EXTREME E Tracing the evolution of electric off-roaders over three years

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Inside the world of modern motorsport technology

Racecar engineering™

BMW GTP goes global

US endurance challenger in the spotlight as World Championship beckons

Pikes Peak

A deep dive into David Donohue's epic Porsche

FORMULA 2
FIA unveils Dallara's next generation single seater

ASTON MARTIN F1
We chart the rise and fall of British team's season

HYBRID DRIVE
What it takes to keep batteries and motors cool

Top Fuel driver, Mike Salinas, made history when he became the first racer in NHRA history to reach 300mph by the 1/8 mile mark at zMax Dragway in North Carolina in September

NHRA

Flying machines

Aerodynamics has a great deal to answer for in terms of racecar development

Aerodynamics has fundamentally changed the way we think of racecars. From the initial spoilers and pylon-mounted wings of the 1960s to the multi-million pound aero departments in all the current F1 teams, aerodynamics has become an increasingly important part of racecar development.

The first goal was to give the vehicle some added load on the tyres to allow it to corner faster without adding mass. This was reasonably easy to achieve with large wings front and rear.

The next step was to make efficient downforce with very little drag penalty. It was during this time that the lift-to-drag ratio became common parlance amongst racecar designers and race engineers. L/D became the ultimate goal to extract performance from racecars with downforce.

My experience was mostly with sportscars, which have two major benefits over open-wheel cars. Firstly, they tend to have a larger plan area than formula cars and don't suffer anything like as much interference from the big rotating masses that are the wheels and tyres.

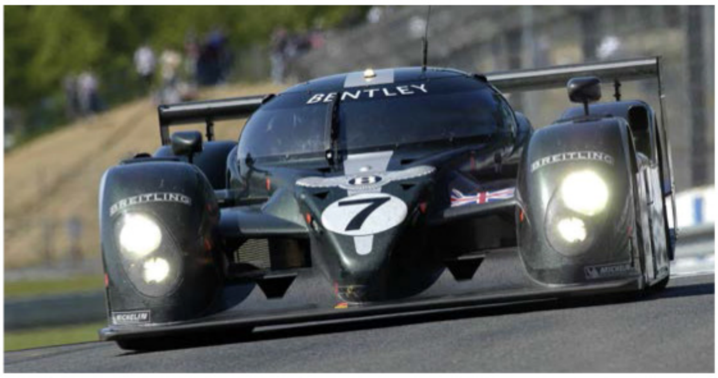
With the advent of skirted F1 cars, L/D numbers reached a peak with the six-wheel Williams car reputedly having a figure exceeding 11. Given that, it is easy to understand why the regulations were swiftly introduced to limit downforce, and so the age of the 'flat-bottomed' car was born.

Group C

In sportscars, the Porsche 956 was a very successful car using modest ground effect to dominate the first years of the Group C era of the early 1980s. The arrival of the Tony Southgate-designed Jaguar moved the game on, both in terms of its all-composite construction and its aerodynamic performance. With L/D figures reaching into the fours and a strong and safe chassis, it was a further progression, despite the car's huge, heavy, high c of g, production-based V12 engine.

When the regulations mandated a 3.5-litre atmo' engine in Group C in 1991, aerodynamic evolution continued apace, with L/Ds into the sixes with the Toyota and Peugeot cars of '92 and '93. This was mainly due to work on front diffusers and their exit tracts aft of the front wheels. The 750kg weight limit made them very quick, even in comparison with F1 cars. Indeed, in early '92, a Toyota TS010 went around Monza inside Senna's F1 lap record of the time.

Those cars were banned the following year and the era of flat-bottom sportscars began. It was possible to get reasonable downforce from sportscars that had a flat bottom between the axles, but there was one unexpected side effect. Designers and engineers had been spoilt by the benign behaviour of the ground-effect cars creating effectively a single 'pool' of low pressure under the car. This gave the drivers a very big 'working window', in today's F1 speak.



The flat-bottom cars exhibited low pressure areas front and rear, and Peter Elleray's 2003 Le Mans-winning Bentley increased the size of these areas to improve its 'operating window'

However, when increasing amounts of low pressure began emerging at either end of the cars, both with serious ride height sensitivity, pitch sensitivity became downright dangerous. No more graphic demonstration of this was the flying Mercedes cars at Le Mans in 1999.

Bentley designer, Peter Elleray, was very aware of these instability issues when he penned the 2001 Le Mans EXP Speed 8, and I was sitting on the sportscar working group at the FIA during this period as we formulated the safety changes that came into the sportscar regulations in 2004.

Martin Brundle said after first driving the Bentley early in 2001 that the car really had a sweet spot, but that it was very difficult to stay in it. So Peter started to look at ways he could give the drivers more consistent, powerful downforce over a larger range of pitch, roll and heave conditions. This was known inside Bentley as aerodynamic torque.

The Bentley EXP Speed 8s of 2001 and 2002 did have good downforce, but it was very dependent on the exact attitude of the car on the circuit. As with all cars with a low front diffuser, this was ride height dependant, and was most powerful as the car braked at high speed. The tyres and suspension squashed, and the diffuser throat moved closer to the ground. This, in turn, moved the centre of pressure forward, so the 'split shift' was forward under braking, which was in a direction the drivers really didn't want as the weight transfer was already adding tothe front tyre load.

The aerodynamics of the 2003 Bentley Speed 8 was a game changer. Whilst it increased the L/D compared to the EXP Speed 8, it retained virtually all its downforce in all the attitude conditions seen on the circuit. It was the first closed-top car to use both side and top exits from the front diffuser, and the careful blending of the airflow aft of the front wheels to both cool the car and provide clean flow to the rear wing marked a step change in its on-track behaviour.

The trick of getting the rear diffuser to stall on the Mercedes F1 car to reduce drag, which occurred towards the end of 2021, was something the EXP Speed 8 had used two decades earlier. This time it was not to reduce drag, but to semi-stall the front diffuser under heavy, high-speed braking to promote a rearward split shift and vastly increase the car's stability under braking.

Despite a reduction of 10 per cent on the air intake restrictor at Le Mans in 2003, the new car was up to five seconds per lap quicker in real race conditions than the previous year.

Thirteen years on from the ground-effect Group C Jaguar, Bentley had a 'flat-bottom' Le Mans winner, which not only exceeded the L/D of the Jaguar, but matched its aerodynamic consistency, and used about 150bhp less to achieve similar speeds.

No more graphic demonstration of this was the flying Mercedes cars at Le Mans in 1999

Beemer up, Scotty

BMW's M Hybrid V8 has had a challenging debut season, but things are looking up for next year

By ANDREW COTTON

BMW was late to the party, announcing it would take part in global prototype racing mid-way through 2021. It took some short cuts to ready the car for the opening race of the season, at Daytona in January 2023, after half a year of testing. Notably, these included using the Dallara chassis that was also destined for use by Cadillac, a modified 4.0-litre V8 engine from its DTM programme, plus the spec hybrid system and battery that are mandatory under LMDh regulations.

The M Hybrid V8 hit the track for the first time mid-2022, but the scale of the job to get the car up to speed against its opposition was huge. There were issues with the development of the hybrid system that held up proceedings for all competing manufacturers and, even once these were sorted, the software war being waged in prototype racing today remains a performance differentiator. As one driver put it, he has yet to see anyone put together an entire good racing weekend.

BMW chose to go with Dallara as its chassis partner, but has re-purposed an engine from its DTM programme to power the hybrid racecar

‘We were in the loop of the [chassis] development from day one’

Valentino Conti, head of track engineering at BMW M Motorsport

Valentino Conti gives a talk to the engineers running the car

BMW's weaknesses are primarily those of reliability, notably of the electronic systems in the new car. The factory programme for the first year saw the RLL team running a car in the IMSA WeatherTech Sportscar Championship in the US. Bobby Rahal already had a good relationship with BMW, so the selection of his team was a natural fit.

Next year, the programme will expand to include the WEC, and Belgian team, WRT, has been selected to run the car for 2024. The team is already familiar with BMW's head of motorsport, Andreas Roos, through its previous long-standing partnership with Audi, and tested at Spa Francorchamps in early August, having already completed a long-distance endurance test.

The first year has not been easy for the US arm of the programme. After a disastrous debut at Daytona, it has improved rapidly since. Victory at the six-hour race at Watkins Glen was a boost for the team mid-season and, with European testing now dramatically increasing the mileage and variety of drivers and circuits – as Porsche and Cadillac have been doing this year – BMW is optimistic it can do even better next year.

Dallara link

BMW had to choose one of four chassis manufacturers to work with in the development of its car. Dallara had already agreed to supply Cadillac, Multimatic was close to the Volkswagen Group, ORECA was full with both Acura and Alpine, while Ligier was open to business. However, BMW chose to go with Dallara, sharing the development programme with Cadillac.

Once the decision to go with the Italian firm was taken, BMW became heavily involved in the chassis particularly. It's a commonly available part, subject to build times, so the German manufacturer found itself looking to work with Cadillac to obtain what it needed from the design. As it turned out, this was quite straightforward.

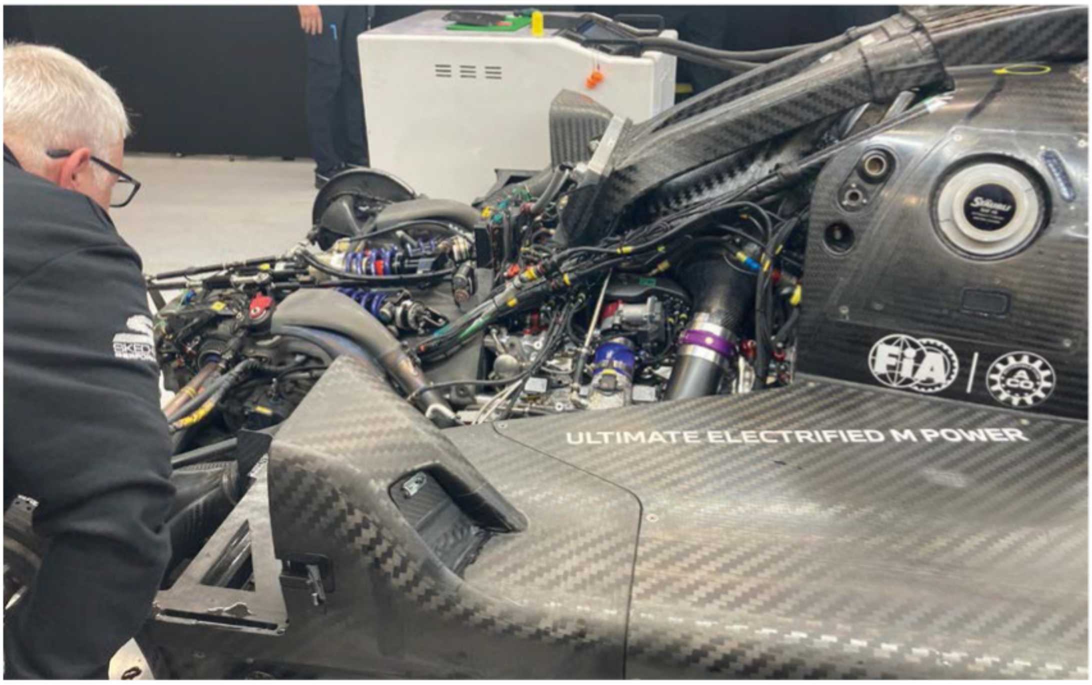
'We were in the loop of the development from day one,' says Valentino Conti, head of track engineering at BMW M Motorsport. 'We had exchanges on a daily basis, and it was very open. It was ideas coming from us,

Next year, the programme will expand to include the WEC, and Belgian team, WRT, has been selected to run the car for 2024

Choosing Dallara as chassis supplier meant BMW's engineers could be involved and take advantage of development work done with Cadillac as well

Valentino Conti, head of track engineering at BMW M Motorsport

Andreas Roos, head of motorsport at BMW



Powering the car is a version of the P66/3 4.0-litre V8 BMW previously ran in the DTM series, modified to work with the LMDh spec hybrid system

Early development paths were hindered by not having a defined tyre model from sole supplier, Michelin, but extensive simulation work paid off

BMW's weaknesses are primarily those of reliability, notably of the electronic systems in the new car

Engineers at BMW drew on the company's extensive experience in both the DTM and Formula E in areas such as electronic control, racing with an electric engine and battery and aerodynamics

and from Cadillac, and they were all channelled into Dallara that already had a lot of experience with these cars. So, from the first day it was basically interaction from us all. We feel like there was no delay from our side from the beginning.'

Of course, the front suspension is mounted onto the Dallara tub, and so needed to be finalised as early as possible. Without a defined tyre model from Michelin this was something of a challenge, but with all three parties working on it simultaneously they felt they got the basics right early on.

'We got the tyre model from Michelin so that helped, and we did a lot of simulations, starting in the simulator,' says Conti. 'You go into that and try to investigate directions with the basic car. Then you say okay, we have this range of kinematics we are going to need and this range of adjustability, so this is the way the damper has to be. Then there is an exchange [of information] and sometimes you have to find compromises.'

Tyre wear and grip levels, particularly on cold tyres, have been a particular bone of contention in endurance racing, which has sought to ban tyre warmers. This should not be an issue for the professional drivers as much as the customers who also race prototypes, but even the professionals have struggled this season [see sidebar on p12]. Managing tyre wear, therefore, and particularly warm-up of the tyre in race conditions, has been a major focus of development for all teams this season.

Bad vibrations

Selecting the P66/3 4.0-litre V8 engine, which was used in the DTM in 2017 and 2018, gave the team some headaches to fix before it had even started. These flat-plane crank engines suffered severe vibration issues when first introduced into the Touring Car programme, and both BMW and Audi had to work hard to fix them before racing commenced.

With other LMDh manufacturers going through the same problems years later, it was no surprise to learn that BMW drew on its DTM experience to manage these vibrations. The unit itself had to be modified to run with a hybrid system, but BMW has never run into the issues suffered by its rivals.

'We have quite a lot of experience with the changes in vibrations that can occur,' confirms Conti. 'From an early stage, we were really looking into that topic and paying attention to it. We even went to testing particularly for that to make sure we were not causing unnecessary trouble, and I think we took the correct path there.

'We were investigating the areas where, let's say, there were vibration spots on the car and we could identify them in the design stage. Our engine guys, along with the experience of Dallara, were looking to avoid mounting problems, where to place ballast and so on. There are certain hot spots.'

Porsche was the development partner for the hybrid system, because it had its car ready first and was willing to invest in the programme. All competing manufacturers were able to help with various spec parts to keep the programme running as Porsche suffered a series of failures, as it turns out, mainly due to the vibrations from the engine.

'For us, it was not clear that they were struggling with the vibrations,' clarifies Conti. 'We now know that [Porsche] have some issues, but in what detail we don't know.

'We are mainly focusing on us and really trying to avoid this situation because we also had it in the past, having a car that was causing us real trauma.'

Baseline control

Another short cut that was taken was the decision to go with the Bosch ECU. While others, such as Acura, chose to use the Formula 1-style TAG system and write their code from scratch, others, including Cadillac, selected Bosch. This meant their systems arrived with code already written. That could have been a blessing, or a curse, but it certainly gave the Dallara chassis customers a good baseline from which to work.

BMW had its own reasons for going with Bosch. It worked with the company in DTM and in Formula E, so to continue was a natural decision. While BMW drew on the experience of its DTM programme to help with the engine, it was also able to reach for its experience in Formula E with the ECU programming.

'The guys from Formula E for sure helped us on all the systems side, on the control side of things,' confirms Conti. 'We already had experience with an electric engine and a battery, so that helped, and the DTM [experience] helped with the aero side, too.

'We were maybe lucky enough to have done that and to go through some other issues and pain beforehand.'

Most of BMW's Formula E engineers stayed with the team after the single-seat electric programme was stopped, and so were shifted across to the LMDh programme. The software war is, says BMW, something like the aero war in Formula 1, in that it is not homologated and there is huge performance potential in getting the system right.

Running in the US has had its benefits, too. There was only one programme on which to focus and one technical specification to work through, but now racing in Europe brings fresh challenges. One is that the fuel is different. The US series uses VP Racing fuel, while the WEC has a deal with TotalEnergies. The tyres are the same across both platforms, but the circuits are completely different in many cases, both in track surfaces and layout, which suits some cars more than others.

Aero configuration is also slightly different between the US and WEC racers, due to minor differences in wind tunnel figures between Windshear and Sauber.

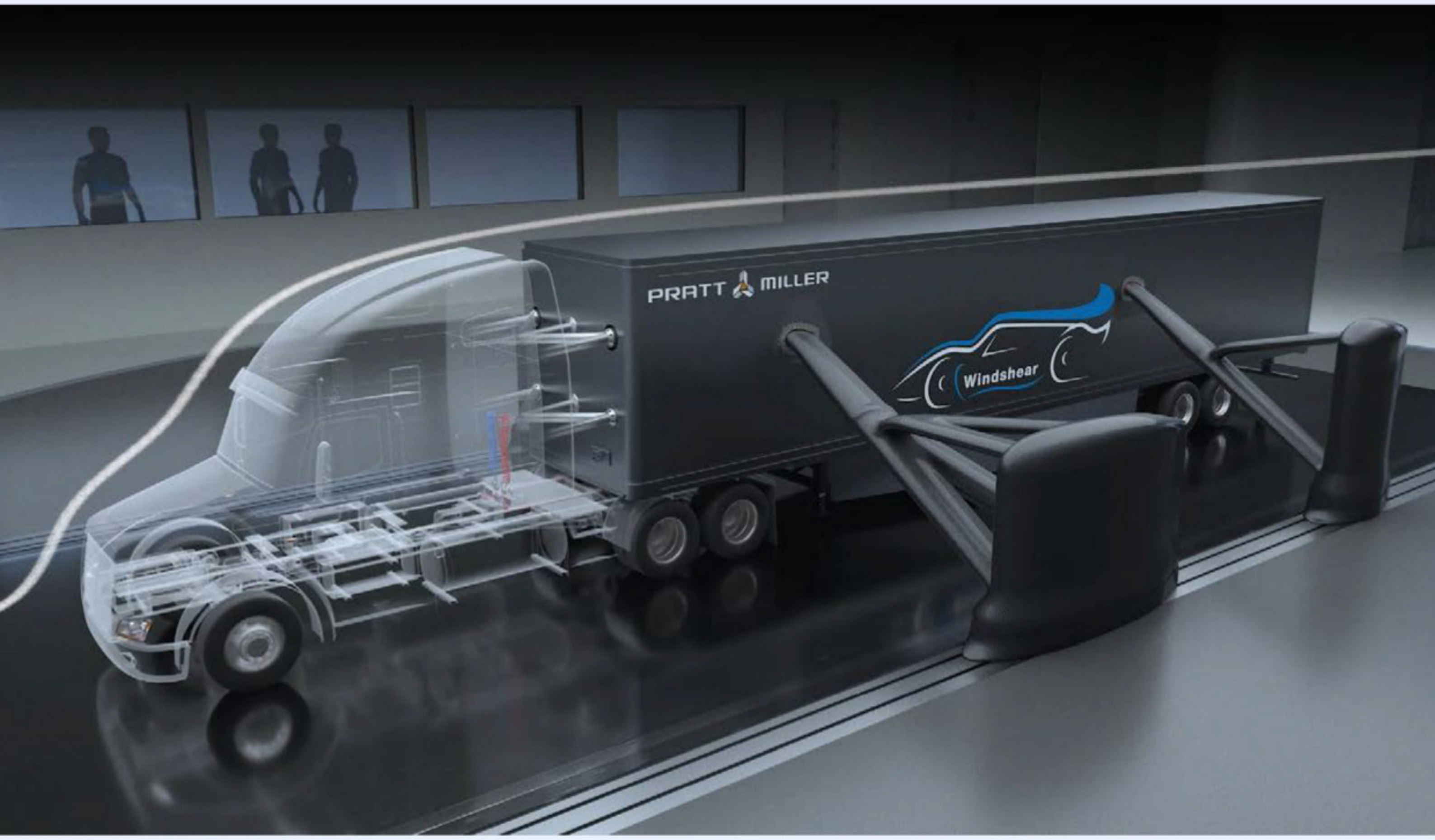
European testing

BMW is working through the list of changes for the car, but has not introduced a big update package for next season. Testing has only just started in Europe and, as of the Spa test, only two drivers, Nick Yelloly and Robin Frijns, had driven the car in both US and European specifications. There was, Yelloly

Racing the car in both the US and Europe brings its own challenges, not least the fact the two series use different fuels. Circuits are wildly different, too

While BMW drew on the experience of its DTM programme to help with the engine, it was also able to draw on its experience from Formula E with the ECU programming

Testing has only recently started in Europe, where TotalEnergies supplies the fuel, but early indications appear to be positive



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'Right now, there are tracks where we are quite close [to the opposition], and the data is comparable'

Valentino Conti, head of track engineering at BMW M Motorsport

guessed, around two tenths of a second difference between the two configurations around Spa, where the compression through Eau Rouge was going to prove valuable when compared to a bumpy US circuit.

'What we are missing is experience with an aero car,' admits Conti. 'Hybrid cars are new for everyone because they were not running them in the US, although they were in Europe. If you take Daytona, or some tracks like that, they are quite European, and then there are other tracks, such as Sebring, that are completely outstanding. So I think the more you run, the more you explore the methodology and structure you bring to testing, and following the steps methodically will bring the improvements.

'Right now, there are tracks where we are quite close [to the opposition], and the data is comparable. And there will be tracks, in America for instance, where because there are bumps you have to run a lot higher [ride height], and soft, in a different window. I can only say that overall directions and philosophies you can apply to either side.'

Performance balance

BMW has steered clear of the Balance of Performance arguments that rage throughout the paddock in the US. The team figures it has enough to deal with just making the car perform before it starts asking the legislators for a boost. That said, it does think the LMDh platform needs help in the WEC to compete with the four-wheel drive LMH cars.

'It does require a certain adjustment between the categories, although I think the step they have done already was in the right direction,' says Conti of the decision to help the manufacturers post Le Mans. 'I don't think it was enough, we'll have to see, but looking at the LMDh class compared to the LMH, I could see that adjustment was required.

'We fully trust the governing body, and are really hopeful this is going to be looked into, to understand the difference and to compensate it accordingly.'

Driver's eye view

Nick Yelloly, BMW factory driver and Aston Martin simulator and development driver

RE: *What are the major differences between driving a US circuit and a European circuit?*
NY: For me, driving on a non-US track is much easier. I was going through Eau Rouge and it was dry, but there were damp patches and, by the second run, I was flat. It doesn't feel that fast, but that's because you have tried to go flat through the kink at Road America and there is a wall close, and it's white knuckles. It is a different type of racing, driving and skill.

The US tracks show up more problems in terms of the systems – the traction control, the way you are working, the brake-by-wire – but set-up wise, we are not massively far apart. Damping is probably the biggest difference, and in general I find the US teams work more on damping than in Europe.

RE: *Is the Eau Rouge compression useful for US tracks?*
NY: It is, and how you sit on the bump rubbers correctly. Also how the power steering assistance runs, so they run slightly more here than in the US. It does nothing in terms of performance, it is just driver feeling.

We changed a couple of bits on the front geometry and pick-up points for the steering to see if we could find something easier through Eau Rouge, and it made no difference in terms of feeling.

In the US, we are not just trying to get the car into the window, we are trying to learn the track in most instances. Acura ran a DPi last year, and Penske have enough data to know how to run the [Porsche], so RLL's first year with a proper prototype, we are not only learning the car systems, we are learning how to get into the window of spring rates on the GTP. Maybe it's similar [to the DPi cars], and they can roll out faster on circuits we haven't been to before.

RE: *On out laps, and at re-starts, it seems to be difficult to switch on the tyres. What is the issue?*
NY: It's tyre temperature, and how the tyre is switching on. You have the soft hot, so they bring the SLT, or soft low temp, they brought to Daytona, [and the high temperature tyre] but you don't have a big crossover. If you are in the bottom end of the medium for example, then you don't know what is going to happen. You don't get much temperature and then the tyre starts to give you the impression you have grip, but you haven't yet.

It's not that the grip is low, it's the snappy behaviour, so you will lock a wheel and cannot recover it. But you can't just say I will go slowly in a race situation, you have to crack on with it, and that's why mistakes are being made.

RE: *Would you agree the software is the biggest lap time progression?*
NY: Making the car consistent is the focus. Where you have the hybrid unit and the mechanical braking system, it is usually the braking system you have to get consistent to give the driver confidence.

You might have the regen' kicking in too aggressively for certain conditions. It is like a handbrake in cold temperatures, it locks the rears and there is nothing the driver can do. The engineers can smooth the transition and re-write the code. It is about brake migration, and it is the same with everyone.

RE: *Bosch has written a basic code, but TAG hasn't. Is that a differentiator?*
NY: With Bosch you can't just do what you want. Things can take a bit longer, but now it's working better and we have found a better direction in terms of unlocking what we need to make things happen.

Going into next year we have a better idea of where the car should start mechanically and so can start to use the software tools to fine tune it, rather than trying to put a plaster on something to cover a mechanical set-up issue, which is less scary for us.

RE: *Is it better to have a driver in the car at the tests who has hybrid experience? GT drivers seem to have migrated well.*
NY: A lot of the top-level GT guys were once single seat drivers. The difference between GTLM and LMDh isn't massive, particularly in slow and medium-speed corners, but in the high-speed corners you arrive faster, so you have to be a bit braver.

You have to hustle this car, and on the brakes it doesn't give you the best feeling and feedback, but that is the same when we went from normally aspirated to turbos in F1. That was in 2015, and by 2019 it was perfect. And that was evolution with budgets like crazy, hundreds of people working day in and day out just on software and it still took them years to get it right.

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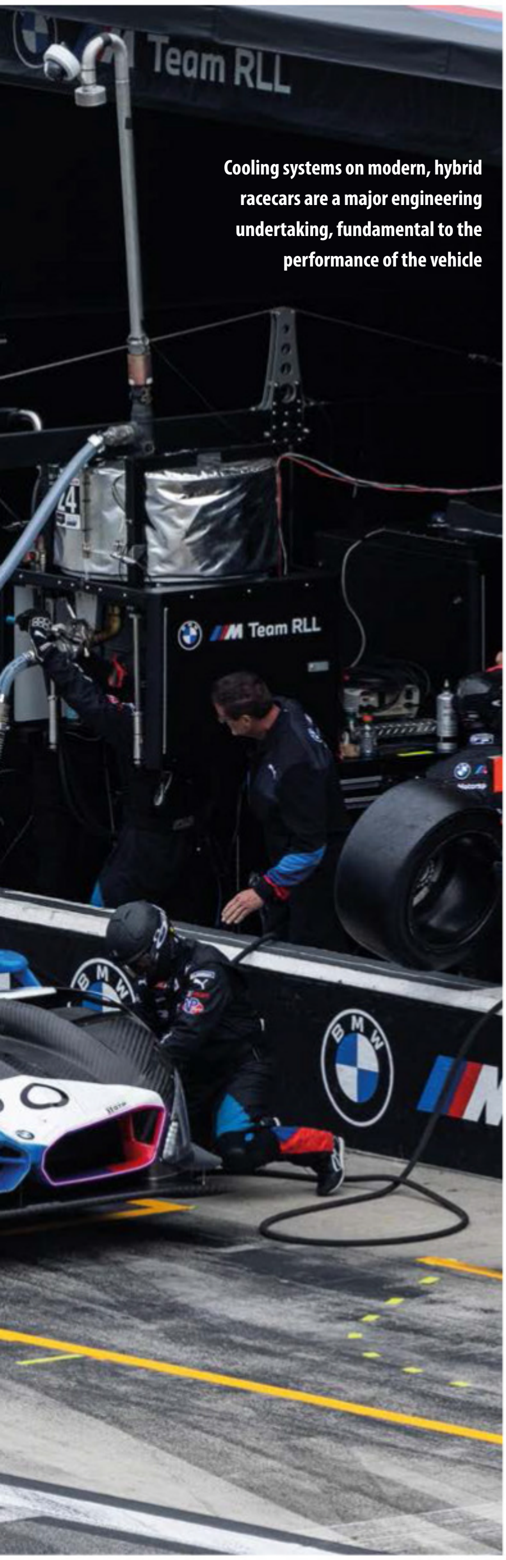
BMW M Motorsport

Package deal

An investigation into the design and development of the cooling systems on board the BMW M Hybrid V8

By JAHEE CAMPBELL-BRENNAN



Cooling systems on modern, hybrid racecars are a major engineering undertaking, fundamental to the performance of the vehicle

It's not only the system level targets that must be met, but also the overall vehicle-level targets of aerodynamic efficiency, weight and packaging, all of which have an impact on vehicle performance

In last month's issue ('Exchange programme' in V33N10), we talked about motorsport cooling systems and their importance in managing the conversion and dissipation of large quantities of energies moving around the racecar.

We noted that racecars are essentially energy conversion mechanisms, but the actual process of energy conversion is far from ideal and the resulting heat generated must be rejected from the systems, both as a matter of performance and robustness.

The architecture of the systems that manage this heat rejection is crucial in maintaining the optimal temperatures required for efficient systems performance, but also impacts design and aerodynamics.

This month, we'll deliver a case study of the engineering process employed to develop the cooling system for a state-of-the-art hybrid racecar, the BMW M Hybrid V8. Produced to 2023 LMDh regulations, this car races at the highest levels of international motorsport in IMSA and, in 2024, the FIA WEC.

As you'd expect, the development of any product at this level is a challenging task, particularly a product with innovation woven into its specification from the beginning.

Preparation and a methodical, well-organised process is key, as well as engaging with the right expertise to develop the system and its components through the use of the latest computational techniques, materials and manufacturing processes.

The M Hybrid V8 was developed as a joint project between BMW Motorsport and Dallara. With engineers from both teams working on the project, the powertrain was developed by BMW in Munich, Germany, while the chassis, powertrain systems and overall vehicle architecture were developed by Dallara in Emilia-Romagna, Italy.

Starting from a blank sheet, the first step in developing any automotive system is to define its objectives. These may at first seem obvious but, as soon as you go into any level of detail, they rapidly increase in complexity, especially when dealing with something other than a regular ICE racecar.

System of four

A modern hybrid racer has four powertrain sub-systems: the combustion engine itself; the electrical powertrain; the turbocharging system and the transmission. From experience, we know each of these sub-systems will generate heat, to the extent that active cooling must be implemented.

The primary objective of the cooling package, then, is to actively remove heat from these four systems and reject it to a different environment. In this case, the ambient air.

As usual in engineering, there are a number of different approaches to any particular problem, so it's no surprise that a variety of different system architectures, configurations and implementations can achieve this first objective.

However, it's not only the system level targets that must be met, but also the overall vehicle-level targets of aerodynamic efficiency, weight and packaging, all of which have an impact on vehicle performance. The development of the cooling system must therefore be considered holistically.

