capped in the sense we were working at a price we were selling to teams, and that was a defined amount of money. However, the more we developed our customer base, the more we had means to develop the engine further. So in the end, what defined our budget was the number of cars we had on the grid!

'We went for more power, but we also looked to get better useability from the engine. The driveability of a turbocharged engine has to be defined in order to be efficient during the traction phases out of corners, particularly with the four front-wheel drive cars in the BTCC.

'There are technical regulations that limit what can be done to many engines, on materials, on how much you can modify the base road engine, and these are things that cannot be modified. A crucial aspect of every base engine that cannot be changed is the port and cylinder head, and this is why there is an equalisation for boost compared to flow efficiency of the engines in the series.'

Magic moments

Since 2015, the engine has been used by more than half of the grid and, in 2020, Ash Sutton won the overall title with a Swindon engine. It ranks among Caillé's proudest moments over the last 12 years, although by no means is it the only one.

'Our first victory came in the last race in 2010, with Andrew Jordan at Brands Hatch, which was a fantastic moment,' remembers Caillé. '2010 was a time where Swindon Powertrain was pulling back from difficult years as a company, and that victory was superb.

'Then there was the Independents' title in 2012, and then in 2014 we won the Manufacturers' title with MG. We have seen teams growing up with our company, young drivers, and [we have won] two Drivers' titles in 2020 and 2021 with Ash Sutton, which are a great end to our era of supplying the TOCA engine.'

Although Swindon Powertrain pitched to continue for the tender, it didn't win this time around, but that was no reason to be despondent as the company will continue in the BTCC regardless.

'As a business person, when you run a programme in motorsport for 12 years, nothing lasts forever, and that is a good time to pass it on to someone to have a go at it,' says Caillé graciously.

In the end, what defined our budget [for development] was the number of cars we had on the grid

Raphaël Caillé, MD at Swindon Powertrain

'We will supply engines to Hyundai for the next phase of the BTCC, so that might be a chance for us to try a few different things. Watch this space.'

Despite some perceptions that Swindon Powertrain has supplied the same unit since 2010, the manufacturer has made both hard and software changes to maintain reliability and improve performance every year. Some of these have led to intrigue in the paddock, but Caillé says it is in the company's nature to keep pushing for innovation.

'For example, anti-lag technology is banned in the championship, but we looked at the calibration off throttle. That made the engine sound like it was going to go bang! Paddock rumours thought it was anti-lag, but it was all within the rules.'

Another sound example was in 2012 when Swindon introduced its 'Map4'.

'In Map4, the engine sounds like it is hunting,' says Caillé, 'but this was our way to cool the turbo much faster. By opening the throttle and cycling through the cylinders at a max rpm of 2000, we circulate air through the turbo more efficiently. Without this function it could take two minutes of idling to get to an exhaust temperature of 600degC. With Map4, you can reach that in 30 seconds. Of course, it needs the driver to remember to enter that mode, and only the best drivers remember every time!'

Open for business

Formula Ford 1600 has been around for over 50 years and is one of the few remaining open single-seater categories. Racecar *asks whether it's still relevant in the modern age*

By MIKE BRESLIN

The internet can be a hit and miss method of research, involving lots of cats and craziness. But every now and then you stumble upon something quite fascinating, such as a list of Formula Fords produced before 1974 in an old rules document (search 'brsccff1600 technical regulations'). It's an interesting read, not least because it contains the likes of Lotus, Lola and March, but also because it's so very, very long. From Alexis to Winkelman, by way of Blackjack, Cougar, Ladybird and Raven, there are 66 marques listed in all. That's a lot of racecars. That's a lot of racecar manufacturers.

Things have changed since then. Dominant marques took over in Formula Ford in the '70s and '80s and the smaller constructors fell by the wayside. In the process, the very nature of the single-seater ladder was skewed. For in the search for an, arguably illusory, level playing field, spec formulae began to appear in the late 1980s, and the rot from the root soon spread to the uppermost branches of the tree.

Formula Ford survived the onslaught from myriad one-make, entry-level series and, while the main championship in the UK went down a number of blind, or at least short sighted, alleys, cars packing the trusty 1600cc crossflow Kent engine continued to race in every corner of Britain and across the world. Many are still racing too, with around 100 entered in the two 2021 season-closing FF1600 jamborees, the Formula Ford Festival at Brands Hatch (98 cars) and the Walter Hayes Trophy at Silverstone (106). All of which must mean there's still a viable market for new single seater producers to do business in, right?

Well, we will come to that in a moment. First, let's remind ourselves of what FF1600 is all about, and that's close competition that won't break the bank.

Value for money

'The racing is mega and the value for money is as good as you're going to get anywhere else in the world,' says Andy Low, team owner and manager of top UK National Championship team, Low Dempsey Racing.

Plenty of current and potential race entries, relatively cheap racing, and just a little room for inventive engineering

Formula Ford has been around since 1967 and the series is as hard fought today as it has always been

Jon Elsey

He's right, too, because when compared to other starter formulae, FF1600 *is* cheap. Budgets for the British F4 Championship, for example, are around the £250,000 mark – although many spend much more with added testing – yet a good season in the National Formula Ford Championship with a professional team can be had for around £40,000-£60,000 (approx. $53,000-$79,500), which usually includes plenty of test days.

That said, there's no doubt FF1600 costs have been escalating recently, largely due to the longevity of the formula. Main reason being, when things are old, they become harder to find, and when they become rare, they start to get expensive. That's as true for engines and gearboxes as it is for Ming vases.

'It is the component side of it that's making it more expensive,' agrees Wayne Poole, boss of long-established FF1600 team, Wayne Poole Racing. 'Calipers are a bit more difficult to get hold of now, so they've become worth a couple of hundred pounds. The real issue, though, is the gearboxes, they're between £5000 and £7000 now.'

Indeed, Hewland Mk9 and LD200 'boxes have almost become collectors' items, as this tale from Formula Ford powerplant builder, Neil Barnett, of Barnett Race Engines, clearly illustrates: 'There was some chap we spoke to who bought something like a Swift 93 that he found in America. He agreed a price with the seller but, when it came to shipping it, he said, "Just send the gearbox, I don't want the rest of the car." That was all he was interested in. I think he only paid about four grand for the car.'

It's the same for the 1600cc crossflow Kent engines, with original blocks that were once readily available for a few pounds now becoming scarce. And some that have survived many decades of racing are no longer in the best of conditions.

'The problem with the old blocks is corrosion, internally,' explains Barnett. 'We come across an increasing number that have started to leak, so you're getting small water holes or cracks appearing in them on the outside surface, on the outside of the water jacket. What's worse, though, is where they actually start to fail internally.

So, you get water pouring into the sump… and the next thing, the oil turns to a sort of mayonnaise and your engine's damaged and needs fairly extensive repairs.'

The new way

Happily, brand new Kent blocks are now available, with Ford Motorsport in the US casting them, perhaps in response to Honda's Fit engine in the States (see box out on p47). Barnett, however, who has been involved in Formula Ford since the late 1970s, believes it was more to do with demand in the UK. 'I think there were various people over here pushing for it,' he says.

As well as the new Kent blocks, newly made steel cranks, rather than the older cast items, are now allowed. But while these changes have meant a ready supply of engines and parts for them, it has by no means brought costs down. '[An engine costs] a lot more now, because you're allowed to use the specified steel crankshaft,' confirms Barnett. 'There might be a theoretical performance advantage from a steel crank, in that it doesn't flex very much, or doesn't flex as much as a cast crank, but they're not exactly high revving engines [around 7200rpm max], so it doesn't really make any difference. Other than adding quite a lot of cost.

'If you build an all-new engine – using a brand new block, new steel crank, steel rods, all new pistons – you're looking at about £11,000 (approx. $14,550). So, it's an expensive option.'

To put that into perspective, 10 years ago a built Kent engine would cost around £4500. The main advantage of an all-new engine is it will last, meaning they are good value in the long run. They also hold their price.

'The Kent engine now is really reliable,' says Gavin Ray, boss of long-time Formula Ford constructor, Ray – a make that's actually on the long list mentioned in the opening. 'It's just the actual cost of a new engine that is the problem. Once you have the engine, though, you have it, and it's always worth the money. With the latest billet steel crank, they're pretty bulletproof now, too.'

When that's added to the cost of a new rolling chassis, which can be picked up relatively cheaply at around £28,000 (approx. $37,100) (for a Ray), you're still looking at a fairly low – in motorsport terms – initial outlay for a competitive, ready-to-race package. Competitive second-hand cars are readily available and are cheaper still.

Where this really works for a race team is that, like the engine, the chassis can be used for years to come. 'They do hold their value,' says Ray. 'When you think how long Formula Fords have been going around, it's not a one-make formula that could stop in three years' time, or have a chassis change so it all gets thrown in the bin. You can buy a Formula Ford one year, use it, put in the garage, and get it out five years later and still go and race with it.'


Bresmedia

Almost the entire history of Formula Ford captured in one corner: a late '80's Van Diemen leads 2018 Ray, early '90's Van Diemen and a 1970's Crossle, during testing for the Formula Ford Festival at Brands Hatch


Bresmedia

A typically pristine Historic Formula Ford. Note the very basic spaceframe, outboard suspension, large rear anti-roll bar and Hewland gearbox. The latter part is becoming harder to find these days, and therefore more expensive

Stepping stone

Of course, where something like F4 scores over FF1600 is in terms of its profile and it being on the FIA-approved single-seater ladder, with the F1 Super Licence points that entails. This means Formula Ford teams can sometimes find it difficult to compete when it comes to enticing young career drivers.

'There's no attraction for the young driver to come to Formula Ford,' says Poole. 'Because they want to go with Carlin or Fortec [teams operating in F4 and further up the ladder], because they feel that's a stepping stone to fame and fortune.'

Low agrees: 'I think people get a bit excited and think, as a young driver, you get out of a go kart and need to get straight into slicks and wings. It's a bit frustrating, really, but that is what is sold to people, the dream.

'But the people who come through Formula Ford generally do a really good job [later in their careers].'

You need look no further than the Team USA Scholarship programme to see this is true. The scheme has been sending youngsters to the UK for the big, end-of-season tournament races since the mid-2000s, with IndyCar aces such as Josef Newgarden and Connor Daly benefiting from it early in their careers (the former won the Kent-engine part of the Festival in 2008, Daly the Walter Hayes the same year).

Formula Ford teams can sometimes find it difficult to compete when it comes to enticing young career drivers

There's still a perception amongst younger drivers – or perhaps younger drivers' dads – that FF1600, with its H-pattern, four-speed gearbox, steel spaceframe, treaded rubber and lack of downforce, is not the way to go.

'One of the problems we have is that people are obsessed with getting their kids into Formula 1 by the time they are 17,' says Ray. 'They're sticking them in an F4 car when they're very young, and by the time they get to 17 they have either blown their money or the kid's lost interest, because [they have found it]

'Even though they're not that fast, they are extremely hard to drive. People don't always appreciate that'

Andy Low, team owner and manager of Low Dempsey Racing


Bresmedia

These days, FF1600s feature wide-track suspension and a pointy-nosed aero approach that's very much focused on low drag. Pictured is a Ray GR19 (left) and Ray GR14

much harder than they expected, because they haven't properly learnt the ropes.'

And there is little doubt there are few better ways to learn the ropes than Formula Ford, chiefly because of the *lack of* what makes F4 so attractive to youngsters – those wings that make them look like baby F1 cars.

'If you learn mechanical grip and driving without the aid of wings, when you move into a winged car, you can then drive a car with less wing, a car that moves around a bit,' says Ray. 'Which then means you're faster, because really, with a lot of the one-make stuff with wings, the quickest driver will have less wing, which makes them fast down the straight.

'You can mask things with wings. I think you have to learn to drive properly first,' Ray adds. 'In other categories that have wings, if there's a driver that wants a certain thing [from the car], the easiest route is just to put more wing on, and then they go slower because of it.'


Bresmedia

The faithful 1600cc Kent crossflow engine has been powering Formula Fords for over 50 years. New blocks are now cast in the US

High mileage

There are other advantages for drivers in FF1600, too. 'It's the mileage you can achieve in a season [with more testing than F4], that's the crucial thing,' says Low. 'It's the mileage we can achieve, and understanding the car without the aero, that's really important.

'They're not an easy car to drive,' he adds. 'Even though they're not that fast, they are extremely hard to drive. People don't always appreciate that.'

Poole agrees: 'They're difficult cars to drive fast. With that in mind, it gives anybody who wishes to try and move on a bit into any other forms of motorsport a really good base to start from.'

Also, being an open formula, there's still car development for drivers, and indeed engineers, to learn one of the most important crafts in racing. 'These days, a lot of that's in the suspension, and damper technology has come on big time, too,' says Poole.

But Formula Ford has been around for a long time now, running pretty much to the same regulations, so performance gains tend to be incremental, which might explain why there are still so many older cars competing and sometimes matching the pace of the new cars, especially in the end-of-season showcase events.

Bresmedia

Undressed Firman RFR21 (produced by Ralph Firman, founder of the Van Diemen marque) showing front suspension. Much current FF1600 race development centres on dampers

So, why buy a brand-new chassis when you can be competitive in a 1999 Van Diemen? 'I'd say the chassis themselves are probably fairly similar now,' says Law. 'It's actually just damping, geometry and aerodynamics [which tends to be focussed on making the car as slippery as possible]. That's the sort of direction everything is headed, but not so much the chassis themselves.'

