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Le Mans 2016

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Formula 1 2017
We investigate new power unit rules and cockpit safety

Hybrid efficiency
Optimising electrified power trains in LMP1

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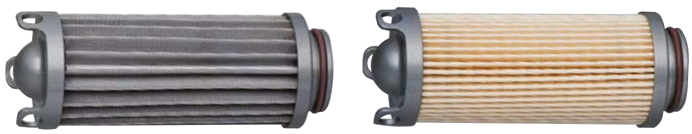

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For the second year in a row Toro Rosso has produced a class leading chassis, despite the fact that it had no idea what engine it would run with until very late in the day. For more turn to page 24

ACCELERATE INNOVATION

AVL RACING

SIMULATE ENGINEER MAKE TEST RACE

Secrets and lies

Is it time for race teams to rid themselves of their obsession with secrecy?

Competition being a zero sum game, in as much as there are only three places on a podium, it is no surprise that teams will try to get any advantage they can at every race.

In a small example, finding out the optimal pressure for your tyres at a given track means you will keep it to yourself to avoid giving competitors any clues if they are adrift on that question, as it could be worth that extra tenth of a second that makes all the difference in qualifying. And it applies to everything else, from set-up to strategy to your driver's headache or indigestion.

On the other hand, the extremes that proliferate at races sometimes border on a farce. The wall of mechanics behind a car at tests and races to avoid giving competitors a view on anything that has been changed; the covering up of mechanical components, even in spec categories; the elaborate use of misdirection and the telling of outright lies on what went on in the session and what incidents slowed you down; the sheltering of cars inside a battened down fortress with security at the doors. All of this is now part of the game.

The spying game

The careful perusal of sector times and the performances of your competitors during sessions does uncover some secrets, as does the judicious use of long lens from the spectator area or edge of the garage, while photos from the photographers also helps in blowing away the equivalent of the fog of war. Perusing social media from the rival teams' drivers is also very informative, and there have even been some cases of miffed drivers posting the relevant data-logger graphs on-line to prove their contention about their engine's performance.

The easiest way is to hire somebody from another team, of course, but that is a short-lived advantage as whatever information they bring will naturally have a short shelf-life once they are cut-off from direct knowledge of what is going on. This loophole has been closed theoretically by the now customary 'gardening leave'. How well this actually works is very dependent on the subject being ethically bound to avoid any communication with his new employer concerning any technical issues. But one is very sceptical about the flight characteristics of porcine objects.

Sitting track-side with a microphone can reveal engine RPM and through that, with some Doppler analysis, the acceleration, ratios, traction control action, blip strategy and lift and coast for the ERS.

Eavesdropping on the radio communications of your opponents with scanners has led to the encrypting of radio transmissions and telemetry. This led to amusing vignettes in Japan, where we had a black section in a closed room listening to the opposition and providing a stream of paper slips with their engineer and driver comments. Our countermeasure, when possible, was to speak in slang with the *gaijin* (non-Japanese) drivers, and especially the French ones, which was guaranteed to escape understanding of even the best linguist in that Japanese championship. The ideal solution was really to lean into the cockpit, and not go via radio for anything that would be informative.

There is a thirst for information that is not run through the spin doctors

XPB

Nissan was very open with information about its GT-R LMP1 programme to begin with, but the shutters came down when the project started to go wrong

Need to know

Let's assume that the paranoid attitude of restricting all information, and enforcing a strict need to know policy in a team itself, is a natural evolution of maintaining any small gain you may have. This has often led to a laughable dance of trying to suppress things which are very evident, especially in those championships with cars which are homologated and have restrictions on the parts used, and in other cases are blatantly obvious. But then one must go through the motions.

Given all that, one would expect the status quo to remain. However, looking at several items, maybe this will have to change. Most other sports have gained public appreciation and new interest by delving deep into all information the media can corral, and passing it to the spectator, improving the spectating experience. Certainly, the results of your very expensive testing or research and development is something that you don't want out there in the wild, but the present lengths of secrecy is cutting out a lot of knowledge that the fans would like to know, and which would improve their experience.

A break with this tradition was tried with the Nissan LMP1 programme last year, where all the information, initially, was streamed to the public, warts and all, showing what was going on in the pits and the briefings with drivers. But as the problems with the project started to delay running, the shutters came down and info dried up considerably. A shame, as there was a very positive reaction from the public, showing there is a thirst out there for information that is not run through the spin doctors of the public relations departments.

Virtual access

Formula E seems to have understood some of this, the Virtually Live company taking the fans into a prototype virtual reality immersion, giving them the best seat in the house, or enabling them to move around virtually anywhere around the paddock, track, possibly riding along in the car, and in the future interact with other members of the public. All part of enhancing a basic human need for interaction with other people.

CGI graphics as used in cinema, and the quality of game simulations, plus the obvious push from major players in the IT industry, will take virtual environments to a photo-real level and could conceivably replace actually going to a sporting venue. The downside for our sport is that the Formula 1 business model could generate a major problem for the race organisers, as depending on spectators to pay the fees to the usual suspects would not work anymore.

But having teams being more open with information would help to keep the fans interested, or maybe even increase what is at the moment a dwindling pool. Having the fan sitting in on the debrief after practice, hearing the engineers discussing the problems and how to solve them, would be very interesting. But somehow one does not see that happening, if only because it would severely dent the aura of the whole sport.

Screen savers

Are new head protection measures proposed for F1 a safety step too far?

To be, or not to be … Safer. That is the question creating much attention currently in F1. I refer to the matter of improving protection of drivers' heads from flying debris by mandating either the halo or the semi-canopy screen device for 2017. It's a pity from the aesthetic aspect that airbags triggered by proximity sensors could not be employed, but I imagine this has been assessed and rejected during the rigorous process that has led to the above solutions. However, only race experience will fully prove their practicality.

Quite what has so energised the FIA on this subject is not clear, but I suspect that Jules Bianchi's fatality at Suzuka, although generally acknowledged as being a violent deceleration injury that no form of head protection could have avoided, set the seal on taking up the results of the experiments that had been ongoing for some time following the Massa 'spring' incident in Hungary in 2009. This push was, no doubt, accelerated by the tragic fate of Justin Wilson and, not so long before, Dan Wheldon, both in Indycar, and also of Henry Surtees in MSV Formula 2.

As with many deliberations that involve more than just the headline factual part of the case, other factors come strongly into play. One can flag up appearance, driver visibility (looking out and looking in), open-cockpit tradition, the appeal of risk – to drivers as well as spectators – plus the effect on performance, and so on, and the answer then becomes more complicated.

Aero screens

F1 cars, of course, used to have windscreens *de rigueur*. These were of various sorts until the advent of the high, horizontal monocoque ahead of the cockpit in cars of the 1990s onwards, when they became miniscule or absent altogether, and thus it has remained. At the beginning there were aero screens, just a simple construct of flat glass and aluminium to deflect stones, insects and other detritus from the driver's face long before the advent of proper helmets, let alone the full-face type. This carried through until the 1950s when plastic, more wrap-around screens of various shapes and sizes were introduced. A particularly good example is the Aston Martin Formula 1 car towards the end of that era, while in the late 1960s and 1970s some very aerodynamic twin-screens were employed by Lotus.

Now drivers sit lower in the cars, which have very high sides, and airflow and materials are totally different. But the big change concerns what is nowadays acceptable as human risk. For some, and it seems for the FIA, ideally there should be no risk (cue the rather strange recent ban on discarding visor rip-offs). Others, including a number of the current drivers, believe that a certain amount of risk is necessary to give the adrenalin rush that comes with challenging potential disaster and beating it, and to maintain the image of F1 as a glamorous but underlyingly dangerous pursuit for the heroes in the cockpit. Undoubtedly there is a strong argument against the further dumbing-down of the dangers inherent in motor racing, and comparison should be made with many other sports. Would mountaineers be as motivated to make hazardous ascents if there was a safety net under them at all times? They surely do it for more than just the view.

XPB

The semi-canopy could be a part of Formula 1 from next season onwards; but will the sport lose a little of its essence with the fitting of such devices?

The risk factor

Jump-jockeys, too, incur frequent falls, stunt pilots crash, and in their case this is usually fatal. The risks in MotoGP and other two-wheeled racing have been reduced by track alterations and great advances in equipment, but almost every pro rider undergoes major surgery during a typical career, and the risk of head injury is ever-present.

What adds to the pro-debate is that, together with spinal injuries, damage to the head is likely the worst that can be suffered these days. So logically it is difficult to make a case against having the kind of protection being proposed. However, again it is not quite so clear-cut. A risk-analysis of serious head injuries suffered in Formula 1 over the last decade would probably show a remarkably low rate, although Fernando Alonso was fortunate in not having become such a statistic at the start of the 2012 Belgian Grand Prix at Spa, and there must have been other near-misses.

Indycar has a higher risk of head injuries, not altogether surprising given the high-speed ovals and speedways with concrete walls that make up a proportion of the championship, but still lower than one might expect. But let's face it, everyday life has the potential for similar injuries.

Consider also that once adopted, such head protection will surely have to be taken up by all forms of contemporary open-cockpit racing cars, at least those taking part in FIA-sanctioned events. Can an F1 driver's safety be considered any more important than a Formula 4 driver's, for example? Where will, or should, the line be drawn?

The big screen

Nevertheless, one can advocate that if preventive measures exist that are practical and don't stop or significantly curtail the activity concerned they should be implemented. In the case of the F1 proposals (putting aside, if one can, the fact that much of the raw challenge of race-driving at this level has already been greatly eroded) the main controversy concerns the appearance of the devices and the departure from the concept of open-cockpit single seaters as being the ultimate in racing cars. Some of this, I believe, is due to unfamiliarity with any kind of screen being fitted for over 20 years, as already mentioned.

None of these earlier designs were as pronounced as the semi-canopy advanced by Red Bull, but maybe with some refinement in shape that would include reducing the height somewhat and blending in better with the overall shape of the car, after a time such a device will look no more out-of-place than bodywork-mounted wings became after their much-criticised introduction in the 1970s. Maybe.

Would mountaineers be as motivated to make hazardous ascents if there was a safety net under them at all times? They surely do it for more than just the view

The entire aero concept of the car has been changed, with the cockpit moved towards the rear of the car in a bid to free up space low down at the front

Back to the drawing board

Audi has pinned its hopes on winning back its Le Mans title from Porsche, and the 2016 World Endurance Championship, with the latest iteration of its R18

By ANDREW COTTON

For the 2016 version of its R18, Audi has embraced change. Gone is the flywheel, replaced by a battery storage system that is mounted high in the nose of the car by the drivers' legs, while the entire aero concept of the car has also been changed, with the cockpit moved towards the rear in a bid to free up space low down at the front, to make full use of the front wing that has been allowed by the regulations since 2014, and to direct the airflow through the car. The rear bias of the car has meant a dramatically different weight distribution and, with the jump from the 4MJ category to 6MJ of energy that can be released, it has dropped from a 7-speed gearbox to a six.

Despite the changes to the hybrid system and the need to recover more energy, the team has elected to stick with the single front-mounted KERS, and says that although it looked at a second energy recovery system, it can recuperate enough through the single motor generator unit.

The engine is modified, but pretty much unchanged, but under the skin there are more extreme differences, including to the F1-derived suspension system, closer in mechanism to that of Porsche but different in detail, but which is more user-friendly and works the front tyres better, addressing one of Audi's main issues in 2014 and 2015 in its low-downforce Le Mans configuration.

One reason for extreme changes to the car made by Audi was a modification to the regulations designed to slow the cars, reducing the energy in the fuel tank by 10MJ. 'The regulations have changed for 2016,' says Jorg Zander, Audi Sport's technical director. 'One of the most important aspects was the energy reduction of 10MJ. We know that we were behind on hybrid energy, so we needed to catch up. If you understand the EoT [Equivalence of Technology] very well, the 6MJ diesel is the best concept from the drivetrain and propulsion point of view, and that is what we opted for. Then we needed to look into the overall concept of the car given the fact that we had to reduce the energy by more than 10MJ, by jumping the class as well, but not to lose any performance. Basically we wanted to achieve more or less the same lap time [as last year].'

Under Equivalence of Technology in the regulations, running a heavier diesel should not be a penalty for Audi against its gasoline rivals. The

The clearest difference between the 2015 version of the R18 (top, in high downforce guise) and this year's (above in Le Mans trim) is that the cockpit of the '16 car has been moved towards the rear. Under the skin the flywheel is discarded in favour of a battery storage system, enabling a move up to the 6MJ category. It does stick with single front-mounted KERS

k-factor is supposed to compensate for the extra weight, but Audi still feels that it cannot run a second MGU in the car. It initially analysed running an MGU-H before the car first raced in 2014, and abandoned the idea due to the weight, the height of the system in the chassis, and what the system delivered.

However, the k-factor does in some way compensate for the weight, so that a 6MJ Audi should be competitive against an 8MJ gasoline car. 'Yes, as far as we understand the EoT, that is the case,' says Zander, although he admits that there is an incentive to jump from the 6MJ category to the 8MJ category for a gasoline car that is not there between the 4MJ and 6MJ categories for diesel. 'If the car works fine, and if we cover the requirements well, then we should be competitive. With the k-factor you have the amount of additional energy, which compensates for the ERS energy that you can't run because of the weight differences of the powertrain. We think that works out quite okay. If you understand the step of reduction of fossil energy from class to class, clearly looking into the step from 6MJ to 8MJ, there is a bit of a difference, and it is something that we are still debating with the FIA and I am convinced that we will find a conclusion there.'

The suspension system on the R18 is now more user-friendly and works the front tyres better

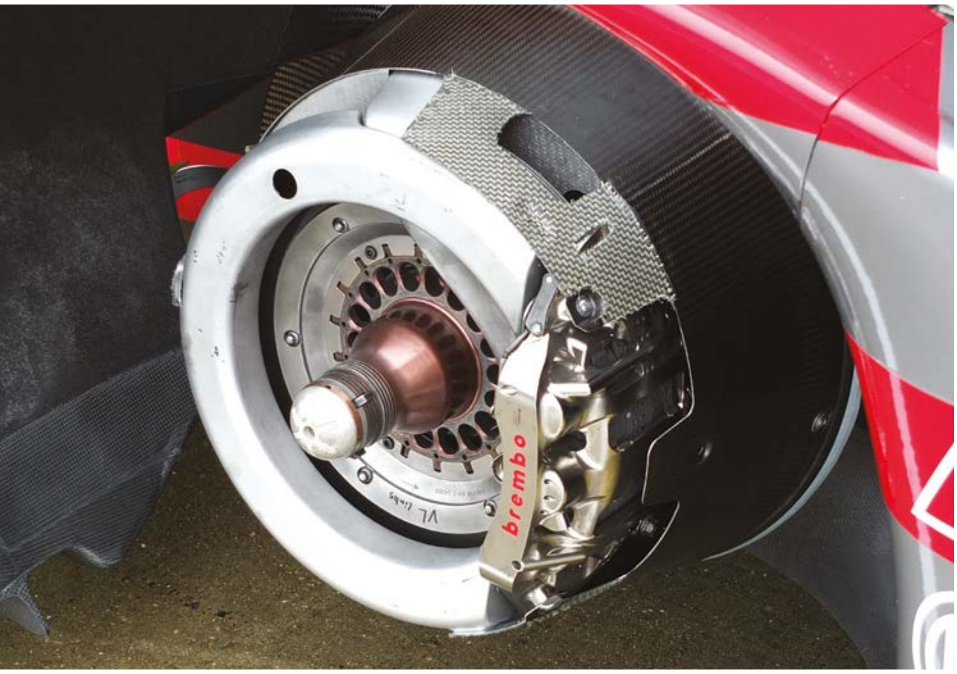
Aerodynamics

The entire car has been designed around a new aero concept, with a high, narrow bulkhead in which the MGU and battery are housed. The cockpit has been moved backwards, and the air channelled through the car, as Audi first tried with the R15 in 2009. One of the main challenges over the past two years for the R18 concept is managing the tyres properly. A reduction in the number of tyres allowed per event in 2015 meant that each car had to double stint at least once. That, coupled with the lift and coast at the end of the straights, which reduces the energy into the tyre, meant that the R18 often struggled with front tyre temperatures. 'Given the requirements for the weight distribution, you have to make sure that you position the weight in the maximum forward position,' explains Zander. 'The tyres have a pretty equal potential front to rear, so you aim for a pretty balanced weight distribution, so we didn't want to give up on that. The weight of the battery system is certainly higher than what we had with the electromechanical system, the flywheel, about 40kg extra for the two 2MJ, and you don't have too much flexibility with the location of the weight.