At the beginning of the M Hybrid V8 project, the overall architecture of the cooling system was scrutinised in great detail. A number of configurations were analysed and weighed up against system targets. The output of this work was to define the optimal architecture for each of the four sub-systems' cooling requirements.

'It took the analysis of many different scenarios and technologies to arrive at our final architecture, and involved decisions such as whether to use a water-to-oil or air-to-oil heat exchanger for the gearbox, and whether to use air-to-air or air-to-water charge air cooling,' notes Massimo Stellato, head of vehicle systems engineering at Dallara.

'For each possibility, we used an analytical approach to quantify the benefits of each with respect to air efficiency, packaging and weight, but also using lap time and CFD simulation to be sure that the maximum performance was limited by the rules only.'

Mass transit

As the cooling system weight is not negligible, the vehicle dynamics team were stakeholders in its architecture also.

The positioning of these masses should be kept as low down in the chassis as possible to minimise weight transfer. It was also important that they were positioned such that the front-to-rear weight distribution was in line with targets.

'At the point in the development of this car where we started to focus on performance, many attributes were still open and undefined, but the main aspect to consider was the weight split window demanded by the tyres. This was recommended to us by Michelin,' explains Luca Bergianti, director of vehicle dynamics and performance at Dallara. 'Guaranteeing this weight split with an almost frozen wheelbase meant the position of the masses, including cooling, were important factors to be considered and optimised.'

Fitting the cooling system around an aerodynamic body that requires a low frontal area, a two-seater survival cell, a regulation wheelbase and driver side view visibility volumes was a difficult task. In this sense, the vehicle dynamics department was largely limited only to giving direction to the wider team on where to best package the main cooling components to hit the weight distribution targets.

Nevertheless, the solution delivered by the M Hybrid V8 development team is as efficient and sophisticated as you'd expect. Two ICE water radiators located in each of the sidepods reject heat from the combustion process to atmosphere. These are adjacent to two air-to-air intercoolers in the same plane, which remove heat generated in the compression of intake air.

These heat exchangers are fed by air inlets at the nose of the car and exhausted at the rear, just above the diffuser. With this arrangement, the low-pressure area generated at the diffuser exit will also help to draw cooling air through the ducting and through the engine bay.

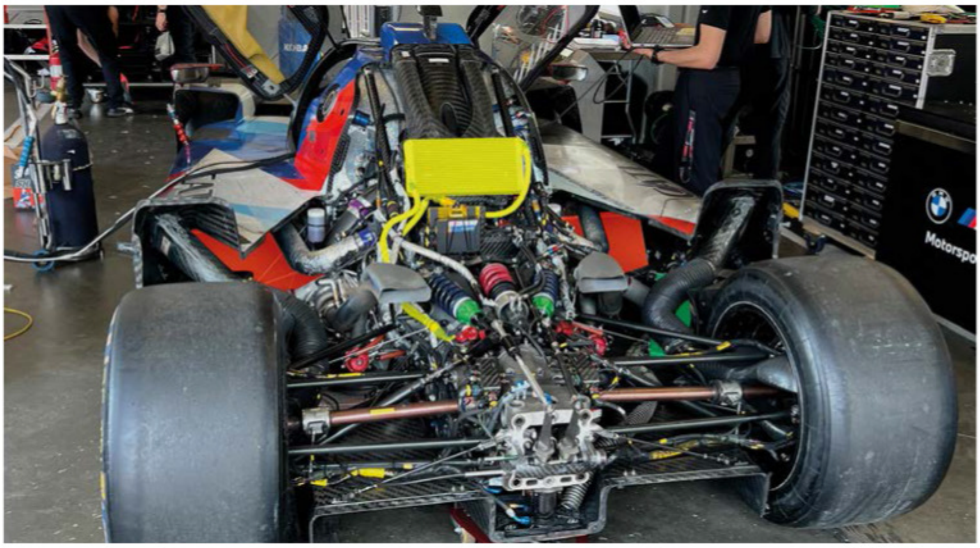
Behind the sidepods in the 'coke line', at each side of the vehicle, are smaller heat exchangers for the electric powertrain systems. These are fed by re-entry flow which travels around the sidepods and enters the ESS ducting just ahead of the rear wheels.

On the left side of the car is the MGU cooler, which cools the electric motors, while on the right side is found the ESS cooler, which cools the battery and associated power electronics.

Located a little higher in the car, within the v of the engine, and fed by air from the central intake snorkel, is the engine oil cooler. The gearbox oil cooler is located behind that.

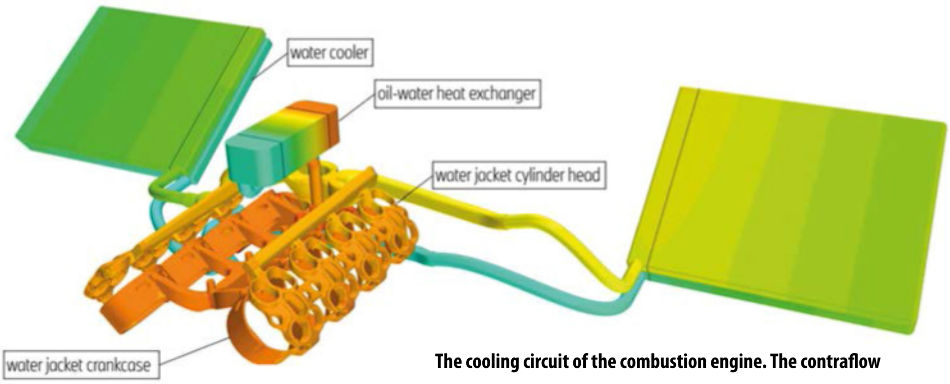
An especially elegant cooling solution in the M Hybrid V8 is in the integration of the engine oil and engine water coolers onto the same circuit. In this arrangement, a compact oil-to-water cooler runs in series to the water loop feeding into the main water-to-air radiators, which have the capacity to dissipate heat from both sources.

This is made possible by the fact engine oil and engine water operate at approximately the same temperature and eliminates the plumbing, radiator core, additional fluids and aerodynamic penalties associated with a separate oil-to-air heat exchanger.



Jahee Campbell-Brennan

The twin air-to-air intercoolers (red), energy storage system cooler (green) and gearbox oil cooler (yellow) can all be seen here on the M Hybrid V8 with the engine cover removed. The engine oil cooler sits centrally in the v of the engine



BMW M Motorsport

The cooling circuit of the combustion engine. The contraflow radiators and oil-to-water heat exchanger are shown here

Charge cooling

The decision of whether to use air-to-air or air-to-water charge air cooling was also the subject of much deliberation. The choice largely comes down to the intricacies of a specific application, rather than a fundamental advantage for either.

General benefits of air-to-air systems are low complexity, low weight and low cost, relative to air-to-water systems, but this doesn't hold true in all scenarios.

'Unlike the engine oil and water, charge air is running at a much lower temperature [<40degC], which means if you use water-to-air intercoolers you need to install a second water circuit running at a different temperature level, and an additional water-to-air cooler to dissipate that heat,' adds Ulrich Schulz, head of powertrain design at BMW M Motorsport.

The distance between the turbochargers and the heat exchangers is a significant deciding factor in this problem. In air-to-air systems, long runs of hose from the turbocharger to the radiator mean large boost pressure drops and a loss of performance. In this situation, air-to-water systems may be advantageous.

In the case of the mid-engined M Hybrid V8, its overall vehicle architecture allows a very short run from the turbochargers to the sidepods where the intercoolers are located. This made an air-to-air system the winner.

Electrical cooling

Packaging of the additional radiators required for the electrical systems also presented some challenges. Firstly, the additional two heat exchangers carry implications on both aerodynamics and packaging. Secondly, it is critical to manage the thermal environment of the electrical system, particularly the electric motors, battery cells and inverter, whose performance is highly influenced by operating temperature and must stay below approximately 60degC at all times.

The low temperature difference (delta T) between the ambient air and the fluids, and the resulting low heat transfer coefficient, caused further challenges in the sense that the radiator cores needed to be very efficient to achieve the required heat rejection.

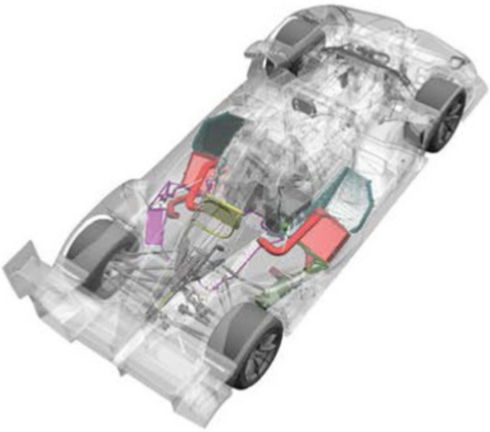
Coming up with an efficient solution required close collaborative work between BMW, Dallara and the radiator core supplier to ensure the heat exchanger cores were installed in the optimal locations and achieved the required efficiency.

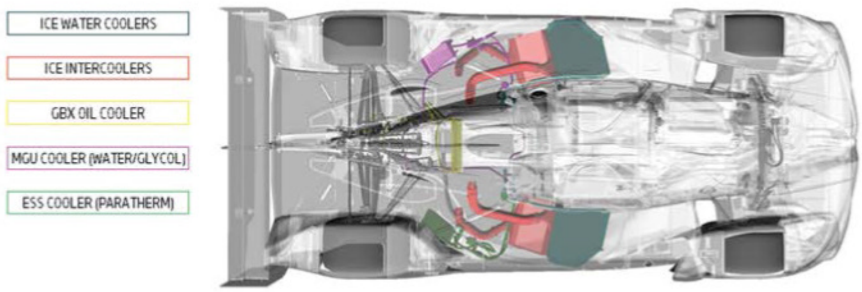
First guess scenario

With the cooling system architecture finalised, the definition of the heat exchangers themselves could begin. To do this, the team needed to know the heat rejection figures required by each sub-system in a critical (worst case) scenario. Due to the compressed timescales in motorsport, this step often has to be initiated while other major vehicle parameters are still being finalised.

An especially elegant cooling solution in the M Hybrid V8 is in the integration of the engine oil and engine water coolers onto the same circuit

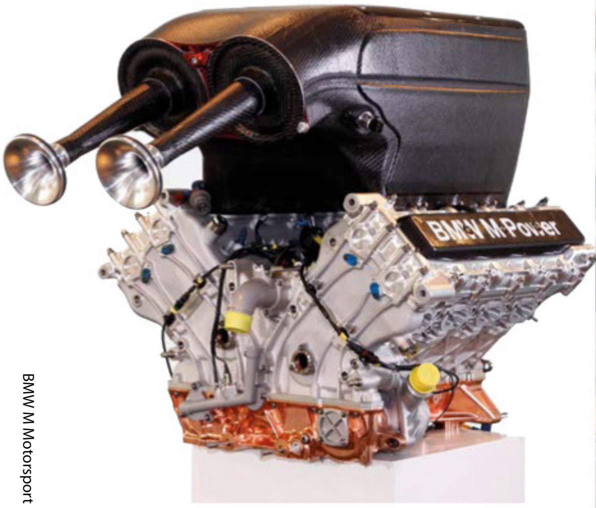
BMW M Motorsport





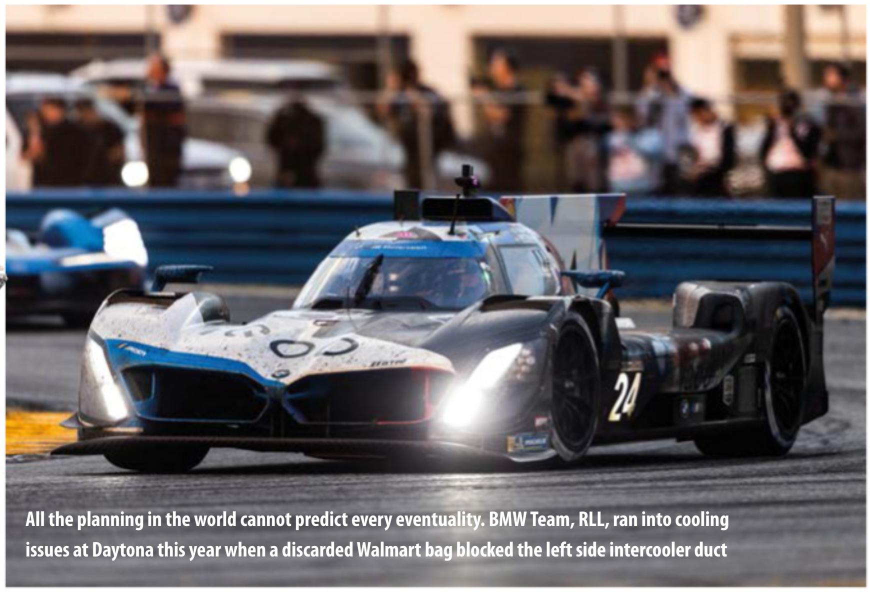
Schematics showing the layout of the main components of the car's cooling systems

BMW M Motorsport



Early work on heat exchanger definitions had to be done using 1D simulations of the car's P66/3 V8 engine

BMW M Motorsport



All the planning in the world cannot predict every eventuality. BMW Team, RLL, ran into cooling issues at Daytona this year when a discarded Walmart bag blocked the left side intercooler duct

This means data on thermal condition requirements hasn't been physically measured, so estimates have to be used.

For the M Hybrid team, these initial estimates were made in 1D simulations, run using assumed parameters of heat inputs and air speeds to provide a first guess at the specification and sizing for components such as pumps and radiator cores.

This is where decisions on radiator core architecture are made and finer details such as the number of passes (through flow, u-flow or even contraflow) considered.

'The challenge in this activity is to predict reliable parameters in the preliminary stages. When you conduct the initial 1D simulations, the powertrain is still under development. You don't have radiator, airflow or heat rejection data, so you have to make estimates,' confirms Stellato. 'With good estimates, though, you develop a solid base for your architecture and, when refined data is available, you'll be in a better position to optimise overall vehicle performance.'

Any significant differences that then become apparent between the estimates made to initiate this process and the final, measured parameters mean a sacrifice must be made from another attribute.

It's tempting to over specify at this stage, but if cores are oversized then there are aerodynamic and weight penalties to absorb. Conversely, undersized cores will require higher flow speeds and changes to pumps to overcome the resulting pressure drops. Or, in extreme cases, de-rating of other components to prevent overheating.

At this stage, it's also crucial to understand that on track, especially the endurance racing this car was designed to participate in, cooling performance delivered by the heat exchangers at the start of the race is not the same as the cooling performance during, or at the end of, the race.

Aside from the obvious ambient changes, debris such as tyre rubber, leaves and stone impacts can obscure and / or damage radiator cores, so some allowance must be made for this during initial calculations to provide a safety margin for degradation.

'At Daytona this year we had an interesting story,' remembers Schulz. 'Around one hour before the end of the race, the left-hand intercooler temperature was rising dramatically. We had to pit the car to inspect it, only to find a large Walmart bag inside the duct of the intercooler! We had a similar issue in F1 at Sao Paolo as there was a lot of newspaper flying around.'

During operation, the vibration input into the components is significant, as are the dynamic pressures seen by the system.

The radiators are fixed to the chassis with anti-vibration mounts to isolate and dampen the vibrations experienced, and pressure seals and vessels must be robust enough to accommodate any pressure spikes that might be seen, both of which can lead to fatigue and failure of the system.

'We especially had an eye on the vibration point as we are running a V8 with a 180-degree crankshaft, which puts a lot of second-order vibrations into the coolers and overall vehicle,' notes Schulz, 'so we made allowances for this from the start of the design process.

Validation process

With robustness a high priority in the initial assumptions for the system, the CFD validation process could begin. This is the point at which the development team can begin to obtain data on the system's performance with real accuracy.

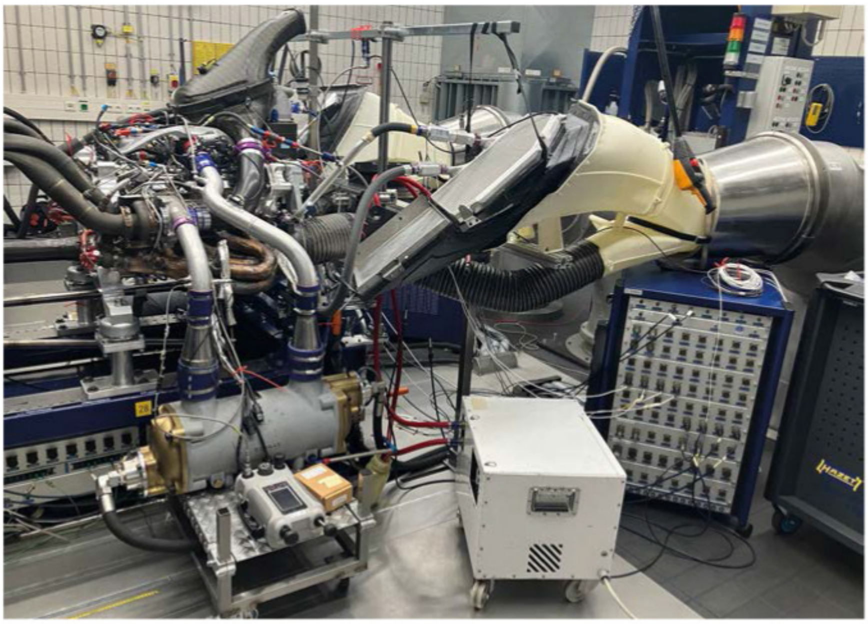
'We perform CFD loops running a full car model and evaluate various cores whilst looking at airside pressure drops and velocities across each core in the system,' explains Yoran Pichon, team lead

'We perform CFD loops running a full car model and evaluate various cores whilst looking at airside pressure drops and velocities across each core in the system'

Yoran Pichon, team lead aerodynamics at BMW Motorsport


BMW M Motorsport

A low pressure area behind the car formed by the underfloor helps draw air through the cooling system and engine bay


BMW M Motorsport

BMW's Formula 1 dyno test cells could accomodate the entire P66/3 powertrain with all its cooling system and ducts attached to allow real-world conditions to be replicated and early validations made against simulation work

aerodynamics at BMW M Motorsport. 'As we go through this process, it's a series of iteration loops and, for every core and architecture we investigate, we take into account the potential impact on the sidepod shapes and vehicle architecture to really understand the impact on aero performance.'

As with any simulation, there must be a process of validation within the methodology to gain confidence in any predictions made.

The approach to this differs with teams and championships, but the M Hybrid V8 project used a scale model wind tunnel to validate its CFD investigations. This ensured the results, which in early stages are used to inform design decisions, could be relied upon.

When the overall vehicle design was deemed mature enough, a full-size vehicle was tested in the wind tunnel and further correlated with CFD. This gives a more accurate and representative insight into the car's aerodynamic performance, and is a step closer towards gaining real confidence in the amassed data.

As well as CFD and wind tunnel testing, BMW also had use of the company's old Formula 1 engine dyno facilities, which allowed the entire powertrain, cooling system and associated ducting to be set up in the test bay and supplied with airflow to simulate track conditions.

While not 100 per cent representative of real-world racing conditions, this step provided the first real-world validation against the simulation predictions and gave the team further confidence to progress into the physical build.

'An important step for the validation process is the test bench activity where we have the engine, radiators, ducts and everything else present. Here we replicate the simulated airflow (output from CFD simulation), vehicle speed, engine speed and throttle (output from vehicle dynamics simulation) during a complete lap as a check that our calculations are okay. It's better that we find mistakes here than at our first track test,' says Stellato.

This methodology of CFD validation against the increasing levels of accuracy provided by scale and full-size wind tunnel models and lab testing is an iterative process that creates a solid and reliable understanding of the aerodynamic performance of the cooling system, as well as its overall impact on the car.

Track testing

With confidence in the engineering gained from these techniques, the design and specification of the car can be frozen to allow for the first prototype chassis to be constructed. Which brings us neatly into the last phase of the development and validation process for the M Hybrid V8 – track testing.

Despite all the recent advances made in simulation technology, we still haven't reached the level of 100 per cent accuracy, which means some level of real-world validation is always required.

Outside of actual race conditions, no other environment carries more validity than track testing, and so a track validation programme is always scheduled to sign off any project long before performance development begins.

In these conditions, the car is instrumented with a whole host of thermocouples and pressure sensors. Engineers can then monitor conditions within the cooling system live, and post event, to analyse how everything is working together, and react accordingly.

'At the beginning of our track testing programme we saw some phenomena in which a thermostat we were using was being placed at exactly its regulation temperature. This caused it to fluctuate between on and off, creating a lot of corresponding pressure peaks within the cooling system that subsequently overloaded the coolant header tanks,' Schulz recalls. 'After a lot of investigation with specifically placed pressure sensors, we diagnosed the issue and implemented a solution, which in this case was to modify and develop our own specific thermostat for the application, and to optimise it in several steps.'

BMW M Motorsport's head of powertrain design, Ulrich Schulz, overseeing track test events early in the M Hybrid V8 programme. Despite huge advances made in simulation, track testing remains an essential milestone in any car development

BMW M Motorsport

As mentioned earlier, cooling systems are designed for worst case conditions, which generally means the hottest days at the highest altitudes, with some built-in margin for degradation. This is slightly at odds with the conditions at the other end of the spectrum in which the air is cold and dry. These two extremes present very different heat rejection requirements, both of which must be catered for in the final system.

Highs and lows

To put that into context on American racetracks, Laguna Seca can reach highs of 43degC, while the 24 hours of Daytona has recorded temperatures as low as zero degC in the early hours of the day. Combined with the track's very high-speed nature, this is a huge change in operating conditions.

Consequently, it's common practice for trackside engineers to use blanking tape, or panels if allowed, to obscure duct or radiator area to decrease the level of heat lost to atmosphere. However, in LMDh, where the M Hybrid V8 will compete, this practice is not permitted for anything other than the brakes.

'The regulations are trying to limit any performance advantages from blanking techniques, which can be gained on a weekend, because the aerodynamic homologation process is already completed and no changes should be made. We can use blanking for brakes, but not powertrain,' confirms Pinchon. 'This leads to a more complicated cooling system using thermostats and variable electric pumps to manage flow and adjust heat rejection in different environments.'

As is common with the trend in modern motorsport of regulations limiting engineering direction, such changes have driven teams to use ever more complex technology and control strategies to maintain optimal operating temperatures in cooling systems. And these days, that's a job for the software engineers.

Indeed, although the team behind the M Hybrid V8 made use of some of the equipment used in the development of the BMW F1 car in 2006, much of the sophisticated technology employed these days didn't even exist back then.

Advancements in computing and CFD technology have enabled larger and more accurate models to predict flow through the radiator cores. This has helped with both flow conditioning and flow distribution to ensure both internal and external flow is stable and well optimised.

'A top performance cooler, such as used in the M Hybrid, performs better than an equivalent radiator from six years ago by around five to seven degrees [C] for the same heat rejection and airflow'

Massimo Stellato, head of vehicle systems engineering at Dallara

'New materials and technology such as micro-pipes have improved radiator cooling performance over the years,' notes Stellato. 'A top performance cooler, such as used in the M Hybrid, performs better than an equivalent radiator from six years ago by around five to seven degrees [C] for the same heat rejection and airflow.'

Fine tuning

Inevitably, hybrid powertrains will continue to increase in complexity, as will the cooling systems required to run them. It seems a foregone conclusion that integrated cooling loops will continue to provide useful advantages. That, and the increased fidelity of data on the thermal capacity of components and fluids will allow system sizing to be even more finely tuned than it already is to gain that competitive advantage.

Right now, electric powertrain systems are a high innovation area, with much research going into developing battery technologies that allow higher operating temperatures, which in turn require smaller heat exchangers, with the associated weight and aerodynamic advantages that brings.

Cooling systems may not win races, but every little advantage helps, and the M Hybrid V8 project has capitalised on that and re-defined the current state-of-the-art to the very limit of what the regulations allow. A fascinating project.

Ongoing Odyssey

How Extreme E's electric off-roader has evolved, and what's to come when hydrogen enters the mix

By DANIEL LLOYD

The Spark-built Odyssey 21 is now at the end of its third season of competition, and has been progressively evolving throughout that time

Extreme E is now three seasons into its ambitious journey of taking electric motorsport out of the city, into the wild.

Created by Formula E architect, Alejandro Agag, the championship's aim is to highlight the destructive impacts of climate change by staging short off-road races in affected environments such as Greenland, Senegal and Chile. Stars such as Lewis Hamilton and Nico Rosberg lend their support to entries, while established teams like Andretti Autosport, McLaren and Chip Ganassi Racing compete.

Although Extreme E is a spec series where the motor, inverter, battery, chassis, along with a number of other components, are tightly controlled to keep costs down, it hasn't been exempted from technical evolution.

The Odyssey 21 of today is a tougher, more reliable beast than the Odyssey 21 of three years ago. The developments that have taken place in that time have laid the groundwork for a platform on which Extreme E can test hydrogen fuel cell capabilities ahead of its next big leap.

The original racer was publicly unveiled in July 2019, and raced for the first time in the sand dunes of north west Saudi Arabia less than two years later. The inaugural championship consisted of five X-Prix events on four continents.

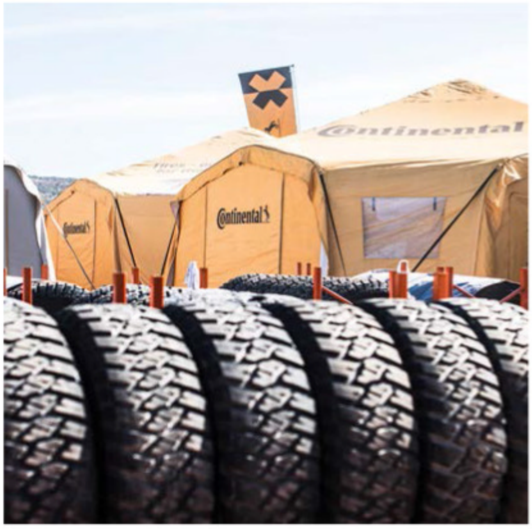
Despite the success of launching a series during the coronavirus pandemic, there were some technical teething issues in the first season. For instance, the suspension package of a three-way adjustable mono damper gave too limited range of movement for the demands of the terrain.

'It went from a single spring and damper package at the rear to a twin [and] we got the extra wheel travel we needed'

Roger Griffiths, team principal at Andretti Autosport

Sardinia 2022 was the first race for the new Fox dual suspension system that increased wheel travel and gave a more predictable ride

Advances in paddock charging infrastructre prompted Extreme E to trial 30kW charging in practice at Sardinia this year, up from 20kW the previous season, while developments in battery cooling have allowed car power to increase



Continental sets different pressure windows for its tyre at each event, depending on the individual course characteristics and conditions

'One of the issues we had with the original damper package was that the car developed a bucking bronco style when it was landing,' says Andretti team principal, Roger Griffiths. 'It would kick the rear up very violently.'

In the first season, American company, Fox, worked with Extreme E on a new suspension layout that addressed concerns surrounding the original BOS package. Tests were held near Las Vegas on a twin spring and damper solution that increased wheel travel for a stronger ride.

Spark Racing Technology modified its chassis at the rear to facilitate the new configuration, gathering all the Odyssey 21s together to complete the work in house. It utilised a handy time slot opened by the cancellation of the Ocean X-Prix to facilitate testing for each team before they raced with Fox's improved suspension at the second round of season two in Sardinia.

'It was predominantly about the ride, and the capability of the car to deal with the conditions we wanted to put them under,' explains Extreme E technical director, Mark Grain. 'Fox did a fantastic job for us, but it was a two-pronged attack for Spark to react and change the rear geometry.'

Griffiths adds: 'It proved to be a pretty significant upgrade package. It went from a single spring and damper package at the rear to a twin [and] we got the extra wheel travel we needed. We had an upgraded front spring and damper package as well. It was a genuinely positive step.'

Battery cooling

The suspension change was a key development but interesting evolutions were also happening deeper inside the vehicle. WAE Technologies developed a 3600-cell, 54kWh battery for Extreme E that initially featured air cooling. According to WAE, this cooling method was developed for the proposed X-Prix format of presenting the action in a documentary style after the fact, which would have allowed plenty of time to cool the battery between races.

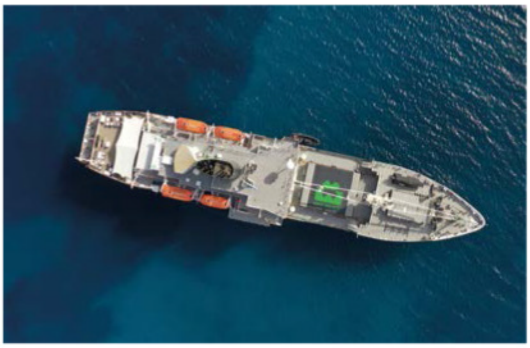
However, when the championship opted for a standard race weekend arrangement with short gaps between sessions, WAE sought to create a new cooling system that could better handle the pressure. The work took place in 2021 ahead of season two.

'The problem is that water and batteries don't like each other,' notes Frederic Riser, chief engineer of mechanical development at WAE, 'and the FIA would never allow a battery to be cooled with water. So, the question became how can I use water to cool the battery, but the water stays outside, and I drain the heat outside the battery?'

During the first season, WAE found its answer in a method used for satellites and power electronics. Its design featured sealed-off aluminium 'microchannels' machined into the cooling plate that carry water over the battery module without making direct contact. The liquid could also dissipate away from the battery in the event of a crash.

'You have a top plate where the water is running, but the water stays out of the battery

WAE's battery cooling developments enabled teams to make the most of the Extreme E power unit



Extreme E transports its paddock on a former postal vessel, *St. Helena*

Away from the racing, Extreme E has kept up its programme of climate awareness activities for drivers

'The Extreme E battery is the first ever FIA-approved battery with a water-cooled system because water stays outside'

Frederic Riser, chief engineer of mechanical development at WAE

and there is no plumbing inside,' explains Riser. 'The Extreme E battery is the first ever FIA-approved battery with a water-cooled system because water stays outside.'

This solution was brought to the 2021 season finale in Dorset. The removable cold plate was taken to the car and placed on top of the battery pack, but access was an issue due to mud and stones blocking the thermal interface. That prompted a further re-working over the winter in time for the 2022 opener.

'The whole system inside was working, but I just couldn't extract the heat,' Riser recalls. 'To prove it, I went to buy 20kg of ice during the race in Dorset and put them directly on the battery. Then it started to work. The problem was with the way I planned to extract the heat. So, what I had to do was to replace the top plate with an onboard active cooling plate, to be more efficient.

'As the original concept was based on a removable cool plate, it was simply square, so some parts of the battery were not directly in contact with the cold. In order to cover the entire battery surface, the active cooling plate had to integrate a more complicated shape.'

WAE's effort over the first and second seasons gave Extreme E a battery cooling system that could handle the pressure of coming in very hot after a run, chilling, and then recharging before running again at no detriment to the power output.

