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# Racecar engineering™


## Peugeot 9X8 2024

### New winged concept for Le Mans prototype

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There are major changes afoot in the world of rallying as organisers aim to reshape the WRC's technical roadmap

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# Belief system

Relying on assumptions when predicting the performance of an F1 car is likely to make an 'ass' out of 'u' and 'me'


XPB

**The physical properties of most aspects of a racecar are now well understood; it's the constant dynamic changes that cause confusion**

Years ago, I took the latest results from the wind tunnel tests on Lotus' next Formula 1 car to show Colin Chapman. He looked at the comparison with the existing car and said, 'Go and show them to the man with the chequered flag.' That car was the T80, and we were about to discover what we didn't know about the aero-elastic characteristics of a ground effect F1 car, the phenomenon that would become known recently as 'porpoising'.

Bouyed by the T79's championship win the year before, I thought we had it handled.

This was in 1978. We didn't have the benefit of computer models or sophisticated simulators, and yet, 44 years later, most of the F1 grid were caught out by the same phenomenon when they started running their 2022 cars to the new aero regulations.

And this was with the benefits of CFD, six-post rigs, simulators and enough computing power to get to Mars. So, how come it is still not possible to accurately predict the performance of an F1 car? The simple answer is that not *everything* is yet known about *all* aspects of an F1 car, and so all these expensive tools incorporate assumptions where knowledge is missing.

To quote the English philosopher and critic, George Henry Lewes, 'we must never assume that which is incapable of proof.'

## Bravado time

Every year, in February and March, the F1 world turns up to testing and technical directors and team principals extol the work of their engineers in developing significant improvements that will move them up the grid. The disappointment and disillusion when this doesn't happen is palpable, especially among the team bosses, who realise they don't know why, and that they themselves can do nothing about it.

Of course, predicting performance relative to one's competitors is always a risky business but, when absolute performance is no better, or sometimes even worse, there has to be an explanation.

Models and simulations these days are based on the best science available: Newton's Laws; material properties; linkage geometry; fluid dynamics; combustion theory; chemistry, and many other engineering interpretations of scientific theory, most of which have stood the test of time.

However, even science admits the best it can do is to come up with 'the least wrong conclusion, based on the evidence available.'

The characteristics of most metallic and composite materials is well established, although not so long ago, British company Rolls-Royce tripped up over the unknown energy absorbing properties of carbon fibre, when it equipped its RB211 big fan engine with CFRP fan blades.

Fluids are another matter entirely. Fluid properties, involving temperature, pressure, velocity, viscosity, compressability, constituents including gas (mainly air) inclusion in liquids, and liquid (mainly water as vapour) inclusion in gases, are partially understood in isolation, but there are high

**Not *everything* is yet known about *all* aspects of an F1 car, and so all these expensive tools incorporate assumptions where knowledge is missing**

**I have been told that Red Bull has a department that examines... all the evidence supporting the conclusions that the development will improve the performance of the car. I can't imagine they are the most popular department**

levels of interdependency. When fluids combust, there is more uncertainty.

Yet fluids dominate the key areas of an F1 car's performance, be it downforce, drag, cooling, power (combustion), tyres (rubber, in its natural form, is a colloid-like milk). So, while it may be possible to model and determine the steady-state performance of fluids, dynamic properties are an order harder, and it is these dynamics that consequently mess up the predictions.

The aerodynamics of an F1 car are subject to turbulence levels caused by the wake of another car, or a cross wind, movement on the suspension (even without porpoising) and very complex flows due to the intense vortices shed by the front wing and tyres. CFD has come a long way in modelling these flows, but does not deal perfectly with dynamic changes in the flows.

Likewise, combustion models are very advanced, but how well they predict the intake flow regimes, mixing with evaporating fuel, ignition, burning and heat exchange, I have no idea, as this is key powertrain IP.

Fluids also influence damper performance, powertrain cooling and lubrication, brakes and tyre cooling, and hydraulic systems.

Then there are the tyres. Being composites of fabrics and elastic polymers, they behave somewhere between a solid and a liquid, the whole of which is given structure by inflation with a gas. Their behaviour, when subjected to steady-state speeds, loads, slip ratios and slip angles, is measured by tyre manufacturers, and their structural dynamics modelled in FEA and rig tested. Yet exactly what happens when the rubber tread meets the stone / tarmac / concrete, either wet or dry, remains something of a mystery.

Of course, the steady-state characteristics do not tell the whole story, as no tyre on any racecar is anything like steady state. Rather, it is subjected to vertical load variations, due to sprung and unsprung dynamics, from around five to over 15Hz, plus much higher vehicle structural frequencies. Consequently, precisely what happens at the interface with the track is not known, as far as I am aware.


**The Lotus 79 was a relatively straightforward racecar, but the aerodynamics were still complicated and that put the engineers working on it (without the benefit of computer models or simulation) to the test as they tried to control its properties**

How these variations in vertical loads, and hence variations in lateral and longitudinal loads, affect what is happening with the rubber of the tread, and how they excite the car and its structure, can therefore only be *assumed* when trying to model and predict the performance of the car.

Still dominating both qualifying and race performance in F1 today, the grip, temperature, degradation and wear of tyres have a large influence on the outcome.

## Firmly held opinion

So what can a modelling or simulation engineer do to improve predictions? The rules and equations upon which the model is written are, where possible, based on proven science and engineering principles but, confronted with an unknown or uncertainty, a gap in the software cannot be left unfilled.

So, it must be filled with a best guess based on assumptions. There's that word again. In the same way religion tends to fill in the gaps in our knowledge of how life and the environment works, these assumptions are based on a belief of how that particular aspect of an F1 car works.

The *Oxford English Dictionary* defines a 'belief' as 'a firmly held opinion', not fact.

It is the quality of these assumptions that determines how well the model or simulation predicts the performance.

Take a 'firmly held opinion' into a court of law and it will quickly be subjected to cross examination about the evidence to support it. Engineering assumptions should be held similarly accountable.

A simple example of not checking an assumption occured some years ago when we, at Team Lotus, put a full hydraulic

**A scale wind tunnel model was the most sophisticated tool available in '78**

system on the 1993 F1 car to power its active suspension. This relied on computer-controlled hydraulic cylinders to support the car and emulate spring dampers. We modelled the hydraulic system to determine pump, tank and accumulator sizes, *assuming* everything would perform as advertised. When we ran it, we found the hydraulic fluid was full of air, rendering it compressable such that the computer and Moog valves lost control of the cylinders.

Back in the workshop, we rigged up a flow meter in the hydraulic system and ran the engine to power the system. Above a certain rpm, the flow meter indicated flow was no longer proportional to rpm, and the return fluid turned milky. The pump was cavitating – a charateristic we had not included in the model. Pressurising the bellhousing tank solved the problem, and we were made wiser by the experience.

I have been told that Red Bull has a department that examines, independently from the engineers originating a new development, all the evidence supporting the conclusions that the development will improve the performance of the car. I can't imagine they are the most popular department in Red Bull, but it may go some way to explaining the team's successes.

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# It’s (now) a wing thing

*After much speculation, Peugeot has taken the wraps off its updated version of the 9X8 prototype and, as predicted, it has sprouted a rear wing*

**By ANDREW COTTON**


Peugeot has changed around 90 percent of the surface area of the new car while also retaining the family resemblance to its predecessor. Long distance testing and two races are in store for the 9X8 2024 before Le Mans in June


**The rules have changed during what has been a turbulent period for the FIA and ACO, and Peugeot was unable to react as quickly to the changes as its arch rival, Toyota**

Peugeot has bowed to the inevitable with the updated version of its FIA World Endurance Championship contender, called the 9X8 2024. As expected, the Hypercar has been equipped with a rear wing as part of a major upgrade package for the first time.

The previous 9X8 relied upon underfloor aero and a front weight bias with the car that debuted at Monza in 2022. The final race for that car was the opening round of the 2024 season in Qatar in March as the update was not yet homologated. Now good to go, the revised 9X8 is a very different beast.

The old car was an extreme design, pushing the limits of the regulations as they were written when the concept was devised. However, the rules have changed during what has been a turbulent period for the FIA and ACO, and Peugeot was unable to react as quickly to the changes as its arch rival, Toyota.

That is not to say the first generation 9X8 was obsolete. It was running second in Qatar before it ran out of fuel, but it proved difficult to balance it against the competition due to its very different design philosophy. The updated car is a more traditional winged prototype concept, although the team behind it is proud of the fact it still looks externally quite similar to the previous model.

Everything seemed to be going well until Sebring in March 2023. The bumpy track there made a mess of the 9X8's aero concept

## Rearward shift

Peugeot has worked hard to move the weight further rearwards, reduced its reliance on underfloor aero, and introduced a rear wing. The team has also switched tyre concept to run a narrower front and wider rear that brings it more in line with its competitors.

The team achieved this while retaining the same tub, engine, gearbox and hybrid system, which helped keep the development cost down to an estimated €10m.

However, technical director, Olivier Jansonnie, says the team has changed around 90 per cent of the surface of the car, putting more air over the top to feed the rear wing rather than under it and through tunnels.

He goes on to say the car is very similar in looks to its predecessor, but has a very different philosophy, and will rely less on the BoP to keep it at the front of the grid.

## Joker in the pack?

From the moment that the 9X8 was launched, rivals were briefing against the car. It was leaked that the team already needed to invoke its joker package before the car had even been revealed to the watching world. That was because it conformed to an older version of the regulations and there was a danger that its tyre size choice could lead to special development from Michelin.

The 9X8 was a concept designed to extremes, taking full advantage of regulations that made the aerodynamic target relatively easy to hit, while also using a powerful front hybrid system and by regulation, front tyres the same width as the rears.

That combination, coupled with a forward weight bias and strong ground effect, enabled Peugeot to dispense with the traditional rear wing. It was so proud of this fact that at the car's first race in 2022, the PR team handed out chocolate wings.

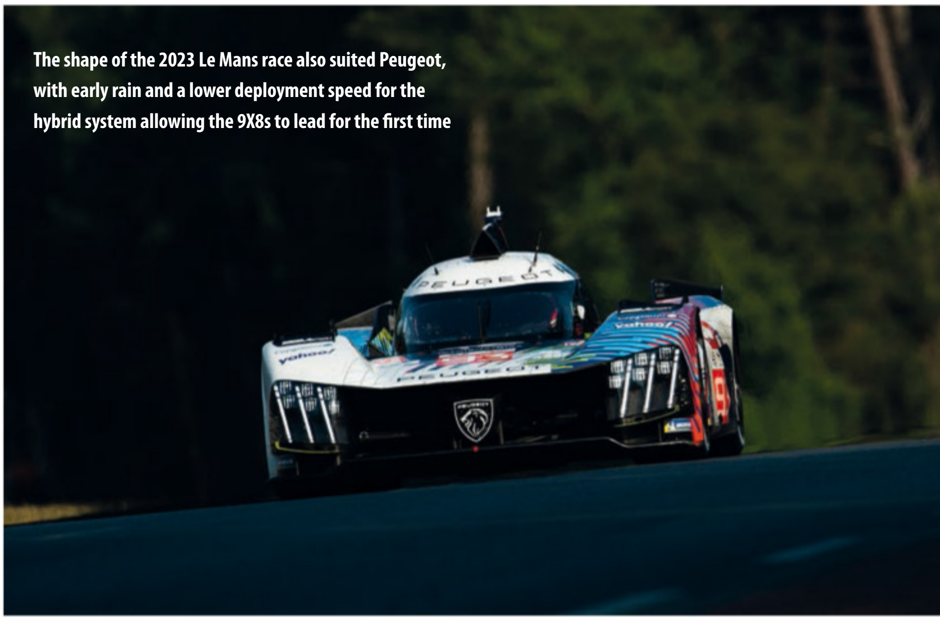
However, convergence with the LMDh-spec cars meant the LMH concept had no


Peugeot was proud of its original, wingless concept, and eventually proved that it could work, but the new car is more traditional in design and will therefore be easier to manage

The big wide-open expanse of Le Mans played to the car's philosophy, but also masked the 9X8's weaknesses

**'Keeping the rear was a challenge with the new rear wing, but we managed to retain the absorbing structure, so did not need to re-crash [test] the car. That was very important for us from a schedule standpoint'**

*Olivier Jansonnie, technical director at Peugeot Sport*



The shape of the 2023 Le Mans race also suited Peugeot, with early rain and a lower deployment speed for the hybrid system allowing the 9X8s to lead for the first time

choice but to change. The four-wheel-drive function was therefore summarily castrated, the front wheels only able to be driven when over a certain speed in the dry (but changeable according to the BoP).

The tyre size requirement was also changed for cars homologated from 2023 onwards and the front differential settings were altered, reducing the ability for the front hybrid system to assist in cornering.

Toyota was able to make the necessary changes before the 2023 season, and did so without using its jokers, but Peugeot could not implement the required design changes in time due to the complexity of its concept.

As Jansonnie famously said, 'It's quicker to re-write a regulation than re-design a car.'

## Proof of concept

Peugeot was stuck with its concept, but determined to make it perform. At Le Mans, the car did work, the track's long straights and smooth surface allowing the aero to work as intended. However, the 2023 season-opener at Sebring was nothing short of a disaster. On the bumpy track, the ground effect proved ineffective, and the weak points in terms of reliability, particularly around the gear change mechanism, were exposed.

Following that race, attended by Stellantis chief executive officer, Carlos Tavares, the team made the decision to start preparations for the 9X8's successor.

The first step was to accept that tyre size would have to change, by regulation. The narrow rear tyre was compromised in its power delivery on the old car and suffered from high wear. As the original concept relied heavily on front drive, which became minimum speed limited, the rear tyres would have to work even harder than originally intended. Switching to the narrower front tyre meant weight distribution had to move rearwards, but the team took advantage of that. The fragile gear change mechanism has been beefed up, with some 4kg added to the weight of the system.

The engine has been similarly modified, while the ballast has moved from the front end. Achieving all of that was not as easy as it sounds as weight distribution and c of g are both closely guarded by regulation.

'The idea was to try to use the new opportunities in the regulations,' says Jansonnie. '[With] the 29 / 34 tyre size, very early in the process we identified that potentially had more performance than the 31 / 31 design. At the time, in 2022, when the decision was taken to open this opportunity,


Peugeot based the car's original development around the 31 / 31 tyre combination, but a change to the regulations now means that it needs to run a narrower front, wider rear, which had a knock-on effect on the car's aero balance and weight distribution

we couldn't re-design the car. It was too late for us since we wanted to have a car ready to race at Monza [in July] 2022.

'Now we have this opportunity, and actually in testing we found that it has even more potential than we had expected from the simulation, which was a surprise to us.

'Then we adapted the aero to match this new tyre dimension so, basically, changing the weight distribution on the car to be much more rearward than the previous version, and changing the aero balance as a consequence.'

## Aero balance

Unsurprisingly, the aero balance is also closely regulated, and ballast may be applied to the car through the BoP system, which makes life a little more complicated than just putting lead into the floor of the car to keep the excess weight as low as possible.

One of the further consequences of the change in weight distribution was that crash testing also had to be carefully considered.

In the end, Peugeot managed to make the changes without needing to re-test the crash structure at the rear of the car.

'Keeping the rear was a challenge with the new rear wing, but we managed to retain the absorbing structure, so didn't need to re-crash [test] the car,' says Jansonnie. 'That was important for us from a schedule standpoint.'

The team also had to do a lot of work on the overall aero concept. Rivals had noted that a shift in aero balance would be helped by the addition of a rear wing, and so it was no surprise that Peugeot followed suit.

From a heavy reliance on underfloor performance in the previous car, the rear wing now needs to be fed, so the splitter has to send more air over the car than before.

Jansonnie says the 9X8 does still retain a strong element of underfloor-generated downforce, but its relationship to the rear wing meant an extensive re-design.

'It's a different concept,' says the Frenchman. 'It's not just an add-on of the rear wing; it is a completely new aero package. But, from the public side of things, the car looks very similar to the previous car, just with a rear wing added.

'If you look carefully, though, you will see we have touched 90-95 per cent of the surfaces of the car, including the complete underfloor. That was one of the challenges, and one of the constraints we had.

'We wanted to keep the overall look of the car, which seems to have been quite a success, and keep the DNA of the brand, while at the same time completely revising it.

'Everything is connected together. If you are going to put some rearward aero balance on the car, you can actually create more downforce from the top of the bodywork, and then you reduce your underfloor downforce simply because you have to fit in the performance window.

'It's interesting to see that you can achieve a quite substantially different aero concept with surfaces that are mostly all changed, but still look the same. If you overlay both cars, the look of the cars is quite interesting.'

While the overall concept has changed, the team says it can still take a benchmark from the original car when it comes to race preparation and set-up. Having already completed around 7-8000km of testing with the 9X8 2024, including two endurance runs (and with more mileage planned before the 24 Hours of Le Mans in June) it is well placed to judge the correlation between the old and updated versions.

**'We wanted to keep the overall look of the car, which seems to have been quite a success, and keep the DNA of the brand, while at the same time completely revising it'**

*Olivier Jansonnie*

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Some of that will be to do with the team operation. When the car raced for the first time in 2022, that was also the first race for the team of mechanics and engineers. Nearly two years later, there is more strength in the team, as well as the car.

## Race preparation

That will surely pay dividends at Le Mans, which the old car contested only once. There, the wingless 9X8 seemed to be in its element, more so than anywhere else, though Jansonnie disagrees with this observation.

'I would not specifically say that Le Mans was good for us because of the ground effect, but I would say that our car concept overall on aero and tyres was probably less of a disadvantage than in other places.

'I still believe we can achieve at least the same performance at Le Mans with the new car as with the old one.

'Secondly, from Le Mans itself, besides the performance, just by doing that race we learned a lot in terms of preparation, how we approach the race, the set-up for the race, the strategy… I think we can for sure carry these over with the new car and be stronger at Le Mans than last year.'

For that all to work, of course, relies on the BoP system that the FIA and ACO have again revised for this year. The race in Qatar was the first time the 9X8 raced within the expected window, and it ran well, almost bringing home a podium finish.

Now, the FIA and ACO will rely on race data, coupled with simulated data but, crucially, will keep secret from the teams and manufacturers what they are using to make their decisions (see p16). They could look at 20 per cent fastest laps, 40 per cent or 60 per cent, which would take further into account the team and tyre wear, for example, while the 20 per cent option would better suit the car's potential to post the fastest lap.

The manufacturers will be better at playing the game if they know the rules, so it's easier for the governing bodies to simply not show them the full picture.

That said, Peugeot believes its updated car will be easier to balance, so it hopes to rely less on the BoP and more on its own traits.

'To put it simply, we still believe it was possible to balance the old car concept, but unfortunately in 2023 this was not done,' says Jansonnie. 'We wanted to get rid of the dependency on the BoP, and do something that is closer to our competition so we don't depend so much on the track layouts.

'We have proven that in low-grip conditions the car was performing better, but we just wanted to put the car back to a more average window and a more similar condition to what our competition is doing.

'In Qatar, for instance, we were in what I call a corner of the BoP, which means maximum power and lowest weight, but then you cannot move from that corner. Now we expect to move to a more average position.'

## Roll with it

One of the other big changes that came through convergence was the introduction of the cockpit-adjustable anti-roll bar, a mechanism used by LMDh cars, while LMH cars were supposed to rely on their front hybrid systems. Once the hybrid system had its capacity reduced, organisers forced the LMH contenders to introduce adjustable anti-roll bars into their existing designs which was not easy in a tightly confined space.

Peugeot has kept its monocoque, and so retained much of the suspension design and pick-up points, but has been able to adapt to the new rule with the evolution of the car.

'Simply, we had more time to design something, and that drove us to do a bit better,' says Jansonnie. 'The constraints haven't changed, and we have not revised the monocoque to do that.

'We don't change what we have already said, that we think this decision of allowing the differential has been taken far too late for the LMH cars. The regulation as we have it now, though, we have to live with, and it is a performance differentiator, so we have to add it somehow, but to do that you end up with something that is complicated.'

Peugeot will debut the 9X8 2024 at Imola and then run it at Spa, giving the FIA and ACO two races to assess it before Le Mans. The team feels it has a good understanding of how the update works, and remains confident the BoP will better suit the new concept.

The wingless 9X8 wasn't successful, it wasn't particularly reliable, but it was memorable. It's a shame the original rules that allowed for novel, more extreme designs have evolved, and that Peugeot ended up treading a well-worn path like the others. However, it's results that count, and Peugeot now has to deliver with its new concept.


The LMDh integration heavily compromised the original design of the Peugeot, with the front hybrid system having its impact reduced. Fortunately, the team was able to retain its monocoque

# Law of averages

*After years of struggling and complaining, the WEC is implementing a new BoP system this year, but with some key details hidden*

**By ANDREW COTTON**

The ongoing saga of Balance of Performance (BoP) took some dramatic steps in the early part of 2024. The FIA and ACO presented their new method of balancing the Hypercars to the media at the opening round of the FIA World Endurance Championship in Qatar. Shortly afterwards, IMSA announced that the method it implemented in GTD at the Daytona 24 Hours was too complicated to replicate for the remainder of the season and so, in agreement with the manufacturers, it reverted to last year's more traditional system.

The performance balancing system for the WEC's flourishing top class was controversial last year. The engineers used first order parameters of weight, power and aerodynamic efficiency to balance the cars. Toyota, however, was better than anyone else in race conditions, notably on second order parameters such as tyre wear and strategy, and won the opening races comfortably.

So for the centenary race at Le Mans, the FIA and ACO changed their minds. Instead of leaving the BoP alone until after Le Mans to prevent sandbagging, as promised, they took into account the second order parameters and promptly upset Toyota. There were even rumours the Japanese manufacturer would cancel its hydrogen programme in protest.

So, post Le Mans, the FIA and ACO reverted to the original BoP format, which led to Ferrari refusing to speak to the media following the Monza race. The Italian constructor clearly felt Toyota had been given an advantage but, as regulations ban teams from speaking about BoP, nothing was said.

## Secret squirrel

Clearly, something had to be done, so the FIA and ACO took the decision to create a new system. This opened the door to multiple options for the organisation, but the governing bodies had to decide. Some, such as Ferrari, wanted to have no performance balancing for cars that had been designed to fit in performance windows. Others, such as Porsche, made it clear that it only signed up to the WEC on the proviso that there was performance balancing.

The rumour was that an agreement had been reached, only to then be put in the bin in favour of a new system that was presented in Qatar ahead of the 2024 season.

'We are looking at the performance of the best car from each manufacturer and we do an average of that,' explained ACO competition director Thierry Bouvet. 'So, let's say you have five manufacturers, we take the best car per manufacturer – so you have five cars – and then we take an average from each of those five cars. That defines the performance window and then hopefully all the cars are inside.'

That 'performance window' is rumoured to be around + / -0.2 per cent. Around a 100-second lap, that's + / - two tenths of a second, though Bouvet was not willing to confirm that figure. This is infuriating for the teams, as is the unwillingness to explain what other performance parameters are being taken into account.

The idea of not telling the manufacturers means teams and manufacturers will not be able to 'game' the system. Obfuscation is deliberate. 'It is linked to lap time simulation,' Bouvet confirmed. 'Homologation parameters are done from wind tunnel data, c of g height, fuel loads. We do the simulation post event, for the next event, but that does not mean we will intervene every race. The BoP can be identical but you will see different figures because it is a different track.

'Describing the whole process, since last year we have a year of data, and we use it. The result of the BoP today is not only due to homologation parameters. The result for Qatar was homologation parameters, which are improved from last year, the result of equivalence of platform, and of the manufacturer compensation.'

## Top speed

One of the big changes to the system will be the study of the cars over 210km/h. The wind tunnels are only able to simulate up to this speed, but there's around 100km/h extra to be had at Le Mans and the cars are clearly performing differently at these speeds, outside the parameters of the BoP.


**The core concept of BoP remains to de-incentivise teams and manufacturers from over spending to try and improve the performance of their cars**


The idea is for the FIA and ACO to make minimal intervention and to prevent Hypercar manufacturers from trying to game the system, though that appears to have still been happening in Qatar

Photos: XPB

Unsurprisingly, some manufacturers promptly pointed at others saying that even extrapolating the information available, top speed performance of rivals was unusual.

To combat this, the FIA and ACO tried to measure the cars at the pre-season test in Qatar, and said they were analysing the data that was available.

'Before, you had some differences in drag and downforce on one car, and you were trying to compensate the difference between power and weight,' explained Bouvet. 'So, if you would have had more because the car was draggy, then you would probably need to add more weight. It was kind of a loop.

'Now, with this two-stage power, we're able to differentiate acceleration and top speed. Basically, that's giving us another tool to be able to address the gap, and as a consequence of that you will have less difference in weight, which you can see in LMGT3, for example.'

In order to prevent teams and manufacturers from playing the game in the run up to Le Mans, the FIA and ACO have stated that the BoP for that race will be separated from all the other tracks.

**The FIA and ACO will take the power, weight and aero efficiency data from the homologation process. They will take the performance data from the simulation process… and match that with a percentage of lap times**

There, they will use the experience from last year, simulated data from the first three races this year (Qatar, Imola and Spa), and will try to balance the cars from there.

If they see a car performing too well, they will react quicker than if a car was too slow, Bouvet indicated. That does rather suggest no one will be trying to appear too fast…

Porsche's problem in that scenario is that it has customer teams in JOTA and Proton that desperately want to beat the factory Penske cars, and it has no control over those teams' performance, unlike both Ferrari and Toyota.

## Cruise control

Le Mans is the longest race on the calendar, and outright performance is often not the key to success. In fact, it's rare for the quickest car to win the race. Therefore, what the BoP has to achieve there is to ensure one car is not cruising to a lap time, while others are pushing hard to achieve that same lap time.

'The idea is to intervene as little as possible,' said Bouvet, re-iterating that the core idea of performance balancing is to prevent the incentive to improve a car and out-spend the opposition, rather than manufacture laptime. 'Within platforms at Le Mans, there was not so much difference between the cars. We don't have to intervene a lot, which is good.' That's why the two regulatory bodies won't get involved in balancing the weight of the drivers. Heavier drivers are at a disadvantage compared to lighter ones in terms of overall lap time, but that's a step too far for endurance racing.

In summary then, the FIA and ACO will take the power, weight and aero efficiency data from the homologation process. They will then take performance data from the simulation process that the FIA is trying to perfect and match that with a percentage of lap times seen in real-world competition.

What percentage of lap time will be analysed is a closely guarded secret. The fastest 20 per cent of lap time, for example, would focus on the outright speed capability of the car, while the fastest 60 per cent of lap time would also take into account set-up and tyre performance.

That's why Cadillac ran multiple stints on the same tyre in Qatar, both slowing the car on track and reducing time spent in the pit.

