ENDURANCE: BMW's motorsport director talks Le Mans and GT3 – p76

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The BTCC is one of the most hotly contested tin top racing series in the world. For 2022, it welcomes a brand new customer engine, new fuel and the first hybrid system in any Touring Car series worldwide

Mark Chivers

The road ahead

How Formula E is pushing development of electric passenger car technology

We are amid a necessary revolution in the motorsport and automotive spheres. The requirement for high-efficiency powertrain to lower CO_2 emissions means race series organisers and governments alike are pushing for equally efficient solutions to the task of moving a vehicle forward.

Motorsport often talks about road relevance, and has had its place in changing, or at least popularising, certain areas in the showroom. Carbon fibre trim is an obvious example, paddle shift gear change another. Likewise, when the turbo F1 era got underway in the 1980s, we saw more turbo cars built for the road.

Right now, though, ecology is a huge subject, so should motorsport play its part in that trend, too?

Intersection

In the contemporary era, the area of motorsport that has attracted the most attention from car manufacturers as a platform for road car development is Formula E. The third generation (Gen3) all-electric racecar that will debut in Season 9 of the Formula E World Championship is designed to be, as former FIA president, Jean Todt, said, 'A machine at the intersection of high performance, efficiency and sustainability.'

The Gen3 Formula E car has been touted as the world's most efficient racecar, but is that just hyperbole? The organisers say at least 40 per cent of the energy used within a race will be produced by the cars' regenerative braking and it will be the first formula car with both front and rear powertrains.

The newly introduced front powertrain adds 250kW of regenerative capacity to the 350kW at the rear, more than doubling the regenerative capability of the current Gen2 car, to 600kW.

The company that designs and supplies the Formula E battery, Atieva, will be the provider of the spec front powertrain kit that will be used by all teams in the Gen3 car. The package includes the Motor Generator Unit (MGU), Motor Control Unit (MCU), transmission and driveshafts.

The California-based company's components will be part of the spec chassis provided by Spark Racing Technologies.

It will also be the first contemporary formula car not to feature hydraulic rear brakes. Thanks to the addition of the front powertrain and its regenerative capability, as well as that on the rear drive system, all rear wheel deceleration will be achieved through electrical regeneration. A

Formula E

The Gen3 Formula E car is being touted as the world's most efficient racecar

maximum of 350kw (470bhp) will be delivered to the rear wheels, making the Gen3 capable of a top speed of 200mph (320km/h).

The Gen3 car is evidence of the progress in EV development achieved by the players in the championship. Formula E asked automotive industry engineers and experts in sustainability how the rules should be laid out in a bid to make the Gen3 rule set a proper proving ground for sustainable, high-performance EVs. The Gen3 car is therefore also the first formula car aligned to Life Cycle Thinking, with a designed-in second life for tyres, broken parts and battery cells. Additionally, we're told, the Gen3 will be net zero carbon, reinforcing Formula E's status as the first motorsports series to be net zero carbon from inception.

While teams are set to take delivery of the Gen3 chassis in spring 2022, following intensive development testing on and off the track, the manufacturers are hard at work developing the rear powertrain for the new season. One example is GKN Automotive, which is partnered with the Jaguar TCS Racing team, and contributes engineering support for the development of the team's powertrain.

Software development

Design of the Formula E powertrain is governed by a stringent set of technical regulations that restricts the scope of development, meaning software is one of the main areas in which performance can be maximised. According to GKN Automotive, it is here that Formula E benefits road products considerably.

Engineers in the Formula E programme bring back to GKN Automotive real-world knowledge that helps them accelerate their software development and promotes knowledge sharing between the two companies, which can only increase the race-to-road benefits derived from partnering with Jaguar TCS Racing.

Seven manufacturers in total have been accepted by the FIA to compete in the start of the Gen3 era. These are DS Automobiles, Jaguar, Mahindra, Maserati, Nissan, NIO 333 and Porsche AG. OEMs such as Hyundai, Ford, BYD and Geely have also looked at Formula E in recent years, but none are thought to have committed to run a Gen3 factory programme.

With many race categories struggling to gain brand interest, could the Formula E concept of providing a tangible road car-relevant technical proving ground become the new way for race series going forward?

The Gen3 is the first formula car aligned to Life Cycle Thinking, with a designed-in second life for tyre, broken parts and battery cells

Money, money, money

Makes the world go round, but it's having an increasingly unsavoury effect on F1

I guess one could say that, given the monstrous happenings in Ukraine – and other countries too, let's not forget – sport of any kind can seem frivolous and self-indulgent. This is not the case, though, because professional sport entertainment provides large scale employment and much-needed mental escape from the terrible news constantly hitting our senses.

Which is why the initial boycott of the recent Saudi Grand Prix, by apparently all the Formula 1 drivers, was unimpressive. The missile strike, fewer than 10 miles from the Jeddah circuit, rightly caused serious concern, but everything seemed to centre around meeting the fears of these 20 highly paid individuals.

Eventually, of course, the race went ahead, but the knee-jerk boycott left a bad taste. Yes, they are the stars of the show, but what else, *really*, makes them so special? Were the opinions of the F1 team personnel and F2 competitors also taken into account? Or the course workers, medical staff, organising personnel, hospitality, media, marketing, PR and sponsor representatives etc?

In thinking only of themselves, as appeared to be the case, the drivers clearly did not consider any of these factors, and showed little sign of loyalty to the sport, let alone the fans, and all those who make F1 happen.

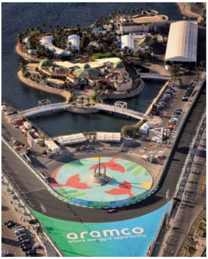
Rights record

Two or three drivers were also vocal concerning racing in Saudi Arabia due to the country's human rights record, calling into question so-called 'sportswashing'. The question is, though, where to stop? China, for example, has a repressive attitude to any of its citizens who don't follow the leadership's rulings. So should F1 take place there? Bahrain and Qatar also have received negative scrutiny.

While cancelling the Russian GP was a no-brainer in the current climate, other situations are more nuanced, and I'm inclined to agree with those who, to quote Toto Wolff, 'would rather come here and make the spotlight shine on the region so it needs to be in a better place.'

Porpoising is creating more fishy tales than fishwives could dream up. For whatever reasons, Mercedes seems to be making heavy weather of sorting its W13 F1 car. Identifying porpoising as the primary reason for the car's handling deficiencies doesn't quite seem to stack up. After all, other cars, not least championship-leading Ferrari, also display this alarming characteristic. Mandating a thicker plank underneath the chassis could be a simple solution, on safety grounds, as all teams would have to run a higher effective ride height, preventing the momentary shutting down of the underbody tunnel airflow. However, that would be rather unfair on those such as Alpine who have already come up with satisfactory solutions.

Mercedes is right not to just throw modifications at the car without first identifying the reason for the problem (I've been there, got the t-shirt) but sometimes, to quote former Williams man, Frank Dernie, a bit of 'hairy-arsed engineering' is required.



XPB

How well researched was the decision to race in Jeddah?

As I've mentioned before, the Silver Arrows team is extremely data driven, which has led to great success over the last eight years. However, too much data can be confusing. Occasionally, intuition, experience and clear thinking is what is required when time is disappearing fast.

If I were in their engineering shoes, Hamilton's comments that whatever they do to the set-up doesn't seem to change much would have me seriously worrying that somewhere in the car there is a fundamental flaw, and not necessarily an aerodynamic one. One would suppose that conformance rig testing of all key components is a fundamental process of building an F1 car, but could it be that something in the cleverly crafted conglomeration of parts escaped the net?

I know from personal experience that it only needs one weak link in the chain, such as a flexing upright / bearing assembly, for example, to completely undermine chassis performance, especially with the loads these heavy and downforce-laden machines create.

In addition, Hamilton's frustrations in Australia at having to back off due to overheating indicate the Brackley team's long-time design concept of taking everything to the limit, on the assumption of being in front, in clean air, may need revising under the new regulations, as so far it has displayed no capability of achieving this.

The budget cap requires teams take a different approach to their design philosophies, and be more agile in their responses to problems.

Worrying words

On a broader front, somewhat worrying is a statement by F1 CEO, Stefano Domenicali, warning it's 'not enough to have a pedigree any more' for races to keep their place on the calendar, and that the arrival of new events would 'force the organisers of traditional grands prix to raise their level of quality.'

Quite what this last comment means is not immediately apparent, but it is a clear breach of Liberty's commitment when acquiring F1 to respect the history of the sport and ensure that the most iconic circuits be retained. Las Vegas may be a turn on for many, and one can understand the financial benefits for all participants, but give me Spa or Suzuka any day where, apart from the driving challenge, the backdrop of trees and greenery creates a much finer canvas than the brash neon clip joint of Nevada at night.

Now pressure is being put on Monaco, that most iconic of all circuits, via Domenicali's words, as part of a political game to squeeze more money out of the Principality.

If not clear before, the driving force behind all this is simply to make F1 more of a cash cow for its owners and the teams, and my regard for Domenicali has ratcheted down a lot due to his role in this.

Finally, while I'm on the subject of Domenicali, he has also strangely commented that, 'while securing an American driver was important, it also has to be real, quick and long-lasting, otherwise it will be a boomerang.' Try to make sense of that – I know I can't.

It only needs one weak link in the chain… to undermine chassis performance

Legendary status

Few would have guessed when IndyCar first put its car design out to tender in 2011 that Dallara's winning bid would still be racing 11 years later. Racecar *looks at the safety upgrades made since*

By ANDREW COTTON

Of the 70 monocoques supplied to teams in that first year [2011], 27 of them are still in service and being raced

The basic chassis may have stayed the same, but there have been numerous safety updates made to it over the years, many in direct response to unusual scenarios presented by accidents

When Dallara landed the contract to provide IndyCar with its spec car for the 2012 season, the Italian manufacturer could not have dreamed that over a decade, and more than 125 monocoques, later, it would still be providing pretty much the same design to the premier US single-seater category.

That is not to say that the design, originally labelled IR12 and later changed to DW12 after the unfortunate passing of British driver, Dan Wheldon, who was instrumental in the development of the car, has gone unchanged. A series of accidents in racing conditions have resulted in real world lessons learned, and they have led to some significant safety upgrades.

During that time, the chassis has weathered major changes in the sport, from the first aerokit that was designed by Dallara, to the manufacturers' own designs from Chevrolet and Honda, back to the Universal Aerokit of 2018. Shortly afterwards, after extensive testing and development by Red Bull Advanced Technologies, the Aeroscreen was added to the chassis in order to provide further protection for drivers in the event of an accident. While the Aeroscreen was designed to reduce the chance of shrapnel entering the cockpit, the fitment process also added torsional strength to the chassis around the cockpit opening.

The chassis is now known as the IR18, although chassis that were originally supplied to teams more than 11 years ago are still eligible to compete with the required updates. Of the 70 monocoques that were supplied to teams in that first year, 27 of them are still in service and being raced. In fact, the only ones that aren't are those written off in crashes, or 11 that have been retired by teams after winning big races such as the Indianapolis 500, or championships.

It's an extraordinary achievement for the manufacturer, but there is more to come. As the hybrid era comes in, now in 2024 following delays, the chassis will continue to be the spec product for the series, with only minor upgrades for additional cooling.

Real-world learnings

It should not be a surprise to learn that the car has been updated following learnings from major crashes on track. After all, while crash testing provides the basic protection requirements, real-world accidents at speed are always more informative, and IndyCar's safety team has never wasted any time in implementing changes.

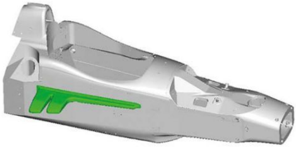
The original design brief was for the chassis, and particularly the bodywork, to prevent one car mounting another and flying through the air if a wheel from one car impacts another.

The first test of the new design came at Sonoma Raceway in 2012, when Sebastien Bourdais and Josef Newgarden came together. Bourdais ran wide on cold tyres across the dirt and, as he came back onto the track, he made contact with Newgarden, who subsequently went off. The American impacted the tyres hard and bounced back into Bourdais. The IndyCar team had seen enough to make its first upgrade to the chassis.

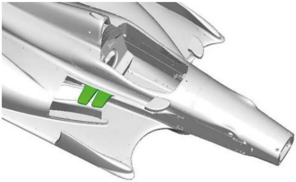
'Newgarden's attenuator punched into the side of the monocoque,' says Alex Timmermans, chief of design at Dallara LLC in the US. 'It cracked and broke the side of the monocoque, so we realised we would like to have more energy absorbing structure and rigidity on the side of the monocoque.'

A bolt-on part, the first of the side impact protection devices that are now common in modern single seaters, was fitted by drilling through the monocoque and bonding in aluminium top hats down the side of the cockpit.

The design was updated later, with the inserts laminated into the monocoque so teams no longer had to drill through the carbon, but they remained bolt-on parts.



Bolt-on side impact structures were designed, developed and instigated in 2013



The new side-impact structures had an immediate impact on driver safety, proven when Justin Wilson put them to a real-world test at Fontana in 2013

T-bone mistake

'We have always been susceptible to t-bone accidents,' notes Timmermans. 'That's when we have either the nose or the attenuator of a car going into the side of another car, and that's when we find we're getting some monocoque damage. That happened a couple of times – think Justin Wilson in Fontana in 2013. I think we can safely say that if it hadn't been there, [the damage and injury] would have been worse. It broke some of the [side impact protection structure].'

In that instance, Wilson lost control on an oval and, as he spun, was caught by Tristan Vautier's car in a classic t-bone situation. Despite the extra side-impact protection, Wilson broke his pelvis in three places.

Working with special panels manufactured by Dallara and installed by Aerodine, the second round of monocoque updates consisted of two solid carbon panels mounted inside and outside the cockpit and a solid carbon structure around the upper opening of the cockpit. Weight of the monocoque increased by 5.3kg in the process, but IndyCar's design team felt the safety improvement was worth the penalty.

'I think we can say that Justin Wilson's 2013 accident was the motivation for that,' says Timmermans. 'The panel marked in green [above, right] was about an eighth of an inch, or 3mm, of solid carbon fibre bonded on, and that basically was the opening area to the radiator inlet duct. That area was therefore unprotected by bodywork, and it just so happened to align with the nose height of the monocoque that was involved in Justin's accident. We had various cracks around the cockpit rim as well, so a further panel was added for that purpose.'

That was a 3mm thick carbon surround laid around the top of the monocoque, and Dallara had to manage the flow of work to each of the cars competing in the 2014 season to carry out that update. Since then, there has been no accident where the nose of one car has ingressed the cockpit of another.

Zylon run

Zylon is a material that has become common in racing circles and the DW12 monocoques were fitted with such panels from the start. In fact, IndyCar chassis have been fitted with Zylon panels since 2008.

Cockpit sides are re-inforced with 5.5mm thick Zylon panels, while behind the rear bulkhead that drops to 3.5mm around the area of the fuel tank bladder. A length of Zylon runs from the front of the cockpit to the rear of the monocoque, and this has become one of the primary safety devices in all forms of motor racing, from Prototypes at Le Mans to IndyCar.

'It has hard to overstate its effectiveness,' says Timmermans. 'That was a big separator between the old monocoques (pre-DW12) and the new ones with Zylon. It is really one of the best improvements that has ever been made.'

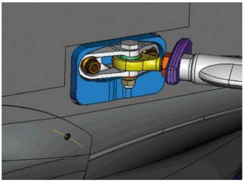
Another year, another accident and another update to the chassis. This time it was James Hinchliffe's crash at Indianapolis in 2015 where the Canadian suffered a punctured leg following a lower wishbone entering the cockpit. Despite all the side-impact safety work that had been undertaken by the technical team, accidents do tend to have a habit of exposing previously unthought-of weaknesses.

Hinchliffe's right front suspension broke as he followed Juan Pablo Montoya around the circuit, and he understeered into the wall. The lower suspension arm impaled his leg and pierced his femoral artery. He was consequently hospitalised for 10 days (far less time than doctors had expected), but IndyCar clearly had to do something to prevent such an accident occurring again.

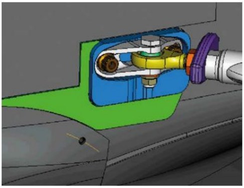
'It was the only time I can think of that we had a wishbone penetrate the monocoque,' notes Timmermans. 'The right front lower wishbone entered through a pocket, where the Zylon goes around it. The suspension mounting block mounts on top of the chassis, which is just pure carbon fibre. The wishbone broke off at the end of the nut and it found an opening.'

The first of a three-part fix was a new mounting point within a recess in the cockpit, [shown in blue in the illustration above right], which would reduce the possibility of the part spearing through the monocoque skin. The second was an extension of the cockpit reinforcement plate [shown in green, above right] that was then covered by an anti-intrusion plate bonded to the top of the cockpit reinforcement. That was enough to

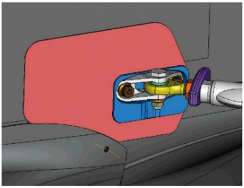
A length of Zylon runs from the front of the cockpit to the rear, and this has become one of the primary safety devices in all forms of motor racing



This anti-intrusion infill block, shown in blue, was introduced in 2015



Along with a cockpit reinforcement extension, shown in green, fitted and bonded to the monocoque around it



That was then covered by a second anti-intrusion plate, shown in red, bonded over the top. The purple collar limited penetration depth

Accidents do tend to have a habit of exposing previously unthought-of weaknesses

Manufacturer-designed aerokits were introduced for the 2015 season, but they featured a wealth of bodywork that often ended up as shrapnel on the circuit. Consequently, they were replaced by the Universal Aerokit in 2018

Manufacturers took different approaches. Honda's 2015 aerokit, for example, wasn't as effective as that of Chevrolet

spread the load in case of an accident, while a rather inelegant but strong washer [shown in purple, above], made up of multiple layers, physically reduced the amount any part was able to penetrate the cockpit. The fix was carried out fast enough that, within two races, each of the cars was fitted with it, ensuring further driver safety for subsequent rounds of the series.

Immediate effect

'As soon as we started working on the project, we were pretty much immediately machining new components, in maybe two days,' recalls Timmermans. 'First was the block that fitted into the hole where Hinchliffe's lower wishbone had penetrated, and sat flush with the monocoque.

'The wishbone sat on top of the block and was held in place. The hardened steel plate created a very hard, low-friction surface for the wishbone to slide along. That was done with a previous car, but we felt that with the Zylon we weren't going to need that panel. As it turns out, we saw the value of it because a hardened stainless steel plate behaves very differently [to Zylon].'

One of the issues that came to light during post-accident investigation was the lower wishbone had been reinforced when the manufacturer aerokits were introduced in 2015. It therefore had a higher resistance to buckling, which moved the area of pressure and, in this particular, unusual case, its tip was able to punch a hole in the monocoque. Timmermans continues: 'When we reinforced it, it stopped buckling, but other things started to break. For instance, the bolt at the end was shearing, and then the rod ends would bottom out, and then it would break the rod end.'

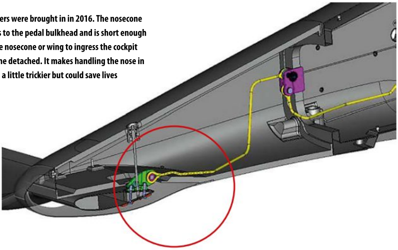
The reinforced washer encourages the rod end to deflect down the side of the cockpit, and this has proven a successful measure in subsequent accidents experienced by other drivers. According to IndyCar, investigations have shown the washer to buckle, so it's doing its job well.

Bodywork tethers

Later, in what turned out to be a traumatic 2015 season, Justin Wilson was involved in an accident that claimed his life. Sage Karem crashed at Pocono and the nosecone

For the 2016 season, IndyCar introduced tethers to hold the larger pieces of bodywork close to the crashed car, in a similar way to how uprights are tethered

Bodywork tethers were brought in in 2016. The nosecone tether attaches to the pedal bulkhead and is short enough not to allow the nosecone or wing to ingress the cockpit should it become detached. It makes handling the nose in race conditions a little trickier but could save lives



of his car flew into the air, impacting the following Wilson on the head as the Briton rounded the corner. It was a shocking incident that took one of the most popular drivers in the paddock, and IndyCar's safety team had to find solutions to prevent another similar tragedy.

In another round of safety bulletins brought in for the 2016 season, IndyCar introduced tethers to hold the larger pieces of bodywork close to a crashed car, in a similar way to how the uprights are tethered. That's easier said than done, however, as the tethers themselves must be attached to a hard point. In the case of the nosecone, for example, they're attached to the pedal bulkhead. A steel plate was added under the front wing main plane to provide the other end for the tether, and these were implemented for the first race of the new year in 2016.

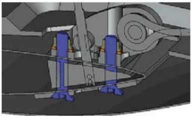
'We made an improvement to the retention of the mounting block by adding reinforcement to the bottom side of the front wing main plane, with the idea that if you have a big accident that detaches the nose from the monocoque you would hopefully be able to hold on to the front wing main plane and nose,' says Timmermans.

One of the complicating factors was that this was the era of manufacturer aerokits, and so a standard solution had to be found.

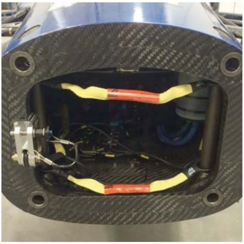
'We spent more time on it that we should have, really,' admits Timmermans. 'We had weeks of going back and forth with different ideas because we were not able to throw away all the front main planes. That just wasn't going to happen, so we had to find a retro-fit solution. When we went back to common parts, we could tether it all the way through.'

In the wings

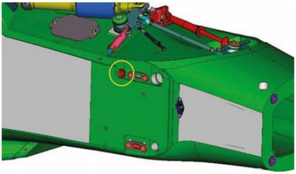
Anyone who was at the Nürburgring in 1997 will recall with horror the F3000 accident that ended the career of Dino Morelli. The County Antrim driver ran into the back of



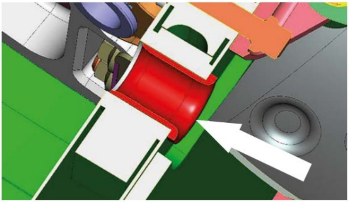
The other end of the tether is mounted under the front wing main plane, and has to be very securely attached. IndyCar mandates the required fitting process



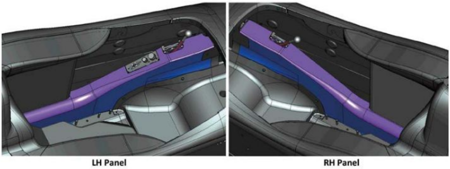
Additional tethers were introduced for the Pocono round in 2016, IndyCar's safety team certifying and supplying them to teams to fit to their cars



Two additional tether bushes were added in 2017 to reduce damage to the monocoque (above) in the event of an accident



Teams had to prepare the bushes and tub pass-through holes before bonding the bushes, shown in red, in from the outside of the tub with epoxy, such as Hysol 9460



EPP foam hip panels replaced the previous carbon versions in 2015 in a bid to control the deceleration rate following side impacts

Gareth Rees' car when Rees ran over a kerb, and the front wing folded underneath the monocoque. Without steering, and in the wet, he drifted towards the pit wall where the unsighted Morelli ran into the back of him. That ripped the nose and wheels from his car and, with throttle wide open, he headed into the barriers at the first corner.

IndyCar says it has never had a case of a wing folding under a car in that way, and that normally on the Speedways wings tend to shatter. On road courses, the wing would break under a car. There are upper and lower nose pins that hold the noses in place, and the tether can be released by a quick-release pin during a race in case of damage.