With that in mind, it's perhaps no surprise that many of the cars offered for sale are updates of previous designs, although there are some truly new cars available, such as those from Ray and Firman – the latter the brainchild of Ralph Firman, the founder and long-time owner of legendary Formula Ford constructor, Van Diemen. Spectrum (based in Australia), Medina and Swift Cooper are other names often found at the top of the timesheets.

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Australian constructor, Spectrum, has had success at home, in the UK with Kevin Mills Racing and in North America. Note the Avon ACB10 treaded tyres, which are used for both dry and wet running

Journeys beyond Kent

While the original Kent-engined Formula Ford continues to thrive, Ford itself first looked to replace it as long ago as 1993, when it introduced the 1.8-litre, 16-valve Zetec motor, which saw service in the main UK championship until 2005. Heavy, and with much of that weight high up, the Zetec was unloved, though it proved very reliable.

Its replacement, the 1.6-litre Duratec (2006-2011), was a great improvement, providing slick-shod Formula Ford action that reminded many of the racing during the category's golden years in the 1970s and '80s.

The problem with having manufacturer backing is that a car maker will always have a new product to sell, which in 2012 led to the 1.6-litre, turbocharged Ecoboost mated to a Mygale chassis with sequential gearbox (although it was not originally intended to be a spec formula). That car even grew wings in 2013.

The chassis remained as the category evolved into MSA Formula in 2015, and then UK Formula 4 in 2016.

Meanwhile, in America, Honda introduced a replacement Formula Ford engine at the tail end of the 2000s, based on the unit from the Honda Fit (sold as the Jazz in the UK) and mapped to match the Kent engine. It is now raced in parts of the US alongside Kents, as Formula F, but, as James Beckett notes, 'It's actually now an old engine itself.'

Back in the UK, at the close of the 2021 season it was announced that the next iteration of British F4 would use a Tatuus chassis, complete with Halo, and also Abarth power. With that, Ford's 54-year official involvement in entry-level British racing abruptly ended. For now, at least.

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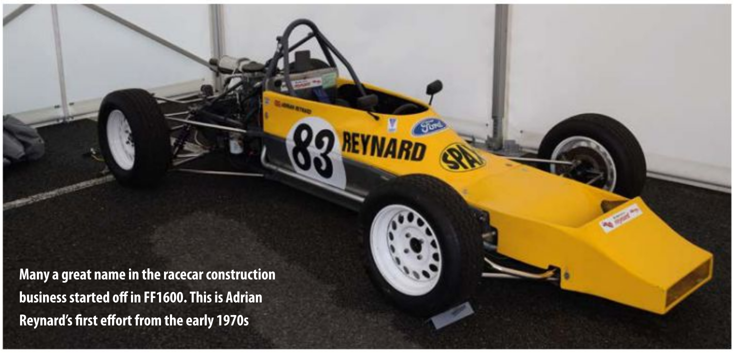
Modern Ray from the rear, showing where the steel spaceframe meets the lightweight aluminium bellhousing that carries the rear suspension and gearbox



Many a great name in the racecar construction business started off in FF1600. This is Adrian Reynard's first effort from the early 1970s

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But the question remains: why, when FF1600 is one of the only single-seater categories you can now actually build cars for, are there not more constructors involved?

'It's a real shame,' says Barnett, 'because I think it is a brilliant formula for bringing on young engineers. 'There is some good stuff going on there, I think people are learning things and doing modifications, but it does seem a shame that there's no one coming in and building new cars. But then when you think of the volume of cars that would get built, I suppose it wouldn't really make it economically viable.'

Alternative routes

This is because the junior single seater market has changed substantially since the 1970s and '80s, when FF1600 was *the* place for a driver to start if they were thinking of building a career in the sport. Now there's F4, the new GB4 and potentially GB3, too.

'It's not like the 1980s, when there was a demand for new cars, and everybody who had a Van Diemen RF85, at the end of the year went to Ralph [Firman] and said, 'I'll have an 86 please.' They then all sold their 85s to somebody else, and that carried on into the RF87 and RF88, too,' says James Beckett, often referred to as a Formula Ford guru, and the man behind the hugely popular Walter Hayes Trophy.

Even if there was still a high demand for cars, any new constructor would be faced with the difficulty of trying to make a product that stands out – that is, wins – in a formula where few development paths have been left untrodden. This is even more difficult because unproven cars are a risk for drivers, their sponsors and the teams that run them, who simply cannot afford a fallow year in terms of results.

'We know that if we buy a brand-new Ray, it's going to be on the money straight away,' confirms Low. 'It's one of the main reasons – one of many reasons, actually – that we use them.'

On top of this, we shouldn't underestimate the challenge facing a new constructor in

A beautifully restored Van Diemen RF92, with monoshock front suspension. There are many old Formula Fords still around, which should ensure the future of the category

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Former Formula 1 driver, Roberto Moreno, raced at the Formula Ford Festival in late October in a Van Diemen RF80 in Canadian Club colours, just as he did in 1980

producing a chassis that can even *match* the current cars, built on the back of many years of experience, especially in the case of Ray and Firman. 'If it was just doing it on a computer, then anyone could build a car,' says Ray. 'But it's experience, and you still have to understand your market.'

Price ceiling

And that last point is a very important consideration. For while the market is now quite small, that which does exist is not – in motorsport terms at least – a high value one. 'The cars are extremely cheap,' says Ray, 'because we know what the market is, and we have to build them for that market.' That's coming from someone who has rolled out around 100 cars over the last decade or so, for various Formula Ford series around the world. 'So other constructors aren't interested in our market, because the likes of Tatuus and Dallara, for the same amount of effort I will take to build a £28,000 car, will build a £100,000 car.'

The same goes for the engines. 'The reality is you never charge as much for the labour building Formula Ford engines because you know you couldn't,' says Barnett.

'It's still a formula where there's a sort of price ceiling on what people will pay'

Neil Barnett of Barnett Race Engines

'It's still a formula where there's a sort of price ceiling on what people will pay.'

None of this means a new constructor won't appear on the scene, of course. But perhaps the really important point is, even if there are no new car makers, there are so many FF1600s already in existence – perhaps even 'thousands of them', Poole estimates quite reasonably – that FF1600 will always have a future of some sort. And if not as a category for modern cars, almost certainly as one for Historics (see box out right).

For the time being, though, things are looking healthy for FF1600, with the UK flagship National Championship attracting an average of 17 cars throughout 2021 (which is the same as F4 and similar to GB3, with 18 cars), while the top regional series, at Castle Combe, featured around 20 cars in each of its races.

Perhaps then it's best to forget about lists containing 66 racecar constructors from the dim and distant past, and just celebrate what FF1600 has right now – plenty of current and potential race entries, relatively cheap racing, and just a little room for inventive engineering. That's much more than most modern single-seater categories can offer these days, after all.

The past and the furious

HSCC

Historic Formula Ford always provides big grids and plenty of action

There used to be a popular bumper sticker that read, 'Old Fords never die, they just get faster'. When it comes to old Formula Fords it might better read, '…they just keep racing'.

There's been a place to race older FF1600s since the early 1980s, with the Pre-'74 Championship in the UK, and there have been many variations on this theme since. Now there's Historic (pre-'72) and Classic (pre-'82), and often a class system for different age groups within regional championships.

Historic FF1600 has been remarkably successful, boasting grids averaging 27 across 2021 and enjoying a profile that is, arguably, even higher than that of the National Championship for modern cars.

'The rules are the same as modern Formula Ford,' says Mike O'Brien, who runs the Classic Team Merlyn operation that is a front runner in the championship. '[But] there are a few differences in the cars, such as the spec of the dampers. You're not allowed to use gas-filled dampers, they have to be twin-tube, oil-filled dampers, which has changed in the last few years. I don't think that's a bad thing. It's not supposed to be a category where you get development, you're supposed to be racing the cars in their original spec.'

The tyres also differ, with Historics running on Avon ACB9s, similar to the old treaded Dunlops, rather than the cut slick-looking Avon ACB10 used on the more modern Formula Fords.

Cars eligible for the championship can be expensive, though, going for as much as £40,000 with engine and gearbox for a good one. But then they do hold their value, and the budget required to run them is reasonable, especially in the context of notoriously expensive historic motorsport.

'In this you could run as an amateur for probably £10,000 a year,' says O'Brien. 'And our budget for our team is about £50,000, for all the races and testing.'


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Mercedes AMG Petronas Formula 1

The influence of data in contemporary motorsport cannot be understated. Formula 1 teams rely on it for almost every decision made, and most of that data is supplied by sensors onboard the car

Sensor and sensibility

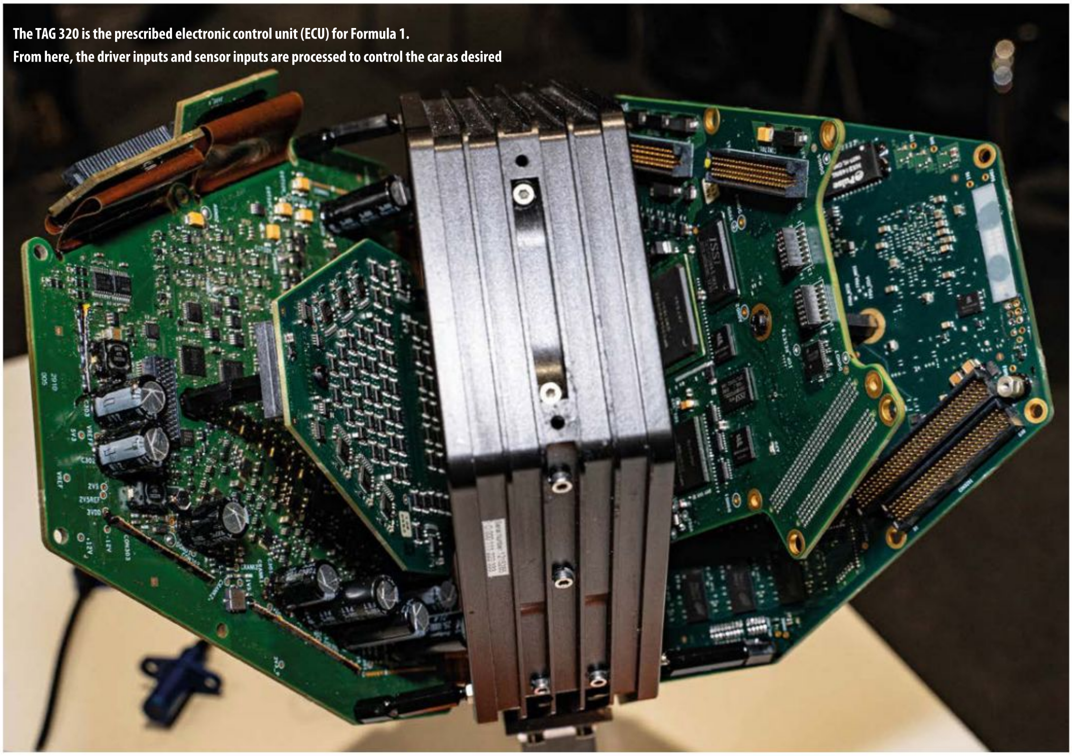
Racecar *looks at the latest advances in sensor technology and how Formula 1 in particular is using them to gain that ever dwindling performance advantage*

By STEWART MITCHELL

With power unit control strategies being the key to Formula 1 performance, data flow is imperative in ensuring a car is at its most competitive

A contemporary generation Formula 1 car is made up of around 25,000 components: 11,000 in the chassis; 6000 in the power unit (PU), electronics another 8500. Each of those must perform within a very specific window for the team and the driver to extract performance potential out of the car. To understand what the individual components are doing, they must be instrumented and monitored by a host of sensors.

The most complex system onboard the cars is the power unit. Currently in F1, this comprises two motor generators, an internal combustion engine (ICE), battery store and control electronics. All of these are sub-systems in themselves and need constant supervising to ensure all elements are operating in the desired way.



The TAG 320 is the prescribed electronic control unit (ECU) for Formula 1. From here, the driver inputs and sensor inputs are processed to control the car as desired

PMW Expo

Monitoring here involves using torque, pressure, temperature, position and speed sensors that relay information to the control electronics and via a telemetry link to trackside engineers and those back at the various factories. With power unit control strategies being the key to Formula 1 performance, this data flow is imperative in ensuring a car is always at its most competitive.

As with any racecar, packaging and weight are crucial design constraints, and every extra sensor added needs to be integrated, and accounted for, in the overall package. The challenge for teams and sensor manufacturers is to produce the smallest, lightest sensors possible, yet still ensure they will survive under race conditions and provide reliable data.

On top of the power unit engineers, the chassis engineers and aerodynamicists also have their own data demands. Engineers need to monitor the loads through chassis and suspension components to ensure they are operating within their design limits and are exploited for the desired performance when needed.

With the restrictions placed on on-track testing and simulation resources in modern Formula 1, each track session is a vital data-gathering exercise.

Providing drive to the rear wheels is the power unit, which is a series of systems made up of components working in harmony, resulting in an output of torque. Measuring that torque is vital in a current Formula 1 car because the relationship between the accelerator pedal and the power unit is no longer an air metering device, it is essentially a torque controller.