'Through the first year, we had been reducing the car's power to make sure the temperature at the end of a run was manageable with the [air] cooling,' says Riser. 'We were adjusting available power around 225kW in the first season, now it's always 300.'

'We did struggle with battery cooling,' says Grain. 'The challenge is to keep the battery at a cool temperature whilst charging. If it starts to get warm, you lose charging effect, so it's a balance. It was definitely a big step forward.'

Renewable tyres

Continental has supplied Extreme E's CrossContact tyre since the start and has made evolutions to it since then. Its 2021 objective was to provide a durable tyre that could take the new car over rugged terrain, but the focus in subsequent seasons has been on implementing sustainable materials.

In season two, Continental constructed the tyre with polyester yarn from recycled PET plastic bottles and extracted silica from the ash of rice husks. One third of the 2022 CrossContact was made from renewable and recycled materials, which accounted for about 10kg of each tyre's weight, according to Continental's customer testing department manager, Nels von Schnakenburg.

'We tested those materials in the racing application, under all those extreme conditions, so we were sure it would be approved for series production,' he says. 'We introduced it in the Premium Contact 7 and Eco Contact 6 tyres. People with normal passenger cars are running with recycled PET products on the street. This was why we stepped into this series.'

The 2023 tyre evolution increased the ratio of renewable materials to 43 per cent

‘We will have set some precedents in Extreme H for hydrogen crash testing that the FIA will be able to pick up on if other series follow us into hydrogen in the future’

Mark Grain, Extreme E technical director

Extreme E’s jump to hydrogen is almost as big as the ones the Odyssey 21 tackles in its existing electric format

Tackling constant challenges

As the Odyssey 21 constructor, Spark has been involved in all Extreme E’s technical evolutions. Racing in complex environments has generated challenges and lessons at every turn of the wheel. During one test with the original season one mono damper, Spark noticed the driveshafts breaking after jumps, but couldn’t change the driveshaft size within its tight production schedule.

‘We decided to limit the stroke of the damper to reduce stress on the driveshaft,’ explains Spark motorsport director, Pierre Prunin. ‘Additionally, we reduced the motor torque.

‘When you jump, your wheels are at full speed, and then when you land you go to car speed on 50kg wheels. That is where you destroy the driveshaft.’

By cutting the torque, Spark safeguarded the driveshafts, but the damper stroke couldn’t be restored, which led to driver complaints and, ultimately, a supplier switch to Fox.

Spark, meanwhile, continued to refine the Odyssey 21 in a myriad other areas.

‘We also worked a lot on the power steering system,’ adds Prunin. ‘Mechanically, we haven’t changed anything massively, but we have beefed up some components. The piston diameter, for example, has been increased by 1mm.

‘We also worked a lot on software, giving some tools for the teams to have fun. And we worked on improving reliability, and discovered many things.’

However, there are some things even the most experienced and prepared suppliers cannot foresee.

‘We had an occurrence where a cameraman passing a car deactivated the Hyperdrive system, because it was all controlled by telemetry,’ Prunin recalls, ‘and an incorrectly programmed radio system stopped the power steering once.

‘For the first two seasons, every single race we had different issues that we had never seen before.’

Clearly, quick reactions are vital in Extreme E.

and removed 2kg of material per tyre, a further carbon reducing measure.

‘The subjective racing performance was improved in terms of stability, cornering performance and braking performance, with less material and more sustainable products,’ adds von Schnakenburg. ‘From a technology perspective, season one to two was a significant [step] because we introduced technology that is now in serial production.

‘In terms of racing performance, season two to three was the most important.’

Extreme E consumes between 350 and 400 tyres per season and Continental closed the loop on its 2021 set by converting the used product into the base for a basketball court that was donated to a youth centre in Hannover. A similar initiative is planned for the 2022 tyres.

Towards hydrogen

Extreme E broke new ground by taking electric motorsport to some of the toughest racing environments on the globe, and now it’s looking to go even further. As part of a closer cooperation with the FIA, Extreme H is set to debut as an FIA championship in 2025 and become the first hydrogen FIA world championship in 2026.

The series is prioritising hydrogen fuel cell technology, although it hasn’t completely ruled out other avenues such as hydrogen internal combustion.

‘When we’re looking at burgeoning technologies, and how we can assist those technologies by racing and improving the breed, hydrogen fuel cell was the obvious choice,’ notes Grain. ‘We can demonstrate that a hydrogen fuel cell car can operate at high speeds over rough terrain. Those were the driving motivations behind the fuel cell route.’

Dynamic testing of Extreme H technology started this year, initially using a mule car

Extreme H is currently in pole position to become the first hydrogen-fuelled FIA World Championship

based on the Odyssey 21, although a bespoke hydrogen racer is coming. It’s understood that the fuel cell will hold 75kWh, while the new floor-based battery, which WAE has developed, will store around 44kWh. It will use the same microchannel cooling system developed from season two.

‘Most of the short-term power, under acceleration, will come from the battery,’ says Riser. ‘The fuel cell will be there to just generate some energy, as an onboard charger.’

Testing will continue next year ahead of the inaugural Extreme H campaign.

Grain hopes the championship’s leap to hydrogen will make it a standard setter in a rapidly developing area: ‘A lot of that work has been done in conjunction with the FIA. You can imagine different crash tests and protocols. This is how Extreme E, as a championship, is playing its part in developing these aspects for broader motor racing.

‘We will have set some precedents in Extreme H for hydrogen crash testing that the FIA will be able to pick up on if other series follow us into hydrogen in the future.’

Even if Extreme E becomes Extreme H, hardly anything on the next generation car will have been developed without learnings from the championship’s electric era. The odyssey continues as technology evolves.

Coming on strong

With a brand new technical facility and a new works partnership agreed from 2026, Aston Martin F1 has a bright future, but first it has to make its 2023 contender consistent

Words and illustrations by PAOLO FILISETTI

Aston Martin describes the chassis as a 'considerable evolution' from last year's AMR22, but it was the aggressive bodywork, with its deeply sculpted sidepods, that was the talking point at the car's unveiling in February

There is a lot going on at Aston Martin F1 at the moment. Not only did the team move up the grid and, in the first half of the season, challenge the front runners on a regular basis, but it also moved to a new technical facility just ahead of the British Grand Prix in July. On top of that, it signed a deal to join up with Honda in a works partnership from 2026.

This is the first new Formula 1 facility to be built in the last 20 years, and it will eventually bring together all the team's engineering capabilities under one roof. The 400,000ft.sq building is on the Formula 1 campus at Silverstone, UK, and will house the team's wind tunnel and simulator when it is completed at the end of 2024. It was opened with a drive through by Lance Stroll in the AMR23 just before the British Grand Prix.

The name Aston Martin returned to Formula 1 in 2021, born out of the Racing Point team. A deal was signed with Mercedes to use the rear end of the car, including engine and gearbox, and that gave the team significant prospects for success.

The hiring of Dan Fallows from Red Bull Racing as technical director was also a step in the right direction, as was bringing in experienced driver, Fernando Alonso, to partner Stroll. All of this gave the team the impetus to push forward with the car, but the AMR23 is a completely different animal compared to its predecessor.

2023 revelation

While the bodywork was upgraded mid-way through the 2022 season, the basis of the car was unchanged as the team had to remain within the cost cap. The launch of the AMR23 changed all that, though. The team says the chassis is an evolution of last year's design, but admits it's a 'considerable' one. However, the world's focus was on the aggressive bodywork when the car was unveiled in February.

Aston Martin was the first to reveal its car in 2023, and it featured deep scallops in the sidepods that caught the eye, and which have since been adopted by rival teams. The system clearly works, as the car could rightly be considered the revelation of the 2023 season.

The Silverstone-based team finished the first part of the season in third place in the standings, having secured six podium finishes in the first eight races with Alonso. The Spaniard continues to impress in the car, despite having last won the Formula 1 World Championship title 17 years ago.

In the last four races before the summer break, starting from the Austrian GP and leading up to the Belgian Grand Prix at the end of July, Lawrence Stroll's team was no longer able to capitalise on the valid basic characteristics of the AMR23, a car that, more than any other on the grid, incorporates many of the characteristics of the Red Bull RB19.

These similarities are not surprising, for at least two reasons. On the one hand, the presence of Fallows, formerly head of aerodynamics for the Milton Keynes-based team, has clearly had an impact on the aero set up of the car. The Briton is certainly familiar with the basic principles of last year's RB18, at least in terms of its design philosophy.

Secondly, the team has developed the concept of the AMR22 along an autonomous path, marrying that of the sloping sides.

Another peculiar element of this project is the accentuated anti-dive effect given to the pushrod front suspension. This feature has ensured perfect balance, especially at the start of the season, and excellent vehicle dynamics, drastically reducing the porpoising effect that has so affected other teams.

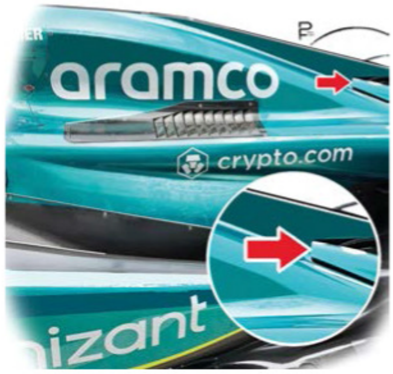
Photo: Mark Sutton

Another peculiar element of this project is the accentuated anti-dive effect given to the pushrod front suspension

LAT

Aston Martin brought a raft of modifications to the Canadian GP, with changes evident to the sidepods, engine cover and floor

Canada: new shark fin on engine cover



At the Canadian Grand Prix, a different profile fin appeared on the engine cover, now shorter to reduce interference with the flow directed to the lower profile beam of the rear wing

The team's previous car, the AMR22, was said to have not enough suspension travel to cope with the porpoising effect, and that has clearly been rectified in the AMR23.

The development of the car initially progressed in small steps, until the Canadian GP, where a large package of modifications made its debut. On that occasion, it was not just a profound evolution of the sidepods, but also of the floor and engine cover. On a visual level, there was an increase in the channel under the sidepods, with the aim of increasing airflow in this area. This concept has been particularly exploited by the Red Bull RB19, though Ferrari also aped the evolution in Spain, having drawn clear inspiration from the British team.

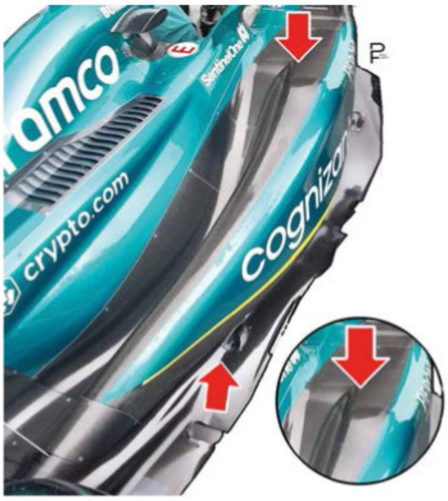
Channel hopping

The narrowing of the upper channel section that characterised the sidepods of the AMR23 from the beginning of the season was interesting, too. Its width has been reduced, but its shape remains unchanged, with an extremely steep slide in the central section to increase the pressure of the flow passing inside it towards the rear.

As a side note, the strong resemblance to the upper part of the new sidepods of Ferrari's SF-23 (introduced at the Spanish GP) had aroused a certain curiosity. Not least because, from Spain onwards, the Italian team drastically reduced the width of its recesses that had been with them since the previous season on the F1-75.

It therefore seems correct to note these two projects, which started from concepts very distant from each other, highlight a strong convergence in aerodynamic solutions across the grid, which could be interpreted as an indication of a more generalised convergence among all single seaters in 2024.

Detail of AMR23 Canada sidepods and comparison with the evolution of the Ferrari SF-23



The reduction in width of the groove that crosses the entire upper profile of the sides is clearly visible. This modification makes the AMR23 very similar to the latest version of the Ferrari SF-23 introduced in Spain

Jake Grant

After six podium finishes in the first eight races, the Aston Martin fell off the pace, only regaining its strength in The Netherlands

AMR23 side view Zandvoort updates

The arrows indicate areas of intervention, in terms of increasing the channel between the sidepods and the floor, and the fin on the engine cover now returning to its original length

In any case, it is correct to emphasise that the Silverstone team, like Ferrari, arrived at the solutions that were introduced in Montreal completely independently, continuing with the development of the AMR23 with a very precise strategy and planning.

To demonstrate this thesis, it is sufficient to point out that in addition to the sidepods and floor, Aston Martin modified its front section and lower volumes, while the engine cover was also the subject of development. From the British GP, it was equipped with a vertical fin reducing in length towards the rear and separated from the engine cover by a large rectangular cut. It's a solution that favours the downwash effect (downward deviation) of the flow directed towards the lower profile of the rear wing to increase air extraction from the diffuser.

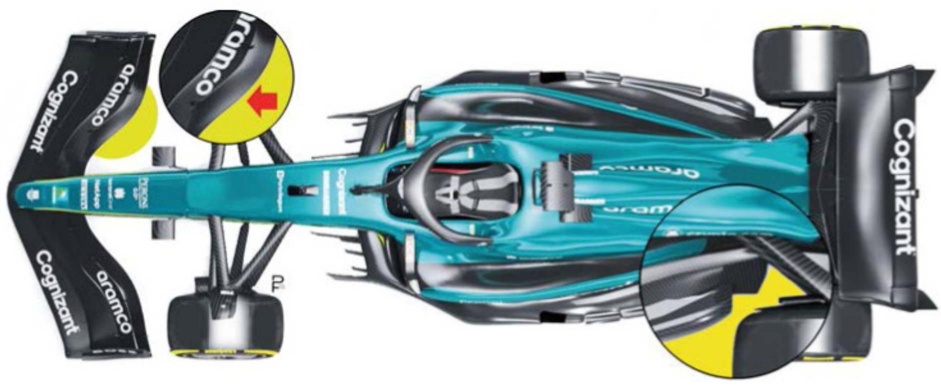
Further development

The development of the AMR23 then continued until the summer break, with minor evolutions introduced at each subsequent race. From now, until the end of the season, it will be a question of fine tuning the car's dynamic (suspension) and aerodynamic settings in an attempt to completely extract the theoretical performances, foreseen in simulations, from the various upgrades.

This could justify the fluctuating performances of the AMR23 after the resumption of the season in The Netherlands. In practice at Zandvoort, the team managed to extract the maximum potential of the AMR23, thanks in part to the layout of the circuit. The subsequent second place achieved by Alonso in the race revitalised Aston Martin's aspirations to be the second force in this year's World Championship, one step above its third place in the standings at the conclusion of the first part of the season.

At Zandvoort, the AMR23 was, objectively, the car that introduced the most extensive

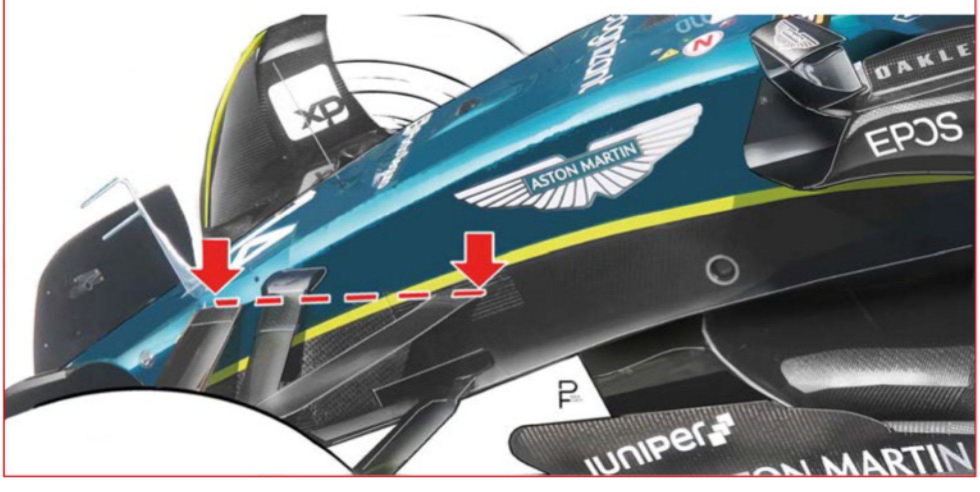
Top view



The circles show the modifications made to the last flap of the front wing, its enlarged chord and more sinuous profile, which increases the outwash effect. At the rear, the modified junction area of the venturi channels at the level of the throat of the diffuser is highlighted

Front suspension: radical anti-dive

Note the strong upwards inclination of the upper wishbone arms of the front suspension. The front pick-up point is decidedly higher than the rear one (indicated by the dotted line), increasing the anti-sinking effect of the front end and favouring the balance of the car



Jake Grant

At Zandvoort for the Dutch GP the next round of updates arrived, this time focusing on the front wing and diffuser. A small winglet on the tail also appeared, then just as quickly disappeared

package of updates, both linked to a new version of the front wing, characterised by a flap with a sinuous profile and the chord, increased specifically for the Dutch track. Even at the level of micro aerodynamics, the car's development appeared decidedly original, and its performance benefited.

The changes made did not only concern the throat of the diffuser (perhaps the most relevant update). In free practice one, a tail winglet was mounted to the rear crushable structure, though this appeared to generate problems during pit stop tests where it was damaged by the rear lifting jack. It was not used for the rest of the weekend.

Broadly competitive

Nevertheless, the AMR23 seemed broadly competitive, almost at the same level shown in the first eight races of the season. On the other hand, at the next race in Italy, at Monza, the car's performance was decidedly mediocre, undoubtedly below the expectations of the Silverstone team's engineers, and reflected a level of performance closer to that seen in the last four races before the summer break.

This fact confirmed the AMR23 prefers high-downforce tracks, rather than those where the crucial factor in the performance equation is top speed on the straights. This clearly links to the car's aerodynamic balance and to the ride heights chosen that cause this parameter to vary significantly.

When running at reduced ride heights, while the downforce generated by the floor radically increases, the AMR23 demonstrates inconsistent dynamic behaviour, and runs slower in a straight line. The cause of this could potentially be induced drag, which effectively cancels out the benefits in terms of top speed guaranteed by a low downforce aerodynamic configuration. It is, in essence, a simple question of flow management between the lower part of the car and the upper part.

Zak Mauger

Development seemed to stall at Monza, the AMR23 off the pace, suggesting it is better suited to high-downforce tracks

Starting from the Singapore event, further updates are to be expected, and the re-introduction of the revised and corrected tail winglet

Starting from the Singapore event, then, further updates are to be expected, and the re-introduction of the revised and corrected tail winglet could see the AMR23 once again in the best condition to express its potential.

Challenge ahead

We believe this constitutes a relevant indication that could also impact the target of the second part of Ferrari's season. For while the SF-23 still seems to have an advantage in terms of overall lap performance in qualifying trim, this would give it – at least theoretically – an advantage on tracks where the starting grid position is crucial to the outcome of the race, as is the case in Singapore. At the same time, if the race pace of the SF-23 turns out to be less than that of the AMR23, the latter could very well make a recovery.

A situation of this type would then be replicable in Qatar, Brazil, Las Vegas and Abu Dhabi, while we would expect to see more parity, in terms of competitiveness of the two cars, in Austin.

If all goes to plan for the Silverstone-based team between now and the end of the 2023 season, Aston Martin could very realistically challenge for second position behind Red Bull, involuntarily favouring the maintenance of Mercedes' current position in the standings, to the detriment of the scuderia from Maranello.

Second order

An new car for the F1 feeder series next season that is both safer and future-proofed for Aramco's new synthetic fuel

By ANDREW COTTON

The new car's aero has been designed to promote close racing, while safety advances include the Halo now being a structural part

The FIA unveiled the next generation of Formula 2 car, developed and built by Dallara, at the Italian Grand Prix at Monza in September.

The car will be around 80 per cent new, according to Pierre-Alain Michot, deputy technical director for Formula 2 and Formula 3. Details of the car are still being finalised and the model is undergoing extensive track testing ahead of delivery to teams.

There are some key points to the new car that were revealed at the launch. It will race throughout the 2024, '25 and '26 seasons with an updated 3.4-litre turbocharged Mecachrome engine that has been designed to take Aramco's synthetic sustainable fuel that will be introduced for the 2025 season.

For the 2024 season, the engine will continue to run on the 55 per cent bio-sourced sustainable fuel, which was first introduced in 2023. The engine is, says Michot, upgraded to ensure it will perform better on the same fuel in 2024. However, the main focus of the upgrade was to integrate 'all the hardware we will need for 2025.'

Few details of the new fuel were given, but Michot did confirm it would have very different behaviour to the current product.

Aero claims

One of the more nebulous claims in the press release is that the nose, front and rear wings and floor have been designed to encourage wheel-to-wheel racing, presumably by reducing the effect of wake from the rear wing, and the reliance on the front wing for overall performance. The car's drag reduction system (DRS) system has also apparently been 'optimised', according to a press release issued at the launch.

The F2 2024 has also been designed to comply with the FIA 2024 specifications for braking, steering effort (which has been reduced in line with FIA standards) and ergonomics, in order to accommodate a wide range of drivers and make the championship as accessible as possible. The cockpit has been designed to protect a range of driver size, from 1.5m to 1.98m in height.

Safety upgrades

Key to the new car, following a series of high-profile accidents, is a focus on safety, particularly at the front. The new car features an impact structure that increases energy absorption in the event of a frontal impact, and increased oblique impact strength, too.

The survival cell is better able to protect drivers and features a new front anti-intrusion panel, as well as increased sidewall and frontal impact load strength. This is all in line with the FIA's increased safety programme.

One of the major safety changes for the new car is a better integration of the Halo into the chassis. Formula 2 was the first single-seat series to introduce the Halo but, it has to be said, the first iteration of the head protection system was not particularly well installed. This latest generation of car has the Halo at its heart from the start of the design process, which allows the load paths to be better distributed around the car, further increasing driver safety.

The nose, front and rear wings and floor have been designed to encourage wheel-to-wheel racing

The Halo was controversial when introduced, but has proven to be a vital safety feature of single-seat racecars, now adopted throughout the FIA's portfolio of racing series.

'Ours was the first car to introduce the Halo and it arrived quite late in the development phase, so we had to add it to an almost finished monocoque,' admits Michot. 'In the end, it was not optimised, as it has been for the new car. That is why we put a lot of effort and improvement into this.

The car's 3.4-litre turbocharged V6 has been upgraded to use the series' new 55 per cent bio-sourced, sustainable fuel

'The Halo remains the same [as the old design] but the integration has been done in a better way. It is still bolted onto the chassis as it was before, but is now structural with the FIA requirements and push tests that we have to do on the car.

'It has been integrated from the beginning of the process, so the way the load is dispersed around the chassis is much better anticipated earlier in the project, and we have been able to save some kilos too.'

The final weight of the car has not yet been disclosed as the team is still testing and doesn't know exact weight and dimension details of some components, such as the television camera loom.

Data network

One of the major features of the 2024 version of the car is that it will feature a new Vehicle Control Unit (VCU), the latest specification from Magneti Marelli. This will improve the amount of data coming from the car and separate various channels that have previously been combined.

'We wanted to move to the latest technology for the car to make sure we can run it efficiently and safely,' says Michot. 'We have increased the number of CAN Bus on the car from three to eight. That means we have now dedicated CAN Bus for different systems on the car.'

This latest generation of car has the Halo at its heart from the start of the design process

The new network is designed more for the organisers of the series than the teams, and there is no desire to start a data war.

'We wanted to keep the same spirit as now,' confirms Michot. 'This is only in the background and doesn't affect the teams. It gives them the same philosophy in terms of data acquisition and system equipment, but for us it makes it more reliable.'

'A huge amount of work has been done by the FIA, Formula 2 and its partners to put together a truly impressive package focused on close racing, the latest safety technologies, even greater environmental sustainability and better accessibility for drivers than ever before,' said FIA deputy president for sport, Robert Reid. 'Seeing design philosophies and technologies cascading down from Formula 1 to the junior categories is a great testament to the FIA single-seater pathway that guides young talents from around the world towards a successful career in top-flight competition.'

TECH SPEC: 2024 FIA Formula 2 car

Dimensions
Length: 5284mm
Width: 1900mm
Height: 1097mm (including FOM roll hoop camera)
Wheelbase: 3135mm

Engine
3.4-litre, V6, single turbo by Mecachrome producing 620bhp at 8750rpm and 570Nm torque at 6000rpm; fly-by-wire accelerator system; rebuild after 8000km

Gearbox
Six-speed longitudinal Hewland sequential; electro-hydraulic command via paddle shift from steering wheel;
ZF Sachs carbon clutch; non-hydraulic ramp differential; no onboard starter

Monocoque and bodywork
Carbon / aluminium honeycomb sandwich structure survival cell; Zylon anti-intrusion panels; carbon front and rear wing; carbon / Kevlar honeycomb body structures, all made by Dallara

Safety standards
Full FIA F1 2024 spec with titanium Halo

Steering system
FIA 2024 spec non-assisted rack and pinion; new XAP steering wheel with dashboard, gear change, clutch and DRS paddles, plus marshalling and VSC display

Electronic features
New Magneti Marelli Marvel VCU 480 ECU / GCU, including data logging system; new Magneti Marelli FOX 442 power supply management unit; CAN data acquisition pre-equipment; beacon receiver; F1-type VSC and marshalling system

Suspension
Pushrod-operated double steel wishbones, twin dampers; torsion bars (front) and springs (rear); adjustable for ride height, camber and toe; two-way (F) / four-way (R) adjustable Koni dampers; adjustable front and rear anti-roll bars

Wheels and tyres
OZ Racing magnesium; 18 x 12in (front); 18 x 13.7in (rear); F2-specific Pirelli slick / wet tyres; Texense TPMS

Brakes
Brembo six-piston monobloc calipers; Carbone Industrie carbon / carbon discs and pads

Fuel
Aramco 55 per cent bio-sourced sustainable fuel for 2024; FIA-standard ATL FT5 125l fuel cell

DRS
Same functionality DRS used in Formula 1 with hydraulic activation

Extinguisher system
FIA-spec, electrically-operated FEV system

The similarities between F1 and F2 cars become more evident with every evolution, reflecting the desires of young motor racing talent who aspire to racing in the premier single-seat category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Hyper drive

A high-downforce single seater that's cheap to operate, easy to run and very fast. Racecar *meets the Australian makers of this refreshingly different creation*

By MIKE BRESLIN

'We understood what it takes to be involved in motorsport on a low budget. It's not about cutting corners'

Dean Crooke, director of engineering at Hyper Racer

Most spec single seater series look pretty much the same these days. They all tick similar technical design concept boxes, largely because they're meant to come across as baby Formula 1 cars, which is understandable, given the ambitions of today's young drivers.

But every now and then a car comes along that is genuinely different, both in terms of aesthetics and design philosophy. Something like the Hyper Racer X1, for instance, a ground-effect racecar conceived for low budget, club level, single-make racing that offers high downforce thrills, yet is simple enough for an owner / driver to run without a team or pit crew.

The X1 is produced by Melbourne, Australia-based father and son team, Jon and Dean Crooke. Crooke senior, the director of design at Hyper Racer, is a former Australian Formula 2 champion and V8 Supercar Group A driver, while Dean, director of engineering and the car's development driver, is an ex-kart champion, experienced race engineer and ace fabricator who has worked in V8 Supercars.

Their new car has grown out of another project, the Hyper Pro Racer, which is a sort of hybrid Superkart / spaceframe racecar that has had some success in its home country, running in its own one-make championship. While lessons were certainly learnt on that project, the X1 is very much its own car, with a very clear philosophy behind it.

'It came about because we understood what it takes to be involved in motorsport on a low budget,' says Dean. 'It's not about cutting corners, it's about the right motor and the right materials throughout the car.

'It's just about making smart decisions to create something someone can run on a reasonable budget.'

Space race

The first of those smart decisions was a minimalist approach in the car's design. Like all racecars, only more so. This means there's no superfluous bodywork, no differential and just two dampers.

Another smart decision was a carry-over, in terms of concept at least, from the previous car. The X1 was always going to be a spaceframe chassis.

'They are strong and repairable,' explains Dean. 'One example that instantly comes to mind is the off-road racing world, where it's specified that [chassis] must be steel. I know the formula car world has gone to carbon tubs, and that's all well and good, but there's nothing wrong with a tube frame.

'The first thing that pushes a car completely out of the price window for most is a carbon tub. That's where it all starts to go wrong for amateur level racing.'

The spaceframe is of 4130 chromoly steel, with curved main rails for added strength, while FIA-spec Diolin anti-intrusion panels are fixed to its flanks. The safety feature that really stands out, however, are the 'Henry bars', the gracefully arching cockpit tubes that have been named as a tribute to Henry Surtees, who died after a wheel hit him during an MSV Formula 2 race at Brands Hatch in 2009.

The Hyper Racer X1 offers high-downforce thrills for club level drivers. The car has been created with a minimalist philosophy and the result is a refreshingly different looking single seater

The FIA-spec Diolin side impact panels are visible here, as is the dramatically-shaped floor. Note the graceful 'Henry bars', an unusually attractive answer to cockpit protection

These are an integral part of the chassis, and probably the most aesthetically pleasing solution to this problem yet seen. There are also a multitude of cross braces throughout the frame, including a zig-zag tube layout that follows and protects the line of the driver's body along the side of the car, and another across the centre of the chassis, which aids crush resistance and adds torsional rigidity.

Importantly, none of this complex tubing is at the expense of driver fit or comfort.

'We put the most important part in the model before we started drawing tubes,' explains Jon. 'And that was the driver's body. I measured all my mates – fat ones, skinny ones, tall ones and short ones – and modelled them all in CAD. I then modelled the tube safety cell around the various driver models to arrive at an office space that accommodated all those drivers with a minimum of unnecessary wasted space.'

Material benefits

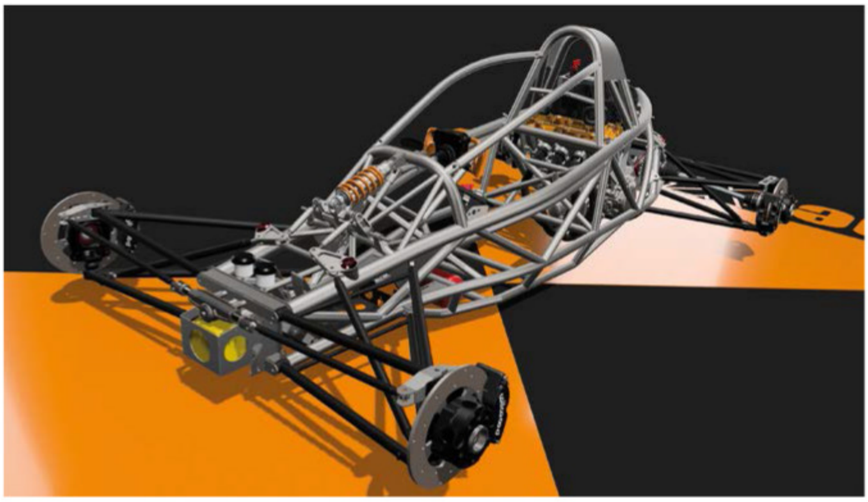
The car is not all steel, of course, and there's plenty of carbon fibre in the bodywork, which is of modular design for ease of replacement, and the aero parts.