On a tight leash

'There was quite a lot of discussion about the length of the tether,' says Timmermans. 'Before the Aeroscreen, we spent a lot of time on tether length, trying to make sure an assembly could not get back into the cockpit. You can see that it's a little bit fiddly when the guys go to change the main plane on pit road because they can't pull the nose very far away from the car as everything is so tight. But that's necessary.'

In 2015, IndyCar introduced expanded foam into the hip panels. This was developed to try to control the deceleration rate and the energy absorption of the drivers in a lateral accident. The routing of the cabling and tubing for the air jacks also had to be revisited to enable the change, which was not the work of a moment.

It came as a consequence of Ryan Hunter-Reay's accident in qualifying at Pocono. The electronic download connector placed in the cockpit was just in the wrong place for the American driver. The connector impacted his hip, and IndyCar was once again forced to make a change in the interests of driver safety. Again, this was a complicated one as there was some plumbing involved.

'We had a problem with side impact where drivers were getting into that connector,' notes Timmermans. 'It's a carbon bracket with a soft, gentle curve around the outside of it.'

Structural sidepods

A further big change came in 2018 with the introduction of the structural sidepod. Rather than have the sidepods as merely housings for radiators and coolers, it was decided that the IR18 chassis would carry a more rigid design to help absorb more energy in the event of a side impact.

In order to do so, the radiators had to be moved forwards to offer some extra protection around the cockpit opening, in a more traditional location for a single seater. The radiator duct was then structurally re-designed to improve stiffness and try to absorb some of the energy, rather than transfer it directly to the cockpit.

'The radiator duct is laid up with 10mm of honeycomb throughout that region, and many plies of carbon and Dyneema, which makes it very strong,' explains Timmermans. 'Normally, you could grab the bodywork and flex it with your hand. This [area] is built more like a nosecone, so it's really stout. On the outside of that is an upper piece, made up of two bonded parts to form top and bottom skins. That is also strong.'

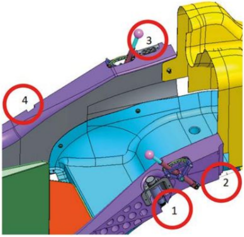
Side-impact structures

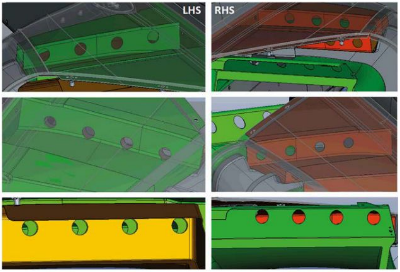
FIA-style side-impact structures were also introduced as an integral part of the design at this point. These were conceived to protect the survival cell in the event of the most dangerous, 90-degree angle of impact.

'That's probably the most threatening for monocoque damage,' confirms Timmermans. 'The u-shaped structure [of the sidepod] is intended to be quite good for side impact. We tried to distribute the force from the middle of the structure to the dash bulkhead and seat back bulkhead. This one is quite difficult to make, though, because it is not a simple, singular laminated component, like a nosecone.

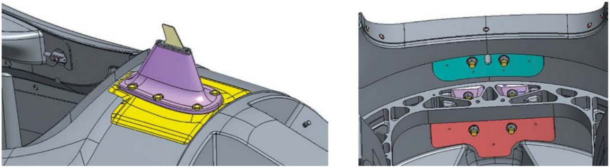
'You can do some pretty advanced, but reliable, simulations of energy absorption in a specific type of impact. But this one, with all the complexities and bonded joints in this area, is much more difficult.

Unusual accidents often drive safety developments. For example, the download connector bracket (1) was re-designed, an approved location decided upon for the intercom (2), ADR bracket (3) and drivers' headset (4). These were not included in the 2018 aerokit





Further side-impact improvements were made in 2018 with the introduction of so-called structural sidepods. These were bolted to the monocoque, with holes drilled in them to reduce buckling strength and protect the monocoque



Called the Advanced Frontal Protection (AFP) device, the nib in front of the cockpit, shown in purple, was designed to deflect any large objects that might impact a driver's head. The mounting point later became important for the introduction of the Red Bull Advanced Technologies-developed Aeroscreen that came after

Takuma Sato was one of the first to properly test the structure when he crashed in Firestone testing in Texas. He touched the outside wall, and that sent the car spinning to the inside wall and a heavy impact. Despite some high loads in the accident, the chassis was hardly damaged.

'You had to get all of the bodywork off the car and hold a straight edge to it, or a template, to find the bow, but it was there,' says Timmermans. 'Our structure exceeded the strength of the monocoque, so we added holes to reduce the buckling strength and encourage more energy absorption before the monocoque could be damaged.

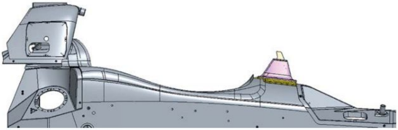
'As you can imagine, our sort of crashes are not particularly similar to Formula 1 crashes,' says Timmermans. 'Our strength requirements are greater than their strength requirements, and we have to be make our car strong enough to crash at the Indianapolis 500.'

Frontal protection

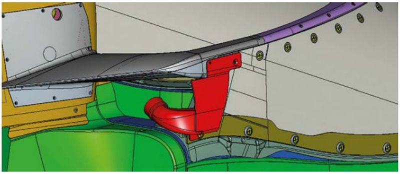
Following Wilson's accident, IndyCar wanted to add something to aid head protection and came up with the Advanced Frontal Protection device, comprising a fin of titanium bolted to the chassis ahead of the cockpit. The idea was to deflect a large component, such as a wheel and tyre, from hitting a driver square on, but it was never properly tested in real-world conditions.

'I am not aware of it ever actually deflecting anything, but we wanted to add head protection to the car and knew that we wanted to have some type of structure in front of and above the driver's helmet,' explains Timmermans. 'We didn't know exactly what it should look like, but we had done some evaluations on various structures and were pretty happy with the idea of connecting those structures to the centre of the monocoque.'

Ultimately, that research formed the basis of the first attempt at mounting the Aeroscreen to the cockpit. The mounting point was strong, integrated and proven to work, and so it was relatively straightforward to make the decision to mount the leading edge of the Aeroscreen in the same place.



The structural updates required for the AFP were performed by Aerodine Composites in time for the 2019 Indy 500



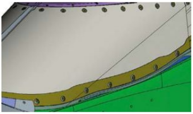
The Aeroscreen that followed had the undesired side effect of reducing airflow to the cockpit, which led to increased heat within. A duct, shown in red, was therefore designed to increase airflow around the head area

'We said let's just bolt on this piece, because I think in the political climate we couldn't just do nothing. But we were not fast enough to do the complete design [then].'

Screening process

The Aeroscreen followed shortly afterwards, of course, comprising a canopy mounted at the front and screwed into the original bolt-on device around the cockpit opening. According to IndyCar's aerodynamic technical director, Tino Belli, 'It was done for driver safety, and the knock-on effect was the carbon fibre piece that got bonded onto the tub added torsional rigidity.'

Naturally, the top of the 'screen frame had to be above the drivers' head to offer maximum protection. As covered in previous editions of *Racecar Engineering*, driver cooling, as well as the mounting process itself, were all challenges that had to be overcome. The trailing edge of the Aeroscreen is bolted to the car's roll hoop, and covered with a faring.



Aeroscreen bottom fastening washers were countersunk in testing, but that changed for the race when an aero washer was used instead

'It's very solid,' says Timmermans. 'We weren't able to find as much strength in the side of the monocoque by the headrest, so we were not able to put full load into that section of the monocoque. Instead, we had to distribute the load through the roll hoop as well.

'We wanted to keep our top frame always above the drivers' head in case something comes down from above. We also have fence poles [which caused the fatal injury to Dan

The RBAT designed Aeroscreen was the second iteration of head protection offered by IndyCar but the complete design helped to elongate the life of the original DW12 chassis

Early iterations of the IndyCar Aeroscreen were mounted to the rollbar fairing, but it was later adapted to connect directly to the rollbar

XPB

Formula 1 tried an Aeroscreen, but Sebastien Vettel said the optical distortion made him feel sick. The Halo was deemed more suitable for the types of accident seen in F1

Wheldon in 2011], and now a fence pole should ride over the top of a [driver's] head.'

That was tested by Callum Ilott, who had a piece of debris strike the top of his crash helmet, removing the tube that feeds cool air onto his head as part of the Aeroscreen cooling package. The debris in that instance had impacted the Aeroscreen and been deflected away from the head, but IndyCar's concern was that with a Halo design, it may have hit the underside of the top frame and struck him.

Protected investment

Loose debris in the cockpit is one of the primary reasons IndyCar went for a full screen, rather than copy Formula 1's Halo. Having an item strike the underside of the top frame and impact the body or helmet of a driver could be catastrophic, so the design team went for a full screen to offer maximum protection.

It's worth noting here that the various updates have not been solely to protect the drivers, but also to protect the teams from writing off their monocoques which, at $140,000 (approx. £107,200) each, represents a huge cost saving for a team when a car is involved in an accident.

Sato's accident at Texas in 2018 exposed another concern. The oil and water tanks, which are pretty stiff and located next to the thinner skin of the cockpit, did deform it slightly. It did not crack the carbon, but outer layers of the plies were damaged, and so IndyCar recommended an optional steel plate for additional protection.

Teams have different perspectives, and you'd be surprised at how many of the good teams look at the dollar side of it

Alex Timmermans, chief of design at Dallara LLC, USA

'Some teams are going to look at it and say if they do have an accident and spend 20 hours trying to get it up to the same spec as the crashed one, that's a performance advantage [in fitting the plate]. Teams have different perspectives, and you'd be surprised at how many of the good teams look at the dollar side of it.'

It's clear that, despite retaining the same chassis design, there have been some significant updates and improvements made for driver safety in that period that will be carried over into the next car. And, having just signed an extension to the long-running deal, it is highly likely that Dallara that will be making them although the timing of their introduction has yet to be confirmed.

Hybrid updates

'I think it's fair to say that when the hybrid comes in, it's going to be with the existing monocoque and bodywork,' concludes Belli. 'There'll be some updates to improve cooling on the right-hand side, because we now have to cool the engine, gearbox and hybrid on the right-hand side, and there will be new Speedway front and rear wings to give teams more option for downforce to go with the extra power. But the rest of the car will remain the same, so it's basically the engine and back end [that will change]. I think it has yet to be decided when we will do a new car.'

For now, the cars is as safe as they can be as the teams head into the month of May at Indianapolis for the Indy 500 2022, and teams, drivers and IndyCar personnel hope for a safe race.

BTCC approved

For the first time since 2011, the British Touring Car Championship has a new preferred engine supplier. Racecar *talks to M-Sport who step up to the challenge*

By STEWART MITCHELL

2022 marks the start of a powertrain revolution for the TOCA-organised British Touring Car Championship (BTCC). The category becomes the first Touring Car series in the world to adopt hybridisation, supplied by Cosworth.

Also new this year is an all-new customer engine package. For the decade since 2011, Swindon Powertrain had supplied a competitive 'TOCA Engine' to the series, with proven durability and strict cost controls, available to all BTCC teams who do not wish to carry out their own engine programme.

But from 2022, that position has been taken by Cumbria-based M-Sport, awarded a five-year contract by the series' organising body to supply the new BTCC TOCA Engine.

With stiff competition from several interested parties the firm, best known for its WRC efforts, was shortlisted to deliver a 10-page pitch to BTCC teams in May 2020. After the presentation, and further discussion with M-Sport managing director, Malcolm Wilson OBE, and technical director, Nigel Arnfield, TOCA selected M-Sport as its preferred supplier.

M-Sport will now oversee the design, development and supply of TOCA Engines to around 50 per cent of the 2022 grid.

'We worked throughout the last two years specifically on this BTCC project,' said Arnfield at the final of three 2022 BTCC pre-season tests held at the Thruxton circuit. 'Designing an engine to these regulations, and ordering and producing the necessary parts, took a lot longer than it would have done before the global pandemic. Manufacturing was difficult for the majority of the time, and getting test engines built so we could do the

BTCC's powertrain revolution starts here with a brand new TOCA Engine and the introduction of hybrid power

'It cuts out all the costly research and development to find an unfair advantage by chasing down an engine with a particular characteristic. It means you can be competitive with whatever you bring'

Nigel Arnfield, technical director at M-Sport

Photo: BTCC

analysis programmes and sign them off on durability before mass production meant this was severely compressed timing.'

Engine overview

M-Sport chose to use the same Ford-based, 2.0-litre, turbocharged, four-cylinder engine as proven in the Rally2 cars it has produced for over 300 customers in the WRC and national rally championships worldwide. The engine model used is the latest evolution of the inline four-cylinder engine Mazda and Ford produce together. It has had around seven iterations in its lifetime, and the last of those is the one M-Sport chose as it is the lightest version of the production engine.

To achieve this, the engine has an all-aluminium stock structure. The open-deck block incorporates the crankcase extending to the sump, while the five main bearing caps are tied together in a frame. Although a proven race engine already, the Rally2 application differs from BTCC.

'Within the bounds of the Rally2 regulations, you push to get as much power as possible from the prescribed capacity of the engine,' Arnfield explains. 'That means you push the limits quite a bit. This isn't the case for the BTCC engine. TOCA balance the engine with the competition, so the project's approach is very different.'

To better explain, all engines in the BTCC are 2.0-litre capacity, four-cylinder, single turbocharged, petrol units.

TOCA defines very clearly in the regulations the required output of the engines. The inlet port flow coefficient and the camshaft profile prescribe the available power, which derives the boost figure, so the field's power balances in terms of mass airflow.

'It's quite a straightforward formula that works,' says Arnfield. 'If you look at how close the racing is, and how close it has been, to come out of the box and be mixing it with the established engines that are several different configurations, it's very effective.'

Internal affairs

All BTCC-approved engines have homologation papers available to the other manufacturers so each can effectively see at least some of the specification of competitor engines. They don't give everything away, of course, because the detail work goes into the valvetrain and camshaft profiles, with the boost being the variable that brings all engines to the same output.

Deeming the cooling and oiling systems sufficient in the stock engine, M-Sport did not address those for the BTCC specification. Internally, M-Sport also opted to retain the production crankshaft, which has rolled fillets and a robust structure. So much so, Ford carries the design through all its models that run a four-cylinder engine. No damping is fitted, it is quite a lightweight design.

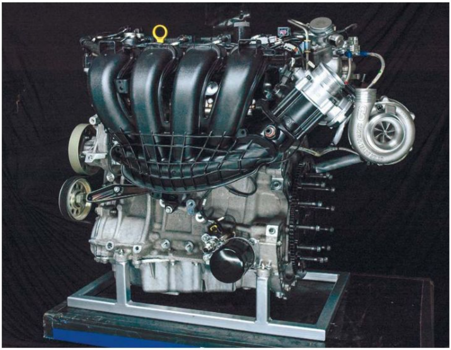
M-Sport uses bespoke connecting rods and pistons to ensure the reliability of those reciprocating components. 'We lengthened the connecting rod a little bit and pushed the pin up into the piston to make a similar displacement and reduce the compression height on the piston,' notes Arnfield. 'The production components here would likely have been good enough, but replacing them was a safer bet.

'This was done primarily for reliability reasons. Pistons in turbocharged engines have a pretty hard time, and I wanted to make sure the connecting rods would be robust for the sort of mileage that this engine will go through between rebuilds.

'Also, being a lease engine, we have to ensure we provide a robust and reliable power unit to our customers.'

Go with the flow

The valvetrain, however, is quite a considerable departure from the stock engine. The valve springs and retainers are the same tried and tested parts as those used on the firm's Rally2 engines. M-sport knew they would be up to the job as the opening and closing camshaft lobe profiles on the BTCC engine aren't as aggressive as typically seen on a race engine. The primary reason for this is the balancing factor in the class. There would be no point building it with an aggressive profile that creates a large mass flow into the combustion chamber as the boost profile would only be reduced to balance the performance against the other engines.



M-Sport

M-Sport readily admits its Ford-based TOCA Engine is not as highly tuned as it's similar Rally2 engine, due to the BTCC regulations

M-Sport

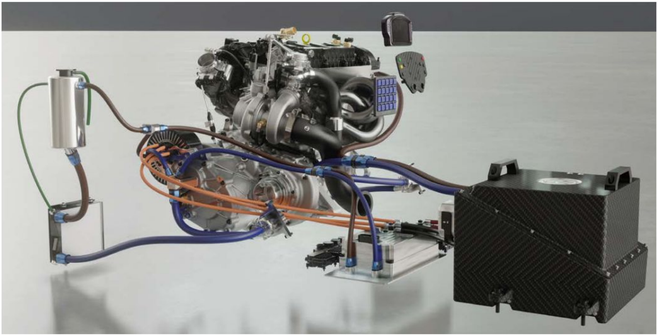
The 2.0-litre, turbocharged, road car-based engine formula remains for the BTCC going into the new era, with subtle modifications made, primarily to the camshafts and valvetrain, to improve performance and durability in a racing application

The greater the area under the valve lift curve, the lower the engine's boost, which pushes the engine manufacturers to design a camshaft profile as economical as possible.

'The valve lift isn't as high as our Rally2 race engine, despite being the same base engine,' explains Arnfield. 'We had several theoretical valve lift curves that our engineers developed from a straightforward 1D model, and we dyno tested six profiles before we settled on the final one.

'It was challenging to arrive at an efficient solution that worked for this application, so I'll be surprised if we revise the camshaft profiles again in the future.

'It's an excellent, cost-effective and fair formula, and there are very few areas where you could quickly gain an advantage. Chasing down performance-enhancing wave reflections going into the combustion chamber on the inlet and scavenging out of the exhaust from the pressure


Cosworth

The 350+bhp internal combustion engine operates in parallel with a Cosworth Electronics-developed 40kW (54bhp) hybrid system and control unit

changes from opening and closing of the valvetrain is ineffective in this formula. The gains you can get with it are minimal.

'The calculation for the boost considers the camshaft profile, so changing the cam' changes the boost. You'll gain with one and lose with the other. It's just a case of being mindful not to do anything with the camshaft profile that will affect the boost calculations.

'The one thing that is unusual in this category compared to others is that we can't modify the inlet port. It is what it is from the base engine. That's on purpose. The flow coefficient used to implement the engine's boost is taken from the base engine's inlet port. It doesn't matter whether you've got a good or lousy port because it gets balanced out with the boost. It cuts out all the costly research and development to find an unfair advantage by chasing down an engine with a particular characteristic. It means you can be competitive with whatever you bring. It also provides scope for the different engines in this category.

'The Mountune engine is the closest to ours. We've used that variant of the Ford engine in the previous incarnation of our R5 Rally powerplant. I'm pretty familiar with that, and that one has a very different port to the engine we've chosen for the BTCC TOCA Engine, which means it'll run a greater boost than we do. But the power, it's roughly equal.'

Lease structure

Leasing one of the M-Sport-built TOCA Engines means the engine remains M-Sport property. It removes any potential for teams to open the engine and start making modifications. Because the engine is leased, it is also sealed, and every competitor that uses the engine is given exactly the same specification. At the end of the season, the engines return to M-Sport for a refresh.

'It makes you focus more on durability and reliability of the components rather than the ultimate performance product,' says Arnfield. 'There's no reason to push yourself to make anything fragile. You don't want to have service intervals throughout the season because that would require the entire batch of engines to come back, which could be expensive and time-consuming. The BTCC season is very full-on, and there wouldn't be an appropriate time to do that given the schedule.

'So, it's 5000 miles before a rebuild, and we thoroughly dyno tested the BTCC

'It was challenging to arrive at an efficient solution that worked for this application, so I'll be surprised if we revise the camshaft profiles again in the future'

Nigel Arnfield, technical director at M-Sport


M-Sport

A batch of identical, sealed unit BTCC TOCA Engines prepared and ready to be delivered to customers

'It's 5000 miles before a rebuild, and we thoroughly dyno tested the BTCC engine to ensure they could comfortably achieve this race milage'

Nigel Arnfield, technical director at M-Sport

engine to ensure they could comfortably achieve this race milage. We have had the transient dyno for over 20 years, and it is by far one of, if not the, most effective development tool we have at M-Sport. Our durability testing included an entire season's worth of racing on the transient dyno using data from the 2019 BTCC season.'

Similarly, the hybrid system is supplied to each team on an annual lease scheme from Cosworth Electronics. This includes on-event support and servicing, maintenance and refurbishment of the units.

The modifications to the current-spec cars to make the alterations included an uprated gearbox casing to incorporate the electric motor, connectors, changes to the intercooler position and some pipework.

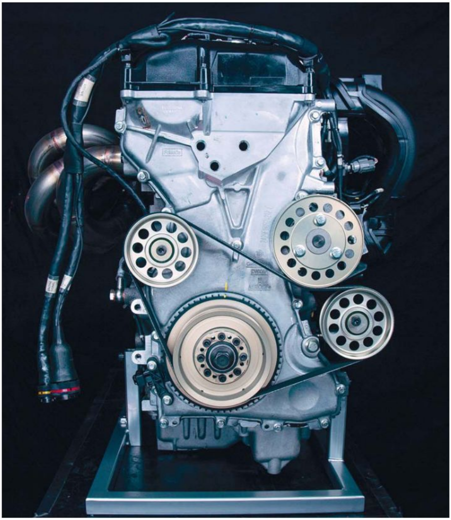
Running the engine

Maximising the engine's BMEP (Brake Mean Effective Pressure) is made straightforward thanks to its dual variable valve timing (both inlet and exhaust). In the BTCC application, it is always running in the fully open variable valve timing mode as engine speeds are so consistently high. This is an efficiency advantage that many race engine regulations have avoided for a long time in favour of more cost-effective fixed camshaft timing.

A mandated 7000rpm redline is enforced for BTCC engines and, during a race, the power units will spend almost all their time between 6000 and 7000rpm, despite vast differences in the circuits on the calendar.

'We developed the engine to perform in the narrow window of rpm, ensuring the shortest time to boost target on a quick tip into the throttle between the throttle achieving 100 per cent position and full boost coming on,' highlights Arnfield.

'We have various methods of reducing the lag to virtually undetectable levels. Because of the high engine speeds we are using, it is a lot easier than with a rally car, where the drivers use a much greater engine speed range and are trying to avoid lag at 3000rpm.



M-Sport

The purpose of the TOCA Engine is to provide a competitive, reliable, lease option for competitors, removing the cost of building, developing and maintaining a race engine themselves. The formula works as approximately half the grid choose to go this route

'The lowest engine speed drivers are tipping into the throttle in BTCC is 5500rpm, and that engine speed helps keep the lag under control.'

There are no driver aids allowed in the BTCC, so drivers must manage traction and tyre saturation throughout the race.

'The best thing we can do is give them the most progressive pedal,' says Arnfield.

Bespoke fuel

The 2022 season introduces a new, bespoke race fuel with a total of 20 per cent renewable components, comprising 15 percent second-generation ethanol content and five percent renewable hydrocarbons. The successful tender for this was submitted by Haltermann Carless, who has supplied the unbranded TOCA control fuel to the BTCC for the last 26 years. The manufacturer calculates the new fuel will give approximately an 18 per cent reduction in greenhouse gasses compared to current UK pump petrol, significantly lowering the fuel's impact on the environment.

A small batch of this new fuel was produced and distributed to all current BTCC engine builders ahead of the season, and the BTCC fuel system supplier, ATL, for trial and test purposes. All tests and examinations of the new fuel have yielded excellent results, with absolutely no adverse effects on either engine performance or the fuel system.

The new fuel will be manufactured for the BTCC by Haltermann Carless at its refinery in Harwich, Essex, UK and distributed directly to the teams at each event by Vital Equipment Ltd.