Torque measurement

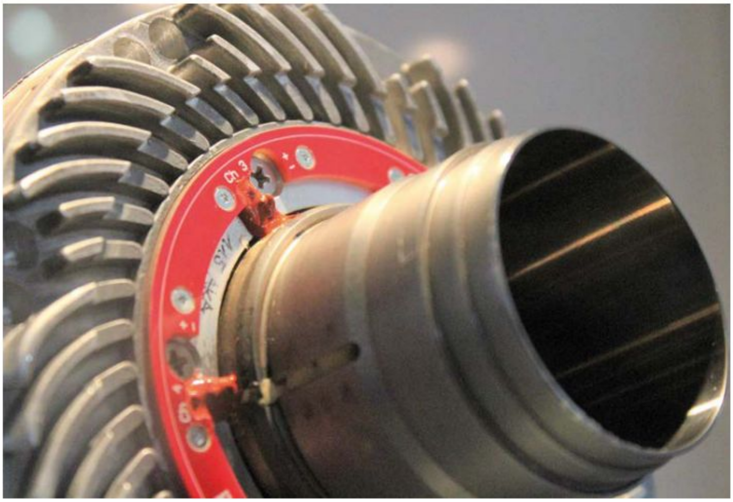
The car's electronics determine how that torque is delivered, and govern the contribution of the ICE and energy recovery system (ERS) to the force that reaches the rear tyres. For power unit control strategies to be implemented, accurate torque measurement at various points in the system, including the kinetic motor generator unit (MGU-K) and the driveshafts, is mandatory.

Engineers use various methods for torque sensing. There are two core methods for measuring the torque applied to a shaft: twist angle and surface strain. The twist angle method unually requires a portion of the shaft being measured to be reduced in diameter, allowing twist under load. A pair of toothed discs attach at either end of this portion, and the twist angle can be determined using the phase difference between magnetically or optically-detected tooth or gap patterns on each disc. Because the discs rotate at the same rate as the output shaft, torque can be measured during revolution. Adding extra toothed wheels at different degrees around the shaft can improve the accuracy of this measurement.

Stewart Mitchell

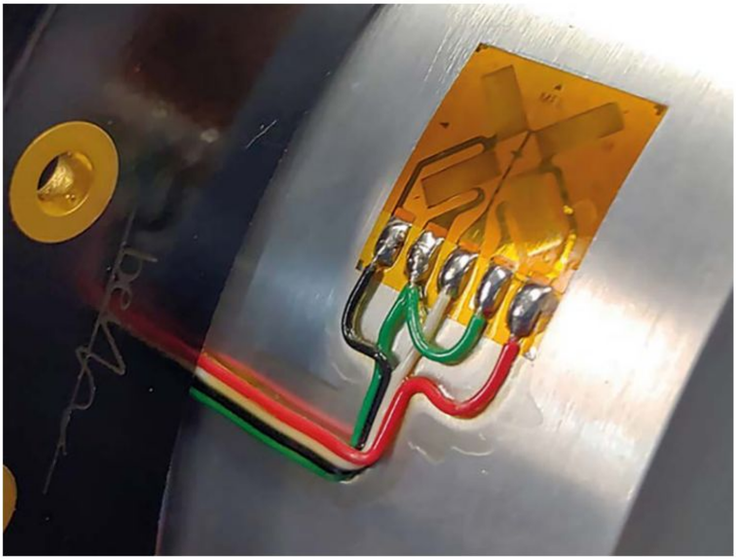
Pressure sensors can be used to correlate air speed and applied load on aerodynamic components of racecars

Another method, piezoresistive strain gauges, attach to the shaft to measure surface strain. Strain here is generally too small to be accurately measured directly, so standard practice is to use four gauges arranged in a Wheatstone bridge circuit. However, this arrangement



Stewart Mitchell

Torque transducer coupled with electromagnetic frequency attenuating technology helps ensure the clear sensor readings required



Binsfeld Engineering Inc

Strain sensor array arranged in a Wheatstone bridge pattern

Accurate torque measurement at various points in the system, including the kinetic motor generator unit (MGU-K) and the driveshafts, is mandatory [in Formula 1]

isn't ideal for rotating assemblies, as it requires coupling the sensor to a rotary transformer, or slip ring, to feed strain-related current to the gauges, or receivers on static elements to acquire the signal from it in a non-contacting mode.

As such, the torque sensing technology favoured by the Formula 1 fraternity is the magneto-elastic type. These produce current (signals) as a function of torsional stress, not strain. As a result, they are mechanically much stiffer than the conventional elastic torque sensors. They also offer a frequency response in the order of 2-4kHz, far higher than the other types.

Magneto-elastic surface stress measuring is also a non-contacting system and is ideal for measuring torque in a compact assembly.

There are two groups of magneto-elastic sensors and each measures magnetic quantities related to the surface shear stress in different ways. One measures magnetic permeability changes in the rotating element's surface caused by stress-induced magnetic anisotropy. Magnetic anisotropy affects the permeance of a magnetic path and this sensor type uses a magnetising source and a sensing coil to measure the change in permeance. These are referred to as PB Type 1 sensors.

The second type, aptly named PB Type 2, uses the stress-inducing magnetic anisotropy to generate a measurable magnetic change in a permanently magnetised magneto-elastically active component.

Magneto-elastic torque

Type 1 sensor are superior to traditional sensing methods because of their wireless transduction, combined with mechanical robustness. However, the permeability-based Type 1 magneto-elastic torque sensors suffer from the fact that permeability does not depend solely on applied torque. Even in a controlled environment, permeability can vary with temperature and magnetisation in any material composition. The result is that in many real-world settings, the changes due to these factors can exceed the changes in permeability caused by applied torque, making the measurements futile.

Type 2 sensors are therefore much more suitable for use in motorsport. They have many of the Type 1 sensor benefits and overcome most of the problems, too. Type 2 sensors are made up of either a thin ring of magneto-elastically active material rigidly attached to a shaft, or by using a portion of the rotating element itself as the magneto-elastically active element. It still measures magneto-elastic energy associated with the principal stresses by which torque is transmitted along the shaft, though here, each moment will rotate towards the nearest positive main stress direction and away from the nearest negative one.

The re-orientation of the magnetisation results in a net axial magnetisation constituent. The divergence of this constituent at the poles of the magnetic field in the space around the shaft is measured with one or more magnetic field sensors. This gets around the problems associated with measuring permeability, allowing for very accurate and repeatable readings. To achieve these, engineers can easily incorporate the polarised bands into the output shaft of a driveshaft on a racecar.

Understanding the speed and acceleration of the rotating assemblies is fundamental in modern motorsport vehicle control and data acquisition. In the contemporary generation of F1 cars, the powertrain regulations present some challenges for sensor manufacturers in this arena. Since the dawn of the hybrid era, speed monitoring for the heat recovery motor generator unit (MGU-H) has been critical, and can see rotational speeds of 100,000rpm.

Measuring rotation

Rotational speed is generally measured using inductive, or Hall effect-type, sensors. Here, the magnetic field around a permanent magnet is manipulated by a ferrous toothed wheel that moves in front of an inductive sensor. A Hall effect sensor is a small sheet of semiconductor material arranged with a constant current flowing across it. A voltage proportional to the field strength and perpendicular to the current flow is then generated across the element in a magnetic field. A permanent magnet in the sensor supplies the magnetic field, so a magnetised wheel is unnecessary.

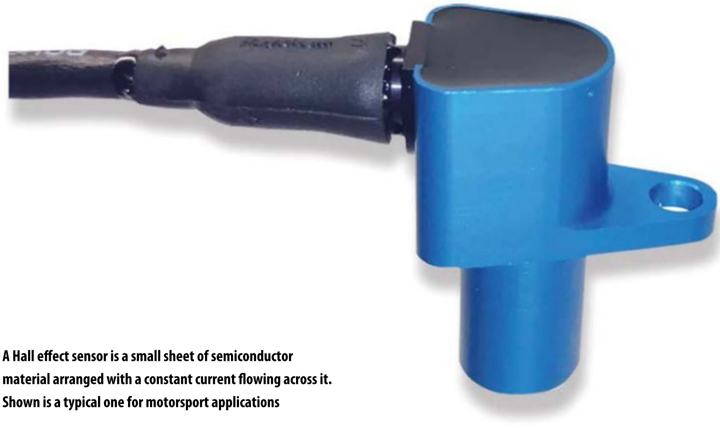
Voltage is the output, and this is generated in a coil of wire in a magnetic field. The coil and magnet are integrated into the sensor body for ease of installation. The induced voltage increases with the speed of movement of the ferrous object and decreases proportionally with distance from the end of the sensor and the moving element.

Hall effect sensors are used in the harshest of environments as they are robust and can measure very high rotational speeds. This makes them ideal for measuring turbo speed for example, or wheel speed.

For MGU-H and turbocharger speed sensing, it is necessary to understand the rotating assembly's characteristics, not just a simple speed reading. In the case of a turbocharger, the blades of the compressor rotor are highly stressed, and any degree of imbalance or vibration can result in catastrophic failure. Engineers can incorporate one or more optic or laser probes into the turbine housing to reflect a beam of light off the blade as it passes. If the blade is rotating at a constant rate, a particular blade should pass each sensor at a predictable time. Any deflection due to vibration causes blades to pass earlier or later than predicted.

The difference between these times can be used to calculate the deflection by measuring the delta from the measured and predicted position for each blade.

The most widespread method for monitoring the compressor blades is the tip timing method, which involves taking an accurate measurement of the times the compressor blades pass by a series of unequally spaced sensors. A powerful laser with a small focus point and high-speed data acquisition can detect tiny vibrations at the turbine tips.



A Hall effect sensor is a small sheet of semiconductor material arranged with a constant current flowing across it. Shown is a typical one for motorsport applications

Bosch Motorsport

Strain gauge mounted to a measured component. In terms of a racecar, this is usually an aerodynamic or suspension component

Michigan Scientific Corp

Stress and strain

Strain gauges are used predominantly in a Formula 1 car's suspension and aerodynamic components. Wishbones and uprights are instrumented with several strain gauges to ascertain the loadings they are subject to. The part's complexity and the axes along which it is loaded determine the orientation and number of gauges necessary, and the data type used to aid in understanding a car's behaviour.

A strain gauge's resistance varies as a force is applied across it. Stress and strain result when an external force is applied to an object. Stress is defined as the object's internal resisting force, while a strain is any displacement or deformation that may occur. Load can be deduced by measuring these forces.

Stress is defined as the object's internal resisting force, while a strain is any displacement or deformation that may occur

The most widely used type of strain gauges used in motorsport are of the bonded foil type, a long standing and straightforward design that dates back to the sport's origins. Here, a thin foil resistor grid bonds directly to the measured object's surface. As the object is subjected to load and deforms, so too does the foil resistor. The resulting change alters the gauge's resistance.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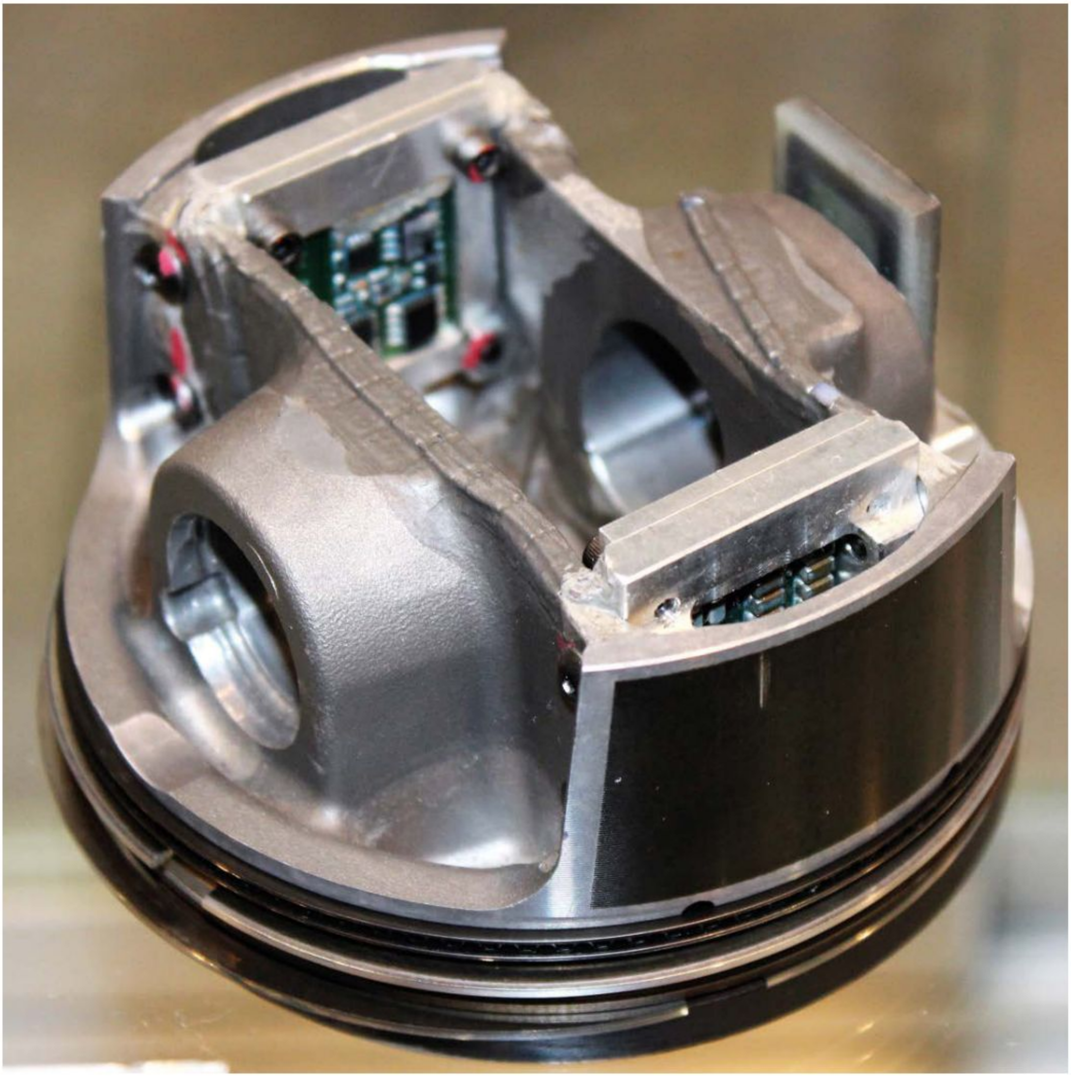

Stewart Mitchell

Position sensing technology embedded into a test piston. Using magneto-resistive technology, the sensor itself can be situated outside the piston chamber and still accurately record results

By measuring this change in resistance and comparing it to a value obtained by calibrating the sensor under laboratory conditions, the strain can be calculated.