'It's predominantly carbon, so the front and rear wings are entirely carbon, except for the front wing end plates, which are glass fibre,' says Dean. 'The seat and head restraint have a lot of Kevlar in them, the sidepods are carbon, and the huge undertray tunnels are carbon, 'glass and core foam materials.

'Also, all the bodywork is vacuum infused carbon, so it's not wet laminated and it's not pre-pregged in an oven. There is a lot of carbon on this car.'

With all that in mind, it's no surprise to learn that the X1 is light, weighing in around the 400kg mark, and can be as low as 390kg in hillclimb / speed spec, without the anti-intrusion panels and reverse gear etc.

Of those carbon parts, it's the aerodynamic elements that really catch the eye, as they're on the large side, to say the least. This is not surprising, though, as from the start the X1 was always going to be a high-downforce racecar.



The X1's spaceframe is constructed from 4130 chromoly steel with curved main rails and a plethora of cross braces

The X1 is extremely quick through the corners, with the spec aero package generating around 600kg of downforce. The car's large, single-plane rear wing helps balance out the powerful ground-effect floor

'One of our philosophies when we were designing it was to give our customers a thrill,' says Jon. 'Driving down a straight at 170mph, or 150mph, you don't really feel that much difference. Do it two or three times and you just feel like you're just driving in a straight line. The thrill comes in the corners.'

Thrill factor

That thrill factor is largely provided by a twin-tunnel, ground-effect floor, which is balanced out with generous over-body aero. While exact downforce figures were not available at

'I measured all my mates – fat ones, skinny ones, tall ones and short ones – and modelled them all in CAD. I then modelled the tube safety cell around the various driver models'

Jon Crooke, director of design at Hyper Racer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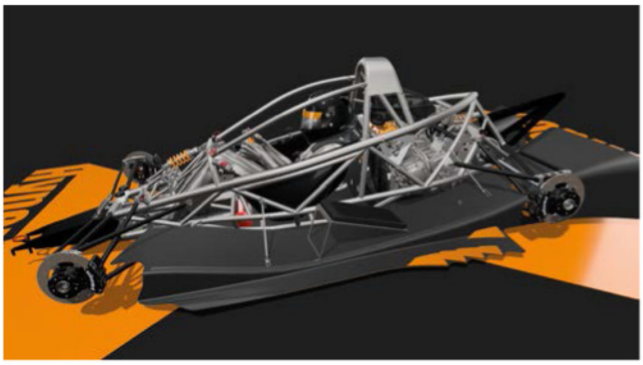
Tunnel exits and large wing and end plates seen from the rear of the X1. Hankook Formula 3 tyres have proved to be very durable, partly thanks to the car's light weight



The extent of the ground-effect floor, which is over three metres in length and made of a combination of carbon fibre and glass fibre, is clear in this CAD image

TECH SPEC: Hyper Racer X1

Engine
Suzuki Hayabusa 1340cc
Power: 198bhp; torque: 150Nm at 7000rpm

Transmission
Gearbox: Suzuki six-speed, lever-shift sequential; final drive: chain and sprockets; Rekluse centrifugal automatic clutch

Chassis
Handmade 4130 chromium-molybdenum alloy steel tube; 'Henry bars' cockpit protection; Diolin side impact protection panels

Bodywork and aerodynamics
Carbon fibre and Kevlar vacuum infused body panels, twin-tunnel, ground-effect undertray; double-element front wing; rear wing

Suspension
Front and rear independent wishbone; pushrod / bellcrank with inboard shocks; Öhlins coilover aluminium monoshock dampers; adjustable toe, camber and anti-roll bar; billet milled aluminium uprights; rack and pinion steering

Brakes
Four-piston Wilwood calipers; 280mm cross-drilled discs; billet milled aluminium brake hats; twin split master cylinder system; Wilwood pads; cockpit-adjustable brake bias

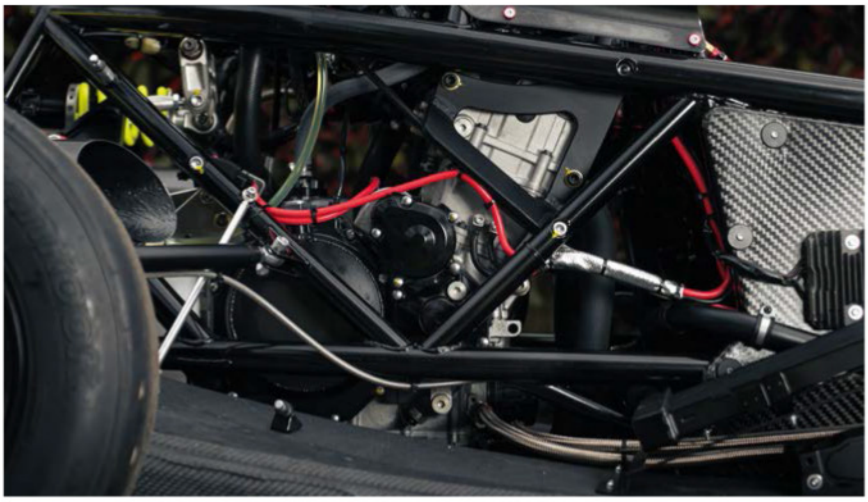
Wheels and tyres
Two-piece aluminium rims (front: 13 x 9in / rear: 13 x 11in); Hankook F3-spec slicks and wets; wheel tether option

Cockpit
Carbon fibre / Kevlar vacuum infused seat and head restraint; F1-style quick release steering wheel; AIM Solo 2 dash; dual pedals (throttle and brake)

Performance
Lateral acceleration up to 2.8*g*; maximum braking declaration 3*g*; acceleration to 100km/h, three seconds; 0 to 200km/h eight seconds; top speed 235km/h (track dependant).

Dimensions
Length: 3850mm; width: 1950mm; height: 980mm; wheelbase:2450mm

Weight
Dry: 390kg (speed events); 400kg (race)



The 198bhp Suzuki Hayabusa engine is standard, apart from some oiling modifications and a re-mapped ECU. The light weight of this unit means the car can run effectively with just a monoshock at the rear (seen here in yellow)

time of writing, estimates are around the 500-600kg mark or, as Jon says, 'enough for the theoretical driving on the ceiling situation.'

But where the X1 really seems to shine on the aerodynamic front is that, unlike cars with restricted over-body aero, such as pre-FIA spec series Formula 3, it is not on a knife edge at the limit, thanks to the beautifully sculptured rear wing.

'With a bigger wing on the back, even if the ride height jumps and the car moves a bit and you start to lose a bit of grip, you've still got a lot of downforce,' says Jon.

Due to the way that the twin-tunnel undertray works, the balance between having front-end grip at lower speeds and then more overall grip at high speeds changes as the car goes faster.

'If you shape your underfloor tray tunnel correctly, you can actually move the centre of pressure back along the tunnel as the speed increases,' continues Jon. 'And that's what we've done here. We get most of our downforce at the centre of the car, under the driver's bum, at low speed, but as soon as it starts to make downforce and squat, it moves back about 45cm or so.'

The aero effect also comes in quite early, in terms of car speed. 'We've got a corner on the track we test at. It's about 100km/h, a 60mph corner,' says Dean. 'When we were running linear sensors on the shocks we were seeing quite amazing downforce numbers here, which really surprised me. I thought on that part of the track we'd be working on mechanical grip alone, but we were still seeing the car compressed through downforce.'

The floor is huge, three metres long in fact, though it is not a single piece.

'The side undertray tunnels are fully carbon fibre and glass fibre, vacuum infused, single piece, but one on each side,' explains Jon. 'They're separate, so you don't have to replace the whole floor if you damage it.'

Hayabusa power

Because of the intricate, dual-element front wing and large rear wing, the car is relatively draggy down the straights. But in a one-make series that's no bad thing for the racing as it aids slipstreaming, and spec racing is what this car is designed for.

That's not to say the X1 is slow in a straight line (235km/h [146mph] is quoted), or in acceleration (0-100km/h [0-62mph] is three seconds), and this is largely thanks to a 1340cc, 198bhp, Suzuki GSX Hayabusa motorcycle engine. On straight power-to-weight, the car's around 500bhp/tonne.

For several reasons, the motorcycle powerplant has been kept standard.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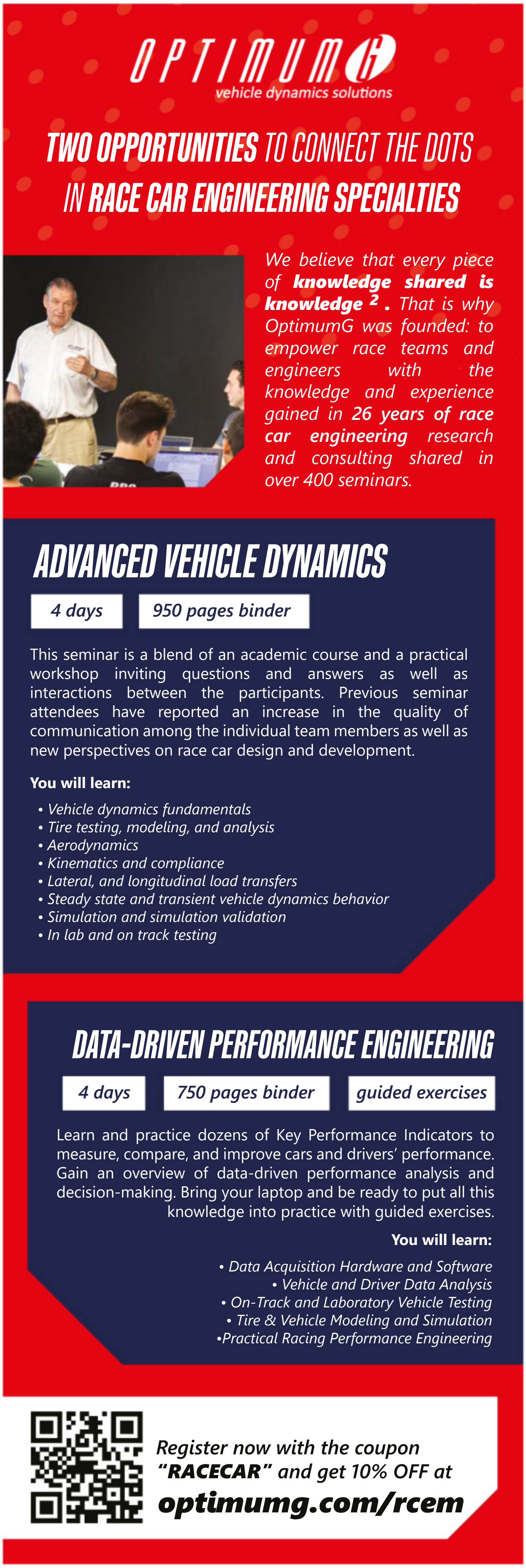
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'We'd already proven that the concept of a locked diff' and single shocks, front and rear, can work and wanted to upscale that, because it's half the cost, half the weight [and] half the maintenance'

Dean Crooke

The suspension is double wishbone with pushrods and bellcranks. Single Öhlins aluminium dampers front and rear are a spec part with fixed settings to help keep set-up and running costs in check

Bespoke steering wheel incorporates specially designed grips for improved ergonomics. Gear selection for the six-speed sequential 'box is via a deliberately 'old school' lever. This car is all about the driving experience

'We keep it stock, for parity of performance and for engine availability,' explains Dean of that decision. 'The only things we do is put our own sump baffle plate in, our own oil fittings and flash the ECU – not for performance reasons, but to turn off some of the emissions control stuff you don't run on a racecar. Otherwise, it is a genuinely stock Hayabusa engine.'

The gearbox is integrated with the engine and is a six-speed sequential. As it's all taken from a Gen 2 Hayabusa, there's no auto-blip, but then this car is all about the driving experience, which is why there's an old fashioned gear lever rather than a paddle shift (though the latter can be fitted if required).

That said, there are only two pedals, throttle and brake, as the X1 has a Rekluse centrifugal automatic clutch, which means standing starts are a little unusual.

'You essentially put your foot down and the centrifugal clutch bites straight away, but at a low rpm, so it puts the power down quite nicely and then, depending on the grip available, it'll break into wheelspin and then you might have to modulate the throttle a bit,' confirms Dean.

'The only downside is you're not on the line with the engine red lining and then letting the clutch fly, which has its pros and cons: it doesn't sound as good, but then it's a lot easier on the driveline.'

Mechanical grip

That driveline feeds direct to the wheels through a chain and sprocket, so there's no expensive differential. Which begs the question, while the car has plenty of grip when the aero load is on, doesn't it push-on at the front with acceleration at low speeds?

'What we've done with the overall geometry of the car is we're running a fair bit of front castor, and we're running a softer front in roll than we are at the rear,' explains Dean. 'All of that is helping the car to sort of roll in to help unweight the inside rear tyre, especially in slow-speed corners when there's not as much aero load. So, essentially, we are getting the inside rear tyre to slightly unload, to help it turn in.'

The suspension is one of the most intriguing aspects of this car, with pushrods and bell cranks operating Öhlins aluminium monoshocks at both ends.

'Right from the very beginning, we were going to go single shock rear,' says Dean. 'We'd already proven that the concept of a locked diff' and single shocks, front and rear, can work [on the Hyper Pro Racer] and wanted to upscale that, because it's half the cost, half the weight, half the maintenance, and it truly can be made to work.

'I think one of the reasons it's not seen on other cars is just weight. Maybe with a big engine and gearbox out the back you start to get to the limit of one shock, but we didn't have that issue with the 'bike engine. And there's nothing in the back of the car because the gearbox is under the engine, so the rear is very manageable.'

This is a high-downforce car, though, so still needs to be held up when at speed.

'We've got pretty aggressive rising rate suspension, in the ratios in the bell cranks,' says Dean. 'The idea being that once it's on track and compressed by 40mm, the rates have gone right up compared to what they were when sitting stationary in the pit lane, but it's still functioning and still on the springs, not on the bump stops.

'We tuned and tested that in the early days for quite a while until we settled on the right spring rates and the right pre-loads. That is now set, so we don't have bell cranks with 35 different holes in them and other things to play with. We've settled on all that stuff, including that the shock in the car is non-adjustable. This is because we didn't want guys going testing for three days before a race meeting with quad-adjustable shocks and then finding tenths of a second and having an advantage.

'That wasn't the whole point at the level we're at. So, it's fixed shock and fixed ratios on the suspension. That's it.'

The aforementioned features all point to something central to the X1 concept. For while the car itself is not especially cheap to buy – £63,500+VAT in the UK [approx. $95,475], which stacks up well against similar racecars, and is certainly good value for the level of performance on offer. Where this machine really scores is with its running costs.

Running costs

'We've got categories here in Australia, a comparable speed, maybe slower, and people are putting A$150,000 [approx. £75,000 / $96,500] or more a year into running their cars. We're running in a five-round series for A$5000 [approx. £2500 / $3215] a year. Just staggeringly different running costs,' says Dean enthusiastically.

Some of this is due to the tyres, as the X1 runs on Hankook Formula 3 rubber, which is proving very durable – partly because the car is around 150kg lighter than an F3 car – but also those standard Hayabusa engines are unlikely to go bang after just a few races.

Perhaps the biggest saving, though, is found in not having to have a team, or even a pit crew, to run an X1. This is the very definition of turnkey motor racing, with the driver / owner needing to do very little work on the car during a race weekend. Or, as the Crookes put it, it's simply 'wash and race'.

'We make everything bar the wheel bearings, the engine and the tyres… The only components in the suspension area that are not ours are the Wilwood brake calipers and pads'

Dean Crooke

That said, this is still a racecar, so there is some adjustability on offer.

'We wanted to minimise the amount of adjustment available, but you obviously still need enough to make it do what you want it to do, and to chase different weather conditions,' says Dean. 'So, the adjustments are what you'd expect: wing angles at both ends; castor; camber; toe-in; toe-out; brake bias; tyre pressures; ride heights… all that kind of stuff to make the car handle how you want it to handle. But we've limited it before you get to four-way adjustable shocks, endless gear ratio changes and things where you start chasing hundredths, or tenths at most. This is where we wanted to draw the line, because the point of diminishing returns is obvious, and it just kills it for an amateur level, weekend racer car.'

Another cost saving measure is that the X1 has been designed with parts that are interchangeable across the car.

'The disc rotor, the brake disc hat and the brake caliper are the same on all four corners,' confirms Dean. 'The wishbones flip left to right, the uprights left and right are the same on the front and then the same left to right on the rear. It's a lot of things, especially the hang-offs, the external stuff, which means you can carry probably a third of the spares you usually would and still be able to fix a corner at the track.'

These are certainly not off-the-shelf road car parts, though, as Dean explains: 'That approach often doesn't get you a great open wheeler, because everything's a little bit big and a little bit inefficient. We make more parts on this car than most people building a car would. We make everything bar the wheel bearings, the engine and the tyres… The only components in the suspension area that are not ours are the Wilwood brake calipers and pads.'

The bespoke parts are exquisitely worked, too, it should be noted.

Where this car also impresses when it comes to the componentry is in the attention to detail. There is a neat clip to hold the steering wheel when it's detached, for instance, and then there's the jewel of a steering wheel itself.

'We had to design it ourselves because we've gone to a full Formula 1-style set up, not like a normal Formula 3-type car where your arms are stretched out a bit and your knees are lower and the steering wheel is a bit lower,' explains Jon. 'Ours is quite high and close. So, usually, your hands would come up to the wheel grip and you're bending your wrists. But with our wheel the face is vertical, but with the grips moulded into it at an angle. That allows the [driver's] arms to come up at almost 45 degrees, which makes it a much more comfortable drive.'

Hyper market

Details like this attest to the fact that a great deal of thought and effort has been put into the X1, and for a very specific purpose. But now the company has a car that is both fast, comfortable to drive and cheap to run, is it mission accomplished?

'We wanted to get it right, and we did a lot more testing than many people would normally do in the early days,' says Dean. 'Now we won't change it. And that obviously works for the racing. It works for branching out around the world too, and not having five different versions.

'It also helps re-sale. Someone could sell one of these cars many years after buying it and it would still be relevant, and therefore still command a high price.'

Talking of sales, the X1 already seems to have captured the imagination of racers, with 19 cars running in a one-make championship in Australia, and another 20+ sold, while interest in the US is already very strong, with a first order of 10 cars sold there, for track day / track resort use at present.

Meanwhile, in the UK, Hyper Racer dealer, Oliver Hulme of Le Mans Coupes, is campaigning a car in the Monoposto Championship to showcase its performance, while there are longer term plans for a spec series in the future.

'It's been designed for someone who wants to have that thrill of high downforce formula driving; to feel like Lewis Hamilton or Nigel Mansell, whoever their hero is, or was,' Hulme says of the X1. 'Yet without the budget of running an F3 car, or the like.

'Also, there's the simplicity of it. It's run a spanner over it 10 minutes before [a race] and then away you go. That's the sort of demographic we're going at.'

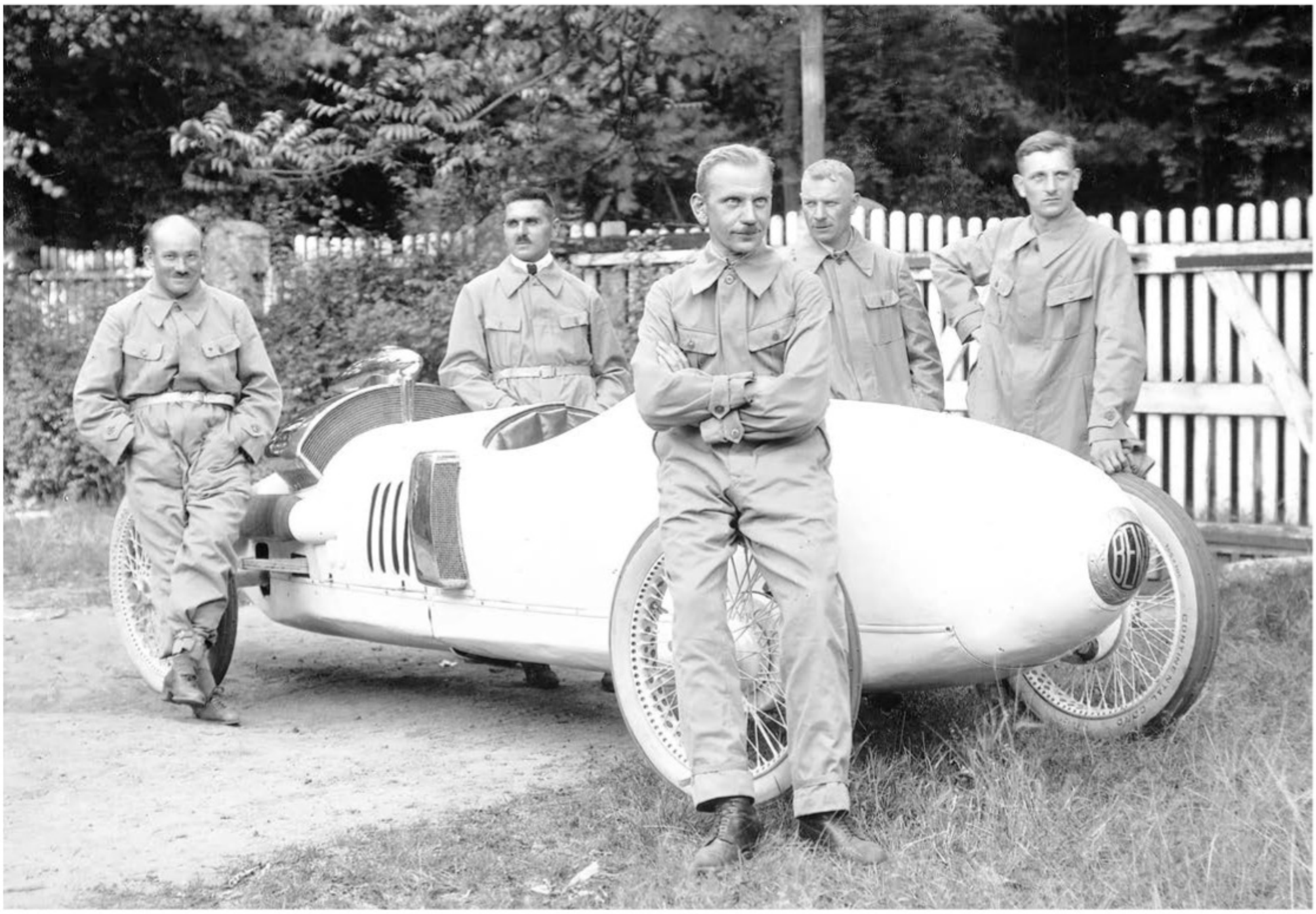
In this plug 'n' play, time-poor age, there are a lot of people who fit that demographic, so the chances are we will see plenty of Hyper Racer X1s on racetracks across the world in the coming years. It's a good job they're not boring to look at, then.

There is already a one-make series up and running in Australia for the X1, while cars have already been sold into the US track day / track resort scene, and there are hopes for spec series in both America and the UK soon

The crying game

In 1923, the appeal of a completely new technology inspired Benz engineers to build the most advanced racer of its time. **Racecar** ***remembers the radical 'teardrop car'***

By KARL LUDVIGSEN



With Willy Walb in the foreground, a proud team pose with their Benz RH, a car stunningly in advance of its time

In the midst of the great war, Hans Nibel assumed the responsibilities of chief engineer at Benz in Mannheim. Under Nibel were Robert Staffin, in charge of engine design, and Max Wagner, the chassis man. In wartime, Arthur Berger headed the Benz aero engine development effort, while director of the experimental department was a tall, serious engineer named Willy Walb.

Under Berger's watchful eye, Walb steadily built a reputation as a perfectionist among a group of perfectionists.

This was the core of the capable crew charged by the board of the *Rheinische Automobil und Motorenfabrik AG Benz & Cie* with creating a new production car programme in the chaotic economy of post-war Germany. The team set its standards high, seeing no reason why they shouldn't advance the technology of the automobile with what they and others learned in wartime. The result would be the most radical racecar the world had yet known.

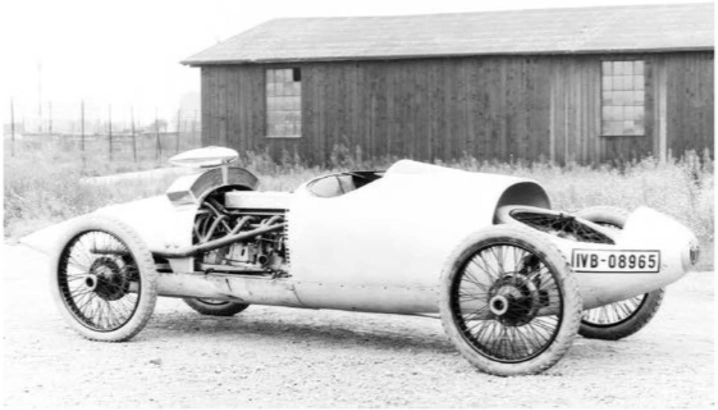
At the first German post-war motor show in September 1921, Nibel and Wagner saw a car that showed a new way forward. On aeroplane builder, Edmund Rumpler's, stand was a chassis, an open model and a closed version of the car he called the *Tropfen Auto* (teardrop car), after its uncompromisingly streamlined shape.

Favourable comment

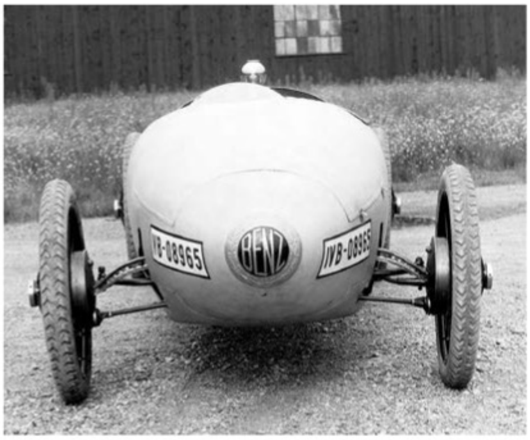
'Here for the first time in more than 10 years,' one report glowed, 'are shown fundamental transformations in the design of the automobile.' Another noted; 'these cars attracted immense attention and generally favourable comment, despite their unusual appearance.'

'Favourable comment' was music to the ears of the Benz men, who felt 49-year

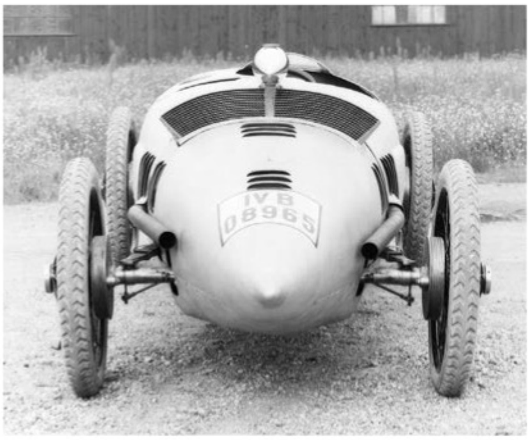
Carrying the Benz badge, this was the *Tropfen-Auto* built by Edmund Rumpler that Benz planned to produce. Perhaps for the best at the time, this didn't come to fruition



Starting in 1922, the Benz team built this first prototype racecar along Rumpler lines. Its original engine was only experimental for testing before the final 2.0-litre six was ready



The 1922 prototype Benz RH had independent front suspension, but this was not pursued in the final design



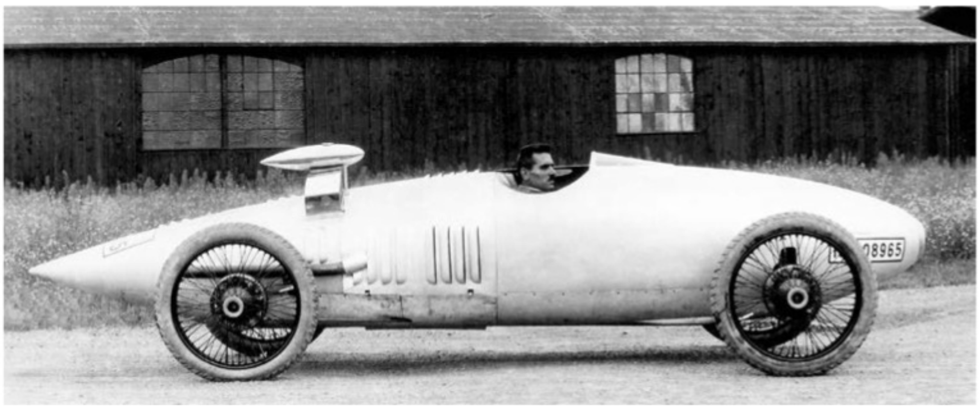
The experimental 1922 car's twin exhaust pipes were clearly visible from the rear. The onboard mechanic's position was covered here

old Rumpler was on the right track. He had married his background as an automotive engineer with his experience as an aviation pioneer to build a precedent-defying automobile that combined a central passenger compartment with a low drag teardrop form, a rear engine and independent rear suspension by swing axles.

Benz took an option on these innovations at the beginning of 1922. On January 21 that year, the conservative Benz board held an exceptional general meeting to learn that their company was negotiating a general licence allowing unlimited sales of cars to Rumpler's designs. With this preliminary agreement in place, a chest full of technical drawings and a long chassis, open, *Tropfen Auto* tourer arrived in Mannheim for experimental work.

The car's original W6 engine was replaced by a Benz inline four and Wagner's chassis men roamed local roads, searching out the car's strengths and weaknesses.

A precedent-defying automobile that combined a central passenger compartment with a low drag teardrop form



The narrow nose and long tail of the 1922 prototype Benz were striking, as was the tiny cockpit for driver and riding mechanic

The Benz board was also persuaded that it would be good 'propaganda' for a future rear-engined production model to anticipate it with a racecar of similar layout. Work was initiated on the design of such a car to suit the 1922 2.0-litre grand prix formula.

Test and tune

Willy Walb was assigned the task of testing the Rumpler *Tropfen-Auto* and conducting its initial assessment and development. In theory, it was a finished design, needing only validating to be made production ready, but Walb's findings suggested the contrary. He concluded there were problems with the Rumpler chassis, especially with the guidance of the swing axles. This gave trouble later when *Tropfen Autos* served as taxis in Berlin.

After these tests, Benz decided not to seek a full licence. Instead, during 1922, it went its own way in the development of a rear-engined passenger car. The decision would require the manufacturer to tiptoe shrewdly through Rumpler's dense maze of patents.