'[With] the reduction of energy you need to find ways to increase efficiency and that was a natural thing that we came across. We have a slightly different concept to the others, probably a higher nose, so you do channel a good portion of air not on top of the bodywork, but along the side and underneath the car. We found our best results with regards to improving efficiency. We are trying to minimise any turbulence and losing energy at the forward part of the car and it is from that perspective a natural evolution to where we have been in the last two years.'

Suspension

Audi used an F1-derived FRIC (Front Rear Interconnected) suspension system in 2015,



Front brakes. Audi has a new brake-by-wire system to cope with the changing brake pedal feel according to whether or not the car is recuperating. Toyota has designed its brakes to work only with the hybrid system

Rear brakes. Both the front and rear suspension have also been changed and the car now features decoupled roll and heave, although there is still a link between the front and rear heave springs, as in Formula 1

but changed it significantly for '16, although is still leaning on Formula 1 for inspiration. It is a system that closely mirrors the so-called Hub Wank system patented by Porsche, with a link between the front and rear heave springs. Audi calls it the LSS, or Linked Suspension System.

The LSS maintains a stable aero platform under acceleration, braking and cornering. Audi has decoupled the roll and heave link that it had last year, although there is still an hydraulic link between the heave springs front and rear. 'It is an all-new design,' Zander confirms. 'There is new functionality on the front and rear suspension; we have decoupled roll and heave, and damping and springing. It is important that you have individual adjustment possibilities, and you don't have any interference from one to the other. That works quite well. Of course, we had to change geometry to some extent, with regard to aerodynamics and the positioning of the wishbones and the linkages. There are no wishbones, they are just linkages. We improved the kinematics to some extent with regards to making the tyre work, so there are positive results from that already. Now it seems that also, with the development from Michelin, we are much closer to an area where we wanted to be.

'We maintained the same philosophy from the quasi-static positions. Where the suspension handles differently is in the transition stages, but anything that is quasi-static in terms of stability platform, with regards to stiffness and damping effects, this kind of philosophy is transferred to that car as well. The LSS system is a very important aspect of the function of the car and the way that the aero works, of course.'

Engine

The 4-litre V6 is retained for a third season, but Audi Sport's head of Engine Technology, Ulrich Baretzky, had to make changes to accommodate the regulations that stipulate a 10MJ reduction in energy contained in the fuel tank. There is a possibility that there could be a further reduction in energy for next season, and compensation for that has already been introduced into the engine design.

'Energy has been reduced, the fuel flow has been reduced and it is clear here that the target was to retain a similar power level, but be more efficient, which meant a lot of development in the combustion functionality, and Mr Baretzky has done a good job there,' Zander says. 'We are not really back to the level where we have been, but we are happy with the results achieved in terms of power. Weight has been reduced, not so much on the engine structure, which is a similar base, but we have rearranged the components to suit the bodywork and packaging. We have moved the weight lower, a little bit. This has also been an aspect, to reduce gravity centre, you naturally do that.'

While Gill was the preferred fuel flow sensor supplier to the competing LMP teams (and is now the sole supplier to Formula 1), it is known that Sentronics was looking to work with Audi and believed that it had a solution to the unique properties of a diesel car, increasing the frequency of the sensor measurement to 2.2mHZ. That largely addressed the 'aliasing' that teams were experiencing, making the sensors more accurate, a particular concern for Audi. While the gasoline cars run with two sensors, one to measure and one as a back up, Audi runs with three, including one monitoring return. That means the fuel flow is a calculation, rather than a measurement, placing yet more reliance on accuracy and repeatability within the sensors. Yet, despite the advantages that Sentronics could offer, Audi has preferred to stick with the original Gill sensor.

'We know Sentronics, we do work with them, and of course we are interested to see what they come up with, and are helping them to develop their hardware, but at the moment we don't feel that there is a necessity to change,' says Zander. 'We got the Gill operating in a relatively stable way, so we know what kind of procedure will work, the FIA can trust the figures.'

One of the main challenges for the R18 is managing the tyres properly

The battery is mounted high in the nose of the 2016 R18, by the drivers' legs. It has been placed there to move the weight distribution further forward as other major components have been moved rearwards to free up the front for aero needs

Audi has moved away from the electro-magnetic steering system and introduced a new, central hydraulic system that has taken over other key systems, such as the gearchange mechanism. It is a system that is more closely linked to Formula 1 than sportscar racing, reflecting the increased number of former F1 mechanics on the team. 'At the end of the day it is all about efficiency and you improve efficiency in some areas. So, with an hydraulic unit you have quite a high level of power available, 3000psi at the heart of the hydraulics, and with this amount of pressure available, you are able to come up with actuators of reasonable size and inertias that are quite fast, and it is more suitable for a car where [with] a demand of quick acceleration and speeds you have to reduce the level of inertia to get the dynamics from the system,' says Zander. 'With electrics, high torque, high forces, sometimes big motors are involved, and they mean high inertia, so they need to be bigger to drive their own inertia and that is contradicting. I think that we also save weight.'

This is all part of the learning process, says Zander. 'The car is altogether a completely new car. You can well imagine that we are going through a steep learning curve of hybrid technology, which is new to everyone. It is technology that you cannot get off the shelf. Also, the level of consultancy is not at the highest level at the moment as this technology is just being explored. It takes time, and is an interesting phase. I hope that we achieve the level that is strong enough to be able to compete on the highest level with the other guys, but I am pretty confident that they went through this two years ago.'

One of the key elements to making the car effective this year is managing the electronic control systems

One of the key elements to making the car effective this year is managing the electronic control systems, including the brake by wire and the traction control systems. Audi, for the first time, is running a traction control system on the front axle, although the gear mechanism at the front has caused problems, not only during race weekends, but also has believed to cause problems in testing, although Zander maintains that the team is confident in its system for Le Mans. 'With traction control you have different grip levels and you have to adapt the progressiveness of the ASR,' says Zander. 'It is a completely new system control mechanism. In some ways we were very much limited. In the past we had a very simple ASR controller, single axle, in-line car model and this is now much more complex. This is where Porsche has an advantage, a time advantage. We will see how fast we can catch up.'

Hybrid system

The change in hybrid system is one of the key elements to the development of the R18. Previously, a change in the regulations made long after Audi had elected to enter the car in the 2MJ category suddenly rendered the decision a poor one (see RCEV24N7) and Audi has been on the back foot ever since. It made the jump to 4MJ in 2015 and this year switched to a battery technology to jump to 6MJ. Thomas Laudenbach was brought in to develop the hybrid system, and admits that the likelihood is that Audi and Toyota, which also switched to batteries this year, will be behind Porsche. 'They have talented engineers and much more time,' he says. 'They are using it already, so it would be strange if they are not ahead. They have more experience with this solution, but I hope that this will not be a disadvantage this year.'

Battery supply

The whole process of selecting a battery partner was hardly a simple matter either. Audi has yet to reveal the identity of its battery partner but there is a short list of companies that are capable of delivering the specification required.

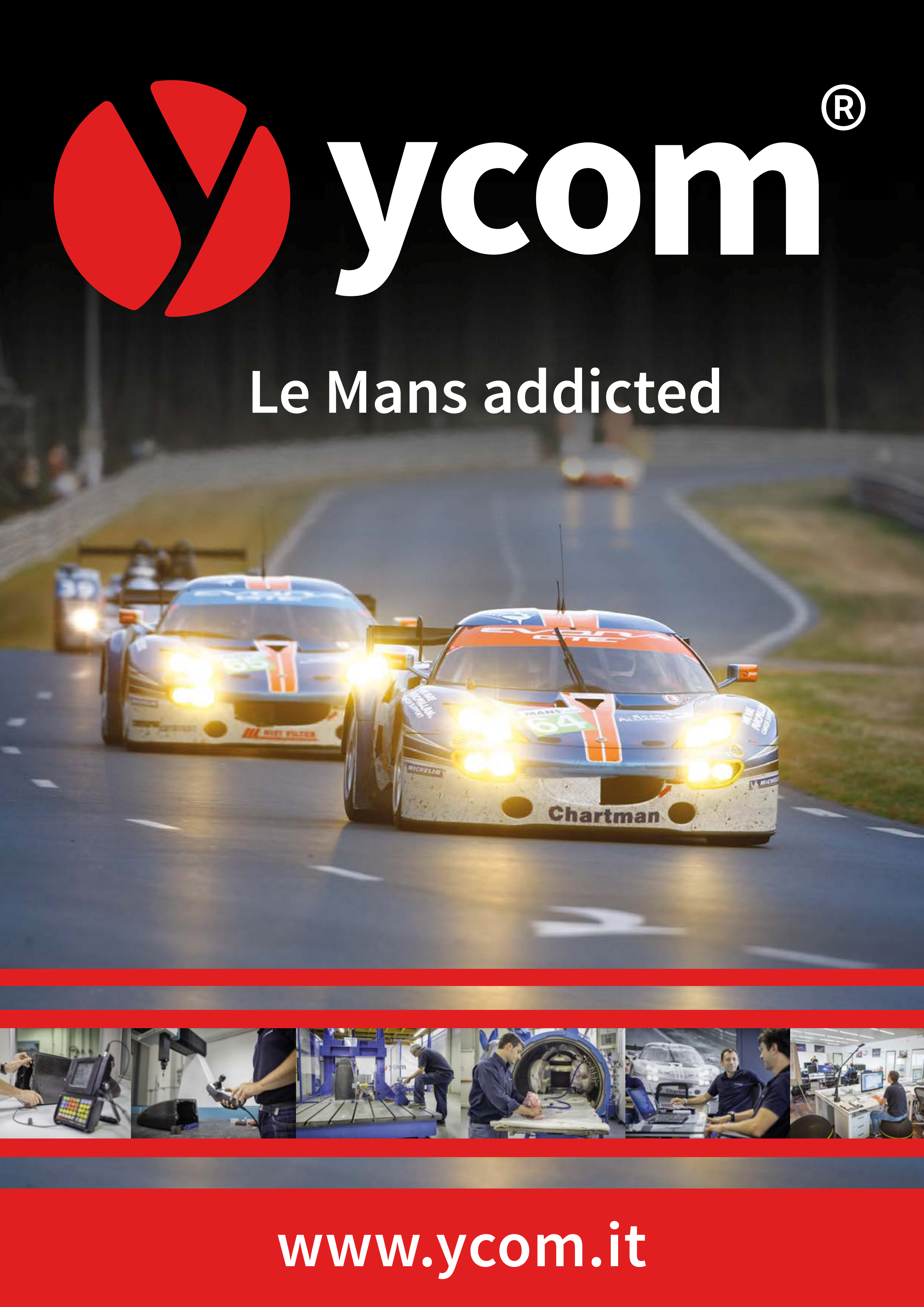
'If you get a data sheet from a cell supplier, this is nice,' says Laudenbach. 'It gives you very precise information about the energy content, that is what the road cars are heading for, but it tells you nothing about what power you can get out of it. They work at a much lower power level, 10 to 15 years of lifetime, and we try to squeeze it out from a power perspective and allow a certain degradation because we have to use it for 30 to 40 hours. This is something [useful], that if you have a cell supplier who is already delivering in motorsport, and knows what you are talking about. If you have a supplier that hasn't been in touch with motorsport they have no clue what their cell is able to do.'

Audi screened a number of potential partners before making tests with a short-list of companies. 'That is not easy because at that stage you don't know your duty cycle,' says Laudenbach. 'You have got to define it because this is not a common or standard test. You try to create a good duty cycle, try to create a profile where that could be the one that comes closest to what you need on the track, and then you test on a single cell basis. You vary the power output, you look to stay in the voltage level that the supplier recommends, and then you see how stable it is, the losses in terms of heat rejection, cooling demands, and then you choose it.

'This [decision] took a few months, and once you have the decision then you have to live with it. This is the one that defines your design concept. You have three different cell types, a round one which I think is in the Porsche, the pouch pack, and the prismatic, and that is it.'

The regulations stipulate a maximum of 1000V, and with road cars heading quickly towards 800V, the racecars are following a similar path. Handling that is not easy, however. 'The voltage level at which a cell works is purely related to the chemistry that you use,' says Laudenbach. 'For example, a certain chemistry is 3.5 to 4V per cell. There is something that you have to keep in mind; voltage up, at the same power, means less current. More current means more weight, because if you run at a high current you need more copper. Copper is heavy.

'Normally you try to come to a high voltage level because you have to save weight. This is DC voltage, not AC because that is easy. This voltage, it gives you some challenges. The FIA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Reliability is a worry for all the major LMP1 manufacturers but for the Audi team a weakness has appeared in the front motor and is a concern ahead of the Le Mans 24 Hour race

Much of the aerodynamic work has been focussed on making full use of the front wing, which has actually been allowed in the regulations since the 2014 season

allows 1000V, that's the limit, and you try to work at a certain level that you can handle, and then you are down to the size of the battery. If you say 4V per cell, 800V is 200 cells in a row. Then you check if your capacity is right. If you have a very low capacity you do two rows, but basically you try to achieve a high voltage level. Standard in road cars are 400V, but they are starting to come to 800V. It is easier at 400V, with the relays, there is a big variety of components that are already there. If you go to 800V or 1000V, it is harder to get these components because they are not standard. That is how you figure out the concept of your battery. You can also use aluminium because it saves some weight, but for the connection it is worse,' Laudenbach says.

With a higher voltage level, it is not only the copper wire that is lighter. Charging the battery is quicker, takes less energy, and therefore requires smaller motors. 'It is always good to work at a higher voltage level, if you want this power, voltage *x*, current *b*. They are linked completely. If you would use half the voltage level, same power, twice as much current. That gives you the demands for how big the wire has to be,' adds Laudenbach. 'You choose the amount of cells on other parameters, like power. Then you look at which voltage level you have to work at. Inside the MGU, it has to live with the voltage level that the battery gives you. For example, I have a 300kW MGU and a battery that is able to deliver 300kW. One will deliver 300kW at 400V with an MGU weighing *x*-kilos. Then you have a battery, also delivering 300kW at 800V, the MGU will be much lighter. And so will the battery, but the whole system is working with this voltage level. You have a voltage lift in the battery, and you need to design the MGU that it is also able of delivering maximum power at low voltage level. If you come to the end of the straight and want to recuperate, the voltage level is low because you just boosted. Then you need maximum power because you have three to four seconds to collect.'