Compared to pure race fuel without any sustainable components, consumption is slightly higher to achieve the same output due to a lower calorific density. For this, M-Sport specifies the injectors and fuel pumps required to deal with the extra volume needed. The same fuel mass is used throughout the race compared to the previous spec fuel, albeit at a slightly higher volume. Arnfield notes that it makes a reasonably subtle change that wasn't challenging to optimise for the application.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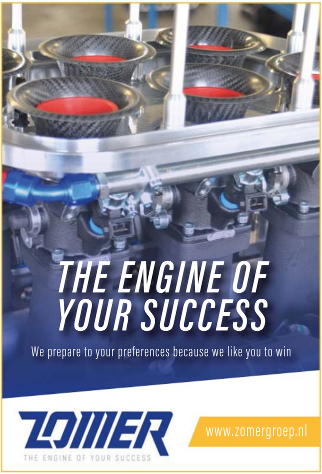
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The integration of the 40kW (approx. 54bhp) Cosworth hybrid system made up of a 60V axial flux permanent magnet motor integrated into the transmission has had minimal effect on the development of the internal combustion engine.

Hybrid power

'The hybrid unit delivers a reasonable amount of power, but is only used as an additional drive device alongside the internal combustion engine, so takes nothing away from the way we would typically configure the internal combustion drivetrain,' explains Arnfield.

'Engine calibration is not tailored to being part of a hybrid drive system. The hybrid system and internal combustion engine have standalone control units. The configuration is designed to prevent costly hybrid control strategy development.

'It does have a reasonable regenerative braking capability, but it doesn't have the sophistication of the management on board to control power systems on the car to make a significant inroad into power strategies with the hybridisation. It would become too challenging and expensive to do that in this category.'

The car's deceleration is more aggressive with the Cosworth hybrid system under regeneration than a car with just an internal combustion engine would see. However, according to Arnfield, this doesn't influence how the ICE calibration is written. It is set up so it's not perceivable to the driver when the hybrid drive is regenerating.

Deployment scale

Hybrid power management replaces the use of success ballast in the series for 2022, with a scale of deployment throughout a race for drivers in the top ten championship positions. Previously, the P1 driver was 'awarded' 75kg, reducing in 9kg increments down to 10th place. Now, a maximum of 15 seconds deployment of the 40kW electric drive is permitted per lap for all drivers from P11 onwards. The deployment duration and number of laps it can be used then decreases incrementally for positions 10 to one. Meaning, in any race under 17 laps, the championship leader has zero hybrid power deployment for the duration of the race.

There is no limit, other than time, on how often drivers can press the boost button during a lap. On Cosworth's performance simulations around the Silverstone circuit, a car deploying full hybrid power would gain eight metres on a competitor coming out of Copse corner. The power boost lasts until the driver presses the hybrid button for a second time, or until the deployment reaches the 15 second time limit, or the driver hits the brakes. It will also deactivate if there is a reduced throttle pressure or a sudden deceleration or acceleration.

Regeneration will take place during the car's braking phase.

Hybrid power will not be available to drivers until after the first lap, and it will only be available when a car is not traction limited. Drivers can alter the level of boost and regeneration in wet conditions and will be able to choose where on track they deploy and regenerate energy. Different maps will also be available.

Should the hybrid unit fail, its independent control means it will not stop the car from running. The driver will simply be left with a car that doesn't have hybrid deployment, the same as the one leading the championship.

Drivers throughout the BTCC paddock have expressed genuine enthusiasm for the new formula, noting that it adds an entirely new element to the competition and requires greater focus on in-race and overall championship strategy.

With this newly introduced emphasis on strategy, teams that play innovative rather than just aggressive may come out on top in this new generation of the BTCC.

M-Sport

Reliability analysis of the new engine package included over 5000 miles of race running on M-Sport's transient dyno

BTCC

The battery for the hybrid system locates where success ballast used to sit, which will no longer be used. Instead, a descending scale of hybrid deployment will be implemented for drivers positioned from second to 10th place. The title-leading driver will have zero

[The new formula] adds an entirely new element to the competition and requires more focus on in-race and overall championship strategy


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Tri-star

Lamborghini has developed the second iteration of its Huracan GT3, based on its incredible STO base model, and says the EVO2 is far more than just an evolution

By ANDREW COTTON

The relationship between track and production cars has taken another step closer for the Lamborghini Squadra Corse team, which in May launched the Huracan EVO2. This is the car that will carry the company's hopes in GT3 racing for at least the next three years, and it is a world away from the existing car that is competing in series around the world in customer hands throughout 2022.

Based on the STO, the new GT3 car features aerodynamic styling from the production-based model, including the engine air intake over the cockpit, a fin on the rear deck and a new bumper design at the rear to help increase total downforce.

The car also features improved traction control systems and ABS, along with even more use of carbon fibre in its outer skin.

Key to its development is improved ease of maintenance, with ancillaries located in more accessible locations, and various quick release mechanisms to speed up service time in the pit in case of repair.

The STO itself was developed using the design of the Super Trofeo, Lamborghini's one-make series that introduced its own EVO2 package at the opening round of the 2022 season at Imola in April. The race featured more than 30 cars. It's a series of upgrades across the board for the Huracan on both road and track.

Improved response

However, the changes to the GT3 version of the car extend far beyond the external, with a completely new throttle system that improves the responsiveness of the engine, upgraded brakes that are of bespoke design for the company, and a real focus on driveability to make it more comfortable for drivers on track, and to work around the Balance of Performance restrictions.

Also new are various safety aspects of the cars, and here Lamborghini has had an extraordinary amount of data to collect in order to make the improvements. Following a large crash for driver, Jack Aitken, at the Spa 24 Hours in 2021, in which his Lamborghini was subjected to three separate high-speed impacts, information gathered from that incident has been put into the new design.

'It is a very different car for many reasons,' says Leonardo Galante, technical lead for motorsport activities, who has overseen all iterations of Huracan GT3 cars since 2015.

'You cannot improve the performance because you have a BoP, so the only thing you can do to improve performance is not power or downforce, it is driveability'

Leonardo Galante, technical lead for motorsport activities at Lamborghini

'We had an idea to develop the car with an air scoop, starting from the Super Trofeo and the Essenza [the SCV12 that was a track-only car], so we tried to keep some style on the car that you can see. This is a Lamborghini, and we are doing the same with the racecars. No compromise, we just want the best. We tried to transfer this to the road car and that gave us the STO.'

This is the first car Lamborghini has built to the new FIA GT3 technical regulations and, as such, there were far more freedoms awarded in areas of the car such as the engine, damping and suspension. However, aerodynamically, the new rules are more restrictive than the outgoing ones.

Broader regulations

Manufacturers sought to have the technical regulations defined, rather than have their projects approved – or otherwise – by a commission, and successfully lobbied the FIA to achieve that goal. The regulations were then permitted to be used further afield than just SRO-organised series, such as the GT World Challenge events, to also include the DTM, and will form the basis of the new GT class at Le Mans.

Aerodynamically, the regulations stipulate that significant parts of the car, such as the roof and doors, are exactly the same as the production car. With the scoop over the roof, airflow into the engine could be optimised, and Lamborghini says it has dropped inlet air temperature by up to 6degC when compared to the side intakes on the 2019 EVO1 model.

'Of course, the air scoop has been optimised with the airflow to get more air for the engine, to improve driveability,' says Galante. 'You cannot improve the performance because you have a BoP, so the only thing you can do to improve performance is not power or downforce, it is driveability.

'That means a lot of things, though, like how the driver is using the engine, the engine braking, thermal progression, traction control… all the things that cannot be controlled by the BoP. And it is good because you have the freedom to do that.'

Advantage fin

Further back from the scoop is the fin that runs along the length of the engine deck. While this has become *de rigueur* in Prototype and single-seater racing, it is unusual to have it in a GT car. However, Lamborghini's race department worked closely with its production car designers to try to bring about just such an advantage on the track.

The fin may help in yaw stability in the event of a spin – the primary reason it was introduced in Sportscar racing – but it has the added benefit of aiding stability in straight line and cornering conditions, too. From the trailing edge of the fin, air is then led to the rear wing which, although it was carried over from the EVO1, was expected to be updated by the design team.

They tried that, but found the aerodynamic efficiency of the older wing was actually better, and so elected not to make any change. Only the wing supports, developed from the STO, are new and now offer more adjustment settings to improve options for the driver.

Key to making the car's aerodynamics more efficient was a development of the underfloor, and further to that came the opportunity to reduce rear wing drag through a new design of rear bumper.

While the regulations state a portion of the floor has to be flat, the front splitter and rear diffuser are allowed to be developed, and Lamborghini has made full use of the opportunities afforded by the 2022 GT3 rules.

Sculpted floor

The front and rear floor is therefore heavily sculpted in order to increase downforce under the body, and great effort has been made to reduce the car's pitch sensitivity, again further improving driveability.

'What we changed was the rear fender, so that looks more like the STO,' explains Galante. 'It will not have the ears [either side of the engine cover] any more, and the floor is feeding the air cleaner. So, you are feeding the wing in a better way and getting the same downforce but with less drag.

'It is a matter of the more mass flow feeding the back of the car, the more downforce with less drag. It is not complicated.

The fin may help in yaw stability in the event of a spin, but it has the added benefit of aiding stability in straight line and cornering conditions, too

The new FIA technical regulations for GT3 stipulate the doors and roof be exactly the same as their production counterparts; the fin and roof-mounted air scoop are new concepts for the EVO2

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'From one plane to another, the floor must be flat, but the splitter and diffuser are really shaped. This not only creates downforce, but you must also decide where the centre of pressure is, and how the air balance changes with set-up changes. The splitter and diffuser tell you a lot in terms of sensitivity, ride height sensitivity, pitch and steering.

'You have to create a car that is less sensitive to set-up changes,' continues Galante. 'Pitch sensitivity, steering sensitivity, the driver does not feel more or less downforce regardless of set-up changes. So under braking, the driver does not feel too much of a shift in terms of aero balance, because the car has less pitch sensitivity.

'The rear is still there in terms of grip. The aero is not changing too much. We have improved downforce when steering and cornering, so we have optimised the set-up phases to create less sensitivity and more predictability, so the car is more understandable for the driver. This is a learning process starting from the first GT3 to the EVO, and now the EVO2, and we are continually improving it.'

Damper development

One of the key areas of development in the new GT3 regulations is damping. While the number of valves in a damper is homologated, the materials and manufacturer are open for teams to select. This is, in part, due to the increased variety of series in which GT3 cars may race, and therefore on the different tyre manufacturers and specifications and circuits the cars will face.

Even in the GT World Challenge events, Pirelli's tyre specification changes from year to year. In 2022, the rubber manufacturer introduced a new front tyre with a stiffer construction and harder compounds to deal with higher temperatures. That, coupled with camber and pressure limits that are now monitored and penalised if exceeded, has meant damping has become even more critical than before. It is, says Galante, a huge area of potential development for Lamborghini's customer teams.

'The FIA recognises we need a certain level of freedom here because if I use a Hankook, Michelin or Pirelli, I must adapt the car.

'Teams can do what they want, but we as a manufacturer can provide guidelines. Damper seat, model, valving is homologated, but you can do what you want [within the damper] so you can do lots of development on that.'

Lamborghini has also turned to a local brake supplier, TM, in order to develop a new, more efficient system for its customers' cars. Another area not controlled by the Balance of Performance, the freedom to develop a bespoke braking system is one that has been welcomed by car designers.

Bespoke braking

Consequently, the EVO2 features Lamborghini-designed pads and discs, upgraded with a view to allowing teams to complete a 24-hour race without change. In the past that was possible, but only under certain conditions and with careful driving. In SRO-organised long-distance races such as the Spa 24 Hours, a technical pit stop was introduced to avoid teams developing quick-change systems, but in other series such a system will be welcome for teams.

'The good thing for us is that we have a good one-make series, and that's a good lab' for us,' says Galante. 'There are a lot of drivers in it, so we get a lot of feedback. We have developed the braking system, transfer it to the endurance [races] and make a difference in terms of brake pad compound and so on.

'We have optimised the set-up phases to create less sensitivity and more predictability so the car is more understandable for the driver'

Leonardo Galante, technical lead for motorsport activities at Lamborghini

Development work was done on the EVO1 wing, but testing showed it offered no aero advantage so the design reverted. The wing supports, however, were modified and offer more adjustability

The biggest visual change to the car is the air scoop and dorsal fin on the roof, the former said to optimise airflow and lower engine inlet temperature by 6degC, again to improve driveability

The main areas of mechanical freedom under the new rules are dampers and braking, so Lamborghini developed its own bespoke brake package, while customer teams can develop dampers

'The braking system is the same as the Trofeo in terms of disc and caliper, so from a management point of view this is better for us. Then we try to make a step forward in performance to GT3. It is a matter of risk. When you decide to not use the caliper from Brembo and do your own, it is at your own risk, but if you have good development and know what you are doing, you can do a lot.

'It is risky, but there is flexibility in that. I can do something that perfectly fits with our car, from temperature range, braking performance, friction, durability and access to the system to replace discs and pads. This way, you have the ability to do something that is only for your car.

'When you use a system from other cars, it's a good story, but you are making compromises. We like to have flexibility.'

A further help to braking capability is a potentially huge change to the throttle system for the EVO2, with all-new, electronically-actuated throttle bodies – one for each cylinder – that replaces the double body system on the old car. This should mean the engine has better responsiveness under acceleration, and engine braking is immediate. It also improves efficiency.

'In the engine, we are improving the electronics and the driveability, how the driver is responsive with the throttle, and with multiple choice of throttle response and engine braking,' says Galante. 'In the old car there was no engine braking control because there was only two throttles and the system was too late [slow] to react.

Development of the floor and diffuser is allowed, so the new car features a heavily sculpted underside and more dramatic diffuser

It is something new that we are figuring out with electronics and sensitivity. We are still in full development on that.'

Safety improvements

Following some high-profile accidents, Lamborghini has increased side-impact protection, as per FIA regulations. The rollcage in the EVO1 was built to the latest safety standards so did not require any changes in the new generation car, other than slight modification of some of the plates around the joints to increase its stiffness in the event of a high-speed impact.

A potentially huge change to the throttle system for the EVO2 [is] all-new, electronically-actuated throttle bodies – one for each cylinder

'It's a new project that reinforces the technological transfer between Lamborghini's motorsport division and the company'

Giorgio Sanna, head of motorsport at Lamborghini

While Lamborghini says the new cars represent an increased bond between road and track, the driver controls are pure racecar

However, as General Motors reasoned years ago, there is a threat to the driver from shrapnel entering the cockpit and damaging a driver's legs, so a honeycomb structure is now mounted between the rollcage and door. This has become common practice in GT3 racing, and Lamborghini has wasted no time in designing its own system.

Mind the gap

By regulation, the side impact protection must use six layers of carbon fibre on the outer skin closest to the door, one layer on the inside closest to the driver, and must comprise 23mm of honeycomb aluminium between the two skins. Finding the carbon with the correct gsm has been something of a headache for car designers of late, particularly in the volume that GT3 manufacturers must produce.

'The function is to close the gap between the rollcage and the door,' explains Galante. 'When you have a crash, one of the most important things for the driver and passenger is body acceleration, so in front, rear and side crash scenarios we look at that. There are some limits to respect and, in these terms, it is *how* you are dissipating energy.

'If you have a gap to the rollcage, then you have a higher peak acceleration, but if you absorb the energy then you have less acceleration of the body, so it is a matter of continuity between the outer shell of the door and the rollcage.'

The seat itself is attached to the rollcage, rather than the aluminium floor in order that it, too, remains in place in the event of a crash. Built to the latest FIA standard, the seat offers maximum driver protection in terms of both body and head.

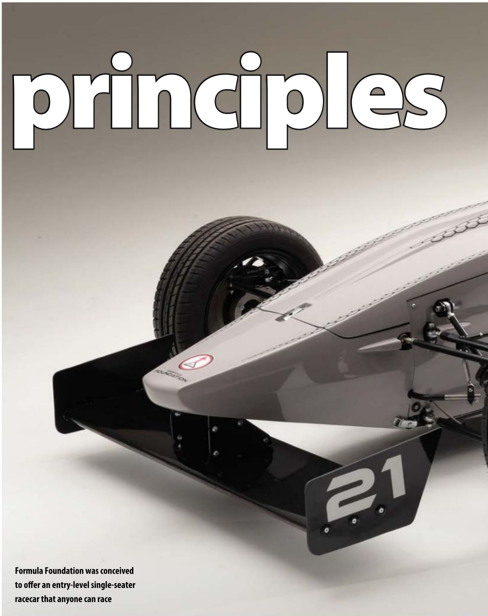
With all of this in mind, it is hardly surprising Lamborghini does not regard the EVO2 as merely an evolution of the 2022 car, more a reflection of an increased bond between its road and track cars.

'It's a new project that reinforces the technological transfer between Lamborghini's motorsport division and the company and inherits two difficult tasks: to prove as successful as the previous generations of the Huracan GT3, which have won more than 40 international titles in six seasons, and to match its commercial success by helping to reach the target of 500 Huracan racecars since 2015,' said Giorgio Sanna, Lamborghini's head of motorsport.

The new car will be delivered to the first customers at the tail end of 2022, and will make its race debut at the Daytona 24 Hours in January 2023.

With high hopes for how they will perform, the first batch of EVO2s will be delivered at the end of this year and are scheduled to make their race debut at the Daytona 24 Hours in February 2023

First principles



Formula Foundation was conceived to offer an entry-level single-seater racecar that anyone can race

Formula Foundation intends to shake up the grass roots racing scene with a clever single seater that's as easy to use and maintain as it is cheap to run. Racecar *spoke to the men behind the concept*

By MIKE BRESLIN

There have been quite a few new, lower level single seaters launched over the past few years, most of them indistinguishable to all but the well-trained eye, largely because they try so hard to look like scaled down Formula 1 cars. It is genuinely refreshing, then, when something truly different comes along, like Formula Foundation.

That said, like many good new ideas, this is actually – at least partly – based on something old. In the mid-1980s, when Formula Ford 1600 budgets were going stratospheric, the then owner of Brands Hatch had the idea of introducing a first in British motorsport, a one-make single-seater championship. It's funny to think that what is now the rule was a revolution in 1987.

And so Formula First was born, featuring a Van Diemen-built car with a transverse-mounted Ford CVH engine, very basic suspension and no aero. It was relatively successful too, with races shown on the BBC's *Top Gear* (a very different show back then) and it featured good, if a little wild, racing.

Formula fade

For some reason, it's hard to find much information these days on Formula First, and it seems to have faded away without a murmur. But every now and then, one of its slightly peculiar looking racecars turns up. For example, a few years ago, a Formula First was brought from Norway to Steve Wills' fabrication firm based in Snetterton for some work. Wills, a former Van Diemen man and a racecar constructor in his own right, producing the Spirit Duratec Formula Ford car in the mid-2000s, was looking for a new project, and this car was inspiration.

'Seeing a Formula First again, it was clear to me there was a market for something similar. A modern day version, really,' he says. 'It's no secret there was a lot of inspiration for the Formula Foundation car there.'

And while the new Formula Foundation car looks quite different from a Formula First, it does share the same philosophy. Richard Huddart, a partner with Wills in RSR Technology that's driving the project, explains: 'Our car is like the linear successor to that, absolutely. The principle of something cheap and affordable is much the same. There are very, very expensive categories

TECH SPEC: Formula Foundation RSR 001

Chassis: MIG-welded spaceframe constructed with T45 and ROPT510 CDS aerospace grade steel tubing, complying with FIA strength and crash testing regulations; 10mm Diolen panels for extra side impact protection

Bodywork: GRP, designed as a multi-piece assembly to avoid high replacement costs after any accidents

Engine: Sealed Ford 1.6-litre SE (Sigma); naturally aspirated; aftermarket ECU with single standard map; bespoke wet sump and exhaust manifold
Power: 120bhp

Gearbox: five-speed standard Ford gearbox with H-pattern selection

Suspension: Double wishbone front and rear; single-adjustable, oil-filled coilover dampers by Protech Shocks fitted outboard

Aerodynamics: Single-plane, partially-adjustable front wing; non-adjustable rear winglets

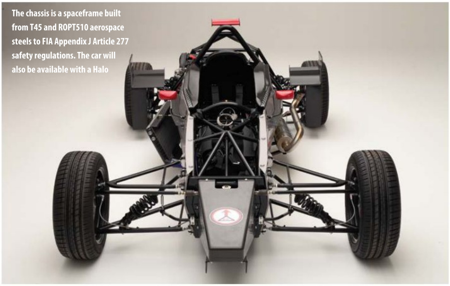
Wheels and tyres: 15in Mini wheels (currently running on Nankang road tyres)

Brakes: Mini discs; Wilwood aluminium front (four-pot) and rear (two-pot) calipers; bespoke stainless steel pedal box; cockpit-adjustable brake bias

Dimensions: Front track - 1727mm; rear track - 1720mm; wheelbase - 2412mm

Weight: approx. 500kg

The concept is *all* about simplicity… The whole idea was dad and lad, mum and daughter, whatever the case is, can get out there and have what we feel is affordable fun



The chassis is a spaceframe built from T45 and ROPT510 aerospace steels to FIA Appendix J Article 277 safety regulations. The car will also be available with a Halo

out there – Formula 4 and the like – and we thought the budgets for these were ludicrous [a UK F4 budget is said to be in the region of £300,000 (approx. $390,600) this year]. The costs simply don't need to be that high.'

Importantly, this is also about providing something that is easy to run. 'We felt there was a need, a requirement, for a very simple car,' continues Wills. 'And the whole car has been designed with simplicity in mind.

'I can't stress that enough. The concept is *all* about simplicity. We have even gone back to shocks at the wheel, so no pushrod suspension, just trying to keep it absolutely simple. You can certainly garage it at home and you don't need a race team to run it.

'The whole idea was dad and lad, mum and daughter, whatever the case is, can get out there and have what we feel is affordable fun.'

This clear focus on simplicity and low cost is one of the reasons the team at RSR has opted for a spaceframe chassis rather than a carbon tub. But that's not to say it's scrimped on safety, quite the opposite. The car has been built to the FIA's Appendix J Article 277, for Formula Libre single seaters. Because of this the remarkably intricate chassis is very meaty, made as it is of T45 and ROPT510 CDS aerospace-grade steel tubing, all designed on CAD, while its safety credentials are bolstered with super strong Diolen (a Kevlar-like material) impact panels fixed to its flanks.

It also has a collapsible steering column and crash structures at the rear and front. And while the car shown in the pictures is not fitted with an F1-style Halo, the team is working on a bolt-on version that can be fitted, or not, as per the regulations of any series that adopts the car.

The problem with all these safety considerations is the base weight has been driven up a bit, to around 500kg once the current steel floor is replaced with aluminium. In the context of this project, more crucially the cost has risen too, to a point a little beyond what RSR was hoping to sell the car for. Estimates are now in the £38,000 (approx. $49,350 / €45,750) region, though that's still not too bad for a brand new single seater.

Cheap runnings

Where this car *really* ticks the boxes when it comes to budget motorsport, however, is with its day-to-day, and indeed year-to-year, running. This is probably best illustrated by the choice of engine, a standard 1.6-litre Ford Sigma SE (aka Zetec or Duratec). The only real modification is a bespoke baffled sump developed to help alleviate concerns over oil starvation during race conditions.

'The engine was used for several reasons,' explains Wills. 'We looked at engines very carefully and selected, with [tuning expert] Scholar's recommendation, the 1.6 SE, which was of course once the Duratec Formula Ford engine. We like the engine, it's ultra reliable and they're very, very cheap, which obviously fits the bill. So we have simply used the standard Ford Focus and Fiesta assembly.'

These power units are no longer available new from Ford, but in some ways that is no bad thing. 'You can buy these engines for as little as £75 now from a breaker's yard, and a very good one with ultra-low milage for around £250. It's just absolutely absurd really,' continues Wills.