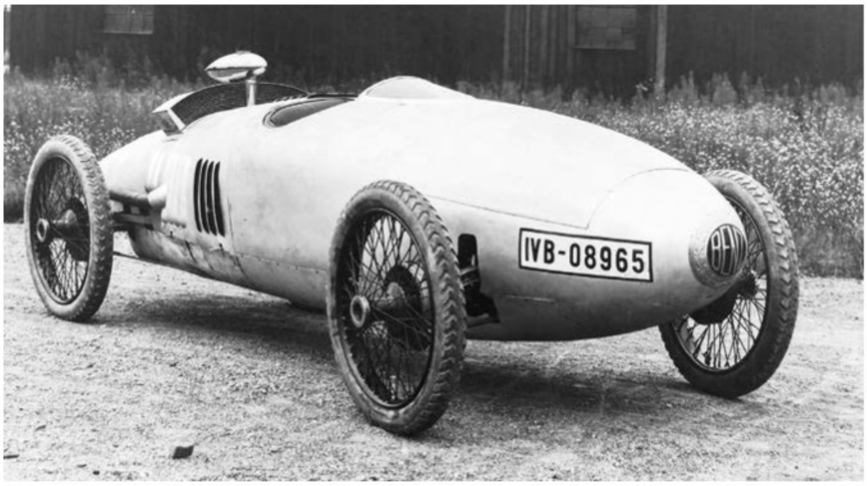
Though delayed by work stoppages, material shortages and the problems of inflation, work on the racecar moved forward. However, it wasn't moving fast enough to meet the initial target; an entry in the inaugural race at Italy's Monza late in 1922.

Serving as a prototype, the first racecar was a marvellously slim machine, an engineer's idea of what a racecar should look like. Its teardrop form and Rumpler ancestry won for it the *Tropfen-Wagen* nickname, but its design and components were part of a Benz RH (*Rennwagen Heckmotor*) series.

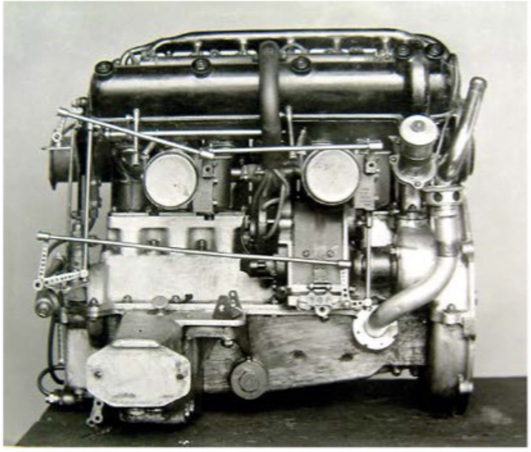
Racing cigar

The prototype Benz RH differed in many ways from the cars that eventually raced at Monza in 1923. RH number one's body was nearer circular in cross section and had a more tapered, slimmer nose – a real 'racing cigar'.

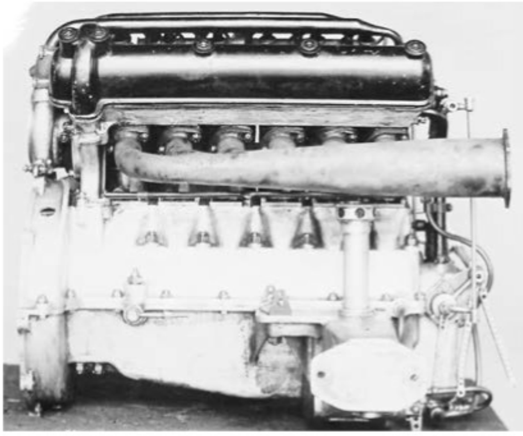
A hatch in the nose opened to give access to a spare wheel, while the fuel tank was in



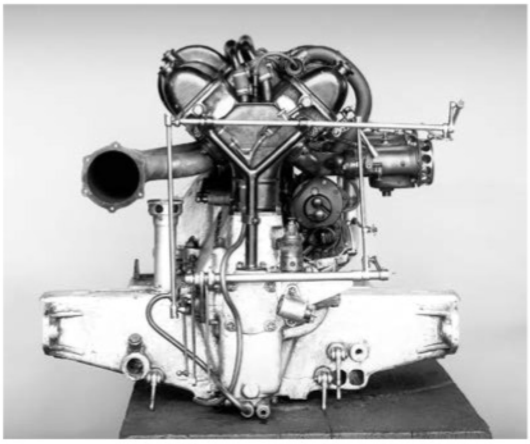
The wheels and tyres of the 1922 RH prototype were larger than those used in the car's final design. A radical cooling system was already employed with a crescent-shaped radiator that owed its design to contemporary aviation practice



Twin sidedraft carburettors fed the six-cylinder engine designed by Arthur Berger and Robert Staffin. Gear drive to the cams was at the rear



The fabricated steel cylinders of the RH were integral with the cylinder heads, made in blocks of three cylinders. The reversed exhaust shown in these engine out of car images suited test bed running



Four front and rear engine bearers added substantially to the RH Benz's frame stiffness. A magneto is tucked into the engine's cooler side

the rear, above the differential. Power for the prototype came from an experimental, overhead valve, four-cylinder engine that needed exhaust pipes on both sides. Experiments with this first RH included varying the size of the externally-mounted radiator behind the engine bay.

Changes to this technician's ideal included compromises with the realities of racing and test experience. Since racing would be on smooth, hard surfaces, the spare wheel was dispensed with, an enlarged fuel tank taking its place. Wheels and tyres were smaller, on a wheelbase of 109.4in. The RH was 'crab tracked' at 55.2in front, 49in rear.

Every possible part was drilled for lightness, including the wheels, front axle, shift lever and gate and the accelerator pedal arm. The official weights of the three cars presented for scrutineering at Monza in 1923 were 1590 (721), 1599 (725) ad 1621lb (735kg).

Chassis detail

The RH's channel-section side rails followed the ovoid plan view of the car. Cross bracing was scanty, with just three crossmembers at the front and one at the extreme rear, where the frame was braced by the engine / transaxle assembly, bolted in at four points.

A dead straight, I section front axle was sprung, like the Rumpler's, by two five-leaf, semi-elliptic springs cantilevered forward. Below the springs, running straight fore and aft, twin radius rods provided front axle guidance. Mounted on a tubular superstructure that also supported the fuel tank, a worm-and-spindle steering gear operated a drag link to the steering arm on the left wheel.

Benz had to use a rear suspension design that wouldn't contravene Rumpler's many patents. As a result, the RH had a more practical system. A differential fixed on the frame drove the axle halfshafts through universal joints in spherical housings, similar to those then widely used for the forward mounting of torque tube axles. Each axle housing had a forged Y at its inner end, attached to two pivots in line with their associated universal joint, mounted on the transaxle case. The axles swung fore and aft.

No shock absorbers were fitted to the rear suspension because the designers judged the scrubbing action of the tyres against the road provided sufficient spring damping with a swing axle layout. Front friction dampers, initially of the contracting band type used on the pre-war cars from Mannheim, were changed before Monza to more modern multiple disc dampers.

During their revision of the first RH prototype, Wagner added the rear brakes to the car's sprung weight by mounting them inboard, flanking the final drive gears. The mechanical brakes were small in size by contemporary standards, with finned and ventilated iron drums.

Something special

The RH's six-cylinder engine was engineered from the ground up for racing under the direction of Arthur Berger, assisted by Robert Staffin. Based on their post-war experiments, they used a four-valve chamber. Its cylinder dimensions were 65 x 100mm for 1997cc. Valves were symmetrically inclined at an included angle of 90 degrees, and in their centre sat a single Beru spark plug at the top of the combustion chamber.

Twin overhead camshafts opened the valves through light finger followers. Cams and valve gear were housed in aluminium chambers attached to the steel cylinders.

At the rear of the engine, a train of gears carried the drive to the camshafts, while a gear on the left side was added to drive the Bosch magneto. A large centrifugal water pump was attached to the back of the engine and driven by an intermediate idler gear.

Berger used techniques he first employed in his *Kaiserpreis*-winning aero engine of 1912 to fabricate the RH's individual cylinders.

[Arthur] Berger used techniques he first employed in his *Kaiserpreis*-winning aero engine of 1912 to fabricate the RH's cylinders

Each had its own steel inner wall surrounded by a welded-on, sheet steel water jacket. Cool water entered each cylinder above the exhaust valve guides and seats from a manifold at the top of the engine. Another manifold extracted warm water above the inlet valve side of the head.

Exhaust manifolding, on the right side, flowed to a single pipe extending out and back along the body. Front and rear groups of three cylinders were fed by individual manifolds, each carrying a single sidedraft Zenith carburettor of 42mm bore. A small balance pipe connected the two manifolds.

Benz hadn't experimented with supercharging during the war and evidently judged it wasn't required here, either.

The Hellmuth Hirth company in Cannstatt, predecessor of today's Mahle KG, produced pistons of magnesium alloy for the Benz RH. These provided a compression ratio that was modest for a 1922 racecar design: 5.8:1.

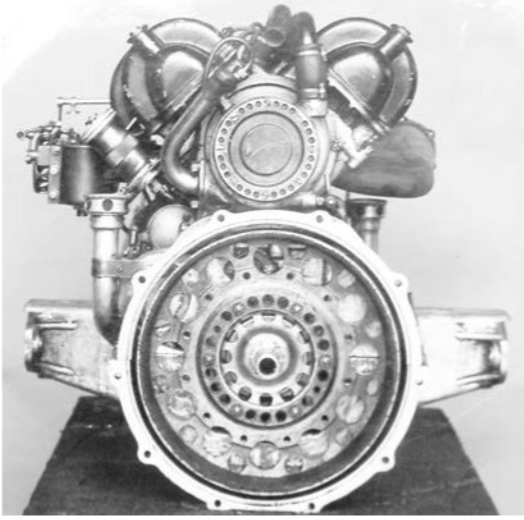
Hirth also manufactured the car's crankshaft, which was fully demountable to permit the use of roller bearings for both the big ends of the steel connecting rods and the seven main bearings.

Perhaps the most eye catching feature of the Benz RH was its radiator. Positioning a radiator above and behind the engine was familiar to all who had been associated with wartime aviation, but Benz mounted it on a structure above the bellhousing, using a core on the 1923 racecars that was 30 per cent larger in area than the one on the 1922 prototype, and much thicker as well.

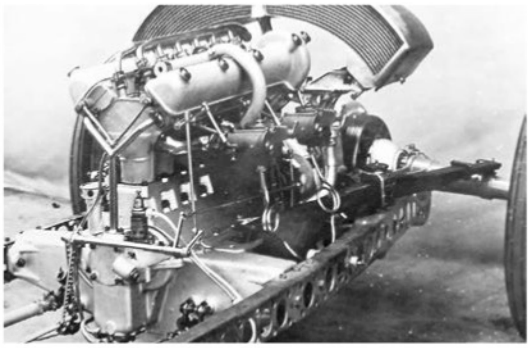
Rakish feature

Water flow through this radiator was from end to end. Hot water rose from the engine to the rakishly streamlined header tank at the top centre. From there, it flowed outward to the ends through the top half of the core. It then reversed direction at the end caps and returned to the centre through the bottom of the core, where the water pump drew it back into the engine.

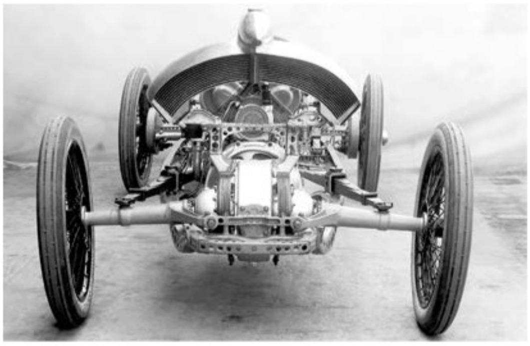
This sufficed to cool an engine that developed 80bhp at 4500rpm and could reach a maximum safe speed of 5400rpm. These were modest numbers in 1923, when the best unblown, 2.0 litre racecars were delivering 100bhp or more, and the early supercharged models were doing even better.



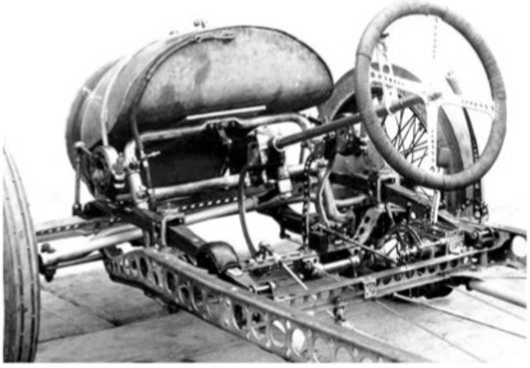
The working surface of the cone-type clutch is visible from the engine's rear view. The water pump is driven directly by a cam drive gear train



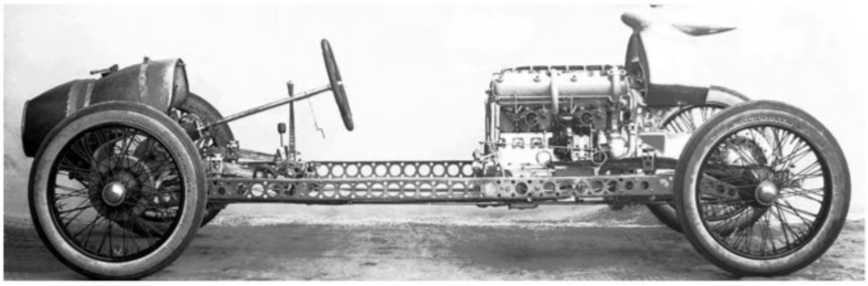
Installed engine image shows the linkages of the throttle and other controls. Coolant is fed directly from the water pump to the radically-shaped radiator and streamlined header tank



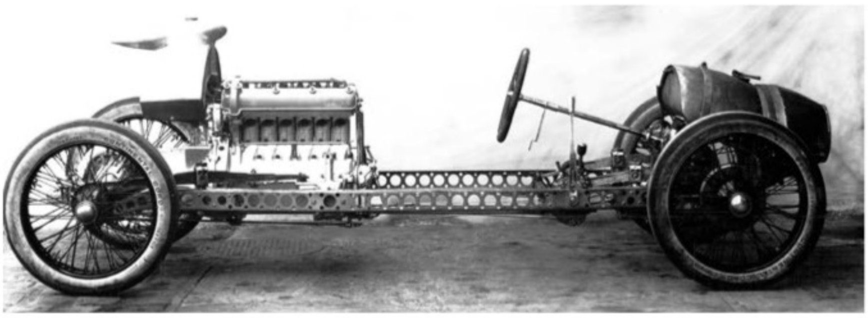
A structure over the bellhousing carries the Benz RH's radiator. Rear axle torque is controlled by pivoting yokes and spring attachments, while the rear brakes are mounted inboard



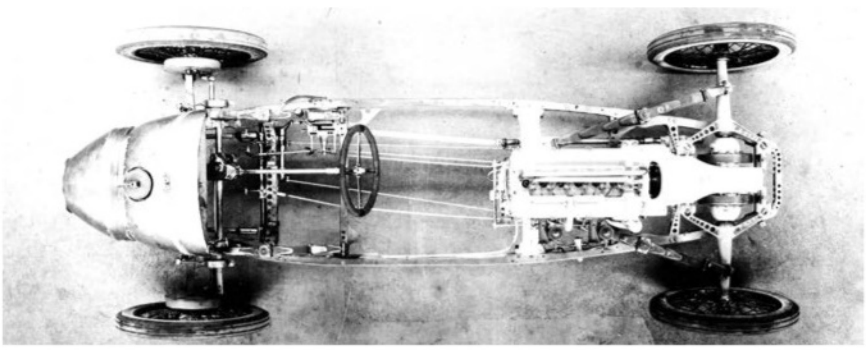
Front semi-elliptic springs are similarly anchored, with extensions carrying the I-beam solid axle. Lower radius arms control axle twist



Extreme drilling of frame side members, and just about every other conceivable part, suggests flexibility, but apparently that was not considered deleterious to the Benz RH's handling qualities



Side views of finished car show the final RH radiator core design to be almost twice as thick as that of the prototype



Frame side rails curve gracefully to suit the plan view of the RH Benz's extreme teardrop streamlining. This angle shows cleaerly how the rear wheels are sprung by semi-elliptic springs clamped to the frame at their centre points

(Later, with three carburetors, the engine was developed to give 90bhp at 5000rpm).

Torque was delivered through a cone clutch to a three-speed transmission between the engine and the final drive gears. It was direct drive in top gear with reductions of 2.0:1 and 3.7:1 in second and third. Its control was a lever at the driver's right, working in a gate with a latch that barred reverse gear.

Seats in the racecars were staggered, with the mechanic more to the rear. Although the occupants' heads protruded more than in the 1922 RH, they were far better shrouded than in any other racing model of 1923.

At the front, the nose became fuller to make room for the 34.3-gallon fuel tank, reached through a faired lid for the filler cap instead of the earlier swing up hatch. On the left side was a Benz RH feature shared with few other grand prix cars: a rear hinged door.

Race debut

Three of the white RH Benzes were completed in time for the Grand Prix of Europe at Monza, Italy on September 9, 1923. They were a welcome addition to a thin field of cars, which included the newly supercharged Fiat eights and the as yet unblown American Millers. Benz veteran, Franz Hörner, handled one Benz, Walb another. The third was driven by the peripatetic Ferdinando Minoia, who had driven a supercharged Mercedes in the Targa the year before.

Official practice for the 500-mile race began on Monday of the week before Sunday's race over the then-unique Monza melding of a road course with a banked 6.2 mile track. The Benz team soon realised the supercharged Fiats, Alfas and the Millers had speed, but the RH was faster than the unblown French entries of Voisin and Rolland-Pilain. Alfa Romeo withdrew its cars after driver, Sivocci, was killed in a practice run.

At the weigh in, all had to be heavier than 1433lb (650kg). Only the Fiats were lighter than the Benzes, by a mere 25lb (11kg).

Some 200,000 people were in the stands and along the course for this, the second major race at Monza. Starting from the grid at 9am, only the three Fiats and a Miller headed the Benzes after the first lap.

Closest to matching the leaders was the experienced Minoia, almost half a minute faster for that lap than his team mates. After five laps he was still among the Millers, while his colleagues fell back. On the sixth of 80 laps, Walb's Benz retired with what was diagnosed as a broken piston.

At half distance, the two surviving Benzes were fifth (Minoia), one lap in arrears, and sixth (Hörner), three laps behind the Fiat trio and Jimmy Murphy's Miller. Everybody then moved up a place when one of the Fiat drivers cried enough.

At the final flag, after five and a half hours of racing, Fiats were one / two, scoring the first grand prix victory for a supercharged car. Murphy's Miller was third, only 5¼ minutes behind the winner. Ferdinando Minoia's Benz came home fifth, and Franz Hörner's sixth, nine laps behind, but still a lap ahead of another Miller entry.

Minoia's success was credited to his smooth, regular pace, so judicious that no changes of his RH's Continental tyres were required.

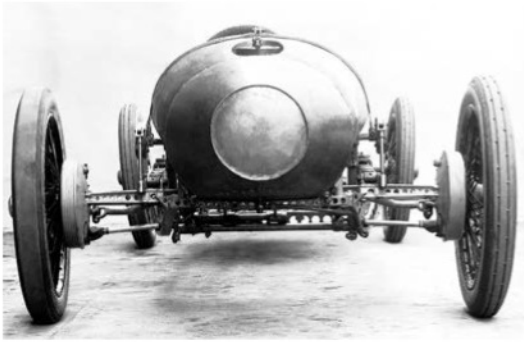
Gold medallion

Though modest against the winner's 150,000-lira award, Minoia received 25,000 lire and Hörner 15,000 for their efforts. Most rewarding for the team from Mannheim, however, was the gold medallion awarded to Max Wagner for his contribution to the Benz RH design as the most outstanding new car. It was an apposite honour for a man, and a company, trying to cope with the galloping inflation of late 1923 Germany.

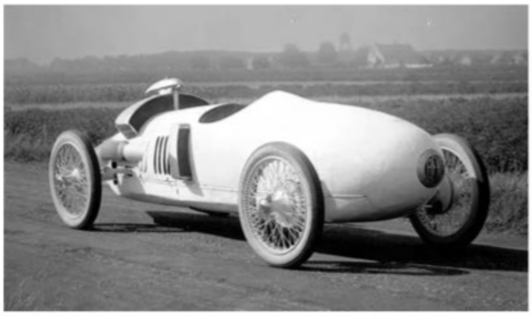
Benz had good reason to be proud of finishing two out of three with such radical cars in their first major race outing.

The economic crisis postponed any thoughts of a continued racing programme

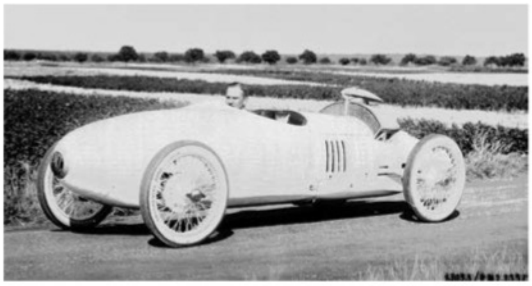
[At Monza] the gold medallion [was] awarded to Max Wagner for his contribution to the Benz RH design as the most outstanding new car



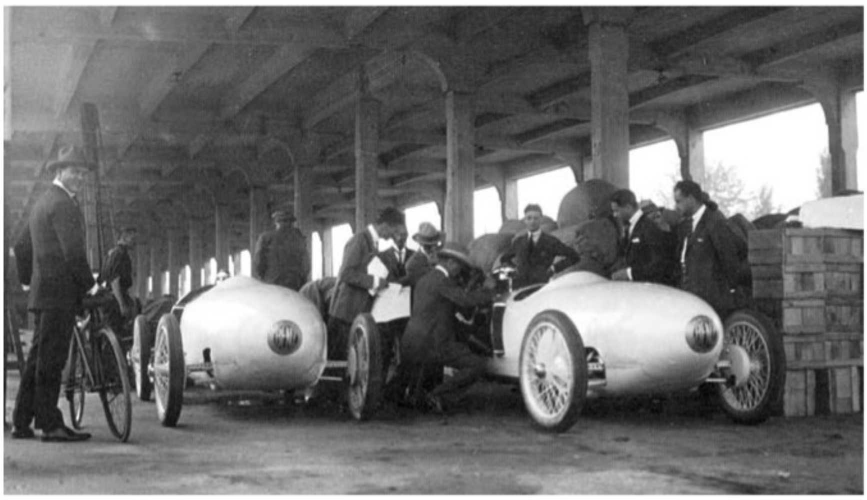
Front mechanical brakes of the RH Benz are well exposed for cooling, while damping at the front is by rotary friction drums



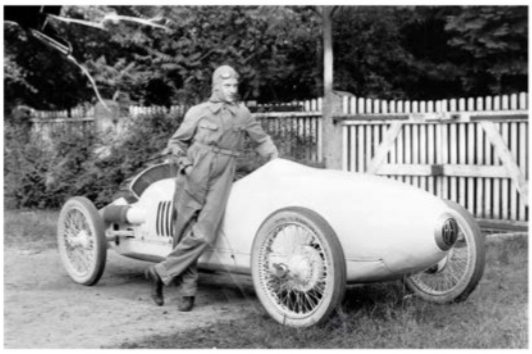
With an extra cooler externally mounted on its right flank for oil, the completed 1923 Benz RH looks every bit the purposeful racecar



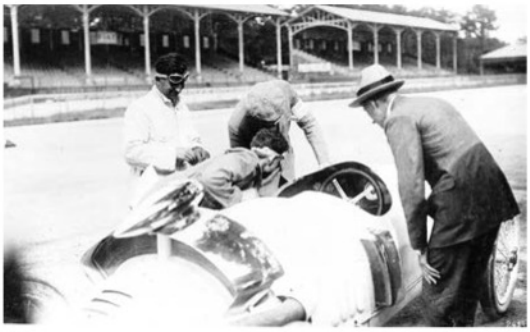
Willy Walb is at its wheel for a portrait of the 1923 Benz RH viewed from its left side. Both driver and mechanic are well concealed



Before proceeding to their race debut at Monza, the Benz team needed to pass the muster of Milan's customs authorities, for whom these radical automobiles were clearly a novelty to be scrutinised in great detail



Posing with the completed Benz RH is Willy Walb, who brought both engineering and racing know how to this radical project



Minoia looks on as engineers and his mechanic tend to last-minute adjustments. The driver has view of the tachometer, while other gauges are situated in the riding mechanic's line of sight

The 2.0-litre grand prix cars take their places for the start on September 9, 1923. This wide area is common to the oval track, seen disappearing off to the left, and the road course on the right

Minoia's Benz is seen here flat out alongside the Fiat 805 of Felice Nazzaro, who placed second. The contrast between their cars is striking

for the RH and, in May 1924, an internal upheaval saw an 'agreement of mutual interest' signed between Benz and its arch rival, the Daimler Motoren Gesellschaft.

Though the final merger of the two firms was delayed for two years, the 1924 agreement led to an immediate sharing of management committees and boards of directors, and also to a trimming of model lines to reduce the degree of direct competition between the two companies. It was a compact in which Stuttgart appeared to exert more economic and management influence than Mannheim.

The reduction of competition affected racing, too. Mercedes, rather than Benz, was given priority in the development of racecars. Although eligible, the RH never competed again in a grand prix or, indeed, outside the borders of Germany. The car only raced a few more times in its original form. At Solitude on May 18 1924 Franz Hörner placed third in class in a hillclimb behind two supercharged 2.0-litre Mercedes in his last successful competition appearance.

Sports car

Towards the end of 1924, the RH was further developed as a 2.0-litre sports car. Changes included an enlarged balance pipe between the engine's two manifolds that could be equipped with a small third carburettor for starting. Like the larger carburettors, this was fitted with a circular air filter. For both starting and generating, a dynamotor was mounted to the rear of the engine, driving through the shaft of the water pump and its gear train.

Of the total of four RH cars built, one (perhaps two) kept the original rear radiator and gained parts that literally expressed the British term, wings (aka fenders). A new nose carried faired-in headlamps and a spare wheel was placed flat inside an upper compartment. This displaced the fuel tank to the extreme rear of the chassis in a new, lower and more rounded tail. Smaller wheels and tyres were used under wings that trailed straight to the rear. Behind the front wheels were low drag spray deflectors.

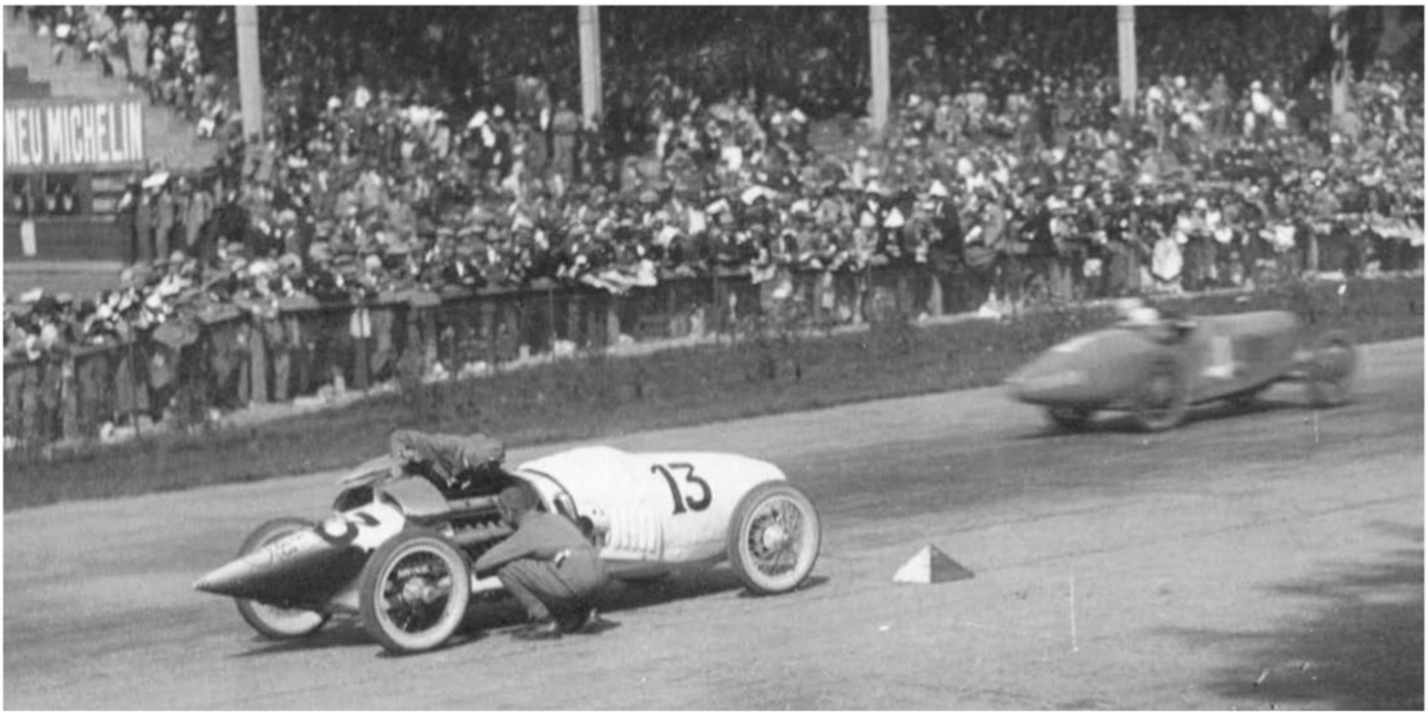
Willy Walb drove the revised sports model in its first appearances in July 1924. At Königstuhl, he won a short and exacting hillclimb outright. Walb then starred more than a year later at Freiburg, winning the Sports Car class in August 1925 in both the sprint event and the classic hillclimb.

In May of 1925, Adolf Rosenberger used one of these cars in his first successful Benz outing. He won and set the fastest lap in a five-lap race for 2.0-litre sports cars at the debut of a new 13.8-mile road circuit at Solitude, near Stuttgart.

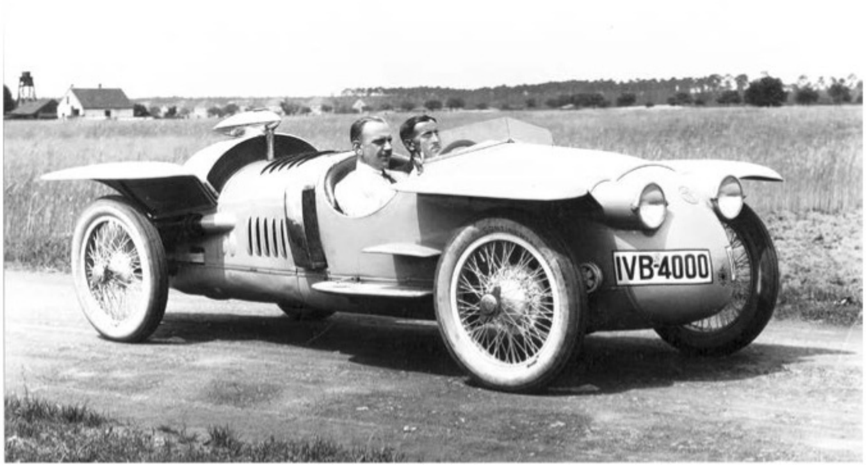
Pseudo sports racer

In 1925, the other remaining RH chassis were converted into pseudo sports cars that were usually raced without the wings. New front bodywork gave them more open cockpits, eliminated doors altogether, and covered a tubular, instead of I-beam, front axle. It also moved the radiator up front, behind a screened, circular opening in the nose.