One of the problems with this type of gauge is the materials used to create the strain gauging elements are also prone to altering their resistance by external factors such as temperature. Differences in readings due to temperature come from two effects. Firstly, the gauge's electrical resistance is somewhat temperature dependent, and so resistance will vary with temperature. The second factor is the differential in thermal expansion between the gauge and the test part, or substrate material.

One of the more common methods of compensating for temperature changes is to have an additional gauge on one arm of the system isolated from any strain. This provides a reference output showing purely the change in resistance due to temperature. By isolating any environmental effects on the primary sensor, a more accurate value can then be calculated for the strain resistance.

When measuring strain in a part such as a wishbone, which will be subject to forces along several different axes as the car accelerates, brakes and turns, engineers will incorporate a number of strain gauges into the component, oriented with the various load paths to isolate each specific load case.

Strain can also be measured by incorporating a load cell. Most Formula 1 teams use load cells in the front wing mounting struts to ascertain downforce distribution across a front wing. Similar units are mounted at the intersection between the rear wing pylons and the gearbox to do the same thing. The readings from both are fed into a model of the load paths and structural compensation models of the front and rear wing, from which the aerodynamic load distribution can be extrapolated. In this example, gauges are bonded into the load cell structure, but they can also be tailored into functional components, minimising the impact on overall vehicle packaging.

All strain gauges need to incorporate a means of amplification to turn the output signal, in millivolts, into volts suitable for input into a data logger or ECU. Amplifiers will often fulfil other roles too, such as stabilising voltages to the strain gauges. Some manufacturers also use dual-output amplifiers that provide two different gain levels for different scenarios. As an example, when a car is driving along a straight, the load variations detected by a wishbone strain gauge will be reasonably small. To obtain detailed data here, engineers will use the high gain amplifier channel. But when the car runs over kerbs, loads spike and vary dramatically, so engineers will choose the data from the low gain amplifier channel.

Position technology

Measuring position or displacement on a given axis is the primary driver for understanding component operation and interrelation of systems in the car under dynamic scenarios. Conventionally, F1 has used linear position technologies such as linear contacting potentiometers, linear variable differential transformers and magneto strictive sensors, though contemporary F1 cars use a non-contact position sensor that relies on magneto-resistive sensing technology to provide positional feedback. The most significant benefit of this sensor type is the sensing element and target can be separated by most non-ferrous materials, including aluminium and stainless steel. Additionally, the sensing element and magnetic target can be separated by an air gap up to 40mm. This is particularly useful to power unit and drivetrain engineers, allowing sensor targets to be mounted in areas where it would not usually be possible to house a traditional sensor as the sensitive sensing element is located outside the component it's measuring.

As it consists of only a magnetic element, magneto-resistive sensing technology can be incorporated into existing components without significant design changes. This allows, for example, the movement of a piston within a complex hydraulic manifold to be measured, where it would be impossible to mount a conventional sensor. Here, the target element is embedded into the piston while the sensing element is located outside the manifold.

Some F1 teams, along with their sensor manufacturer partners, have created similar custom installations for both suspension and hydraulic applications.

Multiple functionalities embedded into singular sensor units is also likely to evolve

Inevitably, sensor manufacturers will continue striving to produce smaller and more accurate sensing units, and to develop new techniques for measuring the previously un-measurable. Multiple functionalities embedded into singular sensor units is also likely to evolve. Detailed comprehension of the relationships between the various physical aspects being measured allows for extrapolation of multiple data sets from a single source.

In such multi-function sensor arrays, the extrapolation is achieved through algorithms coded into the receiver after measurement. Here, the multi-functional sensor data can be inputted into open loop models of system status, which engineers can feed into race strategy software or degradation models of the car. From there, teams can have a full picture of the car's health and confidently decide on the next move.

Winging it

The rise, fall and return of the aero rally car

By LAWRENCE BUTCHER

Think downforce and aerodynamic development, and the mind naturally turns to the world of Sportscars and single seaters. However, since the World Rally Championship (WRC) introduced new rules in 2017, the importance of aerodynamics has grown immeasurably in the sport, becoming an area of intense R&D for teams.

Come 2021 and the arrival of new hybrid machines with spaceframe chassis and silhouette bodies, the rules were being pegged back once again and many of the aero flourishes of the past era will be consigned to the history books. So, what have the teams been up to over the last five years?

Aero through the ages

Of course, aerodynamics has been a consideration in rallying for years, but it was only in the late '70s and into the '80s, as speeds increased dramatically and the aero revolution was well underway in other formulae (think ground effect skirts in F1 and huge tunnels in Group C), that manufacturers started to pay attention on the stages.

For example, the exquisitely-styled Lancia Stratos and 039 were both honed in the Pininfarina wind tunnel in Grugliasco, which fittingly is still used for some WRC aero development to this day by Hyundai. These early efforts were more about reducing drag and making cars stable than downforce generation. However, as the Group B era gathered pace, cars began to sprout ever larger wings and other aero appendages.

With power increasing at a meteoric rate (in 1983, the Lancia 037 pushed out around 300bhp, by 1985 the likes of Audi's Quattro Sport Evo 2 were well over 500bhp), drag was of little issue and the serious pursuit of downforce was on. In the case of the Quattro, it sported a slab-like front air dam working in conjunction with an enormous three-element rear wing, which is said to have produced up to 500kg of downforce under the right conditions. Notably, some elements of the wing's design, such as small winglets affixed to the end plates, can still be recognised in current WRC machines.

Audi was not alone in its pursuit of aerodynamic performance, with Peugeot slapping a giant single-element wing atop the T16, along with dive planes at the front. In Rallycross trim, the car gained a twin-element wing behind the roof-mounted one.

As Group B reached its zenith, Lancia's Delta S4, again honed in the Pininfarina wind tunnel, had a drag coefficient 12 per cent lower than the svelte 037. While the S4 was certainly not a downforce monster, featuring only a modest rear wing, its unraced successor, the Group S Lancia ECV, looked to correct this, with its wing extending far beyond the sides of the rear clamshell.

These Italian efforts pale in comparison to Audi's Group S car, the RS002, however, which had the appearance of a squashed Group C car, replete with an almost comically out of proportion rear wing.

Sadly (or maybe sensibly), the demise of Group B, and the abortion of Group S, put an end to such aerodynamic silliness. Aero certainly didn't go away with Group A, but it became more reserved, with teams having to work within far tighter constraints, thanks to the firmly production car-based rules.

Through the 1990s and into the 2000s, manufacturers steadily found the means to incorporate an ever-growing number of aerodynamic features into their cars and, though constrained, development was just as intense. A glance at any circa 2000 WRC car shows they had spent plenty of time in the wind tunnel. However, the greatest technological innovations during that period came from other areas of the car, specifically the development of active differentials and huge leaps in damper technology.

The Group B vibe

This remained the state of play into the modern WRC era, with aerodynamics kept to modest dimensions by the regulations. Everything changed for 2017, though, and it seemed the Group B vibe was back. Suddenly, the cars switched from looking like (albeit muscular) shopping runabouts to caricatures of their roadgoing brethren, all multi-element wings, dive planes and huge, louvred wheelarches. Aero was once again a major talking point.

In a bid to make the WRC more spectacular, the 2017 rule changes opened the floodgates to aero development. In particular, the regulation bounding boxes for elements such as rear wings and diffuser were maxed out, while areas such as the sides of the cars were opened up for additional aero appendages.

Stellantis

The demise of Group B, and the abortion of Group S, put an end to such aerodynamic silliness

When the new regulation direction was announced in October 2015, Jarmo Mahonen, then FIA Rally director, explained the governing body's motivation as follows: 'All of the sport's stakeholders have been involved… recognising what our fans want to see. The cars will look dramatic and have more character; such are the freedoms we hope to see defined in the final technical regulations. Seeing one of these cars in action will really set the heart racing and that's exactly what was intended.'

In a rare stroke of genius, the FIA and WRC promoter hit the nail squarely on the head.

The regulation changes put into place centred around upping the overall pace of the cars, through a heady combination of engine, chassis and bodywork changes.

Shown here in action on the 1986 Acropolis Rally, the Peugeot T16 Group B car grew a vast rear wing, as well as more subtle aero devices such as dive planes on the front bumper

Audi

Audi's effort for the stillborn Group S category, the RS002, was a pure exercise in aerodynamics

Stellantis

When the T16 Peugeot took to Rallycross, it gained an additional twin-element wing

Stellantis

Early experiments with aero on cars like Lancia's Stratos were aimed at drag reduction

Stellantis

Group B cars of the early '80s, such as the slippery Lancia 037, used immense power to overcome drag

Lawrence Butcher

Post 2017, bounding boxes for areas such as the rear diffuser were used to their max

Though extreme aero went away by regulation in the early 2000s, in 2017 it was back with a bang, as evidenced by this M-Sport Fiesta

Dan Bathie

Lawrence Butcher

Likewise the rear wing and side skirts, shown here in end of current regs aero package

Lawrence Butcher

Rally cars are often damaged so, as well as being functional, aero devices have to be very robust, too

The engines stayed at 1600cc with direct injection and turbocharging, but a restrictor size increase from 33m to 36mm brought power from 300bhp to around 380bhp.

An increase in chassis width naturally resulted in a wider track, with a knock-on effect on suspension geometry. Additionally, the constraints around construction of the front suspension design were reduced. Coupled to these dimensional changes, the FIA also approved the return of active central differentials, though the front and rear units remained mechanical.

The most visual difference, of course, was the aero, and some took greater advantage of this fresh freedom than others, in particular the returning Toyota team. The Yaris WRC looked like it had raided the company's LMP1 parts bin when it arrived, making some of the competition appear positively conservative in comparison. Not only did the car feature a bewildering array of fine aerodynamic details – even the mirrors incorporated winglets – it also brought in a number of interesting, and sometimes controversial, features from circuit racing. Not least an exhaust-blown diffuser.

One might think a 1600cc engine would not provide the same effect as a V8 revving to 19,000rpm, as was used in the heyday of F1 exhaust blowing, but the rally engineers had a trick up their sleeves – anti-lag.

Blown diffusers

These systems see fuel injected off throttle to keep the turbo spinning at high speed, improving throttle response for the driver. As a result, the exhaust flow still has decent velocity, even at part throttle.

Blowing could prove particularly useful in low-speed corners where the velocity of the air flowing under the car is lower, as a diffuser with a steep angle of attack may begin to stall or suffer from flow separation, further reducing its effectiveness. When used correctly, an exhaust blowing system can allow for a more aggressive diffuser with a wider operating window than if it relied purely on passive flow through the underfloor.

Not every team decided to exploit this opportunity. Although Ford never admitted to it (unlike Toyota) M-Sport's Fiesta had a similarly positioned and angled exhaust outlet in the diffuser exit. Citroën and Hyundai, meanwhile, stuck with traditional exhaust systems, and Hyundai continued with this approach until the end of this season.

Why didn't all teams follow this approach? Toyota technical director, Tomo Fowler, once suggested that 'there is a possibility they didn't think about it, but I'd think that unlikely. It's possible they couldn't find a way to test it. I think that most likely, because it is not easy. Or, they found a way to test it and didn't find any gain, but I think that is unlikely.

'I know from what we know, there is almost no disadvantage to doing it. It is a few parts that weigh almost nothing to have it, and I've never seen any downside.'

He did also note that exhaust blowing was only effective under certain conditions, most likely those where ride height can be kept under control, ie tarmac rallies. 'It's application is limited in the rally season, and I think that is evident because if it was a huge thing, it would separate the cars,' he says.