'It is not simple lap time, because it would be too easy,' confirmed Bouvet. 'It is performance related and it is related to correlation of simulation.'

## Rumble on

By keeping the criteria private, it's hard to know what will happen, and difficult to challenge the FIA and ACO on their decisions. This is now a system based on trust, the manufacturers having to hope the FIA and ACO are correct in their sums.

Qatar saw Porsche take the first WEC win for an LMDh car. It remains possible for LMDh and LMH to be balanced against each other; this is now termed 'Equivalence of Platform'.

Where it all falls down is the new circuits on the schedule this year – Qatar, Imola, São Paolo and Austin. For these races, the organisers will have to rely more on simulation data than real-world experience, which makes life even more complicated. Expect this to rumble on for a while yet.

# A sportscar named Desire

*Isotta Fraschini is the latest Hypercar to enter the FIA World Endurance Championship, reviving a legendary name in a modern world*

**By ANDREW COTTON**

Looking through the list of manufacturers competing in the FIA World Endurance Championship this year, it's an impressive array of some of the biggest names in the motoring world. Ferrari, Toyota, Porsche, Peugeot, BMW and Lamborghini, to name just a few. There is one name that sticks out from all the others, though, and that's Isotta Fraschini.

This lesser known car company is currently experiencing what might be termed a second wind. Originally formed in 1900 by Cesare Isotta and brothers Vincenzo, Antonio and Oreste Fraschini, it went racing for the first time in 1907 and then later went on to produce luxury road cars. However, by 1949, the company had stopped making cars and instead focused on trolley buses, having merged with engine manufacturer Breda.

During the 1990s, efforts were made to revive the road car side of the business but, after a few false starts, the company filed for bankruptcy in 1999. That should have been the end of Isotta Fraschini, but things started to move again when the FIA and ACO's top category for endurance racing, Hypercar, was gaining momentum.

The two governing bodies decided that manufacturers 'of sufficient reputation' should be able to enter cars, and that led to the revival of, for example, the Vanwall name through ByKolles. It also brought Isotta Fraschini back out of the shadows, the name being chosen to adorn the prototype that was being designed by Michelotto.

It wasn't hard to see why Michelotto wanted in. It hadn't produced a prototype since the 1990s, when it was involved in the Ferrari 333SP (Michelotto produced 26 of the 40 examples built) but, since then, it has focused on GT racing, working closely with Ferrari to produce the GTE and GT3 cars that competed around the world.

## Prime time

With the regulations making it relatively inexpensive to produce a Hypercar, at least compared to the old LMP1 cars, and with a BoP system in place to prevent ongoing development costs, this was a prime time to build a car and go racing at Le Mans.

However, the size of the task cannot be underestimated. It took Peugeot more than 18 months to provide a competitive car with its 9X8. Ferrari leaned heavily on its production car and F1 expertise to bring its 499P up to speed, while Toyota has been in the top class for more than a decade, and comfortably won the WEC titles in 2023.

It was also glaringly obvious at the first race of the 2024 season that another niche LMH constructor, Glickenhaus, was absent. Having followed the old adage that to make a small fortune in racing, start with a big one, Jim Glickenhaus had pulled out, preferring to spend his money on other projects that were more relevant to what the company sold on the road, and new technologies such as hydrogen.

There were raised eyebrows at the Qatar race in March when the Isotta Fraschini Tipo 6 LMH Competizione qualified four seconds off the pace, and then raced with a three-second gap to the front-running cars.

Eventually, the vehicle retired in the fifth hour when a suspension mounting broke.

The project had already courted controversy when the Duqueine team was appointed to run the car after an initial deal with Vector Sport fell through. British squad Vector had been in line to run the car, but was replaced shortly after the programme received its entry to the 2024 season.

**Bouyed by the FIA and ACO's enthusiasm for manufacturers of sufficient reputation, Michelotto revived an Italian motorsport brand that hasn't raced for over 100 years**

So, the Tipo 6-C was both controversial and slow, and the team had also nominated inexperienced drivers to the WEC in order to reduce the pressure of outside judgement. At face value, the whole project didn't look like a particularly good idea.

Under the surface, however, is a very experienced team with some high quality engineering partners and, of course, a committed plan to improve quickly.

As a hybrid LMH car manufacturer, Isotta Fraschini was forced to take the route of carrying a front-mounted hybrid and perfecting a four-wheel-drive system from the outset. That meant it faced the same complicated electronics that the bigger manufacturers were dealing with, but with a fraction of the budget. The car also features the now-standard 900V electrical system to aid fast charge and recharge.

The front motor of the hybrid system kicks in over a certain speed, regulated by the BoP, when it replaces the energy provided by the engine. Peak power is limited by regulation and the power delivery has to match a set torque curve. Getting close to that curve without breaching it, even over a kerb or a bump, is one of the major tasks facing the engineers programming the system.

It took years for even Toyota to meet that curve and, when it did, it was a huge performance ad`vantage. For Isotta Fraschini to be able to achieve that in the first race was perhaps asking too much. What the team was able to do was match the Xtrac-provided hardware to the Bosch electronics. Neither of these companies is new to the WEC game, and so have a baseline from which to work.

## Bespoke engine

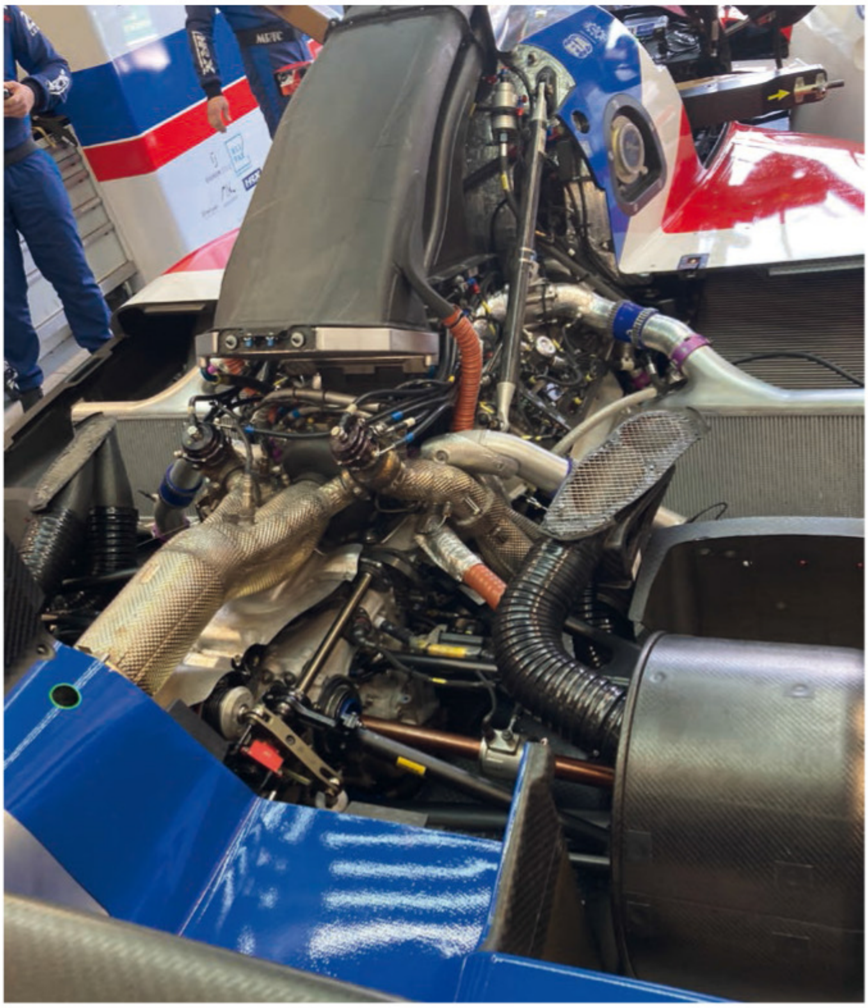
The car was designed at Michelotto by Luigi Dindo. It is powered by an all-new, bespoke, 3.0-litre, 90-degree V6 engine that has been developed for the project by HWA in Germany. The unit has a single turbocharger, similar to that of the Alpine A424, and the turbo sits outside the v of the engine.

Power is fed to the rear wheels through the tried and trusted, seven-speed Xtrac P1395 gearbox, mounted transversely.

The design of the chassis was supposed to have been undertaken by Christiano Michelotto, but the popular Italian who was heavily involved in the development, build and delivery of the GT3 Ferraris, was relieved of his post by his father after the company lost the Ferrari 296 GT3 deal to ORECA.

That left Dindo, the long-serving designer of the company, to produce an LMH car fit to take on the biggest and best in the endurance racing world. A weighty responsibility.

The idea was to build a pure racecar to the current LMH regulations, and then produce customer cars at a later date.



The engine is a bespoke 3.0-litre V6 turbo developed by HWA. Battery comes from WAE and electric motor from Bosch

The chassis of the Isotta Fraschini was designed entirely at Michelotto to current Le Mans Hypercar regulations


Partners are established players in sportscar racing, such as Brembo, Bosch and Multimatic, so component quality is high

As the Isotta Fraschini name is owned by the same parent company as Michelotto, it made sense to link the two programmes.

'The aerodynamics were modelled with Williams, and then we did a real car, 1:1 scale, with Sauber,' says the head of motorsport at Isotta Fraschini, Claudio Berro.

The cars all produce similar amounts of drag and downforce, performance balanced in the Sauber wind tunnel to ensure parity, so hitting the figures was not a particularly arduous challenge. What is more difficult is ensuring the car remains in that performance window in all conditions.

While the minimum weight in Hypercar is 1030kg, the Isotta Fraschini is not at the limit, and the Tipo 6-C raced in Qatar at 1085kg. It also ran with the highest amount of energy per stint, suggesting it needed it to produce comparable lap times to others in the class.

With all of that in place, the company turned towards other partners already involved in sportscar racing.

**As with all things in racing, money is the key to survival, so the company plans to build a trackday version, in a similar financial model to the Ferrari 499P Modificata, as well as a road car**

'The MGU is made with a company [Bosch] that works with Xtrac,' confirms Berro. 'All the mechanical parts are made by Xtrac. They supply us the parts and we integrate it with the MGU. Then we have our inverter inside.

'The brakes are by Brembo, so are of top quality. For the material, we do the best. Multimatic provides the suspension and Bosch the electronics. The quality of the components is so high.'

That said, one of the key issues facing teams is tyre wear. With Michelin pushing for a reduction in the number of tyres consumed during a race, emphasis is placed on the ability of cars to double stint around ordinary tracks and triple stint at Le Mans.

The Tipo 6-C still has a lot to learn running on a track with multiple other cars, and LMGT3 tyres from Goodyear laying down rubber. So, in qualifying, the team did not focus too much on overall fastest lap time.

The issue with the pace is, according to Berro, possible to rectify. 'Probably, performance will be better in the race than qualifying,' said the Italian ahead of the 1812km race. 'The car works with the tyre very well, but we don't explore the limit of settings for qualifying. For the race, the car is in a good way. It's important to stay with the group, and in a 10-hour race if you start on line five or line eight, it doesn't mean anything.'

After selecting two inexperienced drivers alongside Jean-Karl Vernay, the team hoped to relieve the pressure of expectation.

However, the car was far off the pace in Qatar and needs to improve quickly. That, says Berro, will come from set-up and team application; they can then start to look at the BoP to help them move up the grid.

## Branching out

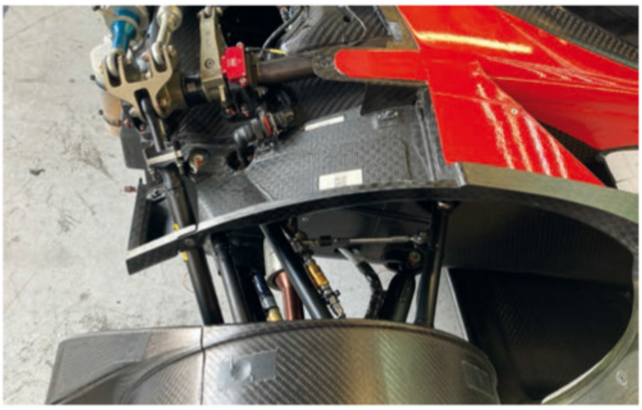
As with all things in racing, money is the key to survival, so the company plans to build a trackday version, in a similar financial model to the Ferrari 499P Modificata, and a road car.

The former was presented to the public at Imola in November 2023, while Isotta is currently working up a two-seater road car that is expected to break cover shortly.

'We make one prototype, and we showed the car in Imola,' says Berro. 'It's 90 per cent similar to the racecar but we have work to do. Now we start to study a double seat so we have a two-seater hypercar. This is our target.

'For now, we race this extreme car to show the brand, then we show the car like the Valkyrie. We use the same technology as this car to show on the race and the road. The engine is not for the road, due to emissions, but the concept is here. We have the potential for 1000bhp, and we need the same for the road. We don't need any more.'

It's clear there is a long way to go with this project, and the level of competition means it's going to be tough even to stay in the game. As more cars from resource-laden manufacturers continue to arrive, the Isotta Fraschini has to step up and be counted.



Suspension is double wishbone and torsion bar with integrated brake-by-wire system, carbon discs and a combination of six-piston (front) and four-piston (rear) calipers by Brembo

Steering is by way of electric steering rack, while the majority of the control systems onboard come from Bosch Motorsport, including the ECU, VCU and PowerBox

Isotta Fraschini signed two Silver-rated WEC rookies to partner Vernay. It says this will relieve pressure, but is such an approach tenable considering the level of competition?


F1 is approaching its biggest engine regulation overhaul since the introduction of the 1.6-litre V6 hybrids back in 2014 (pictured)

*Formula 1 has been racing with hybrids for a decade now, but a new era begins in 2026.* Racecar *spoke to FIA single seater director, Nikolas Tombazis, to find out what we should expect under the new engine regime*

**By CHRISTIAN MENATH**


# Power Unit 2.0


XPB

FIA single seater director, Nikolas Tombazis, has been central in developing the new regulations that feature less complex, less efficient ICE PUs, with more emphasis put on the electric side

A decade ago, a new era began in Formula 1. High-revving, naturally-aspirated V8 engines had had their day. Since then, manufacturers no longer talked of engines, but of Power Units. Mercedes High Performance Engines therefore became Mercedes High Performance Powertrains.

In addition to the combustion engine, there was now also a turbocharger with an electric component, the MGU-H, as well as further development of the former KERS, which was now called MGU-K. At 120kW, the Motor Generator Unit-Kinetic, delivered twice as much power as KERS to the crankshaft, with the electrical energy temporarily stockpiled in the 4MJ Energy Store.

The engine manufacturers agreed on these regulations around 15 years ago. Even then, electrification and high-efficiency engines were still magic words in the automotive industry.

However, the Power Unit was not immediately well received in Formula 1. Too complicated, too expensive, too heavy, too quiet, so the critics kept saying. Well, 10 years later, the criticism has fallen almost silent. All manufacturers now have the technology under control and are at a similar performance level. Consequently, the regulations on the powertrain side have remained largely unchanged.

This will all be different in 2026. Years of discussion, negotiation and haggling culminated in version one of the 2026 regulations on 16 August 2022. The negotiations were complicated because the FIA had to take various points of view into account. On the one hand, there were the manufacturers already involved – Mercedes, Ferrari, Renault and Honda. On the other, there were potential newcomers to the series.

So, while the FIA didn't want to scare off any of the established manufacturers, it also wanted to keep the entry barrier as low as possible for interested parties.

## Efficiency compromise

That, in a nutshell, is why the new regulations are a compromise. At first glance, everything looks like it remains the same with the combustion engine and it's the rest of the Power Unit that has changed quite a lot.

The 1.6-litre, V6, turbocharged ICE remains, but the MGU-H has been removed. The elimination of the electric turbocharger was the most important point in order to attract new manufacturers.

The electric motor rotates up to 125,000 times per minute, delivers between 60 and 70kW and switches back and forth between power delivery and harvesting in the shortest possible time. The MGU-H is probably the single most complicated component in the current Power Unit, but this marvel of technology is what makes the engines so incredibly efficient. Its elimination will inevitably make the 2026 engines *less* efficient.

The thermal efficiency of the engines today is over 50 per cent. With a maximum fuel flow of 100kg per hour from 10,500rpm, the power units achieve a system output of over 1000bhp.

It's not just the removal of the MGU-H that will reduce efficiency; the combustion engine will suffer as a result of other measures, too. Although key parameters such as stroke and bore remain identical, further restrictions are being brought in on the combustion engine side. For example, the maximum compression ratio will be reduced from 18:1 to 16:1.

'Of course, you lose a little bit of efficiency,' admits Nikolas Tombazis, single seater director at the FIA, in an interview with *Racecar Engineering* for this article.

'18:1 would lead to a more efficient engine. While we don't want to negate that, ultimately, these engines are a compromise between different parameters: cost, efficiency, whether it is possible for newcomers to get into the sport – and all of these parameters are slightly contradictory. In the end, the solution has to be a compromise.'

This is also the reason why the combustion engine has been limited to the essentials. Variable geometry turbochargers

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Formula 1 currently uses 10 per cent renewable ethanol fuel, but the 2026 rules take sustainability further by removing the fossil fuel content entirely, in the push for carbon neutrality by 2030

Audi

**'We've wanted to simplify the ICE in order to make it possible for newcomers to come into the sport and not have to go through a few years of humiliation before they can be competitive'**

*Nikolas Tombazis, single seater director at the FIA*


Audi, one of the new manufacturers coming into F1, argued for the use of aluminium pistons rather than steel ones

are still not permitted, and variable intake trumpets will be banned again under the new 2026 regulations.

'Variable geometry technology is quite high and quite expensive and would mean that this area is subject to constant change. We felt this was not an area where we wanted to fight a battle,' says Tombazis.

'We've wanted to simplify the ICE in order to make it possible for newcomers to come into the sport and not have to go through a few years of humiliation before they can be competitive. It's still going to be very difficult for them. I'm not saying it's going to be easy, but we wanted to make some simplifications.'

The incentives have paid off. Audi and Red Bull Powertrains (with Ford) will join in 2026, while Honda will return with Aston Martin.

Thanks to the slight simplifications, the newcomers will be able to catch up more quickly with the largely unchanged combustion engine. The reduction of the compression ratio illustrates the approach.

'To work at the compression ratio of 18:1, you would need to get there very gradually, step after step after step,' explains Tombazis, 'and we don't want them to make new engines every year. We felt that if we left it at 18:1, it would just increase the gap between newcomers and the incumbents.'

At the same time, this means only the basic architecture of the existing engines remains suitable. Also because the previously unlimited boost pressure is now being limited to 4.8bar since the MGU-H was removed. So, in effect, all new Power Unit development will start virtually from scratch.

## Material matters

Another concession has been the permitted piston material. Aluminium pistons were extensively discussed, but existing PU manufacturers wanted to keep steel pistons.

'It was a big topic,' recalls Tombazis. 'When we did the analysis, we found that aluminium would have been more expensive and less performant. Therefore, it was decided that pistons had to be made out of steel.'

This conclusion was no great surprise to many as the incumbent manufacturers had already gone through this process. In retrospect, the switch from aluminium to steel was one of the trend reversals in Formula 1 Power Unit development.

'I guess the steel piston is a good example. We were definitely coming to the limits of what was possible with aluminium ones. It just came to that tipping point, and that was an interesting journey to go through,' recalls Mercedes engine boss, Hywel Thomas.

Even with the lower compression ratio, steel is still the material of choice for pistons.

'The way these engines work is very close to the knock level; the pressures are extremely high,' says Tombazis. 'So aluminium cannot be as effective.

'It would make them a lot cheaper as an individual unit because these pistons are very expensive to machine, and very complicated, but considering a whole engine has to last, on average, about eight races, the benefit of the extra reliability [of steel] outweighs that.'

## Pioneering role

So, accepting that the new F1 ICE will be significantly less efficient in 2026, how does this fit with the current zeitgeist?

The answer is fuel. While the current fuel only has to contain 10 per cent advanced sustainable ethanol, fuel in 2026 will have to be completely sustainable. This was not only a key criterion for new entrants, but for *all* manufacturers. This change was even able to persuade Honda to revoke its withdrawal.

The aim is to shift the technological pioneering role on the combustion side towards drop-in fuel.

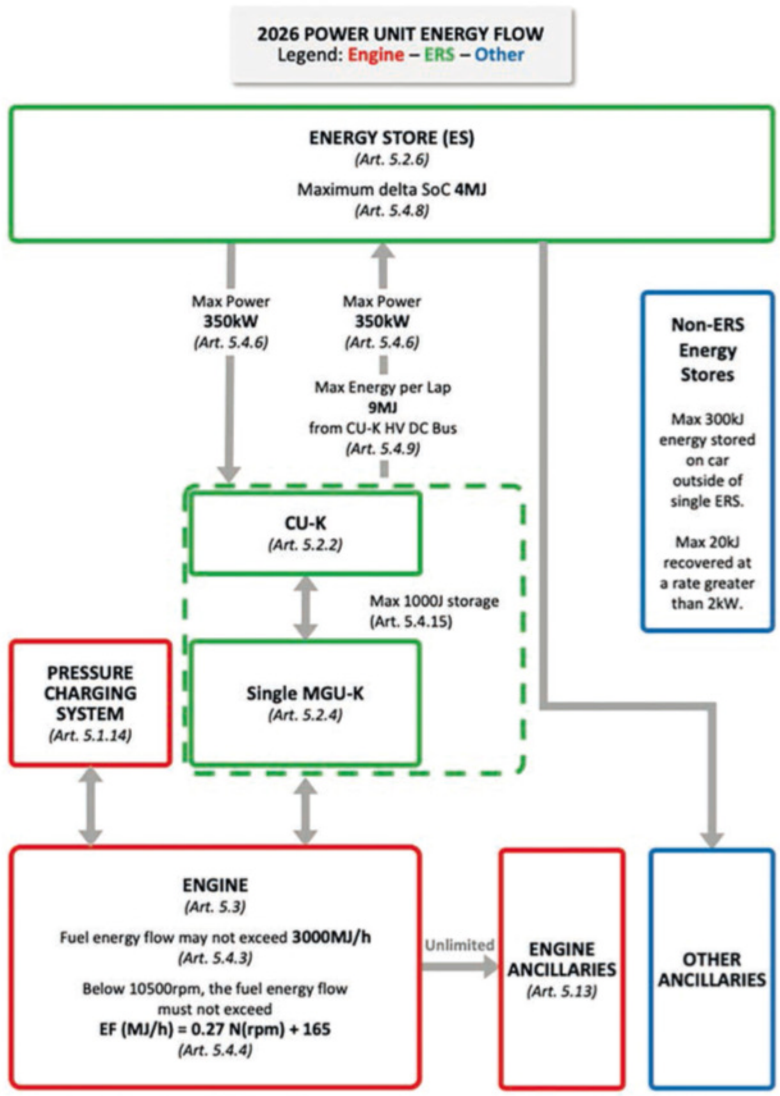
'We've eliminated the fossil components in the fuel, and fuel manufacturers now need to develop manufacturing and production techniques for such fuels,' says Tombazis.

As a result, the efficiency of the combustion engine is no longer so elementary from an environmental perspective. Especially as the proportion of combustion engine power will also be drastically reduced. In 2026, the maximum fuel flow of 100kg per hour will become a maximum energy flow of 3000MJ per hour from 10,500rpm. The mode of operation remains the same. Fuel flow will still be measured, and the energy content of the homologated petrol will be determined in the laboratory. Tombazis explains the thinking behind the decision:

'We felt it was more correct to have an energy limit because it means if you have a component with maybe a bit smaller energy density per unit mass - but otherwise a very good fuel - it should be allowed, not stopped.

FIA

**Energy flows, power and energy storage and state of charge limits for the 2026 F1 PU regulations**




When the car is on the track a lap will be measured on each successive crossing of the timing line, however, when entering the pits the lap will end, and the next one will begin, at the start of the pit lane (as defined in the F1 Sporting Regulations).

FIA

**2026 Power Unit element minimum mass limits (for reference only)**

| ESME | MGUK | MGU-K mechanical transmission | ICE | TC | Powerbox |
|---|---|---|---|---|---|
| | | | No individual mass limit | Min **12kg** | No individual mass limit |
| Min **35kg** | Min **16kg** | Assumed **4kg** | Min ICE+TC+Powerbox **130kg** | | |

**2026 Power Unit mass allowances as weighed**

| | | ESME min mass as weighed | | MGUK min mass as weighed | | Not weighed | | ICE min mass as weighed | | Total PU minimum mass |
|---|---|---|---|---|---|---|---|---|---|---|
| Drive in MGUK | > | 35kg | > | 20kg | > | – | > | 130kg | > | 185kg |
| Drive split | > | 35kg | > | 18kg | > | – | > | 132kg | > | 185kg |
| Drive in ICE | > | 35kg | > | 16kg | > | – | > | 134kg | > | 185kg |

Getty Images


The new rules aim to entice new powertrain constructors and manufacturers into F1. So far, Red Bull Powertrains and Audi have signed up, while Honda is returning as Aston Martin's PU supplier

**'That's why we've made these regulations. To make sure fuel development happens at the fuel manufacturer and engine development happens at the PU manufacturer'**

XPB


One of the major demands of the interested OEMs was a more equal split between internal combustion engine and electric power

This, however, shifts the problem to the chassis side, as it could possibly mean larger fuel tanks are required.

## Pump up the volume

'We don't expect a huge variation there. I don't think anyone is going to come with a fuel that needs twice the volume, or something like that. Plus, there is a limit on energy content per kilo,' notes Tombazis.

The lower heating value (LHV), the available thermal energy produced by the combustion of one kilogram of fuel, must be between 38 and 41MJ, according to the new regulations. The competition is therefore not only between the engine manufacturers, but also between the oil companies.

There are measures in place to ensure no engine manufacturer has an advantage in this respect. Development on single-cylinder test benches is permitted, but strictly controlled.

'It must not be designed by the PU manufacturer. They can get a generic one-cylinder engine,' confirms Tombazis. 'That's why we've made these regulations. To make sure fuel development happens at the fuel manufacturer and engine development happens at the PU manufacturer.'

The 3000MJ per hour limit means significantly less power, even without taking into account the lower combustion efficiency. Converted into today's mass flow, this equates to a reduction of around 25 per cent.

ICEs are currently expected to have an output of around 400kW in 2026. In return, the proportion of e-power will be significantly increased. In the new era, the MGU-K will be allowed to deliver an additional 350kW to the crankshaft, rather than the current 120kW.

The almost equal split between the combustion engine and the electric motor was a major wish of the OEMs.