'But another reason for the engine choice is the name Ford has that little bit of a ring to it, for motorsport. The Ford engine was also good as non-turbo, and there are no other similar engines available in today's world that are naturally aspirated. They're all turbo power units these days.'

There are several reasons why a non-turbo engine was desirable, as Wills explains: 'We knew turbo would give us more problems. There's more initial cost with the fly-by-wire throttle, the ECUs are twice the price and heat management is a problem. So the only real engine to choose was this one. Okay, it's not great that it's out of production, but then again so is the Kent engine.'

We like the [Ford Sigma SE] engine, it's ultra-reliable and they're very, very cheap... we have simply used the standard Ford Focus and Fiesta assembly

Mention of the Kent engine is telling, for it is these ageing units – all well over 50-years old now – and the full-race gearboxes used in the Formula Ford 1600 category that have caused major cost issues for that venerable formula in recent years (see *RE* V32N2).

The car packs a production-based 1.6-litre Ford Sigma SE engine. It is completely standard except for a bespoke baffled sump, tubular exhaust and an aftermarket, single-map ECU. The car's builders say a replacement unit can be bought for as little as £75

The wheels are from the BMW Mini and other parts, such as the radiator and brake discs, are sourced from basic road cars, greatly reducing the cost of spares

In a similar vein, this is why RSR has also decided to keep things equally simple by retaining the five-speed, H-pattern gearbox that comes with the Sigma engine.

'It's not ideal when you can't buy one brand new from Ford, but it is a way forward,' says Wills. 'It's obviously much cheaper than a sequential and paddle shift, and the engine and gearbox assembly is so reliable, and so easy to use. You just switch it on and away you go, which is a key point with this car.'

As a package, they're not too heavy either. 'The actual assembly – the whole gearbox and engine, dressed – weighs about 130kg,' says Wills. 'From memory, I think the engine is about 80kg of that, with certain aspects a bit high. The starting motor, for instance.

'But the Yamaha engine it is based on is almost like a motorcycle engine, when you start studying it. It's really quite petite.'

Sealed bids

The plan is for the engines to be dyno'd and then sealed, so that organisations running a series featuring the car can stop any performance modifications being made by competitors who might be looking for an unfair advantage. RSR has also resisted the temptation to breathe on the engine in any significant way, sticking close to the driving philosophy behind this car.

'We didn't really want too much power,' says Wills. '120bhp at the crank is what it's got, and all that's been added is an aftermarket exhaust, manifold and ECU. That's it. There's no trickery, no special cams, nothing. It is absolutely straight from a Ford Fiesta.'

While that might sound basic, the design of the installation took some serious thinking and quite a few man hours. The result is a very neat solution, especially the work with the exhaust system, which is tightly packaged inside the left sidepod.

'We know noise is a problem these days, and with the SE engine, with the exhaust manifold at the back, we couldn't package any real silencers,' says Wills. 'So we ran the exhaust forward, in what we call a trombone style. It goes right the way down the car, through a cat', and then turns back, before coming out at the top of the sidepod.'

Counterbalancing that exhaust on the right-hand side of the car is the single aluminium radiator, which looks very much like a standard one taken from a small road car. Because that's exactly what it is.

'The exhaust consumes the space for a left-hand radiator,' explains Wills, 'and the radiator on the right is a standard Vauxhall Corsa B one, £35 from your local motor factors. Because it's just a standard motor it's cooling, one radiator does the job.

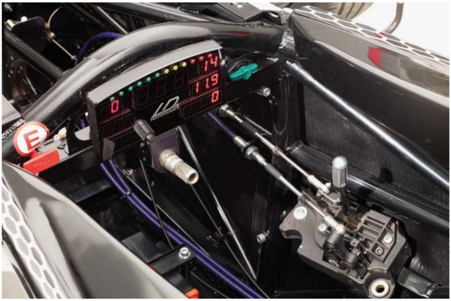
'The car's done a lot of laps in Finland, and they had a very hot summer last year, much hotter than I imagined, but it was still fine.'

Using a road car radiator offers further useful cost advantages, as Wills explains: 'One of the big things with this concept, why all this has been done, is we haven't the money to keep a large stock of bespoke radiators on the shelves at any one time. But that's good for the customer, because when people have to go back to the racecar manufacturer to buy parts, that rattles them, as it's usually expensive. Buying from a regular road car parts retailer is far cheaper.'

This same approach has been taken with the wheels – and even the wheel bolts – and also the brake discs, which are all from the BMW Mini (though the calipers are by Wilwood, which actually worked out cheaper than buying those from BMW).

When people have to go back to the racecar manufacturer to buy parts, that rattles them, as it's usually expensive. Buying from a regular road car parts retailer is far cheaper

To help fit a silencer to keep noise levels within today's acceptable limits, the exhaust needed to go through some serious contortions along the chassis before emerging out of the top of the left-hand sidepod



By choosing the standard five-speed Ford manual transmission that comes with the Sigma engine, the team has avoided the huge outlay associated with paddleshift gearboxes. If a customer should need another one, it's a couple of hundred quid from a breaker's

The aerodynamic package is simple, and partly driven by modern customer demands. It comprises a partially-adjustable front wing, two pairs of fixed winglets towards the rear and an LMP-style rear fin

The styling at the rear is especially neat. The RSR team hopes the car will be racing in a spec series, perhaps in the UK or Finland, by next year

Meanwhile, the suspension is as simple as possible, harking back to Formula Fords of old, with a double-wishbone layout and a single-adjustment, oil-filled coilover damper from UK supplier Protech Shocks, fitted outboard. Sensibly, the wishbones are non-handed to reduce spares cost.

'We simply fabricated each arm so they're interchangeable, so the left is the right and the right the left,' says Wills. 'This means you need only carry one spare top wishbone. There's nothing new there, of course, but it took a bit of doing.

'We've tried to think the suspension through with simplicity in mind in every area, to give the customers every possible chance to run the car themselves.'

Aero element

While the suspension should be simple to work with for both mechanics and drivers, the inclusion of an aerodynamic element, in the shape of the adjustable front wing and fixed winglets towards the rear, is perhaps surprising. When questioned, Wills admits he did think about presenting the car without aero, as is the case with Formula Ford.

'I would love to have it cleaner, but one of the issues we had is that to run the crash test with the crash box, we had to have a stepped floor. Not *that* stepped, but it is stepped, which I don't particularly like, and the wing disguises that.

'Also, I don't think in today's world you can sell a car without a front wing on it. Youngsters want to see some aero bits and pieces on a racecar.'

There is also a distinctive fin at the rear, though this is more practical than aesthetic. 'The reason for the high tail at the back is to get through the relevant crash test for the roll hoop structure loads,' explains Wills. 'To do this, we have to run some braces at the rear of the car, and the tail is a result of that.'

Which leads us to the overall aesthetic of the car, which in racecar engineering terms should mean nothing. If it's fast it's beautiful, someone once said. But that's not necessarily the case when it comes to a spec car (though even with one-make formulae other things, safety in particular, do take precedence).

It's interesting to recall that when Damon Hill (then an F3 driver) tested the new Formula First for a weekly motorsport publication in the '80s, he wrote something along the lines of: 'It's not only a piece of cake to drive, but it also looks like a piece of cake'. In comparison, and as far as bakery products are concerned, it's clear the Formula Foundation car is no wedge of Black Forest gateau. In fact, it's quite a neat-looking device, even better when you see it for real, but you can never be certain that the looks of any racecar will attract customers. This is not something that's lost on Wills.

Formula E-asy

The engine bay is said to be large enough to take a variety of power units, including electric

Visually, the Formula Foundation car probably looks more like a Formula E machine than a more conventional single seater. Long term, the same might be said of the mechanicals, for there is room in the chassis, and inclination in the team, to develop an electric version of this low-cost racer.

'We've gone into it in quite a lot of detail,' says Huddart. 'We're quite advanced on it already, and it could be done very easily, and not too far into the future. Technically, we know it's doable, it's just trying to work the magic of trying to get it at a price that is acceptable. But it would be a perfect car as an electric single seater.'

That said, there are issues in going electric. 'It's not the motor. It's not the inverter. It's not the electronic control of the battery package. It's none of that,' says Huddart. 'It's the cost of the batteries, and the weight of the batteries. That's where the problem lies.'

If this should happen, and it is very much an 'if' at the time of writing, then RSR plans to make the replacement powertrain interchangeable with the ICE car. 'If the electric version comes, you would be able to convert your present car into the Formula Foundation Electric, or whatever we decide to call it,' says Huddart enthusiastically.

While there will be safety aspects to bear in mind, such as marshals handling the cars, the brevity of club races in the UK, where they can be as short as 15 minutes, means that in the future a car package like this might be just the thing for racers looking for a start in electric motorsport.

'What we were afraid of was that the car was going to look like a Formula First,' he says. 'We had this sort of wide bum, if you like, where the engine sits across the chassis. But what we did – which was Richard's idea – was we went for what we felt was the Formula E look, a sort of delta. That way we tried to keep it looking really modern.

'We also package-protected the rear end for various modifications that may come along, including electric [see box out above].'

If we're being honest, though, it's not the looks of the Formula Foundation car that will attract serious customers anyway, it's that philosophy of simplicity and useability that is more likely to clinch sales. And on that score, RSR has another trick up its sleeve.

'One thing we're quite happy to do is to sell the car as a kit,' says Huddart. 'Like people buy a kit car. You buy the chassis, and the bodywork, and then they can build up the rest of the car themselves.'

The idea of building the car as a kit brings a bit of a hobbyist element to the table, reminding us that motorsport should be fun, and that's the case with this car on track too, where it's said to be a real joy to drive.

That's the opinion of former F1 driver, JJ Lehto, at any rate, who revelled in some flat-out laps in the car at the Alastaro circuit in Finland last summer, telling Wills that it was a delight to slide on the limit.

I don't think in today's world you can sell a car without a front wing on it. Youngsters want to see some aero bits and pieces on a racecar

Finland is, in fact, where there has been the most interest in this project so far, with talk of it being run under the Formula A banner. Meanwhile, in the UK the car is to be displayed at BRSCC meetings this season to drum up interest for a spec series, while the possibility that it might form the basis of a racing school fleet has also been mooted.

Wherever it ends up racing, the philosophy behind Formula Foundation means it has every chance of being a success. And because of the sheer hard work and common sense ingenuity that's been expended in developing this utterly useable racecar, it thoroughly deserves whatever success comes its way, too.

Visible advantage

No racecar exemplified the admirable freedom of the 1960's Can-Am series more than the 1966 Chaparral 2E. It was just a surprise it took so long for its competitors to catch on

By KARL LUDVIGSEN

Plunging through the Corkscrew at Laguna Seca, the Chaparral 2E really showed its capability in the hands of its creator. It was the best race of the '66 season for Jim Hall and team mate, Phil Hill

Jim Hall's Chaparrals were the cars to beat when the Can-Am series was born. In the SCCA's US Road Racing Championship (USRRC), the amateur series that predated, and later paralleled, Can-Am, the Chaparral 2A had been almost unbeatable. Its outstanding success in 1964 and 1965 in the USRRC helped make it the top Can-Am favourite.

At that time, Hap Sharp, a partner in the Chaparral Cars company, based in Midland, Texas, shared the driving in the two-car team with Hall. Older than Hall, Sharp was a source of good ideas which, when bounced against his partner's sound engineering education from Cal Tech, produced results.

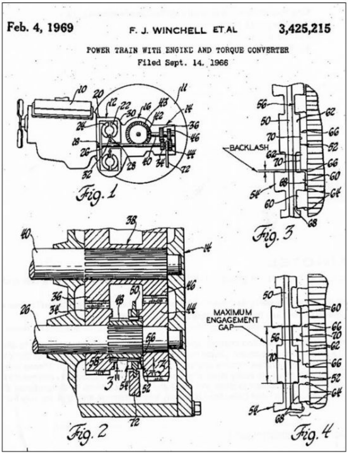
The car's pace was such that, before the USRRC race at Watkins Glen in 1965, Dic Van der Feen of the SCCA took Hall aside and pleaded; 'Couldn't you just take it a little easy this time, and not lap the cars behind you? It makes it look so bad when they're lapped.'

Hall said he'd think about it, and then went out and, under pressure from Sharp, went so fast that the third-place car was triple lapped. When he saw Van der Feen after the race, he struck his forehead, rolled his eyes skyward and said, 'I'm sorry Dic, I forgot all about it.'

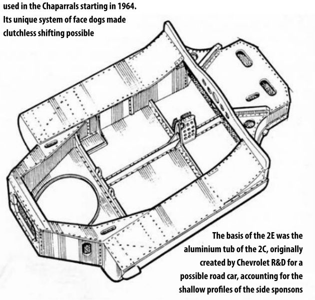
By 1966, Hall was making his first big attempt to win races in Europe with Chaparral coupés, an effort that took far more time than he expected. The 2D coupés were the USRRC roadsters fitted with glass fibre tubs and rebuilt for long-distance racing. One of them won the Nürburgring 1000 Kilometres with Phil Hill and Jo Bonnier driving, and Hap Sharp the team chief.

British effort

1966 also saw the maturing of early attempts by the British to build cars to use the big American V8 engines that were on offer. With these behind their drivers, both Lola and McLaren became major competitors for the first time. But they were entering a field that for several years had been dominated by American-built, mid-engined specials, mixing powerful V8s with Cooper and Lotus chassis.



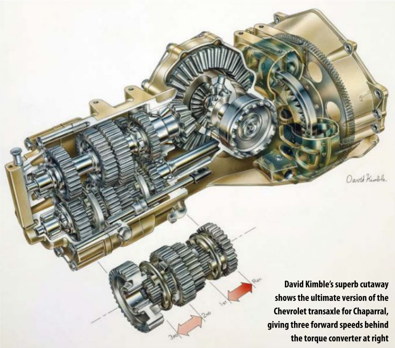
Chevrolet's Frank Winchell patented the torque-converter transmission used in the Chaparrals starting in 1964. Its unique system of face dogs made clutchless shifting possible



The basis of the 2E was the aluminium tub of the 2C, originally created by Chevrolet R&D for a possible road car, accounting for the shallow profiles of the side sponsons

'It isn't surprising we changed to aluminium. With glass fibre, you're committed to that shape and size when you build moulds'

Jim Hall



David Kimble's superb cutaway shows the ultimate version of the Chevrolet transaxle for Chaparral, giving three forward speeds behind the torque converter at right

The Chaparral was the best of the all-new American cars that followed this first experimental stage.

A couple of years earlier, the Texans had forged a link with an arm of General Motors that was thrusting in new directions under the guidance of engineer, Frank Winchell. This was Chevrolet's research and development arm, to which Hall and Sharp had been introduced by styling chief, Bill Mitchell.

With Corvair, the R&D people had been experimenting with mid-engined chassis and, in 1963, in a project headed by a young engineer named Jim Musser, built an aluminium monocoque with racing suspension, the latest wide tyres, a tuned engine and ultra-thin GRP panels rivetted and bonded with an oven-cured 3M adhesive. Weighing 1450lb (658kg), the GS-IIb reached 198mph at GM's Milford Proving Grounds.

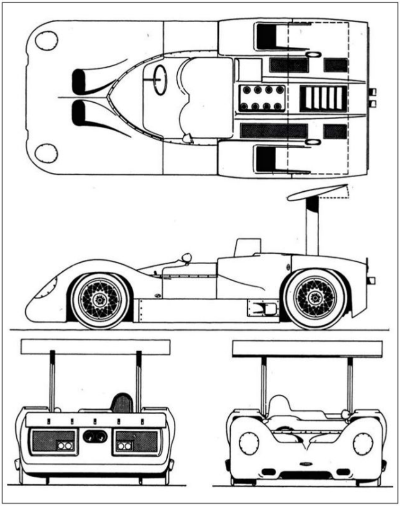
Enter 2C

Toward the end of 1965, at the Kent, Washington USRRC race, a new Chaparral was introduced, the 2C. Its basis was the aluminium-framed GS-IIb tub built by Chevy R&D and it was smaller and lighter than the more rugged, glass fibre-monocoque Chaparral 2A. The previous car's frame weighed 140lb (64kg), more than double the heft of the 2C tub, yet was no stiffer.

'It isn't surprising we changed to aluminium,' Hall remarked later. 'With glass fibre, you're committed to that shape and size when you build moulds, so you've either got to be very fluent or spend a lot of money to rebuild the mould all the time.'

A feature of the frame was that its cockpit-side, fuel-bearing sponsons were shallow by racing tub standards. Though not deeply detrimental, they were intended to help entry and exit from the road car for which the frame was originally designed. A disadvantage from the racing drivers' standpoint was it amplified vibrations and stresses that the glass fibre tub previously absorbed. These came both from the track and from the suspension's anti-dive and anti-squat geometry, which fed impacts back into the frame. Drivers dubbed it the 'EBJ', for eyeball jiggler.

More visible than the frame was the 2C's driver-controlled rear spoiler. Large, fixed spoilers had been steadily growing at the rear



A four-view illustration depicts the Chaparral 2E as it appeared in the early races of the 1966 Can-Am season with its wing no wider than the car. Wheels shown are a design by a Chevrolet engineer

Bereft of decals and with Hall at the wheel, the new 2E was pristine as it prepared for its first laps of Bridgehampton

Jim Hall's design of the tail and rear deck of the 2E was exemplary. Note a space was left clear for fitting a Texas number plate

Engineer, Troy Rogers, checks a detail on the 2E's wing, shown here in its default position for maximum downforce

of sports racers, to the point where their drag had become a disadvantage. The 2C had a big spoiler that defaulted to the erect position, and could be made to lie almost flat by a push on a pedal to the left of the brake pedal. In the Chaparral, this was easily achieved thanks to its radical transmission.

Dynaflow sound

During the '64 season, it slowly became clear to its rivals on track that the Chaparral 2A had something different in the transmission department. What surprised Musser was that they took so long to notice. 'I thought the sound of the car on the track would give it away. It had a Buick Dynaflow sound.'

That wasn't surprising because, in principle, the gearbox was identical to the original 1948 Dynaflow, which relied on a hydraulic torque converter to give a 3.1:1 torque multiplication.

'The automatic transmission was Hap's idea,' noted Hall. 'He drove my first car, the Chaparral 2, that had a 327 Chevy, a big gearbox and quite small tyres in those days, and it would spin the wheels in just about any gear up to fourth. He got out of it and asked, "Well, what's the transmission for?"

'We then thought, what if we use a torque converter to multiply torque for starting? We were working on that pretty hard when I got associated with a Frank Winchell, who was in charge of Chevy's R&D department in Detroit. He said, "Golly, I've got some ideas about that."

'He came up with that transmission for a prototype car they built in 1964, and I tested the transmission in our car. It was very, very good and easy to drive. We thought it had a lot of potential. So they made a deal to let us use it as a piece of test equipment.'

'I feel this automatic transmission is the greatest innovation in auto racing today,' said Roger Penske, who was racing one of the Chaparrals at the time. 'We thought at first it might be a problem because of the wear on brakes when you can't use your engine for braking. However, with the breakthroughs in brake technology, and the better cornering power of the new tyres, you can go into corners deeper, and faster, without losing control. You can also keep both hands on the wheel… and you can use left-foot braking and save time between the start of braking and the return of your foot to the gas pedal.

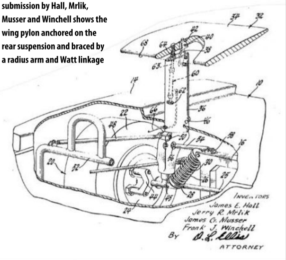
'Jim's transmission gives the engine increased life of 50 to 100 per cent,' Penske added, 'because there are no downshifts where you have a chance of over-revving the engine when accelerating out of a corner.

'You don't wind up and then drop down… wind up, drop down… and then wind up until you finally get it in a high gear. With the automatic, you have consistent rpm climb. There's no quick acceleration of rpm unless you hit oil or water on the course where it will make the wheels spin. As long as the wheels aren't spinning, you have constant application of torque and horsepower to the rear wheels.'

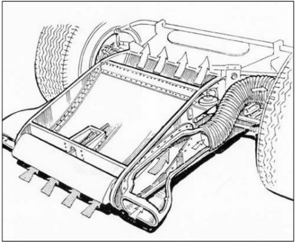
Married elements

As described in the patent that he and Jerry Mrlik lodged on 14 September 1966, a further development of Frank Winchell's transmission married a three-element torque converter with a two-speed manual shift. Winchell set out the concept of a transmission that could 'maintain converter output torque and approximately peak engine torque

This illustration from a patent submission by Hall, Mrlik, Musser and Winchell shows the wing pylon anchored on the rear suspension and braced by a radius arm and Watt linkage



A detachable steering wheel was needed for 2E entry. Gateless shift lever operated the transmission's three forward speeds. Vents to release pressurised air from the front wheelhouses are now simple holes, deemed easier to make than the earlier louvres



When depressed to feather the wing, the left-hand pedal also operated a cable that opened a flap at the front to admit air that added balancing frontal downforce. Side apertures delivered brake cooling air

At Bridgehampton, Phil Hill's 2E (wearing Hall's no.66 for the race) appeared with a white wing. He proved quick, but was troubled by teething problems on the fast track

throughout the speed range in which engine torque increases with increasing engine speed.' Also illustrated in the patent was the special design of face-dog clutches that made the box easy to shift without a clutch.

At first, the gearbox – inspired by the quickchange centre sections made for Indy cars by Ted Halibrand – served solely for forward and reverse. But as tyres improved, better starting torque was required. For this, and a higher top speed, a second speed took the place of reverse. Finally, Chevrolet added a third speed when Chaparral competed in endurance events abroad. This arrangement was used in the 2E as well.

'In the 2E, you were often able to leave it in one gear, without shifting as you would in an ordinary racecar'

Phil Hill

'This worked fine,' said 2E driver, Phil Hill, of the gearbox, 'except it wouldn't tolerate being yanked into gear while the car was stationary, even with the engine at a slow idle. You had to actually stop the engine, then put it in gear and only then could you fire it up again.

'The procedure for driving off was like this: engage first gear, then start the engine while holding the car with your left foot on the brake pedal, which was on the left and meant to be used with the left foot only. Release the brake and drive off. You could shift at any speed you wished into the next gear. You could even start off in second or third gear, though with less performance.

'Shifting did require actively getting it out of gear in that millisecond when the power let loose,' Hill continued, 'and then smartly timing it into the next gear. It was as easy and simple as that, with a conventional H-pattern shifter but no clutch.

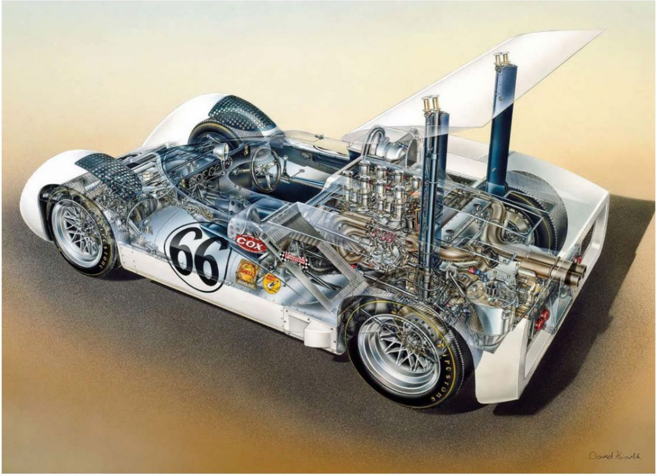
'Downshifting, I'd lift a bit to take the pressure off the dogs, snick the lever into neutral, add a quick stab of revs and go down. That sounds like a series of small events but, in reality, it was one quick, easy motion.