As on the other sports versions, the fuel tank was moved back into an extended tail. No windscreen or deflector was fitted. This version of the RH was the least harmonious in appearance, but the most prescient in forecasting the shape of its



In front of the main crowd on the 'road' side of the track, Walb and Werle struggle to find the fault causing their early retirement. It subsequently turned out to be a broken piston



For its 'wings', the 1924 sports car version of the RH adopted a drag-reducing style then widely used in closed racecars

In a speed trial at Badenia in July 1925, Walb's RH was clocked at an unprecedented 168km/h (104mph), the highest speed ever officially recorded by the type

spiritual successor a decade later: the grand prix Auto Union. Rosenberger had a good run with this type of RH. He set a new record for the Herkules Hill Climb near Kassel in May 1925.

Speed machine

Meanwhile, a new Benz adherent was Carl Hermann Tigler, a privateer who raced an RH in several events in late 1924 and early '25. Tigler's best day was May 30, 1925, when Opel baptised its new high speed test track with a series of races. Tigler set the fastest average there with 79mph over 10 laps.

Tigler, Walb and Rosenberger all showed during those two seasons that the Benz RH had an edge in circuit speed over the 1.5-litre supercharged Mercedes, but could not come close to the speed the 2.0-litre blown cars from Untertürkheim were capable of.

In a speed trial at Badenia in July 1925, Walb's RH was clocked at an unprecedented 168km/h (104mph), the highest speed ever officially recorded by the type.

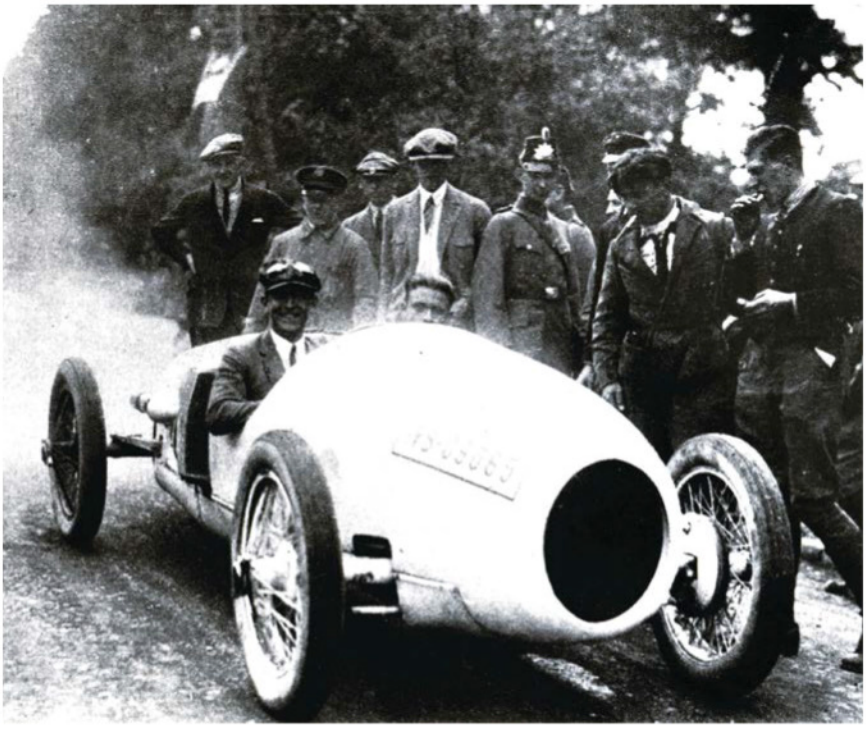
Official factory entries of the Benz *Tropfen-Wagen* ceased at the end of 1925. While it featured in motor show displays after then, it was last seen in action in 1930 when one was demonstrated to a magazine editor. 'Taking 150 degree turns on the outside,' he wrote, 'braking so hard the stones scattered, the car didn't swerve from its path a single millimeter. It steers more easily than any other car I know.'

The three million marks (about half a million dollars in today's money) that the RH programme had cost Benz had long ago been written off and, seemingly, forgotten.

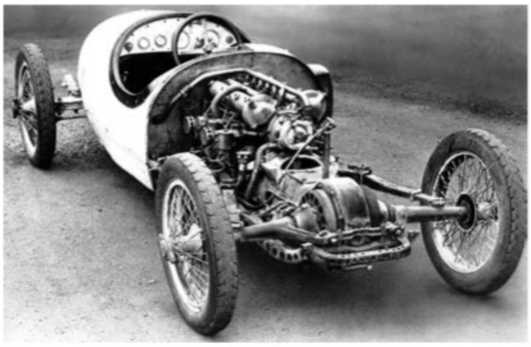
Sadly, not one of these spectacular 'racing cars of the future' survived.

Fuel had to be moved to the rear to make room for a mandatory spare wheel in the sports version of the Benz RH. Walb is at the wheel here

On the twisty Solitude Hill Climb near Stuttgart on May 18 1924, Franz Hörner took third place in his Benz RH at an average speed of 56.1mph



Rebuilt for sprinting with a more conventional, nose-mounted radiator, this Benz RH appeared at the 1925 Herkules Hill Climb. Its driver, Adolf Rosenberger, set a new track record there and became a great fan of the model



The widened body needed for the sports version of the RH was kept when the cars competed in unlimited events, as this one was doing some time in the later 1920s

The last public appearance of a Benz RH was by a nose radiator model at a 1933 exposition, together with an older Benz racer. Thereafter, the cars were lost from view and none survive today

SHUTTERSTOCK

Total control racing

In part one of a two-part series on control systems, we investigate how they work and recent advances made to improve their performance

By GEMMA HATTON

There are no back-up ECUs on a Formula 1 car. Instead, complex redundancy strategies have been implemented in the McLaren Applied ECU in order that it can continue operating the control systems of the car, even if a failure occurs

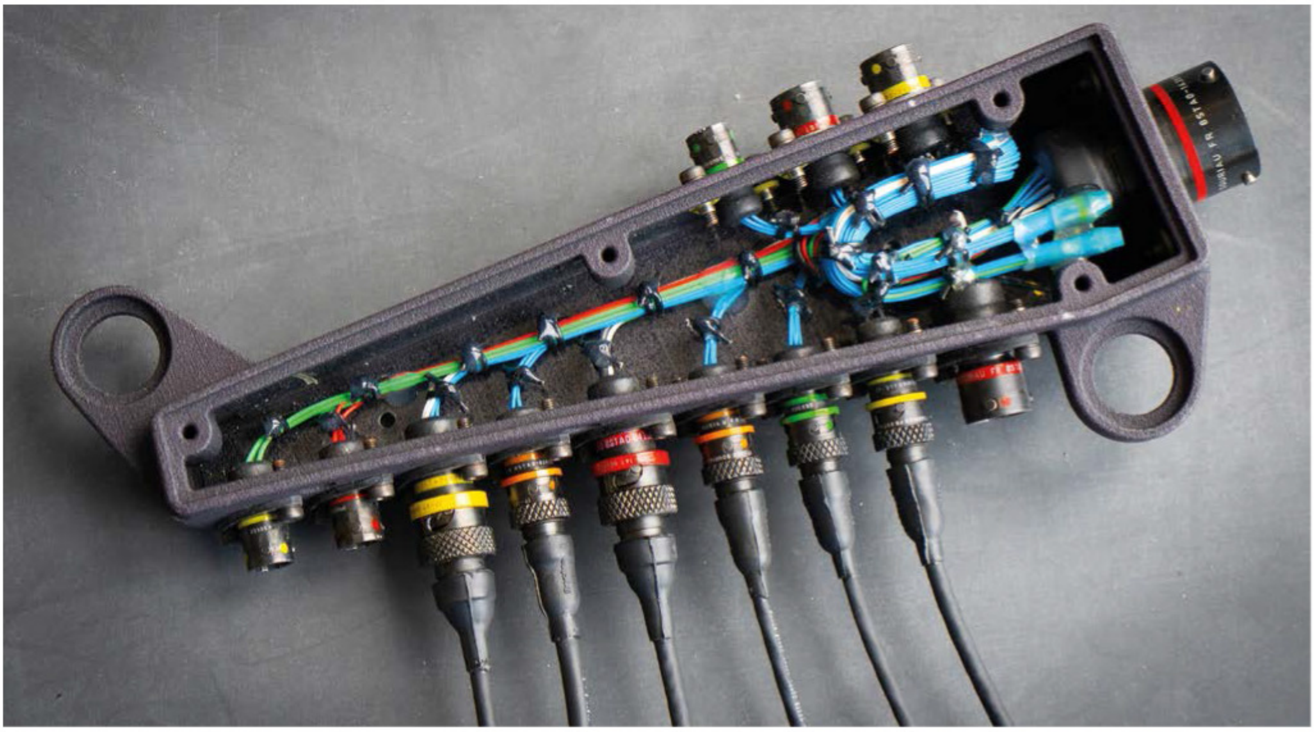
Whether it is an engine, battery or gearbox, engineers are constantly trying to quantify the performance of components using metrics such as power, energy, speed, efficiency and range. In reality, these performance figures can only be achieved if parts are effectively controlled to operate at their maximum potential, and this is where the subjects of this feature come in.

'Control systems are the basis of what makes a car run nowadays. You wouldn't be able to run an engine or an electric powertrain without a control system operating in the background,' highlights Rui Lopes, principal software engineer at Prodrive.

'A control system essentially harnesses all the raw capabilities of a vehicle and synchronises them together to achieve the maximum performance possible of the vehicle as a whole. We use control systems for controlling simple things such as a headlamp, to more complex systems such as the chassis, engine and traction control,' Lopes continues.

'A control system essentially harnesses all the raw capabilities of a vehicle and synchronises them together to achieve the maximum performance possible of the vehicle as a whole'

Rui Lopes, principal software engineer at Prodrive



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Data acquisition is a key part of a control system as it provides sensor data to the controller, which uses this information to calculate the required action of the actuators

'Ideally, you want to be operating at the limiting factor at all times. For example, if tyre grip is the limiting factor, you want to develop a vehicle to be on that limit under all conditions. However, to get to that point, you need to make sure all the other systems are operating at their maximum potential first.'

Defining control

A control system is a combination of control software embedded within a control unit, mechanical components and electronic devices that regulates the behaviour of a system to perform a specific function. This is achieved through control loops that consist of data acquisition, control logic and final actuation.

The data acquisition system, typically comprising a variety of sensing devices, or sensors, converts a physical measurement into an electrical signal, which can then be interpreted by the controller, also known as an ECU (Electronic Control Unit).

The controller processes these signals and executes the control logic to generate the output commands that action the actuators to effectively control the behaviour of the system. Actuators can be a hydraulic valve, an electro-mechanical device, a relay or another control unit, and its purpose is to translate the electrical command from the controller into a physical action. This is then linked to the part being controlled, such as turning a motor on or off.

'Typically, control systems in vehicles consist of sensors, driver inputs, a control unit, communication channels with other control units and the controlled actuators themselves, which are all connected within the vehicle by a wiring harness,' explains Miriam Lorenzo, chief engineer at Drive System Design.

'The goal of a control system is to achieve, or contribute to, a vehicle function effectively and safely, whilst meeting some vehicle performance requirements with very little or no human interaction.

'Take the example of an automatic transmission. To change gears, a driver will select the direction, the control system will then determine, based on information from the vehicle and transmission sensors, if the required conditions for the requested action are satisfied. Once the conditions have been satisfied, the control unit will execute complex control algorithms to engage the appropriate gear and clutches to achieve the driver's selected direction.'

Open and closed loop

There are two different types of control systems: open loop and closed loop. Open loop control systems have no feedback in the control loop, so the control action is independent of whether the desired output was achieved or not. A closed loop control system, on the other hand, has a feedback path from the output to the input. The control action depends on the difference between the target action and the measured feedback.

'Open loop systems tend to be simpler, although not always, and will have a relatively fixed response and be vulnerable to outside disturbances,' explains John McKenna, principal software engineer at Cosworth. 'Closed loop systems can be designed to meet optimum performance criteria, even with these external influences present.'

'Typically, control systems in vehicles consist of sensors, driver inputs, a control unit, communication channels with other control units and the controlled actuators themselves'

Miriam Lorenzo, chief engineer at Drive System Design

The majority of the driver requirements from the engine are an example of open loop control. When a driver presses the throttle pedal, they are demanding an increase in output from the engine, and it is only their skill behind the wheel that corrects that output as they race around the track.

Whereas when traction control is enabled, for example, the amount of wheel slip can be automatically controlled by the feedback given by each wheel's rotational speed. This is then used to determine the instantaneous correction of the engine output torque to maintain the desired slip ratio and provide optimum acceleration, resulting in a closed loop system.

The evolution of ECUs

In the past, control systems within a racecar used to have a distributed architecture, where a number of ECUs, spread around the car, managed all the control loops. 'This approach helped reduce the wiring loom

Renvale Limited

With increasingly complicated onboard electronic systems, the wiring harnesses that connect all the elements of a racecar's control systems together also have to be robust and fit for purpose

routing for electrical loads and also separate sensitive, high precision measurements,' says McKenna. 'It also allowed for some control over the weight distribution around the car. However, these types of systems are generally highly complex, relatively expensive and also somewhat vulnerable to loss of communication between boxes.'

Now, manufacturers are focused on developing more centralised systems with fewer – ideally one – ECU that can interface with a plethora of devices.

'ECUs now have to cope with high numbers of analogue and digital inputs, as well as a wide variety of output actuator driving capabilities,' continues McKenna. 'Getting the right mix of inputs and outputs to cover the large range of applications is a real challenge, because the more pins you have the larger the box becomes, and in motorsport, teams want everything as small as possible.'

This shift to fewer ECUs has led to the development of complex control strategies that allow the car's systems to keep going, even if there is a failure.

'On a Formula 1 car, for vital signals such as throttle and brake pedal position we use multiple sensors for each and are constantly checking them against each other to ensure they are reporting the same measurements,' explains John Shepherd, application development team lead at McLaren Applied. 'If one fails, we can switch to another.

'It's a similar story with vehicle speed. This is calculated from the highest wheel speed of the front or rear axle depending on the conditions. If one wheel speed sensor on an axle fails, we switch to the other. If they both fail, in the case of the rear axle, we reverse calculate from the shaft speed of the gearbox.'

For other sensors, safe default values are used to keep the system functioning, but these inputs will be flagged, alerting the system not to trust the information. This triggers the controller to operate differently, either switching to another input or reducing functionality.

'We can also use models to estimate values,' adds Shepherd. 'If a temperature sensor fails, for example, we can use values directly from a model. Or in some cases, we run models alongside sensors to estimate what the sensor should be reading. If the measurements start drifting from the estimates, this suggests the sensor is failing. We could then apply a weighting factor to indicate how much the system should trust this signal.

'So we have implemented comprehensive redundancy strategies to ensure the system remains as stable as possible.'

This redundancy approach is particularly important in rallying, where the priority is to keep the car going until the end of the stage.

'We extensively use control systems to create alternate strategies and improve the reliability of our cars, which has been key to our recent success in Dakar,' highlights Lopes. 'Five years ago, if a sensor failed, we would just use a default value and accept the performance degradation that came with that so that we could get to the end of the stage. Nowadays, we have models running in the background that replicate the behaviour of a sensor more accurately.

'We have put a lot of effort into developing these control systems and now have strategies that mitigate almost every scenario of electrical failure within the car. So, unless it's a severe mechanical failure, our cars will make it to the end of the stage.'

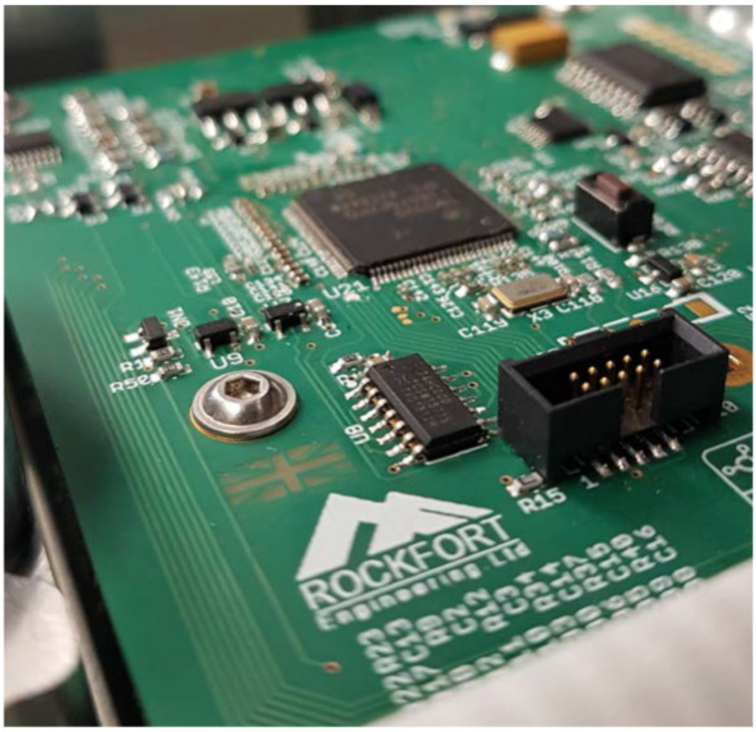
'The MCU is essentially the brain of the controller and the most important part, but it's only a small part of the overall equation'

Quentin Coret, technical specialist at Drive System Design

Performance

At the core of any control system is the controller, which computes the calculations necessary to determine what action should be taken. These are completed by a microcontroller, or MicroController Unit (MCU), but this only makes up a small part of the controller itself.

'A controller is made up of hundreds of components and the MCU is only one of them,' explains Quentin Coret, technical specialist at Drive System Design. 'There is also a lot of electrical signal processing as the controller needs to be able to cope with all the necessary inputs and outputs, communication buses such as CAN [Controller Area Network] and read both digital and analogue signals. The MCU is essentially the brain of the controller and the most important part, but it's only a small part of the overall equation.'



An example of a controller with a microcontroller unit (MCU) installed in the centre (the black square)

'Microprocessors are actually relatively simple at their core,' says Angus Lyon, director of Rockfort Engineering. 'They have a pre-programmed set of instructions that essentially boil down to simple maths and data manipulation operations. The performance of a microprocessor is measured by the range of values it can compute in bits, and the speed at which it can execute these calculations.'

A 'bit' refers to the number of binary digits that can be processed by a microprocessor at any one time. For example, a simple eight-bit microprocessor can compute eight bits of data and, as binary is base two (because the values can either be 0 or 1), the maximum number it can store is 2^8, which is 256.

'Whereas a 64-bit processor can cope with a maximum value of many millions,' continues Lyon. 'The higher the number of bits within a processor, the more powerful it is because it can compute larger sums in a single step.

'Then there's how quickly these sums can be calculated, which is measured by clock speed. This is essentially the number of cycles the processor can execute per second. Today's more powerful processors can run at 1-2GHz, which is over one billion calculations a second.'

Another tactic to boosting processing power is to run multiple processing cores. Each core computes one set of calculations, but by running several cores with a multi-core processor, computations can run in parallel, simultaneously.

'There are other elements that dictate the performance of microprocessors, such as faster communication mechanisms and memory, which allow data to be moved around at a faster rate, as well as faster calculations with modern microprocessors,' says Lyon. 'If we go back to the fuel injection systems of the 1970s and '80s, they were typically eight-bit, single-core microprocessors, probably running at under 2MHz clock speed. So the technology couldn't cope with complex software. Whereas some of the latest ECUs today are 64-bit, quad core, running at a few GHz, allowing significantly more complex software to be run.'

Calibration stage

Once a control system has been defined and the software has been implemented on the controller, the next stage is calibration. Calibration defines how the controller is configured, how the controller will behave and can be changed depending on the environment in which the controller is deployed. For example, ambient temperature or pressure.

'You're essentially looking at recorded data, or analysing driver feedback, to see whether the system has behaved in the way you wanted it do,' explains Shepherd. 'For example, if you were calibrating gear shifts, you don't want the gear shifts to unsettle the balance of the car, particularly downshifts under braking. Car stability is less of a problem under acceleration, whereas during braking balance tends to be more unstable, so it's vital to calibrate the control system to achieve the smoothest downshifts possible.'

'Calibration is the most important stage of developing a control system, because it provides the customer with the ability to calibrate the strategy to the

The role of a control systems engineer

As the performance gains in racecars continue to shift from mechanical to electrical, control systems engineers are playing an increasingly important role within race teams today. This is due to a myriad factors. Firstly, the switch to hybrid, electric and hydrogen powertrains require new and more complex control strategies. Secondly, the advancements in computing and software capability continues to expose new opportunities to achieve faster response times, as well as more stable and refined control.

Finally, there is the cost factor. It is much cheaper to improve and update software than hardware and, as governing bodies press on with their cost-saving tactics, software is becoming an important strategy to improving car performance.

Take the example of Formula E. Software development has become as important to the series as aerodynamics is to Formula 1. Consequently, Formula E teams release new and improved versions of their software for every race, in a similar way to how constant aerodynamic upgrades are introduced in Formula 1.

So, what does a control systems engineer do? They are responsible for running and developing all the electrically-controlled systems on the car. This includes monitoring the performance of the powertrain, gearbox, differential, suspension and brakes, as well as all the functions of the steering wheel. They also need to ensure all these systems are operating within the legal requirements of the regulations for that series, and communicate any software changes to the driver and the rest of the team.

Calibration is also a major part of the job description, which involves writing, testing and optimising software through online simulations, hardware-in-the-loop (HIL), driver-in-the-loop (DIL) and on-track testing using tools such as MATLAB and Simulink.

'To be a successful control systems engineer, you need to understand both the electrical and mechanical side of a racecar at the same time,' concludes Lopes. 'It's not just a matter of designing an effective control system, as an engineer you need to really get to grips with the mechanical systems you are controlling as this is the only way to truly add performance. This is what makes the role so interesting in motorsport today, but also very challenging.'

performance criteria they require,' highlights McKenna. 'It accounts for about 90 per cent of what we spend our time doing.

'We capture the customer requirements, then design a control strategy to meet their needs. That might be an embedded code implementation or an auto coded solution. The calibration interface provides the customer with the ability to flexibly adjust the performance and operating criteria of that strategy.'

This tuning process is most commonly achieved through the use of PID (Proportional Integral Derivative) controllers, which are common in motorsport control systems. PID controllers essentially read a sensor input and then calculate the optimum action of the actuator by summing the responses of three coefficients – proportional, integral and derivative. These coefficients are initially provided by the manufacturer, but can then be fine-tuned by the customer to output the required response to achieve the maximum performance of the system.

'Ideally, each coefficient will be calibrated under controlled, steady-state conditions, with minimal noise and disturbance from the outside world, perhaps using a model of the system, so that a set of baseline values can be accurately determined,' explains Shepherd. 'Once that is done, each coefficient will then be fine tuned to make the system more robust to noise, sensor drift or wear over time. This helps the controller react in a consistent manner under all circumstances.'

The proportional, integral and derivative coefficients each have a different function. The proportional component is effectively an error term and is the difference between the target the system is trying to achieve and the output it is actually achieving. This component then adjusts the output of the process to try and reach the target more accurately.

'For example, if a driver has demanded 100 per cent throttle, a controller will send a demand to the throttle actuator to move the throttle body to 100 per cent position,' continues Shepherd. 'There is then some feedback on the actual position of the throttle body and this difference between the demand and the actual position will give an error. Let's say the throttle body position is only 95 per cent, so you have five per cent error. This is then multiplied by the proportional term of the controller, which will increase the demand to try and achieve 100 per cent throttle. So, the proportional term is essentially always trying to get the output of the control system to match the target.'

Minimising error

The integral coefficient sums the error over time and adjusts the output to minimise this error. This helps reduce the steady-state error to zero and, ultimately, improve the overall stability of the control system.

Finally, the derivative component adjusts the output based on the rate of change of the error, which can help to further improve the stability of the system, as well as achieve faster response times.

'The derivative term can be the hardest to configure because it can make the system unstable if not calibrated correctly,' notes Shepherd. 'That's why, for many systems, only the proportional and integral terms are used for calibration.'

In next month's edition of *Racecar Engineering* we will look at how control systems are used in motorsport to improve the performance of the powertrain, chassis and transmission.

'We have put a lot of effort into developing these control systems and now have strategies that mitigate almost every scenario of electrical failure within the car'

Rui Lopes, principal software engineer at Prodrive

Safety car lap time delta control system

One example of a control system you will likely be familiar with is the safety car lap time delta, which drivers are often heard complaining about on the radio during a race.

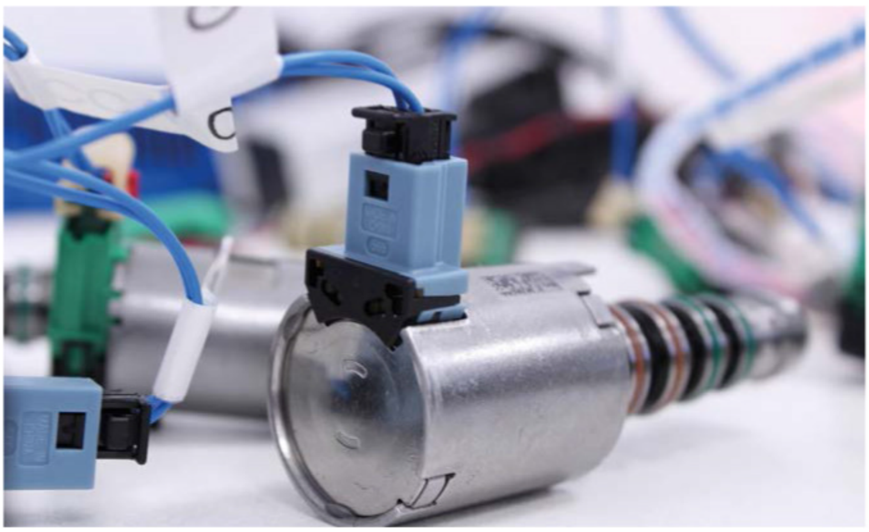
When a safety car is out on track, drivers are given a target delta time. This is essentially where the FIA has split the track up into 50m segments and specified the minimum time allowed for a car to complete each section. As the cars follow the safety car around the track, the ECU is continuously adding up the minimum time for each segment. If a driver's lap time is less than the FIA-specified lap time at any point around the track, they are going too fast and could be at risk of a penalty.

'This information is fed back to the drivers via a safety car lap time delta on the dashboard,' explains John Shepherd, application development team lead at McLaren Applied. 'On average, drivers have to maintain a positive lap time delta, and therefore go slower than this target time, throughout the lap.

'This is an example of a control system where the driver makes up part of the control loop. They are fed information via the lap time delta on how fast they are going, and then act like a controller, adjusting the output – which in this case is the car's speed – to meet the target time.'

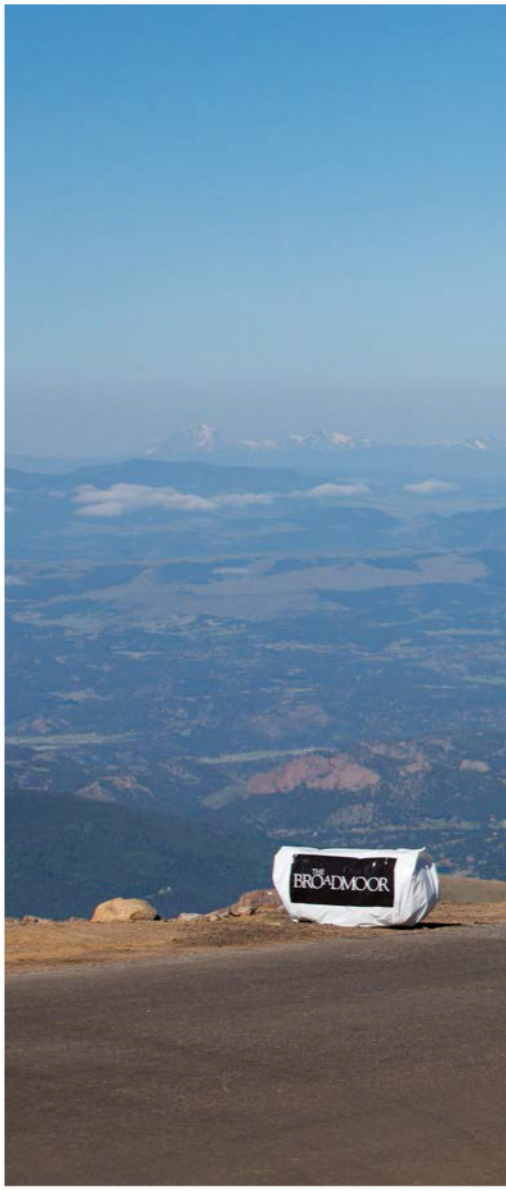
'Calibration is the most important stage of developing a control system, because it provides the customer with the ability to calibrate the strategy to the performance criteria they require'

John McKenna, principal software engineer at Cosworth



This Mechatronic sensor is a small part of the complex control system that enables gear changes in a modern racecar

Running up that Hill



How a small, independent team approached, and won, the TA1 class at the 2023 Pikes Peak International Hill Climb

By **TOMMY PARRY**

Although Porsche's 991.2 GT2 RS Clubsport leaves the Flacht factory an impressive circuit car, it requires a few modifications and a capable team if it wants to compete at the sharp end at North America's most prestigious hillclimb.

The Clubsport builds upon the GT2 RS strassenversion and features a lighter carbon body, removable roof section, re-designed rear wing, larger front canards, an integrated safety 'cage and all the necessary safety accoutrements needed for track work and some wheel-to-wheel racing.

In 2022, Brumos Racing purchased one of these rare cars with the intention of taking it to the Pikes Peak International Hill Climb. To tailor its Clubsport to the specific environmental challenges faced over a 5000ft climb to a 14,114ft summit, Brumos brought on five groups with the necessary expertise.

Each specialist was tasked with one area of performance. Verus Engineering would provide aerodynamic advice and CFD analysis, Airtech Advanced Materials Group would design and manufacture the moulds for various new parts utilising their additive manufacturing facilities, TracTive Suspension would handle the damping and matters of mechanical grip, while M-Engineering was tasked with optimising the powertrain.

Advisory role

Serving as a catalyst of sorts was BBi, a Porsche specialist from Southern California with numerous campaigns at Pikes Peak over the last two decades under its belt. BBi also laid the foundations for this project by inviting both Airtech and Verus to the party and, since 2021, has been involved with Brumos, and with driver David Donohue, Le Mans GT2 winner and Pikes Peak regular.