Red Bull Powertrains, the only independent engine manufacturer currently operating in the championship, would prefer to push more petrol through the injection nozzles. This is because the 2026 Power Unit only works to a limited extent.

The size of the energy storage unit remains unchanged at 4MJ for weight reasons, but the maximum e-boost has almost tripled. If more electrical power can be delivered, the electrical energy must also be fed in. However, the MGU-H is no longer there as a power supplier. Instead, the MGU-K is allowed to slow down the crankshaft more.

## Battery development

Up to now, only 2MJ per lap may be recuperated at the rear axle. In 2026 it will be 9MJ. The battery must therefore be fully charged and discharged on average more than twice per lap. For this reason, the focus of battery development will now shift to power density, not energy density.

Consequently, the regulations for battery technology are much more open than for combustion engines. Manufacturing processes are more free and additive manufacturing is now playing a greater role.

'It was identified that some of the exhaust components, for example, were actually cheaper to make with additive manufacturing,' acknowledges Tombazis.

Certain parts, such as the three-into-one collector, can now come from the 3D printer.

'There are some areas of the engine, like the cylinder head, which cannot be additive manufactured for cost reasons. Generally speaking, though, AM is an area where we are modernising the regulations for 2026, and that also applies on the chassis side.'

Back to the energy dilemma. In racing mode, a maximum of 9MJ may be consumed and released by the MGU-K per lap, but in qualifying, 13MJ can be released if the battery is full at the start of the lap.

However, even 13MJ is not enough on most tracks to deliver full power every time at full throttle. 13MJ is 13,000kW seconds. With 350kW of electric power, that's a good 37 seconds of full power available, but the energy storage system is currently only sufficient for 33.3 seconds of full e-power, plus a contribution from the MGU-H.

The full power output time is similar, but there is one major difference: when the e-power stops in 2026, only 400 combustion engine kW will remain. Recuperating 9MJ per lap will therefore be a Herculean task.

Initially, there was talk of recuperation on the front axle, as well as recuperation via the crankshaft on the rear axle as before. In future, the power units will be operated like a serial hybrid. In partial load operation, when the driver is not calling for full power, the combustion engine will charge the battery.

That alone is not enough, so the 2026 chassis regulations must follow suit and produce cars with less aerodynamic drag.

**Initially, there was talk of recuperation on the front axle, as well as recuperation via the crankshaft on the rear axle as before. In the future, power units will be operated like a serial hybrid**

'I think perhaps where we need to pay urgent attention before it's too late is to look at the ratio between combustion power and electrical power to ensure we're not creating a technical Frankenstein that will require the chassis to compensate to such a degree, with moveable aero to reduce the drag to such a level that the racing will be affected,' warns Red Bull's Christian Horner.

## Speed profile

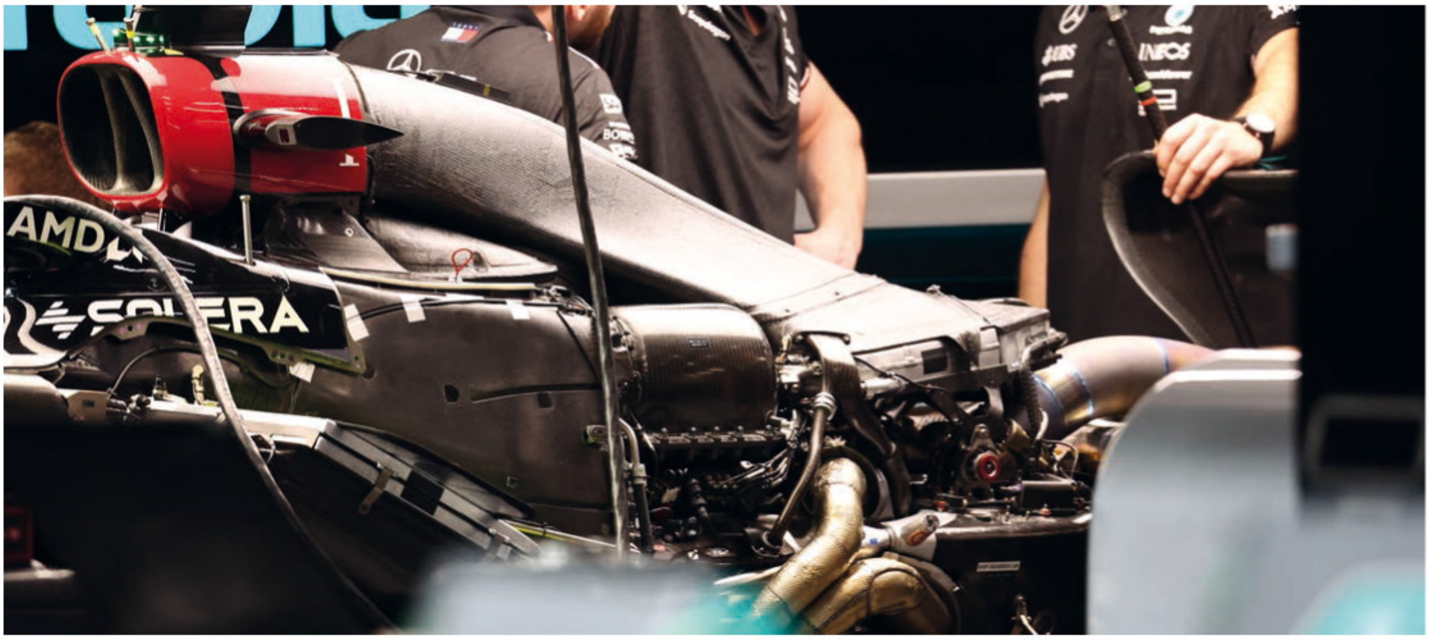
Max Verstappen, for one, was very worried about the speed profile, as on some tracks drivers have to downshift at the end of long straights well before the braking zone.

According to FIA analyses, such fears are unfounded. Nevertheless, adjustments will still be made to the regulations.

'What we are dealing with is just making sure that at circuits with very long straights we distribute the power more evenly along the straight and don't have it all at the start.


XPB

**Rules such as the 'three per cent' clause are part of the FIA's plan to develop engine regulations that are as equal as possible, making it harder for any team or manufacturer to gain an advantage**



The MGU-H will no longer be present in 2026, yet engine weight is set to increase further still as the MGU-K becomes more powerful

I think that has been working quite okay now,' says Tombazis, adding, 'We also wanted to make sure on some circuits that we don't have any stupidly high speeds, and we've also got that under control now.'

Currently, lap time-optimised, maximum power is delivered as soon as traction permits, but because only a limited amount of energy is available, the power output then decreases as the straight progresses. In order to prevent this, appropriate adjustments will be made in the next version of the regulations.

For some tracks, there will even be special rules regarding energy output. 'That will be the exception, not the norm,' says Tombazis.

## Heavy weights

That was not the only criticism of the new engine regulations. The complex technologies onboard were largely responsible for the weight explosion of the cars in 2014, which saw the current Power Units weighing in at a whopping 151kg. Although the MGU-H will be omitted in 2026, the more powerful MGU-K, in particular, will continue to drive up the weight, so the entire Power Unit looks likely to weigh at least 185kg.

However, there was no requirement in the the new regulations to impose a limit here. Because a budget cap now applies to the engine manufacturers for the first time, the lightweight arms race would have regulated itself. In contrast to the chassis, there are no major safety concerns being flagged up.

'We had infinite discussions with the PU manufacturers about weight and they were all very concerned about this topic in case it became a battleground. All of them pushed very hard for a weight limit,' says Tombazis.

Ultimately, the FIA did not want to give too much freedom here in order to avoid putting unnecessary pressure on the system.

**'We had infinite discussion with the PU manufacturers about weight and they were all very concerned about this topic in case it became a battleground. All of them pushed very hard for a weight limit'**

'We don't want to say you just have the cost cap and can do what you want with everything else, because we feel it then puts enormous pressure on the cost cap, which can lead to distortions, or to even breaches.'

In contrast to the current engine freeze, more thought has been given to potential problem cases this time around. For example, what happens if a manufacturer is too far behind? If a three per cent deficit in the combustion engine is exceeded, additional updates can be made. The exact nature of this process is still being defined, but it's not just about peak performance.

'It is more like an integrated power, but it's not exactly a simple integration,' says Tombazis. 'It depends on how power is delivered around the track.

'We are planning to refine this particular clause a bit more. We want to find a range of conditions. If an engine is running much cooler than another engine, for example, that is also a drawback. So you may have equal power between two engines, but an engine may have to run 10 degrees cooler than another to achieve that, which then increases the amount of cooling needed.'

It's clear there is still work to do on the finer details, but the 2026 Formula 1 Power Unit regulations certainly look to be a big step in the right direction.

## Industry view

Cambridge University spin-off company Echion is involved in developing battery technologies for heavy duty vehicles, and has developed an anode material called XNO, based on mixed niobium oxide ompositions and microparticle designs. It says this provides 'substantial amounts of power' while also supporting ultra-fast charging and higher capacity retention at fast charging rates compared to LTO and graphite.

Increasing the battery's responsibility in the power unit will see teams pay greater attention to battery design, from overall weight down to the molecular detail of the battery anode material, says Echion. Under the 2026 regulations, harvestable energy per lap of the ERS-K will increase as will peak power provided to the MGU-K. However, the amount of energy that can be used from the battery at any one time is still capped. The 2026 competition will therefore be a battle of fast-charging batteries, with teams likely to trial different approaches. Manufacturers might opt for chemistries that minimise degradation, reducing the need for oversized batteries.

This leads to the area of development around anode materials. The anode is an area where battery manufacturers are already working hard to improve charge rates, capacity and performance. Anode materials, says Echion, have the potential to unlock more power from traditional lithium-ion batteries.

# Back to the future

*The FIA has recommended that the World Rally Championship drop hybrid powertrains for 2025 with a view to a new rule set for 2026. The FIA's David Richards and Andrew Wheatley take us through the plans*

**By ANDREW COTTON**

Hybrid powertrains were introduced to the FIA World Rally Championship (WRC) in 2022, at the behest of the manufacturers who felt they needed to race what they sold for the road. However, following a decision to closely examine what is needed to make the WRC sustainable for the future, that decision has been undone, and from next year the cars will revert to non-hybrid status.

The focus is very much on sustainability, not only from a technical perspective but from a sporting one, too. Dropping hybrids means Rally1 cars will be less costly to buy, cheaper to run and the gap to the slower Rally2 machinery will be closed, allowing the manufacturers involved in that class to more easily make the step up.

Taken in isolation, dropping hybrid is a shock to the system. The WRC is mid-contract with official supplier, Compact Dynamics, and the manufacturers are not selling fewer hybrid road cars, so on the face of it, it seems to be a rushed call.

Not so, says FIA Foundation chair and former Subaru rally team boss, David Richards. This is the first step in a major re-think of rallying, and a crucial move towards fulfilling the FIA's mandate to improve grass roots competition.

***Racecar Engineering*: What was behind the decision to drop hybrids from the World Rally Championship for 2025?**

**David Richards:** The initiative, or the demand, came from the fans who are all asking what is going on with the world championship, that questioning of it.

And then [FIA president] Mohammed Ben Sulayem said in Baku in December that it's about time we did something around this.

Robert [Reid, FIA deputy president for Sport] and I put our hands up and volunteered to get stuck in and try to write a report and make some recommendations. We commandeered [FIA World Motor Sport Council members] Gary Connolly and Andrew Mallalieu, and, of course, supported by Andrew Wheatley [FIA rally director] and Xavier [Mestelan Pinon, FIA chief technical and safety officer].

We said, let's just do something quickly. We can't just sit around and let things carry on as they are without putting some proposals on the table.

We looked at all sorts of things; we had a complete look at the whole process. We didn't just say, do we need hybrids? Or what are we going to do for Rally2? We asked, what's important about the World Rally Championship? What are the key aspects of it that we need to protect and ensure for the future? What are the demands of promotion and marketing that we're not doing today?

And then finally, on the technical side, where are the car manufacturers going? What are their requirements? How do we encourage greater participation at the top level?

It was a holistic look; it wasn't just an issue about hybrids.

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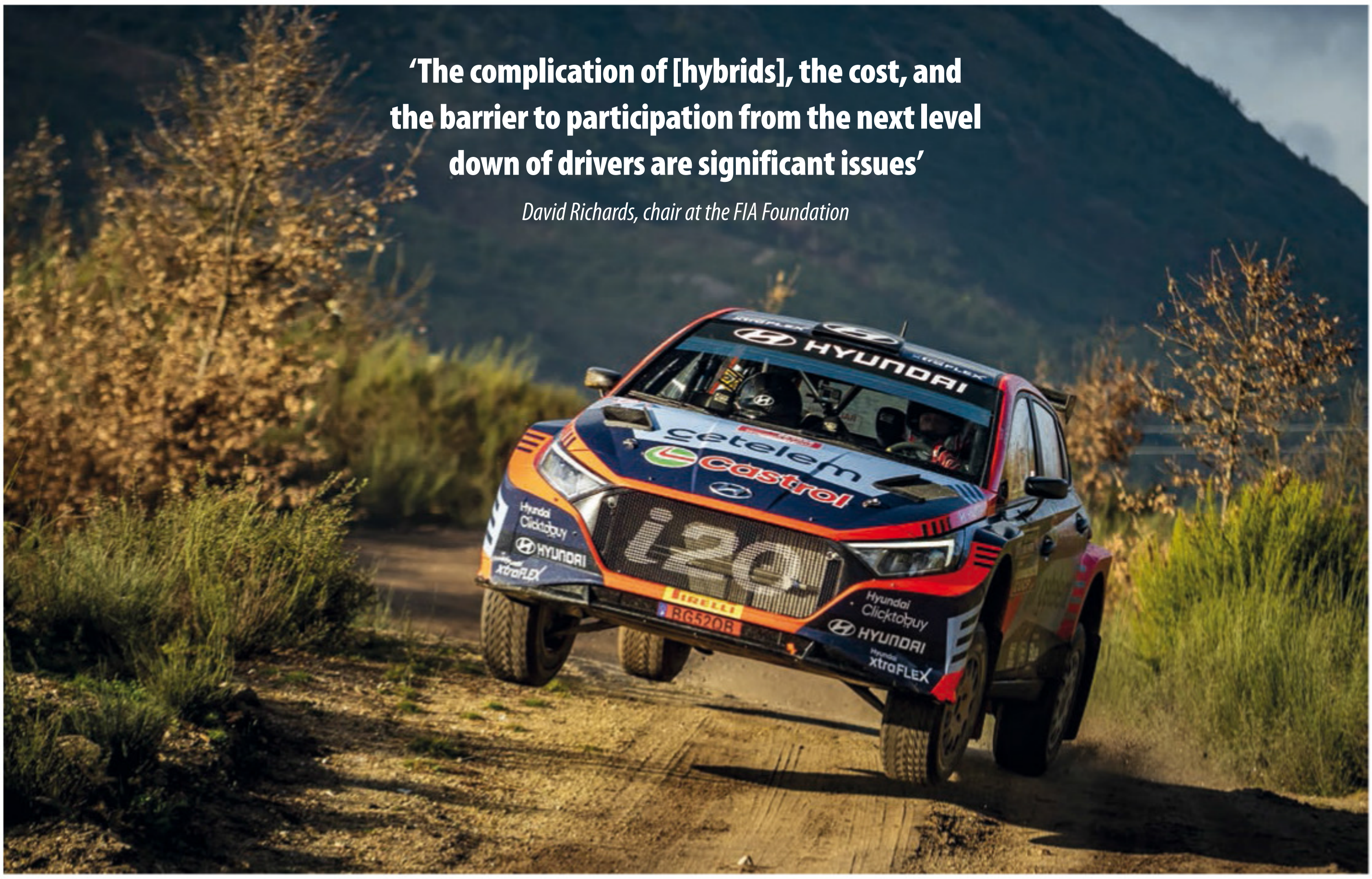
**‘The complication of [hybrids], the cost, and the barrier to participation from the next level down of drivers are significant issues’**

*David Richards, chair at the FIA Foundation*

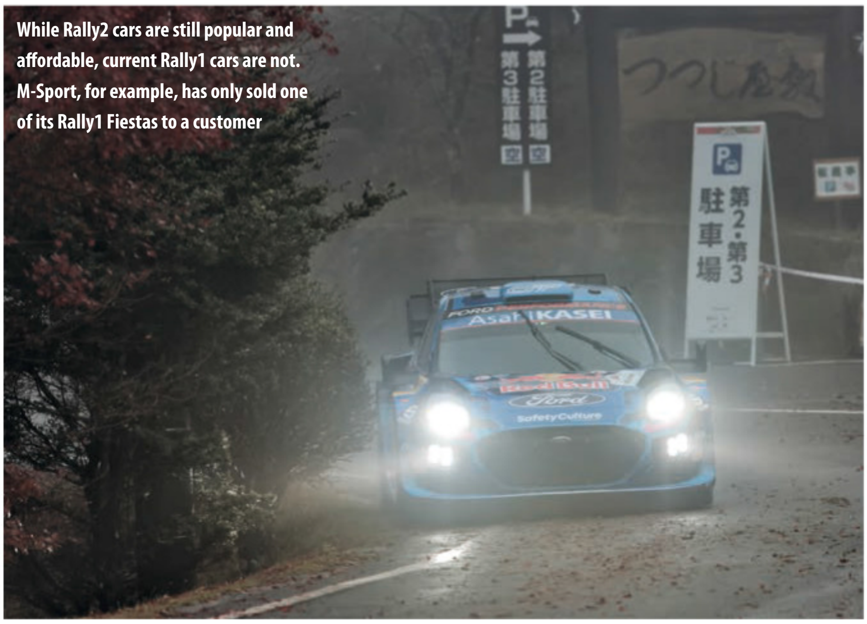



**A big part of the decision-making process was to bring Rally1 and Rally2 closer together, in order to provide a more achievable step between the two classes for younger teams and drivers**

**RE:** ***We’re in the middle of a rule cycle and the manufacturers have already invested a lot of time and money into getting to grips with the hybrid system and the strategies it involves. How dramatic is the change in philosophy going to be after this decision?***
**DR:** It has been done in conjunction with the manufacturers. They were involved at the beginning of December and have been party to discussions right the way through the process.

I wouldn’t say every decision taken has been unanimous, but I would say it’s definitely a majority decision that hybrids should take a back seat now. The complication of them, the cost, and the barrier to participation from the next level down of drivers are significant issues.
**Andrew Wheatley:** I think that’s fair to say. Each manufacturer has a different reason why they would like or not like hybrid but, for the greater good of the sport, this was perceived as a positive step forward.

XPB




**While Rally2 cars are still popular and affordable, current Rally1 cars are not. M-Sport, for example, has only sold one of its Rally1 Fiestas to a customer**

The other thing that’s important to bear in mind is that this 2025 / 2026 regulation is a step towards the new 2026 rules. It’s part of a transition. The intention is that the new regulations will be published at the start of 2025 for the 2026 application, and then into the 2027 world championship.

It makes sense when you see the transition from where we are now to where we’re going, to see how this develops in these steps.

**RE:** ***We note that WRC uses a sustainable fuel supplied by P1, and Formula 1 will introduce sustainable fuel to its 2026 technical regulations. The torque curve changes also closely resemble what’s happening in FIA GT3. Is this part of a wider FIA strategy, or is this specific to rallying?***
**DR:** I think from a rally point of view, it’s a logical step. It’s therefore no coincidence that other motorsports are following a similar trend.

**RE:** ***Sustainable fuel is an emerging technology - we should be shouting it from the rooftops - but currently it’s not a very well communicated strategy. Do you have plans to change this?***
**DR:** Rally is a wonderful platform for sustainable fuels, and we tend to push very hard on that front, making sure it gets the promotion and publicity it deserves, which I don’t think it has today.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**'One of the simple things to help reduce the cost of aerodynamic development is a top speed cap'**

*Andrew Wheatley, FIA rally director*

In a further move to keep a lid on costs, top speeds will be limited in 2026, while hydrogen remains on the cards as rallying seeks to remain open minded about future fuel sources

That's where the promotion of the sport, and communication, comes in.

Hand in glove with the changes to technical, it's a significant commitment from the FIA, to promote the sport more effectively and to review the commercial aspects of it to build a better profile.

I don't think anyone can criticise the TV coverage it gets today. It's been superb and the promoters are doing an excellent job. But their focus has been very much TV centric. We intend to broaden that now to make sure we communicate not just to the fan base, which the TV tends to do, but to the broader public and those on the periphery of the WRC. Or those that we've lost in recent years and need to capture back.

***RE:* Rally2 cars will be closer to Rally1, making it easier for those in the secondary class to race in the top level of WRC. Was that one of the reasons to drop hybrid?**

**DR:** That's a good observation. The perception and the truth, from what I'm told by drivers who tried to make this transition, is that it's an extremely difficult step. Andrew has some anecdotal evidence of drivers that have done it and has spoken to them afterwards.

**AW:** It's easy if you step into a full factory team environment, and you're engaged from the start with all that application. Where it's challenging for drivers is trying to step into that environment. That's the difficult bit.

At the moment, the step between Rally2 and Rally1, in terms of performance, is relatively small, but in terms of the whole process it's much more complex. That's another thing we're talking about with this transition to the next set of technical regulations, to enable those two disciplines to come closer together. They won't merge, because that's impossible as they're fundamentally different philosophies; [Rally2] is a customer philosophy, and [Rally1] is purely professional.

However, it will enable those drivers to take one step closer to being able to show their worth. Secondly, it will allow the Rally1 category to come down one small step so drivers can make that transition without full factory support, and all the simulation and testing that comes with that.

***RE:* Do you think it's fair to say people have underestimated the technical leap that hybrid has required?**

**DR:** One of the other aspects, of course, is that whereas Malcolm Wilson [M-Sport] used to regularly sell a number of cars to private competitors, he has so far only sold one of the latest generation cars. The private competitors have all seen the problems of [hybrid], the expense, and there's just no demand for these cars.

So, the secondary market, those gentleman drivers who would have turned up at the World Rally Championship and made up the top 20, just don't exist anymore.

**AW:** That's the bit that's missing right now.

***RE:* The idea is for the 2026 Rally1 regulations to have a common safety cell onto which the manufacturers can hang their bodywork. What is the background to this decision?**

**DR:** To be honest with you, that was not the original idea. The original thought process, before we researched this properly, was that a more powerful Rally2 car would be the answer. But what became apparent talking to the manufacturers was that the cars currently competing in Rally2 are reaching the end of their lives. And, in that segment of the market, there are no cars going to follow behind internal combustion engines.

To base the Rally1 regulations on a standard road 'shell was just not feasible, or at least if it was, it would be extraordinarily costly. So, the new concept is an extension of what we have today.

All the safety work from today's Rally1 cars will carry over to the new version. It will be a sort of evolution, if you like.

The proposal is that it's slightly larger than the current car, which will not only give increased safety, but make it more relevant to the cars the manufacturers are promoting.

The intent is for the FIA to homologate a set of tooling and have an authorised supplier sell it, allowing manufacturers, or tuners, anywhere in the world to make the spaceframe. So it's the tooling that will be standardised.

TV coverage of rallying, including special made for TV stages, is already excellent, but there are even greater marketing opportunities out there to be exploited

Tom Banks

**Currently, Rally1 is purely professional, while Rally2 is a customer philosophy. The new rules aim to change this position**

> **'One of the great things about the WRC is that we must look to engage and embrace all the new technologies the car manufacturers are looking to promote… whether it's electric, hydrogen, whatever it might be'**
>
> *David Richards*

XPB

They would then acquire homologated bodywork from the car manufacturers, which would fit on the same pick-up points, so you just decide whether you want a Ford, Toyota, Hyundai or whatever.

Other manufacturers could then come along and homologate their bodywork, again to fit that chassis.

We will ask for the bodywork to be made of sustainable, reusable materials.

The current proposal is to have options for the transmission. We won't do a tender for that, instead allowing transmission suppliers to offer a standard unit that fits the chassis, at a certain price. Those will be homologated, and customers choose which one to go for.

Engines will be bought from the manufacturer; the same engine as in Rally2.

With those constraints, it should be an easy car to build anywhere in the world. And it should keep the price down as well.

**RE:** ***You've suggested a car cost of €400,000 (approx. £342,300 / US$435,700). How does that compare to the current Rally1 cars?***

**DR:** Double that price.

Personally, I think the new car will be below that figure, looking at comparable GT4 cars, which are about £280,000 (approx. $356,600). I don't see these cars being much more complicated than that.

Now that we've set that target, though, we mustn't let it escalate.

**AW:** There are a couple of interesting things here. There is the torque meter on the engine, which does restrict the development race. The manufacturers still want to have the lightest and most reliable unit they can, but searching for the last 2bhp, that's the expensive bit.

Also, by reducing the aerodynamics, we again stop some of the peak development cost. One of the simple things to help reduce the cost of aerodynamic development is a top speed cap. The current Rally1 can peak at around 195km/h but you're talking about *very* small periods where it's at that speed, so the amount of work that has to be done to get ultimate efficiency at that speed is disproportionate to the benefit.

The homologation approach to the transmission also opens the doorway a little bit for more people.

One crucial thing, though, is the safety cell is being designed around an electric vehicle architecture, the intention being for it to accommodate that as well.

**DR:** In circuit racing, if you have a small discrepancy in performance, that makes all the difference, and the driver is less of an influence.

In rallying, a driver has a far greater influence in the overall performance. If we get everything right, and I'm confident we will, you could put one of the top drivers into any of these cars and they'll get the same performance. That levels the playing field enormously.

It also allows younger drivers to come through and shows the talent more easily, which is not happening today. This is a democratisation of the World Rally Championship, which it always used to be.

If you look at the past, you could go out and buy the same car the factory was selling, and you could be competitive. In the Subaru days, we would be selling 20 of these cars a year. Malcolm [Wilson] would be doing the same with his Fiestas. That's not possible today, and that is not healthy for the sport, in our view.

**RE:** ***Hydrogen is a major focus of the FIA at the moment. Do you see that fuel being used in the World Rally Championship any time soon?***

**DR:** One of the great things about the WRC is we must look to engage and embrace all the new technologies the car manufacturers are looking to promote because that's how we'll encourage them into the championship, whether it's electric, hydrogen, whatever it might be. We must protect that for the future.

But, at the same time, we've got to be very cautious that we don't create an imbalance and don't end up with all the problems that are raised around balancing performance.

If there are ways of controlling engine performance, so it's the same running on hydrogen as on a sustainable fuel, that should be taken on board as soon as possible.

Liquid-based hydrogen seems to be a sensible route forward, and the FIA is doing a lot of research into it at the moment, a lot of crash protection testing, and I suspect it'll only be a matter of time before that's feasible.