'Thanks to the torque converter in the 2E, we had three ranges: zero to about 110mph, zero to 150 and zero to 190. This added flexibility. You didn't have to be continually changing up or down to get to the gear and range of speed appropriate for a particular part of the circuit. In the 2E, you were often able to leave it in one gear, without shifting as you would in an ordinary racecar.'

Standing start

'There was only one drawback,' Hill admitted, 'the combination of this gearbox and the torque converter meant the 2E suffered off the line. Races had standing starts and the Chaparral couldn't accelerate from a stop like an ordinary racecar. With a clutch, you can store up some power in the flywheel and dump it through the clutch to the wheels to get off the line quickly. But you can't build up that sort of force in a torque converter, so we lost our advantage at the start.

'The difference was enough that, although we could qualify in the front row, sometimes we'd be in the second or third row by the time we reached the first corner.'



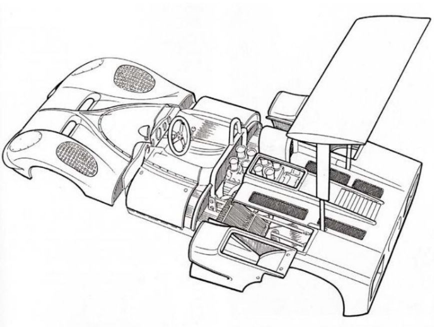
David Kimble captured the features of the Chaparral 2E beautifully in this full-car cutaway, including the aerofoil-section tubes that carried the wings with the hydraulic actuators hidden within

The one-off Chaparral 2C was a proven user of the torque-converter transmission and foot-operated spoiler by the time Jim Hall drove it in the Northwest Grand Prix at Kent, Washington on 10 October 1965. Hall won both heats and finished first overall in the 2C, with Sharp second in a 2A. Satisfying as this result was for the team, it was destined to be Hall's last victory at the wheel of a racecar.

New and improved

Meanwhile, back in Midland, the Chaparral crew, of which Franz Weis and Troy Rogers were stalwarts, were fabricating two completely new Chaparral racercars, save for their 2C-type tubs, drivetrains, tubular front wishbone suspensions and anti-roll bars. Unlike the rest of the field, they ran larger 16in wheels to have enough room for 12in disc brakes with ventilated Kelsey-Hayes discs and Girling calipers. Firestone provided special tyres for the team.

The design of the new 1966 Chaparral 2Es was revolutionary, as my spies in Detroit had warned me, so I wasn't as astonished as other railbirds when the two white cars were unloaded from their usual pick-up-towed trailers at Bridgehampton for the second Can-Am race of '66 on 18 September.



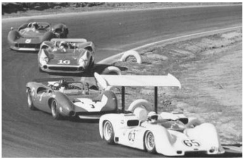
Brian Hatton's more simplistic illustration exposes the 2E's rear suspension trailing arms and forward-sloping water and oil radiators. It's slightly incorrect in that the instrument panel was actually further forward than shown

At Laguna Seca in '66, Phil Hill won the first heat and finished in second place in the second heat, giving him enough points to win the overall race. The Chaparrals were at their zenith here

Jim Hall reverted to smaller air inlets for his 2E's radiators at the faster Riverside circuit, shown here with his wing in the high-downforce default position. He placed second, behind Lola-driving series champion, John Surtees

When the 2Es arrived at Laguna Seca, they had wider wings with added end plates that markedly increased efficiency. An adjustable tail spoiler was also added, shown here retracted

Of the two 2Es fielded at Laguna Seca in 1966, Jim Hall's differed in having larger air inlets for its radiators. This was achieved by cutting them further back, making them closer to the warm-air exhausts



At Riverside, here heading the Lolas of Graham Hill (3) and George Follmer (16) and the McLaren of Chris Amon (5), Phil Hill had to retire his 2E with fuel pressure problems

'Wait until you see it…' I was told by friends at the Bridge. 'It's… it's… it's got a great big wing on the back!' Indeed, it did.

Wing thinking

Swiss racer / engineer, Michael May, is rightly celebrated as the first to fit a proper downforce-generating wing to a racecar. He did so in 1956. He and a colleague designed and built an inverted aerofoil mounted on pylons to his Porsche 550 Spyder in the position it would add the most downforce to all four wheels. Moreover, he fitted a lever so the driver could adjust the wing for maximum downforce or minimum drag. The rig proved so effective that Porsche lobbied successfully for its removal at Nürburgring and Monza.

Being an engineer like May, and one who associated with some equally good engineers at Chevrolet, Hall was the man to tackle the wing idea properly, albeit a decade later.

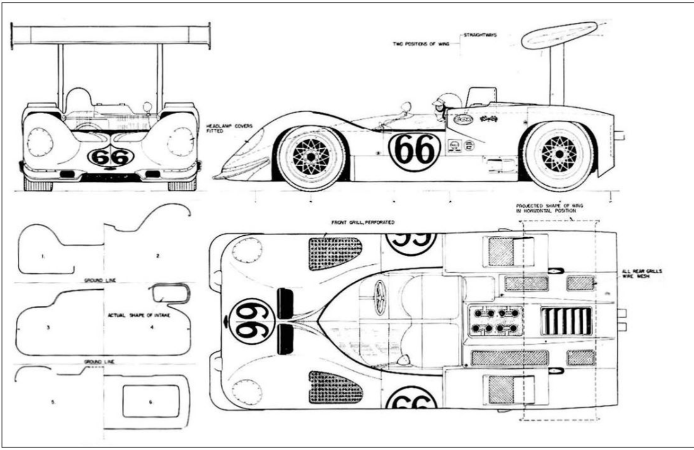
Shaping of all elements of the Chaparral 2E was masterful. It looked like no other racecar

'I studied aerodynamics and thermodynamics in college,' Hall recalled, 'and I learned to fly as a teenager, so I had experience with aeroplanes. All that went together for me. I can look at an aerofoil, or get an aerofoil book, and calculate the amount of force we're going to get from this or that size wing, which is the way Chaparrals were built. We knew approximately what kind of force this wing was going to produce before we actually built it.'

Working in close conjunction with his friends at Chevy, Hall's breakthrough was in mounting the wing-carrying struts on the rear hub carriers so that force was applied directly from the wing to the rear wheels and tyres. This was done through tall pylons that held the wing well clear of disturbances around the car's airflow. Holding the pylons in place was a form of lateral Watt linkage and parallel trailing arms akin to those guiding the wheels.

Internally, the aerofoil-shaped struts carried the hydraulic system that was used to change the angle of the wing while the car was moving. In its default position, the wing was angled downward at an angle of 17-18 degrees to generate 240lb of rear downforce at 100mph to help cornering, acceleration and braking. Using a left-foot pedal, the driver 'feathered' it to four or five degrees below

Having lost the right front corner of his 2E in an early fracas with Parnelli Jones, Hill finished a troubled seventh at Las Vegas after his wing was removed for its insubordination



horizontal (depending on the circuit being raced on) on straights to reduce drag.

Applied for on 22 March 1967, the entire aerofoil system was patented in the names of James Hall, Jerry Mrlik, James Musser and Frank Winchell.

Force control

With this anchoring to the rear hubs, Hall noted that downforce is 'not transmitted through the body and spring system of the car. Now you can control the pitch angle of the car very much better because you don't have to worry about this big force going into the bodywork.

'The other feature of it is that it's controllable by the driver in the cockpit. The wing's centre of pressure is forward of its pivot, so it always wants to turn away from where it's hinged. If it's in this position, it wants to stay there.

'The driver has a pedal next to the brake pedal. When he gets out on the straight and realises he's not accelerating as fast as he'd like to, he just takes his foot over and pushes on the pedal. That trims the wing out and adjusts the front downforce. When he gets to the end of the straight, he takes his foot off that pedal and puts it on the brake. So it's automatic. It's fail safe. You can't go into the corner with the wing in the wrong position. We left foot braked and right foot accelerated.'

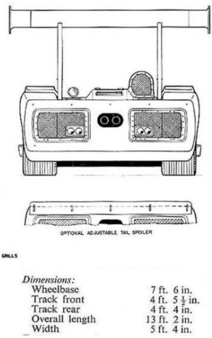
In a coda to the 1966 season, Hap Sharp had his only 2E drive, winning the 25-lap Governor's Trophy race at Nassau. This overhead photograph taken there gives us a chance to see the chassis beneath the bodywork semi-exposed

Adjusting front downforce to balance that of the wing was the function of an upward-sweeping air duct in the nose, where a radiator would normally be. When open, this duct produced an aerodynamic reaction that forced the car's nose downward. Linked with the wing-controlling pedal was a flap that closed off the duct when the wing was 'feathered', reducing both downforce and drag.

So, where was the radiator? As part of a major effort to shift weight to the rear driving

'In 1966, when we ran the 2E, that dramatic moment in aerodynamics, it wasn't ready. If we had worked on it, we would have won almost every race'

Jim Hall



A four-view drawing of the 2E showed the front 'whisker' spoilers that were added for the west coast Can-Am campaign to counterbalance the added downforce of the wider wing

wheels, two Harrison aluminium radiators were mounted athwart the engine, ahead of the rear wheels, and sloping forward. Air entered them through forward-facing scoops and exited through large horizontal apertures above the radiators.

Another benefit of this positioning was greatly reduced cockpit temperatures. Earlier Chaparral cockpits became so hot that, late in their development, a dedicated driver-cooling duct was installed.

Other measures to shift weight rearward included cylindrical tanks for engine oil and fuel at the extreme rear. This higher rearward weight bias meant better braking, with the rear wheels still able to contribute during high *g* racing stops. Overall, the 2E weighed 1365lb (619kg).

Shape fantastic

Shaping of all elements of the Chaparral 2E was masterful. It looked like no other racecar, a hi-tech machine for speed created by some futuristic institute's brilliant engineers. Its rear deck alone was a festival of fascinating panels, pipes, ducts and screens. This was a credit to Hall, who said, 'I shaped the bodies. I'm the guy that went out there and shaped them. Most of the shapes on Chaparrals were my sculpture. I'd come back after dinner and go to work on the clay and make the changes I thought necessary. The guys would come back in the morning and smooth it all out, make it look okay. And then I'd critique it and do it again.'

'Overall,' wrote Chaparral chroniclers, Richard Falconer and Doug Nye, 'the new Chaparral 2E's body gloriously emphasised the project's painstakingly pragmatic approach, not only to the science of aerodynamics, but also to the practicality of covering the most with the least.

'The panels did nothing more than hug the mechanical components housed within: the header tank became part of the headrest, the windshield was sharply veed in sympathy with the twin outlets for the nose venturi tunnel, and so on. The Chaparral 2E breathed pure function with a futuristic sense of style never forgotten.'

Bumpy start

Delayed in his testing routine by the big European endurance effort, Hall hadn't been able to test the 2E as thoroughly as he had wished. The fast, bumpy Bridgehampton track finished the job for him when a bolt worked its way out of the Watt linkage on Phil Hill's car in practice, sending him off the track. Hill consequently took over Hall's car for the race, but had trouble with the hydraulic wing-trimming control and sticking throttles. From second place at the start, he fell to a disappointing fourth at the finish.

Like Hill had at Bridgehampton, Hall set the fastest lap at Mosport before retiring. Hill was delayed there by a bumping incident, but managed to hold onto second place.

In their third outing at Laguna Seca, the 2Es dominated both practice and the race. New, wider wings with end plates were fitted as the team gained confidence in the radical system, allowing the white cars to soar up and down the hilly California course with arrogant ease.

'The 2Es finally fulfilled their potential at Laguna Seca,' said Hill, 'with Jim setting a new lap record in qualifying. We were 1-2 (Hill-Hall) in the first heat, and 2-3 (ditto) in the second, giving me the overall win.'

Powered by special, aluminium-block, 327ci Chevy engines with Chevrolet's homemade, Weber-type carburettors, the Chaparrals had between 420 and 450bhp at 6,800rpm and torque curves tailored to the torque converter characteristics. This was not quite enough horsepower, however, to put on a strong show at the fast Riverside track – the only Can-Am the team entered that year without collecting the fastest race lap. Hall placed second there.

They looked stronger in the 1966 Can-Am finale at Stardust Raceway, Las Vegas, where Hill and Hall shared the front row of the grid, the latter setting another new track record.

Unfortunately, things didn't go quite to plan in the race itself, as Hill related: 'Soon into the race, the rod that actuated the wing on Hall's car broke and the wing began to flap up and down. He retired, and not long after the same thing happened to my car.

'That was one thing about Chaparrals: no one could ever complain they got the lesser car because they were identical.

'To be safe, they removed my wing, but now the handling was unbelievably awful, oversteering so badly I could hardly drive the car. I skated home to seventh. So ended the race and my Can-Am career, but I can't imagine a more interesting car in which to do it.'

Safety factors

Hill and Hall subsequently finished the '66 Can-Am season only fourth and fifth on points, though their cars had clearly been the quickest on track. The quiet precision of the Chaparral team operation, developed through the successful USRRC seasons, was still evident, but Hall admitted there were problems: 'In designing for aerodynamic loads on remote-mounted wings, nobody gave enough safety factor for the inertia loads that came into the support strut from the acceleration from the wheel bumps. That's a high cyclical load.'

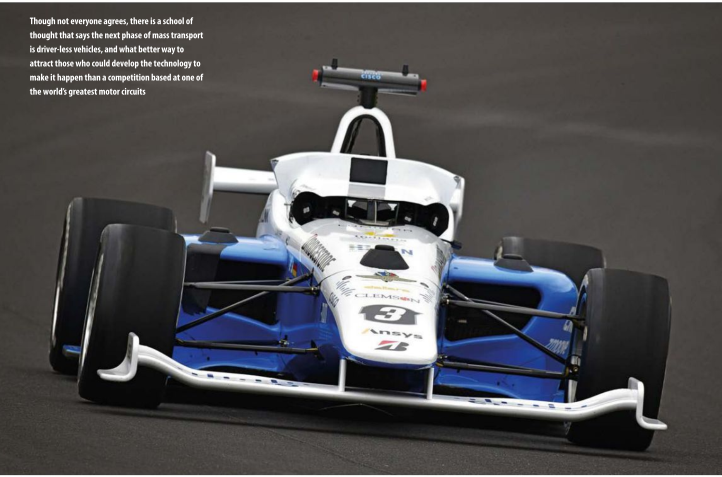
Jim Hall summed up the 2E story as follows: 'In 1966, we decided to build a car that embodied everything we'd learned about aerodynamics up to that point, and maybe a little bit about vehicle dynamics, too. So we did a lot of things with 2E that were different from the earlier cars.

'It was very successful in the sense that it was fast and easy to set up when we went to the racetrack. I think it was a really versatile, good racecar. It was just not very reliable, and we didn't win many races. So, from that standpoint, it wasn't as good.'

Asked what he would do differently with the benefit of hindsight, Hall replied: 'I would have slowed down the pace of our development, given myself time to make sure I had a reliable product. In 1966, when we ran the 2E, that dramatic moment in aerodynamics, it wasn't ready. If we had worked on it, we would have won almost every race.

'In '66 and '67, GM put a lot of pressure on me to run an alloy big block. I had 11 engine failures in one season. So my career – our career at Chaparral, I should say – was marred by me jumping in too fast, trying to do things outside our capabilities in manpower and time.'

Of the 2E he added, 'We probably introduced it a little too early. We should've had more testing on it. But that's just the way we did things. We were a small team. We built the cars in the winter and took them racing in the summer. That was it. We were the small team from Texas that rolled in with a pick-up and a trailer and ran our races and left. And it was fun.'



Though not everyone agrees, there is a school of thought that says the next phase of mass transport is driver-less vehicles, and what better way to attract those who could develop the technology to make it happen than a competition based at one of the world's greatest motor circuits

Algorithm racing

How the IAC is bringing students from around the world together to show how motorsport can lead the way in autonomous vehicle development

By LAWRENCE BUTCHER, with research by LEIGH O'GORMAN

Autonomous racing is a curious and somewhat divisive topic. To many fans, removing the driver from the equation is anathema, literally stripping the soul out of the sport. However, the clue can be found in the name 'motor' sport. It is, and always has been, a competition between drivers and machines. As such, racing has always been a battle of engineers as much as drivers, and herein lies its appeal for the development of autonomous technologies.

Pivotal to achieving reliable and safe autonomous vehicle operations on public roads is being able to deal with what are known as edge cases, the terminology used to describe unexpected events. Edge cases can take a variety of forms, from handling adverse weather to erratic behaviour by pedestrians. Motorsport is a development accelerator and, if an autonomous vehicle's AI can handle such decisions at the very limits of its abilities in the heat of competition, this *should* translate to improved performance on road. Enter the Indy Autonomous Challenge (IAC), a competition that pits autonomous vehicles against each other around some of the USA's great oval tracks.

Paul Mitchell is president and CEO of IAC, and also of Energy Systems Network (ESN), an Indianapolis-based not-for-profit organisation working on developing an integrated energy ecosystem through cross-industry collaborations. ESN is also the lead backer of the competition. According to Mitchell, inspiration for the IAC stemmed from the DARPA Grand Challenges of 2004 and 2005, which saw autonomous vehicles attempting to traverse a desert course in California, competing for a prize put up by the US Defense Advanced Research Projects Agency.

Racecar covered these events in detail at the time and, in 2018, Mitchell and others at ESN felt a similar challenge, harnessing the appeal of motorsport, could help drive current autonomous vehicle development.

Brightest minds

With the kernel of an idea brewing, Mitchell invited Sebastian Thrun, who headed the original DARPA Grand Challenge-winning

If an autonomous vehicle's AI can handle such decisions at the very limits of its abilities in the heat of competition, this *should* translate to improved performance on road

When it became clear early on that those who entered the IAC weren't interested in designing the car itself, a deal was done to use a Dallara IL15 Indy Lights chassis…

…and students at Clemson University in North Carolina developed it into the AD21 for use in the competition. US company, Autonomous Stuff, then took it through to series (of 10) production

team from Stanford University, to visit the 2018 Indy 500. After DARPA, Thrun went on to found Google's self-driving operation, which became Waymo, and now heads up Kitty Hawk, a company developing remote piloted air taxis.

'He was very insistent that we need something like that again. We needed to find a way to get the best and brightest minds to focus on this next phase of automation, and what better way to do that than through a prize competition and by leveraging the platform of motorsport,' recalls Mitchell.

The idea of an autonomous racing challenge was well received by both industry and academia thanks to, Mitchell says, three clearly stated goals laid down at its inception. 'First, we wanted to advance the state of the art of autonomous technology, to test out and validate edge cases – high speed automation with close encounters of autonomous vehicles at high speeds.

'Second, we wanted to attract the best and brightest minds from around the world to focus on vehicle automation.

'Third was to win hearts and minds with the general public – people who are familiar with motorsport. If they can see a car going 150-160mph – we hope 200mph – around a famous racetrack, then that may get them to say, "I guess if it can do that, maybe I can be comfortable turning on my ADAS lane control when I'm on the highway."'

The organisation held several working groups through 2018-'19, hammering out the shape of the competition, with Mitchell noting it quickly became clear where the main interest group was.

'It was largely made up of computer engineers, computer scientists, AI and roboticists. They were not car people.'

Those that wanted in were predominantly involved in writing code, which could be applied to anything from robotics to medical research. As a result, while the hook for the competition would be running a car autonomously at high speed, the focus didn't need to be on the traditional challenges of race engineering. It was here that Clemson University entered the frame.

Deep Orange

Every year, students from the department of engineering at Clemson University in North Carolina take part in its Deep Orange project, a programme for masters students where they build a prototype vehicle. Robert Prucka, the Alan Kulwicki Professor of Motorsports Engineering at Clemson, attended an early meeting of the IAC. 'Pretty much everybody in the room, except for me, just wanted to work on the autonomy piece, nobody really wanted to work on the vehicle itself,' he says. 'They wanted a vehicle to just show up that they could operate, and that made sense, because the computer science world is very different from the mechanical engineering world I live in.'

After some discussion, it was agreed that Clemson would take on the task of developing a suitable vehicle, a win-win for both the university and IAC. It removed the need for competitors to be involved in the vehicle development, while Clemson's

While the hook for the competition would be running a car autonomously at high speed, the focus didn't need to be on the traditional challenges of race engineering


Students, mostly computer scientists, from all over the world rose to the challenge


Amongst the aims of the project was proving the manufacturability of concepts


Packaging the hardware required into the cars gave an insight into racecar engineering


It was agreed early on that the focus should be on the software required to run the cars

students would have a truly cutting-edge project to get their teeth into.

'I loved this idea, because it was *for* students, and was to be utilised by students around the world. It wasn't a professional racing series, and it really fitted the mission of the university to help build this vehicle with students, for students,' enthuses Prucka.

Building a car capable of lapping at high speed on an oval, from scratch, would have been a tall order, even for a department of Clemson's calibre. Instead, it was decided to take an existing design and adapt it for the challenge at hand. The logical choice was the Dallara IL15 chassis used in Indy Lights, an already optimised package. The Clemson students could then focus their attention on integrating the hardware needed for automation, rather than spending time designing a tub, suspension and aero package from the ground up.

Having Clemson on board also removed a major cost hurdle for IAC, as the university footed the bill for the development process. This was a result, as even a basic car build programme would easily have run into the multiple million dollar bracket. 'Just knowing some of the prices of vehicle engineering, and what it would have taken, the Indy Autonomous Challenge potentially would have struggled to stay afloat had it gone a private route and had somebody else engineer it,' notes Prucka.

'We engineered it for free. Of course, that has risks, because we engineered it with a bunch of students, which adds a little time to the development. Taking the IL15 – it's open wheel and has that look of an IndyCar – and converting it over to autonomous was the lowest risk way forward that could be done in the shortest timeline.'

From Mitchell's perspective, using a car from a single supplier was the ideal solution, given the main aim of the competition.

'It was a pretty broad consensus that the competition should really be about the software, and not designing your own car. DARPA had allowed competitors to do both, but I think many of the people who had been involved in DARPA felt that might not have been the most efficient way to do things. So, we wanted to normalise the vehicle component of the competition, and then have the real competition be around the software to pilot those vehicles.'

Assemble autobots

The student team at Clemson set about assembling a comprehensive autonomous hardware stack for the IL15, consisting of perception systems and solutions to automate steering, throttle and braking, backed up with the computing power needed to coordinate these elements. Though some of the teams that signed up for the competition were keen to use their own

The logical choice [for the vehicle] was the Dallara IL15 chassis used in Indy Lights, an already optimised package

hardware, it was decided the stack should be standardised across all cars competing.

The perception element of the system is handled by a combination of LiDAR, radar and cameras. Here, industry sponsors were invaluable to ensuring some of the best kit on the market could be used. For example, three Luminar Hydra H3 LiDAR sensors with a 250m range and 360-degree field of view provide a long-distance data point cloud, augmented by four APTIV radars to monitor objects surrounding the vehicle.

Six cameras are fitted, which feature customisable frame rates to allow for high-speed object tracking, and are also capable of forward-looking stereo vision.

The sensors are backed up by two NovAtel global navigation satellite systems (GNSS) with RTK correction giving better than 2cm positional accuracy, while a Cisco networking switch synchronises all the perception

sensors using a precision time protocol (PTP), capable of transferring data at up to 40Gbps for processing and storage.

This data is handled by a high-performance compute set up supplied by ADLINK, while a vehicle supervisory controller from New Eagle monitors all onboard systems and executes complex tasks via student-designed software, which handles all race control commands and operates onboard actuators. These commands are put into practice using drive and brake-by-wire systems developed under a joint venture between automotive Tier 1s, Schaeffler and Paravan, a similar system to the one trialled in DTM competition.