'With the conditions that we have now, the diesel will always be heavier than a petrol engine'

Energy storage

Audi looked at all scenarios for energy storage, including the super capacitor system used by Toyota in 2014 and '15, and sticking with the flywheel concept. The team discounted both in favour of the batteries, which gave more freedom in terms of strategy. 'My brief was to choose the best that we can have,' says Laudenbach. 'We looked at super capacitors, but it clearly was not the way to go. [Toyota] came to that conclusion by running it, and we by looking at data sheets, and making calculations. It was not the right way to go, although the handling would have been easier.

'We made also a comparison with the flywheel that would have given us the potential to do 6MJ, and the different flywheel concepts to what we had in the car. That would have been heavier than we now have. What we have now is a lot of freedom in terms of energy. The parameter that you are focussed on is the power unit. We have some strategic freedom on the track, which Porsche had last year, and we could all see that in qualifying. This would not have been possible with the flywheel because the limiting factor would be the energy. Then you look at the trade off, to judge and to get the number for the advantage that you get from this kind of freedom. It is not that easy because you can play with the parameters, build a model for the car simulation, but the result is as good as the model, and the model is as good as the boundary conditions that you define. At that stage you have to make a decision. You do not know where you will end up with the weight, the power, or the degradation. Am I in a position to have this for the whole race, or six hours, or 10? These are all things that we try to analyse. In the end you don't have it 100 per cent. Then you have to fix it and go for it.'

The battery is mounted high in the nose, by the drivers' legs, placed there partly to move the weight distribution further forward while also to keep the underside of the tub clear for the aero. The front-mounted KERS also resides inside the cockpit and at Spa, when it failed due to high loading in testing, the oil leaked throughout the cockpit, necessitating an overnight repair as key components had to be removed to access the failed part.

The single MGU was partly driven by a need to save weight, but the team felt that it could recharge the battery fast enough without the need for a second system. 'With the conditions that we have now, from the weight perspective, the diesel engine will always be heavier than a petrol engine, which is in some way corrected by the k-factor, so we can only put one system in right now,' says Laudenbach. 'That puts a lot of pressure on battery development. The nicest system is the one from Porsche [which has developed an MGU-H]. They are on the brakes and not recuperating from the engine, and when they are off the brakes, they have a small amount of power feeding the battery. We have to do it all at the front, which is 350kW on the recuperation side, and this is the figure that you have to design the battery for.' Audi also has a new brake-by-wire system to cope with changing brake pedal feel according to whether or not the car is recuperating.

Toyota and Audi have developed dramatically different cars in 2016, and Porsche has suffered its own dramas in the opening races. Each will bring only two cars to Le Mans this year. So reliability, rather than outright speed, could decide the race.

Harvest **festival**

As the WEC manufacturers gear up for Le Mans we take an in-depth look at both new and potential efficiency drivers in the LMP1-H category

By PETER WRIGHT

The WEC's Silverstone 6 hour race in April offered the first opportunity of the year to evaluate the development and changes put in place by the big three LMP1-H protagonists in anticipation of the main event, the Le Mans 24 Hours.

The LMP1 regulations are a set of carefully crafted rules that aim to offer all the contestants the maximum technical freedom, but pull the different configurations together to equalise the performance of these technologies, for close and exciting competition. The FIA and ACO have been very successful in activating this through the use of a Fuel Technology Factor (FTF), a K Technology Factor (KTF), which balances fuel and powertrain weight, and an ERS incentive, thereby attracting heavy hitters Audi, Porsche, and Toyota into the arena with markedly different cars and powertrains.

The parameters that make up these factors are carefully measured and, after two years of the formula, the diesel and gasoline cars are proving to be very equal. With the key performance parameter, power, so well balanced, the two main differentiators are aerodynamics and delivered power, or in other words the use of available energy. It is the latter I want to discuss here.

Flow rate

The peak power and average power produced by the ICE is controlled by the maximum total/lap and flow rate of fuel energy into it. The maximum power and average power/lap, i.e. energy/lap, of the two ERS systems are simply stated in the regulations, according to the MJ class chosen by the manufacturer. The energy/lap of the ICE and ERS systems are matched up using the Equivalence of Technology (EoT), which is calculated from the FTF and KTF for each MJ class of diesel and gasoline.

These are almost fixed and separated, but in the calculation for the FTF, which is based on measured Brake Specific Fuel Consumption (BSFC), there is a critical adjustment for 'effect of exhaust gas recovery system'. It is recognised that the BSFC will be increased by the back-pressure of an ERS that uses exhaust energy recovery and an MGU-H, and so the FTF is corrected – how exactly is not clear. Porsche are the only ones *directly* affected by this. Thus,

if the ICE engines are tightly controlled for performance, and maximum and average/lap ERS is prescribed, the differences between the cars will be how much energy they are able to harvest/lap via their ERS systems.

Harvesting power and energy/lap are not regulated. A measure of how critical this is as a performance differentiator is the fact that it is impossible to get an LMP1 engineer to speak about the rating of their ERS systems in harvesting mode, or about the strategies they employ to harvest and deploy ERS system energy. Incidentally, it is just as impossible to get an Formula 1 powertrain engineer to speak out on the same topic.

In actual fact, close inspection of Appendix B of the LMP1 technical regulations states that the maximum released power of the ERS is 300kW, with an interesting footnote: 'Not limited on Grade 1 circuits'. Of the WEC circuits, only Le Mans is not Grade 1, so, in theory at least, more than 300kW could be deployed everywhere else. With Le Mans being the focus for WEC contestants, is it likely that the LMP1 manufacturers would build oversize ERS systems for other circuits? They might, as the limit would be set by the ERS control system and there are reasons for building systems that are more powerful, as we shall see. It would all depend on whether the MGU or the ES, batteries in all cases, is the power-limiting factor.

Right from the start of KERS in F1, simulation engineers determined that the optimum strategy for the deployment of harvested energy was to use it to accelerate as hard as traction allowed at the start of a straight, in order to reach the ICE-only sustainable top speed as soon as possible. The question then became; which straights to use it on, which itself depended on where and how much energy could be harvested under braking. More deployment power means achieving the Vmax earlier, with an overall time saving.

However, it is during the braking/harvesting phases that ERS power really counts. The three LMP1-Hs employ different ERS systems, with Porsche and Toyota both using two, and Audi just a single system, see **Table 1**. It is unlikely that the deployment is used on the rear axle of the Toyota unless the front axle is traction limited while the ICE-powered rear axle is not. Mind you, 400cv through the front wheels at low speed is quite challenging (ask Nissan).

Trade-off

When the brakes are first applied from high-speed, around 340kph, they absorb several thousand kW. To enable the ERS system(s) to harvest this would need massively powerful MGUs, controllers and batteries. Thus there is a trade-off between power/weight/size versus harvested energy/braking event. With the limit on deployed energy/lap calculated for each circuit based on the MJ classes for Le Mans, it is a question of whether sufficient energy can be harvested to meet this prescribed quota each lap. Toyota gains from being able to harvest from both axles, benefiting from its 2009 Formula 1 experience, when only the rear axle was permitted in the KERS era.

Therefore, as a result much of the available kinetic energy available under braking is discarded to the brake discs, as building a more powerful system to benefit from a brief period at high-speed takes its toll on the size of the batteries (power density limits of current Li ion technologies) and also the cooling requirements for the system. Where this compromise lies, no one is saying.

As speed declines, the torque for a given power rating must increase proportionally. At some point the maximum electrical current of the various parts of the system limits torque. This limit will manifest itself by maximum permitted temperatures throughout the system.

If one assumes that all three contestants are able to harvest roughly the same amount of energy/lap through their front axle systems, which one could surmise is Audi's selected 6MJ limit for Le Mans, then logically the

Table 1

	Harvesting	Deployment
Porsche	Front axle Exhaust turbine	Front axle
Audi	Front axle	Front axle
Toyota	Front axle Rear axle	Front axle Rear axle (?)

The 'city' credentials of an LMP1-H car are demonstrated by regulating that they must only use electric power in the pit lane

It is impossible to get an LMP1 engineer to speak about the rating of their ERS systems in harvesting mode

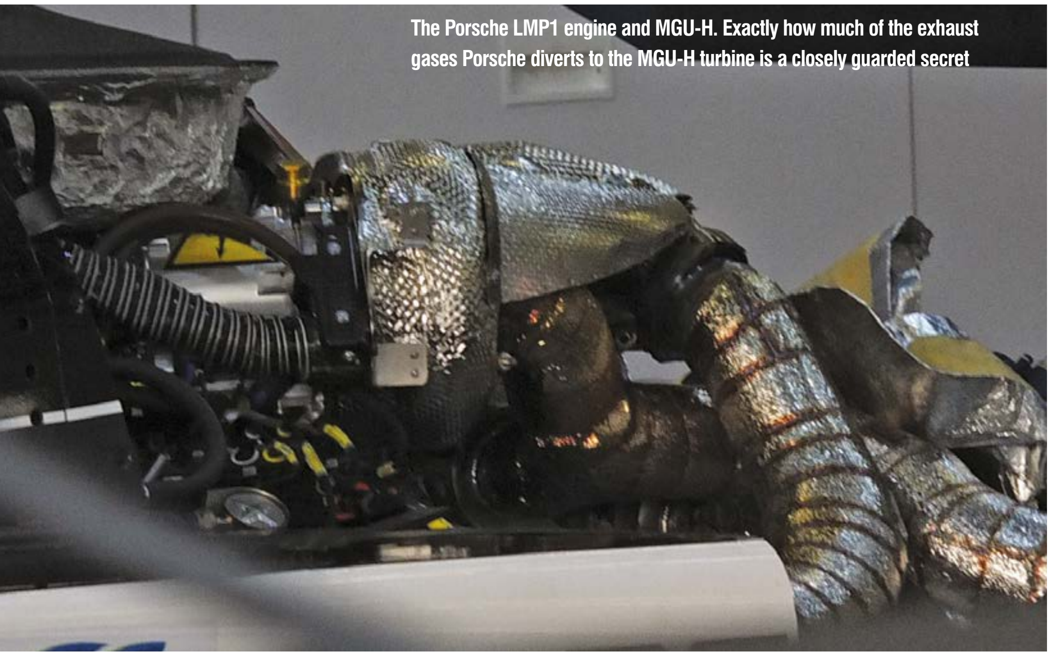
Toyota harvests 2MJ from the rear axle, and the Porsche 2MJ from the exhaust.

Exactly when and how much of the exhaust gases Porsche diverts to the MGU-H turbine is a closely guarded secret, but, by way of illustration, using it under all full-throttle conditions at Le Mans would gather the 2MJ from something like a 15kW system. One can surmise that it is probably a more powerful system, used less often.

Toyota's Pascal Vasselon offered the information that F1 MGU-H's started out at 30kW, and have been developed to over 100kW. Just how Porsche uses its system may depend on how the adjustment for 'exhaust energy gas recovery system' is calculated, and how it affects the measured BSFC and FTF. Complicated?

Finally, there is the question of using any unused fuel allocation, either a surplus/lap or when using the ICE below the maximum fuel flow rate, to harvest energy into the ES. Vasselon says: 'It is a no-brainer when it is wet'. Under wet conditions it is neither possible to harvest sufficient energy to meet the deployment allocation, nor to use the fuel energy flow rate fully. For Porsche it is straightforward to divert some more exhaust energy to the MGU, and even to fuel the ICE in excess of what it needs to deliver the required torque to the rear wheels. For Toyota it is possible to set up the ICE to produce an excess of torque at the rear axle and then absorb some of it in the MGU. With the freedom to use traction control in LMP1, this is straightforward and legal. Audi would have to use the ICE-only powered rear axle to push the front axle and so absorb energy at the front.

If energy harvesting from fuel burn were used when the fuel/lap is a limitation, then the driver would have to lift off earlier before the end of the straight, to conserve fuel in compensation. When and where this makes sense from an overall lap time, or the ability to overtake, is down to the strategists. In LMP1, the drivers may receive guidance from their strategists by radio. Vasselon: 'Strategy may change 10 times per lap!' Do they do it? They won't say. Which probably means they do.


The Porsche LMP1 engine and MGU-H. Exactly how much of the exhaust gases Porsche diverts to the MGU-H turbine is a closely guarded secret


Porsche's V4 internal combustion engine. New combustion technology is at the heart of modern race powerplant development

Combustion technology

With so much emphasis in both LMP1 and in Formula 1 on ICE efficiency, there has been plenty of speculation about some of the combustion technology being explored or employed by the development engineers for these remarkable engines.

At the core of efficient combustion is achieving a high-pressure ratio (turbo boost plus compression ratio) without knocking, and the ability to initiate combustion of the leanest possible air/fuel charge. There is nothing new in this and the Ricardo company, among others, has researched this topic for many, many years. It has indicated for some time that future road car ICEs will be a merging of gasoline spark ignition and diesel compression ignition technologies, to utilise the best of both.

First some terminology: HCSI: Homogenous charge spark ignition (gasoline); SCCI: Stratified charge compression ignition (diesel); HCCI: Homogenous charge compression ignition (gasoline); PCCI: Premix control compression ignition (diesel); RCCI: Reactivity control compression ignition (gasoline and diesel).

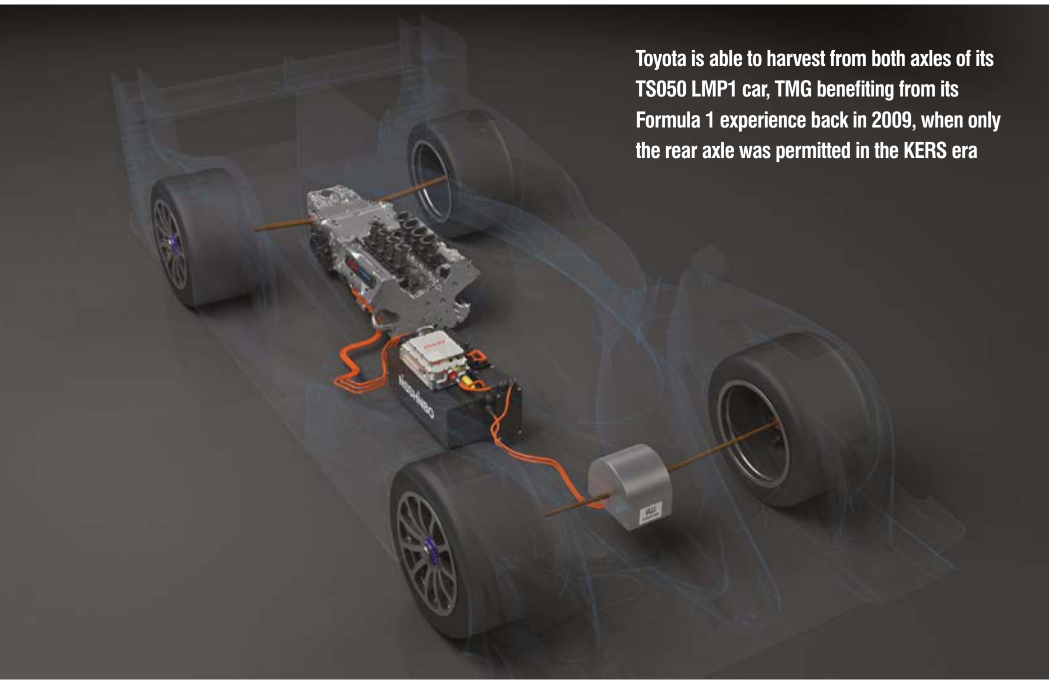
The terminology that popped up recently with respect to Formula 1 is HCCI. This is nothing new; those who spent part of their youth trying to get an ether-fuelled model aircraft 'diesel' engine to start, will have been confronted by the difficulties of initiating combustion of a homogenous charge, by compression, under all operating conditions.