Knowing Toyota, and their enthusiasm for [hydrogen], I suspect they'll be pushing us to bring that into the world championship.

Jedis have been a familiar sight in UK motorsport for 40 years now. The single seater started off as a hillclimber but has been raced on circuits since the 1990s

Jon Elsey

# Star fighter

*British racecar constructor, Jedi, turns 40 this year, and its diminutive creation is still turning heads, winning races and shaking up the motorsport establishment*

**By MIKE BRESLIN**

Jedis posted the fastest lap of the season at two UK circuits last year, Brands Hatch Indy and Silverstone International. That news will come as no surprise to many on the British club racing scene, for this potent little racecar has been punching above its weight – currently just 350kg – for four decades now.

Remarkably, during that time its design has not strayed far from the initial concept, yet it remains fast and relevant, now plying its trade in its own F1000 championship, while it also gives Formula 3 cars a run for their money in Monoposto races.

Wellingborough, Northamptonshire-based Jedi Racing Cars is owned and run by father and son, John and Frazer Corbyn, although John is semi-retired and 'now only comes in six days a week,' jokes Frazer.

John designed and built the first Jedi in 1984, with the help of Roger Grigg, who did the drawings. It was Frazer, at the time a *Star Wars* obsessed young lad, who named it.

**Chassis is of spaceframe construction, making it both strong and cheap to fix. Additional safety measures include anti-intrusion plates**

## Hill start

However, to really understand this car and, by extension, the company that makes it, you need to look at its story, which did not begin a long time ago in a galaxy far, far away, but in the sport of hillclimbing.

We're used to seeing bike-engined racecars these days but, in 1984, when the first Jedi made its debut with a Suzuki T500 engine, they were a rare thing indeed.

'I think the first car wasn't only right, it was also built at the right time,' says Frazer. 'There was nothing else like it. Other bike-engine cars had been done, there was the Johnny Walker 4 for example, but this was different.

'This was the first time anybody really successfully used a two-stroke,' John explains. 'And the car was *very* light. It was the same weight as the bike that donated the engine.'

Initially, there was no intention to sell the car but, with its success on the hills, potential customers soon came knocking at the door.

By the late 1990s, when Jedis were also out on the circuits, that interest increased exponentially, and the little racecars have been a staple of UK club racing ever since.

Partly to mark the 40th anniversary of the original car, 'Number 1' is at present being rebuilt at Jedi's factory, and in its naked spaceframe form it is noticeably similar to the current Mk7 frames sitting alongside it.

'The car has never really chopped and changed too much,' confirms Frazer. 'When Number 1 is rebuilt, we'll stick it next to a current Mk7, and you'll immediately see the shared DNA between the two cars.

'It's a bit like the original Lotus 7 and the current Caterham. It's never really changed much, it's just evolved.'

One of the clearest signs of the Jedi's evolution was an early alteration to the frame.

'The chassis is now deeper, because it was designed to run 10in wheels originally,' says John, 'but we very quickly moved on to 13in, so we lowered it, which then lowered the driver and the engine, and that was a bonus.'

## Spaceframe chassis

More recently, for the Mk6, which represented one of the biggest performance hikes in the car's history, the chassis was altered again, this time at the front to allow for a higher nose, and we'll come to why later. However, while there have undoubtedly been changes, there has never been any thought of moving away from a spaceframe, for a multitude of reasons.

'It's a tough car,' says Frazer, 'and the good thing about a spaceframe is you can repair it fairly easily. You can also see damage.

Jon Elsey


**Bodywork is of a modular design and comes in seven separate pieces. This was a consideration right from the start, again to help keep potential (perhaps inevitable) crash damage costs down**

The race prep shop at Jedi's Wellingborough base. The cars compete in their own F1000 championship, and also in Monoposto

'No one will argue against carbon tubs being the correct direction for the high-end stuff, but there's a cost with it. Also, can you see the damage? There are lots of second hand cars out there with carbon tubs, and sometimes you wonder how many of them have been x-rayed, just to see what has happened to them.

'With this car, it's just the direction we carried on with. Because the performance was there, and the safety record was so good, we simply never needed to change it.'

The steel used for most of the spaceframe structure is ERW, while the roll hoop and sidebars are CDS. The chassis is also clad in stressed aluminium panels.

'We've made certain modifications to it over the years,' admits Frazer. 'ROPS [the then new Roll Over Protection System regulations] was a thing we had to go through a few years ago, but we got through that and, in the process, had the roll hoop tested at MIRA.

'We wanted to do our own [hoop] because we really wanted the car to still look the same. And for our customers, we didn't want to put a completely different roll hoop on it, because then it would require different bodywork, and so on, and more expense.'

## Budget bodywork

There isn't a huge amount of bodywork on a Jedi, and what there is is of a modular design, which is a trend with racecar builders in recent times, although the British constructor took this approach from the start.

'The bodywork is done in sections because I had a smash at Prescott in a Formula Ford 2000 once and the bodywork was all one piece, so it cost a lot to fix,' explains John. 'So, when I did this, I thought we'll have a separate nosecone, separate cockpit surrounds, everything separate. That way you don't have to replace everything if you do have a shunt.'

That said, the original car was even more basic in terms of the bodywork, being just a GRP nosecone and aluminium sides.

'Then, as we started needing more cooling on the cars, we began putting sidepods and engine covers on,' says Frazer.

As far as materials are concerned, Jedi bodies are still mostly GRP and aluminium.

'Again, it's the big carbon debate,' notes Frazer. 'You might ask why don't we do carbon wings? And people do ask us that. Well, we *can* do carbon wings. The problem is that the front wing always gets hit straight away in an accident, and aluminium wings are much cheaper to produce, which means it's cheaper for the customer.

### TECH SPEC: Jedi Mk 7

**Chassis**
Tubular steel spaceframe; built-in front end crash structure; removable foot box protection; side impact bars; anti-intrusion plates

**Engine**
Dry sumped Suzuki GSX-R1000 (K8); power: 170bhp at the wheels

**Transmission**
Six-speed Suzuki gearbox; chain drive with Quaife ATB LSD

**Bodywork**
Modular design with seven GRP elements

**Aerodynamics**
Adjustable twin-element aluminium front and rear wings; front splitter and diffuser; rear diffuser

**Suspension**
Adjustable rod end suspension with unequal length wishbones; double adjustable coilover dampers to Jedi specification

**Brakes**
AP two-pot calipers front and rear; Ferodo pads

**Tyres**
Hoosier slicks and wets

**Cooling**
Radiator and oil cooler in sidepods

**Dash and datalogging**
Carbon dash with choice of instrumentation

**Safety**
Foam moulded seat; FIA-approved, six-point, HANS-friendly harness with HANS-spec mounting points; two-way, plumbed-in fire extinguisher system

**Weight**
350kg

Jon Elsey

**The most commonly used engine for the spec F1000 championship is the Suzuki GSX-R1000… giving around 170bhp at the wheels and revving to 13,500rpm**

Most Jedis now pack a dry sumped Suzuki GSX-R1000 (K8) motorcycle engine, which produces 170bhp at the wheels

'Also, this is club racing, and who wants carbon all over the track, which can then go through tyres?'

## Engine evolution

Perhaps the biggest changes the car has seen over the years have come with the bewildering array of powerplants run in Jedis, from Yamaha TZ and R1 engines, to Honda CBR 600s, Fireblade engines and many more.

In the beginning, John had to solve the problems associated with early bike-engine cars, such as oil surge and poor pick-up, which was sorted easily enough on the original car by fitting a dry sump system.

'Not only did this cure any problems with the oiling, but also the main problem of overheating,' recalls John. 'It cured that instantly. We found we could run half the cooling system, and so we ran with one radiator instead of two.'

It's possible to fit more powerful engines into a Jedi, including Suzuki's legendary 1300cc Hayabusa, but John feels this has a detrimental effect on the car's weight distribution, and the extra power does not necessarily equate to lower lap times. With this in mind, the most commonly used engine for the spec F1000 championship is the Suzuki GSX-R1000, which Frazer describes as 'just brilliant', giving around 170bhp at the wheels and revving to 13,500rpm.

It remains pretty much factory standard, too. 'We dry sump it,' he says. 'Then, for F1000 it's a tight rule book, so basically, they're just blueprinted. You can skim the head slightly and you can port them, but you've got to have standard crank, rods, pistons and valves. You've also got to use standard cams, but you can put an aftermarket slotted cam wheel on the end, just so you can tickle up your timing a little bit.'

F1000 engines are generally put together by specialist engine builders, but the K8 unit most commonly used is becoming a little old now. Fortunately, there is a newer alternative in the GSX-S engine, which is found in Suzuki's range of sports tourers.

'It's got different cams in it, different valves and different pistons,' notes John, 'but to get the right power, you just swap all those for the K8 bits. As the rest of it is all new, you're then sort of getting a new K8.'

There are also some cars using Yamaha R1 engines in the F1000 championship, while anything goes in Monoposto. Indeed, one Jedi in that championship is competing with a BMW S1000RR unit (see RE V34N12).

## Shift and diff'

The Suzuki engines are very reliable, though Frazer says they don't like to be over-revved on the downshift, which brings us neatly to the car's gearbox. This, as with most motorbike-engine racecars, is integrated with the powerplant and it's a six-speed sequential unit. Where the Jedi differs from other similar cars, though, is in its lack of a paddle shift.

'We have had inquiries asking if we can go down the paddle shift route,' Frazer acknowledges, 'and we can do it, there are systems we know will work. The issue is what it does to performance and cost in a one-make championship.

'You can run them on hills, or sprints, even in Monoposto, but in a one-make championship, if putting a paddle shift on makes a difference to lap time, then it'll become the thing to have. But not everyone has the same budget, and you have to look after the whole group.

'If the guys with the money can afford it, but there's a portion of the grid that can't afford it, it's no longer a level playing field.'

To transmit the power, Jedis use a superbike O-ring chain, which is easily strong enough to last a season or more, chiefly because even though it transfers power through relatively wide tyres compared to a motorbike, it does not need to do so through a swinging arm.

However, it's with the differential that Jedi broke new ground all those years ago.

'This was one of the things dad did that nobody had done at the time, design a diff' set up specifically for a bike engine car,' says Frazer. 'He took a Mini diff', and that Mini diff' is used to running in engine oil in a Mini gearbox; it's part of the engine. So, you have to put a pot on that, and run it so the oil is sealed within it. The first one he did for the first car was a dog food tin! And that stayed on the car for a season. After that, we had proper machined cans.'

The current Jedi uses a Quaife ATB limited slip differential, which is ideal in such a light car with a relatively powerful engine.

'It's just improved everything, and it's strong as well,' says Frazer.

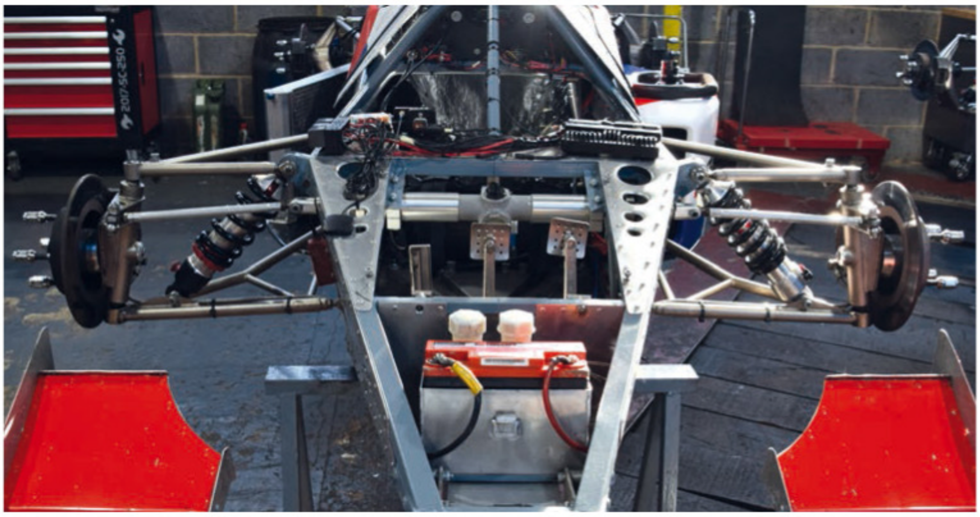
## Simple suspension

Those who race Jedis, such as F1000 front runner, Dan Gore, have told *Racecar* they're great fun to drive, and to slide, which is down to the combination of power, differential and the relatively light aero, but also the suspension. The latter is another area where Jedi got it right first time around.

Yet, interestingly, when the car first saw the light of day in 1984, it was bucking contemporary trends in suspension design by not using inboard coilover dampers. That philosophy continues to this day.

'We didn't want to do that,' says John. 'We wanted something really simple. But we do have very strong front springs set at a high angle, so they change rates very quickly… It runs on average about 700lb front springs and 250 rears. If you have a soft rear, you get good traction on the rear, while the front controls the roll.'

It is possible to go to inboard suspension with a Jedi, but again the constructor has felt no need to do so. The car works as it is, and its entire concept has always been about straightforwardness. Hence the lack of any suspension aids such as anti-roll bars.



Jedi has used outboard suspension since the car's inception. It has no anti-roll bars, relying on its stiff front springs to control roll

Jon Elsey

Rear aero comprises a centre post, twin-element wing and diffuser, but Jedis are not high downforce cars, which means close racing

Jedi has resisted the temptation to go with a paddle gear shift mechanism to keep costs down in its one-make championship. The gearbox is a stock Suzuki six-speed sequential

**'This is club racing, and who wants carbon all over the track, which can then go through tyres?'**

*Frazer Corbyn*

'You change the front springs if it's wet,' says John, matter-of-factly.

There is also adjustment available in the unequal length double wishbone suspension.

'You can adjust pretty much everything you need to,' says Frazer. 'You can adjust your cambers, toe, caster; the shock absorber is adjustable, with separate bump and rebound, and you can also use alternative springs.'

## Changing rubber

While the suspension concept has been proved to work very well over many years, there has been one fundamental change forced upon Jedi recently. This is due to the recent upheaval in the motorsport tyre industry in the UK, as detailed in *RE* V34N4.

Although it has now been announced that Avon tyres will return under new management, with no stock available at the start of the season to see it through 2024, F1000 made the decision to switch to Hoosier slicks, and early indications are that the US manufacturer has supplied a very decent tyre.

'In some ways there are areas where it's better than an Avon,' says Frazer. 'There are also areas where it's not quite so good. But the areas where it's not so good I think can be improved with very fine set-up changes, not only on the chassis, but also with how we're running the tyre.'

Meanwhile, in a bid to reduce costs in F1000, Jedi has introduced a new tyre use rule.

'We've seen situations recently where people have used a couple of sets of tyres over a race weekend,' says Frazer, 'but obviously not everyone is in a position to do that, so now you'll only be allowed to register a number of tyres per race weekend and, out of those, only four can be new.'

## Aero package

Helping to get the most from those tyres is a neat aero package which, while it obviously has a job to do, is certainly not the be all and end all with this car.

'Let's not pretend this is a full aero car. It's not,' says Frazer. 'It's a car that was built for mechanical grip. It was originally built without any wings at all but, as the car got quicker, it needed some aero on it to take over when required. So, we started putting wings on it.

'We've now got a full floor, a splitter and diffuser at the front, a diffuser at the back and fully adjustable front and rear wings. It's still as simple as it can be though.'

One of the noticeable aero tweaks, which was originally introduced on the Mk6, is the higher nose mentioned earlier, along with an underslung wing that is also a bit bigger than on previous cars. It's a very neat approach and a good way to gain additional front downforce on a small car.

Best of all, it has been developed using old fashioned engineering nous, rather than CFD. As Frazer says, 'This car has seen none of that.'

It's interesting that in Monoposto, where these cars will often nibble at the rear diffusers of F3s, it's the low drag and mechanical grip that gives the Jedi its rapid lap times, through the high straight-line speed that results. The car's relative lack of downforce also means Jedis can run close together in F1000, which produces some great racing.

Jedis have been used in a number of one-make, single-seater series over the years, including Formula 600, Formula Honda – with manufacturer support – and Formula Jedi, but around six years ago the company settled on the F1000 name. This coincided with a change of organising club from the BRSCC to the 750 Motor Club, and since then it has never looked back, with grids regularly hovering around the 20-car mark.

## Competitive cost

It's no surprise the cars are so popular, for they give phenomenal bang for buck, reaching 60mph in just three seconds and being capable of up to 150mph. All this for around £40,000 (approx. US$51,175) plus tax for a complete new car. If that's a bit much for your pocket, there are plenty of cheaper, second hand examples around, too.

Running them on a tight budget is also possible, with some owner / drivers telling *Racecar* they have completed a season in F1000 for between £10,000 and £12,000 (approx. $12,795-$15,350), while arrive and drive deals, which are offered by teams and also by Jedi itself, come in around the £30,000 mark (approx. $38,380).

It's interesting to note that it costs that much to race in the Star of Tomorrow Formula Ford 1600 series in 1984, when the first Jedi was built, which further points to how competitive the cost of racing these cars is.

Another popular option is owning the car, but having it run from and by the factory. Arrive and drive your own car, if you will.

Because F1000 is a spec championship, there is little ongoing development of the current Jedi, and the Corbyns feel this is another important point.

'As a manufacturer, the only thing we're doing by not bringing out rafts of regular updates is shooting ourselves in the foot,' says Frazer, smiling. 'But we believe that if you buy a second-hand car, or you buy a new car for F1000, or even Monoposto, this looks after your investment a little bit. You know your car is still going to be relevant, if you later want to sell it.'

Jedi, as a company, remains extremely busy, both with its work organising the championship and running cars, as well as the engineering projects it does for race teams and other racecar constructors.

With such a strong second hand market for its products, it doesn't build as many new cars these days as it used to, and a lot of the day-to-day work is spares, repairs, maintenance and service work.

Sensibly, Jedi has also made the effort to diversify in recent years, building aerospace-spec fuel cells for Shadow Microlight aircraft, for example, among other projects.

All of this is the work of a small team, just five or six heads, including fabricators, Rocky Botticelli and Frazer himself, plus former Jedi racer, Murfie Aldridge, and one or two part-time employees. Between them, they do pretty much everything, except for some of the more specialised CNC work.

**Current car has an undercut to work the front wing more efficiently. All aero development is the result of experience, not CFD**

Jon Elsey

**F1000 grids are healthy, with around 20 cars regularly lining up, thanks to the great performance-to-price ratio. Jedis can also be raced for around £10,000 a season, yet post some of the fastest lap times in the UK**

'We like to do as much as we can in house, because that way we can regulate what stock we hold,' says Frazer. 'We've always liked to rely on ourselves.'

## Jedi master?

As for the future, Jedi is aiming to carry on as it always has, building on the approach that has served it well for 40 years.

'I think right now it's about keeping everything as stable as we can for the customer base,' Frazer says. 'We've never chopped and changed the design, so I can't see the point in doing that now. It's still a quick car, and it's surviving in the modern world. There's also something a little bit retro about it, and I think people quite like that.

'The only way we would maybe change the design would be for the hillclimb side.'

Which raises an interesting question: might Jedi consider building an all-new car specifically for the hills?

'I think in some respects, for dad, there's unfinished business there,' says Frazer. 'As a company, we were hillclimbing into the late '90s, but quite early on dad recognised how expensive the arms race in that sport would become. Sure enough, there are some very high end, bespoke hillclimb cars now that have been developed for that purpose with the right budgets behind them.

**'It's still a quick car, and it's surviving in the modern world. There's also something a little bit retro about it, and I think people quite like that'**

*Frazer Corbyn*

'For us to be on a level playing field with them would take the right customer, with the right investment. But, yes, there is some unfinished business there.'

In the meantime, Jedi will continue to do what it does best, provide blindingly fast, affordable racecars based on sound principles and no-nonsense engineering.

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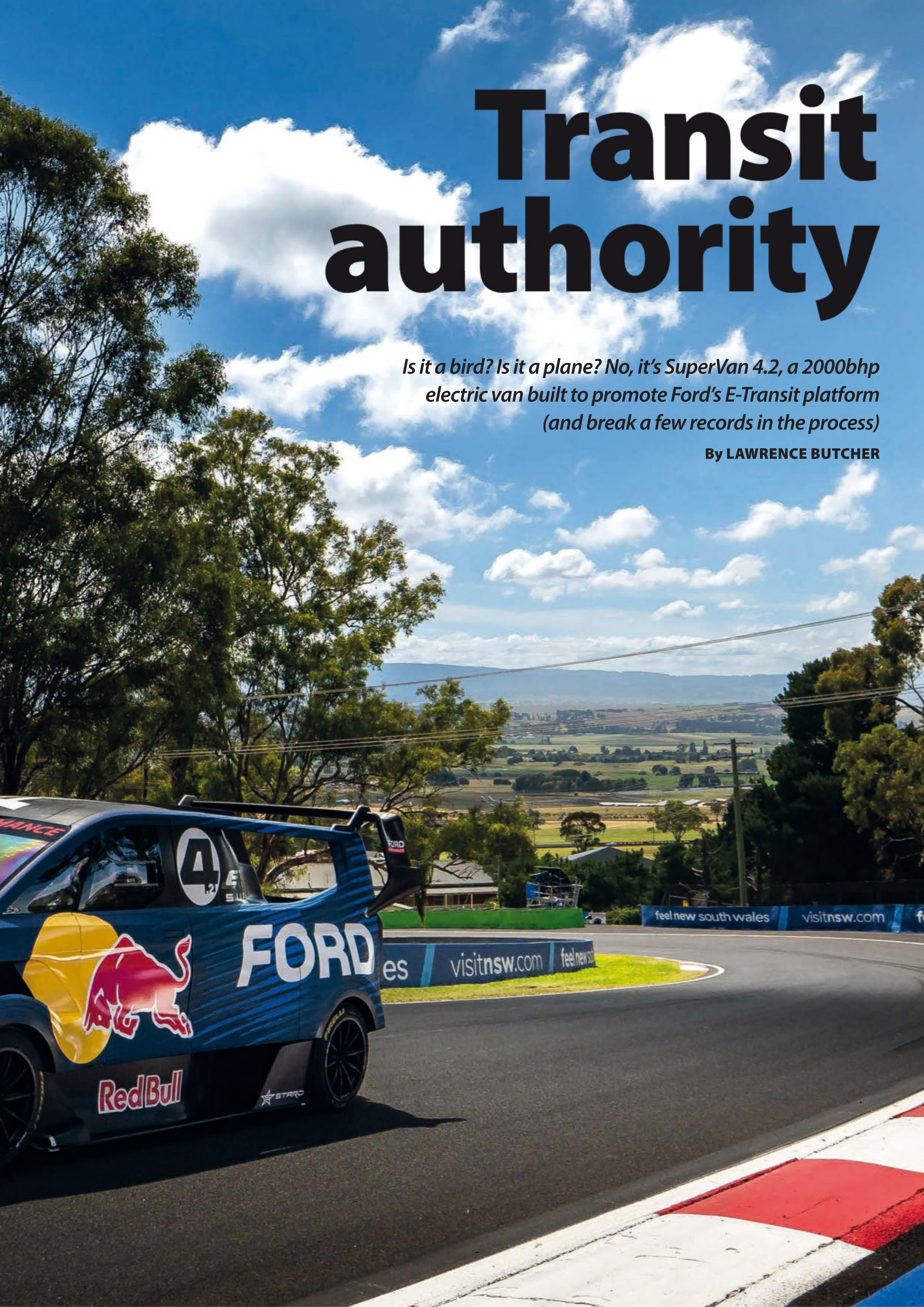
# Transit authority

*Is it a bird? Is it a plane? No, it's SuperVan 4.2, a 2000bhp electric van built to promote Ford's E-Transit platform (and break a few records in the process)*

**By LAWRENCE BUTCHER**




**The plan with SuperVan 4.2 is to attack lap records on some of the world's most demanding circuits. At Mount Panorama in Australia, Romain Dumas re-set the non-race lap record to 1m56.3247s**

The first SuperVan, built for Ford by Terry Drury Racing in 1971, was a decidedly analogue affair, featuring a tube frame chassis and the engine and gearbox from a GT40 mounted in the load area. It was used as a promotional tool, even lapping the Nürburgring in a respectable nine minutes and 13 seconds, and was a roaring success for the company.

SuperVan 2 followed in 1984, this time with a Cosworth DFL motor, and that was followed up with the SuperVan 3 in the 1990s, again using Cosworth power, this time an HB.

Following a near 30-year hiatus, Ford has upped its efforts to employ demonstration and prototype cars, both as R&D platforms and marketing tools, leading to the return of the unhinged Transit concept, SuperVan 4 in 2022.

Developed in conjunction with STARD, the Austrian-based creator of racing EV powertrains, it was based around the recently launched E-Transit, pepped up with a quad electric motor drivetrain putting out a frankly ludicrous (for a delivery van) 2000bhp.

This was a good starting point, but the company really wanted to make a statement with this evolution of the concept, and only the heat of competition could provide that. But where can you take something that doesn't fall within any recognised rule set and race it? Pikes Peak, of course.

Enter SuperVan 4.2, which took the underpinnings of version 4, turned everything up to 11 and took on the best of the rest at the Race to the Clouds in 2023.

Sriram Pakkam, lead engineer on the project at Ford Performance, outlines the company's reasoning.

'We've got all the NASCAR stuff, sportscars, Formula 1, and then you've got these EV demonstrators that we're really pushing. If you look at all the other series we're participating in, there are rule sets which vary in how restrictive they are, technically speaking. The point with these demonstrators is to take those shackles off and just let physics be your rule set. Go as hard as you can, until the limit of physics prevents you from going any further.'

## Pushing the limits

This approach has been applied to a range of demonstrators Ford has rolled out recently.

'We have eight or nine of them, all pushing in very different directions,' continues Pakkam. 'When it comes to something like SuperVan 4.2, we're pushing the limits on aerodynamics, on how you load tyres up. I mean, we're literally running out of tyre on this thing.'

Across these other demonstrators, which include the Mustang Cobra Jet 1800 electric drag car, an off-road performance version of the F-150 Lightning and the Mustang Mach-E 1400, the company is working on all areas of vehicle performance, from cell and battery pack system development to motor and inverter technology.

'In some, we play with just pushing off road suspension to the extreme and

**Ford sees its current range of performance demonstrators as test beds for pushing various areas of its automotive technology to the limits**


**Finding suitable tyres for the SuperVan 4.2 project in a very short timeframe tested the engineers at Ford's partner company, Pirelli**


**‘The point with these demonstrators is to take those shackles off and just let physics be your rule set. Go as hard as you can, until the limit of physics prevents you from going any further’**

*Sriram Pakkam, lead engineer on the Transit 4.2 project at Ford Performance* seeing what effect that has on an electrified drivetrain,' says Pakkam. 'For us, it's always to technically explore and learn. And at the same time, our engineers get to operate on the limit in some of these regimes.'