For 2023, it was agreed BBi would continue in an advisory role, using its knowledge and experience to guide the continued development of the car that Donohue campaigned at Pikes Peak in 2022.

This latest version was set to have improved aerodynamics and chassis dynamics, as well as powertrain revisions where the previous iteration had left some room for improvement.

Thanks in large part to Brumos doing the preparation work, and Porsche Colorado Springs providing the crew and logistical support in Colorado, the 2023 effort proved that a small, well-organised team with a modest budget can still take it to the factory-backed teams at The Race To The Clouds.

Though Brumos and BBi had already completed most of the car by 2022, Dano Davis at Brumos Racing was intent on improving it further, within the realm of financial reason, of course.

'We never knew exactly how much we were working with, but we knew it wasn't wise to beg Brumos for any more money,' Donohue laughs.

The moderate budget – at least when compared to some factory efforts – and the need to make a mark in a class its customer base could relate to pushed BBi to pick the class called Time Attack 1, TA1 for short.

'TA1 has allowed privateers to come in and compete against the bigger guys over the last couple [of] years,' notes Dmitiry Orlov, technical director at BBi.

Mainly due to budget, but also to recent changes in TA1 powertrain regulations, the car would be down on horsepower relative to the competition, so BBi altered its design ethos accordingly.

'We knew the other TA1 entrants with factory twin-turbo powerplants had higher power ceilings. For that reason, we decided we would have to find additional speed in the corners,' Orlov continues.

'We knew the other TA1 entrants with factory twin-turbo powerplants had higher power ceilings… [so] decided we would have to find additional speed in the corners'

Dmitiry Orlov, technical director at BBi

Aero priority

With the priority placed on the aero package, the team started to seek out maximum downforce and an amenable aero balance.

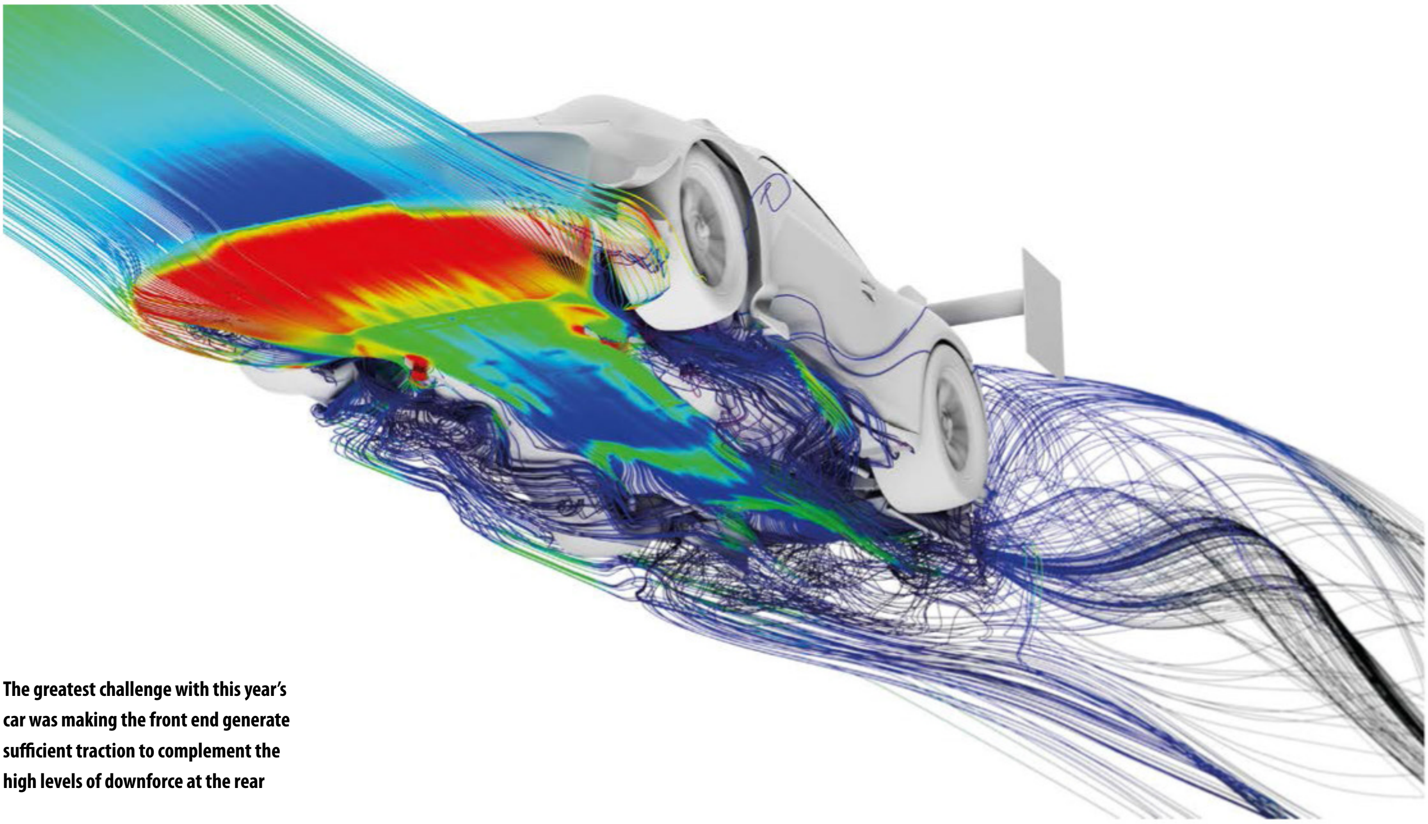
The first version of Verus Engineering's rear wing, designed for the previous year's car,

First in class and fourth overall is proof positive that a small team, if organised properly, and workjing with the right partners, can still challenge the manufacturers at Pikes Peak

Larry Chen

Confidence on the brakes required a re-shaping of the rear wing supports, which Donohue spearheaded in Fusion 360

Larry Chen



The greatest challenge with this year's car was making the front end generate sufficient traction to complement the high levels of downforce at the rear

Verus Engineering

was already quite capable of making all the downforce needed at the rear. The challenge became complementing the rear end with sufficient front grip, which had always been a challenge with the Clubsport. The chosen solution was to widen the front track to accommodate the largest possible front splitter, and wider wheels and tyres.

With Pikes Peak's abundance of hairpins, and virtually non-existent margin for error in places, the consequences of pushing slightly wide could be disastrous.

'I needed a responsive front end, particularly in the faster sections,' notes Donohue sagely.

Using the information obtained through Verus' CFD testing, BBi, Donohue and Airtech devised a comprehensive plan for improving the aerodynamic elements Airtech had contributed to the last couple of years.

'This year, we aimed to improve efficiency, increase element robustness and recycle as much of our process to save time, while working with a manageable level of lift and a moderate budget,' says Gregory Haye, director of additive manufacturing at Airtech.

One of the first items on the docket was improving the centre radiator duct's crack-prone design. The earlier version of the duct was composed of three bonded pieces, due to size constraints of the previous vendor's printer. Airtech provided 3D Systems, its new supplier for the 2023 campaign, with a single-piece re-design, the manufacturing parameters and a sample of its prototype, carbon fibre-reinforced nylon material. Sturdiness of the printed part was paramount, largely because the 2023 car, particularly its front end, would be subjected to even greater downforce than last year's version.

Real estate

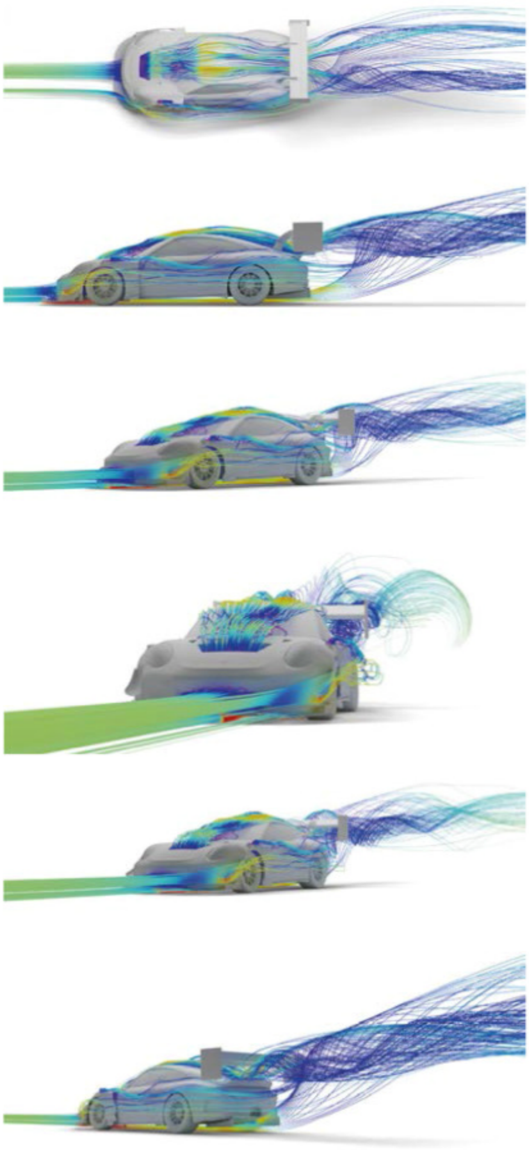
To obtain the most grip and reassurance from the front end, the team had to make the absolute most of the limited real estate. One of the more significant changes was borrowed from the 991-generation GT3 R, notably its massive single radiator mounted at a 45-degree angle underneath a shapely 'frunk' lid [bonnet].

In comparison, the GT2 RS Clubsport's standard arrangement features three radiators across the front end of the car, mirrored in its roadgoing counterpart.

Consolidating three cores into one centrally-mounted item allowed the team to block off the two larger bumper inlets and take advantage of the valuable space freed up to fit two larger splitter tunnels to improve airflow underneath the car.

To maximise the surface area of the Polyweave splitter, and increase the size of the frontal footprint, BBi and Airtech fitted a set of widebody carbon wings, which were later adorned with several aero accessories. First, they decided to vent the top of the front wings by cutting rectangular holes with a 30mm flick at the leading edge to pull pressure out of the wheel wells. Then, because the BBi-designed wings are open at the rear, Verus added another wicker, this time 20mm tall, atop its trailing edge.

The direction for damper development was agreed after Donohue bumped into



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one of his old sparring partners at Daytona. Johannes van Overbeek, an IMSA race winner who stood on the podium at Sebring, Daytona and Le Mans, had taken up a business development role with TracTive Suspension, a Dutch damper company with an intriguing technology that would suit the varied surface at Pikes Peak.

The TracTive semi-active dampers use electronically-controlled dynamic dampening adjustment valves, which can change the damping almost instantaneously.

'Based on the *g*-sensor input, we can change the damping in milliseconds' says TracTive's Rob Jacobs.

The team employ this rapid change in damping to alter front stiffness, rear stiffness, pitch and roll to suit changes in road surface.

Its responsiveness alone is worth a tip of the hat, but this damper's salient appeal is in its ability to minimise set-up compromises.

'The front and rear axles can be controlled independently of each other. We can also change pitch and dive independently of roll,' continues Jacobs. 'This allows us, for example, to optimise corner-exit traction without sacrificing lateral stiffness for fast transitions.'

The real-world improvements are considerable. The semi-active suspension's improved compliance means it can be run roughly ten per cent softer than comparable passive shocks while still retaining the same degree of body control.

First tests with the new dampers showed encouraging results. Ultimately, the roll control from the TracTive system allowed Donohue to run with both anti-roll bars disconnected without any cost. Removing the rear bar was especially helpful in the numerous low-speed traction zones.

'I had trouble trusting the suspension at first,' Donohue admits. 'It was just so comfortable, I didn't believe it would provide enough support when I needed it to. But the harder I pushed, the better it got.'

The choice of TracTive offered a secondary, unexpected benefit, too. Donohue lauded the suspension for the way it saved his perpetually exhausted crew from having to get under the car on a cold Colorado morning. Instead of asking them to turn wrenches on the frigid pavement, or dirt, he could use the control display in the centre console to make changes to the pre-sets, which could then be toggled through with buttons on the steering wheel.

'My crew is made up of techs at Porsche Colorado Springs. They have to get up at 2am for practice, and then work a full day after that. When they're that tired, I don't want to ask any more of them than I have to.'

Larry Chen

Changing from three radiators to one at the front enabled the team to re-purpose the bumper inlets into splitter tunnels

Power ceiling

As former factory support for Porsche North America, with many years at Pikes Peak, M-Engineering has learned the mountain's unique demands. The TA1 rule set essentially prevented it from using any turbochargers large enough to require bigger injectors or fuel pumps. This was the factor lowering the Porsche's potential power ceiling.

'Basically, we were stuck with the stock Clubsport powertrain,' says Orlov.

Pikes Peak's abundance of hairpins, and the Clubsport's enviable rear-engine traction, could lead some to believe that a set of small, snappy turbochargers prioritising response at the expense of top end would be best. However, that's not necessarily the case.

The thin air imposes obvious cooling problems, but also forces turbochargers to work even harder.

'The factory ECU adjusts turbo speed to suit barometric pressure and, in order to maintain boost pressure as the intake

The semi-active suspension's improved compliance means it can be run roughly ten per cent softer than comparable passive shocks while still retaining the same degree of body control

Larry Chen

Chassis upgrades included using TracTive semi-active dampers with electronically-controlled dynamic dampening adjustment valves

Trevor Lyden

The changes in atmospheric pressure experienced during the 5000ft climb mean the factory turbochargers could be overspun, so an M-Engineering hybrid turbo with larger internals was used

charge reduces, the turbocharger must spin faster. We found it's just too easy to overspin a small turbocharger at the top of the mountain,' notes Mitchell McKee, engineer at M-Engineering.

So, at the price of slightly more lag, M-Engineering opted for a larger size turbo so the horsepower and torque figures could be achieved at a lower boost pressure, thereby reducing turbo speed. The takeaway here: larger turbo wheel dimensions made it easier to maintain an average level of engine performance from the start to the summit.

The other limitation to consider was Porsche's variable turbine geometry (VTG) technology. As the factory ECU is designed to manage two turbochargers with VTG, most conventional aftermarket turbochargers would also require an aftermarket ECU, as well as a different fuelling system.

In light of these constraints, the team decided that the simplest, most cost-effective solution was to use M-Engineering's 'hybrid turbochargers'. These take the factory turbo housings and replace the internals with larger VTG turbine and compressor wheels, which, thankfully, are still compatible with the factory ECU.

Although the larger internals increased lag, M-Engineering compensated for low-end losses by playing with the ECU's anti-lag system. In an off-throttle situation, the ECU holds the throttle plate open and feeds the intake manifold with a few pounds of boost via a fresh air valve.

All that was needed to round out this package was an in-house ECU flash for cam timing, boost pressure, fuel and ignition, together with a raised redline. The resulting figures: 850bhp at redline and 700ft.lbs of torque at 4300rpm.

The larger internals also shifted the powerband a couple of thousand revs to the right, softening power delivery somewhat.

Flash in the 'box

Even with the gentler torque onset, the transmission was tweaked to minimise any potential damage. A gearbox re-flash, again using M-Engineering's software, lengthened shift speeds to assist here.

Because excessive torque figures at lower engine speeds would put additional strain on the gearbox (transmission cooling was considered marginal even before the power hike), this was a compromise worth making.

Careful planning, thorough CFD analysis and a few years' experience meant the team was familiar with the key items that needed to be addressed. One particular issue that arose in 2021, and hadn't been solved in 2022, was the rear wing mounts.

Though the rear wing could produce 1200lb of downforce on the mountain, inadequate wing support had rendered that aero grip inconsistent.

'The wing was initially mounted to the tub by the rear window and the stock wing mounts, but the sheet metal underneath the mounts would flex and cause the wing to trim out,' Donohue explains.

He began his late-stage alterations using the programs he'd grown familiar with. Verus had given him a window for relocation and, with the help of Autodesk Fusion 360 for modelling and finite element analysis, Donohue sketched out several rough designs with different mounting points and heights. He sent these off to Verus to run the maths and pick the best.

The chosen mounts feature a longitudinal stabilising rod under the decklid that runs forward through the firewall and connects to a bracket on the rear shock tower. The main strut then attaches to a double-shear mount, which sits on top of the rear engine mount – another piece inspired by the GT3 R (992).

The resulting rigidity ensures consistent downforce at speed, and the carefully located separation point on the wing guarantees steady downforce, regardless of attitude.

Donohue later showed his design to Owen Hayes, former president of Porsche Motorsport North America. His droll response: 'You know, you really don't want a failure there – Pikes Peak is a rather binary place.'

'The factory ECU adjusts turbo speed to suit barometric pressure and… we found it's just too easy to overspin a small turbocharger at the top of the mountain'

Mitchell McKee, engineer at M-Engineering

Larry Chen

Finding the right rhythm over the bumpy, unforgiving top section of the track was facilitated by driver-operated pre-sets on the car's TracTive dampers, and going to a set of medium tyres at the rear

The team arrived at Colorado Springs bleary eyed but eager to proceed with the limited testing opportunities offered over the month before the event. Frustratingly, drivers are restricted to running only one of the course's three sections at a time. Performance on the first and second sections of the course were auspicious, but snow, ice, and low visibility cancelled several days of pre-race week testing on the top section, which Donohue says is the trickiest bit.

Operating window

Thankfully, by the time he rolled up to the starting line at 10am, the sun had been shining long enough to warm the road's surface. Tyre blankets helped bring the tyres within their window for the first few corners, which don't require too much in the way of braking.

Medium-speed transitions are everywhere in the first section, though there are a few longish straights and a handful of hairpins, too. The middle section is then mostly switchbacks and a steep climb. It's the upper third that requires the most circumspection, its isolated, fast corners flanked by steep hillsides and a fast, bumpy section known as Boulder Park. Without question, these are the most intimidating sections of the course.

It's common to see tyre performance fall in the top third of the track, where ambient temperatures are considerably colder. That hurdle was raised further still by the added challenge of tyre degradation. Brumos' first tyre strategy, tested long before race day, was to go for the softest Yokohama A40 slicks at all four corners, but the rears struggled under the demands of the surface.

Retaining the softs at the front axle and switching to a set of A60 mediums at the rear offered the right balance of grip and stamina over a 10-minute blitz, although Donohue noticed rear performance began to dwindle as he neared the summit.

To complicate matters, powertrain temperatures were marginal come the third section, so Donohue started short shifting to keep the pot from boiling over.

Come race day, with only blue skies filling his windows, Donohue crossed the finish line and parked his crackling car in the gravel lot before checking his time. 9:18.053. Fast enough for first in TA1 and fourth overall.

Post-race, Donohue carried himself in front of the camera with the normal polished, presentable, easy confidence he's known for. Though his composure was in no doubt influenced by his many miles at Pikes Peak, his cool demeanour was, in some significant part, testament to a confidence-inspiring car and the careful preparation he and his colleagues had gone through to get it there.

Resource management

Regardless of budget constraints, they did everything in their power to make the most of the resources available to them. Donohue even went the extra mile and tried his hand at Fusion 360 to shape some of the parts which, after a few minor adjustments from the pros, made their way onto the car.

'Our 2023 success is a result of choosing the right partners and playing to their strengths. Brumos truly capitalised on what BBi, Verus Engineering, TracTive Suspension, M-Engineering and Airtech do best,' Donohue concludes.

> **Retaining the soft [Yokohama A40 slick tyres] at the front axle and switching to a a set of A60 mediums at the rear offered the right balance of grip and stamina over a 10-minute blitz**

'Additionally, it would be a crime not to mention the efforts made at Porsche Colorado Springs during June, and the Brumos Collection in the months prior. It was Brumos that was preparing the car for months beforehand, and then at Porsche Colorado Springs, with their incredible techs waking up at 2am for practice.

'As with all successful teams, it was our passion, competence and commitment that made success possible.'

All that effort, stellar weather and a fantastic platform to build upon made up for the relative lack of budget and proved, once again, that smaller outfits still have a place at the front at The Race To The Clouds.

Advanced Engineering UK opens its doors

Re-branded and re-engineered, the UK's largest engineering show is set to be better than ever in 2023

Advanced Engineering, the UK's largest annual gathering of engineering and manufacturing professionals, will open its doors on 1-2 November at the NEC, Birmingham. Now in its 14th year, this year's show comes with a fresh and future-focused re-brand, removing the old show zones and introducing a new main stage.

In order to meet the future demands of the engineering and manufacturing sectors, the show has been re-engineered to encourage even more cross-industry collaboration.

The organisers understood that the old layout felt limiting for exhibitors, and that visitors tended to walk the entire show floor, regardless of their specific industry. So this year, the long-established composite zone will remain, but the automotive, aerospace and connected manufacturing zones will be removed.

These sectors will still have a strong presence at the event, with the industry-specific forums remaining. There will also be a main, central stage on this year's floorplan where discussions about key challenges in the industry will be discussed.

Guest speakers

With the re-brand, Advanced Engineering returns with a speaker programme made up of some of the leading figures in UK engineering and manufacturing. This year's day one keynote is Richard Noble, OBE, former holder of the World Land Speed Record and serial innovator at ThrustWSH. Also on the main stage, Eman Martin-Vignerte, director of external affairs and government relations at Bosch, will share her thoughts on digitalisation and automation.

In the afternoon, there will be a women in manufacturing panel, followed by a discussion from a Make UK representative on how new industrial technologies are affecting the skilled workforce.

On day two, the opening keynote will be given by Make UK, and will be followed by talks from Made in Britain on innovation in British engineering and design, and a second panel on women in composites.

Two exciting competitions will also be held on the main stage, with the Enabling Innovation competition in the morning and the SAMPE Design and Make competition in the afternoon.

Groundbreaking innovation

Advanced Engineering will also showcase six groundbreaking innovations throughout its exhibition area. One of these is the prototype of the ThrustWSH boat, which will be accompanied by a presentation from Richard Noble OBE on the main stage. In what is a collaborative effort with PRF Composites, ThrustWSH has achieved the World Land Speed Record and will allow visitors at the show to see whether the boat can conquer the water speed record.

In addition, MGI Engineering is speeding ahead in its journey to net zero and will demonstrate never before seen technologies to the sector, including an F1 car and eVTOL drones.

Meanwhile, SCU Motorsport has also booked an exclusive exhibitor spot, pioneering its 3D learning environment for students that will involve augmented reality, virtual reality and mixed reality technologies. This will feature a 3D virtual motorsport garage, too.

Cyclopic stands as a Clean-Tech enterprise also dedicated to advancing technologies for achieving net zero goals. It will introduce the enhanced manoeuvrability of an E-Corner platform, shedding light on innovative centreless wheel technology.

What's more, advanced manufacturing experts from the University of Manchester have a spot to showcase new technologies, products and processes. Hosted by the Graphene Engineering Innovation Centre (GEIC), visitors can see the extraordinary properties of graphene and other 2D materials.

Finally, space engineering company, Gravitilab Aerospace Services, is displaying its patent protected drop pod, which provides unique microgravity environments at relatively low altitudes.

To secure your visitor pass, see a current exhibitor list and check out the growing list of confirmed speakers, visit the Advanced Engineering website — **advancedengineeringuk.com.**

Simulation in action

Data engineering on track at the 2023 World Time Attack Challenge

By DANNY NOWLAN

Image courtesy of WTAC

The subject of this month's discussion is the Tanuki S-13 Tilt that races in the World Time Attack Challenge Pro / Pro Am class

One of my favourite events that I am involved with is the World Time Attack Challenge (WTAC), which is held every September / October at Eastern Creek Raceway, now called Sydney Motorsport Park.

Yes, the cars in the Open class and above look like the love child of the Batmobile and Keith Richards, and yes, most of the car prep is a bit casual, to put it politely, but it is a technically open event and, as such, makes a refreshing change from the dead end of spec formula and tight formula regulations that most motorsport regulators today seem to think is a good idea.

For this year's event, I was race engineering the Tanuki S-13 Tilt in the Pro / Pro Am class. This car started life as the MCA Hammerhead but changed hands and went through a considerable mid-life upgrade. We are now talking 1000bhp and more downforce than an LMP2 car. This is the car shown in the opening image.

The other thing that makes this category unusual is that it's an open tyre formula, and this year allowed slick tyres for the first time.

The one big constraint of the programme I was involved with was that it all came together quite late in the day, which induced its own set of challenges.

The purpose of this article is to give you the good, the bad and the ugly of what went down, but also, perhaps more importantly, to show how you can improvise and still be effecctive when things are not perfect.

Also, given how motor racing in general has guzzled the spec kool aid straight from a storm drain, it also gives some salutatory lessons in how to handle an open formula.

Pre-event work

To get us started, let's discuss the pre-event preparation because this was really enlightening, on a number of levels.

Before we did anything, I insisted on a car measure up. In any vehicle modelling / engineering endeavour, you can be forgiven a multitude of sins, but one you can't be forgiven for is not measuring up motion ratios. You can kind of get away with not measuring the hard points, though at some point you will still need to do it, but without the motion ratios you are sunk.

So, the first thing we did once the car started to run was to do a ride height sweep. Being a re-birthed car, some might have tried to go straight out and set the fastest lap time, but that is a time-wasting, ego-driven exercise if you haven't done the basics first. Given the amount of downforce these cars run, not to do your basic measurements first borders on criminally negligent, and I have zero desire to do prison time.

So, what we did was run through my usual aero test programme, as shown in **table 1**.

Where,

frh_0 = baseline front ride height, as specified in the starting set-up
rrh_0 = baseline rear ride height, as specified in the starting set-up
d_rrh = delta rear ride height
d_frh = delta front ride height

Since this is a live racecar, I'm not going to tell you what test points we went to.

One of the challenges I faced at this stage of the programme was the car's reliability

Table 1: Aero test procedure for a Sportscar

Run no.	Set-up
1	frh_0 and rrh_0 + baseline rear wing
2	frh_0 and $rrh_0 + d\_rrh$ + baseline rear wing
3	frh_0 and $rrh_0 + 2*d\_rrh$ + baseline rear wing
4	frh_0 and $rrh_0 + 3*d\_rrh$ + baseline rear wing
5	$frh_0 - d\_rrh$ and rrh_0 + baseline rear wing
6	$frh_0 + d\_rrh$ and rrh_0 + baseline rear wing
7	frh_0 and rrh_0 + baseline rear wing
8	frh_0 and rrh_0 + baseline rear wing + 2 holes
9	frh_0 and rrh_0 + baseline rear wing + 3 holes

Fig 2: Tanuki aeromap constructed from race data

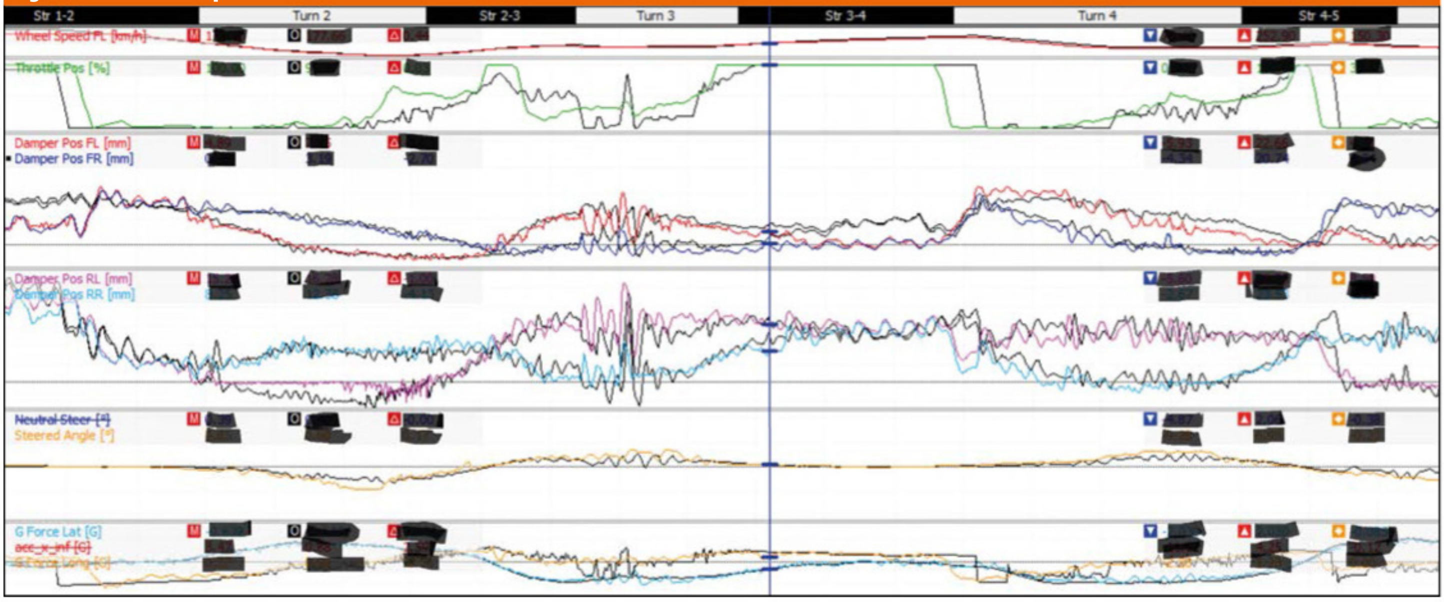
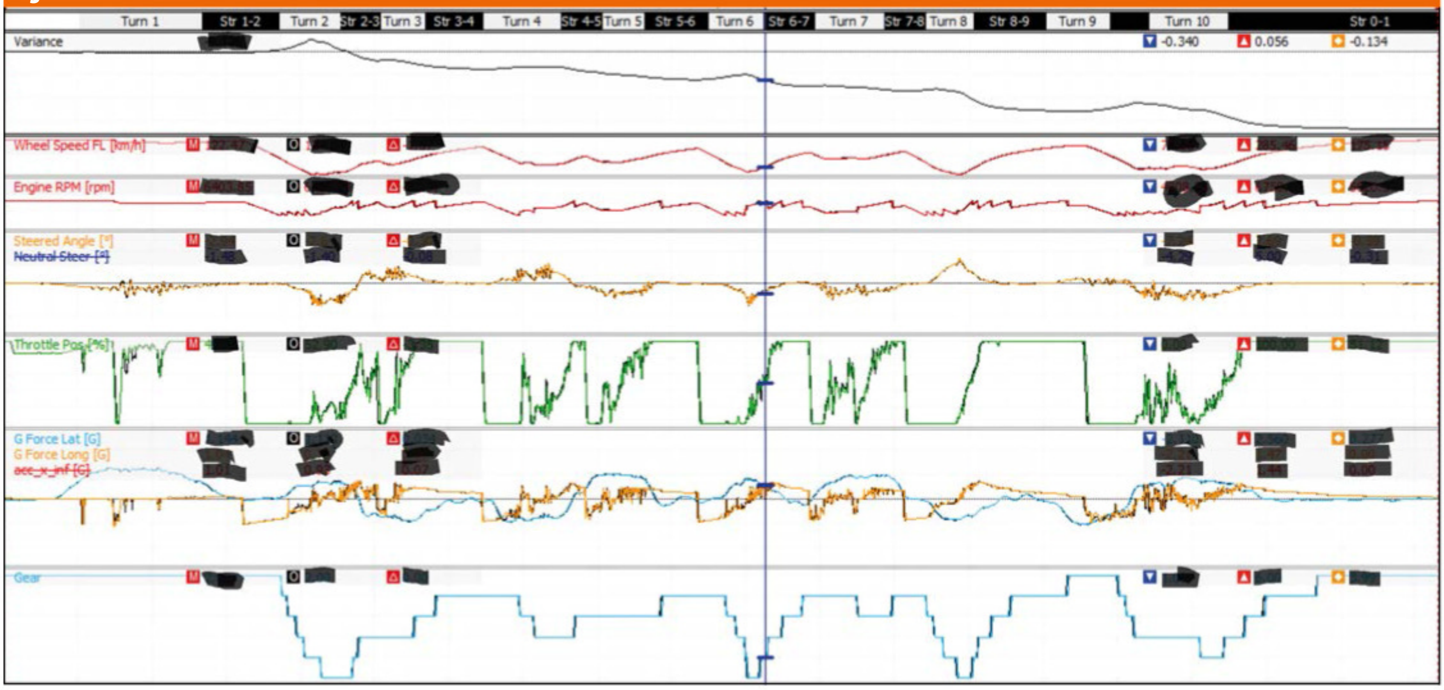


Fig 3: Pro driver to ChassisSim correlation



issues, which meant ride height sweeps were more constrained than I would have liked. However, the car was perfectly fit for purpose to get an aeromap out. A redacted version of which is shown in **figure 2**.