Response time

A prime consideration when specifying the hardware stack was ensuring latency was kept to an absolute minimum. 'On the vehicle, there are staged control systems that have different response times,' explains Prucka. 'The steering system and the brakes operate at around 1000Hz, then you go to another level that is the core backbone of the whole vehicle – we call that the Raptor System – which coordinates all the actions on the vehicle at about 100Hz. The computing systems are in the 10Hz or faster range – they're asking for steering changes and that side of things.'

As Prucka notes, a high-speed, reliable communication network was intrinsic to keeping latency low and ensuring data used to pilot the vehicle was correctly synchronised.

'High speeds are a big challenge, because you are moving 80-90m/s at top speed and just small changes in synchronisation, even between the cameras and the Lidars, can make the scene not stitch together very well.'

This is where the Cisco PTP (Precision Time Protocol) came into its own, keeping all of the data flows perfectly in time.

Of course, there were plenty of hiccups along the way getting the various elements of the system to work harmoniously together, some of which could not be eliminated entirely, as Prucka recalls.

'One of the challenges we saw throughout is that from time to time, the GPS system would get confused – probably related to vibrations – because it's not just using GPS, it also has accelerometers and gyroscopes to figure out exactly where the car thinks it is on the track. If you put a high-level vibration into that module, it can become confused.'

However, this is representative of the kind of challenges competitors would encounter in the real world of autonomous driving.

'The teams worked through that [issue] over time… We were putting these systems into applications they were never designed to be in, and over the course of the competition they learned to pick out different signals and watch for those issues,' states Prucka.

With the competiton focused on automation, you didn't expect a regular flag start with a human being, did you?

The team at Clemson built what was by then dubbed the AD21 to a stage where it was a rolling prototype. At which point a mainstay of the autonomous vehicle development community in the US, Autonomous Stuff (which has worked on vehicle integration projects for many big industry players), was called upon to 'productionise' the car and build up the 10 units needed for competition.

'They had the know how in terms of sourcing parts, building harnesses and creating a process to rinse and repeat that design across 10 cars,' says Mitchell.

Fit for purpose

In addition to equipping the IL15 with a comprehensive autonomous driving stack, some areas of the car's traditional hardware needed modification to suit the nature of the competition. Most significantly, the original Indy Lights engine – a 2.0-litre, inline four developed by AER – was ditched. Prucka explains that while an excellent unit, it was not ideal for teams unfamiliar with handling high-end racing equipment. They just needed something with enough power to get the cars up to speed that could be run with minimal specialist knowledge.

'The universities were going to take these vehicles home at some point, and we wanted a production-style engine that was very robust, that the teams could start up and do a lot of development work with, without needing an engineer around.'

Another consideration was the need to also operate at very low speeds. The cars weren't just flung out on track and expected to run flat out immediately, teams had to undertake a variety of slow laps to allow their software to learn and map the tracks.

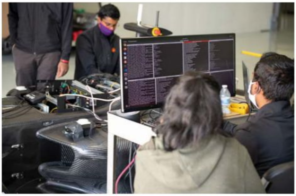
'We went after a production engine, with production cams and valve overlap, so that way the idle speed could be low. That would allow us to do as low as possible ground speed, at around 20mph or so,' explains Prucka.

A prime consideration when specifying the hardware stack was ensuring latency was kept to an absolute minimum

To hit this brief, a Honda K20-based turbocharged I4 from 4 Piston Racing based in Danville, Indiana, was brought in. The base engine is modified with elements such as a structural dry sump that allow it to take the place of the AER unit, which runs fully stressed. It is then coupled to a slightly unusual clutch set up. The reason for this is Prucka feels it would have been a waste of resources for teams to try and figure out how to autonomously find the bite point on a traditional multi-plate clutch. To circumvent this, a 5½in anti-stall unit developed by Sachs for the WEC is used, which relies on a series of weighted levers (much like a drag racing clutch) to engage the plates as rpm increases, removing the need for a clutch pedal.

Further unforeseen situations occurred due to the fact most of the teams involved were unfamiliar with oval racing, even more so with how drivers handled the cars.

'One of the things we found that surprised us was the teams were trying to maintain a speed, or set a speed target for themselves, and that forced them to make constant throttle position adjustments at frequencies a lot higher than a driver would do,' says Prucka. 'That was causing problems within the engine controller because it was trying to hunt around for a target it could never hit. We saw some issues where the engine control would go into limp mode because it was seeing these different inputs it wasn't used to seeing.



Communication is key, and never more so than when 'talking' to a car at race speed

Teams monitor every aspect of the car when running and in the pits at the sensor suite

Race procedure started at low speed with the cars building up gradually to 160+ mph

Though plenty of data is available for the IL15, a tyre change caused a few headaches

'The engine company worked through that and put filters in place, and spoke with the teams to make sure they could smooth that out, but their effort to try to get really tight speed control caused other issues you wouldn't normally see, because the human driver would allow the speed to float a little bit and base how they drove on feel, knowing what speed they were at.'

With the autonomous stack built and integrated, a comprehensive track testing and development programme was a must before they were dispatched to teams. Unlike with a regular racecar, where a shakedown would be followed by high-speed running, for the AV21 everything had to start at a crawl.

Validation data

'One of the challenges was the car was never intended to have a driver. So you have to build speed slowly over time, and you have no validation data during the engineering process at high speeds. There's almost no way to get accurate validation data,' says Prucka.

A big issue for teams was getting the software to react in the way a human would, with minute throttle variations based on conditions

However, the advantage of using the IL15 base was that data on set-ups, aero maps and the like is readily available. From an aerodynamics perspective, there was a worry that the addition of the autonomous hardware in the cockpit area, taking up a larger volume than the driver's head, would upset the airflow to the rear wing. This proved to be the case as speeds began to increase. However, some tweaks to increase rear downforce seemed to fix that issue.

It should be noted that extensive CFD simulation was also undertaken on the cars, in conjunction with Ansys.

A slight spanner in the works was the use of a different tyre to regular Indy Lights, with a switch from Cooper to Bridgestone.

'The tyre changed and that created a lot of uncertainty,' recalls Prucka. 'We had great tyre models from Bridgestone, but when they ran the first event [in November 2021] at Indianapolis, and even a bit at Las Vegas, the temperatures were pretty low and right on the borderline of what you would operate a race at, so it was really nerve racking.'

Competition time

The competition format as it currently stands sees the cars run together in pairs, following a qualification time trial to seed the nine teams that have so far signed up. The teams consist of members from 19 universities and eight different countries around the world.

Teams had to learn how to control a racecar at speed, and how drivers race on an oval

With so much technology on board, systems integration is a major part of the competition

The car's original AER race engine was replaced with a Honda K20 production unit

Collaborating with industry leaders, the teams had access to the latest technologies

The head-to-head races involve one car acting as the leader and the other as the passer, which must then execute an uncontested pass. At that point, the roles reverse, with passes attempted at ever-increasing speed until the chasing car cannot make a pass.

Early achievements

Ultimately, the teams involved in the IAC are not yet at a point where they are chasing the last few percent of performance. Simply moving the cars around a track at a reasonable rate, in tandem with another vehicle, is achievement enough. But at the second IAC event, held at Las Vegas Motor Speedway during the CES technology conference in January this year, the bar was raised higher and the fastest lap of the event was pushed up to just shy of 165mph.

The impressive on-track performance was down to both the sound engineering undertaken by the students at Clemson University, and the software stacks developed by all the competing teams. For one, TUM Autonomous Motorsport (Technical University of Munich, Germany), which won the inaugural Indy event and was runner-up in Vegas, its software stack was divided into three pathways – sense, planning and action. For 'sense', data from the LiDAR, radar, cameras and GPS was used to map out the on-track environment, including other cars and the track limits.

However, achieving perception at high speeds can prove a challenge. Phillip Karle, team lead with TUM explains: 'With high speeds, there's not much research or knowledge about the behaviour of sensors, so it was quite challenging detecting other objects, following them and then predicting correctly where they go.

'If you imagine a laser scanner, it scans the environment, but it can get some sort of motion blur, so it just triggers the laser beams, but there is a delay and you get a blur in your surroundings. That's quite challenging because you don't get such a focused perception input from the sensors as you have at low speeds.'

Karle acknowledges, however, that it was the 'planning' phase that drove much of the TUM software concept.

'Plan is not just plan to drive straight ahead, but also for us to predict other road users like in a regular driving scenario, which an experienced driver has. This is necessary so we cannot just plan with the current state around us, but also plan two or five seconds ahead.

Gary Nastase

TUM (Technical University of Munich) Autonomous Motorsport won the inaugural event at Indy and came runner-up in Las Vegas

IMSA

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International Motor Sports Association, LLC (IMSA) was originally founded in 1969 and owns a long and rich history in sports car racing. Today, IMSA is the sanctioning body of the **IMSA** WeatherTech SportsCar Championship, the premier sports car racing series in North America. **IMSA** also sanctions the IMSA Michelin Pilot Challenge and the IMSA Prototype Challenge, as well as four one-make series: Ferrari Challenge North America, Idemitsu Mazda MX-5 Cup presented by BFGoodrich Tires, Lamborghini Super Trofeo North America and Porsche Carrera Cup North America. **IMSA** – a company within the **NASCAR** family – is the exclusive strategic partner in North America with the Automobile Club de l'Ouest (ACO) which operates the 24 Hours of Le Mans as a part of the FIA World Endurance Championship.

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- Professional motorsports experience required, team or manufacturer experience preferred
- Professional experience with motorsports data acquisition
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- Skilled with Excel, data interpreter platforms, and data logging configurators
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- Experienced with both Controller Area Network (CAN) and IT network technologies
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- Adept at multitasking and project management
- Drive for highest quality work
- Data driven decisions using solid engineering fundamentals
- Ability to travel up to 50%, including weekends

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- Leads scope, requirements, development, sourcing, documentation, integration, and operations of third-party sourced vehicle, trackside, and virtual systems.
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- Manages department of full-time and part-time engineers and technicians.
- Technical oversight of event operations, protocols, and procedures for High Voltage Hybrid and EV systems.
- Assists in research and series related development of alternative and new energy powertrains.
- Assist in regulation authoring and aide stakeholders with rules interpretation.

Required skills/experience:

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- Professional motorsports experience required
- Understanding of vehicle systems and control systems
- Experience working with high voltage hybrid and EV powertrains
- Professional experience with motorsports data acquisition
- Skilled with Excel, MATLAB, and C#.
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- Adept at multitasking and project management
- Drive for highest quality work
- Data driven decisions using solid engineering fundamentals
- Ability to travel up to 50%, including weekends

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'Motion prediction and planning are two modules that are closely related to each other, and this is a great part of planning.'

As an example of that, the planning phase must decide how a car should behave when a committed overtake crosses into an impossible window – a scenario human drivers regularly handle. 'You have one chance with high speeds,' notes Karle gravely, 'and you could crash if you don't have the possibility to brake accurately.'

Real world scenarios

Unfortunately for TUM, when it reached the final of the Vegas event, a miscalculation led to its car spinning out just after it had been passed by overall winner, PoliMOVE (a joint effort between Politecnico di Milano and the University of Alabama). Karle put this down to the team's algorithms not being refined enough to determine that the reliability of its sensor data was beginning to become an issue as speeds increased due to motion blur in both the LiDAR and visual camera systems.

'The algorithm on its own has to have awareness in case of a dangerous situation, and we have to decelerate and not push the limits further. That's what a human driver does intuitively when you can't see that much, or when it's icy on the road. It's an insight that we got over there,' explains Karle. 'An algorithm has to be capable of taking the situation when it's a little bit more critical, and to react respectively to reduce the risk for the road users.

'It is possible to handle this with algorithms, it's just that you need more experience at those speeds [to do it]. There will be progress in the sensor development but, with current sensors, it's also possible that we just have to collect enough data to improve algorithms for high speeds.'

Despite these, and other, teething problems, in Prucka's opinion, development of Deep Orange 12 has been a very useful learning experience.

'It's all about trying to keep it as simple as possible, because when there's powertrain or race control, or anything like that, it's hard enough just to get the vehicle to go and communicate, so they want to just focus on software. The rest of the vehicle doesn't need to be a technical marvel, it just needs to function, but so much effort goes into replacing the driver.'

He suggests that some elements from IAC could be integrated into traditional racing in areas such as safety, highlighting recent accidents, such as Antoine Hubert's, where it was not the crash that caused issues, but the aftermath created by following cars. If the sensors and data links used in IAC could be harnessed to provide rapid warnings of an incident ahead, they could gain vital fractions of a second needed to respond.

Another issue found was sensor data reliability at speed, where vibration caused motion blur in the lidar and visual camera systems

Gary Nastase

Overall winners were PoliMOVE, a collaboration between Politecnico di Milano, Italy and the University of Alabama, USA

He was also surprised at the commercial prospects the competition opened up. 'It was interesting because an entirely new sponsor set could be engaged, and some of the companies completely loved the idea,' he says. 'That was encouraging, and we really didn't see the power of what we had done until the 'phone started ringing after the first event.'

Adding speed

As for the future of the IAC, the first two events at Indy and Vegas were deemed a success and now, according to Mitchell, the goal now is to add speed.

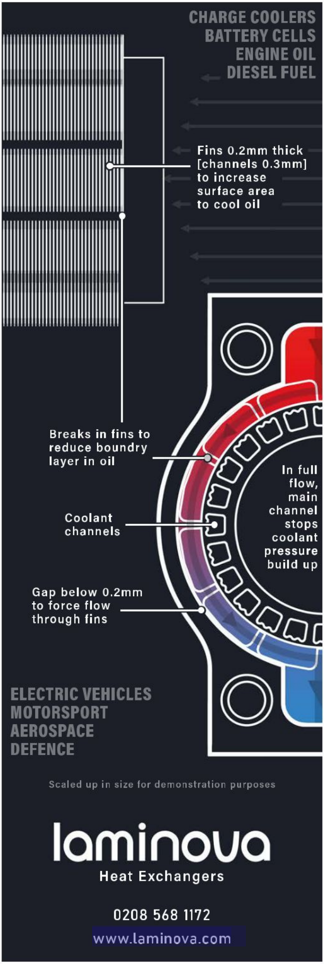
'[At Vegas] they probably could have done one more speed increase, and then the cars would have reached their top speed for the way that package was set up. So we do have plans to increase the speeds of our vehicles.

Our goal is to try to get the cars to be able to touch 200mph, and be able to certainly hit the 190s in the next rounds of competition

We're going to continue to use the same engine, but we're going to be changing the turbocharger package to build in some additional horsepower.

'Our goal is to try to get the cars to be able to touch 200mph, and be able to certainly hit the 190s in the next rounds of competition.'

Could 2022 see the first 200mph, driverless lap of Indy? I wouldn't bet against it.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Steering group

An in-depth look at developments in the most direct interface between driver and vehicle

By JAHEE CAMPBELL-BRENNAN

The steering system on a racecar is a sub-system that stays largely behind the scenes in discussions around vehicle performance, yet in the pursuit of victory it plays a significant role. The design and operation of the steering system can, literally, make or break a racecar.

Like many components, the steering system is a small piece in a much bigger puzzle but, once you scratch the surface and look a little deeper, it's clear to see the engineering is remarkably involved and its technical intricacy is up there with the best.

As the main control interface between the driver and car, the operation of the steering system has a direct influence on the chassis dynamics and the driver's ability to accurately and confidently control the vehicle.

As its basic function, the steering system exists to provide a mechanism of changing the car's trajectory by rotating the front wheels around a steering axis. The precise orientation of this axis in 3D space is key in defining steering kinematics, which controls the orientation of the tyre relative to the track surface as it is steered.

By defining the moment arms associated with the steering system's operation, the orientation of the steering axis also controls the magnitude of forces transmitted to the driver from the contact patch via the system during steering, throttle and brake applications by defining the mechanical trail (caster) and scrub ratio (king pin inclination).

Optimal performance

Optimal geometry for performance usually results in large values of these parameters, which means high forces are transmitted into the structure of the system. This consideration is important on two levels.

Firstly, as the driver interfaces directly with the front wheels via the steering column, any forces generated within the system are directly felt through the steering wheel, which is key in determining not only the levels of feedback the driver receives, but also with respect to ergonomic concerns around steering effort.

Its operation must be favourable to the driver with respect to metrics such as the steering ratio, which defines the angle of steer introduced with each unit of rotation at the steering wheel. The larger the steering ratio, the lower the torque required by the driver to implement the change, but the more turns needed to go from lock to lock.

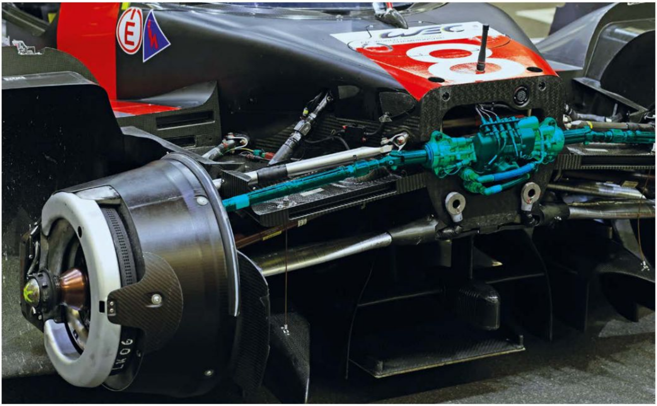
The steering ratio therefore influences the effort required to maintain control of the wheel through a corner as lateral acceleration builds. In a practical sense, this means at the weight and level of lateral forces generated by today's high-downforce racecars, the steering forces can be very high.

Secondly, as a load bearing structure, steering systems naturally undergo a level

XPB

Cornering loads at high speeds are large, which means a good deal of force is required by the person behind the steering wheel to maintain complete control of the trajectory of the vehicle

Ferdi Kräling



MATLAB view of a traditional steering system in a formula car, showing the position of the rack and pinion, hydraulic assist pump and associated hardware, sensors and steering arms

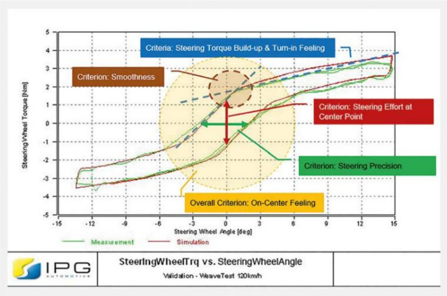
of structural compliance of magnitude proportional to the longitudinal or lateral acceleration. This compliance affects dynamics by creating an understeering or oversteering effect, which means the system must also perform without being overly affected by deflections under load.

Just taking all this into account, it's clear to see that developing an effective, useable steering system is starting to look a lot more complex than you might at first presume.

High performance automotive steering systems today universally involve a rack and pinion, a mechanism that converts the rotational movement of a pinion gear on the steering column into a lateral movement at the steering rack. As the driver turns the wheel, the rack extends at one end and retracts at the other.

Due to the steering kinematics required for performance, optimal geometry usually produces forces too strenuous for the driver to manage with strength alone. Combined with significant aerodynamic loads in high-speed corners, this means a level of mechanical assistance is required to maintain reasonable ergonomics for the driver.

IPG Automotive



A typical characterisation of steering systems in terms of the torque supplied across its operating range

Hydraulic assist

In motorsport, this assistance traditionally uses hydraulic pressure generated by an engine-driven pump to augment the driver's steering inputs. It's an old technology that has been substantially developed over the years, is reliable and well understood.

The same basic rack and pinion approach is used as in unassisted systems, with the hydraulic pump supplying a cylinder located at the rack with fluid under high pressure. Within the cylinder is a piston that drives the movement of the steering arms.

As the torque applied to the steering wheel is varied by the driver, the deflection of a torsion bar mounted inline with the steering column and the pinion gear rotates a spool valve and exposes orifices depending on its rotational displacement. This modulates the oil flow to the cylinder and defines the 'boost curve' of the system.

Being the main interface between the driver and car, the steering system must provide a linear input-output relationship to ensure predictability. This means there should be no sharp steps in the boost curve.

Due to the nature of hydraulic systems, the viscous damping and inertia of the mechanical parts introduces a level of hysteresis into the system, damping out much of the micro feedback 'noise' from the road surface. Nevertheless, feedback through the steering wheel provides an important indication of driving conditions.

'High-downforce cars such as GT500 or LMP2 have a lot of assistance to provide the torque required through high-speed corners, so you don't get much 'feel' through the wheel as such,' explains Jann Mardenborough, NISMO factory driver. 'The steering does progressively load up at higher cornering speeds, but you don't get the sensation of feeling individual bumps or notches in the road surface like you might expect. It just weights up, you don't get much else in terms of physical feedback.'

Aligning moment

The physics driving this feedback is the 'aligning moment' (Mz) generated by lateral forces at the contact patches. Towards the limit of grip, the aligning moment contribution from the tyre falls off and is felt by the driver as a lightening of the steering. This is a valuable indicator of the conditions at the contact patch, and the driver must be able to feel this clearly to make precise adjustments and remain in control.

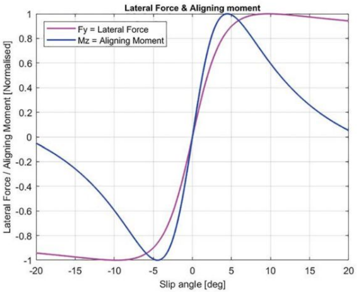
'It's definitely quite a clear feeling when you're over that peak, as the steering loses a lot of weight,' continues Mardenborough. 'I drove a truck from the [European Truck Racing Championship] that gave almost no feedback at the wheel and it was very difficult to feel where the limit of grip was. You'd overshoot and the only cue to tell you what was going on was a lot of vibration through the wheel.'

Similarly, in braking. When one wheel loses traction, the forces communicated into the steering system by the front wheels via the scrub radii become unbalanced and generate torque at the steering wheel, informing the driver that a wheel has locked up.

These early warning systems are very transient qualities and depending on the level of inertia and damping shown. Assisted steering systems influence how the signs are communicated to the driver, so system sizing becomes a dominant factor here – larger and more substantial systems introduce a greater amount of filtering to the signals.

Hydraulic systems generally perform quite well in this respect, maintaining a linear, positive and confidence-inspiring connection between driver and machine. Today, though, with the push for optimum efficiency, alternative solutions are desired.

The pump of a hydraulic steering set up is driven by the engine's auxiliary drive system, which means there is a constant power drain on the engine, even when assistance is not needed. This is an obvious source of inefficiency that can't be avoided.



Graph showing the relationship between slip angle and aligning moment (Mz)

With the power assist required from the steering system of racing trucks, such as these in the European Truck Racing Championship, steering feedback is largely eliminated

Buggyra Racing

XPB

Cars such as the 911 GT3 R use electro-hydraulic assist to improve efficiency whilst retaining the characteristics of a hydraulic system

In their operation, these systems generate enough heat to require their own heat exchanger and associated cooling circuit. More inefficiency. In addition to the weight penalty, dissipating this much energy either means you're producing less power, or you're using more fuel than you need to.

Electro-hydraulic assist

Electro-hydraulic power steering has therefore been introduced as a solution to this constant working of the fluid, introducing an electric motor into the system to drive the hydraulic pump only when required. This is a sure improvement, but is a less than streamlined solution as both an electric motor *and* hydraulic pump are required. The energy saving comes from the fact that the pump is driven only when required.

Electric Power Assisted Steering (EPAS) is a further, relatively modern refinement to steering systems, which removes the hydraulic element completely and relies solely on an electric motor to drive the pinion gear. It has been established for many years on road cars, but is more recently seeing exposure in motorsport.

'The first benefit of EPAS in motorsport is reliability,' says Tim Sherrington, application engineer at IPG Automotive UK, a company that offers simulation services to the industry. 'Removing an entire hydraulic circuit, with high-pressure pump and associated cooling lines, is a big benefit. The EPAS system is body mounted, which is also a kinder environment in terms of heat and vibration.'