## Technology transfer

These demo cars are not simply marketing and hardware research tools, although the processes and tools the team at Ford Performance develop feed back into the production car side of the company.

'There's never a sweet, easy, bullet that says, yep, this bit came off this car and goes into this production vehicle. It's all in the details, the minutiae,' says Pakkam. 'All of us, from vehicle dynamics, the aerodynamicists and the powertrain specialists, we're all sitting together, working through the details. And all those details come together to give you a nice technology transfer.'

The plan for SuperVan 4.2 was straightforward: go out and break records. In particular, the Open class record at Pikes Peak. It smashed that goal, with Romain Dumas clocking a time of 8m 47.682s up the mountain in 2023, clear of the previous mark by 36 seconds.

In the process, the team also came tantalisingly close to winning overall.

Then, earlier this year, Ford took the beast down under and obliterated the Bathurst (non-race) record, lapping Mount Panorama in 1:56.3247, topping 180mph in the process.

'4.2 is about tackling records around circuits, taking the SuperVan 4.0, and the great level of powertrain technology we had on that, and then improving the chassis to take on stuff like Pikes Peak, Bathurst and other demanding, iconic racetracks around the world,' notes Pakkam.

For Pikes Peak, the van ran a three-motor set up, and added an additional one at Bathurst, which meant either 1400bhp or 2000bhp on tap, though the bulk of the highly condensed development programme focused more on the aerodynamics and chassis package than outright power.

First up, a diet was in order. 4.0 still retained a significant portion of the standard Transit sheet metal, which was ditched on 4.2 in favour of a full carbon jacket. The chassis also went to a full tube frame this time round. Those two modifications trimmed a phenomenal 400kg from the overall weight, or the equivalent of a ready-to-race Formula Ford from the overall mass.

## Aero scrutiny

The aerodynamics also came in for close scrutiny, as Pakkam details. 'Aerodynamically speaking, between 4 and 4.2, I know they kind of look the same but, once you look hard enough, you'll see things like the massive double diffuser and rear wings. It really has changed a lot,' he says.

'It's a very simple brief in terms of aerodynamics; just get the most you can, right?' he continues before adding a caveat. 'But at the same time, you want to add it with a good lift over drag ratio, and this is the case in all the series we do.

'Just blindly adding downforce is never going to benefit you. You need to do it at the right ratio, and right level of performance. At Pikes Peak, for example, in our simulations

**'Just blindly adding downforce is never going to benefit you. You need to do it at the right ratio, and right level of performance'**

*Sriram Pakkam*

we looked at the sensitivity to lift over drag and asked what sort of lift or drag ratio we wanted to hit. Is it 2.5:1 or is it three to one? Where does it start to really benefit?'

This is where having almost limitless power comes in handy. At 1400bhp, being traction limited is more of a concern than being drag limited. 'The difference at Pikes Peak is the total level of downforce; we could just go crazy,' says Pakkam.

However, for the Bathurst assault, this approach had to be dialled back, not because the van ran out of power, but because, as Pakkam puts it, 'the tyres are just going to blow past a certain point.'

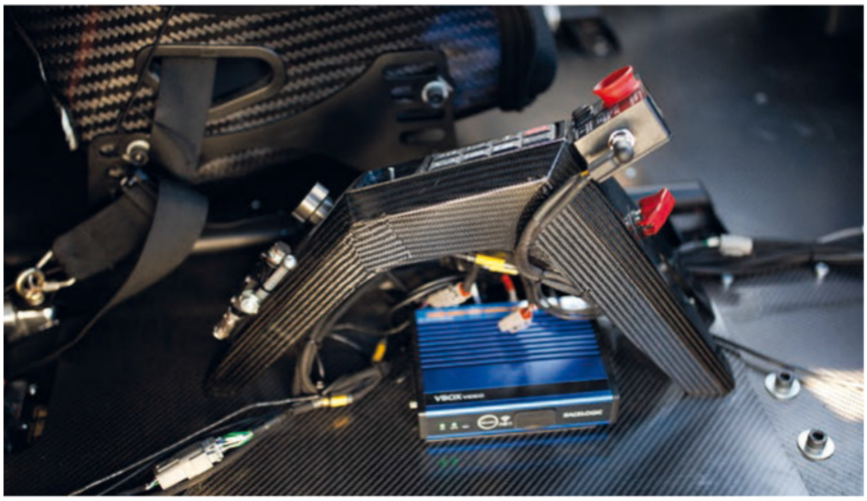
On the topic of tyres, Ford worked closely with partner, Pirelli, but clearly, developing a purpose-made tyre in such a short period of time was never going to happen. So, the engineers at Pirelli helped the team find a balance between what they wanted to do and what existing tyres could safely handle.

Development of the aero package was conducted purely in CFD, with Pakkam noting that there simply wasn't time to run the van in a wind tunnel. Fortunately, Ford has developed some robust correlation processes

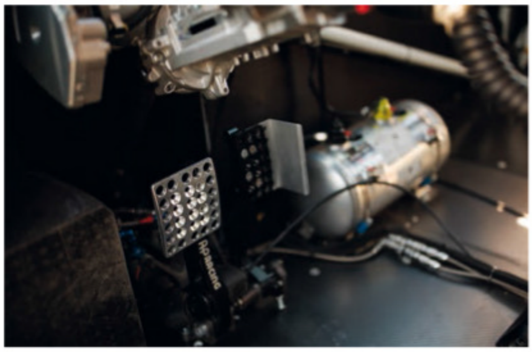

**SuperVan 4.2 is the first in a long line of Ford SuperVans to feature an all-carbon fibre body. Aerodynamics have been significantly re-booted from the 4.0 version of 2022 that it is based upon**

Depending on where it is racing, SuperVan 4.2 features either a three or four-motor drivetrain, offering the team a choice of 1400bhp or 2000bhp. Naturally, at such extreme power levels, the cooling package has its work cut out

Where previous versions of SuperVan deliberately retained major parts of the Transit base vehicle, 4.2 is an out and out silhouette machine



The whole powertrain is of modular design, so can easily be tweaked to suit different environments and challenges. Ford says it's also very tunable and uses DiL simulators and desktop physics models to validate the project's aims



EVs are ideally suited to events like Pikes Peak where instant torque response and lack of atmospheric effect on the motors pays dividends

between CFD, track and tunnel, so the team was happy to go down this route.

'We're fairly confident on that so, once we got the van ready, there was correlation work done from the track to CFD. Generally speaking, all the changes we made, like dropping or raising ride heights, wing angle adjustments, they all correlated very well.'

The benefit of working outside of a rule set also meant the team wasn't chasing absolute values, hunting for fractions of a per cent of downforce or drag. Instead, it just needed to ensure the aero was consistent.

'You just want to know that the change you're making is going to respond the way you think it is,' concurs Pakkam.

Linked to the aero package is the cooling system, which, unsurprisingly, has its work cut out. Pakkam says the heat rejection from the powertrain in 4.2 is considerably higher than it was with SuperVan 4.0.

'When you're running our sort of power level and need robustness, running at those levels with wide open throttle, you're putting huge amounts of current through the contactors and the busbars. If you don't design that right, there's a very real chance you will literally melt the contactors.

'We're running into very extreme regimes of electrical performance, and you have to design your cooling to protect from that.'

Ensuring everything stays within the right parameters is a balancing act between all the different systems. From an aero perspective, Pakkam notes that while at Pikes Peak the top speeds are relatively low, meaning drag is less of an issue, the reduction in air density as the van climbs the mountain impacts cooling.

'There is less mass flow to the coolers [higher up the track], but this if offset by the reduction in full throttle compared to running on a traditional racetrack.'

## Modular tuning

This is just one element of the equation. The way the battery cells are tuned, the discharge rates and a host of other factors are also tweaked to suit individual conditions, which is where the modular nature of SuperVan's powertrain pays dividends.

'It's highly tuneable and very modular, and that in many ways is the power of the thing,' asserts Pakkam.

An EV powertrain offers a level of flexibility it would be impossible to achieve with an ICE. 'Modularity is key,' says Pakkam. 'Targets are super important. You need to know what you are aiming to do with the vehicle, and the only way you can figure that out is by simulating around either your Driver-in-the-Loop simulator or desktop physics models. Those tell you roughly what a vehicle is capable of, so we run various scenarios on each of these things. Max power is almost always not the answer.'

Being able to switch configurations easily makes it simpler to find the right compromise from track to track, but the impact of changing layouts still needs to be considered from a whole vehicle performance perspective. For example, swapping from three to four motors changes the axle weights.

'It's a huge set of parameters we feed in, and you get this sort of Pareto frontier of the most ideal trade-off for weight vs power. When you have a modular vehicle, it's easier to get the set up you need,' says Pakkam.

Vital to finding those trade-offs are accurate models, with multiphysics battery models near the top of this list. The individual cells need to be modelled at a thermal and chemical level, and then the interactions at pack level need to be understood. Are there hot or cold spots? How close can individual cells be pushed to their limits? Does this limit change when in a pack?

All these factors, and countless others, need to be understood and then integrated into the models that run the BMS.

'This kind of thing is what the production teams are thinking about constantly,' says Pakkam. 'If you want to squeeze every last bit of power out of your vehicle, you need very strong cell modelling and understanding.

'For example, you use more energy dense type cells, which vary in how the cathode and anode are designed, on a production vehicle, whereas we go for a high discharge cathode and anode. It's just a different application of the same understanding and chemistry, and this is where going down to that level really starts to transfer across in terms of knowledge, process and methodology.'

It is notable that, while SuperVan 4.2 can happily run with a quad motor set up, the team has chosen not to go the route of using torque vectoring and instead relies on traditional mechanical differentials.

'That's where it gets interesting,' says Pakkam. 'There're various ways of using a quad motor set up; you could do it in the torque vectoring style, you could put a small differential in between. We modelled those approaches and decided instead to have the motors interlinked with an LSD type set up.'

The reasoning, according to Pakkam, is performance related, with the characteristics of a torque vectoring system less suitable for the types of conditions the van will run under.

'Depending on how out of shape you get, and the differential and speed between your left and right tyre, generally, when you're doing a torque vectoring type set up, you're essentially cutting the torque out of that side of it. Whereas with an LSD, you're transferring that same amount of torque to the wheel that has grip.'

## Maximum performance

With this in mind – and Pakkam reinforces that it is very application specific – an LSD was going to let the team, and Romain Dumas in particular, extract the absolute maximum performance from the van.

The driver's needs mustn't be forgotten and, experienced as Dumas is, what models say is perfect cannot be taken at face value, particularly in terms of driveability on very demanding tracks. Hence Ford added the ability to switch power maps on the fly.

'In the virtual world, the driver doesn't use 2000bhp all the time. They go at half throttle when needed,' explains Pakkam, 'but that's not how it really works. You can't just tell Romain to go half throttle. No, he wants the dynamics that come with going full throttle, and the way that applies the load to the tyres, even when he doesn't want 2000bhp.'

**The individual cells need to be modelled at a thermal and chemical level, and then the interactions at pack level need to be understood… and then integrated into the models that run the BMS**

At Bathurst, for example, the team had Dumas using different maps for different sectors of the track. In the tighter sectors, 2000bhp was overkill, so he could flip to a lower power setting and still have the car behave how he wanted it to, but then crank it up to full power on the faster sections.

There are, of course, a whole host of other parameters that can be played with, such as energy recuperation for just one example.

'Regen' performance comes into it, and adds a whole new dimension,' says Pakkam. 'You can change brake settings based on that because of what's possible with the combination of regen' and mechanical brakes. You can really blow up the number of settings you can tweak.'

What's next for Super Van 4.2? More record attempts are on the cards, and we wouldn't be surprised if some of the current high-profile electric vehicle records in Europe are in Ford's sights. There is also unfinished business at Pikes Peak, though for 2024 Ford will use an all-new F-150 Lightning-based concept to gun for the overall win. Maybe the SuperVan could carry the tools?


The team uses different, driver-controllable maps to get the maximum performance out of the vehicle. A lower power map was used in the tighter sectors at Bathurst, for example, where the full 2000bhp on tap would have been overkill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# Control environment


Formula E

In series like Formula E, energy is like gold. Managing it effectively is essential to success

*How the increasingly complex world of motorsport electronics is, for now at least, an open avenue of performance development*

**By JAHEE CAMPBELL-BRENNAN**

In the high adrenaline world of motorsport, the quest for speed, efficiency, and precision is part of the game. At the heart of this pursuit lies the complex and sophisticated realm of control systems – a convergence of mechanical innovation, electronic ingenuity and software sophistication. Today, these systems are integral to the performance, safety and competitiveness of racing vehicles.

The domain of control systems and mechatronics is a broad and highly developed sub-sector in the world of motorsport. From battery controllers to chassis systems, drive-by-wire to hybrid powertrain integration, control systems have become pivotal in defining the capabilities of a modern racecar.

As these systems evolve, they push the boundaries of what is technically possible and re-shape the very nature of racing.

Control systems have evolved to allow very fine, automated control of mechanical components on modern racecars.

They comprise three main components: sensors to measure the physical quantities we want the system to influence; controllers, which run software algorithms and perform the calculations to generate a control output, and actuators, which achieve a desired result.

## Control evolution

One of the earliest examples of automotive control systems was electronic fuel injection, which evolved from the trusty mechanical carburettor assembly into the complex port injection systems we have today.

Once, the driver would manually operate a choke valve to make basic adjustments to the air / fuel ratio for different conditions, such as on a cold start where a rich mixture is needed, then leaning it out when the system is up to operating temperature.

By automating this system, the task was not only removed from the driver (providing some great marketing material), but finer, more accurate control was possible.

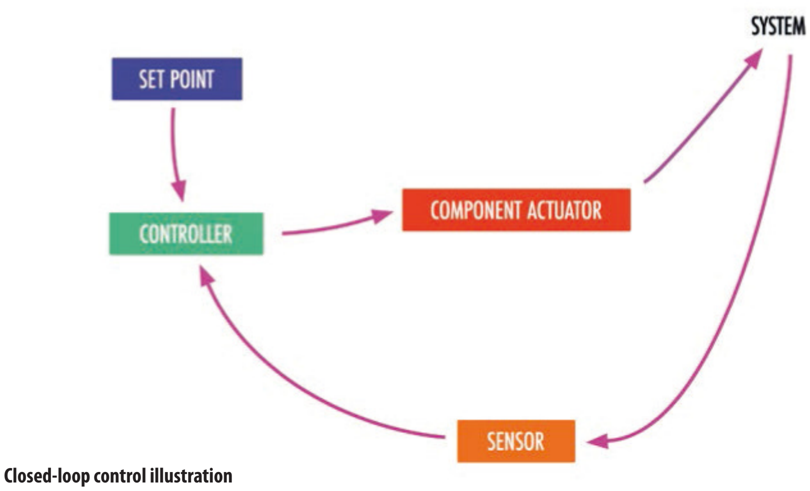
The result was fuel economy and emissions gains, a smoother running engine and an easier car to drive.

In this simple example, sensors measure things like airflow into the engine, air and water temperatures, exhaust $O_2$, throttle position and engine speed, and feed these into a control unit. There, an adjustment to injector duty is calculated from a look-up-table to alter the duration of injector spray and keep the engine in its optimal region for a given air intake.

Today, we are in an age where sensor sophistication, processing power and mechanical components offer such precision that in a modern combustion engine, dozens of control systems manage operation to maximise efficiency and performance throughout the operating range.

Chassis systems have also benefited from this technology. ABS controls caliper clamping force to maximise deceleration, while traction control ensures wheelspin is controlled at corner exits.

Wavey Dynamics




Closed-loop control illustration

**The role of sensors, particularly in the chassis and integrated powertrain systems, has evolved from mere trackside data collection to becoming pivotal in real-time decision making processes**

The proliferation of electrified powertrains has initiated a step change in this technology and not only amplified the technical challenges, but opened new avenues of performance optimisation, which, for a motorsport engineer, is where the fun resides.

In this performance-orientated environment, the role of sensors, particularly in the chassis and integrated powertrain systems, has evolved from mere trackside data collection to becoming pivotal in real-time decision making processes, providing vital data that feeds into sophisticated control algorithms and informs a wealth of choices.

These algorithms make split-second decisions on control actions, translating complex data into precise actuator responses with the goal of minimising lap times and optimising energy management, all whilst staying within new regulatory boundaries.

## Harder, faster, smarter

As we explore this dynamic world of control systems, we'll see how cutting-edge software and hardware innovations come together to create not just faster, but smarter racecars.

There are many different methods of implementing control to bridge the gap between electronics and machine, but the one thing all the techniques have in common is they all use closed-loop control.

In a closed loop, the response of the system environment to a control action is measured and fed back into the system in a correction loop until the desired condition is reached.

There are two main approaches with control algorithms. They can be reactive and generate a control output based on live observations - examples of this are PID (Proportional Integral Derivative), State-Space or Fuzzy Logic (see box out below).

The second approach, and one which is more appropriate to the complexity of

## Reactive control approaches

### PID

Proportional Integral Derivative is a reactive control strategy based on three distinct components. The first, a **Proportional** control output, is calculated based on the difference between a desired and measured condition. This correction is substantial and acts immediately.

However, this approach can accumulate errors, perhaps due to changing environmental conditions or a bias arising from sensor issues. To address this, an **Integral** component of the controller calculates an output based on the time integral of the error.

Then, to prevent oscillation or overshoot in the control action, the controller includes a **Derivative** component. This part calculates the rate of change of the measured quantity and acts to dampen the response to avoid overshoot.

An example of a PID system is in traction control. Here, the initial control output, proportional to the difference in wheel speed between the measured and expected value, is fine tuned by calculating the time integral of its error. This accounts for varying track conditions or tyre wear. Additionally, the derivative of the wheel speed is calculated, and a correction is applied to prevent overshoot and ensure stability, based on how fast the wheel speed is changing.

### Fuzzy Logic

This method of control is an approach that deals with approximate reasoning, akin to human decision-making processes, rather than precise calculations. In this method, variables are processed in degrees of truth (0.0 to 1.0) rather than in binary terms (true or false).

This makes it more appropriate in systems with high non-linearity and hysteresis, such as turbocharger wastegate actuation. Here, Fuzzy Logic can interpret varying degrees of engine parameters like throttle position, engine speed and load to adjust the boost pressure.

This method allows for smoother and more responsive turbo control over the PID method, enhancing engine performance under different racing conditions.

### MPC and Space-State

Model Predictive Control is another notable advancement in control system complexity, relative to PID, and generates control outputs in a predictive manner.

Utilising a mathematical model, MPC implements control outputs based either on first principles or through data-driven system identification, and references the model to predict a future state and control the system accordingly.

State-Space control is an application of MPC that works well in complex, dynamic systems where set points frequently change. This method has been used in engine calibration to replace the traditional look-up table approach to fuelling.

Capturing complex interactions within the engine that are difficult to quantify, predictive control can better manage the transient behaviours of an engine, like sudden accelerations or load changes, allowing for the optimisation of engine settings in real time to achieve better fuel efficiency and performance.

modern systems, is a predictive approach, where mathematical models of the system predict future states and provide control based on present observations. These are especially appropriate where measurement of physical quantities is not easy.

Naturally, such sophisticated control comes at the cost of high computational demand, and the necessity for precise modelling. That means a lot more resource.

## Complex motivator

Unsurprisingly, the motivator behind the complexity correlates strongly with the advent of electronic powertrains. This also aligns with the broader push for sustainability in motorsport, where many regulations now limit the amount of energy a racecar can use over an event, either in the form of fossil fuels or electricity.

Making best use of every single available unit of energy is not just good practice, it's a competitive advantage.

This complexity, due to complex, non-linear systems that draw from a wide range of physical measurements drives the wider use of proactive control, though often reactive strategies such as PID are integrated into these model-based strategies.

An example of this can be seen with electric motors. While simpler in parts present, they are complex in the finer details and the focus needed to get the most out of them in terms of energy efficiency and torque delivery for a given power supply.

Field Oriented Control (FOC) is a method employed to maximise this efficiency and torque across the operating range.

This control approach decouples torque and magnetic flux by controlling stator current, unlike traditional methods that simultaneously affect torque and flux by manipulating voltage and frequency.

This is crucial because the optimal flux for generating torque with the most efficiency varies at different loads and speeds.

The net efficiency gain of FOC lies in its adaptability to fine tune the motor's operation for varying conditions, from producing high torque at low speeds to maintaining efficiency at high speeds. PID elements in FOC are integral to regulate the currents required to achieve this.

This adaptability results in enhanced performance, reduced energy consumption and decreased wear and tear on the motor.

## Integrated approach

To this point, we've considered control systems on a component basis, which is straightforward in the sense that each component is operating in isolation, without having to know the states of other parts on the vehicle.

**Making best use of every single available unit of energy is not just good practice, it's a competitive advantage**

However, when multiple systems must be coordinated to both work and communicate together, an integrated approach is required.

Perhaps the most common application of this in motorsport today is in hybrid vehicles, where the total torque delivered to the contact patches of the tyres is a combination of inputs from up to three systems (the combustion engine, the friction brakes and the e-motor).

Enabling these different systems, each working with their own physical principles, to contribute to driving and braking torque in a performant, robust manner, as well as ensuring the driver feels confident to extract the maximum performance available from the chassis, is not an easy task.

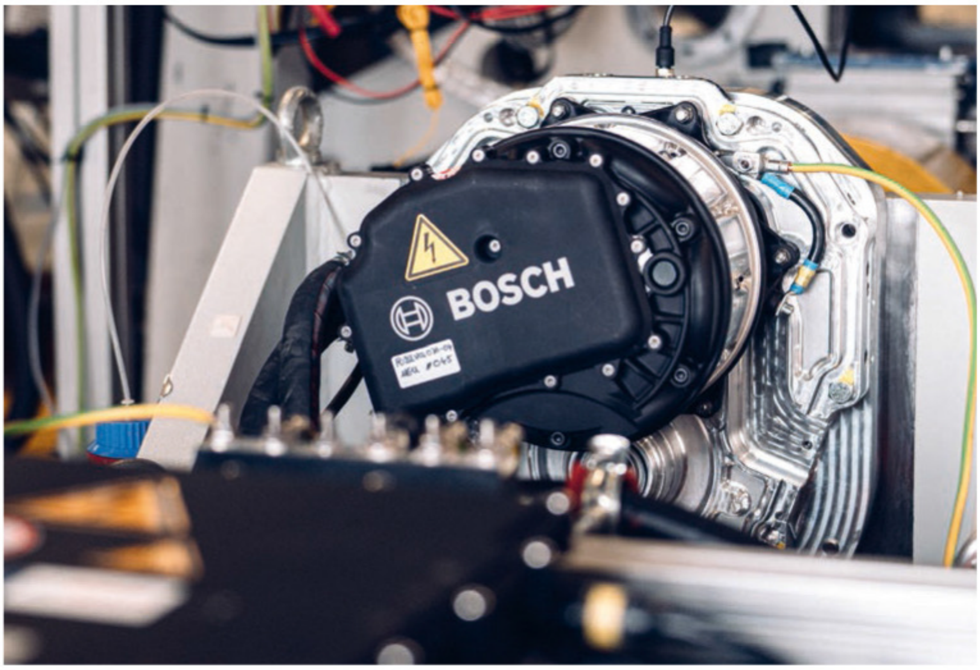
So, how do you enable these key vehicle systems to interact and communicate with each other in the same language?

The most effective method employs a torque guided structure that, at vehicle level, enables all the systems to communicate in a common language – torque.

Ferrari

**Ferrari uses a central vehicle control unit (VCU) to orchestrate torque and manage energy distribution around the 499P's many complex, integrated systems, each of which has its own controller**

Bosch Motorsport




Field Oriented Control (FOC) is a specialised strategy used to maximise the efficiency of MGUs across their entire operating range

**The torque master, or VCU, defines the set point, but it is down to single components like the ECU, or drive inverter, to ensure the torque set point is met with a certain accuracy within a particular time**

'The torque demand is the key language for communication between all the hybrid systems. This means the combustion, hybrid and braking systems are managed by defining a torque set point. This is managed by a vehicle supervisor, which is essentially a 'torque master," explains Vincent Parvaud, product manager for e-mobility at Bosch Motorsport, which supplies the spec electric motor to the LMDh platform.

Logically, this has to happen on a vehicle level, though with the oversight of a 'supervisor' to orchestrate the systems.

'The inputs to the torque master depend, firstly, on how complex you'd like to make the strategy, but also on regulations. Main inputs are throttle pedal position and brake pressure, but you could use wheel speed, yaw rate or anything you'd like to control torque and do some really nice vehicle dynamics stuff,' says Karl Kloess, system expert for e-mobility at Bosch Motorsport.