'Getting aero to work on a rally car is a much bigger challenge than a track car'

Simon Carrier, design engineer on Toyota's 2017 Yaris WRC

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Borrowing from circuit racing practice, the Yaris WRC had an exhaust blown diffuser

Dan Bathie

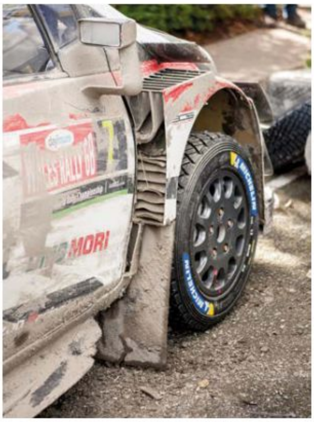
The key to rally aerodynamics is finding a best compromise package that works in all environments

Dan Bathie

Exhaust-blown diffusers proved very successful, but are now outlawed by regulation

Dan Bathie

To ensure diffusers still worked at low speed, fuel was injected off throttle to keep the turbo spinning



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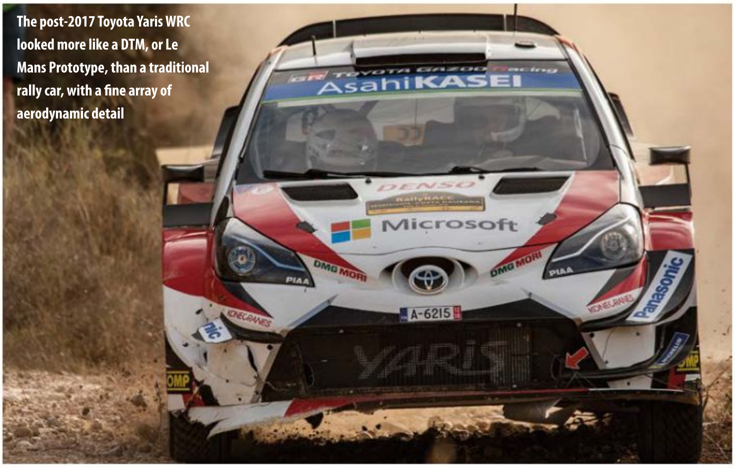
As well as being robust, aero packages must be able to cope with extreme ingress of mud, snow and rain



The post-2017 Toyota Yaris WRC looked more like a DTM, or Le Mans Prototype, than a traditional rally car, with a fine array of aerodynamic detail

Lawrence Butcher

As with every element of the sport, creating an effective aero package is about achieving the best compromise. From smooth tarmac stages, through the mixed ice and snow of the Monte, to the flat-out blasts of Finland, no one size fits all but, with regulations homologating bodywork for a season, teams have had to find a happy medium.

Philosophical differences

As Simon Carrier, who spearheaded the initial design of Toyota's WRC Yaris for 2017, explained, the challenges inherent in developing aerodynamics for rallying are quite different to those found on track.

'Getting aero to work on a rally car is a much bigger challenge than a track car. The principle of a track car is to keep the chassis as stable as possible, so it sits in an optimised position throughout a circuit to get the best from the aero. On a rally car, you can't do that.

'You can't sacrifice suspension travel for aero like you can with a track car. So we have had to come up with an aero package that works in all types of chassis attitudes, over a vast range of possible conditions that the car is going to run in. We can't end up with a car that has great aero at one particular ride height and one pitch angle but, as soon as you deviate from that, you lose the aero. That results in a car that is unstable and potentially unsafe. The real challenge is to get good aero performance but in all possible conditions.'

As 2017 rolled around, it was clear each of the WRC constructors had taken their own, unique approach to their car's aerodynamic philosophy. 'If you look at all the cars, there are clearly differences, and I think ours is probably the most extreme,' says Fowler.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'Our philosophy is we need a robust aero package that works at high yaw angles, high pitch angles, across the range of conditions'

Chris Williams, technical director at M-Sport

The sills on the Toyota WRC saw significant detail improvements over the years, many aimed at strengthening them against impact

'I think one thing that we did quite well in the beginning was identifying the complexity of the regulation change. We made some good choices about the amount of research we did in specific areas, rather than just dismissing things out of hand. Some of those brought gains, some wasted our time but, in the end, it came out well.'

Of course, taking Fowler's approach was viable for a well-resourced manufacturer team, less so when resources were scarcer, such as has often been the case for M-Sport. Though the team saw an increase in backing from Ford following its manufacturer and drivers' title win in 2017, it has never been awash with cash, and as such its development process had to be more targeted. For example, the team's 2017 car was designed solely using CFD, only subject to wind tunnel development later as Ford's support grew.

Predictable package

As the team's technical director, Chris Williams, explains, having a predictable overall car package from a behavioural perspective was its primary concern, rather than one with a narrow operating window.

'One philosophy is that you can set the car up in a very specific way and have to drive it in a very particular manner, within very tight parameters, but you can't do that on every event. Our philosophy, therefore, is we need a robust aero package that works at high yaw angles, high pitch angles, across the range of conditions.'

As the seasons passed and jokers were played, teams began to converge on a more Toyota-esque approach. It is notable that Citroën, which pulled the plug on its works effort at the end of 2019, started with a fairly conservative concept, but was working on an aero kit for the 2019 C3 that was arguably more extreme than any other. Its efforts sought to address issue of front-end grip (WRC cars have a tendency to understeer) and, in addition to stacking dive planes three deep on the flanks of the car, also added end plates to those dive planes. Sadly, due to homologation issues, Citroën never ran the concept in competition.

Adapting circuit race technology to a motorsport category that takes place on all manner of terrain, and where the competing cars' proximity to it varies wildly, added greatly to the technical challenge of engineering an aero device like the Citroën WRC's underbody

It is a fact of life that rally cars have a habit of ending up in the scenery. Indeed, an engineer working in the category once observed that they have yet to find drivers more creative than those in rallying when it comes to tearing parts off cars. This reality applies to aerodynamic devices just as much as to wheels and bodywork. All the aero flicks and flourishes mean nothing if they are deposited at the side of the road within a hundred yards of a stage start. One technical director even quipped that if you want to see the WRC's carbon footprint, it's scattered around the forests of North Wales.

Survivability

With the new-found freedom to adorn their cars with all manner of aero trinkets, teams were presented with two problems: making parts durable enough that they stayed on the car long enough to make a difference. Then ensuring that when they were unceremoniously knocked off, the balance of the car didn't drastically change. M-Sport's Williams noted that its cars could

Hyundai stuck with a more traditional approach to its aero development, eschewing the apparent advantage of blown diffusers

A load of hot air

A glance inside the engine bays of either M-Sport or Toyota's 2017-'21 WRC machines reveals a plethora of complex, sculpted ductwork. While these undoubtedly contribute to cooling the powertrain, control of the inlet and exhaust flows from the engine bays were also put to good use in influencing the cars' aerodynamic performance.

Taking the M-Sport Fiesta as an example, air is fed through the intercooler from the front grille, pulled by a pair of large fans sited behind the air-to-air heat exchanger, before being vented out over the bonnet. One engineer explained that this high temperature air rejoins the flow over the front of the car at the trailing edge of the front wheelarches, the idea being to create a separation boundary layer in this area, forcing the air that is disturbed by the rotating wheel away from the car. This has the effect of reducing the turbulent airflow directly influencing the front of the car, improving the performance of the aerodynamic devices.

The vent sizing could be adjusted on different events to balance the potential aero gains against the cooling needs of the engine, helped by the fact that many of the components fell under the 'variant' heading of the rules, meaning jokers were not needed to alter them.

This is a fiendishly complex area of aerodynamic development, requiring advanced CFD simulation to figure out. As such, from 2022 onwards, it has been deemed an unnecessary excess, with much tighter control over duct design and development brought in. Still, it was interesting while it lasted.

Lawrence Butcher

Pipes feed vented air out through adjustable bonnet vents in the M-Sport Fiesta...

Lawrence Butcher

...while in the Toyota, two fans draw air into the engine bay through the intercooler

handle losing small aerodynamic parts but, if a splitter or wing went astray, 'the sensitivity can become extreme.'

While this is less of an issue on lower speed gravel stages, in somewhere like Finland, where speeds are much higher, shedding a key aero part could be terminal.

Teams were accepting that certain parts would need replacing almost at each service, but throughout the five-year evolution of the WRC field, solutions were found to increase their survival rate. One example of this was Toyota's 2019 re-design on its side sills. The basic shape was kept the same as it was proved to work well aerodynamically, but the lay up of the part was altered to make it more rugged. 'That sort of feature – a big, wide, thin sill – does not lend itself to being smashed into rocks,' notes Fowler.

However, in line with its aerodynamic philosophy mentioned earlier, he adds that 'we wanted to put all the aerodynamic features there [on the car] even if we didn't think they would last, because at least we would have them some of the time. Now we are looking at how to extend that time and trying to find the best overall performance.'

End of an era

Come Monte Carlo 2022, a new age will dawn for WRC aerodynamics. Though the cars look pretty much the same at first glance (except the Fiesta, which is now a Puma), the rules have been pared back in the name of costs. The bounding boxes for the rear wing and sides of the cars are retained, but diffusers are out, as it would seem are features such as dive planes. There is also a noticeable

Come Monte Carlo 2022, a new age will dawn for WRC aerodynamics

clampdown on cunning use of cooling airflows through the cars (see box out above), while teams will also have to contend with the added demand of keeping batteries and hybrid system within their thermal limits.

Finally, it would be remiss not to note that there was much more to the last five years of World Rally Car development than just the aero parts on show. For example, the strides made in damper technology have been phenomenal, allowing cars to achieve scarcely believable levels of stability, which certainly helps the aero. Unfortunately, you'll have more luck getting blood from a stone than persuading a WRC engineer to talk about their dampers (just mentioning fluid-based inerters gets them flustered enough).

No doubt aero development will remain important in the new era but, with tighter homologation rules and less chances for updates, alongside the resource demands of learning about hybrids, it looks like the aero excesses of the past half decade will mark a high point for some time to come.

The aerodynamic developments of the 2017-2021 crop of cars will make way as new regulations aimed at cutting costs reduce the available options from 2022

Lawrence Butcher

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Competition, take two

How the ChassisSim Race Engineering competition showed up some tips, tricks and pitfalls to avoid when using simulation

By DANNY NOWLAN

Based on what we did during 2020's lockdown in the ChassisSim Race Engineering competition, and the positive response we received to it, we decided to run it again in 2021.

As with the first competition, the winning entries showed some innovative approaches, but also highlighted some pitfalls showing how you don't use racecar simulation. Given what a great learning experience it proved to be, some of the lessons learned are what I'll be discussing in this article.

The focus of this year's competition was engineering a mid-engined GT3 car at Bathurst. I did this for a couple of reasons. Firstly, thanks to Covid, we will not be seeing a GT3 car at Bathurst for a while. Given this is both a tragedy and a travesty, I felt it my civic duty to address this. Secondly, the vehicle model I gave the contestant was based on the ChassisSim LP560 GT3 template. As the vast majority of the GT3 cars we have out there can trace their DNA back to this, it was a far less eccentric car than the LMP2+ car we used the previous year.

Like in the first competition, the basis of the scoring wasn't just testing raw car speed, but also driveability. It was no accident therefore that we used a tame racing driver to then drive the result in ChassisSim Driver in the Loop. **Table 1** shows the guide to scoring that was issued to all contestants.

As can be clearly seen, if you just designed for raw speed and forgot about driveability, you would be punished. Conversely, you could put together a driveable car but, if it didn't have the pace, you would also be penalised. Welcome to the world in which the race engineer exists.

One of the things we will consequently discuss is the competitors who fell for the trap of pure speed and then got punished badly in the DIL section.

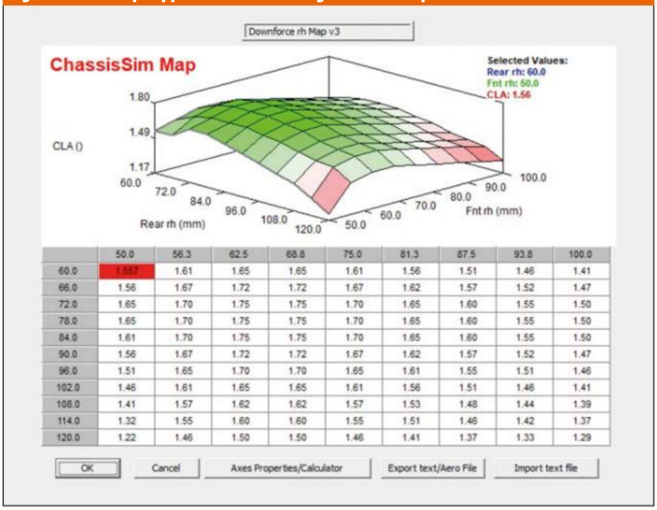
Setting limits

The other thing we did was to strictly limit some of the parameters you could play with, but encourage freedom in others.