With hydraulic systems, the response can only be relatively one dimensional: you input a certain steering torque, you get a certain force at the steering arms. With EPAS, a new dimension of control is added as there is a layer of logic controlling the response.

'We have what we call a boost curve in assistance systems, and with EPAS we have much more control over this than in traditional systems. This means we can vary the assistance depending on things like vehicle speed,' adds Sherrington.

Perhaps the hardest part of implementing EPAS systems, particularly in a performance environment such as motorsport, is having the feedback of an analogue system replicated faithfully enough to allow the driver to stay connected to the conditions at the contact patch. This is largely governed by the inherent damping of the system.

The qualities of this damping is an area in which EPAS and hydraulic systems have some inherent differences.

The electric motors used in EPAS need to be sizeable to provide the torque required to achieve the assistance targets dictated by the boost curve, which means they have high inertia and suffer from magnetic damping. This defines the level of hysteresis they show.

Dörr Motorsport

Dörr Motorsport was involved in the development of Schaeffler-Paravan's Space Drive steer-by-wire system on its McLaren 570s GT4

Hydraulic systems inherently have a lower damping value and therefore demonstrate less hysteresis than EPAS.

Electro-hydraulic systems lie somewhere in the middle of this, where the performance of a hydraulic system can be maintained whilst benefiting from some of the efficiency gains of full EPAS.

Artifical damping

Going all the way with full EPAS requires some additional consideration to recreate the favoured performance of hydraulic systems, as Sherrington explains:

'With EPAS, you must tune the level of damping artificially with the motor. Generally, you want as little damping as possible as this keeps hysteresis low, but you still need some level to keep the system stable from a controls perspective.

'The different levels of hysteresis is what's blocking some of the detail from reaching the driver in EPAS, so is where a lot of the controls focus is, in developing algorithms that optimise this and also maintain linearity in the steering response.'

With the addition of these control algorithms, you have the freedom to introduce variable damping maps to modulate damping at different speeds and improve the feeling of stability for the driver.

'You can even start thinking about yaw rate-dependent damping, too. It opens a huge amount of possibilities,' adds Sherrington.

As with any mechanical system, an EPAS system has a resonant frequency associated with it, which can also be problematic from a controls perspective.

'You can actually end up running into resonance with the whole subframe and steering system so you have to be very careful

With hydraulic systems, the response can only be relatively one dimensional… With EPAS, a new dimension of control is added as there is a layer of logic controlling the response

to design the system to have a very high natural frequency, and to design the steering geometry such that you don't need an overly powerful motor to drive the system. This minimises hysteresis and maintains linearity,' notes Sherrington.

Steer-by-wire

Technology doesn't stand still, of course, and, as the science of control rapidly moves forwards and redefines what's possible, the automotive sector is exploring the new possibilities created by augmenting EPAS with steer-by-wire (SBW) technology, more commonly seen on new generation road cars.

With steer-by-wire, the mechanical linkage between the steering wheels and road wheels is removed entirely. The steering wheel becomes the input to a potentiometer, which communicates with a rack-mounted electric motor. To maintain some feel at the steering wheel, a separate motor is mounted to it to provide steering torque according to some pre-defined control strategy.

The first benefit of steer-by-wire in motorsport is in its packaging benefits.

Not having to give up valuable space in the engine bay, or space which otherwise might be used for improved aero, is a clear advantage that most designers would take with both hands.

In addition, the requirements of steering response whilst driving straight ahead with the wheel 'on centre' are quite different to when the wheel is loaded mid-corner. To provide desirable behaviour in this respect, variable ratio systems that alter the angles of the gear teeth on the rack feature quite extensively in performance steering systems.

On centre, the response of the system must be sufficiently relaxed to allow the driver to make minute adjustments in vehicle placement on track without feeling 'darty', whilst in the cornering phase, where the loaded tyres are less responsive to small inputs, the steering must quicken for precise control to ensure small steering inputs have tangible effect on the car's attitude.

By varying the angle of the gears on the rack, the system can be designed to produce a steering angle-dependant ratio. Being hardware based, though, the ratio is ultimately set between certain fixed parameters defined by the gear geometry.

Perhaps the largest performance benefit of steer-by-wire systems is that the steering ratio can be software controlled between infinite ratios to suit the driver, steering velocity, yaw rate, track conditions, tyres, set-up and anything else engineers may dream of.

Remove the rack altogether and implement individual actuation at each wheel and you can even vary toe dynamically or program variable Ackermann percentages depending on speed and corner radius, as just a couple of examples. From a pure performance point of view, steer-by-wire does revolutionise what it's possible to achieve with a steering system.

It's not all roses though. Removing the mechanical connection between the road and the driver's hands presents almost as many challenges as it solves, and these challenges are more serious than the benefits.

Safety concerns

'Safety is a big concern with steer-by-wire, and there have to be many layers of redundancies built in,' says Sherrington. 'There needs to be a hierarchy of signal priorities and checksums to ensure sensor signals are validated. It also needs to be designed such that there's no single point of failure so, if any one aspect fails, the overall system can continue to function.

'The amount of different things that could happen are huge. If a power connector fails, how does the system switch to another circuit? If an ECU fails, how does the other one seamlessly take control?' Clearly, such concerns are not trivial.

Dörr Motorsport

Driver, Fred Martin-Dye, who drove the McLaren GT4, noted no difference in lap time with the Space Drive steer-by-wire system, but says it provided a slightly different driving experience, especially when running over kerbs where the impact shock was reduced

On top of all the engineering involved, drivers also have to overcome certain perceptions about technology like this.

'In Super GT, we had issues with our power steering pump, which wasn't strong enough for high-speed corners like 130R at Suzuka,' recalls Mardenborough. 'You'd have power steering on the entry without issue, but at peak *g* at the apex, it would just lock as it didn't have the power to add any more steering angle. You can imagine how that felt.

'At least in this condition you can still muscle your way around, but without that direct connection how do you manage those kinds of situations? My initial feelings are that I'm not comfortable with it.'

Another interesting point of discussion is the performance of steer-by-wire systems over the range of conditions experienced in racing. In wet conditions, the response of the tyres is very different to dry, for example.

'In dry conditions, the feedback you receive is mainly an increase in steering weight, but in wet it's a little different. Through the steering you can feel the tyre slip a little more, and vibrate as it does so, almost like you can feel the tread blocks compressing and moving about,' notes Mardenborough. 'These are important signals about what's happening and where the grip is.'

With steer-by-wire and no direct method of transmission for those feelings, drivers may have to find other, less salient cues to drive around that sensory vacuum. These may be less accurate, and not positively reinforcing for drivers. Cue more challenges ahead for the controls teams.

'My first thoughts are that it was very impressive,' comments Fred Martin-Dye, who drove a Mclaren 570s GT4 fitted with the Schaeffler-Paravan Space Drive system in the ADAC Germany championship.

'If you're on fresh tyres and the car is set up well, I think I would have needed somebody to tell me it was a steer-by-wire system.

'There's a chicane on the back part of Oschersleben in which the racing line is straight over two kerbs. That was perhaps where the differences presented themself. With standard steering, those kerbs send a lot of impact shock through the steering, which I didn't feel with steer-by-wire, but maybe I only notice that because I have driven both systems and have a comparison. It didn't affect lap time at all.'

Latency also becomes a consideration in steer-by-wire systems. With no direct connection, a driver's input at the wheel must be detected and processed by the system's control unit, passed to the steering rack motor and then actuated. This all takes time.

Excessive latency creates a scenario where the steering wheel and road wheels are out of phase – something which would become more apparent at high steering speeds.

Removing the mechanical connection between the road and the driver's hands presents almost as many challenges as it solves, and these challenges are more serious than the benefits

XPB

Driving under wet conditions generates very different sensations at drivers' hands than in dry, an interesting and difficult problem for steer-by-wire to overcome because the method of transmission of steering 'feel' doesn't exist in the traditional way

'One area in which its presence was somewhat more pronounced was in oversteer situations as you quickly return the steering to straight ahead after correction. With the SBW system, the steering would go very light and the sensation was almost like my hands and the wheels were out of sync. It was a bit disconcerting initially, but the engineers did manage to improve this as time went on,' continues Martin-Dye.

'Overall, I think it was a great system and, even during that season, many of the issues we experienced were improved by the engineers, so I've no doubt these teething problems will only continue to improve.'

Off-track simulation, which is a massively growing tool in automotive system development finds another, very effective use in developing these systems to improve their responses and refine control strategies.

Validation systems

Validating steer-by-wire systems in a safe, quick and cost-effective way is the domain of Hardware-in-Loop (HiL) simulation. This is also an ideal place to develop robust safety protocols for the system.

'HiL systems bring great advantages to the development process. You can set up the steering system exactly as it would be in the real vehicle, with all joints and mounts. The steering arms are then subjected to forces by linear actuators according to a particular road profile to replicate real vehicle inputs,' says Will Snyder, sales engineer at IPG Automotive UK.

'If driver feel is to be developed, you can actually include a Driver-in-Loop (DiL) with this system, too.'

Driver-in-Loop in this context allows the driver to take the wheel of the simulator, with real steering hardware, and be exposed to specific driving conditions. The subjective feedback gained here can be very beneficial for producing systems that drivers are comfortable and familiar with.

'Eventually, EPAS and steer-by-wire will replace hydraulic systems entirely as they are just more efficient and flexible in terms of what they're delivering,' adds Snyder. 'Much of the current work with EPAS systems is to make them feel like traditional, more analogue hydraulic systems. If this frame of mind switches, they'll be judged differently.'

It seems steer-by-wire is inevitable and, as the technology develops, it will be honed as our understanding and experience grows, aiding its reputation as reliable technology.

It's interesting to question the development targets though. Do we need to be trying to recreate the feel of older systems, or are there other methods of simulated feedback which can be equally useful?

Driver feedback so far has been positive, but it seems there is something missing compared to the quality of 'feel' presented by traditional hydraulic systems. Moving from analogue to digital systems does bring advantages, but right now there seems to be something lost in translation.

IPG Automotive

DiL and HiL are proving valuable instruments in developing steering systems using EPAS and steer-by-wire

The porpoise effect Part two

A case study approach to understand what drives this phenomenon

By DANNY NOWLAN

XPB

At Barcelona Ferrari's 2022 car suffered from porpoising, but Carlos Sainz (left) and team-mate Charles Leclerc (in car) are now proving competitive following fast work from their engineers

In last month's article on porpoising, I gave a broad overview of what the effect was, and a case study of how the approaches to dealing with it were applied to a high-downforce open wheeler.

What that article lacked, however, was detail, because I was talking about a live racecar and was unable to share any particulars about the programme. So, to address this, I have taken one of the ChassisSim templates and radically increased the downforce so I can give you some actual numbers and a quantitive case study. Along the way, I'm pleased to say a lot was learned, in particular the limits of what you can actually do, and what you should be thinking about.

This is what we'll be discussing in depth in this article.

First things first. While my initial comments on porpoising still stand, one thing I was remiss in not mentioning was what you can do about porpoising is highly dependent on the relationship between the platform and tyre stiffness. To understand why this is, let's refer to the quarter car model of a car's suspension, as shown in **Figure 1**.

The relationship between tyre spring stiffness and platform stiffness will dictate what you can do about porpoising. In particular, **equation 1** explains it.

$$K_{eq} = \frac{K_B \cdot K_T}{K_B + K_T}$$

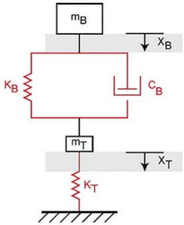
$$\%x_B = 100 \cdot \frac{K_T}{K_B + K_T} \qquad \textbf{(1)}$$

Where,

K_{eq} = equivalent spring rate of the body and tyre spring combined
K_B = spring rate of the sprung mass
K_T = spring rate of the tyre
$\%x_b$ = percentage of movement of the sprung mass

The vital point to note here is your absolute limit is the spring rate of the tyre, particularly if the tyre spring rate is too low. If we cross reference this to **Figure 1**, you'll see you can do everything you want with the body spring and damper but, fundamentally, there is little you can do to solve the problem.

Fig 1: Quarter car model of the car's suspension



The parameters are

m_B = mass of the sprung mass (kg)
m_T = mass of the unsprung mass (kg)
K_B = sprung mass spring rate (N/m)
C_B = sprung mass damping (N/m/s)
K_T = tyre spring rate (N/m)

What you can do about porpoising is highly dependent on the relationship between the platform and tyre stiffness

So, let's now talk about the racecar particulars. These are outlined in **Table 1**. To add a bit more colour to this, **Figure 2** is the C_LA front and rear ride height map.

One thing to note here is that the values in these maps have been normalised to aid the illustration. The actual numbers are multiplied by the C_LA number in **Table 1**.

Aero oscillation

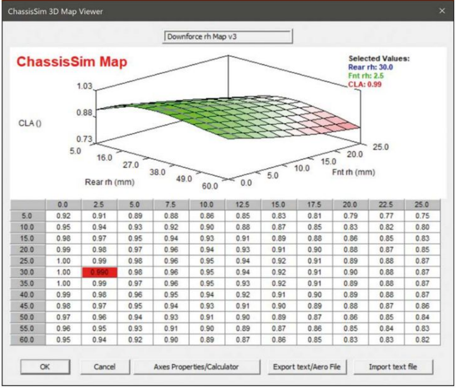
The real challenge in setting up this car is manifold. Firstly, there is quite a bit of aero variation here. While not porpoising in the strictest sense, this car will be prone to a lot of aero-induced oscillation.

Secondly, the car is producing peak downforce between zero and 8mm of front ride height. This is going to dictate a very stiff front heave spring / bump rubber package.

Table 1: Example racecar particulars

Item	Value
C_LA	6
Aero balance on front axle	45%
Car mass	800kg
Weight distribution at the front	45%
Front rh	70mm
Rear rh	80mm
Front spring rate	270 N/mm
Rear spring rate	350 N/mm
Front tyre spring rate	220 N/mm
Rear tyre spring rate	270 N/mm
All motion ratios front and rear	1
Circuit	Eastern Creek

Fig 2: Front and rear ride height map



	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
5.0	0.92	0.91	0.89	0.88	0.86	0.85	0.83	0.81	0.79	0.77	0.75
10.0	0.95	0.94	0.93	0.92	0.90	0.88	0.87	0.85	0.83	0.82	0.80
15.0	0.98	0.97	0.95	0.94	0.93	0.91	0.89	0.88	0.86	0.85	0.83
20.0	0.99	0.98	0.97	0.96	0.94	0.93	0.91	0.90	0.88	0.87	0.85
25.0	1.00	0.99	0.98	0.96	0.95	0.94	0.92	0.91	0.89	0.88	0.87
30.0	1.00	0.990	0.98	0.96	0.95	0.94	0.92	0.91	0.90	0.88	0.87
35.0	1.00	0.99	0.97	0.96	0.95	0.93	0.92	0.91	0.89	0.88	0.87
40.0	0.99	0.98	0.96	0.95	0.94	0.92	0.91	0.90	0.89	0.88	0.87
45.0	0.98	0.97	0.95	0.94	0.93	0.91	0.90	0.89	0.88	0.87	0.86
50.0	0.97	0.96	0.94	0.93	0.91	0.90	0.89	0.87	0.86	0.85	0.84
55.0	0.96	0.95	0.93	0.91	0.90	0.89	0.87	0.86	0.85	0.84	0.83
60.0	0.95	0.94	0.92	0.90	0.89	0.87	0.86	0.85	0.83	0.83	0.82

The first challenge in resolving the set-up for the racecar is to figure out what the limit condition is

The first challenge, then, in resolving the set-up for the racecar is to figure out what the limit condition is.

From some preliminary simulation work I did, the mid-corner speeds are typically 200km/h and end-of-straight speed is 300km/h. For the mid-corner speed, **equation 2** is what we have in terms of downforce requirements.

$$
\begin{aligned}
F_{aero\_f} &= ab_f \cdot 0.5 \cdot \rho \cdot V^2 \cdot C_L A \\
&= 0.45 \cdot 0.5 \cdot 1.225 \cdot \left(\frac{220}{3.6}\right)^2 \cdot 6 \\
&= 6176.04N \\
F_{aero\_r} &= ab_r \cdot 0.5 \cdot \rho \cdot V^2 \cdot C_L A \\
&= 0.55 \cdot 0.5 \cdot 1.225 \cdot \left(\frac{220}{3.6}\right)^2 \cdot 6 \\
&= 7548.54N
\end{aligned} \tag{2}
$$

So, in terms of tyre deflection, what we are looking at is shown in **equation 3**.

$$
\begin{aligned}
td_f &= \frac{F_{aero\_f}}{2 \cdot k_{tf}} \\
&= \frac{6176.04N}{2 \cdot 220} \\
&= 9.09mm \\
td_r &= \frac{F_{aero\_r}}{2 \cdot k_{tr}} \\
&= \frac{7548.54N}{2 \cdot 270} \\
&= 13.98mm
\end{aligned} \tag{3}
$$

The reason we have multiplied the tyre spring rate by two is to account for the fact there are two tyres holding the car up. As can be seen with the cornering limit combined with the static ride heights, we are comfortably within specs of the current spring rates.

True limit

The true limit condition is the end-of-straight condition, and if we re-run the numbers at 300km/h, things become most revealing, as **equation 4** shows.

$$
\begin{aligned}
F_{aero\_f} &= ab_f \cdot 0.5 \cdot \rho \cdot V^2 \cdot C_L A \\
&= 0.45 \cdot 0.5 \cdot 1.225 \cdot \left(\frac{300}{3.6}\right)^2 \cdot 6 \\
&= 11484.4N \\
F_{aero\_r} &= ab_r \cdot 0.5 \cdot \rho \cdot V^2 \cdot C_L A \\
&= 0.55 \cdot 0.5 \cdot 1.225 \cdot \left(\frac{300}{3.6}\right)^2 \cdot 6 \\
&= 14036.45N
\end{aligned} \tag{4}
$$

The tyre deflection now becomes as shown in **equation 5**.

$$
\begin{aligned}
td_f &= \frac{F_{aero\_f}}{2 \cdot k_{tf}} \\
&= \frac{11484.4N}{2 \cdot 220} \\
&= 26.1mm \\
td_r &= \frac{F_{aero\_r}}{2 \cdot k_{tr}} \\
&= \frac{14036.45N}{2 \cdot 270} \\
&= 26mm
\end{aligned} \tag{5}
$$

What is immediately clear to see is that the end-of-straight condition is the limit condition, since the tyre deflection is almost half of the ride height value.

Spring deflection

The next challenge is to determine the front and rear spring rates. The first step in choosing this is to figure out the spring deflection you need. So, what we will choose is 10mm at the front and 20mm at the rear. This is being driven by two key considerations. Firstly, we want some wiggle room in terms of how we can adjust ride height (remember, the kerbs get a vote, too). Also, if we refer back to **Figure 2**, we are going to be highly constrained in terms of what we can do with our front ride height.

To start working out the effective spring rates, we'll use **equation 6**.

$$\begin{aligned} k_{f\_eff} &= \frac{F_{aero\_f}}{2 \cdot ft\_damp} \\ &= \frac{11484.4N}{2 \cdot 10} \\ &= 574.2N/mm \\ k_{r\_eff} &= \frac{F_{aero\_r}}{2 \cdot rear\_damp} \\ &= \frac{14036.45N}{2 \cdot 20} \\ &= 350.9N/mm \end{aligned} \tag{6}$$

The reason we can do such a simple calculation in this equation is the motion ratios front and rear are one. The big take away from **equation 6** is that we don't need to run a rear bump rubber (that said, we will run one anyway, just as a precaution), but we have a bit of work to do at the front.

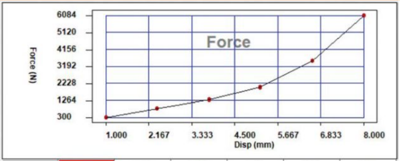
The next port of call at the front is to figure out the total force we'll need for the front bump rubber, which we will run on the third, or heave, spring. Doing the maths, the answer is produced by **equation 7**.

$$\begin{aligned} BR\_force_{fnt} &= F_{aero\_f} - 2 \cdot k_f \cdot ft\_damp \\ &= 11484.4N - 2 \cdot 270 \cdot 10 \\ &= 6084.4N \end{aligned} \tag{7}$$

Given that we don't want any huge discontinuities in the bump rubber, we will have this engage at a ground gap of 2mm. The bump rubber curve is shown in **Figure 3**.

Now we have established the springing, we need to establish the base damper parameters. The rear is pretty straightforward, but I'm going to cheat a little bit and select a rear spring rate of 330N/mm. This brings the natural frequency at the rear in line with the front without the third spring.

Fig 3: Applied front third spring bump rubber curve



disp	1.000	2.400	3.800	5.200	6.600	8.000
Force	300.000	800.000	1301.000	2000.000	3500.000	6084.000

But what is the base spring rate we should select for the front? We choose a mid-point for the engagement of the third spring because this is what we'll expect at the mid-corner conditions of the high-speed turns. Here we'll see 5mm of bump rubber deflection. This is a spring rate of 500N/mm and so, split at the main spring where the damper is, this equates to an effective spring rate of 520N/mm (270 + 250N/mm).

The base damping rate at the front is therefore given by **equation 8**. And at the rear, it is as shown in **equation 9**.

$$\begin{aligned} m_{bf} &= 180kg \\ \omega_0 &= \sqrt{\frac{520 \times 10^3}{180}} \\ &= 53.74rad/s \\ C_{B\_fnt} &= 2 \cdot \omega_0 \cdot m_b \\ &= 19349.4N/m/s \end{aligned} \tag{8}$$

$$\begin{aligned} m_{br} &= 220kg \\ \omega_0 &= \sqrt{\frac{330 \times 10^3}{220}} \\ &= 38.72rad/s \\ C_{B\_rear} &= 2 \cdot \omega_0 \cdot m_b \\ &= 17041N/m/s \end{aligned} \tag{9}$$

Now we have the base damping rates, we can start the work with the shaker rig toolbox. The base damper curve will be a bypass of 50mm/s. Note that is only an educated guess, but one based on a good deal of experience. That said, the base damping curve will be a damping ratio of one in the low speed and 0.5 in the high speed. And remember we are choosing a speed of 200km/h here, since this is the mid-corner condition.

The shaker rig toolbox results, in this case unredacted, are shown in **Figure 4**.

A very quick observation is that the baseline run was the spring rates we specified with the dampers as per the car model, not our specification that we just discussed.

From this run log, a couple of things pop out immediately. Firstly, don't be shy about aggressive damping rates in the low speed, as that was imperative to keep the car's platform controlled. Also note the drop in contact patch load variation when we went from run one to two, when the higher damping rates where applied.

Given our goal was to control this as a porpoising simulation, the final configuration chosen was that shown in run seven. The reason being the big drop in the cross pitch mode response, which should drastically reduce any porpoising behaviour.

To conclude this section of our discussion, let's look at the final damper curves. These are presented in **Figures 5** and **6**.

With the fronts in the low-speed bump we have kept very close to a damping ratio of one, forced upon us because of the high springing. In the high-speed bump, we have kept to a damping ratio of 0.5. No major surprises there.

You'll note in rebound, the damping rates are less. This was driven by managing the contact patch load variation at the front. The rear is very interesting though. In the high speed, the damping ratios are 0.5 in bump and 0.4 in rebound. Again, nothing particularly unusual about this. But note the high damping ratio of 1.17 in the low speed, which was to control the cross pitch mode.

Sometimes, this is just the way the cards fall to achieve the outcome you are after.