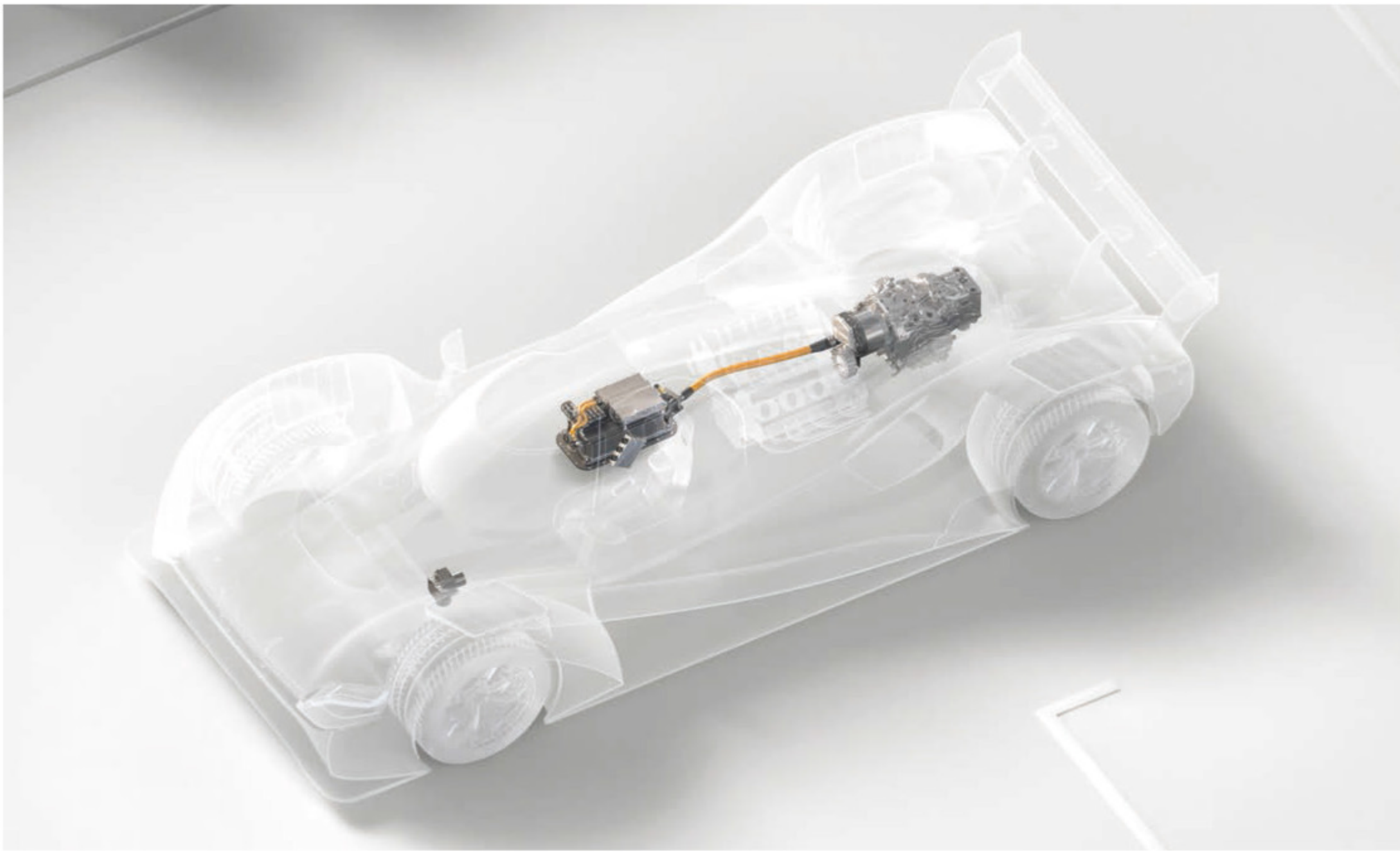
Ferrari designed its latest endurance racecar, the 499P, to hybrid LMH regulations, opting to design its control architecture in house, but following a very similar approach.

'Of course, we have a controller for the internal combustion engine, for the gearbox, for the clutch, for the voltage battery, for the electric motor, and for all the major components. The controllers are coordinated by this overall brain we have in the car,' concurs Ferdinando Cannizzo, head of endurance racecars at the Italian constructor.

'We call this the Vehicle Control Unit (VCU) and, essentially, it interprets the driver commands and merges the responses in what we call general traction and energy optimisation management.'

The torque master, or VCU, defines the set point, but it is down to single components like the ECU, or drive inverter, to ensure the torque set point is met with a certain accuracy within a particular time.

Bosch Motorsport



Hybrids in LMH and LMDh blend torque from ICE and e-motor, and regen' using a torque guided approach which enables all the onboard systems to commmunicate using a common language

Cars such as the 499P built to the LMH rule set have an additional avenue of performance over LMDh in that the electric motor drives the front wheels over certain speeds, making the cars 4WD.

Defining the torque split between the front and rear axles is a performance concern, not only to maintain the correct chassis balance, but also to ensure tyre life is maximised. This then needs to be adapted for different track conditions, phases of a corner and tyre degradation states.

'Depending on each situation, we could find this split based on the available grip and whether we are in the straight or the corner, but also taking into consideration some other elements like the state of charge of the battery, the power required, the temperature and whether we need 4WD for handling control or not,' adds Cannizzo.

These calculations are all made within the VCU, which uses a model-based approach to define instantaneous set points for its systems.

To do this, the VCU must have a clear understanding of the environment it is working in and of the vehicle state. To operate with the fidelity and constraints required, instrumentation is extensive.

## Sensor fusion

For the variables which can't be directly measured, sensor fusion is used to make inferences based on what can be measured.

'We are firstly measuring the torque output at the driveshaft,' notes Cannizzo. 'This is basically our target control, which we need to match based on the VCU's instruction. We must not over or undershoot the target the VCU is giving to us.

'We are taking into consideration the grip level, accelerations in x, y and z and we are looking at things like speed, engine and e-system state, turbocharger speeds and targets to respond in the right way in order to give the driver the best feedback to improve their performance.'

What's exciting about this level of integration is the depth of models that can be made for extracting car performance. Ferrari, for example, has implemented a real-time tyre model into the car, which predicts the vertical loads, wear and thermal state of the tyre to estimate grip and provide wheel torque appropriately.

'It's not the same complexity as the DiL model, as we need to calculate quickly, but there is a simplified tyre model to estimate grip based on certain measurements in order to define traction control, for example,' explains Cannizzo.

'If the driver tries to make an overtake on a dirty part of the track with low grip, the system needs to re-estimate, live, in order for the TC to react.'

Make no mistake, this is the cutting edge of modern racecar technology.

## Driver control

So far, we have talked about how these advances in control benefit the mechanical aspects of the vehicle, but haven't considered the living, breathing component of a racecar.

Anyone who has watched high-level motorsport in recent times will be familiar with the multitude of buttons and switches on the steering wheel and dashboard. These are another way for the driver to interface with the car's systems.

**'We are taking into consideration the grip level, accelerations in x, y and z and we are looking at things like speed, engine and e-system state, turbocharger speeds and targets to respond in the right way in order to give the driver the best feedback to improve their performance'**

*Ferdinando Cannizzo, head of endurance racecars at Ferrari*

Consequently, involving drivers from the beginning of the development cycle is smart in any project. A comfortable, confident driver is more likely to be a fast driver but, with all this additional customisation of vehicle functions, having their input feedback into the development of the car's systems is integral. Simplicity is the name of the game here. Intelligent, ergonomic design in order to inspire intuitive car / driver interface is crucial.

As you'd expect, some groundbreaking things are being done here too, with the drivers now able to modify not only the car's response to basic control inputs from the pedals, but also driver assistance, in novel and fascinating ways to suit personal preferences or racing conditions.

'We can completely control things such as the shape of the pedal curve, which alters the way in which the pedal requests torque, and the torque split between front and rear axle depending on balance

**The driver has not been entirely forgotten in the modern racecar. If regulations allow, they are able to alter torque curves, the way the throttle pedal requests torque and adjust axle torque split**

or degradation of the car. They can also stiffen or soften the front and rear [anti-] roll bars on the car,' explains Cannizzo.

'On the chassis side, with the TC system, we give the driver the ability to set up when to start controlling or cutting traction in the corner. They can also adjust the level or intensity of the torque cut and how long the cut will last, down to the specific corner.'

## Comms network

With the VCU taking information from all these sensors and exchanging large quantities of data between all the component controllers to achieve this, a strong, robust communication network is required. A combination of CAN (Controller Area Network) and ethernet lines is the best solution for this in a racecar environment.

CAN communication is robust, reliable and well suited to electronically noisy environments like motorsport, with low latency and, importantly, the ability to provide consistency in timing of data packets.

CAN allows multiple devices to be linked in a 'daisy chain' arrangement, which reduces wiring complexity and weight.

For applications requiring very high data rates, ethernet lines are more suited.

'We have around 10 major ECUs in the car, and many more smart components,' notes Cannizzo. 'In total, we have around a dozen CAN communication lines in the car.'

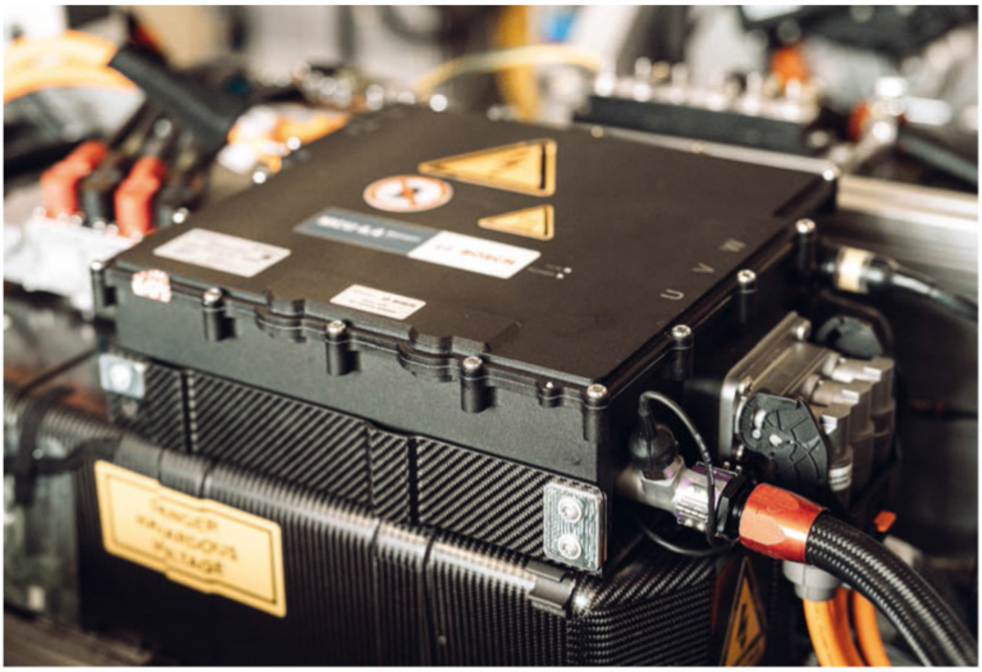
That's a lot of computing power and a lot of data bandwidth. To obtain the best solution, some specialised integrated circuits are employed in the form of FPGA (Field Programmable Gate Array) semiconductors.

FPGAs have architecture that can be configured specifically for the type of computing they will be doing, meaning they excel at parallel processing, allowing them to perform multitudes of operations simultaneously. This sets them apart from the microprocessors we find in our home electronics, which have a fixed, generalised architecture and compute tasks in series.

With such precise and dynamic control requirements, the timing and integrity of messages is crucial, which is another area where FPGAs shine. Any hesitancy or mistimed messages can bring the whole system to an abrupt halt.

The key phrase here is 'real-time' processing, which FPGA achieves by synchronising the clock cycles of each controller in the network. In a well designed system, the timing of each sent and received message is consistent and reliable.

'An interesting anecdote on this kind of system is in Formula 1,' says Parvaud. 'In the past, we had cylinder pressure sensors and we had a device allowing real-time analysis of the cylinder pressure signals for each combustion cycle.



Bosch Motorsport

**An example of one of the many electronic controllers featuring on today's high-tech racecars**

We had closed-loop control based on these signals, synchronised to be able to correct for the next combustion cycle.'

For a V10 turning at 19,000rpm, that's a combustion event every 0.63ms.

Just operating these systems coherently is one thing. Doing it better than your competitors is an edge. In short, if your algorithms are more precise, and your systems are better integrated, there are clear performance gains to be had.

## Lucrative field

Development of controls technology is also an area not currently closed down by regulations, so investing time and resources in it can be lucrative.

Ferrari's LMH programme, for example, has a controls team of 10 full-time engineers, while the VCU and control software, as well as most of the major hardware controllers for components such as the battery and electric motor, are developed in house.

OEMs and teams can also, in the case of Bosch Motorsport's experience, hand it over to the system supplier, and some clients opt to have them design the software control as well as supply the hardware.

'We are using a MATLAB / Simulink environment to develop our control structures using a model-based approach,' notes Parvaud. 'It allows us a common language with which to exchange ideas and cooperate. We can also simulate the whole system with this.'

When the software models are created, real-world verification is initially tasked to HiL (Hardware-in-Loop) testing, which allows the real hardware to be connected to a simulation environment that replicates the operational context of the system.

**If your algorithms are more precise, and your systems are better integrated, there are clear performance gains to be had**

This allows controllers to be provided with artificial sensor inputs to test how the system reacts.

In fact, the entire system can be built and run in a HiL simulation, but in an environment this complex and dynamic, it's more feasible to test individual systems or components. Because of this, the objective with HiL testing isn't so much performance development but functionality and error proofing to ensure the system can resume after a fault, for example.

Again, the CAN system is very effective, but can also be fragile in certain ways. Some of the controllers share lines so, if one of the controllers on the line sends a delayed message, or sends a message with an incorrect ID, it can commonly disturb the whole system.

Losing communication in a motorsport situation, with critical systems such as torque control or battery isolation monitoring, can mean the end of a race.

## System verification

'You need to test a number of scenarios and understand that you can get back to normal operation,' concurs Kloess. 'If the system develops a fault, you need some code in place to exit the fault and resume normal operation without resorting to a reset.'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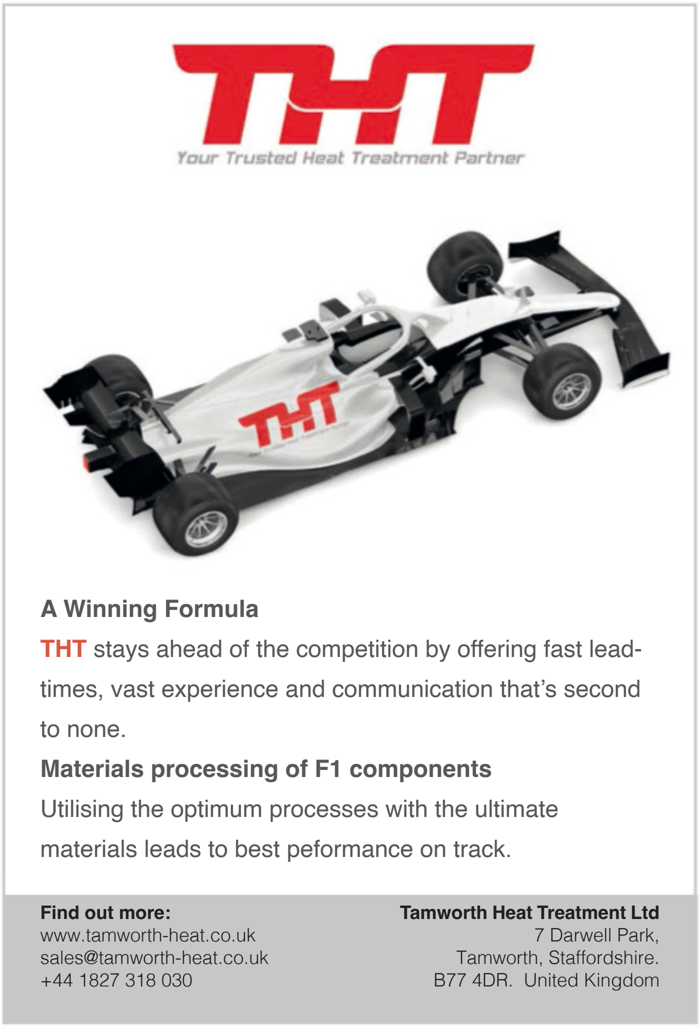
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'Sometimes there can be a few milliseconds delay in signals, which can break the whole system down. You need to test these failure cases very early in the programme with the HiL.'

To further verify functionality and robustness, organisations such as Ferrari will use a complete chassis dyno to run a rolling chassis with all the powertrain and chassis systems intact, perhaps just minus bodywork, through an endurance test to replicate the conditions encountered during a 24-hour race at Le Mans, for example.

Performance testing is usually performed on the DiL simulator, which doesn't have all the hardware, but contains all the software and controls logic required to tune the system. With today's sophisticated vehicle dynamics models, many of the dynamic conditions of racing can be captured.

Nevertheless, it is still not possible to replicate the physical world with 100 per cent fidelity in simulation, so there's a big element of physical track testing still required to provide both the system robustness and performance correlation.

Arguably, the most difficult task is capturing all the dynamic qualities of the system in the models. It's one thing to make things function on paper but, in the dynamic environment of racing, scenarios can be encountered that the system finds difficult to replicate.

'Every test or race we are learning something,' says Cannizzo. 'How to make things happen more efficiently, or how to match the function of one system to the other in a more effective way. This also has to be in a method which the driver is comfortable with.'

Retirements have always been a part of racing, but with such extensive use of circuitry in modern racecars, the risk of electrical failure or malfunction is more prevalent than ever.

## Self-help systems

A by-product of all the instrumentation and code onboard is the ability for the car to self-diagnose failures or performance degradation in its systems.

Once an error is detected, it can be handled in one of two ways. The system can be designed to self-recover, without any intervention from the driver or team, or it can alert engineers at the garage of an issue, who can then advise the driver on some corrections to make via the steering wheel.

This is where having a robust DFMEA early in the programme is essential. This allows these failures to be foreseen and mitigations incorporated to manage them with little or no reduced performance. One can only imagine the length of the DFMEA for the 499P's hybrid powertrain systems.


**Control systems must be designed to work around failures and degradation, keeping the car running at least until it reaches the pit**

'With any potential failure, our question is always the same,' says Cannizzo. 'How can we finish the race? Is there any chance to keep going, even with reduced performance?

'We always want to find an alternative mode of operation to carry on with the car to the end of the race, or at least the next pit stop.'

This is a particular area of development where machine learning is being explored with the target of helping the driver to select the right car settings in order to manage specific race phases or events.

We are still riding the wave of this revolution of controls, and there's no doubt their use in automotive control systems is only going to increase.

Further development will involve ever more sophisticated and precise models, which can handle more calculations and react even faster, and the demand for more processing power will no doubt follow.

'A clear future direction is the continued demand for additional processing power to grow the complexity of control systems. We just launched the development of our fourth-generation modules and a key improvement is in processing power,' states Parvaud. 'Each time we release a system we believe it will stay relevant for 10 years or so, but have found after three or four years we are already revisiting computational power.'

Largely out of view, these quiet but extremely powerful innovations have transformed what's at the core of top-level racing, from efficiency and reliability to performance.

**Regulations will largely dictate what future motorsport electronics will be able to influence… If we follow patterns of the past, though, as controls teams expand and grow, the investment into both engineering and software / hardware will surely be curtailed**

There's no doubt we are in a new era of automotive electronics paralleling the revolution in electrification.

And while we navigate the labyrinth of complex control systems in today's motorsport, their profound impact extends beyond mere speed and efficiency, not only re-defining vehicle performance but also safety, sustainable racing and bringing us into a new era of deeper driver / vehicle synergy.

Regulations will largely dictate what future motorsport electronics will be able to influence, and how much technical freedom will be possible. If we follow patterns of the past, though, as controls teams expand and grow, the investment into both engineering and software / hardware will surely be curtailed at some point to ensure parity among competition.

Until then, these silent but highly impactful areas of vehicle development will continue to influence races from the shadows.

# Just press print

***Racecar* investigates the current state-of-the-art in 3D printing technology and asks if AI is poised to take over the industry**

**By GEMMA HATTON**

Today's Formula 1 teams manufacture over 9000 3D printed parts each season. Yet to accurately print these components requires a whole realm of engineering practices, known as Design for Additive Manufacturing (DfAM). This is essentially the methodology behind optimising the form and function of a part to not only achieve accurate builds, but also to fully exploit the capabilities of additive manufacturing.

'When developing a part for 3D printing, you have to consider how it is orientated, the thickness of the layers and whether it is self-supporting, or requires supports to be altered,' highlights Allen Kreemer, principal applications engineer at Stratasys.

'Then you have to optimise the parameters of the printer to carefully control the bonding between the layers of powder or filament for a successful build.

3D Systems

**Formula 1 teams now 3D print thousands of parts each season, and around 70 per cent of the bodywork of a typical wind tunnel model will be additive manufactured using SLA technology**

'On some of our printers, there are over 350 parameter sets just to make filament come out of a nozzle accurately and reliably.'

There is a plethora of 3D printing technologies on the market today, but typically they fall into three main categories: powder-based, liquid-based and filament-based. Each has its own variety of associated processes, depending on the type of material and printer that is being used.

In motorsport, the predominant powder-based process is Powder Bed Fusion (PBF). This is where a roller, or blade, applies a thin layer of powder over a build plate. Lasers, or other radiant heat sources, above then melt the powder particles according to the cross section of that layer of the part.

Excess powder is removed after the printing process is complete, the build plate drops and the re-coater applies a new layer of powder on top. This process repeats until the entire geometry of the part is printed.

PBF can be used for printing polymers such as in Selective Laser Sintering (SLS) and SAF (Selective Absorption Fusion), as well as metals in Direct Metal Laser Sintering (DMLS).

## Highest resolution

Instead of powder, resin-based technologies, such as Stereolithography (SLA), Digital Light Processing (DLP) and Polyjet use a vat or injet heads filled with photosensitive resin to print plastic components. The build plate is moved precisely in very thin layers, resulting in the highest resolution of 3D printed parts available.

In the case of DLP, the surface quality achieved is comparable to injection moulding. UV lasers, DLP projectors or injet nozzles draw the cross section of the part, selectively curing the liquid. Once a layer is complete, the build plate moves and the printer cures the next layer of resin to the part.

Filament-based printers, on the other hand, such as Fused Deposition Modelling (FDM) extrude a thermoplastic filament through a nozzle, which deposits thin strands along predefined paths onto the build plate. The filament then solidifies as it cools and the build plate drops, ready for the next layer to be applied.

'Deciding which technology will achieve the best printed part comes down to a process of elimination,' says Kreemer. 'You first have to ask yourself, what does victory look like for the part? Once the customer has defined the mechanical loading, heat deflection or chemical exposure required, that often eliminates a number of processes and materials right at the start.

'Typically, we find that production parts on racecars such as body panels, ducts and brackets are best suited for FDM, while engine components are best for DMLS and scale model aerodynamic test parts are best done using SLA.

'On average, the thickness of layers FDM can print in ranges between 127 to 500 microns, whereas SLA, DMLS and SLS can print layers as thin as 100 microns and Polyjet and DLP even thinner at 14-20 microns.'

## Orientation day

The first stage of making a part ready for 3D printing is to orientate it in a way that gives the printer the best chance of building a part that accurately represents the original design.

'Certain orientations will give you a much better representation of the CAD model without having to resort to post processing after the part has been printed,' explains Colin Blain, Advanced Applications Engineer at 3D Systems.

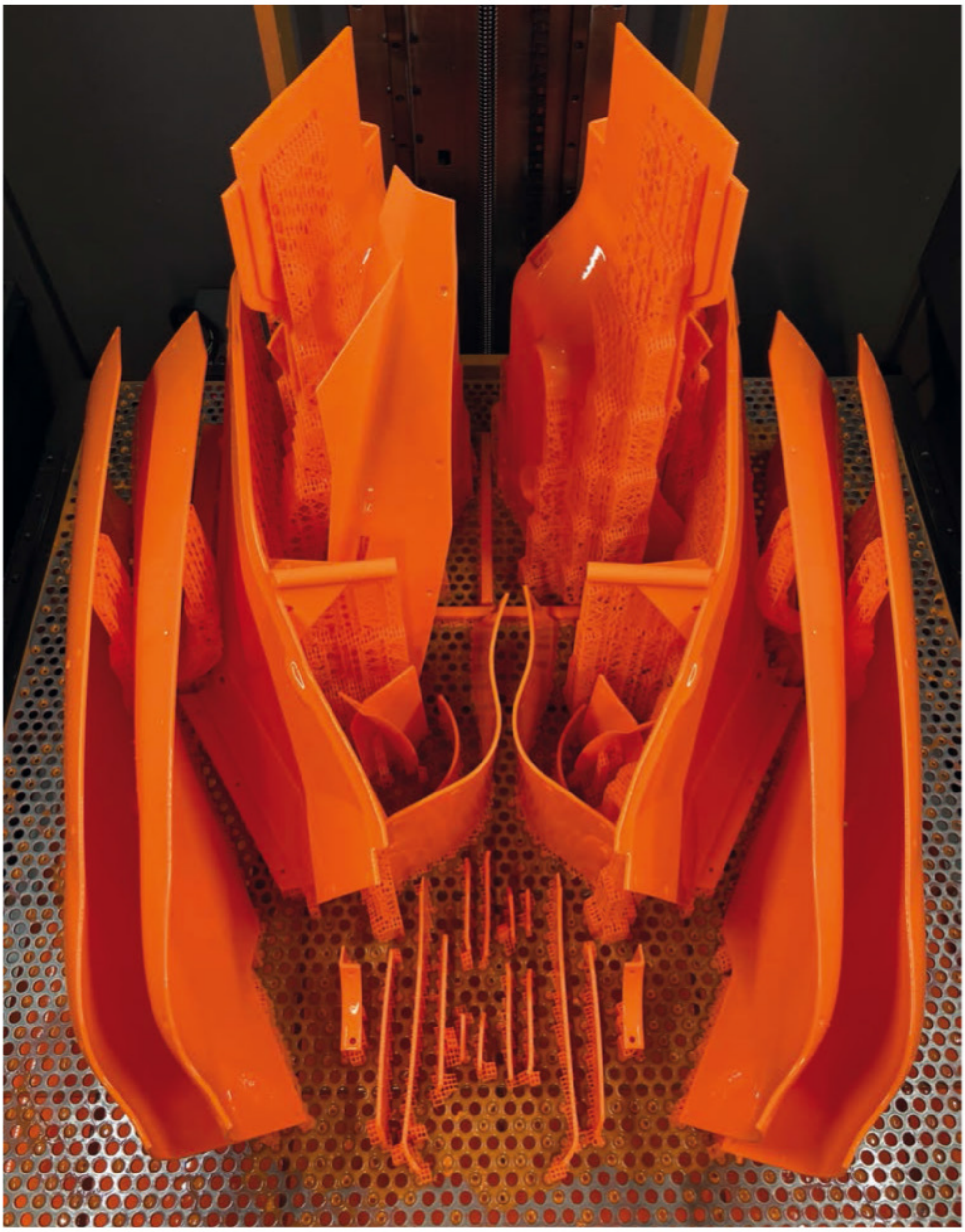
'It's similar to the contours on a map. Instead of printing shallow gradients with large gaps between the edges of the layers, you ideally want to orientate the part so the layers have high gradients, making the edges of the layers as vertical as possible.

'For example, if we wanted to print a tube, orientating this horizontally means you would have to section those curves into flat planar, 2D cross sections. Even if the layers are extremely thin, the layering or 'stair stepping' will be far more pronounced where the curvature of the part approaches horizontal. Whereas, if you orientated the tube vertically, you only have to print rings that are stacked perfectly on top of each other.

'So, the more you can orientate your layers to the vertical axis, the closer your printed part will be to your original design, and the higher the quality of the surface finish.'