Unlike an HCSI or SCCI, an HCCI combustion process is lean, low temperature and generates a flameless release of energy uniformly throughout the combustion chamber. The whole mixture is burned simultaneously and

Under wet conditions it is neither possible to harvest sufficient energy to meet the deployment allocation, nor to use the fuel energy flow rate fully

results in high-power/unit fuel energy and low NOx and PM. Thus it is primarily aimed at the road car ICE. The key technologies are those needed to ensure a correctly timed combustion under all operating conditions, in the absence of a timed spark or precise diesel injection to initiate it. EGR, variable valve lift and timing are all needed, the latter two technologies banned in WEC and F1.

PCCI and RCCI are technologies aimed at taking control of the timing of combustion through premixing and the final injection of fuel to start combustion, and the use of two different fuels, blended in the cylinder, respectively. All of which seems to make HCCI an unsuitable candidate for a racing engine. What is clear is that the engine and fuel R&D that has gone into these road car technologies will have yielded a deep understanding of the combustion process, and will benefit those powertrain engineers who have access to it.



Toyota is able to harvest from both axles of its TS050 LMP1 car, TMG benefiting from its Formula 1 experience back in 2009, when only the rear axle was permitted in the KERS era

Toyota's internal combustion unit is just about visible here. The hybrid nature of the LMP1 category has been a major reason for its success. Toyota recently managed a full lap of Spa, although at very low speed, on its ERS system alone

Knock-knock

Persuading a very lean mixture to ignite without knocking is a key to efficiency. The process most likely to be used in a racing engine is one where the main charge is very lean, but a richer pocket of fuel and air is located around the spark plug, such that the spark ignites it and the flame spreads through the leaner main charge. This can be accomplished with precise injection patterns and event timing. In some road car applications, the initial combustion takes place in a chamber surrounding the spark plug, and the flame enters the main chamber as jets through orifices. This results in a more uniform combustion, preventing pockets where the pressure rises and knocking could occur. Whether this has been applied to F1 or WEC engines is not certain, but just maybe some of this is what Mercedes used two tokens for in Russia, when it changed components in the fuel system on all its F1 engines, and demonstrated its biggest advantage of the year to date.

These developments are exactly those that the FIA and ACO set out to encourage when they laid out the LMP1 and Formula 1 regulations, succeeding in attracting seven major manufacturers to the two championships so far. For LMP1-H, they are also open to other, in some cases radical, new technologies that a manufacturer may wish to demonstrate and promote. What they won't do is let it upset the close nature of the competition. The EoT system handles all likely hydrocarbon fuel systems, and so would allow a wide range of liquid and gaseous fuels, once the characteristics of the fuel and the energy conversion system are established.

New technologies

The ACO uses its Garage 56 to make a full assessment of new fuels/technologies in a competitive environment, before applying the EoT to them to ensure no unseen advantage upsets the apple-cart. In 2017, the experienced Welter Racing team will return to Le Mans with a bio-methane fuelled, 1.2-litre, turbocharged, 3-cylinder powered racecar.

Manufacturers are also pushing for alternative forms and levels of electrification. A full BEV is not going to be able to compete at Le Mans for a very long time because of range limitation. Nissan achieved just one lap at racing speeds with its ZEOD, under electric power alone. The current breed of cars are parallel hybrids, but the ACO has received a number of proposals for series hybrids. The problem has been that these projects have also incorporated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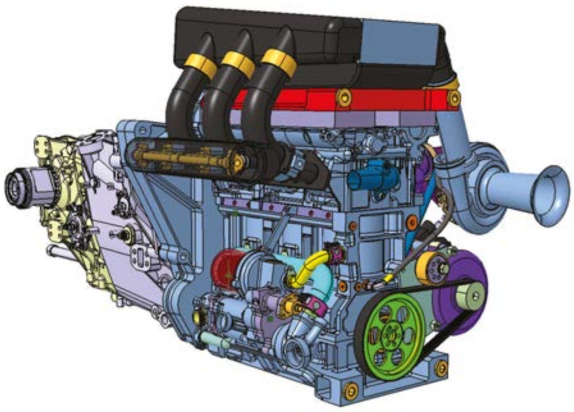
The Green GT H2 is said to be the first electric-hydrogen racecar. Hydrogen cars at Le Mans could become a reality by 2020



Welter Racing will return to Le Mans in 2017 as the Garage 56 entry, its car propelled by this bio-methane fuelled, 1.2-litre, turbocharged, 3-cylinder powerplant

full-time 4WD, with individual wheel motors and torque vectoring. The performance advantages are too great and very difficult to balance.

Even harder are the approaches to the ACO to race a hydrogen fuel cell car. They would love to have such cars racing in 2020/2022, which would require regulation to be finalised in 2019, but even that is quite a challenge. New EoT-balancing regulations would have to take account of the efficiency of energy conversion, refuelling time, safety, weight, and the effect of low temperature heat rejection on the aerodynamics. Whether it will be possible to come up with a fair equivalence, or whether a separate category would need to be established, is nowhere near decided yet.

Some manufacturers would like the equivalency to be based on CO2, either well-to-wheel for the fuel, or even cradle-to-grave for the whole car plus fuel. Radical, but not excluded by the ACO or the FIA.

Since Volkswagen dragged NOx on to centre stage, the issue of local emissions is also being discussed. Racing powertrain developers tend to measure NOx and other tailpipe emissions on the dyno, because their equipment has the capability to do so, but not to take much notice of the results, as they are not referred to in the regulations.

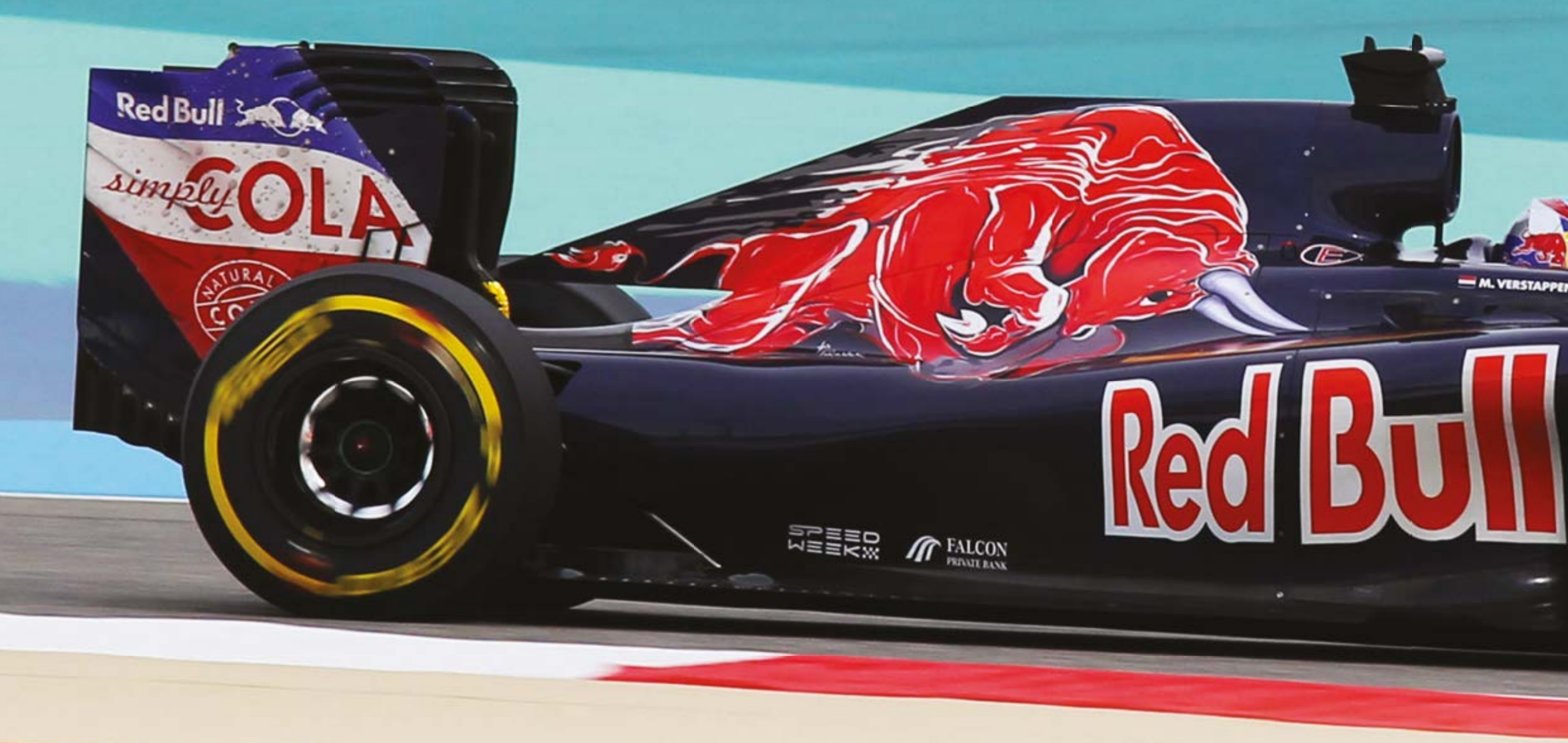
Street cred

The 'city' credentials of an LMP1-H car are demonstrated by regulating that they must only use electric power in the pit lane; not so silly really as dual-use cars in the future are likely to be electric for short range use in cities, and employ a high-efficiency, fossil-fuelled ICE for long-range, high-speed use inter-city. Fascinatingly, Toyota recently managed a full lap of Spa at significantly low speed, on its ERS system alone, in order to qualify for points at the recent six hour race there.

The World Endurance Championship is very healthy, highly competitive, attractive to fans, and is managing to bring motorsport into the high efficiency, low CO2 emissions technology environment, where manufacturers want to be, while avoiding the self-criticism that Formula 1 is suffering from. Where it goes next is currently featuring strongly in discussions among the stakeholders, and getting it right is essential for the long-term support of the manufacturers in this fascinating championship.

After two years of the formula, the diesel and gasoline cars are proving to be very equal

Forza Faenza



A falling out between a car manufacturer and an energy drinks company resulted in a team of designers and engineers in Italy facing a race against time to create a new Formula 1 car in time for the 2016 season. What they created is, according to many in the paddock, one of the best chassis of the year.

When Toro Rosso technical director James Key and the design team at the Faenza-based outfit started to lay out the concept of a new grand prix car, dubbed the STR11, they believed that they were working on a Renault-powered racecar, so it is perhaps no surprise that the direction pursued was similar to that of its last two cars, both of which were designed to accommodate the Renault RS34 power unit.

A bombshell was dropped. The STR11 would not be a Renault-powered car after all. Indeed, it was not clear which unit it would be fitted with

'The STR11 is really an evolution of STR10 by and large in terms of concept an philosophy,' Key says. 'There are only certain concepts which carried over from STR9, very few, the principles were established on that car in 2014 but we took a lot of them and revised them for 2015. So while there are a few concepts which are similar, you should look at the STR9 as the grandfather if you like, but it's not a baseline for either car, we did not evolve exclusively from that.'

During the 2015 season the Toro Rosso was described as perhaps the second-best chassis in Formula 1. Indeed, GPS data showed that in some corners the STR10 was at least a match for the otherwise dominant Mercedes W06. As a result of this there was much speculation about what the Toro Rosso could do had it been fitted with a more competitive and reliable power unit. The aim for the 2016 car, according to Key, was to preserve the strengths of that design while addressing some of its weaknesses.

'We wanted to concentrate on improving the low-speed cornering capability of the car. Last year's car was a big step forward and particularly good in medium and high speed corners, but we have felt our lower speed performance was not as competitive as we would like', Key says. 'That has been one area which has led to a change in approach for our 2016 car.'

This can be seen when looking at the suspension layout of the STR11 in comparison with the STR10, for while it retains the conventional concept of double wishbones all round with push rod actuated torsion bars at the front and pull rod actuated bars at the rear, many of the minor details have changed.

Optimised suspension

'The suspension internals are pretty similar to what we had in 2015 though the layout has been adapted to fit the available space in the chassis which is smaller on this car,' Key says. 'At this stage there is nothing really new there, but externally we looked at a lot of different options in terms of geometries.

'We looked at the front wheel centreline, various iterations of wishbone shape and angle and the impact on aero and compliance that they had. We went through that process many times to come to the best solution. The result was having a suspension that is higher than it was in 2015, though it's not the most extreme example on the grid. We also have a Mercedes style very narrow span lower wishbone which was a big bit of work in terms of structures, and with the axle blowing it was

A late switch to Ferrari power meant Toro Rosso faced a huge challenge to get its STR11 ready for the 2016 season. Yet against all odds the team seems to have produced another gem

By SAM COLLINS

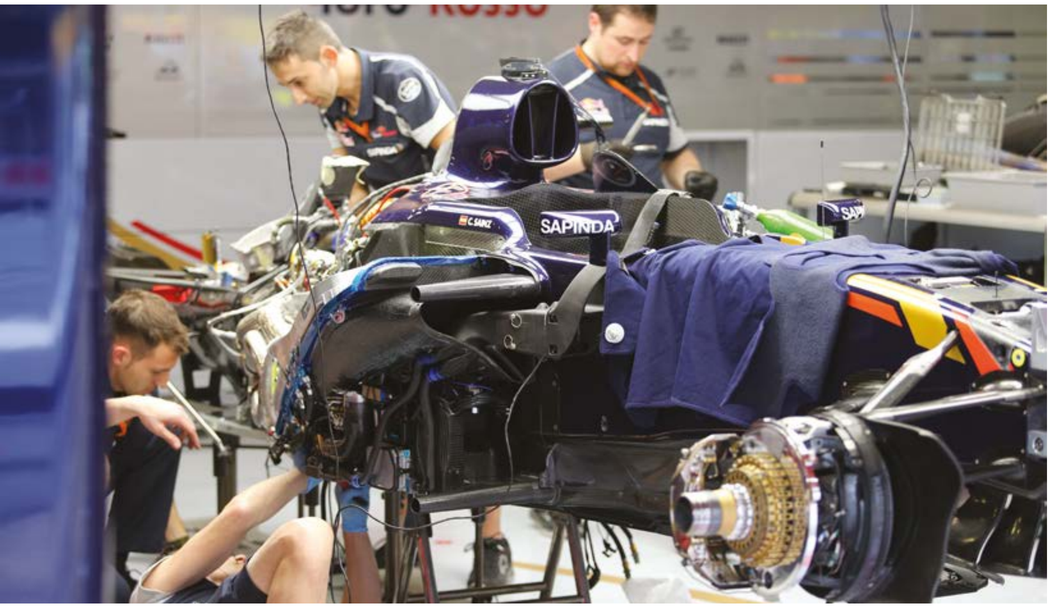
all a big philosophical change to the suspension compared to last year,' Key says.

Indeed the front end of the STR11 features a number of small innovations and new features, most notably the adoption of the 'blown nuts' used on and off by a number of other teams for some seasons now, as well as a further development of the vented nose concept (aka the S-Duct) pioneered by Key with Sauber in 2010 and widely copied by other teams since.