Table 1: ChassisSim competition scoring guide

Competitor	LTS place	DIL place	Final score	Place
A	1	1	1+1 = 2	1
B	2	2	2+2 = 4	2
C	3	3	3+3 = 6	3
D	4	4	4+4 = 8	4
E	5	5	5+5 = 10	5

Figure 1: Aeromap supplied for the mid-engined GT3 competition car



	50.0	56.3	62.5	68.8	75.0	81.3	87.5	93.8	100.0
60.0	1.557	1.61	1.65	1.65	1.61	1.56	1.51	1.46	1.41
66.0	1.56	1.67	1.72	1.72	1.67	1.62	1.57	1.52	1.47
72.0	1.65	1.70	1.75	1.75	1.70	1.65	1.60	1.55	1.50
78.0	1.65	1.70	1.75	1.75	1.70	1.65	1.60	1.55	1.50
84.0	1.61	1.70	1.75	1.75	1.70	1.65	1.60	1.55	1.50
90.0	1.56	1.67	1.72	1.72	1.67	1.62	1.57	1.52	1.47
96.0	1.51	1.65	1.70	1.70	1.65	1.61	1.55	1.51	1.46
102.0	1.46	1.61	1.65	1.65	1.61	1.56	1.51	1.46	1.41
108.0	1.41	1.57	1.62	1.62	1.57	1.53	1.48	1.44	1.39
114.0	1.32	1.55	1.60	1.60	1.55	1.51	1.46	1.42	1.37
120.0	1.22	1.46	1.50	1.50	1.46	1.41	1.37	1.33	1.29

In both competitions, this wasn't driven by the fact that I have finally seen the light on spec formulae (I haven't!), but because I didn't want the competition degenerating into a complete free for all.

So, the masses / inertias, wheelbases, tyre and aero models were all fixed. Everything else was free. That said, some lessons were learned in this that I will be tightening up on for next year's competition.

Before we get into this in depth, a quick mention of the challenges of the GT3 category are required. What makes GT3 so interesting is it lies in the halfway house between a mechanical and an aero formula.

Over the last couple of years, the pendulum has swung more to the aero side, but a good rule of thumb is to pay close attention to both the aero and mechanical grip aspects of a GT3 car.

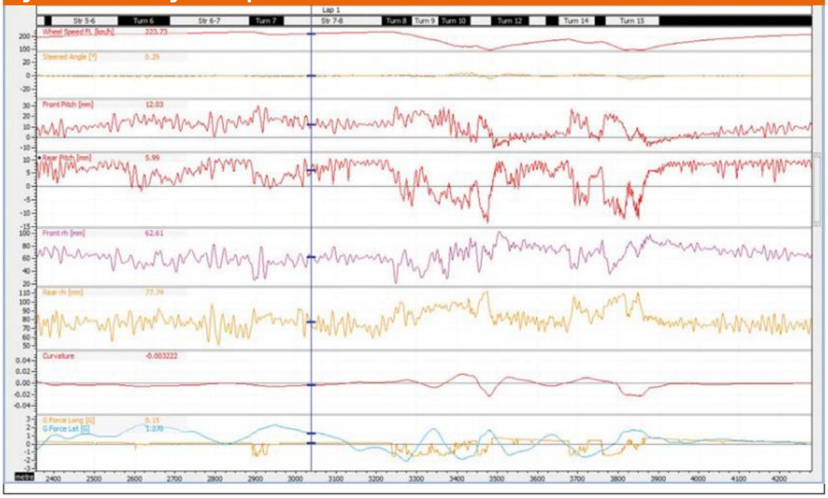
As with the previous year's winning entries, the finalists in the 2021 competition nailed where you needed to be in the aero. This is particularly critical for a track like Bathurst, particularly as you go up Sulman and McPhillamy Park to Skyline, where you are looking at mid-corner speeds of up to 200km/h. Ignore aero at your peril here.

The aeromap contestants had to play with is shown above in **Figure 1**.

A good rule of thumb is to pay close attention to both the aero and mechanical grip aspects of a GT3 car

The skill shown here was in making the damper stiff where it needed to be, and not stiff where it was required

Figure 2: Rear ride height envelope



From the aeromap provided, the sweet spot is a front ride height between 62.5 and 69mm and a rear ride height of 72-84mm. Reviewing the data of one of the podium entries is most enlightening. This is illustrated in **Figure 2**.

Due to the nature of Bathurst, you have a lot of bumps and undulations so can't set the car too low. The winning entry's front ride height of 62mm and rear ride height of 80mm was right in the pocket.

The other common theme with the winning entries was they backed off on spring rates but had higher damping rates. This I thought particularly clever, and **Figure 3** shows the front damping curve of the winning entry.

The skill shown here was in making the damper stiff where it needed to be, and not stiff where it was required. So, compared to the baseline, the front bump was significantly stiffer, and the bypass went to 120mm/s. However, at high speed a much lower damping rate was used.

This, combined with a lower spring rate, showed a considerable improvement in the delta tyre loads, as illustrated by **Figure 4**, where the baseline is coloured and the winning entry is black for clarity.

Reduced variation

I would now draw your attention to the third and fourth traces in **Figure 4**, which are the front and rear tyre loads respectively. Note the reduced variation evident, particularly between 2600 and 2740m. At a track like Bathurst, you would sell family members to achieve a delta like this.

Alas, there were also some all-too-common pits the competitors fell into. Firstly, while the winning entries were fast and showed considerable improvement in grip over the baseline, their stability was marginal. One of the key feedback points from the racing driver was, while the winning entries were fast and great for a qualifying lap, they would really struggle over a stint distance due to the high bar rates. This is a good example of how something can be great for a simulator that knows exactly where the grip is, but a real driver will struggle with. The plot from the lap time simulation of the winning driver shown in **Figure 5** illustrates why.

As can be seen, right at the mid-corner condition, the stability index is varying between -5 and -10 per cent. This is not a show stopper in the strictest sense but, if you recall my previous article where I discussed some rough guides on where you should be aiming for in terms of driver stability, this is strictly professional race driver material. And given how unforgiving a track like Bathurst can be, this can cost you dearly if things go wrong.

The soft trap

The other huge trap some of the competitors fell into was going ridiculously soft. In particular, I need to call out those who are active in FSAE / Formula Student on this.

On paper, yes, this is a very fast solution, for two key reasons: firstly, the contact patch load variations look sensational. Secondly, since the simulator knows the grip exactly, it's not particularly fazed by the chassis moving all over the place.

This is the common trap all transient simulation packages and shaker rigs fall into, and it's driven by how good the contact patch load variation looks.

However, what happens in the real world is totally different, for two key reasons. The first is that with the chassis bouncing around like there is no tomorrow, an actual driver

Figure 3: Winning entry's front damper curve

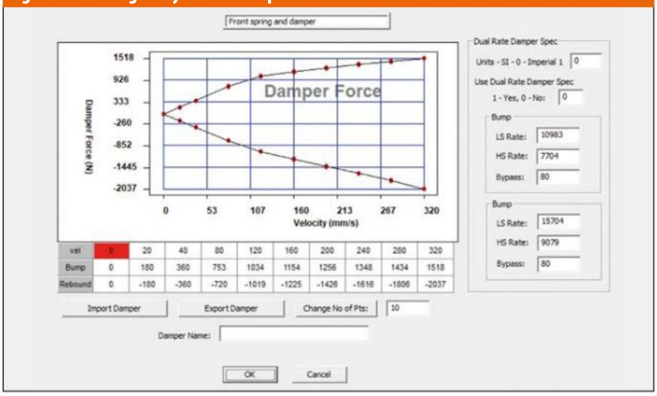
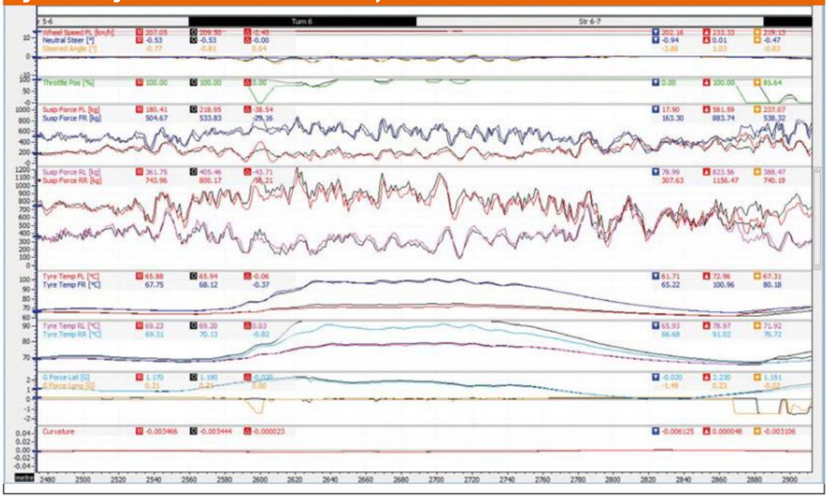
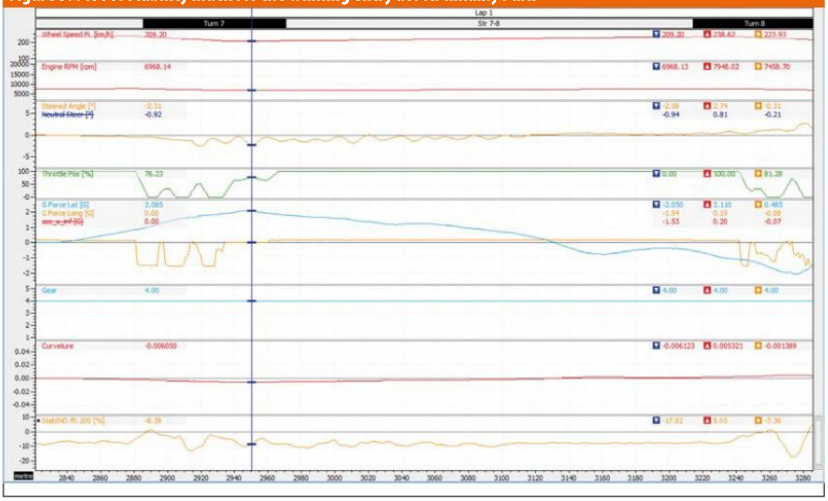


Figure 4: Change between the baseline and delta tyre loads



If you start making changes greater than, say, 30 per cent of your base spring rates, you are out of the window

Figure 5: Plot of stability index for the winning entry at McPhillamy Park



Your simulator is a calculator, not a magic wand, and you need to treat it as such

will really struggle to retain control. Again, doubly so at a fast, undulating, on-camber track like Bathurst. Driving on a set-up like this will destroy driver confidence.

To prove the point, when those set-ups were trialled by our tame racing driver, he barely got through turn one, let alone start to work his way up the mountain. And a lot of very colourful four-letter words were uttered in the process!

Tyre temperature

The other reason this won't work in the real world is tyre heating. I have discussed on many occasions how your selection of springs, bar rates and geometry settings isn't just dictated by ground clearances, but by bringing the tyres up to temperature. If you start making changes greater than, say, 30 per cent of your base spring rates, you are out of the window. This is a hard limit on the delta of simulated changes that a lot of simulation users forget, and I'll be implementing into the rules for next year's competition.

A quick note here about the limitation we have just discussed with regards to tyre heating. Every simulation package you use will be limited by this. Tyre models with their traction circle radius as a function of load only are affected by this, but it also extends to 3D models (traction circle as a function of load and temperature as well). This really underscores why your simulator is a calculator, not a magic wand, and you need to treat it as such.

In closing, as with the previous year's simulation competition, the 2021 competition was revealing on many levels. It really illustrated what racecar simulation can do very well, which is finding the aero sweet spot and how to exploit the relationship between spring and dampers. Alas, it also showed up some of the pitfalls discussed above.

However, the great news is, once you're aware of this and know what the boundaries are, you have a very potent weapon in your hands. Provided you remember the bit about simulation being a calculator, not a wand.

IN BRIEF

Hyundai Motorsport GmbH has confirmed that team principal, **Andrea Adamo**, has departed the company after six years due to personal reasons. His day-to-day responsibilities, which include the FIA World Rally Championship, Pure ETCR and customer racing operations, will be assumed by company president, **Scott Noh**, with support from respective department managers until a new appointment is announced.

'After six years with Hyundai Motorsport, we have mutually agreed for me to step down from my role as team principal,' said Adamo in a statement. 'It is time for me to reflect on a relentless and successful period in my career, one full of high points, happy memories and titles.'

These include the FIA Touring Car Cup in 2018 and 2019, and the WRC titles in 2019 and 2020.

The **British Touring Car Championship** has confirmed a full grid for 2022, with all of its 32 TOCA BTCC Licences (TBLs) allocated. The championship has 29 for teams, and has agreed to loan out its three TBLs to meet demand. The full grid is a particular achievement as the series moves into a new era for 2022, with additional hybrid power for the cars that will also use 20 per cent sustainable fuel.

'The demand for the BTCC has never been greater,' said BTCC chief executive, **Alan Gow**. 'Clearly, this also means I've failed to achieve my long-stated aim of reducing the grid size. Whilst that remains the goal going forward, admittedly it's a nice problem to have.'

Ligier Automotive has confirmed that **Franck Tiné** has joined the company as motorsport director after seven seasons as sporting director at Sebastien Loeb Racing. Tiné created a gateway structure between Europe and Asia for young, talented European drivers struggling to find the budget to race in Asia. He then launched LAP Sport Management, supervising up and coming talent, before working as a management consultant for various GT and Touring Car championships.

FIA confirms 2026 F1 engine regs

Mid-December, the FIA confirmed that new F1 engine regulations will be introduced in 2026, and laid out the key objectives that have been thrashed out over the course of the 2021 season for the units.