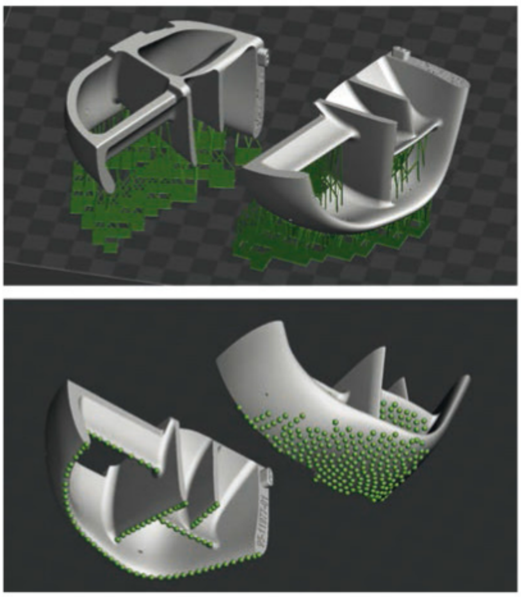
Positioning the part vertically can also help reduce the cross-sectional area on the build plate. This not only facilitates the printing of several parts in one go, but also reduces heat build up and the subsequent risk of distortion or warpage, leading to a higher quality component.'

'When determining the orientation of a part for 3D printing, it's a balancing act between reducing the cross-sectional area, managing the loading or forces in the final use environment of the part and achieving a high quality surface finish,' says Kreemer.



Stratasys

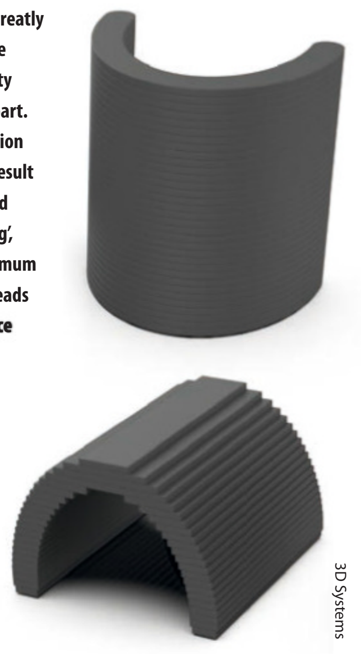
McLaren uses Stratasys SLA 3D printers to make wind tunnel F1 parts, allowing it to go from CAD to printed part in three to four days



3D Systems

The orientation of the part on the right has been optimised, requiring fewer support structures, less post processing and cleaner surfaces

Orientation greatly influences the surface quality of a printed part. Poor orientation (below) can result in pronounced 'stair stepping', whereas optimum orientation leads to high surface quality and accuracy



3D Systems

SSYS


Penske's brake caliper ducts are 3D printed on Stratasys' Neo800 machine

**'On average, the thickness of layers FDM can print in ranges between 127 to 500 microns, whereas SLA, DMLS and SLS can print layers as thin as 100 microns and Polyjet and DLP even thinner at 14-20 microns'**

*Allen Kreemer, principal applications engineer at Stratasys*

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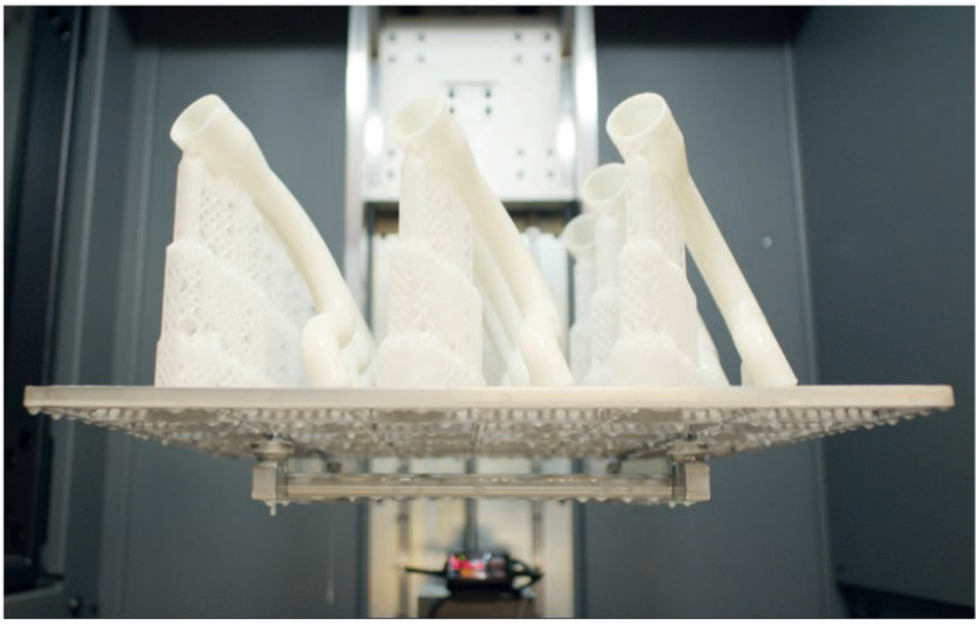


As a general rule in FDM, any features with overhang angles greater than 45 degrees to the z axis require support structures

'So, we tend to orient parts such as curved panels vertically and blockier flat parts for tooling and fixtures horizontally.'

## Support act

Once the orientation has been decided, the next question is whether the part requires any supporting structures, either internally or externally. A general rule of thumb in DfAM is that any feature with an overhang angle below 45 degrees to the z axis is self-supporting, otherwise some kind of assistance is required.

This is particularly relevant in FDM, where layers are applied on top of each other. If the layer on top is at an angle greater than 45 degrees, it will overhang the layer beneath by more than 50 per cent, causing the top layer to droop because it cannot support itself during the manufacturing process.

Powder-based technologies such as SLS, on the other hand, require no assistance as the surrounding powder bed supports the entire geometry, including any overhangs.

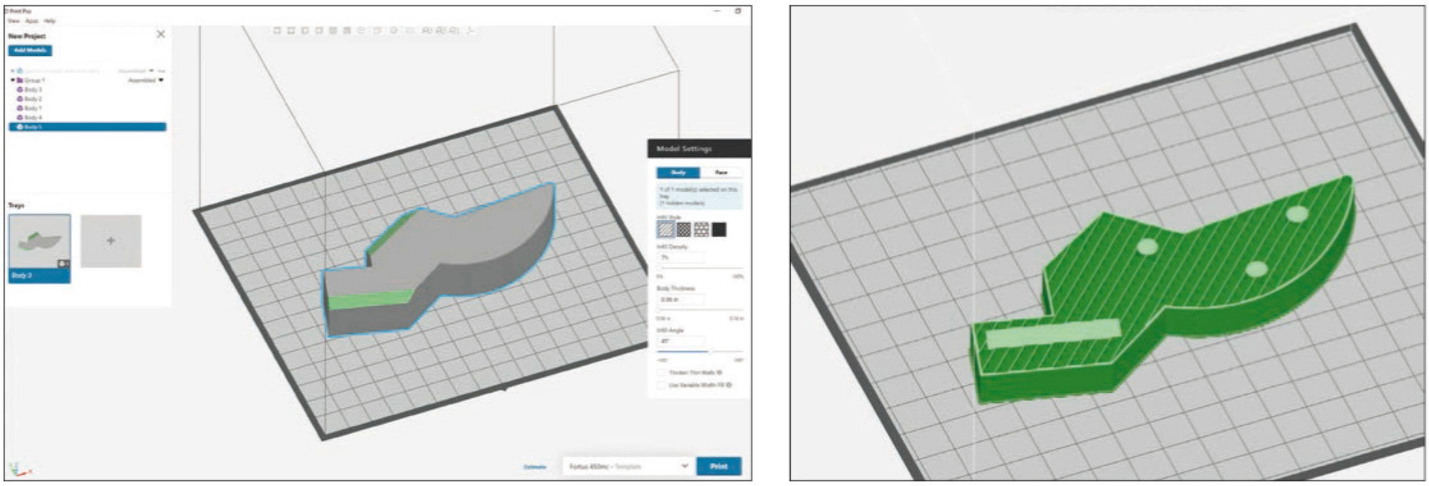
The precise geometry of these supports can be defined by intuitive software.

'Our software generates support structures autonomously based on a predefined minimum angle of the surfaces of the part,' explains Blain. 'The software also looks out for any down-facing features that come into play during the print. Any features that hang past horizontal, when sliced into 2D cross sections, will form islands that are initially disconnected from the main geometry, so we have to provide support structures for those, too.

'We can also design these supports to be multifunctional,' continues Blain. 'Often, we will have some sacrificial geometry that serves as a support structure, as well as a means of holding the component during post processing and handling further downstream – similar to the tabs in an Airfix model. These are then removed just before the part is ready to be used.'

Internal supports also need to be considered to provide the strength and rigidity required for hollow parts. These can include simple cylindrical elements supporting internal overhangs or more complex lattice structures. The latter can also be used instead of a solid interior fill, significantly reducing weight, build time and cost of the part.

'Let's say you have designed a 20mm thick part in CAD, and you want a honeycomb internal fill within the bulk of that part and some solid mounting points,' says Kreemer. 'Our software, GrabCAD Print, has a multi solid import function so, when the CAD is imported, our software remembers the locations of those solid and honeycomb regions and automatically generates your selected internal fill structure.'



Stratasys

FDM printers from Stratasys include a multi-solid import function, which automatically generates internal lattice or honeycomb support structures

**Whether it is filament, powder or resin, each material needs to be applied within a precise temperature range to ensure effective adhesion between the layers**

Conflux Technology

Conflux Technology uses Laser Powder Bed Fusion with metallic particles as small as 0.09mm to make its motorsport heat exchangers

The removal of these support structures also has to be considered during the design process as these supports need to be removed quickly and without damaging features or surface finishes.

'In the case of our 3D-printed metal heat exchangers, we are often printing intricate geometries that have fluid paths less than one millimetre wide, so we need to avoid having to remove any internal supports,' highlights Ashley Dowle, senior design engineer at Conflux Technology. 'That's why we optimise our designs to be self-supporting wherever possible.

'It's a similar consideration for powder removal. The particles of the metal powders we use can be up to 0.09mm across, and any blockages can increase pressure drop and lower the overall performance of the heat exchanger. We therefore try to design fluid channels with as straight an exit path to the ports as possible, to facilitate easier powder removal. However, with such complex geometries this is often very difficult.'

When the optimal orientation and supporting structures have been defined within the CAD model, it then needs to be sliced into thin layers, and again, this is achieved through software.

'You can vary the thickness of the layers,' says Blain. 'Obviously, the thicknesses you can print will depend on the technology you are using, but if an area of a part is featureless, there is little benefit in printing in fine layers.

'We typically define the thicknesses in ranges. So, if all the detail of a part is from zero to 20mm, we choose a layer thickness of 50 microns, for example, and then use 100-micron layers for the rest of the part.'

Once sliced, the software then sends the coordinates of each of these layers to the printer, which compiles the file and then begins the printing process.

## Temperature control

One of the most important factors in printing high-quality parts is managing the build up of temperature during the printing process. Whether it is filament, powder or resin, each material needs to be applied within a precise temperature range to ensure effective adhesion between the layers. Too hot and the material will have low viscosity, which will reduce the precision of the layers and features. Too cold and the material will not adhere and the part won't be accurate.

Once applied, the layers then need to cool and solidify at a consistent rate to achieve a tight microstructure and superior mechanical properties.

Each type of printing technology has its own specific challenges when it comes to managing temperatures. The lasers used in SLS, DMP and SLA need to be hot enough to melt the material but not too hot that the lasers destroy it. This often leads to temperatures in the powder or resin bed exceeding 2000degC (3630degF), yet there is nowhere for this heat to dissipate because the part is immersed in the powder or resin bed. This can lead to overheating and hot spots.

Over in FDM, the temperature of the nozzle needs to be carefully controlled to ensure filament is extruded at the right viscosity. If the heat at the nozzle migrates up the extruder assembly, it can soften the filament upstream, causing it to swell and create a blockage.

'Adding new hot layers, on top of already cooling layers, creates a temperature gradient,' highlights Dowle. 'Depending on the geometries and wall thicknesses being built, these gradients might be quite extreme in places, and this is where warping can occur.

'Generally speaking, it is better if the part is as symmetrical as possible, relative to the z axis, or build direction, and that any wall thickness changes are gradual. Otherwise, you may find significant warpage occurs.

'If, say, we had to build a large rectangular part at 45 degrees from the z axis, any of the larger flat surfaces may deviate from the design.

**'The evolution of the 2D printer was over a long period of time and I'd say we're 40 to 60 per cent of the way there with 3D printing'**

*Allen Kreemer*

'The down skins may also suffer from poor definition and / or porosity. This could be a problem in the end product.'

To help control temperatures during the printing process, heaters, ventilation and cameras are often integrated into the printers. Stratasys, for example, has developed a closed-loop thermal control system within its machines. Its FDM printers utilise heaters and convection to ensure the air has consistent thermal behaviour, while its powder-based SAF (Selective Absorption Fusion) technology combines an infrared camera and heaters to continuously monitor and adjust the temperature of the active print layer.

'Controlling the temperature to within a tight range is really critical for geometrical accuracy and adhesion between layers,' explains Kreemer. 'Our SAF printers use an infrared camera and over a dozen ceramic heaters in the hood assembly that sits above the active build layer. This technology jets out an infrared absorption fluid onto the powder bed, which is then exposed to infrared energy, fusing the layers together. So we know what the cross section of each layer looks like before it is fused and, by monitoring the temperature distribution, we can see if an area is getting too hot. If that occurs, we turn that heater down. If an area is becoming too cold, we turn that heater up.

'Each layer takes around 12 seconds, so this temperature control needs to have a very fast response. By keeping the temperature tightly controlled we can achieve nearly isotropic material properties that are comparable to injection moulding. It also helps guarantee accuracy and repeatability.'

## Simulated future

With simulation already automating some of the stages of transforming a CAD model into a 3D-printed part, you might be wondering how long it will be before simulation can take care of the entire process.

'In terms of pressing a button and printing, we are kind of already there,' says Blain. 'We are already using numerous pieces of software for generating supports and dividing the part into layers. In fact, for some other applications, such as for the dental industry, the data is loaded in and the parts are orientated, supported and sent to a printer without any human intervention at all.


SSYS

A 3D-printed fan used in IndyCar to cool the driver during practice sessions. The housing is printed in Nylon 12 CF on Stratasys' Fortus 900mc with a comparison between the bare surface finish (left) vs painted (right)


SSYS

The LED lenses on the Acura ARX-05 DPi sportscars were 3D printed from 2018 to 2020. Originally, these were made of cast polycarbonate, but 3D printing accelerated lead times from several weeks to just eight days

'However, a lot of the more complex parts for motorsport don't lend themselves to that and do require some human expertise,' continues Blain. 'The big shift has been in data quality and reliability, as well as the quality of the STL files from CAD, which has improved greatly over the last 20 years, so the support generation is now much more accurate.'

'If you think back to the old dot matrix 2D printers in the late 1980s, users had to set margins, indents and all sorts of printing parameters just to get a sheet of paper to come out of the printer,' recalls Kreemer. 'Now, you can hit print on your iPhone and print any document on whatever printer you want.

'The evolution of the 2D printer was over a long period of time and I'd say we're 40 to 60 per cent of the way there with 3D printing.'

The big opportunities for simulation in 3D printing lie in utilising AI to automate data processing. The algorithms underpinning AI and machine learning are ideal for iterating through large volumes of data to converge on an optimised result, and this could accelerate the task of tuning printing parameters.

'That tribal knowledge of tuning hundreds of parameters in the development lab is slow and tedious,' notes Kreemer. 'It's a necessary evil, but I don't feel it's a value add for the customer to be aware of this effort because, at the end of the day, they just want to hit print and produce a high-quality part.

'So, that's a big area of opportunity for machine learning. Parts could be put through high-resolution photogrammetry and the algorithms could analyse the geometry, surface finish and automatically tweak the parameters to improve it.'

The orientation of a part could also be another process that would benefit from AI.

'That's where I think AI could play a huge part,' says Blain. 'We're not far away from loading a CAD file and automatically printing it, but fundamental to that is the initial part orientation because that has the biggest influence on the quality of the final part.

'AI could help define optimum orientation, which might not necessarily be the quickest print, but the best for quality, whilst at the same time helping maximise production.'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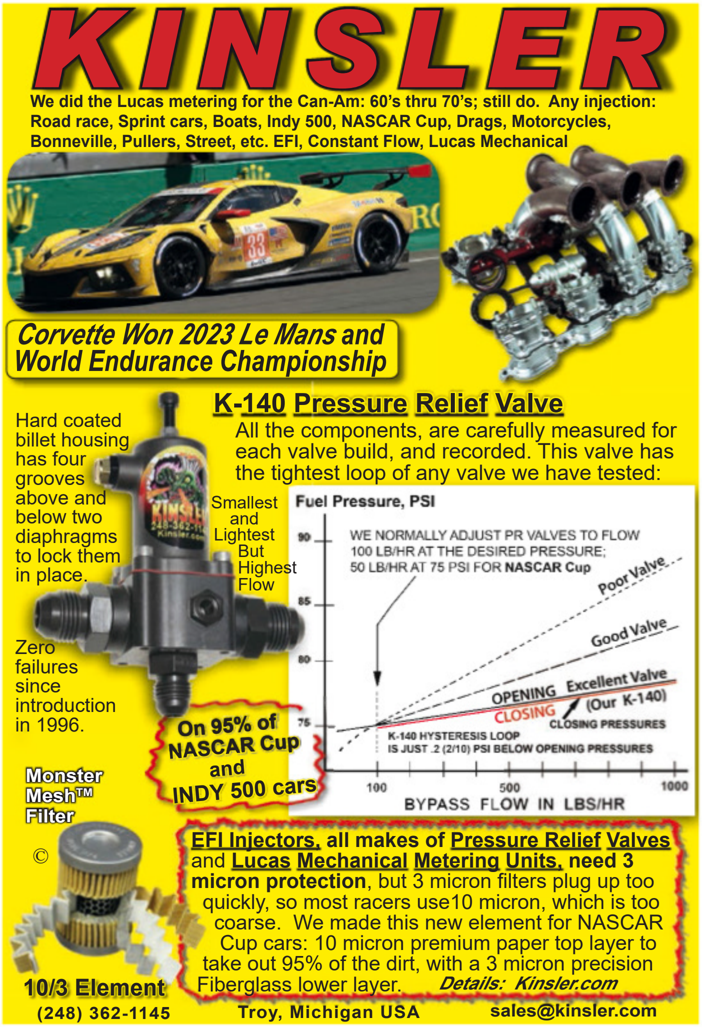
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# Spreading disease

Why motorsport must stop the insanity of ever-tighter technical regulations

By DANNY NOWLAN

XPB

F3000 in 1991, when the rule book was open and the racing grids were full. Despite what some now cite as the problems with open technical regulations, back then teams could afford to race

One of the great paradoxes of motor racing is for something that professes to be a technical sport, it has the most Jekyll and Hyde relationship with technology of any area of engineering I have encountered.

A few classic examples are Balance of Performance, which in recent years has got its tentacles into just about all forms of the sport, the dominance of single spec (or near single spec) formulae and regulatory bodies mandating competitors must run x brand of spring, damper or data system.

Add to this the second there is a processional race, the commentators wheeling out the familiar punching bags of aero and technology spoiling the show. Not only do comments like this have no basis: in fact, if not addressed, there is a very real chance they will kill the sport completely. This is what we'll be discussing in this article.

## Tipping point

The reason we are in this mess is that as costs were climbing in the late 1980s to mid-'90s, motorsport regulatory bodies started panicking. The tipping point was when the Williams Formula 1 team fielded a combination of effective active suspension and a works engine. The resident techno hysteria in motorsport immediately went into overdrive and the FIA promptly banned active suspension and traction control for the 1994 F1 season.

The other thing that emerged around that time was the concept of spec formulae, which started with F3000 in 1996, and then spread to most major open-wheel series in the decade and a half that followed.

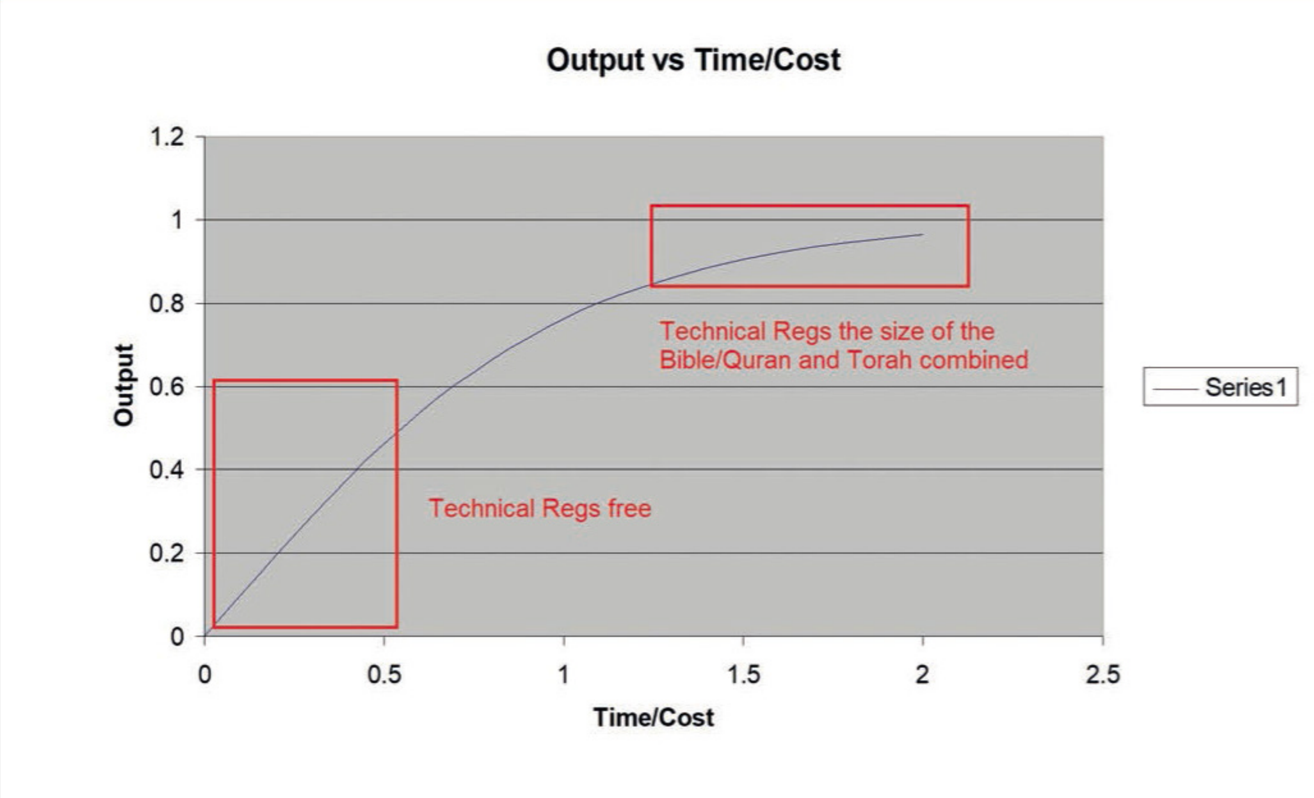
So, how did all this work out?

In IndyCar's golden era of CART and Champ Car, Penske and Chip Ganassi Racing ruled the roost. That said, there were a lot of other good operations that kept them on their toes. Fast forward the tape to now and it's largely Penske and Ganassi again at the top of the championship's spec incarnation.

FIA Formula 2 is another case in point. In 1995, the last season of the free technical era of F3000, the operating budget per car was about £600,000 (approx. US$770,000). Today, the operating budget of a typical Formula 2 team is in the order of two to four million pounds.

**A budget cap will address this somewhat, but it won't account for technical infrastructure that is already invested**

**Fig 1: Reward vs cost / time curve**




**An unintended consequence of all this is the ladder that teams previously used to move up into Formula 1 is now completely shattered**

An unintended consequence of all this is the ladder that teams previously used to move up into Formula 1 is now completely shattered. The evolution of Jordan Racing into Jordan Grand Prix, that would then eventually morph into Aston Martin Racing is most instructive here.

Eddie Jordan's team started competing in F3 in the early 1980s, and then moved to F3000 before entering F1 in 1991. The team experienced quite a few bumps along the way, but it showed it could be done.

## Series disconnect

Even as late as 1995, the things that separated an F3000 car from an F1 car were the engine, the lack of carbon-carbon brakes and details of the aero. Now, FIA F2 and F1 are so disconnected, the only things they have in common are they are both open wheelers that run downforce with $C_LA$ values of more then 3.5 and they have DRS. Consequently, the jump for aspiring F2 teams wanting to do F1 is now virtually impossible.

Need further proof? Let's put some figures to the idea that tightening technical regs is a bad idea with a cost / return / development curve, as shown in **figure 1**.

This makes for sobering reading. To go from zero to one on the time / cost axis nets you 80 per cent of the reward. But to then go from one to two brings just a 15 per cent increase in performance. What is shown here is a tanh curve, but that is pretty much standard engineering knowledge.

## Cold facts

There are some rather stark examples that represent the first part of the curve. Firstly, let's wind the clocks back to the later stages of the Cold War. The Soviet Union Fulcrum and Flanker family of jets had a fraction of the development budget of their western 'teen' counterparts (namely F-14, F-15, F-16 and F-18), yet their aero propulsive performance was near identical.

The reason was very simple. The Flanker and Fulcrum were well developed where they needed to be, but the back of the jet looked like a dog's breakfast.

A more motor racing relevant case is the cockpit X-wings that appeared on the Tyrrell 025 F1 car in 1997. Everyone looked at them and said, 'What the?!' yet it allowed a dying Formula 1 team a decent shot at getting back into the mix. Then, of course, the FIA, in its infinite wisdom, banned them.

The second part of the curve is where the big formulae are right now.

I remember spending some time with Dave Williams on the Multimatic rig in Thetford in the UK in mid-2008 (for the uninitiated, Dave was the father of Lotus' F1 active suspension, and is one of the sharpest minds I've come across in this business). He made the point that when you tighten regulations, you always end up spending more money.

## Arms race

The reason for this is shown by the second part of the curve in **figure 1**. Far from cutting costs, all that happens is the teams that have more money, and better technical infrastructure, spend more trying to figure out how to make a wing flex 2mm to pass an FIA test, yet deflect 4mm on track. And so the arms race begins.