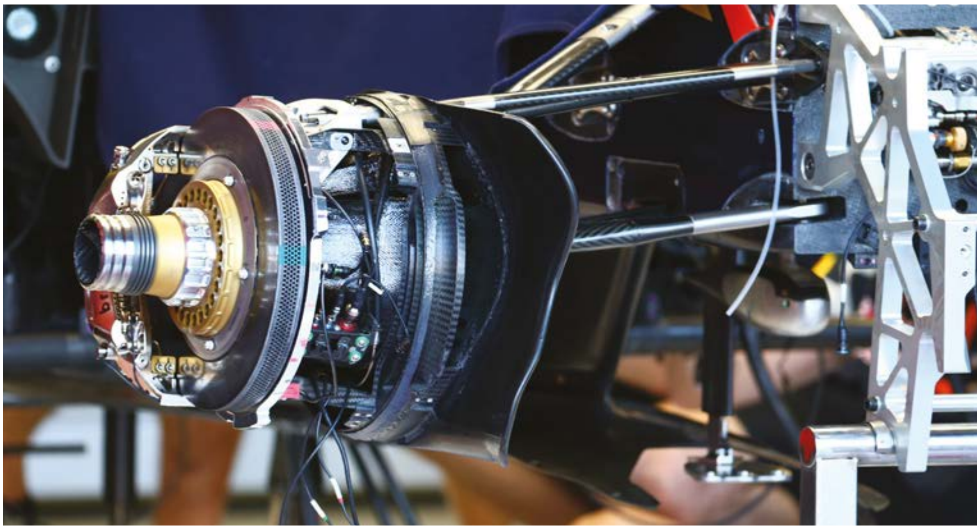
'The nose duct and the blown axle are there for different things,' Key explains. 'With the nose you are basically sucking boundary layer off the surface of the underside of the nose and using a low pressure area on the upper side of the nose to suck it out. It just helps in terms of losses downstream of that point. That works well sometimes and not so well at others, it all depends on a lot of geometry forward of that point but it's not actually a very big player.'

Despite this, the STR11 does feature a notable step in the execution of these ducts. While most teams use what seem to be fairly basic scoops on the underside of the nose, the Toro Rosso is equipped with a neat array of NACA ducts feeding an exit on the upper surface of the chassis. 'The arrangement of the ducts we have is just a function of the geometry of the nose, where the losses and boundary

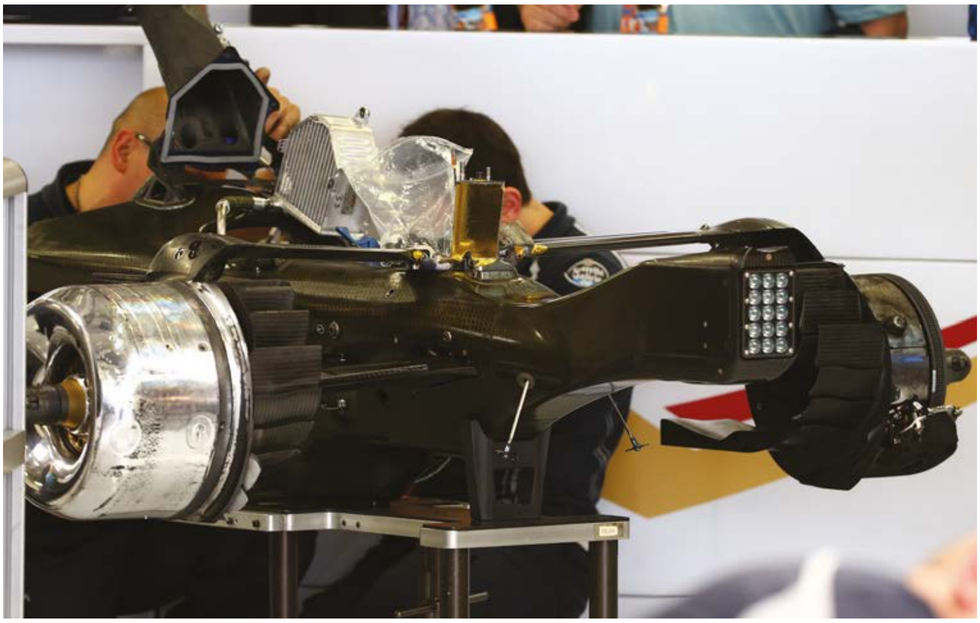
An emergency pit stop for a new nose cone presents a great opportunity to take a look at the new under nose ducts on the STR11. These help to pull the boundary layer off the surface of the underside of the nose and then a low pressure area on the upper side is used to suck it out. The arrangement of the ducts is just a function of the geometry of the nose



A determination to stick with the cooling and the aero concept of the car meant a great deal of re-packaging of components was needed once the deal with Ferrari was signed. The high-mounted central coolers are a trademark Toro Rosso feature



Front brakes. The Brembo calipers – with friction material supplied by the same firm – are positioned at the rear of the STR11's discs. The upright design has been adjusted from the STR10 to fit with the car's tweaked suspension geometry



The STR11 has a carbon fibre composite bellhousing and similarly constructed gearbox casing. Inside the casing is a hydraulically operated 8-speed sequential gearbox supplied by Red Bull Technology. The hydraulic system is by Xtrac

layers build up,' Key says. 'Back in the Sauber days it was just a basic scoop under the nose to over the nose, Mercedes have a kind of shark's mouth shape, but it's all about the nose shape and what works best for you.'

The adoption of the blown front axle is something that Key feels is a more major step in terms of the aerodynamic performance of the car and highlights it as an area which opens up new development opportunities. 'It is to do with managing the effect of the front tyre on parts of the car downstream of it. It is something which again sometimes works and sometimes does not. It has certain characteristics suitable for certain circumstances and not for others. It is a complicated thing, but it opens up some new areas to explore', he says.

Engine crisis

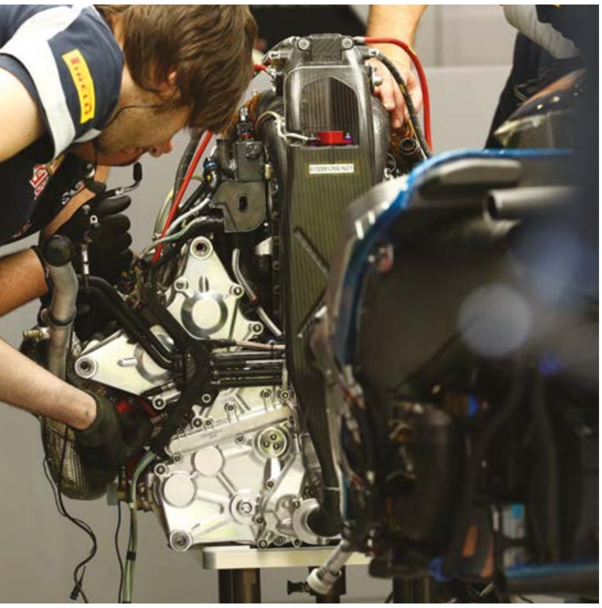
Around the time that many of the longer lead-time items on the car were being finalised, including a new composite gearbox casing, a bombshell was dropped: the STR11 would not be a Renault-powered car after all. Indeed, it was not clear which unit it would be fitted with. Ferrari, Honda and a Mecachrome 3.4-litre normally aspirated V6 engine were all apparently on the cards at some point.

'When the engine change decision was made we had to put a large part of the project effectively on hold,' Key says. 'This did not stop us developing, but did increasingly constrain the flexibility we had to design in what was at that stage an unknown power unit. When the agreement was finally given the go-ahead and we were able to discuss details with our partners at Ferrari, it was the clear that the task ahead was significant.'

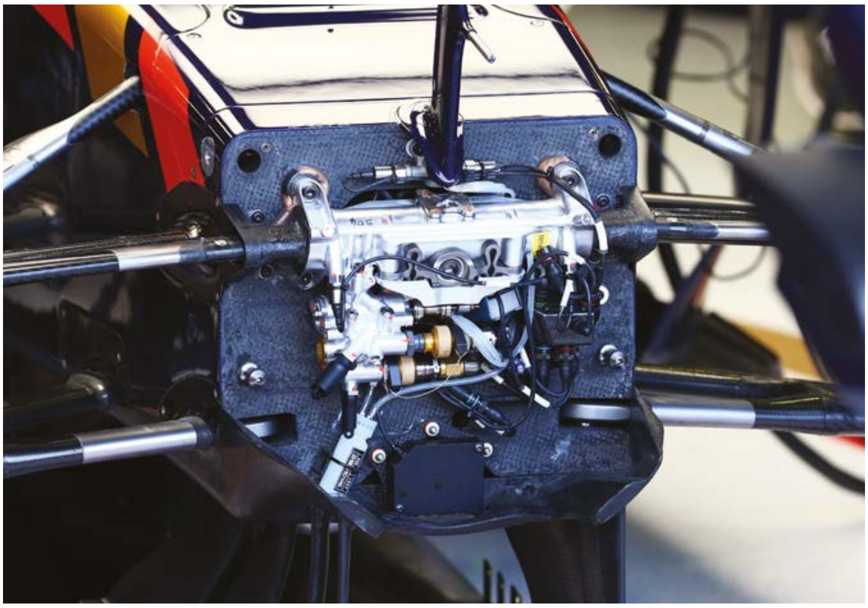
Ferrari power

Even before a deal was formally struck for the car to use the 2015 specification Ferrari power unit, the Toro Rosso engineers were trying to design an installation for it, despite not having any official data on it at all. 'When it became clear we would be using something different we looked at all the pictures we could find of the Ferrari engine and realised that it was clearly very different,' Key says. 'But we tried to build up a very rough idea of its external shape on the assumption that that is the engine we would be using. We tried to see if that would fit the main ideas of where we wanted to place things on the car. It was simply a dimensional check, it was not a serious technical check. We did not have heat rejection information, electronic data or anything like that. From that preliminary work it appeared that the Ferrari V6 would fit inside our packaging space.

'We packaged everything the way we wanted for the chassis; we had packaging shape, cooling concept and a bodywork shape, and that was all based around the Renault engine. When doing these cars you start with the power unit and build up from there. We had to do it



A late deal to run with Ferrari's 2015 power unit complicated the design process substantially but the STR11 was completed on time



While the rear of the STR11 is quite different the front remains largely similar to last year's STR10. Shown here is its conventional bulkhead and an assisted steering rack that is manufactured in-house by Toro Rosso

Rear wing support

Toro Rosso pioneered a new approach to the rear wing support on its cars some time ago. The current generation of power units have the single large tail pipe located in the exact spot where the rear wing pylon or pylons need to be mounted to the upper surface of the transmission casing. To get around this some teams have experimented with inverted Y shapes at the base of the wing pylons, asymmetric supports, or just opted for the simpler but less efficient twin supports. Toro Rosso, on the other hand, simply decided to put the wing support directly through the tailpipe itself.

'It's pretty tricky to do that because you have to minimise any power unit performance implications from having the support running through the pipe,' James Key says. 'You have to do a lot of CFD work on the exit flow from the turbo to get the pylon design sorted out, then you have to look at the construction of the tailpipe. A failure in this area is real disaster as you can imagine. There is a lot of work that went into working out the shape of the pipe in order to minimise stress raisers. In fact there is a fair bit of cooling going on there, once you have done it once it gets easier though and it is a design we like.' It's also effective, and copied by a number of teams in 2016, including McLaren.

Toro Rosso's wing support actually goes through the tailpipe. It's a solution that's been copied by other teams this season

in reverse. We had to shoe-horn the Ferrari engine into the space we had defined and this was not easy,' Key says.'

As said, a decision was taken by Key and the Toro Rosso engineers to push on with their car concept regardless of the lack of data that they had regarding the Ferrari power unit. This included one of the major elements of the design which houses heat exchangers near the centreline of the car, fed by ducting on the roll hoop. This is something which has been a feature of all recent STR designs.

Cooling concept

'It was apparent from the outset that the cooling concept is fundamentally different between the two power units,' Key says. 'But the high-mounted central coolers is one of the concepts that has carried over. It was one of the first things we wanted to look at as the cooling layout is really what defined whether we could keep our aerodynamic concept and bodywork shape. Our philosophy always had the upper coolers as part of it. Having the coolers there is efficient. It's not ideal in terms of CofG, but the efficiency gain outweighs that and it reduces the frontal area. Other people had taken this approach too but we have been quite extreme with it, especially last year. It was a case of adapting that to the Ferrari engine and trying to judge that just from pictures. Trying to work out volumes from that, and the car is based on that early work done without all the data.'

By the time that the Toro Rosso engineers sat down with Ferrari, the time-frame was incredibly short. The car had to be on track for the first day of testing on 22 February. 'We had our first technical meeting with Ferrari on the 1st of December 2015, that is how late we were,' Key reveals. 'Not only were we very late we then made life difficult for ourselves. I said "Let's try to take the performance benefit of this engine and not make any compromises to the car." That meant that we would not change the aerodynamic concept at all, and that is what we tried to do. So externally the car should look the way we originally intended, even though it was designed around a different power unit.

'This was incredibly difficult though, firstly because in reality nothing was really compatible. We quickly found that, strictly speaking, we did not have space for everything so we had to spend a huge amount of time packaging and re-packaging parts, and understanding ways we could squeeze everything together while respecting our aero surfaces. Take the bodywork off the car and it's jam-packed full of stuff. To be honest everyone involved did an amazing job, the design office, the electronics guys, had to work double speed, procurement and production made it all happen and our suppliers including Ferrari, of course, all worked incredibly well together to make it happen,' Key says.