Some things to note about the aeromaps shown. Since I couldn't get to the ride heights I wanted, they look a bit flat, but were still useful for correlation purposes.

One thing I should have done is extend the aeromap by making an educated guess. Oh well, you live and learn.

This does help illustrate a very important point though. A tool like ChassisSim is a calculator, not a magic wand. Use it as such.

Once the aeromap was established, the next challenge was tyre modelling, and this is what we tested at Sydney Motorsport Park in July. At that test, some of the car's past gremlins came back to bite us. For some weird reason, the lateral accelerometer was misbehaving in turn one. This meant the usual game plan of the ChassisSim tyre force modelling toolbox was not viable. Fortunately, I've modelled enough LMP3 / P2 / P1 tyres in my time that I was able to improvise.

Matched pair

I also messed up in not nailing down the car's weight distribution properties. That all being said, the approach here was to take the car's steer angle and match that as close as possible to the pro driver. The correlation is shown in **figure 3**. As usual, the actual data is coloured and the simulation is shown in black.

To put a few things into perspective, traction control was in the process of being developed for this car, which explains the discrepancy between the simulated and actual throttle pedal applications.

If we look at speed, acceleration and the dampers though (apart from an anomaly with the front dampers) we have pretty much nailed what the car is doing.

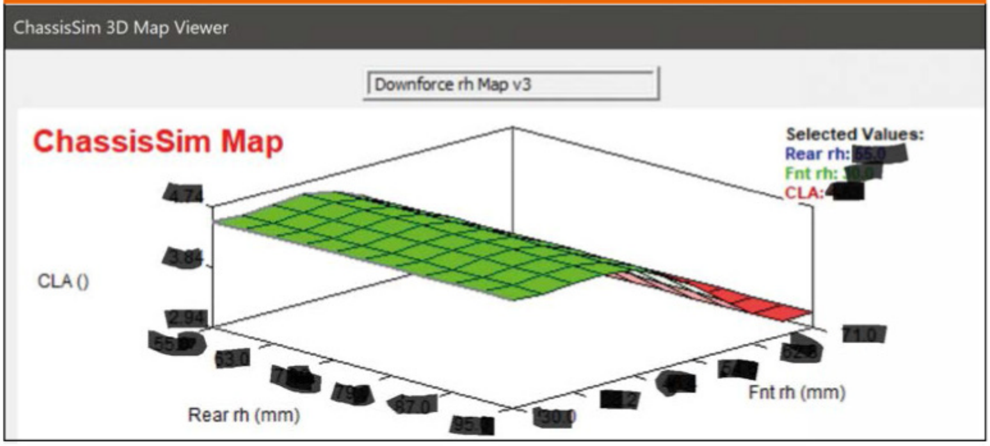
One thing to note about the steering: the simulated steering is about 20 per cent less then the actual steer. This is a knock-on effect of ChassisSim driver-in-the-loop.

I also did a lot of work on the stability index channels to make sure the tyres were dialled in properly. In particular, correlating the driver feedback to what I knew tallied with known stability index numbers. Was it perfect? Hell no, but it got the job done.

Next, it was time to refine the set-up, and the first port of call was the dampers. This is where the shaker rig toolbox came in.

The way the weekend panned out was a really good case study of showing what happens with you apply a deliberate and methodical approach

Fig 4: Example of a good simulated change



One of the historic problems with this car's previous incarnation as the Hammerhead was its pitch characteristics. Let's just say for now that it had some rather notable suspension movements.

Ultimately, I came up with a damper spec that addressed this. I was able to get close to what I wanted at the rear, but not the complete picture for reasons I won't discuss here. However, as we'll see shortly, I came close enough to what I was looking for to get the job done. Sadly, for reasons beyond the scope of this article, I couldn't address the fronts.

The pre set-up analysis on ChassisSim would be both revealing and a life saver. For obvious reasons, I can't tell you the exact changes that were made, but there were four in particular that really stood out. A summary of the deltas is shown in **table 2**.

The four changes were all cumulative, and we knew they were good because **figure 4** shows what the C-Time looked like.

Table 2: Chassis changes that worked

Change	Lap time delta
Change A	0.3s
Change B	0.2s
Change C	0.3s
Change D	0.3s

Note the top line, which is the compare time, and just how consistent it is. Also note there are no big jumps in speed, steer or throttle. This is therefore a total no brainer to put on the car, and all the other changes exhibited the same characteristics. When you are doing simulated changes, these are the kinds of changes you wish for.

Run time

Now it was time to run the car, and I want to open this section of the discussion with a warning. One of the traps you can easily fall into with open formulae such as Time Attack is throwing Hail Mary passes on set-up.

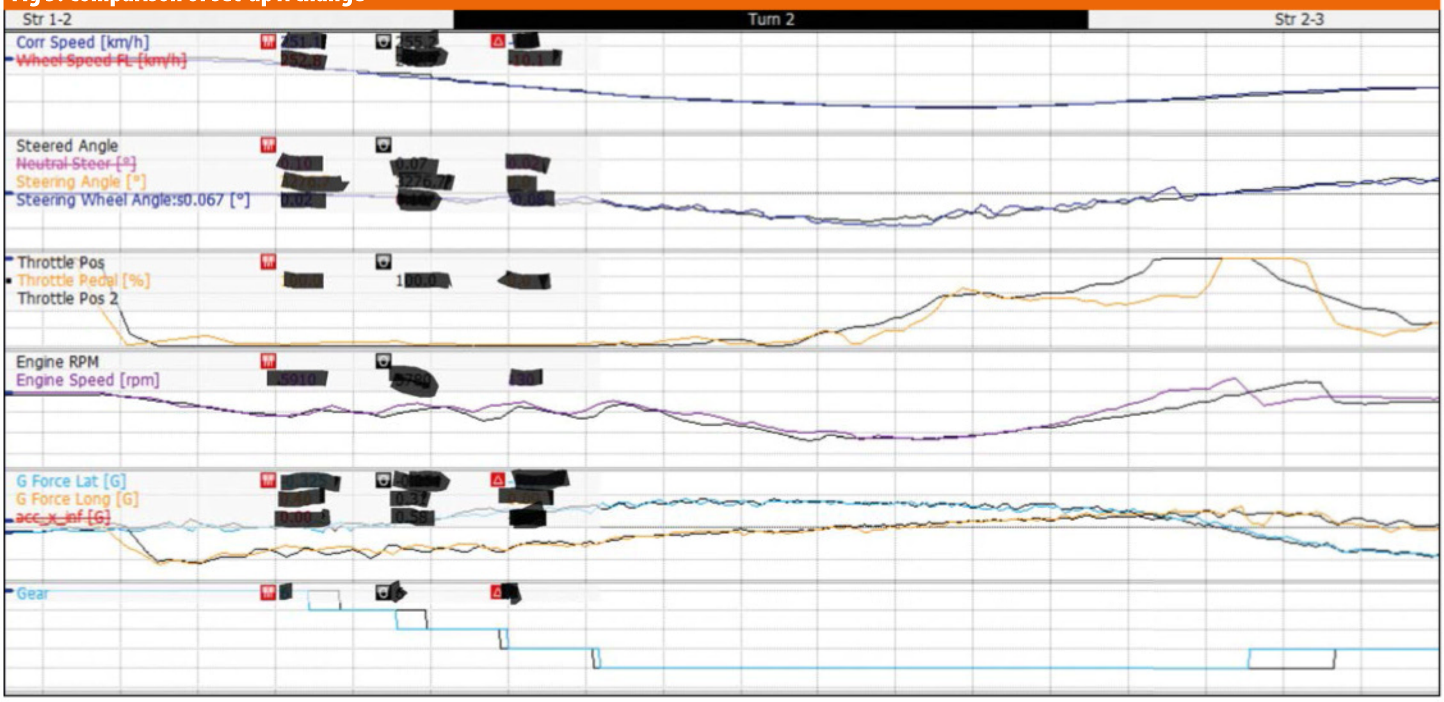
What I mean by a Hail Mary pass is when you throw the ball in the air and hope to goodness someone up there catches it! You have to resist that temptation with everything you have because most times it will backfire on you. Any Hail Mary passes I have made in my career that have worked are very much exceptions that prove the rule.

The way the weekend panned out was a really good case study of showing what happens when you apply a deliberate and methodical approach.

The format of the weekend is a test day on the Thursday and then you run on Friday and Saturday. So, on Thursday we chipped away at the damping and made steady progress, but we also used change A as well. The end result of that is shown in **figure 5**.

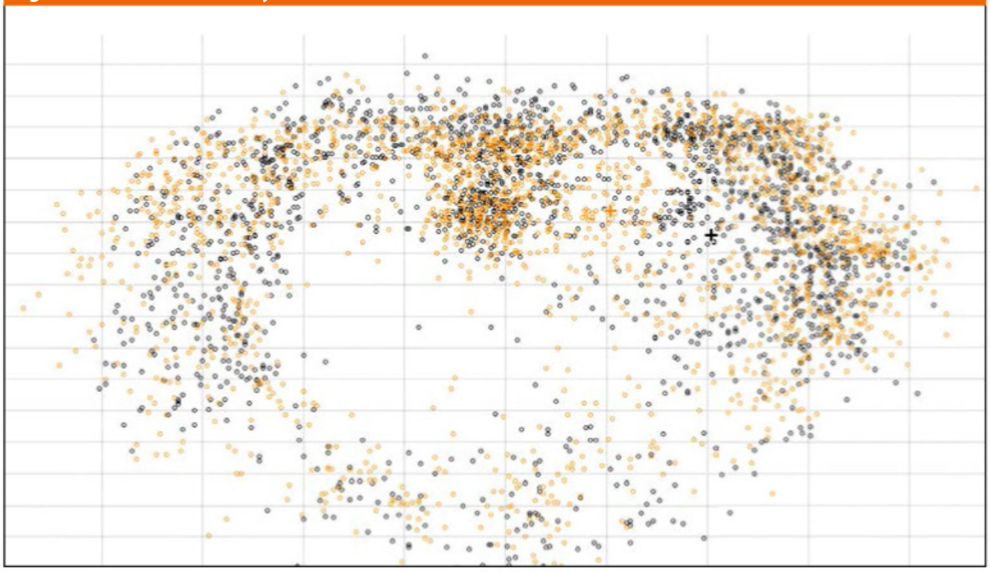
As can be seen in the steering trace, there was a lot less understeer and the speed trace showed more grip, which was bang in line with the simulated predictions. Implementing change C also showed the same trends.

Fig 5: Comparison of set-up A change



The take away here is not to be sucked in by brand B having a better reputation than brand A. It's about what works best on the car you are engineering

Fig 6: Brand A vs brand B tyres



For reasons I won't discuss here, changes B and D could not be applied, so the rest of the time was spent dialling in the rear dampers. Unfortunately, we had to live with the front dampers as is.

Where things could have gone better was with tyre choice, and here some sobering lessons had to be digested. A disclaimer is that not a lot of information was available about the tyres and how they would react to large amounts of downforce, so this part of the programme was always going to be a bit suck it and see.

The bulk of the testing was conducted on a set of brand A tyres. Good progress was made with those, but there were sets of brand B and brand C tyres available that, due to testing limitations, we only achieved extremely limited running on. The g-g diagram of the brand A and B tyres is seen in **figure 6**.

The brand A tyres are coloured and the brand B tyres are black. As can be seen, while the brand B tyres are better longitudinally, the brand A tyres are better laterally and fill out more of the g-g diagram. The difference between the brand C and brand A tyres was even more pronounced, as shown in **figure 7** (here, brand A tyres are the coloured trace and brand C tyres the black one).

Note also the steering trace here, showing oversteer on the way in and at mid-corner. The take away here is not to be sucked in by brand B having a better reputation than brand A. It's about what works best on the car you are engineering.

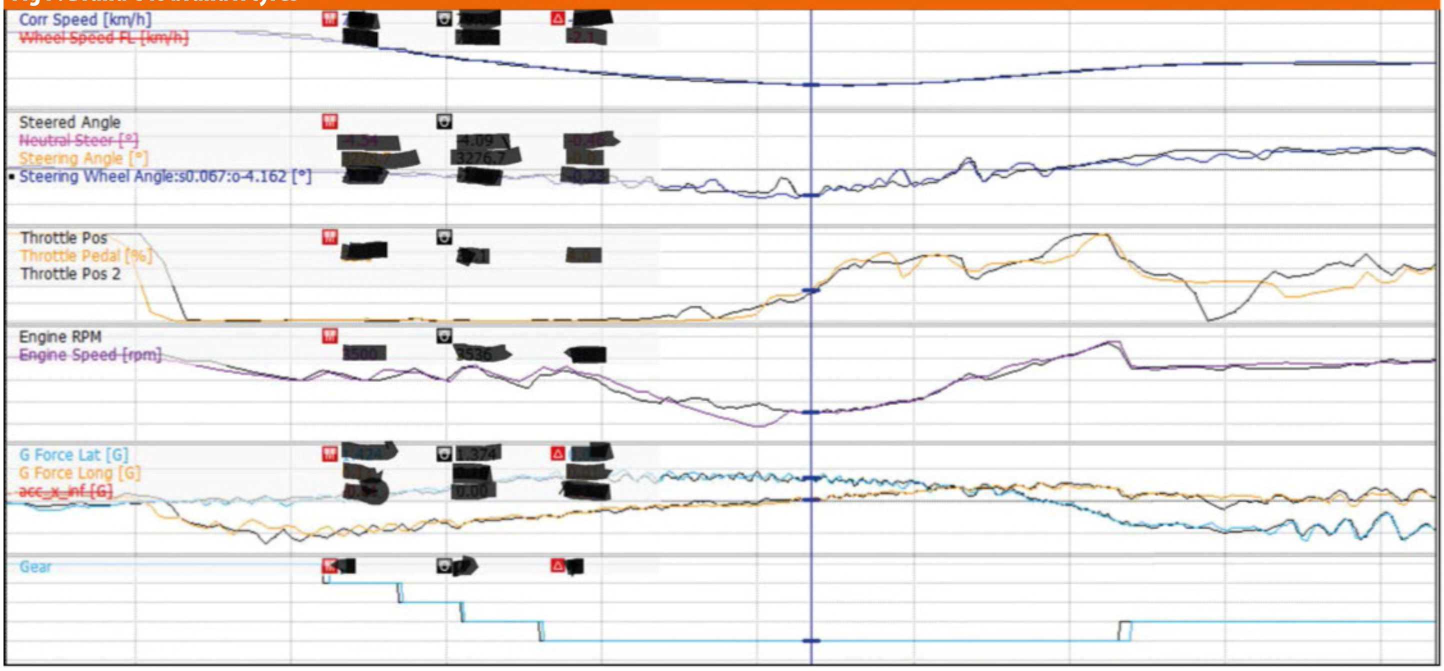
What this all shows is that even with an open formula, deliberate and careful preparation is essential. Looking at how the vehicle models were developed, despite the handicaps, the set-up was worked on sensibly and methodically. When it comes to vehicle set-up the tortoise will beat the hare every time.

Conclusion

In closing, many lessons were learned from data engineering the Tanuki S-13 Tilt at this year's World Time Attack Challenge. The first thing to take away is that if things don't go to plan, there are always work arounds (all the work ChassisSim was involved with from LMP3 to LMP1, for example, was a life saver here).

In terms of the set-up development, it was all common sense stuff, and the development path during the event followed a known and understood trajectory. The key mis-step was being sucked into the brand trap with respect to the tyres. The final arbiter is *always* what works best on the car, and nothing replaces careful and deliberate development.

Fig 7: Brand C vs brand A tyres



Not so flexible friends

The FIA introduced Technical Directive 18 at the Singapore Grand Prix, designed to curb the practice of flexing bodywork. The TD was intended to provide clarity around bodywork design details, 'in particular front and rear wings,' according to an FIA report.

'There are a lot of clever engineers out there looking to get the most out of the regulations, and we have to make sure that everyone has a common understanding of where the boundaries are, and we have to be fair and balance them across the whole group in how we apply them,' said FIA single seater technical director, Tim Goss.

'In recent times we have seen a little bit too much freedom being applied to the design details of aerodynamic components.'

The flexibility contravenes Article 3.2.2 because it 'exploits regions of purposely designed localised compliance and / or relative motion between adjacent components.'

XPB

The FIA will now be paying close attention to the intersections between wings and bodywork

In layman's terms, there is now clearer guidance around how components are joined together.

'For us, the important bit of Article 3.2.2 is that 'all aerodynamic components or bodywork influencing the car's aerodynamic performance must be rigidly secured and immobile with respect to their frame of reference, and that they must make use a uniform, solid, hard, continuous surface,' continues Goss.

'Now, quite clearly things cannot be totally rigid. So, we have a range of load deflection tests that define how much elements can bend and we've evolved those tests to represent what the teams are trying to achieve on track and to put a sensible limit on them.

'The TD is just about making sure that we, the FIA, and the teams, all have a common understanding of where we will draw the line in terms of those design details.'

TD 18 has included a line stating that 'regardless of conformity with the load tests defined in Article 3.15 [the FIA] would consider any design which uses the relative motion between adjacent components of mechanisms in order to maximise aerodynamic deformation to be in breach of Article 3.2.2.'

Focus has been less on the wings themselves, and more on the join of the wings to the nose and the rear impact structure, as well as to the end plates. To ensure transparency, the FIA will also now request additional drawings of the structural designs of areas of concern.

Teams and the FIA have been in discussions over this matter for many weeks, and at the Italian Grand Prix, before the draft directive was issued in time for the Singapore GP.

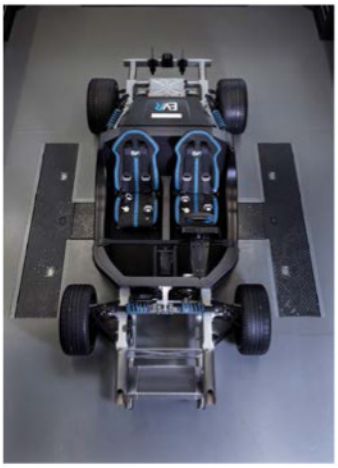
WAE unveil multi-use hydrogen chassis package

WAE Technologies (WAE) has unveiled its latest hydrogen fuel cell electric vehicle. The EVRh has been developed to demonstrate the potential of hydrogen-powered powertrain systems through implementation in a high-performance vehicle application

Produced by WAE in Oxfordshire, UK, EVRh combines the company's extensive vehicle and powertrain engineering experience with a cutting-edge H_2 fuel cell system in one package, allowing for end users to have zero tailpipe emissions driving.

The launch of EVRh comes exactly one year since the reveal of WAE's fully electric EVR and is being treated as a parallel-hybrid derivative of the company's EVR rolling chassis concept. The difference is EVRh utilises an H_2 fuel cell system to produce electricity through a chemical reaction between hydrogen and oxygen in a fuel cell stack, paired with WAE's systems integration and electrification technology.

Featuring a lightweight composite structure, the high-performance H_2 fuel cell and battery system are situated in the middle of the vehicle, optimising its c of g.

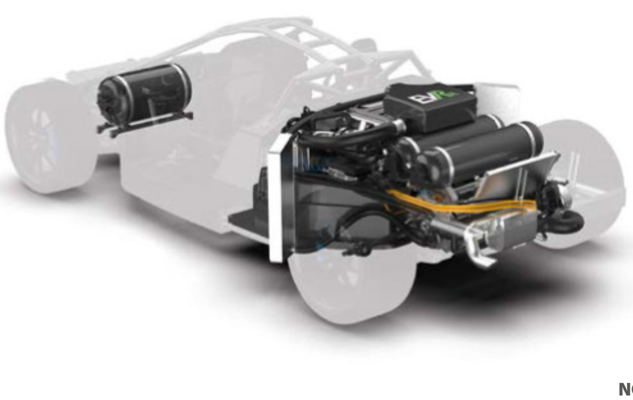


WAE's state-of-the-art, hydrogen-powered powertrain offers numerous possibilities to manufacturers, OEM and Tier 1 suppliers

The platform's inherent design flexibility will enable manufacturers to create different configurations from track-only vehicles, where power-to-weight is maximised, to roadgoing models of both open-roof Targa and fixed-roof GT style.

The powertrain has a state-of-the-art, liquid-cooled FCEV battery pack at its core and is capable of discharging 430kW of power and having a 120kW charge power, enabling sub-2.5 sec 0-100km/h acceleration capability.

Hydrogen storage is in two tanks with a combined volume of 100l, enabling a range of 600km.



All-wheel drive and rear-wheel drive layouts are both supported through EVRh's multiple e-motor configurations.

With the entire engineering and assembly of the hydrogen hybrid powertrain completed by WAE, it offers manufacturers an accelerated route to market, significantly reducing time and cost from development to market launch.

Similarly, both OEMs and Tier 1s have the chance to incorporate new products into the powertrain using EVRh, since the rolling chassis can undergo continuous enhancements using WAE's latest motor and battery technologies.

'Since its inception in 2010, WAE has been dedicated to innovating cutting-edge and transformative technologies across a variety of applications and industries,' says Paul McNamara, technical director for WAE Technologies. 'EVRh is another key example of WAE's capabilities in the development of solutions for zero carbon vehicles, enabling state-of-the-art FCEV vehicles to be brought to market rapidly and cost effectively.'

STCC's new electric racer

The Swedish Touring Car Championship (STCC) has launched its first new electric car, a Tesla Model 3, and will race the cars in 2024 against the likes of BMW's i4, Cupra's Born and Volkswagen's ID.3.

Designed by Stockholm-based EPWR, the 550bhp car is 100 per cent electric, rear-wheel drive and will be exclusively charged with renewable energy during the season via Atlas Copco's ZenergiZe energy storage system.

The cars are built on the original chassis of each model and then modified for racing by EPWR, including conversion to a raw natural composite exterior using a high-performance natural fibre used in Formula 1 and elsewhere.

Cars will feature common parts, have aero that allows close racing and no driver aids, such as ABS or stability control.

Power is stored in a 45kWh / 800V battery and will have 50kW of regen' to ensure impressive braking performance, we're told.

Weighing in at 1450kg, including the driver, the chassis will meet all current FIA technical regulations for safety.

'Now we look forward to the upcoming tests on Swedish tracks where we will be able to collect a large amount of data in our continuous development work for 2024 and beyond,' says Micke Jansson, CEO of EPWR.

Clad in a natural composite exterior, the new Tesla Model 3-based racecar comes with 550bhp, 50kW of regen' and rear-wheel drive only

Honda brings HPD into global HRC fold

One of the most famous names in American motor racing, HPD, is to be incorporated into Honda's global racing programme from 2024, it was confirmed in September.

Honda Performance Development was originally set up to run in IndyCar, but has since expandad to include Touring Car, single seaters and endurance racing in the US.

HPD will now be known as Honda Racing Corporation (HRC) US, and with this change the company will play an integral role in Honda's global motorsports activities, which includes its Formula 1 programme that will continue beyond 2026.

Knowledge has already been shared between HPD and Honda's F1 team in the development of the ARX-06 prototype that uses an F1-spec TAG ECU from McLaren.

Collaborating as one global entity, the two independent arms of Honda will combine their unique expertise and resources to strengthen Honda's overall motorsports capabilities.

Knowledge will now be shared across all branches of Honda's motor racing programme

The idea is to ensure the two company's engineering talent can be spread across multiple motor racing platforms, offering opportunities that were not previously available.

'Our goal is to increase the HRC brand and sustain the success of our racing activities,' says Koji Watanabe, president of HRC Japan. 'Our race engineers in the US and Japan will be stronger together and I am so happy to welcome our US associates to the HRC team.'

There was no confirmation at the announcement that the decision-making process would change, or that there was any more likelihood of the Acura ARX-06 racing at Le Mans, but it had previously been stated that a WEC programme would be a decision from Honda in Japan. That now appears more likely than ever.

For the company's IndyCar programme, more engineers are likely to be available to help develop the car, particularly its electronics.

'We will continue to challenge ourselves in US motorsport activities as we develop our people and technology to compete on a rapidly changing global motorsport stage,' said David Salters, president of HPD.

The new arrangement will come into force at the start of January 2024, so the ARX-06 will run at the Rolex 24 at Daytona with a new livery that features the HRC logo.

IN BRIEF

Formula 1 confirmed that **DHL's** new fleet of trucks running on biofuel reduced carbon emissions by an average of 83 per cent when compared to fossil fuel-driven trucks across the European leg of the 2023 season, according to the FIA. 18 trucks completed over 10,600km transporting 300 tonnes of freight per race.

The **Extreme E** series has extended its deal with free-to-air broadcaster, **ITV**, in the UK. A new multi-year partnership follows on from the channel broadcasting the events from the series' inception in 2021.

The five-round **World Rally-Raid Championship** schedule has been confirmed for next season, with a round in Portugal replacing that in Mexico during April. The event starts with the Dakar rally, before heading to Abu Dhabi, Portugal, Argentina and Morocco.

The **FIA** has confirmed each of the 10 teams competing in the 2022 Formula 1 World Championship met the cost control limits and issued certificates of compliance to each of them. The cost cap formula was introduced in 2021 with a view to improving the sustainability of the championship.

BMW has continued to test the evolution of its GT3 car that is scheduled to be introduced in 2025. The M4 GT3 features new aero, a new differential and new front suspension to try to work better with Pirelli's new-for-2025 tyre. The car will continue testing in the hands of the WRT team that will also run the factory prototypes.

Supercar manufacturer, **Bizzarrini**, has launched its new Hyper GT car, the Giotto, with a naturally aspirated V12 engine developed by British company **Cosworth**. Testing is expected to start in 2024 with delivery to customers scheduled for 2026.

In similar news, British manufacturer, **Lotus**, has launched its new electric Grand Tourer, the Emeya, its first four-door hyper GT car. Production is slated to begin in 2024.

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Flexible friends

De-coupling aero parts seems to be the latest trend in F1. Enter the FIA

The FIA has once again had to issue a Technical Directive aimed at reducing the flexibility of bodywork components, notably the fixation points of the front and rear wings.

Flexible bodywork is nothing new – all teams and manufacturers have tried it with varying degrees of success. The idea is to make a component stiff enough to withstand the load deflection test, but then bend at speed. The problem is that the FIA load deflection tests are well known so, as long as your part is strong enough in the direction and location in which it's tested, the rest of it is pretty much free. It's usually the responsibility of a rival competitor to raise an issue if something is suspected. The FIA only ensures that cars conform to its tests.

What interested me was that TD018 drove a coach and horses through that plan. If the FIA now suspects something, it can demand a team provide drawings of the part to ensure it meets with their expectations. This has all been discussed and agreed with the teams competing in the championship.

It's all a bit vague, but now it's vague in favour of the FIA. Teams like vague, of course, as it offers the possibility of wiggle room. They now just have to work harder to find it.

> **Teams like vague, of course, as if offers the possibility of wiggle room. They now just have to work harder to find it**

Working Group

I was reminded of the FIA Technical Working Groups as they discussed the future LMP1 regulations. According to one who was in them, teams were asking at an early stage what the maximum deflection that could be applied to a piece of bodywork was. The mole was a little disheartened by this. He was hoping the focus would be on the hybrid powertrain, rather than the bodywork. It was of no surprise to find the cars immediately proved controversial.

Having been primed that there were some games being played, it seemed polite to stand on the grid as the cars were lined up for their annual photoshoot to see what happened. Toyota's Pascal Vasselon was the first on the scene, walking around the back of the Porsche. He pressed down on the engine cover either side of the fin, and found it was not attached to anything. It flexed with the lightest of touches. The inference was that the rear deck of the car would sit down at speed, offering less drag. Porsche argued that it was only there for the group photo, and that the part did not have the necessary brackets that were to be raced.

The next thing that happened was that reports came back that Toyota was also messing around with flexible bodywork, but this time the rear wing was rotating backwards at speed. Sadly, photographers were reluctant to go into the woods and take a panning shot of the car at 200mph so we could see what was going on.

Slow motion

It therefore took until warm up to see what was actually happening when slow motion television pictures were beamed into the press room. The rear wing flexed as the car was televised going through the Porsche Curves. It was, said one driver, not helpful as they never knew what level of downforce they would have as they tackled one of the quickest sequences of corners on any race track in the world. It was quietly removed for the 24-hour race.

That only left Audi, and we couldn't work out what it was doing. It turns out that, having broken several chassis through kerb strikes, the team had introduced a damping system to the floor to absorb the impact. By happy consequence, that also meant the floor could flex at the other end of the spring limit, effectively reducing ride height.

That year was one of the most fun we had ever had while reporting the build up to the race, as the manufacturers were banned from talking to the media about such things, and FIA representatives weren't keen to say anything either. Eventually, though, they had to, in the form of official documentation, which was happily handed out by the FIA press officer.

At time of writing, I don't know which teams are most affected by TD018. The FIA says it is not targeting one particular car, or team, and, by the look of it, multiple teams were suspected of decoupling their wings from their end plates, or from their mounting points, allowing deflection between the parts and an aero advantage.

Red Bull had what appeared to be an evil handling car that weekend, raising eyebrows, but then dominated the Japanese Grand Prix the next weekend, and earned another Constructors' title, suggesting it wasn't them. Designer Adrian Newey hinted in Singapore that they were just having a bad weekend. It sometimes goes that way, and even a World Champion team can sometimes get it wrong.

ANDREW COTTON Editor