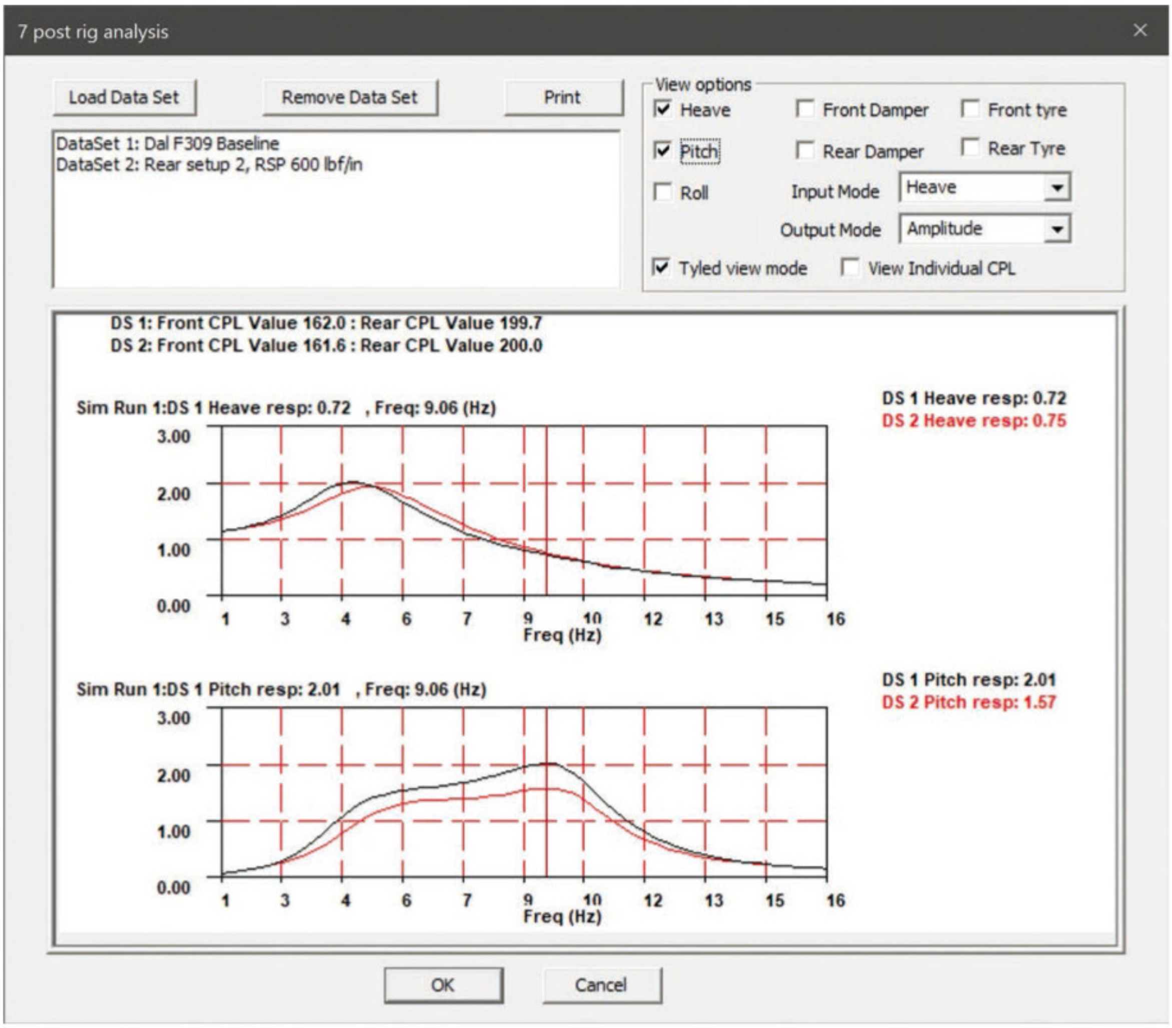
A budget cap will address this somewhat, but it won't account for technical infrastructure that is already invested.

Little wonder team principals like Guenther Steiner have given us such a colourful demonstration of the English language, because in this environment they are taking a water pistol to a gun fight.

To further illustrate the situation, let's review the validity, or lack of, introducing spec dampers us engineers cannot touch.

In last year's ChassisSim bootcamps, I gave the students a demonstration of how to use the shaker rig toolbox, a virtual equivalent of the shaker rigs you see at facilities like Sauber and Multimatic. Some of the results are shown in **table 1**.

**Fig 2: F3 bootcamp shaker rig results**




**There are options here, and for a team running in any of the mid-level formulae, these sorts of costs are not a deal breaker**

The shaker rig plot of Set-up 1 versus Set-up 4 in **figure 2** shows a stark picture. Note these different set-ups represent changes in rear damping and tweaking the springs only. The grand total of time I spent on this? Seven minutes, and another 10 minutes explaining it to the students.

**Table 1: Results of the F3 shaker rig demo**

| Set-up | CPL front | CPL rear | Cross pitch | Comment |
|---|---|---|---|---|
| Set-up 1 | 162 | 199.7 | 2.01 | Baseline |
| Set-up 2 | 162.2 | 201.7 | 1.84 | CPL worse but like the CP |
| Set-up 3 | 162.7 | 204 | 1.6 | Another improvement |
| Set-up 4 | 161.6 | 200 | 1.57 | Sell your family members and put this set-up on the car immediately |

## Common myth

This blows away the myth that tuning dampers is hard. That belief might have had some validity 20-25 years ago, but not today. The number of papers and books written on the subject by people like Jorge Segers (and me) are testament to this.

The real power of something like this, though, is to offer a mid-level team the tools required to give a front-running team a genuine scare out on track. So tell me, how exactly does this spoil the show?

The most common riposte to that is to say it's too expensive, so let's look at what you need to spend to make this happen.

**Table 2** lists some rough costs for doing this. Admittedly, a good set of four-way adjustable dampers aren't cheap (the numbers here are taken from JRI and Penske at the PRI Show when I was costing dampers for some Time Attack customers) but, believe me, they pay off.

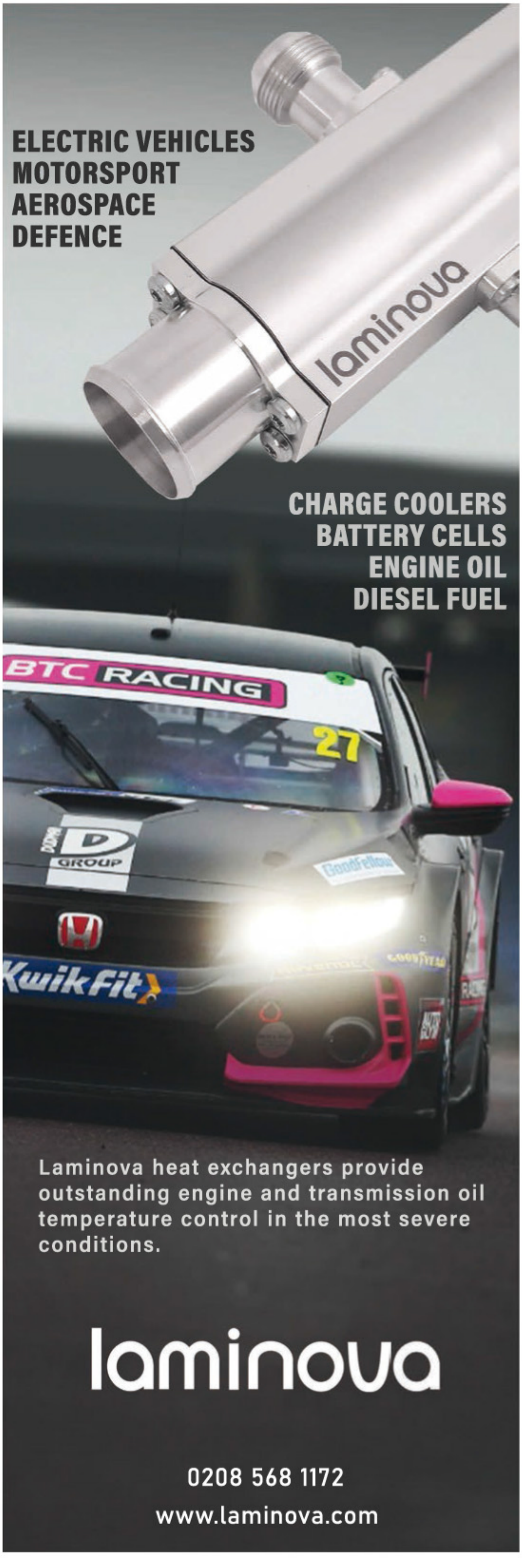
The damper dyno can be anything from a basic one like an SPA dyno, all the way to a full CTS Automation dyno.

The ChassisSim licence needed to run these calculations is based on two options. Firstly, using the online sim' and track replay. That's not as effective as the shaker rig toolbox but it will still get the job done. It only starts to become expensive when you are on a full ChassisSim licence.

**Table 2: Cost for having a free (not spec) damper**

| Item | Cost (US$) |
|---|---|
| Four-way adjustable damper | $10,000 |
| Damper dyno | $5000-$15,000 |
| ChassisSim licence | $500-$10,000 |

Still, it shows there are various options open to you here, and for a team running in any of the mid-level formulae, these sorts of costs are not a deal breaker.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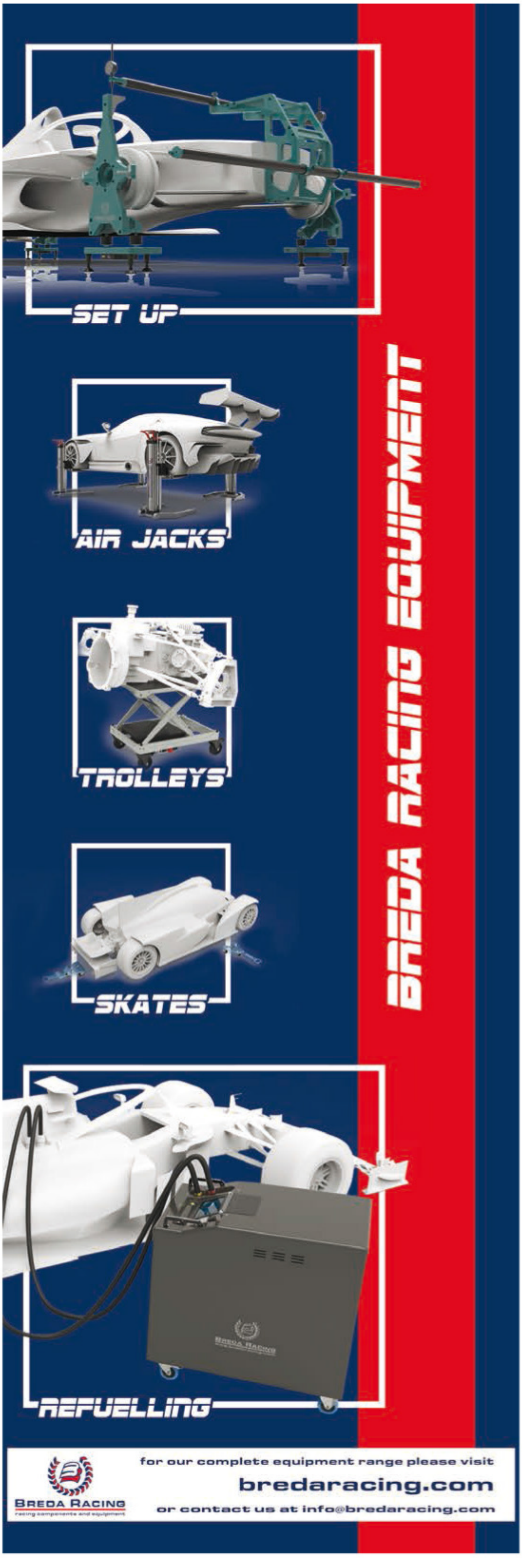
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For any club racers reading this, what I have presented here is the gold-plated option. There are cheaper dampers available and many other ways you can save money.

The point I'm making is the case for a sealed damper is untenable on multiple levels, with cost being just one of them.

## Robbing the young

The other, more insidious thing about tightening regulations is it robs current and future generations of motorsport engineers of vital training and experience. I raised this point in my article about the pitfalls of trying to slot Formula Student / FSAE engineers straight into high-end motor racing teams, but it's worth stating again here.

I came into the sport at the tail end of the era when open-wheel formulae were still relatively technically free. When I was doing Formula Ford, for example, I was playing with four-way adjustable dampers.

In my first foray into British F3 in 1998, we didn't think twice about putting cars on a shaker rig and playing with wing positions.

When I did Australian F3000, I was working with hydraulically-actuated third springs. I could go on.

Did I get it right all the time? Hell no, but the experience was invaluable, and it laid the firm foundations for where I am today.

Adrian Newey is another good example of this. Everyone talks about Adrian as if he is a living engineering deity, but if you read his autobiography, *How To Build A Car*, you'll soon realise that one of the things that makes him so good is the sheer number of racecars he had to design with only limited rule restrictions. Then he race engineered them. Experience, experimentation and then yet more experience.

## Narrow boundaries

If you look at F2, F3 and F4 today, engineers working in those categories have extremely narrow boundaries around what can be adjusted on the cars they are engineering, in terms of spring, damper and geometry choices. And don't even think about messing with the aerodynamics / bodywork.

One could contend Formula Student / FSAE can plug that gap but, as I have discussed at length in the past, the cars they are designing and working on are so unrepresentative that young engineers are in no position to go straight from their experience there into F1 or sportscars and hope to hit the ground running.

One series that does give me hope is Time Attack and hillclimbing, notably Pikes Peak. I've written about the former on a number of occasions and, if you look at money spent vs performance in that context, because the rule book is so free, it blows the myth that technical development bankrupts you right out of the water.

**Nothing replaces real experience, yet constricting the technical pathways available to young engineers by ever tighter regulations is robbing them of the ability to gain the valuable technical insight**

Time Attack also offers an exciting platform for engineers to try stuff, and the lessons learnt in doing that (and not always getting it right) are invaluable, whatever motor racing discipline you then go into.

The take away here is that nothing replaces real experience, yet constricting the technical pathways available to young engineers by ever tighter regulations is robbing them of the ability to gain the valuable technical insight that older engineers like me took for granted. Sadly, the fallout of this is something I now have to deal with on a near daily basis.

The future of motorsport relies on recognising and addressing this situation.

## IN BRIEF

**AP Racing** has become the exclusive clutch supplier for IndyCar. All 28 cars this season are using the company's CP8278 three-plate, 10-bolt clutch, which features a pull-type configuration and a cushion pressure plate designed to help with modulation.

The FIA has partnered with **AVL Racetech** for the Austrian firm to become its official vehicle simulation software supplier. FIA chief technical and safety officer, Xavier Mestelan Pinon, said AVL's software plays a 'pivotal role' in developing technical regulations, facilitating circuit homologations and analysing future technologies.

**Audi** is completing a takeover of Sauber Group, purchasing 100 per cent of the shares in the Swiss company and signalling its intentions to push on with its 2026 Formula 1 entry.

Andreas Seidl will be Audi F1 Team CEO, while Audi technical chief, Oliver Hoffmann, will become head of the Sauber board and Audi Formula Racing's shareholder committee.

**Lamborghini** announced the sudden exit of its motorsport director, Giorgio Sanna, in March. Sanna had been at the helm of the Italian marque's racing activities since 2015, overseeing its growth in GT3 and its prototype debut with the SC63 LMDh. Lamborghini's chief technical officer, Rouven Mohr, has stepped into the directorial role on an interim basis.

**McLaren Trophy** will expand to North America with a new regional series in 2025, following two seasons in Europe. Fellow British manufacturer, **BAC**, has launched what it calls the world's fastest single-make series, using a race-prepared version of the Mono. Races will take place in the Middle East this winter.

As reported in last month's issue, **Nova Motorsport** has acquired the assets and brand licence to produce Avon racing tyres. It has obtained residual stock from Avon's former owner, Cooper Tire, and plans to introduce an updated range in the second half of this year.

# FIA full steam ahead on liquid hydrogen

**The FIA will concentrate its** sustainable powertrain efforts on the promotion of hydrogen stored in liquid form.

After the first FIA World Motor Sport Council meeting of the year, the global motorsport body gave further details on its preferred strategy of implementing hydrogen technology as it tries to reduce motorsport's carbon emissions.

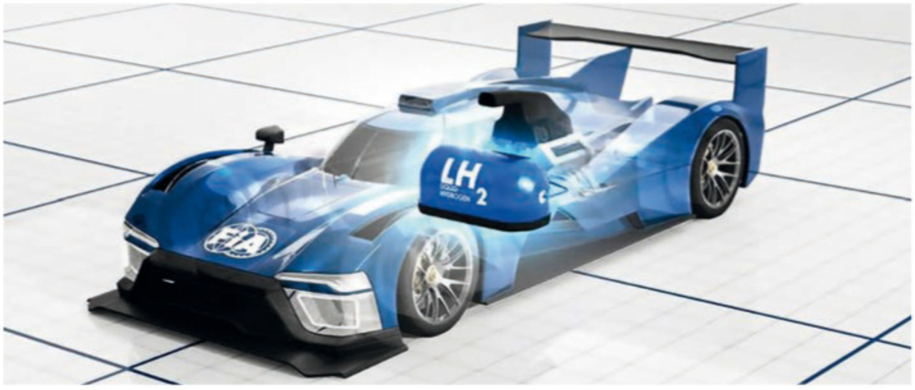
It is looking at liquid hydrogen (LH2) because of the lower volume and weight of the storage tank vs hydrogen stored as compressed gas. The FIA deems LH2 storage to be 'better suited to the demanding environment of motorsport competitions, where optimisation is key.'

Liquid and compressed gas are the two main types of mobile hydrogen storage, but there is no global consensus on which is best. Hydrogen has a low volumetric energy density, so it needs to be liquefied or compressed to be stored in a racecar. Its low boiling point (-252.9degC) means that any liquefied storage system must withstand very cold temperatures.

Despite pressing on with LH2, the FIA will keep looking at compressed gas hydrogen storage on the side, as long as 'minimum safety and technical requirements are met.'

An FIA technical working group has been active since 2019 to explore hydrogen regulations and safety with manufacturers. Last year, an independent think tank was set up between Extreme H and Formula 1, which was described as a 'welcome addition' by FIA chief technical and safety officer Xavier Mestelan Pinon.

'One of the missions of motorsport is to serve the automotive sector and, for this reason, the more forums there are [for stakeholders] to exchange know-how the better,' he said. 'This is something that will drive research and development forward, benefiting motorsport, mobility and, of course, the environment.'




FIA

The FIA is putting most of its focus on hydrogen stored in liquid form as it aims to develop more sustainable racing

# All-new technical triumvirate at Alpine

**Alpine has re-structured its** Formula 1 technical team after two key figures resigned. The Renault brand confirmed after a lacklustre season-opening Bahrain Grand Prix that technical director, Matt Harman, and head of aerodynamics, Dirk de Beer, were leaving to 'seek new challenges' elsewhere.

Alpine entered the 2024 season hoping its A524 car would spur a push beyond the midfield like McLaren and Aston Martin last year, but the team failed to score points in the first two races.

Alpine's re-structure divides the technical director role into three positions. Joe Burnell leads the engineering sub-department, while David Wheater oversees aerodynamics and Ciaron Pilbeam heads up performance.

XPB

Matt Harman had been part of the Enstone structure since 2018, having moved there from Mercedes. De Beer joined Enstone in late 2019

All three were already working for Alpine, which is based across facilities in Enstone, UK and Viry, France.

'We have decided to make these organisational changes as we can clearly see that we are not where we want, or need to be, in terms of performance level, so it is time to take another step in terms of organisation and people,' said Alpine F1 team principal, Bruno Famin, who thanked Harman and de Beer for their efforts.

'The new three-pillared structure with three technical directors, each specialising in different areas, will bring better work and collaboration across our technical areas and contribute to delivering performance from the factories to the racetrack.'

Adding to what has been a disquieting period for Alpine's F1 programme, former team consultant, Bob Bell, has joined Aston Martin in a new executive technical role.

# Le Mans limits LMP2 gear ratios

**The 24 Hours of Le Mans will** mandate a single set of gear ratios for LMP2 cars at this year's race, after previously allowing teams to choose from different options.

A handful of teams, including Inter Europol Competition and Prema, used shorter gear ratios last year to improve the acceleration of their Oreca 07s.

A bulletin from the FIA and Le Mans organiser, the ACO, confirmed that 'set 3' will be the only permitted gear ratio package this time around. *Racecar* understands this set was the longest of the three permitted in the past, while the reason to implement a single, common package was made to ensure greater parity in the field, which consists of privateer teams. The bulletin mentioned stratification between Hypercar and LMP2, however this was not part of the thinking for limiting the gear ratio options and was instead related to other technical parameters.

Inter Europol team manager, Sascha Fassbender, feels the move will 'take a little bit of freedom away' from competitors.

'Teams can use this as a successful tool,' he said. 'If we go more to a 'stock' car, it takes away the inspiration of the teams that they have in setting up the car.

'But we take it as it is, and we will try to defend our title.'

For stratification, cars will continue to run with 35mm air restrictors linked to the Gibson V8 engine. There is still a rev limit of 8000rpm in the first five gears and 8500rpm in sixth, plus a 75-litre fuel capacity and 950kg minimum weight.

When it was a full-time class in the FIA World Endurance Championship last year, LMP2 had a 63-litre fuel tank at races outside of Le Mans.

There are 16 LMP2s at the 24-hour classic this summer, all of them Orecas using the same Xtrac six-speed sequential gearbox.


XPB

**Polish team, Inter Europol, won the LMP2 class at Le Mans last year and was one outfit that used the option of shorter ratios in the race. For this year's competition, all cars will have to run with the same ratios**

# IMSA rolls back on BoP approach in GTD

**The IMSA SportsCar** Championship reverted to its original approach to Balance of Performance in the two GT Daytona classes after the season-opening Daytona 24 Hours. That race saw IMSA introduce a new system that tried to find common performance targets between the various GT3 cars.

However, after discussions with the car manufacturers, the sanctioning body re-took control over setting the BoP parameters ahead of the 12 Hours of Sebring.

In December, IMSA held a test at Daytona where it organised run plans for each car to gather data. It then shared that data with the manufacturers, which were given a say in setting their cars' performance targets for the Roar pre-event test and the race itself.

A total of 11 meetings between IMSA and the manufacturers have taken place since August.

'The OEMs felt that carrying on in a manner [of] working towards the common performance targets would prove to be difficult, particularly as there was no opportunity to conduct a Sebring sanctioned test,' said IMSA's senior technical director, Matt Kurdock.

'IMSA took some of the 2023 data, in combination with some of the Daytona data, and devised a BoP solution for Sebring that combined those sources with trying to hit a common performance target.'

The reverted BoP approach is likely to continue at the rounds after Sebring as IMSA seeks to ensure stability in its performance balancing task. It is unclear if the system trialled at Daytona will return.

'IMSA's goal is stability in the Balance of Performance process,' Kurdock added. 'Once we get to more of our traditional circuits, we feel that we can enter more of a rolling BoP process where we're not having to invent a clean sheet BoP race to race. [Instead] we're able to make small performance adjustments based on demonstrated data from Sebring and beyond.'

Racecar engineering

Inside the world of modern motorsport technology

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# To be or not to be?

## The ongoing case for, and against, hybrids in motorsport

The recommendation by the FIA to drop hybrids from the World Rally Championship in the middle of a rule cycle is a strange one but, at the same time, long term one that can be understood.

On the face of it, the teams have been busy managing the technology in competition, the FIA has mastered the safety aspects and the manufacturers have what they wanted: a car that carries similar badging to their products sold on the road. But not the same technology, of course. What's needed in competition bears little resemblance to what's needed on the run to the shops, but at least the manufacturers involved can claim they race what they sell.

However, the decision is worth more than that. It needs to be as there are contracts in place with the supplier, and the manufacturers who based their costs on developing hybrid over four years, not two, and now will have to optimise their cars without the electric energy. It remains to be seen how they react and whether or not they accept the FIA's recommendations. With only Ford, Toyota and Hyundai competing in the top Rally1 class, there needs to be a closer association with the Rally2 cars, drivers, and teams.

The FIA has an eye on the Citroëns, Skodas and Volkswagens that compete in Rally2. The hybrid systems took the Rally1 cars too far away from the other categories and so dropping it makes sense. The question is what now happens to Rally2? The cars are popular: Toyota recently launched a new GR Yaris for the class, M-Sport has sold hundreds of Fords and Hyundai has sold 90 units of its i20 N models. Will a silhouette Rally2 car be as popular as the current one?

### Majority decision

Hybridisation of Rally1 also threatened the customer racing departments, which have relied instead on Rally2 sales. As we have written in previous articles, the hybrid system was not yet perfect and teams have had to find work arounds.

Losing it is therefore probably a welcome decision for those that are running the system in competition. For the manufacturers, though, it's a different story. As David Richards points out on p32, the decision to drop hybrids was not unanimous, but was agreed by the majority.

Such a major technical regulation change during a rules cycle is never going to be universally popular. Hyundai, for example, stated that it needs to 'conduct a deep dive into our short and mid-term plans' after initially setting up its programme around a long-term hybrid investment.

WRC cars of the future will be lighter in weight, easier to build, safer and just as fun to watch. They will also carry good credentials for the environment, with less complication and producing less $CO_2$ per kilometre than cars of even five years ago, thanks to the sustainable fuel that will be used to power them.

While the WRC long-term planning department put all this into place, the British Touring Car Championship's boss Alan Gow stated in an interview with *Autosport* that his series would not be changing its position on hybrids within the current rule cycle. That caveat does leave the door open to drop hybrid systems in the future if necessary.

**What's needed in competition bears little resemblance to what's needed on the run to the shops**

### Masters of technology

As for the drivers, they are quite capable of driving the hybrid cars to their limit, and across the sport it seems they are quickly able to understand what they are doing. It took F1 teams years to master the technology, even with their huge budgets, while it has taken sportscar teams longer still. They are now there, helped by simulators. If teams had to rely on track running only, they may well have had a problem.

That's why a driver like Oliver Bearman was able to step up to Ferrari's F1 car in Jeddah. He is used to driving hybrids on the simulator and, despite only limited real world track testing, delivered a point-scoring debut which was as much a testament to the virtual world as to his maturity.

On a side-note, Formula 1 will have to be careful when it goes to a more powerful hybrid system in 2026. Once that technology is mastered, and reliability rates are as high as they currently are, there will still need to be a marketing case for this expensive technology, and we can then all focus on that, rather than WhatsApp messages. At the moment the technology is reliable. It's rare to have a hybrid or battery failure, and we are more focused on power games of the boardroom variety than on track.

That said, during a discussion around the benefit of hybrid systems to the LMDh cars that compete in the WEC and IMSA, there was a slight hesitation from one of the engineers. 'Why don't you highlight the efficiency of these cars compared to the old DPi cars that raced in IMSA from 2017 to 2022?' I asked. 'There isn't a benefit,' came the reply. 'The cars are heavier, faster and less fuel efficient. The fuel that goes into them is better for the environment, but they drink plenty of it.' Clearly, there's still work to do.

**ANDREW COTTON** Editor


180 MPH WITHOUT MOVING AN INCH