Installation issues

But the installation of the engine was more complex than reorganising everything underneath the rear bodywork, it also had a profound impact on the design of the monocoque itself. 'I can't give too many details of the exact installation requirements as that would breach Ferrari's IP, but it was completely different to what we had before,' Key says. 'Every power unit is different, if you just look at

'The cooling concept is fundamentally different between the two power units'

The STR11's rear Brembo brakes, along with the fronts, are activated by a Toro Rosso developed brake by wire system

TECH SPEC

Toro Rosso STR11

Category: Formula 1

Engine: Ferrari 060

Chassis material: Composite monocoque structure

Front suspension: Upper and lower carbon wishbones, pushrod, torsion bar springs, anti roll bars
Rear suspension: Upper and lower carbon wishbones, pullrod, torsion bar springs, anti roll bars Assisted Steering
Rack: Scuderia Toro Rosso

Bellhousing: Carbon fibre composite
Gearbox maincase: Scuderia Toro Rosso, carbon fibre
Gears: 8-speed sequential; hydraulically operated. Supplied by Red Bull Technology, Xtrac Hydraulic system
Clutch: AP Racing

Exhaust: Scuderia Toro Rosso, Inconel

Calipers: Brembo

Friction material: Brembo

Brake By Wire: Scuderia Toro Rosso

Cockpit instrumentation: Scuderia Toro Rosso
Steering wheel: Scuderia Toro Rosso
Driver's seat: Carbon fibre construction, moulded to driver's shape
Seat belts: OMP/Sabelt
Pedals: Scuderia Toro Rosso
Extinguisher system: Scuderia Toro Rosso/FEV

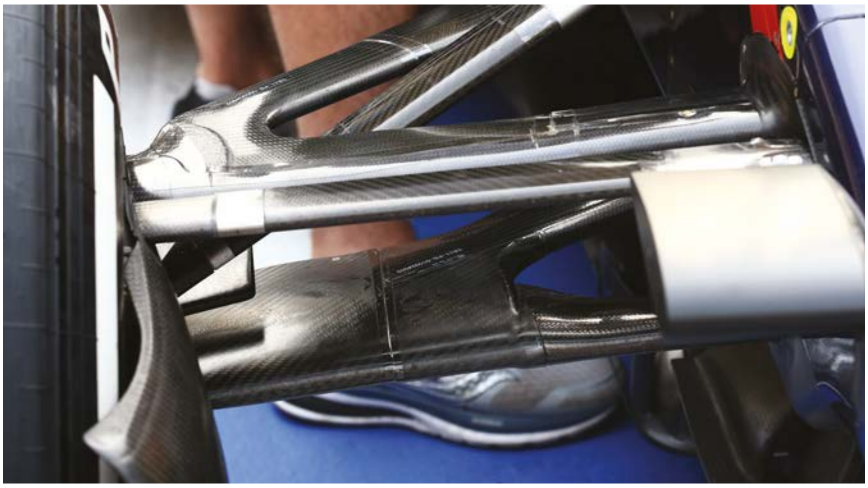
Wheels: Apptech, magnesium alloy
Tyres: Pirelli

Fuel system: ATL tank with Scuderia Toro Rosso internals

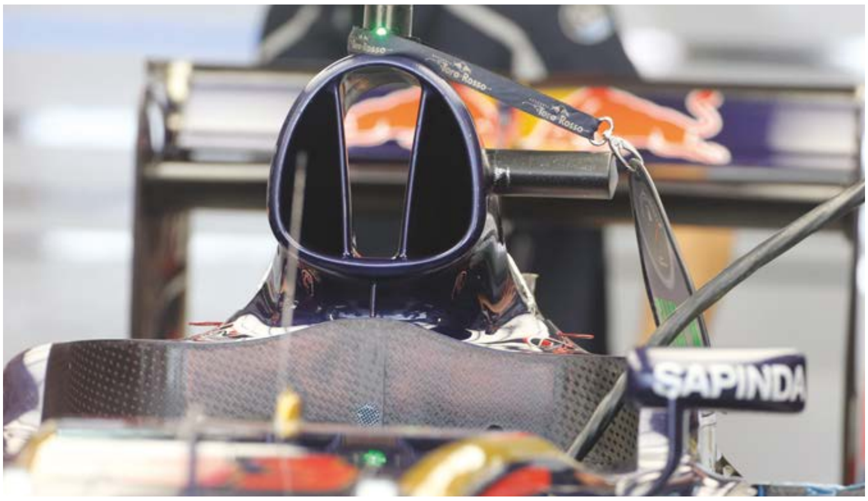
Bodywork material: Carbon fibre composite

Overall weight: 702kg (including driver and camera)

Ferrari 060
Displacement and V angle: 1600cc, 90-degree V6, 24 valves
Rev Limit: 15,000rpm
Pressure charging: Single Honeywell turbo
Bore & stroke: 80mm x 53mm
Injection system: Magneti Marelli injectors / direct fuel injection 500bar
MGU-K: Magneti Marelli, Max 50,000rpm
MGU-K power: Max 120kW
Energy recovered by MGU-K: Max 2 MJ/lap
Energy released by MGU-K: Max 4 MJ/lap
MGU-H rpm: 125,000rpm
Energy recovered by MGU-H: unlimited (>2 MJ/lap)



STR11 retains the STR10's conventional concept of double wishbones all round with push rod actuated torsion bars at the front and pull rod actuated bars at the rear, but there have been many detail changes



Main air intake is split into three with the central segment feeding combustion air to the Ferrari V6 while the portions either side feed cooling air to other components, possibly the charge air cooler, or a pair of coolers

the pictures and things you hear in conversation in the paddock, you start to realise that while all four units do the same thing, the only thing that is the same between them is the regulated bit, which is the engine mounting points.

'Everything else is different. Even fuel capacities can be different in terms of the volume you need for 100kg of fuel. For us it was not only the back-face of the monocoque, which as you would expect had to change, it was also everything aft of the front of the cockpit template. You have the energy store inside the fuel cell volume for starters and they differ significantly from unit to unit, too. Because the rear face of the chassis is different, and the fuel cell volume, your roll hoop design has to change too. So you have a large structural chunk of the chassis, and a very complicated bit as well, influenced by which engine you are using. In the V8 days it was a horrible thing to do, but you could chop the back of your chassis off and rework it to go from one engine to the next. You simply cannot do that with these power units. Now you just take the front of the chassis, keep that, and replace the rest of it.'

Toro Rosso managed to pull the car together in the very small amount of time available and while it rolled out without a paint scheme applied (the Toro Rosso is still hand painted) it was on schedule. From the start of testing the STR11 ran well and was faster than expected as well as much more reliable, clocking up more laps than any other car bar the Mercedes W07. Even Key himself admits that he did not expect to be able to achieve that.

Following the Spanish Grand Prix in May, Toro Rosso sat in fifth place in the constructors' championship, the STR11 having proven to be a highly capable machine which looks like a regular points finisher. Notably ,the team is also the best of the Ferrari customers, even though the others, Haas and Sauber, use the more potent 2016 specification Ferrari power unit, and both had much longer lead times with their racecar development.

But Toro Rosso staff are open about their belief that they expect the STR11's form to fade a little as the season goes on and other teams receive upgraded power units, while the old Ferrari design will remain as it is now. Key and his team have already turned much of their attention to an all-new car for 2017, which will likely be fitted with a state of the art power unit. It could be a car to watch next year.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After over a year of debate, dispute and speculation, F1 has finally settled on a new set of technical and sporting regulations for the 2017 and 2018 seasons. As expected the rules will see the cars built to a higher weight limit, with wider bodywork and tyres and more dramatic looking aerodynamic devices. Those changes have largely been detailed elsewhere (see V26N5), but the more recent changes to the regulations relating to the power units have been less widely discussed. In nutshell, the headlines relating to the design of the units have remained unchanged – a direct injection 1600cc turbo V6 mated to an electro turbo-compound hybrid system – but the details of many sub systems have been adjusted.

From the moment that the new regulations were introduced in 2014 there were a number of very vocal figures in the sport who felt that the power unit had become too much of a performance differentiator, Red Bull team principal Christian Horner among them: 'I think Formula 1 has the three elements which should have equal weight: the driver, the chassis and the engine. So if one of those elements isn't quite right, the other two can compensate. I think in today's Formula we've offset that balance, so you've probably got, 50 per cent engine, 25 per cent chassis, 25 per cent driver.'

Convergence of power

Under pressure from the likes of Red Bull, and notably Bernie Ecclestone, Formula 1's rule makers have now moved to redress this balance somewhat by adjusting the regulations to allow the performance levels of the four different power units to converge, with the aim of reducing the huge advantage that Mercedes HPP is perceived to have. 'One our main objectives with the rule changes was to help performance convergence,' the FIA's head of powertrain, Fabrice Lom, says. 'To do that the first big thing that people thought was important is to have stability in the regulations. There was a lot of discussion of changing completely the regulations, going back to normally-aspirated engines, no hybrid. Nobody wanted that because the trend in the world is to go hybrid and low consumption, but also they thought if there's a big change there will be a redistribution of the cards, and there could be a big difference in performance between the power unit manufacturers, so they said that stability of regulations would help a lot.'

To allow for power unit manufacturers to be able to close the gap, the much debated upgrade token system has been dropped entirely, allowing for free performance development during the season; the idea being that the law of diminishing returns will apply and, over time, the performance of the units will converge naturally.

Perhaps in an attempt to accelerate this process a number of component weight restrictions have been introduced, as well as some minor changes in the material specifications. Both MGUs will now have a minimum weight applied of 7kg for the kinetic and 4kg for the heat. Inside the combustion engine similar minimum weights are being applied, too, with the minimum piston weight set at 300g, and the connecting rod also at a 300g. The piston weight includes the pin, rings and retaining clips, while the rod weight includes the bolts and bearings.

The crankshaft will be restricted, too, both in terms of weights and dimensionally, the main bearing journal is limited to a minimum of 43.95mm and the pin bearing journal 37.95mm. A complete crankshaft assembly including all balance weights, bolts and bungs must weigh at least 5.3kg. The total power unit minimum weight remains

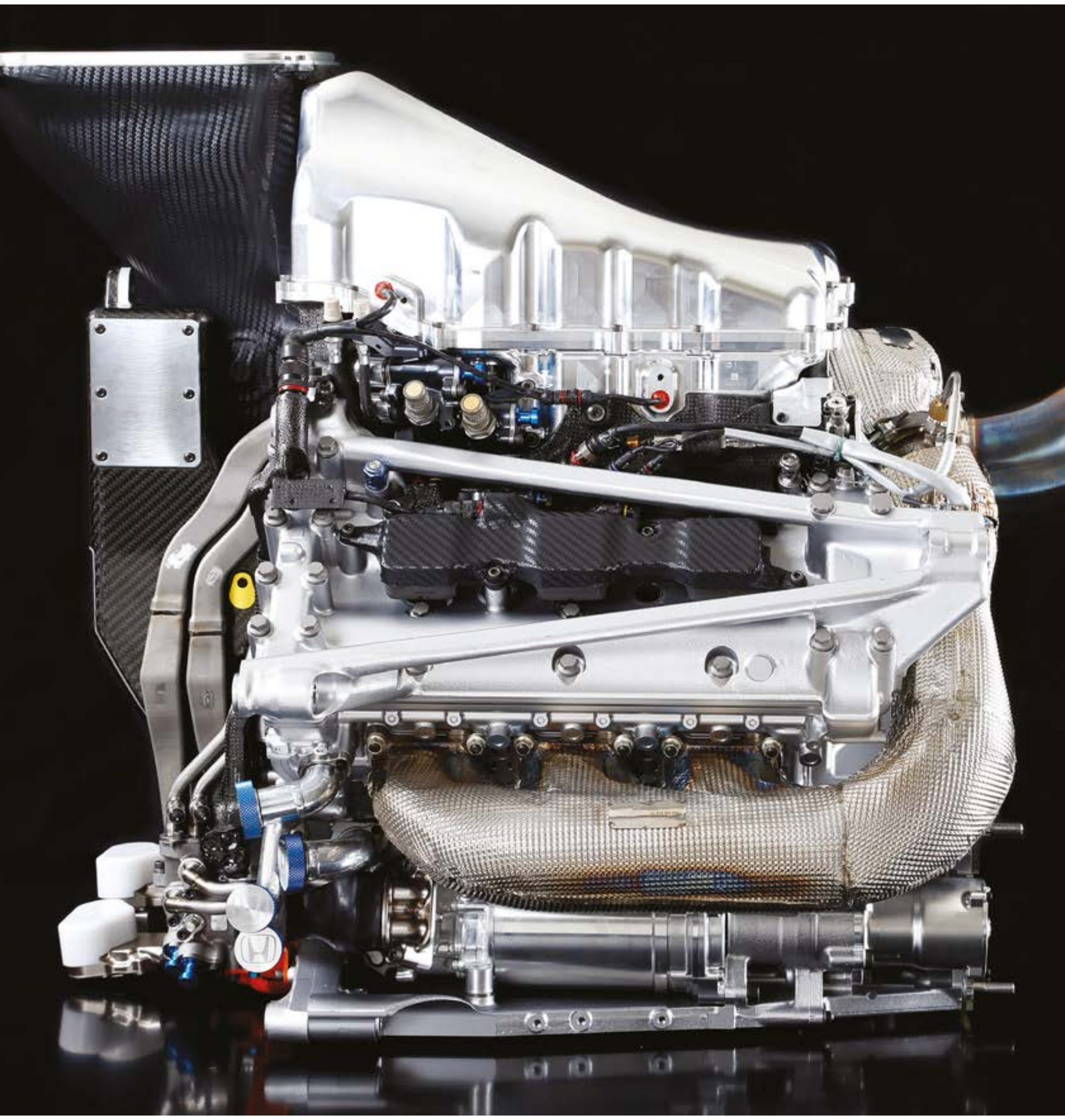
No smoke without fire: the debate over Formula 1 power units has been heated and divisive over the past year, but now the teams and the FIA have finally agreed a new set of engine rules

Power games

After much deliberation the F1 power unit regulations for the next two years are finally in place. But what are the implications for the engine builders and the teams?

By SAM COLLINS

The much debated upgrade token system has been dropped entirely allowing for free performance development during the season



There will be no major changes in the basic engineering philosophy of F1 PUs in 2017; they will still be 1.6-litre turbocharged V6 hybrids

'There has never really been as much of a link between an engineer developing a Formula 1 engine and an engineer developing a road car engine as there is now'

unchanged at 145kg. 'These limits were put where the best [power unit] is today so that people know the target, and also allow us to stop the best ones developing more, to go lighter or smaller, so that we put something like a bit of a barrier to development,' Lom says.

In 2018, an additional restriction is also being introduced on the temperature of the air in the plenum, which will have to be more than 10degC above the ambient temperature. On top of that more of the ERS control systems will have to be packaged inside the monocoque.

One aspect of power unit development which has been at the forefront of Formula 1 research and development work, particularly over the last 12 to 18 months, is the combustion process, and this is an area where significant innovations are now being applied. But the FIA has now moved to restrict performance in this area somewhat, with a maximum compression ratio of 18:1 being enforced from 2017 onwards, again in order to force performance convergence.

Part way through the 2015 season, Ferrari adopted the Mahle Turbulent Jet Ignition concept on its Formula 1 V6, a technology which is thought to have featured on the Mercedes unit since 2014. The technology, which was patented relatively recently, relies, according to its inventor, the Mahle Group, 'on a special surface ignition, which in turn allows for higher engine performance. The ingenious trick here is that the air-fuel mixture is pre-ignited in a pre-chamber around the spark plug.' This results in the formation of plasma jets that reach the piston primarily at the outer edge and ignite the remainder of the mixture. While ignition normally takes place in the centre of the cylinder, with Mahle Jet Ignition it essentially takes place from the outside toward the inside. This allows significantly better combustion of the fuel mixture. The result is more power with considerably less residue. 'With this lean burn combustion process a substantially greater efficiency can be achieved than with previous ignition concepts,' Mahle tells us.

High compression

This is not the only technology under development in this area, as the quest for efficiency grows the levels of compression have risen substantially, to the point where at least partial compression ignition is almost possible. 'In theory the higher the compression the higher the potential efficiency, but it also brings a risk of knock with it,' Yusuke Hasegawa of Honda R&D says. 'So the level set at 18:1 is high enough for us not to care about it for now. HCCI [see page 16] and pre-chamber systems are very much in the R&D phase at the moment.'

These sentiments are echoed by Renaultsport F1's technical director (power unit) Remi Taffin, who says: 'If you look at 18:1 and look at the maximum cylinder pressure it's frightening, but that new regulatory limit is not a restriction on us. We don't think we will reach that any time soon. I know what the constraints are, I look at the materials technologies I have around me and I don't think there is anything to cope with this for the next five or six years. These regulations will not stand for the next 20 years. Look at it in that way, the limit is far away enough that it is not limiting us.'