Following extensive meetings with manufacturer representatives, the FIA was able to push through its vision for the future of the most watched motor racing category in the world.

Four key objectives were planned for the future regulations. These include: a powerful environmental message and the use of 100 per cent sustainable fuel; significant cost reduction through technical, operational and financial regulations; to make it possible for newcomers to join the sport at a competitive level; to protect the show with high-revving power units and the ability for drivers to race.

For the power unit specifically, the FIA confirmed it will retain the current 1.6-litre V6 architecture, but increase the electrical power to 350kW, while also removing the exhaust-driven energy recovery system, MGU-H.

The FIA also confirmed it will introduce a cost cap to the power unit, which should take out a significant amount of the investment required for teams to compete.

At time of writing, the final details of the regulations have yet to be finalised, but the FIA has targeted the early part of 2022 for its World Motorsport Council to approve them, giving teams four years to develop and produce engines ready for track testing at the end of 2025.

100 per cent sustainable fuel, cost reduction and more accessibility, all while protecting the show

Ben Sulayem wins FIA vote

XPB images

14-time Middle East Rally Champion succeeds Jean Todt as FIA president

Mohammed Ben Sulayem won more than 60 per cent of the votes and will succeed Jean Todt as president of the FIA on a four-year term.

Sulayem, 60, from the United Arab Emirates, was previously the FIA World Motor Sport vice president for the Middle East. A former Rally driver, he was 14-time FIA Middle East Rally Champion and won 61 international events.

His campaign ran under the banner 'FIA for Members', and committed to double motorsport participation worldwide, strengthen diversity and inclusion and be a leading opinion former on sustainable mobility.

AVL's balancing act

Austrian company, AVL, has extended its partnership with the DTM and DTM Trophy and will continue to provide the Balance of Performance service to the series in 2022.

The company had already proved its worth in 2021, balancing seven different brands competing with GT3 cars, including Audi, BMW, Mercedes-AMG, Ferrari, Lamborghini, McLaren and Porsche with its own exclusive BoP system.

After proving its BoP system in 2021, AVL Racing will balance both DTM and DTM Trophy in 2022

'The DTM-specific method, based on state-of-the-art virtual simulation of cars and the environment of the vehicle with great depth of detail, taking into account a large database and without the real-life insights of a test driver, has proven to be eminently reliable,' said Michael Resi, director of competition and technology at the ITR.

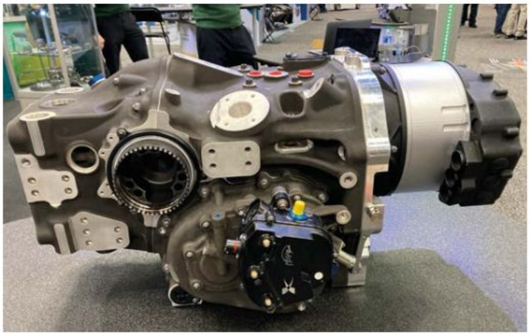
'Just like our new race director, Scott Elkins will be responsible for both DTM and DTM Trophy in future, AVL Racing will now also be taking care of the vehicle balancing for both series,' confirmed Frederic Elsner, director of events and operations, ITR. 'As a result, we will implement an identical quality standard in DTM and DTM Trophy.'

Xtrac unveils 1359 LMDh ’box

British gearbox specialist, Xtrac, has officially unveiled its new gearbox, the 1359, which will service each of the LMDh cars that are eligible to compete in IMSA and in the World Endurance Championship.

The seven-speed gearbox is designed to accommodate the new hybrid system from Bosch and to help teams adapt to new regulations that are coming for the 2022 season. LMDh cars are eligible to run in 2022, but it is believed that most will compete for the first time in 2023 as none have tested at time of writing.

New regulations will limit the number of ratio sets available to teams throughout the season in a bid to control costs, and so the extra gear, compared to the 1159 ’box currently run in the DPi chassis, will help teams to cope with the different types of circuit encountered on the schedule around the world.



It’s not a spec ’box, but it may as well be as all four LMDh constructors are using the Xtrac unit

The 1359 gearbox features cooling options on both sides, according to preference for engine choice, an internal oil tank and a pre-loaded differential.

Although choice of gearbox manufacturer is free under LMDh regulations, each of the four chassis designers have opted for Xtrac to supply the gearbox and have worked with the company to specify the location of the rear suspension pick-up points that work for each of their chassis designs.

Brembo launches Late Model brake system

Brake specialist, Brembo, launched an all-new brake system for Late Model racers at the PRI Show in Indianapolis in December. The system is engineered specifically for competition and includes calipers, discs, brackets and hardware for an accessible price, says the company.

The forged aluminium, asymmetric calipers are radial mounted, offering a robust stopping solution for dirt and asphalt racing, as well as improved driver pedal feel.

The internal fluid passages offer a smooth external design that will not be affected by the dirt, rocks and other track debris that can gather in calipers with external fluid lines.

Brake discs comprise premium materials cast at Brembo’s own foundry and come in multiple sizes. The calipers are designed for extended wear life, greater thermal capacity and are machine balanced to Brembo’s standards.

Pads are made up of the latest compounds available to suit driver and track preferences, and are designed to work with the low-drag Brembo Late Model caliper.

‘The demands of Late Model racing drove the design of the system and will offer racers on dirt or on pavement a higher level of stopping power, as well as improved pedal feel, reliability, and serviceability,’ said Dan Sandberg, Brembo North America president and CEO. ‘Competitors will get Brembo performance with a price point that is in line with the spirit of Late Model competition.’

A new, high quality stopping solution priced in line with the spirit of Late Model competition

IN BRIEF

Ligier has unveiled the JS PX, a track special based on the company’s LMP2 chassis, but fitted with an 825bhp, twin turbo V6 engine. The car should be capable of lapping Le Mans in 3m19s, according to the manufacturer, were the car to be eligible to race.

Clive Sutton, the high-performance and luxury car retailer, will bring the world’s only Shelby-licenced Cobras to the UK. Three right-hand drive versions of Cobra continuation and replica models are prepared by Superformance.

Racing Force International, a company of the Racing Force Group, has signed a multi-year deal with **Ferrari**, appointing **Bell Helmets** as Technical Partner of the iconic Italian car manufacturer. The partnership deal states that Ferrari will use Bell Helmets in every racing activity for the coming years, from the Ferrari Challenge to Formula 1, including all Ferrari Competizioni GT drivers and the Ferrari Attivita Sportive GT world, in addition to the official crews of the Hypercar in the FIA WEC.

Racing Force SPA has also signed a deal with the FIA, which will see race officials, safety car drivers and FIA personnel in OMP fireproof suits. The decision comes at the end of a tender process in which the main operators participated.

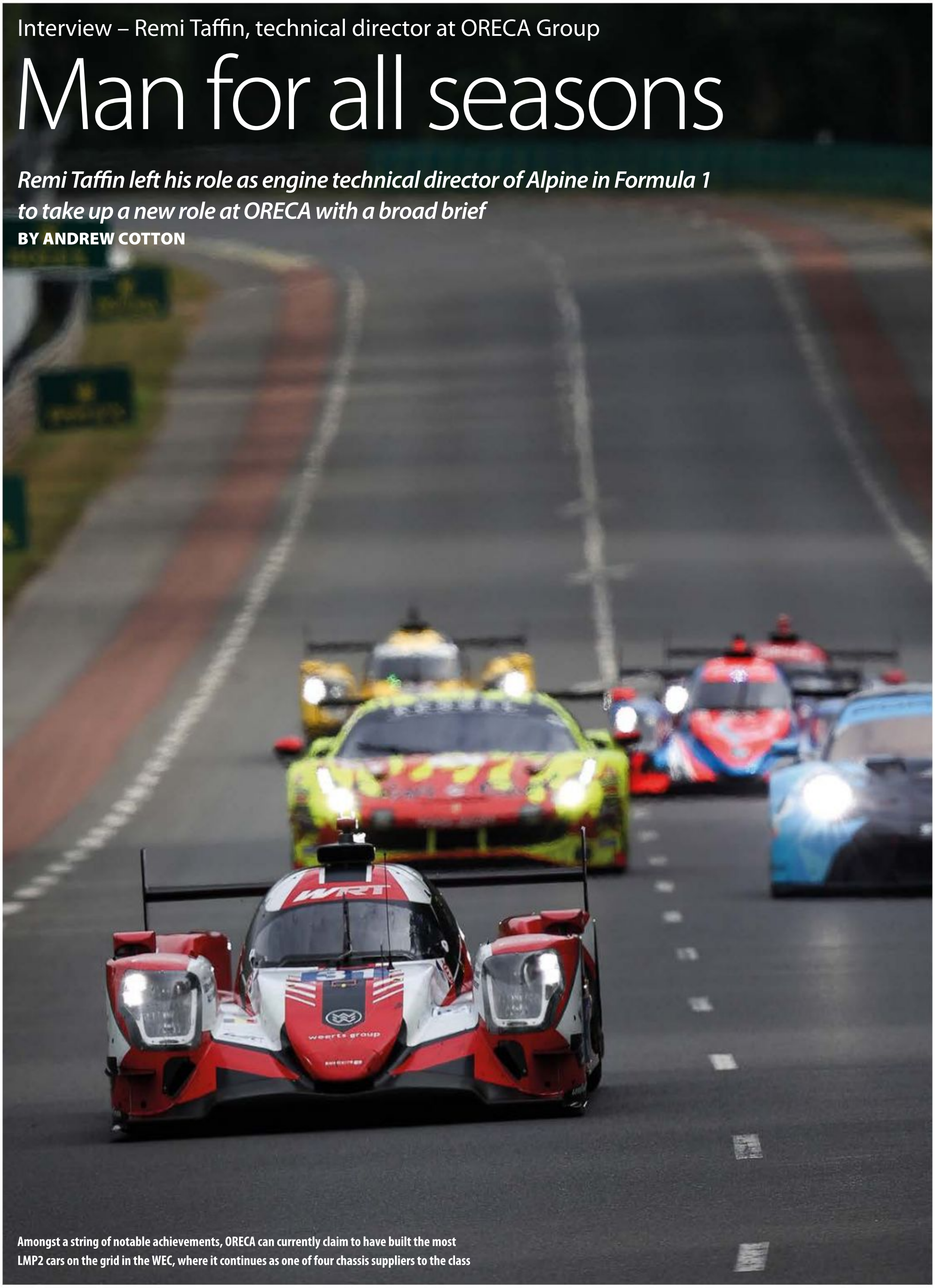
NASCAR and leading sports streaming service, **FloSports**, have signed a multi-year partnership that will see FloSports host NASCAR’s grass-roots sports, including the ARCA series, Whelen Modified Tour, Pinty’s Series and Advance Auto Parts Weekly Series. The companies are aligned with a shared mission of delivering the best in grass roots motorsport around the world.

Interview – Remi Taffin, technical director at ORECA Group

Man for all seasons

Remi Taffin left his role as engine technical director of Alpine in Formula 1 to take up a new role at ORECA with a broad brief

BY ANDREW COTTON



XPB Images

Amongst a string of notable achievements, ORECA can currently claim to have built the most LMP2 cars on the grid in the WEC, where it continues as one of four chassis suppliers to the class

ORECA

One of the main reasons Taffin chose to make the move to ORECA is to gain further experience in the endurance sector, but also because the constructor is involved in so many different categories

Following a 20-year career with Renault, it was with some surprise that Remi Taffin left the company during the middle of the 2021 season, having become engine technical director for the French team's Formula 1 programme.

Rumours immediately linked him to Red Bull, with whom he had worked when the Milton-Keynes based team ran Renault engines, and was in the process of taking over the IP from Honda for the current power units. Taffin would have been a perfect fit.

However, although the Frenchman confirms he had other offers on the table within Formula 1, both from teams and from power unit suppliers (which strongly indicates Red Bull), he also had another that proved to be rather intriguing. A 'phone call from Hugues de Chaunac, founder and chairman of the French company ORECA, turned into a marathon conversation that convinced him to consider a future outside Formula 1.

ORECA is a company on the move. Having won Le Mans multiple times, running the Mazda in 1991 and with Toyota during the hybrid era, it has also scored class wins with the Dodge Vipers and, more recently, in LMP2 as a chassis supplier. It produces cars for the LMP2 category and currently enjoys the largest share of the grid in the WEC and at Le Mans, where it was selected to continue as one of the four chassis suppliers to the class.

Technology hub

It is also a multiple French Formula 3 champion team and World Touring Car Championship winner with SEAT while, from a technology standpoint, the company runs its own engine department from its base in Magny Cours. On top of all that, it recently signed a deal with Red Bull to produce chassis for its hydrogen car, and confirmed it will supply the LMDh chassis to Acura, as well as Alpine.

It wasn't hard to see the attraction for Taffin. ORECA is

This was an opportunity too good to miss

based in Signes in the south of France, and just announced it will build a new structure on its complex behind the Paul Ricard circuit to build the new 2023 Ferrari GT3 cars, having taken over the contract from Michelotto.

Co-ordinating this increase in manufacturing and technology, as well as overseeing the development of the Ferrari in conjunction with the Italian manufacturer was always going to be a big job. And this year it became clear that its technical director, David Floury, who had been seconded to Toyota to help run its WEC programme, would be taking up the role full time in Cologne. For both de Chaunac and for Taffin, this was an opportunity too good to miss.