Lap time validation

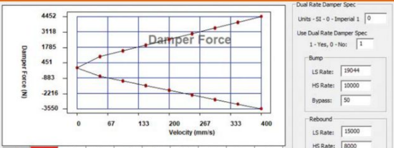
The final validation was to run this through lap time simulation, and the results are shown in **Figure 7**.

The baseline with the dampers set to that of the baseline ChassisSim model are coloured, while the new damper specifications, as per run seven, are in black.

Fig 4: Shaker rig run log

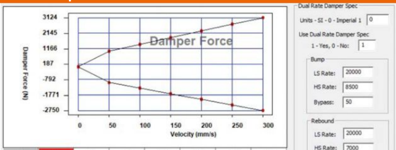
	Setup	Heave Res freq	Heave Resp	Cross Pitch	CPL Fnt	CPL Rear	Comments
3	Baseline	4.45	5.39	3.7	163.1	218.9	One word - awful
4	Spring Damper Package 1, RSP 330 N/mm LS DR 1, HS DR 0.5	4.65	3.77	1.51	161.4	208.2	Significant improvements everywhere - More work to be done - rear can be tuned down a bit
5	Rear LSB 20K Rear LSR 15K	4.65	3.76	1.48	161.5	208.1	Slight improvement but nothing dramatic
6	Rear LSR 12K	4.65	3.76	1.52	161.5	207.8	Cross Pitch response worse but rear CPL better 207.8 kgf
7	Rear LSR 20K, Rear HSR 7K	4.65	3.78	1.46	161.4	208.7	CPL is worse but the shape of the cross pitch response is definitely better
8	Rear Spring 350 N/mm	4.77	3.94	1.42	161.9	209.7	Heave and CPL response is worse, That being said another step forward in the cross pitch mode response
9	Fnt LSB 25K, Fnt HSR 8K	4.73	3.89	1.45	162	209.7	Overall not a step forward.
10	Fnt LSR 15K, Fnt HSR 8k	4.69	3.94	1.27	161.8	209.2	Heave response is worse but the cross pitch mode is a massive step forward.
11	Fnt HSB 25K	4.69	3.86	1.33	161.9	209.3	Heave response is a bit better but the cross pitch is worse.

Fig 5: Final front damper curve



vel	0	50	100	150	200	250	300	350	400
Bump	0	952	1452	1951	2452	2952	3452	3952	4452
Rebound	0	-750	-1150	-1550	-1950	-2350	-2750	-3150	-3550

Fig 6: Final rear damper curve



vel	0	50	100	150	200	250	300
Bump	0	1000	1425	1850	2275	2700	3124
Rebound	0	-1000	-1349	-1700	-2050	-2400	-2750

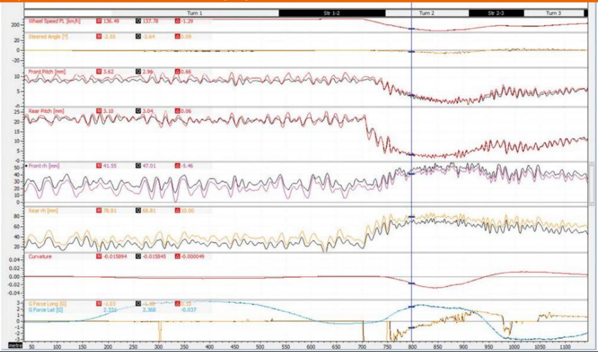
The traces of note are the front and rear pitch (average of the left and right damper movement of the front and rear respectively) and the front and rear ride height. But note the reduction in oscillation of the pitches and ride heights. This gives you a much more stable platform to lean on.

While this is a considerable improvement, it's still not a night and day situation. Reason being the front tyre doesn't have enough spring rate. So, while we did an effective job of improving the damper movement, it didn't translate completely to the ride heights. This situation was also present at the rear, albeit slightly better because of the higher tyre spring rate.

Consequently, while there are gains to be had, if you are running on marshmallow tyres, your hands are very much tied.

Hopefully, this has shown, numerically, how to deal with porpoising and aero-induced pitch oscillations on a high-downforce racecar. Using a combination of hand calculations and simulations we were able to make considerable progress toward negating the porpoising effect, but weren't able to alleviate it entirely due to the low tyre spring rates. Some improvement is better than none though, right?

Fig 7: Comparison of the baseline model to the final damper specification



IN BRIEF

Sean Kim has been announced as the new President of **Hyundai Motorsport GmbH** with immediate effect, based at the company's Alzenau headquarters. Kim replaces **Scott Noh** who has returned to Korea after four years at the helm. Kim will manage the company's involvement in the World Rally Championship, the ETCR and its customer racing programme.

Riedel Communications has been named as the official supplier of motorsports communications for the FIA. The partnership is the culmination of a two-decade relationship between the organisations. Riedel will supply the FIA with hardware and software technologies to take safety, sustainability and innovation across all global FIA championship series to the next level, says an FIA press release.

Tag Heuer has renewed its partnership with **IndyCar** and the Indianapolis Motor Speedway. The manufacturer began its association with IndyCar in 2014 and will this year produce a special edition watch for the winning driver and chief mechanic of the Indy 500, and the series champion, at the end of the season.

The ACO has confirmed ***The Stranglers*** as the headline act at the 24 Hours of Le Mans in June. **Pete Doherty** will top the bill on the Thursday.

Swiss company, **Bcomp**, will supply its natural fibre technologies to **HWA AG**, development partner of Mercedes-AMG, for the new front bumpers on the Mercedes-AMG GT4 cars. These will be phased in during May to replace existing carbon fibre panels.

Spanish brand, **Cupra Racing**, is the first manufacturer to commit to the eTCR series under the FIA banner this year. The company has formed a partnership with **Mattias Ekstrom's** EKS team, which won the championship last year under its previous guise as PURE ETCR, ready for competition in the new series using the 500kW (670bhp) Cupra eRacer.

Minardi in new FIA role

Gian Carlo Minardi, the former grand prix team owner who has recently taken over as head of the Imola circuit, has been confirmed as the new president of the FIA Single-Seater Commission. The Italian has also been president of the Automobile Club d'Italia Land Speed Records Commission since 2004.

FIA president, Mohammed ben Sulayem, said of the appointment: 'I warmly welcome the election of Gian Carlo Minardi as FIA Single-Seater Commission president. He is a major figure in motorsport and I look forward to working with him to further develop the single-seater pyramid around the world.'

That 'pyramid' starts with Formula 4 and escalates through Formula 3, 2 and into F1, but high costs to compete have led to other, more cost-effective series starting up with the aim of providing young drivers with a place to hone their racing skills.


XPB

New Single-Seater Commission president

Both Formula 3 and Formula 2 are dominated by chassis manufacturer Dallara, while Formula 1 sees the Italian constructor supply only the Haas team. It is hoped that more diversification in the development process will be forthcoming over the next five years.

Minardi started out as a competitor in the late 1960s before he switched to team management in Formula Italia. He eventually took his Formula 2 team into Formula 1 in 1985 where an engine supply partnership with Ferrari followed.

Minardi was acquired by Paul Stoddart in 2001 before it became Scuderia Toro Roso and, since 2020, has been known as Alpha Tauri. The team continues to be based in Faenza, Italy.

Canadian E-Fest postponed

The Formula E race scheduled to take place in Vancouver, Canada in July, has been postponed for a year. A cryptic statement appeared on the Formula E website stating that 'after intensive review with the City of Vancouver, OSS Group has had to make the incredibly difficult decision to postpone the Canadian E-Fest until 2023. The City of Vancouver fully supports the postponement. Delivery of a world-class event is of the utmost importance to the organisation.'

Some media outlets have pointed to a technicality in filing paperwork that meant the series did not receive a permit to host the weekend, which was also supposed to feature a music festival and business forum.

The decision to postpone the weekend means there is a six-week gap in the schedule that stretches from the Jakarta E-Prix on 4 June to a race in New York on 16-17 July.


Sam Bloxham

The Formula E race scheduled to take place in Vancouver in July will not occur, apparently due to an oversight in filing the appropriate paperwork

Jakob Ebrey

Formula 4 has partnered with Haltermann Carless to help reduce emissions and take another step toward its target of a net-zero carbon footprint

British F4 switches to Hiperflo sustainable fuel

The ROKiT F4 British Championship will adopt Carless' sustainable racing fuel as part of a new partnership between the two brands. The move to sustainable fuel aligns with Motorsport UK's Sustainability Strategy, which outlines the organisation's commitment to tackling climate change and targeting a net-zero carbon footprint.

The series will mandate the use of Carless' Hiperflo R20 performance fuel across all of the category's new-for-2022 Tatuus T-421 cars for a three-year period, starting this season. The fuel contains a total of 20 per cent renewable components, comprising 15 per cent second-generation ethanol and five per cent renewable hydrocarbons. This is said to give up to an 18 per cent reduction in greenhouse gas emissions compared to current pump fuel.

As well as helping to reduce the championship's carbon footprint, the mandating of fuels also helps feed into the series' equalisation programme, led by the scrutineering team and Neil Brown Engineering, to ensure parity of performance across all competitors.

'As the championship heads into a new era with the Tatuus chassis and Abarth engine, we are proud to be supporting the championship with the introduction of a sustainable racing fuel,' says Adrian Stuart, sales executive performance fuels UK at Carless. 'As the world moves to de-carbonise the transportation sector, the introduction of Hiperflo R20 is an important step toward significantly reducing greenhouse gas emissions. We believe that, along with electrification, renewable and sustainable fuel plays an integral part in this movement for road, as well as motorsport, vehicles.'

IN BRIEF

The Italian constructor, **Romeo Ferraris**, has also committed to the FIA eTCR series with its version of the Alfa Romeo Giulia ETCR. The team, based in Opera, Italy, finished second in the 2021 manufacturers' classification. The series starts at Pau on 6-8 May.

The **FIA World Endurance Championship** has launched its version of a behind the scenes television production, called *WEC full access*. The 2022 season features six races, and each will be streamed on YouTube in four episodes, making 24 in total. New episodes will be available every Friday on the WEC YouTube channel.

Falken Tyres has developed a novel method of monitoring tyre wear. The 'Miniature Energy Harvester' has been developed in conjunction with professor Hiroshi Tani of the Kansai University in Japan. It uses the rotation of the tyre to generate electricity and supply power to peripheral sensors installed in the tyre without relying on batteries. The technology allows the calculation of a tyre's contact patch and wheel rotations, and harvests stress levels based on amplitude changes induced by tyre rotation.

Pointless press release of the year award goes to **Porsche**, which confirmed the next **Rennsport Reunion** will take place in 2023, but it is unable to confirm a date, time or location.

BMW M4 GT4 TESTED AT THE 'RING

Julian Kroehl

BMW's new M4 GT4 had its first race in the Nordschleife Endurance Series (NLS) at the end of April, winning the SP8 class. During the car's development phase, the focus was on ease of use for both teams and mechanics, so the complete drivetrain, including engine, seven-speed transmission and electronics, are all taken from the roadgoing M4 for this entry-level GT contender

Interview – Andreas Roos

M-people

BMW has an ambitious motorsport programme on the go, with the M4 GT3 and an LMDh Prototype project as highlights. Motorsport director, Andreas Roos, sat down with* Racecar Engineering *to discuss the future

BY ANDREW COTTON

This is a big year for BMW M, one in which it will compete for overall wins at the biggest GT3 races in the world, including the Nürburgring and Spa 24-hour races, while it will also continue the development of its Le Mans Prototype programme with a view to it making its race debut at Daytona in January.

This is also the 50th anniversary of the M brand, one that will be celebrated with the launch of new models, including the M3 Touring, M2 and X M, the four-wheel drive model. Celebrations will focus around the Nürburgring 24-hours at the end of May, with a huge effort to try to win the race for the first time since 2020, when the brand won the shortened race with its M6 GT3.

Endurance colours

The two programmes, GT3 and LMDh, nail BMW's colours firmly to the endurance racing post, having withdrawn from the all-electric Formula E series and having cancelled its hydrogen Le Mans programme that, for a long time, looked to be part of its Prototype racing future.

For Andreas Roos, formerly with Audi Sport in WRX, the DTM and as project manager of factory racing, and who in February became head of BMW M Motorsport, the brand now has an ideal platform to support BMW's production car strategy with its racing programme, although there are some challenges ahead.

The LMDh project, a Le Mans Prototype based on a chassis developed by Dallara, and which will feature a spec hybrid system, is running later in its development cycle than rivals Porsche, simply because the decision to race in the US was taken later than most of its competitors.

Andreas Beil

The DTM adopted GT3 regulations for the short term, and the series allows manufacturers to compete in a sprint format with a single driver

'It is a tough challenge, we cannot say anything else. We are still on target, but it will be an intensive [development] time'

The Nürburgring 24 hours celebrates its golden anniversary in May, as does BMW's 'M' brand. The combined events are likely to involve quite a lot of beer

Daniel Reinhart

The company will share development of the chassis with Cadillac, which will continue to use the Dallara chassis as a basis for its own Prototype.

While Cadillac has committed to the WEC, BMW has yet to do so, and right now has not even committed to racing at Le Mans in 2023. It has, however, confirmed a US Prototype racing programme with the Rahal Letterman team for next season.

The car is expected to hit the track in the first half of 2022, ready for competition at the 24 Hours of Daytona in January.

Aggressive schedule

'We took the decision quite late for the LMDh programme,' admits Roos. 'It is a tight time schedule, really aggressive, but we are on schedule so, as long as nothing goes wrong, it will all work out.

'It is a tough challenge, we cannot say anything else. We are still on target, but it will be an intensive [development] time.'

One of the key elements to the new class will be that the LMH cars – ground-up designed, four-wheel-drive hybrids from the likes of Peugeot, Toyota and Ferrari – will also be allowed to race in the US following an agreement between the organising bodies on either side of the Atlantic.

The organisers believe they are on top of the performance balancing, but Roos isn't alone in feeling that balancing the different concepts won't be easy.

'BoP is always a challenge, but the biggest thing is with the LMH cars, especially when you play in such a high league, everyone is pushing,' says the German. 'There is an open discussion between IMSA and the ACO, and with the FIA. It will be a challenge, but at the end we have to get it to work

'The problem in the WEC is that everyone will focus on Le Mans, and so the races up to Le Mans will be especially tricky. That is the one that you want to win.

'But for us, the first race at Daytona is one of the most important. And then there is Sebring, so those first two are the biggest ones [for us].'

Competitive advantage

The organising bodies have agreed the basic parameters for the two different Prototype concepts, and the manufacturers are working together to ensure they can all race against each other fairly. Although, of course, they will all be hoping to retain a competitive advantage for their concept, and their brand.

'I have to say that the convergence meetings between LMH and LMDh, they are based on facts,' says Roos. 'It is not easy because [performance] is also track dependent. On some tracks the LMH car might have an advantage over the LMDh car because they are two different types of concept.

'The discussions we had on convergence, both parties could bring their facts to the table, and the FIA, IMSA and the ACO looked at them, and then we tried to agree on something.

'From the facts we could see, it should be okay-ish. It is difficult to say, though, as you don't know the others' cars.

'[Right now] we are all in simulations and trying to find out what advantages the others could bring, but we will see when the cars are on track. It's certainly not going to be straightforward.'

The regulations have now been released, and particular attention paid to the bodywork. Specifically, the amount it can flex. With that specified, it seems that one of the potential loopholes has been closed, and Roos believes this was because of the previous experience of the FIA and the ACO at Le Mans.

'The problem in the WEC is that everyone will focus on Le Mans… But for us, the first race at Daytona is one of the most important. And then there is Sebring'

'We all know flexible aero devices are not allowed. We all know they will be checked and we all know the ACO and the FIA have a lot of experience with such things from the LMP1 days,' he says with a smile. 'You see it already when you follow the development of the regulations of LMP1. There were more specified items to show what the car should look like.'

Common development

Roos was involved in the planning for the DTM, when Audi, Mercedes and BMW each developed a part of what became a common car platform, and says the feeling is similar with the LMDh development. It's a sentiment that was echoed by IMSA at the 12 Hours of Sebring in March. Williams Advanced Engineering provides the battery, Bosch the MGU and Xtrac the gearbox for the LMDh cars and each of them are pushing hard to get everything ready in time for the start of IMSA's season.

Manufacturers are sharing components to put development miles on them so the common parts are ready when needed.

'I have to say I was involved in the meetings about LMDh with my former company, and it was really interesting how well the LMDh partners were working together, all of them, including the hybrid partners,' notes Roos.

'It is really working very well at the moment, and everyone has the focus to get everything on track.

'For sure, latest at Daytona, everyone will fight for themselves. I don't think the gloves will come off before that though. It's a very open discussion at the moment, we even help each other when parts are missing, and that is nice. We all have the same approach.

Sam Cobb

The WeatherTech Sportscar series in the US is a key market for BMW, which has competed in GTE and now in GT Daytona, for GT3 cars. The LMDh project is currently scheduled to only run in the US

'I had a bit of a similar feeling when I did the DTM at the start because when you develop common parts, you have the same goal. You have to get the common parts ready and working, but at some point you separate and do your own thing.'

Shifting sands

In GT3 world, the sands are shifting in favour of the manufacturers. The regulation set is now being used by all SRO series, Stéphane Ratel having created the category and developed it, but it has been more widely distributed by the FIA which always owned the rule-set. Now, it is used in the DTM series as factory sprint racing, and in 2024 it will be introduced to the 24 Hours of Le Mans, replacing GTE.

GTE ground to a halt this year in IMSA, and in the WEC it has continued for one final swansong but, as all the manufacturers competing have a GT3 alternative, the decision's been made to do so.

Manufacturers are committed to keeping the LMDh platform as the place for their factory racing programmes, and those with an LMDh car are keen the GT3 class be for pro-am drivers only. However, those that don't have a Prototype are still pressing for factory teams to be involved.

'It is good that you can run a full factory LMDh and a customer racing GT3, so for us it is nice to have a pro category, but it is not an issue,' says Roos. 'BMW customer racing is a big topic, so there must also be an option to run a pro-am. I can understand that the ACO wants to split it, so you have the pros in LMDh and the amateurs in GT3. I think that it is more up to the manufacturers that are not competing in LMDh, because they will push more for GT3. I think it is okay that there is an amateur class for GT3.'

But the fly in the ointment is the Ford Mustang built by Multimatic and scheduled for introduction in 2024. The car has proved controversial as it is not considered a prestige brand by some, worthy of competition against the likes of Porsche, Lamborghini or Ferrari.

According to Ratel, the Mustang opens the door to any manufacturer that currently produces a two-door coupé to create a GT3 derivative, and that would water down the entire class. Roos, however, disagrees.

'We don't know how the new Ford will look. It is a brand new car, so it is difficult to judge. We have to be open and see the information from Ford and see if it fits [the GT3 rule set]. Everyone knows what the Ford Mustang looks like at the moment but they will bring a new car and we will see if it rises in the segment to a higher level.

'You also have to look at the Corvette, as the base model does not meet the price cap. They are a brand like everyone else.'

With LMDh and GT3 seemingly fixed in endurance racing, and with the ACO pressing ahead with its hydrogen class at Le Mans in 2025, it was some surprise to learn that BMW would not be part of it. Roos's predecessor, Jens Marquardt, was a firm advocate of hydrogen racing and had a Prototype designed, but right now Roos says that's not an option for the company's racing department.

'If you look at the strategy for BMW, it is going down the road of battery electric cars, so this is where we also have to follow with motorsport'

'At the moment we are not investigating that. If you look at the strategy for BMW, it is going down the road of battery electric cars, so this is where we also have to follow with motorsport because what you do in motorsport has to reflect what you are selling.

'We are doing a marketing thing. Motorsport has to do something to show where the brand leads. No one knows where it goes in the future.'

BMW's LMDh car will feature a Dallara chassis and spec hybrid system, combined with an Xtrac gearbox. The engine and aero kit is unique to the brand, meaning engine architecture can follow the corporate path, while Balance of Performance will eliminate any disadvantage

Land of confusion?

Trying to make sense of what is happening on planet VAG

Much has been written about the future of the Volkswagen Group and its prospective entry to Formula 1, but there is a lot going on in the background that garners less media coverage. In isolation, the strange choices of Audi in the last few years have gained some traction in the media but, if you link them all together, they paint an interesting picture. For example: the withdrawal of the company from Formula E when the company remains committed to selling electric cars; the cancellation of the company's LMDh programme (officially it's only 'paused') soon after confirmation that it will race at Le Mans and having taken delivery of its cars; the lack of customer support for the American market and GT racing with the R8 when there is no other customer racing project, and the introduction of a Dakar programme using an old DTM engine in a mightily heavy machine as a headline programme.

The obvious conclusion is that Audi is withdrawing from its traditional forms of motor racing, and is putting its considerable weight behind the proposed F1 project. However, the company re-iterated that this is not the case. Audi has a history of unlikely stories being true, so let's take the statement at face value.

Agressive actions

Let's start with the postponement of the LMDh project. The spine of the car, and engine, was to be shared with Porsche, whose test programme is aggressive. The suppliers have all confirmed Porsche's schedule is hard to keep up with and perhaps Audi would not have been ready in time. However, it took delivery of two chassis and the engine, suspension, gearbox and hybrid systems that are exactly the same as those Porsche is already testing on track for them.

Perhaps the VW Group, having lost production car sales for various reasons, including the war in Ukraine, cannot see any point in having two brands race each other at Le Mans with essentially the same car. Hard to argue that one (the WEC project with the 919 and R18 only worked because they had different drivetrain concepts, one diesel with flywheel energy storage, the other petrol with a battery).

Another theory is that Porsche has gone so aggressive on its design and supply chain in its bid to win Le Mans with an LMDh base that even Audi couldn't make a business case out of using the same car. The Porsche apparently costs in the region of €2.9 million (approx. $3.15m) per car, including the engine and a set of wheels. The spares package is another half million on top. One might be able to justify that cost as a Porsche, but as an Audi?

Formula E champions electric racing, and Audi is certainly an advocate for electric cars, so why withdraw from the battery-centric series? One observer noted that Formula 1's battery technology, thanks in part to the series' incredible budgets, is superior to that of Formula E so it makes more sense to put the effort there.

And here I believe we start to get to the root of Audi's thinking. It has turned its back on LMDh, with a spec hybrid and battery system, and it has turned its back on Formula E, with a spec battery. In their place, it has turned to Dakar, where it can develop its own technology, and is looking at Formula 1 for the same reason. It is also rumoured that the company is looking for a further project for the e-tron GT. The mind boggles.

Formula 1's battery technology...is superior to that of Formula E

There is no racing platform for the e-tron GT, not even electric GT would cater for such a vehicle, but in Audi's new way of thinking it makes sense to *create* something for such a car.

Likewise, the Mission E from Porsche is also looking for a place to race (and budget to develop). It wouldn't surprise me at all if, some time in the future, Audi produces a render of an electric GT racecar, in the same way Porsche showed off its Mission E concept in 2021.

Sister act

What's certain is the two sister entities are looking for a route into racing where they can develop their own technology, but on the cheap. Therefore, they are both looking at Formula 1. Porsche would produce the engine following a tie in with Red Bull Advances Technologies, while Audi would develop the hybrid system. The rumoured links to McLaren also make sense as Audi does not have a successor to the R8. Yet, as a sister brand to Lamborghini and Porsche, arguably it is looking at the wrong end of the market, but that's another topic.

There is one further question. When Porsche and Audi went into the WEC, Peter Wright wrote of their battle for development supremacy. Porsche won the battery development project. But if they are looking to tie in together in F1, Audi would develop the battery hybrid, yet Porsche has partnered with electric vehicle specialists Rimac. That's a topic for another column, but with the VW Group's F1 decision coming soon, it seems to make sense.

ANDREW COTTON Editor

Inside the world of modern motorsport technology
Racecar engineering

PIT CREW

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