In addition to the limit on compression ratio, the FIA will also introduce restrictions on the number of different fuels used by each team, with only five fuels allowed per season and two per event. Fuel development has been a major area of performance gain under the current formula, especially when allied with the combustion developments, and the limits have

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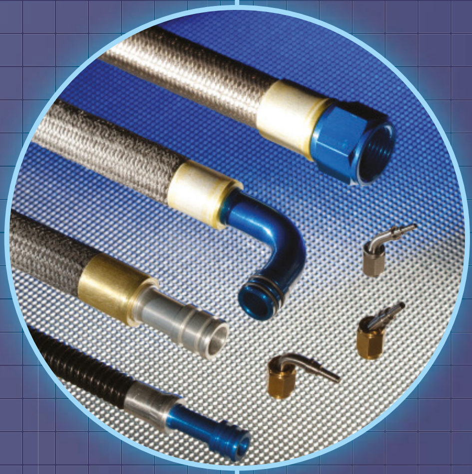

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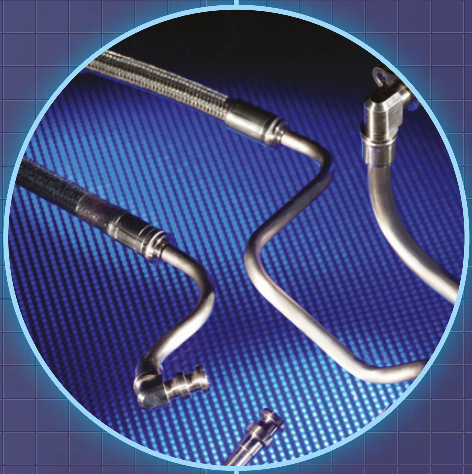

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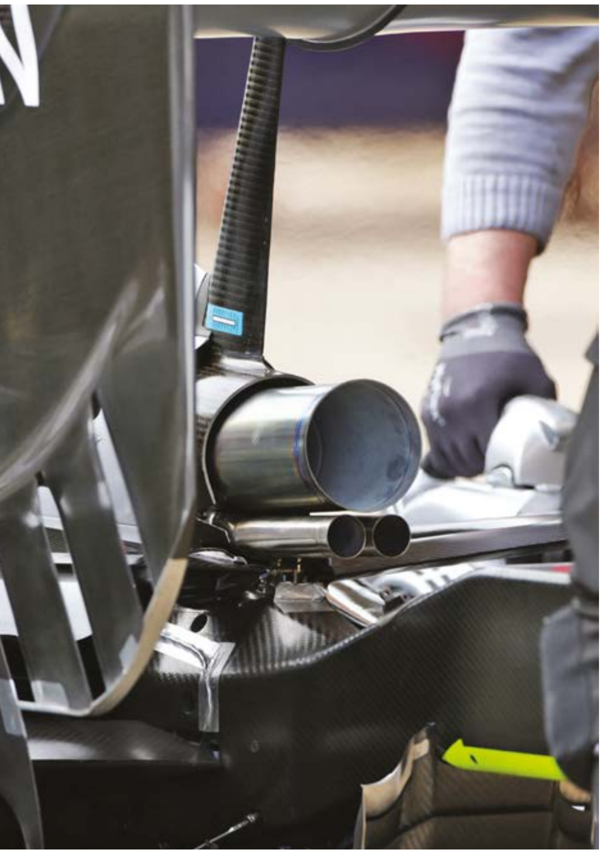
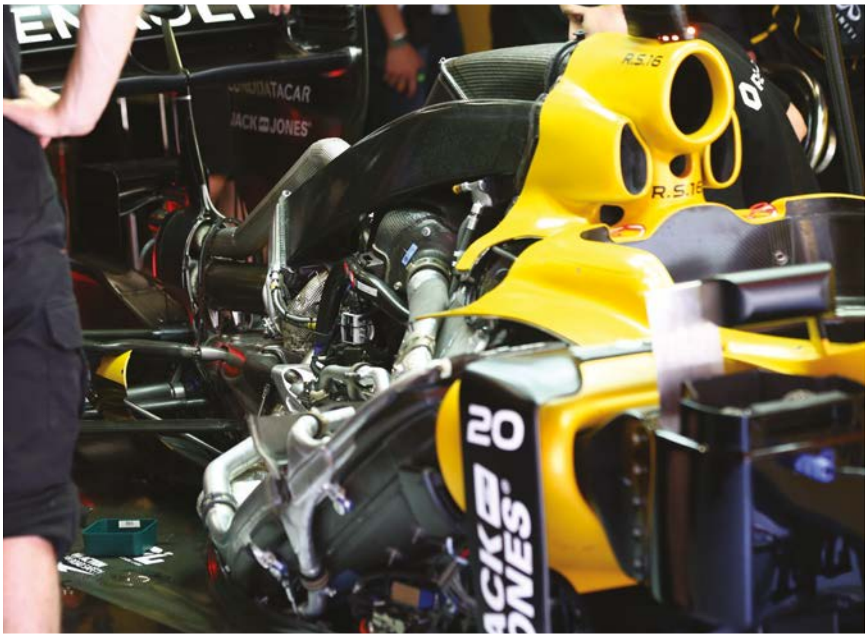


F1 cars will feature a sound generator from 2017, but details of its design and operation are not yet available. The picture shows an earlier attempt to improve the engine noise; waste gate exit pipes



Renault's current power unit, the RE16. The French firm has struggled to keep pace with its rivals in recent seasons but the dropping of the engine token system could give it more scope to develop its PU next year

been introduced for similar reasons. 'It's all about how your ICE is working,' Taffin explains. 'If you look at how the fuel developed, early on we look to get the best out of the knock sensitivity, then as you develop the combustion chamber you get a bit more freedom to develop the fuel, as you can be a bit less knock sensitive, but get a bit more energy from the fuel.'

Each car will be able to use a little more fuel in 2017, as the maximum amount used on each car for the duration of the race will increase from 100kg to 105kg, to deal with the wider, heavier and more draggy cars defined by the chassis rules. It is not a change all were in favour of. Mercedes boss Toto Wolff says: 'Claire Williams [Williams deputy team principal] raised [this] in the meeting itself, that the whole world is looking to reduce emissions, and she asked can we possibly vote in favour of an increased fuel allowance from 100kg to 105kg?' All Mercedes-powered teams voted against the increase, but they were in the minority.

It could be argued (and has been) that the new restrictions, especially those impacting fuel development and compression ratio, could reduce the relevance of F1 to production car R&D – the very reason the current power units were introduced in the first place. 'When we started to discuss convergence, there were suggestions of defining a power limit, but we were totally against that,' Hasegawa says. 'But it is natural to have some kind of limitation as this is a sport, not pure R&D. You cannot have infinite development, so some kind of restriction is necessary. Technical freedom is a good thing, that is our philosophy as a company, but we don't want to make everything ourselves. Why would we design a coffee cup when we can just buy a perfectly good one?

'I think restrictions can reduce the value of F1 R&D to production cars, but it very much depends on the parts restricted, and what those restrictions are. If you restrict everything then the sport has no meaning and it has no value to us anymore. I think the 2017 regulations do not restrict us really, at least not so far.'

'The new regulatory limit is not a restriction on us, we don't think we will reach that any time soon'

R&D relevance

Taffin points out that while some of the combustion techniques under development have some very real applications to the mainstream, the way Formula 1 uses its engines is very different and as a result technology transfer is not all that straightforward. 'We are using engines that are not all that close to what you see in production,' he says. 'We are revving to 11,000rpm or more and we spend a lot of time at full throttle. If you work out how much time you spend at full throttle in your road car, you understand that the duty cycle is not in the same area. But saying that, there has never really been as much of a link between an engineer developing a Formula 1 engine and an engineer developing a road car engine as there is now, and that it is probably the best thing about these rules. Even if the technology cannot be switched directly from race to road.'

With the changes made to the technical regulations aimed at forcing the varying performance levels of the power units to converge, the FIA has decided that it will monitor very closely if indeed convergence is taking place. 'We have a process agreed with the power unit manufacturers, we don't look at lap times, we have tools to simulate everything, so we can calculate the performance of the power unit itself on each car and we transform this in a power index,' Lom says. 'You have this hybrid system and an engine and you cannot only talk about horsepower, so it is translated into a power index. We check every car, every lap of the first three races. We take the best of each power unit for each race and each PU manufacturer, then we do the average over the three races. This should give a power index of performance for each power unit manufacturer.'

If one power unit is found to be substantially above or below the rest on this Index of Performance (Lom stresses that this is not a Balance of Performance) then Lom's team at the FIA will escalate the situation. 'We will report to the Strategy Group, and the action is a decision of the Strategy Group. We will check this in the first three races, which is [at a time] that is before the deadline to make a change at the majority for the following year,' Lom says.

Not all of the changes are directly aimed at encouraging convergence. Many changes to both the technical and sporting regulations are aimed at reducing costs and ensuring that every team in F1 has a guaranteed supply of power units, something which was not the case at the start of 2016, and could have conceivably seen three teams drop out of the sport as a result.

The first step in this process did not quite go as far as a pure cost cap, but is a direct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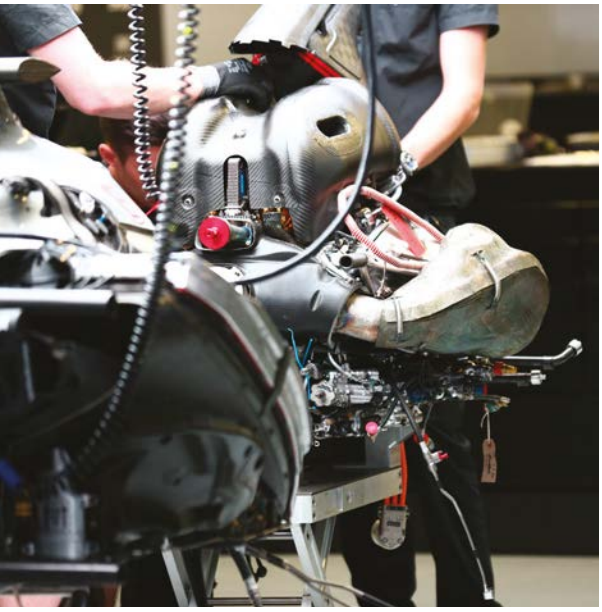
‘One of our main objectives with the rule changes was convergence of performance’



The Mercedes HPP power unit seems to have a big advantage at present; which is why the new engine technical regulations have been formulated with convergence of performance in mind

Honda has been forced to enlarge its power unit manufacturing facilities in England (pictured) and Japan, largely as a response to new F1 engine rules which might oblige it to supply an extra team

F1 single spec sensors

Regulation 5.13.1: ‘Any pressure sensor used to measure pressure of any fluid necessary to ensure the power unit functions correctly at all times (including but not limited to coolant, oil, fuel and air) must be manufactured by an FIA designated supplier to a specification determined by the FIA. Cylinder pressure sensors are excluded from this requirement.’

Regulation 5.13.2: ‘With the exception of exhaust temperature sensors and temperature sensors embedded in electronic boxes, any temperature sensor used to measure temperature of any fluid necessary to ensure the power unit functions correctly at all times (including but not limited to coolant, oil, fuel and air) must be manufactured by an FIA designated supplier to a specification determined by the FIA.’

Both MGUs will have a minimum weight applied from 2017. This will be 7kg for the kinetic (K) (pictured) and 4kg for the heat (H)

reduction in the price charged to customer teams. This reduction is €1m in 2017, compared to the price in 2016, and it’s reduced by €4m, compared to 2016, from 2018 onwards. From 2018 a cost cap of €12m is applied to teams working with new suppliers (that is, if they have switched from one supplier to take an engine suppy from another).

In order to get the manufacturers to agree to this reduction in price the FIA had to take other steps, Lom says: ‘We cannot ask the power unit manufacturers to reduce price without reducing cost. So to reduce the cost, firstly in 2017, we will go down to four power units per driver per season, instead of five today, whatever the number of grands prix. In 2018, and this is a big task for them, we will go down to three ICE, plus turbo, plus MGU-H, and only two energy stores, control electronics and MGU-K. So it’s nearly 50 per cent fewer parts, so it should reduce the cost by a nice amount.’

While this is a reduction on total price paid out per team, it is actually an increase in price per power unit with the reduction of number of units allowed per season. Not all of the power unit manufacturers are entirely happy about the reduction in units, and Lom’s comments came as a surprise to some in the paddock.

‘It is very tough even now,’ Hasegawa says. ‘Last year we struggled to achieve the durability. This year it’s much better but we are still struggling, so longer mileage is pretty tough. Bringing in longer mileage, we need some more time to do that, even just for life testing. In some ways that actually increases the cost for us, not reduces it.

‘I think it’s true that when you want to make something last longer you get it heavier, and as a whole vehicle that is not efficient, so it’s a bit controversial. If you want to make a car faster, of course, you would make the power unit lighter, it’s the opposite direction for an endurance car.’

Hasegawa went on to hint that he felt that the 2018 price level was a bit too low and suggested that Honda would end up having to subsidise customer teams if it had to.

In a further effort to reduce the cost of the units the FIA has regulated that it will restrict the sensors used in some areas of the power unit to a single specification (see box out below left). ‘It is a small part of the reduction but it is a bit of a reduction,’ Lom says. ‘In general terms all pressure and temperature sensors, apart from in-cylinder pressure sensors and sensors embedded in electronic boxes, will be control parts.’

Power supply

Finally, the last objective of the 2017 changes was to ensure that all teams had access to a power unit supply. If by June 2016 a team had yet to be allocated a power unit then the manufacturer with the smallest number of customer teams will be obliged to supply whatever team lacks an engine. Every power unit manufacturer is obliged to have the capability to supply an equal share of the grid, so with 11 teams in Formula 1 at the moment each must be able to supply three teams (rounded up from 2.75). This has seen Honda significantly increase its facilities in both Japan and the UK. A complex set of regulations about the specifics of supply appear in the rulebook (including a rather unnecessary equation), but as things stand if any Ferrari or Mercedes powered team loses its supply then by default it will run with a Honda, while if Red Bull loses its supply there will be a coin toss to see if it runs either a Honda or Renault power unit.

As the seemingly endless discussions about the 2017 and 2018 rules come to a long overdue conclusion thoughts now turn to the future of the sport in the years to come. ‘One possibility is increasing the importance of the electronic parts,’ says Hasegawa. ‘Right now we have a 120kW limitation, and an energy limitation. If those limitations are removed then I think the cars might be a lot more exciting.’

Speed dating

The on-off romance between Super GT and DTM continues but will these two hi-tech race series ever tie the knot? *Racecar* talked to GTA boss Masaaki Bandoh about this and other matters

By SAM COLLINS

The GT500 cars in Super GT use many of the DTM technical regulations including its aero – note the rear wing – but full convergence has been slow in coming with 2019 now the target

Toyota (in the shape of Lexus, pictured), Nissan and Honda's participation in GT500 means that the top Japanese marques are well represented in Super GT

With its close racing, star drivers, tyre war, and works teams, Super GT has become a significant part of the international motor racing landscape in recent years. Under the leadership of GT Association (GTA) chairman Masaaki Bandoh, it has undergone an overhaul and it now has plans for a major expansion. The most notable change has been the introduction of a new technical rulebook for the GT500 class, which saw the Japanese manufacturer teams adopt almost all of the DTM technical regulations albeit with a similar, but different, variant of the chassis used in Europe.

This change was made originally to allow GT500 and DTM to have fully harmonised regulations and create a single super class, but for various reasons this unification has never quite happened. Yet the plans to achieve it continue to have an impact on the Japanese series. 'We started to work with DTM in 2014. We wanted to unify the technical regulations and create Class 1, a global racing class with at least six manufacturers running works cars,' Bandoh explains. 'The fully unified regulations were scheduled to be introduced in 2017, with a new monocoque, but there were some sticking points in these negotiations and that has delayed things a bit. But despite that we will still stick to the original plan and bring in some new technical regulations into Super GT in 2017. This means that 2016 is a transitional year, so we have frozen the aerodynamic development of the cars to allow the manufacturers to prepare for the new rules.'