'I had a window that opened earlier in the year when I left Alpine, and I basically took a few months to see what would be the next chapter for me,' says Taffin, who only started his tenure at ORECA in late December, but who expects to become heavily involved in the endurance racing scene.

'The obvious one was to continue to work in Formula 1, and I had some links with different teams and power unit manufacturers, but I thought that it was maybe time, after 20 years in the category, to see different things.'

Situation vacant

'It was something like summer, and I was not really yet into the detail of my new job, when I had a 'phone call from Hugues. He said he had this position he could offer me, what did I think? We had a half-hour discussion, that led to an hour, then to another hour, and that is how it all started.'

'I basically decided to move to ORECA for more than one reason.

The first is that it is an established company in the motorsport industry. ORECA is quite deep into endurance programmes, which I was keen to explore, and is building cars, making chassis, which was the other facet of the world I have been into in the last 20 years.

'On top of that, Hugues wanted to try to build up on the current activities in ORECA Magny Cours building engines, and Signes building chassis.'

The assumption, given Taffin's background, is that the Magny Cours-based engine facility would be his first priority. The World Endurance Championship will go to a new biofuel, supplied by TotalEnergies, in 2022, and there is a major drive towards hydrogen in endurance racing in the next four years. Riding the crest of that wave would be a logical step, but instead Taffin is tasked primarily with the facility at Signes, and ramping production up to meet with a massively increased demand.

'I have to say that the activity in Magny Cours is well established, with quite a few customer applications,' confirms the Frenchman. 'We are looking at Dakar applications, and I would say it is not the first priority within ORECA Group for me today. Instead, that is to try to get the activities in Signes to the spec we need to deliver our projects – GT3 and two LMDh cars – which is taking most of the resources.

'Maybe going back to Magny Cours, that could be something for the second stage. The team there is delivering a lot and it is not cruising, but they have a grip on what they are doing so I was basically asked by Hugues to try to focus on Signes.

'Having said that, we also have in mind a few ideas. There is a lot going on in the energy front with biofuels, hydrogen and so on, and that is obviously a subject we will try to tackle as soon as we can.'

The Alpine coincidence

On the subject of that increased demand, one of the key signings this year was Alpine, which will use an ORECA chassis as it returns to Le Mans in 2024. It was natural to assume Taffin was one of the central reasons behind the French manufacturer selecting ORECA as its chassis partner for LMDh.

The regulations stipulate that one of four manufacturers may build cars to the rule set, including Dallara, Multimatic and Ligier, as well as ORECA. Alpine was known to be looking at both ORECA and Ligier to supply its chassis, but in the end plumped for the former, which shortly afterwards confirmed Taffin to replace Floury.

'That is how it appears, but it was not linked,' argues Taffin. 'The choice was made without parties knowing I was doing this, and obviously Alpine didn't know, so it was more of a coincidence.'

The ORECA chassis will have two applications, as a factory car for both Alpine and Acura, which in December also confirmed a widely reported rumour that ORECA would continue as its partner, and as a customer car for the next generation of LMP2 cars.

The new Acura will hit the track in competition in 2023, and so development to take its powertrain will come first. The new Alpine will race in 2024 at the same time as the customer-facing LMP2 chassis.

'It does not really change how we run our LMDh programme and chassis design,' said Taffin of the challenges of building cars for two manufacturers, and for customers as well. 'We are only looking at making the best

One of the new projects that will fall under Taffin in the short term is the development of the Ferrari GT3 car

LMDh car, but this is in isolation. If you look at the bigger picture, the LMDh was supposed to be derived from LMP2, but LMP2 will be created after LMDh.

'I guess the main thing we will be suffering is the potential knock-on effect of developing for LMDh first, and the economic perspective that you see when you derive a car from an existing car. You keep the costs low and try to make it as efficient as it should be. We will be doing a bit of that. If you ask me *how* much, though, I don't know.'

All change Ferrari

One of the new projects that will fall under Taffin is the development of the Ferrari GT3 car, which will race in 2023 after a season of testing. Working in collaboration with Ferrari, ORECA will supply not only its endurance expertise, but will also build the cars. It's a major change for the Italian manufacturer after years of service from Michelotto, and ORECA is expanding to accommodate the new contract. By regulation, there will need to be more than 20 cars delivered for competition in the first two years after introduction but, given the fact it's a Ferrari, the likelihood is this will be a mightily popular car.

'This year we have been advising them [Ferrari] on what has been done and what can be optimised. Where we will have most of our role is building the cars, and looking after them and the customers,' says Taffin. 'Next year, we will be developing the car. The car will be on track before the first race, and we will deliver our experience there too, but the development on track will be done with the Ferrari guys from Maranello.'

It's going to be a busy few years for Taffin at ORECA, but it signifies a return to a more versatile role than he may have been used to in Formula 1.

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Taffin's initial role will be to focus on production at ORECA's Signes factory, where the new Ferrari GT3 cars will be built, as well as two LMDh chassis


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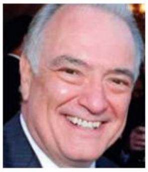

Full steam ahead

Welcome to 2022 – a year of exciting opportunities

The outcome of the final grand prix of the year in Abu Dhabi typifies the business year of 2021. Unpredictable, complicated, exciting, unfair, and unwelcome interference from governing bodies! Whoever you supported, you will agree it was a memorable end to a close-fought championship and attracted huge audiences.

Led by this surge of interest in F1, motorsport in general is in a better position now than for many years. Competitors and spectators are growing fast, giving some security for future motorsport business.

However, the Abu Dhabi race reminded me of the dangers in welcoming cameras or sound 'behind the scenes' of any sport. Decisions made, under pressure, in the last laps will make for a stunning final Netflix programme, but turning a sport into one 'made for TV' brings problems.

Any sport's popularity relies on the audience witnessing a *real* sporting challenge between competitors, be they Olympic athletes, footballers in the FA Cup or drivers at Le Mans. Abu Dhabi certainly provided entertaining TV, and perhaps even an insight into the F1 of the future.

The incredible increase in audience numbers achieved by the Liberty Group are long overdue, attracting a worldwide audience of all ages. They are opening up Formula 1 to a valuable, growing audience by embracing young drivers such as Norris, Verstappen and Russell, amongst others.

A recent F1 poll shows the average age of viewers dropping to 32, and the female audience doubling to nearly 20 per cent. Social media fans are also growing. Verstappen has two million Instagram followers, but he's a way to go to catch the older Hamilton, who has over 18 million.

But whilst increasing new fans is vital, it is important to retain their original supporters, too.

Regulation energy

All this action in Formula 1, one way or another, increases the size of the motorsport market as a whole, as well as interest in all forms of motorsport competition, and the business opportunities linked to it. Despite the strange times we live in, in general motorsport business remained good in 2021, and into 2022. Demand has been high as new technical regulations affect junior formulae all the way through to endurance and Formula 1. These changes create an energy, which spreads throughout our whole business community.

That said, global difficulties across a variety of supply chains are still proving difficult to overcome. Failure in the supply of computer chips is reaching danger level, and OEMS will soon be unable to meet sales demands due to this. The motorsport supply chain will then get drawn into a dangerous situation.

XPB Images

Young, exciting drivers like Formula 1's Lando Norris are broadening interest in motorsport and making it more appealing to a younger, growing generation

Along with supply shortages, our businesses are handling exceptional, unpredictable price increases. To obtain some vital supplies, there is now virtually an auction, after which the highest bidder then passes along those price increases to their customers.

Motorsport benefits by handling small volumes, but a 'black hole' from limited materials or components will damage businesses in 2022. What a challenge – great demand on one hand, but supply chaos on the other.

The fast-growing popularity of F1 across the USA will see at least two grands prix next year. This is the largest national motorsport marketplace in the world and has grown with only limited European or UK suppliers. As audiences start to witness the performance of an F1 car, other US domestic series will be curious to learn more about the supply chain behind their technology. Again, good news for the UK's Motorsport Valley businesses.

A few companies have supplied specific series in the USA, but now NASCAR, endurance Sportscars, IndyCar and others will look to our community for supplies. To find ways to engage with this vast new market, contact the MIA at www.the-mia.com. We have offices in Indianapolis and Charlotte, the two primary motorsport centres, ready to help you.

Market forces

The recent Performance Racing Industry (PRI) show in Indianapolis was, once again, extremely popular, demonstrating America's independence from other international market conditions. Americans will race *anything*, so add this market to your future plans.

The MIA's Energy Efficient Motorsport conference is now planned for March 23 2022, at the NEC, Birmingham. It will host outstanding speakers sharing their knowledge of various powertrain solutions for motorsport, particularly both hydrogen and sustainable fuels. Join us there, where we will discuss the future of hydrogen in motorsport.

Battery is already well established as a leading solution, but has problems ahead. They are suitable for urban environments, but long-distance travel currently limits their potential. We also need to resolve the disposal of the batteries and the scarcity of some of their materials, and the social problems attached to these issues.

Both the air and marine markets are looking into complementary solutions. Battery power has limited appeal to those on water and in the air, and motorsport can work with these sectors to test, develop and prototype solutions powered by hydrogen. The limitations of green hydrogen are primarily in the manufacturing process but, with volume production, these will be overcome.

Based on these exciting new technology challenges, and the fast-growing popularity of motorsport, 2022 will bring new business to our community. I look forward to seeing you at future MIA events and wish you every success.

For more information on the MIA, check out www.the-mia.com – or contact info@the-mia.com.

What a challenge – great demand on one hand, but supply chaos on another

Inside the world of modern motorsport technology
Racecar engineering

PIT CREW

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Safety first

Some things exist for a reason, and it's not a reason to argue

As the dust starts to settle on the 2021 Formula 1 World Championship, it's a good time to look back on possibly the most dramatic of all years. Before we start, let me congratulate Red Bull and its lead driver, Max Verstappen, on a worthy Drivers' title, and Mercedes on winning the Constructors' title. Honours even, although the world more easily recognises the individual drivers' title than the one that acknowledges the team aspect of the sport.

Verstappen and Lewis Hamilton were in a class of their own in the second half of the year, consistently leaving the rest of the field way behind, including their own team mates. Their consistency and speed was breathtaking, but so was the reliability of their cars. Neither had a mechanical breakdown throughout the season, allowing their drivers to push to the absolute limits, producing the most extraordinary of shows.

However, there were some alarming aspects to the season that need to be addressed urgently. One of those is that the FIA puts a stop to teams being able to harangue the race director by radio. Imagine the chaos if football team managers were able to address the referee directly. So why should racing permit such lobbying in a high-stress situation and try to force mistakes?

Driving standards

The inconsistency surrounding driving standards cannot be allowed to continue in motor racing's most watched category either. If a driver takes action to avoid an accident, they should not be penalised for it. Should another driver put their car in a position that an accident is the only solution, they *should* be penalised. It's not complicated. With such fine margins between two extraordinary drivers, this year that line has become somehow blurred. Clarification will lead to further rules, making the sport even more regulated, but that is necessary here.

As drivers exploit every opportunity, so too the arguments become more ridiculous. What is a race director supposed to do when the DRS detection line becomes a weaponised part of the track? The only solution is to change the rules and force the race director to dictate the point on the circuit where such a move can take place, and tell the teams and the drivers when that should happen. That is not the job of a race director but, in the interest of safety, it probably will be in future.

Before anyone starts waving their arms around, I'll acknowledge here that F1 is not an isolated incident. In the final round of the World Endurance Championship, Ferrari was ordered to give the lead back to the Porsche it punted off during their battle for GT honours and, as the lead car slowed on the main straight to do that, the Porsche dived into the pits. The penalty was considered served, Porsche cried foul and it tainted the season. They also had BoP to complain about, but that's an argument for another day.

Strategic weapon

In terms of the safety car, and time lost behind it, that's just racing. I would far rather drivers and teams accepted the safety car is an aptly-named device, not a strategic weapon.

In F1, Mercedes lost out this time, having controlled the final race admirably, and lost its advantage in the process. That's tough, but fair. Where race direction totally failed, however, was to confirm that cars between the title contenders would not be able to unlap themselves, and then changed that to allow only the cars between the leader and second place to pass. That decision was, I think, made for the show rather than the sport. It therefore wasn't right and, not only did it affect the outcome of the race, it unfairly penalised those lapped cars behind Verstappen who completely lost touch with those they were fighting ahead of them. And let's not forget, Hamilton had lapped those cars on track *before* the safety car came out, so they were in play in real time.

There needs to be a recognition of safety that reaches beyond competition

In my opinion, there needs to be a recognition of safety that reaches beyond competition. It's harder to accept that in sprint racing than endurance racing, granted, but protecting marshals and drivers that may be injured in their crashed cars is more important than the outcome of a race.

There are some sacred elements to racing that must be protected, in all forms of the sport. Safety cars are there for one reason – to protect those dealing with accidents or incident. The Virtual Safety Car is merely a faster way to get cars to reduce speed. There is a simple suggestion to improve safety, which is to close the pits under caution. F1 cars don't need fuel to complete the race so, if a car carries the wrong tyre, or damage, before the caution period, there is no argument to say they should rectify that with reduced penalty. Leave the race director alone, close the pits under caution, respect safety. It should be simple.

ANDREW COTTON Editor