East meets west

The aerodynamic rules for GT500 and DTM are largely identical, as are most of the mechanical parts, but one major difference is that the Japanese cars run the cutting-edge 2-litre turbocharged direct injection in-line four Nippon Race Engine (NRE), while DTM retains its outmoded normally-aspirated port injection 4-litre V8. DTM did attempt to introduce its own version of the NRE but the project stalled and ITR, the promoter of DTM, decided to stick with its old V8s for the time being. GTA, however, continued with at least some of the jointly planned changes. 'The biggest change in 2017 is a reduction in downforce levels by 25 per cent,' Bandoh says. 'We will keep the same monocoque, however. We have to do this for safety at some tracks because the cars are becoming very fast, too fast perhaps, but the main reason to cut the downforce is that this is what was agreed with DTM, a downforce reduction of 25 to 30 per cent, and that is the direction we are sticking with.'

The mooted Super GT *vs* DTM challenge races in 2016 and 2017 will not now take place, while a V8-powered Team Studie run DTM BMW in GT500 will also not happen, for while Bandoh has stated in the past that he would accept a V8-powered DTM car in GT500, and would even give it a very favourable BoP, the German brands do not want to compete under any kind of performance balancing. Tyre regulations are also something of a difficult area. Super GT is a tyre war class at its heart, and many teams get significant funding from the tyre manufacturers, but DTM uses a spec tyre. Yet despite these hurdles the

'The project has restarted and the idea will be for the unification or harmonisation to now happen in 2019'

Masaaki Bandoh says the partnership with DTM is not dead and although plans for a match race this year have been dropped he's keen such an event should take place in the future

full ITR/GTA partnership plan has not been shelved, even if at times it seems that way. 'The partnership with DTM is not dead,' Bandoh insists. 'It was agreed to pause things for a little while but it has not stopped and we will be meeting with them again soon. The project has restarted, and the idea will be for the unification or harmonisation to now happen in 2019, that is the target. But we will discuss more common parts usage from 2017.'

Divergent development

When the DTM introduced its new formula in 2012 the big three German brands all built cars to the rule book, but in the years since then all three have introduced new models. The GT500 cars built to the same rules were first revealed in 2013, and all the brands have kept the same models throughout, though all have been developed significantly. In that time Honda's NSX concept car has gone into production and the Nissan GT-R has had a facelift.

'I think we may see at least one new model in GT500 next year,' Bandoh says. 'Then we may see even more new models in 2019 or 2020. I think from 2019 we will have no mid-engined cars in Class 1, so then Honda may need a new model for that.' Staff at Toyota Racing Development (TRD) have also indicated to *Racecar* that it is planning on introducing a new GT500 car in 2017.

In the past GT500 has been a purely engineering-driven class, mostly funded and driven by the R&D departments of the three big Japanese automakers. Conversely DTM is driven by the marketing departments of the big three German brands, who had very different aims when they created the technical regulations. This difference in racing cultures is the biggest hurdle to overcome in the unification of the two classes. GT500 has engine and aerodynamic development freedoms, while in DTM the engine specifications are frozen and aerodynamic updates are made only once every two or three years. The introduction of the DTM rules to GT500 has frustrated engineers at all three of the big Japanese brands, who want the ability to make bigger changes than the rules allow, with Honda the most outspoken of them all.

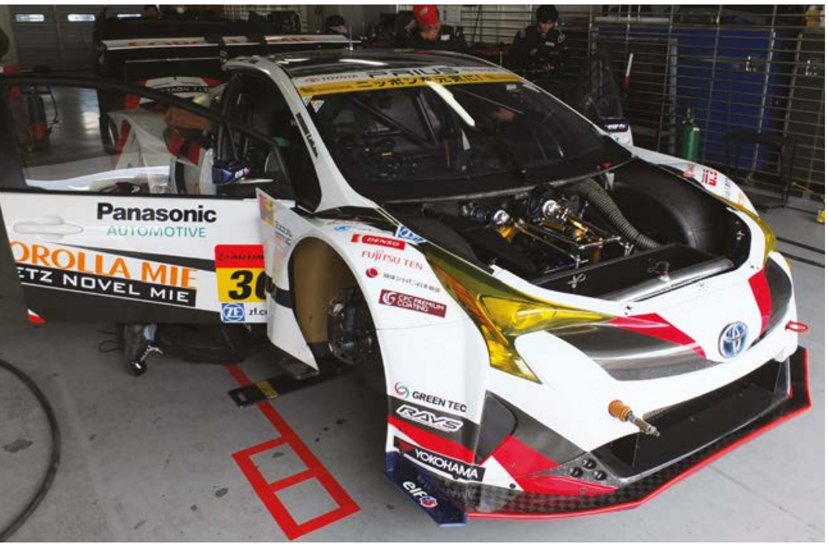
'I don't care about the engineers wanting more technical freedom,' Bandoh says. 'I have a clear job. I have make sure the series has good racing and is sustainable. The engineers always want to develop things to improve car performance but we have to think about the cost, the marketing and the impact on the racing.' With a growing overseas fan base and a strong following domestically, it would appear that he is achieving all those goals.

One of the aims of the unification of GT500 and DTM rules was to spread that formula globally and the USA was a major target. All six of the brands have big markets there. 'It would be nice if IMSA would start a series for Class 1 cars but that series would I hope be contested primarily by USA manufacturers. For that series to work it needs the American brands; without them it is impossible,' Bandoh says.

Mazda makes five?

Super GT itself could still feature some additional nameplates in future, the most obvious one of these is Mazda. Its omission from Super GT is glaring. 'We used to have the RE Amemiya Mazda RX-7s using a 20B triple rotary engine, but the team didn't get a lot of support from the manufacturer,' Bandoh says. 'I get the impression that some brands don't care enough about motorsport and that is a shame. If Mazda want to do motorsport then it makes a lot of sense for them to do Super GT, they should do that before going to race in the USA.'

Super GT actually has four manufacturers fully engaged as series partners. The fourth one, Subaru, only contests the GT300 class with a single BRZ built



All bar one of the GT300 'Mother Chassis' cars have been based on the Toyota GT86. Balancing the performance of the lower class cars is one of many hurdles facing a Super GT/DTM tie-up

An engine shortage could mean that there are few new GT300-MC cars built. There are just two cars' worth of the single-spec GTA-branded V8 now available

to the JAF GT300 technical regulations. The existence of GT300 actually means that GTA can only go so far in order to accommodate the DTM manufacturers, as Super GT is very much a two class championship. 'We have to consider the GT300 class when looking at changes to the GT500 cars, they cannot become slower than the GT300 cars, so we have to be careful about that as GT300 is very popular, and we don't want to make GT300 slower,' Bandoh says.

SRO partnership

In 2016, GTA has forged a partnership with Stephane Ratel which sees SRO technical director Claude Surmont calculating the Balance of Performance (BoP) for both the Blancpain Endurance Series and GT300. His task is complicated by the fact that GT300 uses three separate sets of technical regulations: FIA GT3, JAF GT300 and the GTA's Mother Chassis rules. And that is not the Belgian's only headache, according to Bandoh: 'Our series is different to others which use GT3 cars as we have a tyre war, but the Pirelli tyre used in Blancpain seems to have similar performance characteristics to the Yokohama GT300 tyre. But 2016 may be a difficult one for JAF GT300 cars.'

The GT300 class has always been pitched as a battle between European sportscars and Japanese tuners, but fears that the imported GT3 cars were beginning to eclipse the cars built by smaller local outfits saw GTA introduce a new type of GT300 car built around a common monocoque chassis. These Mother Chassis (MC) cars were introduced in late 2015. A number of them have been built, mainly for Super GT, but one did contest some races in the Thai Supercar Challenge. All but one of the new MC cars have been built as Toyota GT86s, a Lotus Evora the sole exception. 'The performance of the MC cars is improving, and we are looking at lowering the running costs for these cars,' Bandoh says.

An engine supply shortage could also impact the creation of new GT300-MC cars; they use a single-spec GTA-branded V8, but there are few of these units now available. 'The supply is a bit limited at the moment,' Bandoh says. 'We have two more cars' worth of engine supply guaranteed but that's it. We would look at an alternative engine for the MC cars if somebody wanted to go that way. The choice is not obvious though. The Honda LMP2 is a bit too expensive, the TOM'S V6 used in Interproto is a good price but its quite heavy. But if a manufacturer had a good suitable performing engine at a good price then I would definitely consider it.'

One option which may have potential in future is the mooted customer version of the Nippon Race Engines used in GT500 and Super Formula. It is clear that the NRE engine manufacturers are evaluating the creation of a customer variant of their engines, and perhaps this points to a potential solution to one of the issues with DTM and GT500 unification. The Japanese manufacturers insist on being allowed to develop their engines, while the Germans demand a specification freeze to keep costs down. If a customer version of the NRE was developed with a fixed specification then perhaps this could be used in Class 1 challenge races, while GT500 would continue as a development class. While Bandoh does not suggest this possibility, the potential is obvious.

GT300 expansion

Expansion is on the agenda in GT300 as well as GT500, the second tier of Super GT has already become part of the Thai Supercar Challenge and links with GT Asia and the Asian Le Mans Series are also being developed. Its clear that Bandoh sees Super GT expanding beyond the Japanese home islands in the near future, and not just with the one flyaway race which has been on the calendar for years. 'We already have the race in Thailand. Through our relationship with SRO we will have some involvement in the Sepang 12 hours and if the feeling after that is good we will look at a return for the series there. Bandoh says. 'China is also a place of interest for us, we are considering a joint event there with SRO, probably a street circuit. There has also been interest from the Middle East to go and have a race there as well, perhaps in Bahrain on the Formula 1 circuit.'

The big match

For now, though, Bandoh's real focus is getting the relationship with the Germans to bear fruit, and he is pushing hard for a head to head exhibition race sooner rather than later. 'We would like to have a match some day soon with GT500 going head to head with DTM. It would be good to do that in Germany. Perhaps we could have one race for the GT500 cars and the DTM cars going head to head, then maybe a second with the top teams from GT3 in SRO series, all the German brands, Porsche, Audi, Mercedes, BMW, taking on the best Super GT GT300 teams. It would not just be the GT3 cars but all GT300. I think if the European fans see the Mother Chassis cars and the JAF GT300 cars they would be amazed by them. SRO could do the BoP because it already does that in Blancpain, and we have the same cars in GT300 anyway. This is just an idea. I will propose it because I think it will be a great event and would let us showcase what it is we do.'

One of the aims of the unification of GT500 and DTM rules was to spread that formula globally and the USA was a major target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Estate of the art

Subaru's Levorg GT is not the first estate car to be campaigned in the BTCC but – after a shaky start – it looks like it has a real chance of being the most successful. *Racecar* visited works team BMR to get the inside line

By SIMON McBEATH

When it was announced that Subaru was to enter the cut and thrust of the British Touring Car Championship, which of us immediately thought: 'They'll be using the new Levorg GT estate then'? Few, I'd say. Partly this was down to decades of watching Imprezas achieving worldwide rallying successes. And partly it was because few (in the UK at least) had heard of the Levorg. In that sense Subaru's entry into the BTCC has already been a huge success. After just three BTCC meetings at writing time, the exercise has put the model in the minds of millions of race goers, magazine readers and TV viewers.

The Levorg GT is, in fact, the latest evolution of Subaru's most popular model, the Legacy Tourer, so in marketing terms it was a logical decision by Subaru to pick the Levorg. But what then were the technical challenges behind turning an elegant sports tourer into a racer with the potential to win?

It was Team BMR which took on the task of designing and constructing Subaru's first touring car. A young team it may be, having become the self-contained outfit it now is as recently as mid-2014, but BTCC owner/driver Warren Scott's Team BMR BTCC Racing Team, based in a new bespoke race-shop in rural Hertfordshire, has firmly established itself as a serious player. It won the 2015 BTCC Independent Team Championship, the Independent Drivers' Championship and the overall Team Championship, just missing out on the overall Drivers' title with its quartet of Volkswagen CCs.

But the partnership with Subaru, finalised in early December 2015, meant stepping up another level, to that of constructor, with an unenviably short time to achieve the task of designing and building the cars ahead of the pre-2016 seasonal preliminaries in late March. Add in the small detail of setting up the new race-shop facility, commenced in Autumn 2015 and still in-progress at writing time, and it becomes apparent that this is not a work-shy group of people.

An early team decision was to run four cars again. As team manager Alan Cole (ex-Arena International Motorsport) explained: 'The design effort is no greater and the production times for parts are only slightly greater with four sets of parts than for two or three sets.' But at the outset chief designer Carl Faux (ex-Triple Eight/RML/Swindon Engines) argued firmly against four cars: 'I much preferred the notion of two, three at most. But we have achieved building four cars, so I was wrong,' he admitted. Nevertheless, the December start meant there were just 87 days to get those four cars ready to take on to the track!

Plato's philosophy

Former double BTC championship winner and, since 2015, Team BMR driver Jason Plato had, it seems, been courting Subaru for some time before the deal was sealed in late 2015, and for Faux it was an opportunity to put a theory to the test. He, too, had been supporting the notion of a Subaru, two principle perceived advantages being highlighted. The first was the flat-4 boxer engine. The technical regulations stipulate the crankshaft centreline height, but clearly the flat-4's overall centre of gravity is lower than a conventional upright engine. Being a short engine compared to in-line fours, and sitting

In marketing terms it was a logical decision by Subaru to pick the Levorg

Team BMR principal Warren Scott, who is also one of the squad's drivers, awaiting pit lane attention

The BTCC spec suspension on one of the four Levorg racecars being set up on the flat floor in the still to be completed Team BMR race-shop. The 'shop is located on the Scott family's thriving farming enterprise in Hertfordshire, just north of London

well back in the car would also help with weight distribution and low polar moment of inertia.

Four-wheel-drive is not permitted in the BTCC, but the Levorg in standard production specification is 4wd. But running it as rear-wheel-drive, as is permitted, was the second area of theoretical advantage. Faux: 'A small rule amendment gave rear-wheel-drive cars an aerodynamic balance improvement and overall load increase from mid-2013. And while I was with Triple Eight I ran lots of simulations comparing the MG (Fwd) with the BMW (Rwd), and the weight distribution benefits, added to the aero benefits, mean a Rwd car should be faster.'

So it was time to put theory into practice, and Team BMR set about the steep learning curve of becoming a constructor, instilling the motorsport mentality of ultra-quick turnaround times with local manufacturing companies, lining up key technical partners and organising areas of responsibility within the team. 'We got going in early December 2015,' Faux says. 'We weren't going to get the CAD from Japan in time so we scanned a road car and I reverse engineered that into CAD, using Autodesk's suite of products. I was responsible for the exterior of the car, and chief engineer Kevin Berry [ex-West Surrey Racing/Triple Eight] was in charge of the chassis, roll cage installation and so on.'

Cole observed: 'In Carl and Kevin we really do have two of the best in the business, and it's interesting to see them working together. They have very different approaches and can argue vigorously over a problem until they sort it out, but they don't fall out. Sometimes, though, I had to step in and tell them if they didn't make a decision then I'd make it for them. That usually did the trick!'

During what must have been a particularly frenetic work spell, in two weeks the roll cage had been designed, the shells were in production, the engine, radiator and intercooler installations were being done in parallel, and by Christmas Eve the bodywork was underway. Engine builder Mountune was not announced as exclusive project partners until mid-January, but its work was already happening in parallel. At the end of January the first shell was completed, and by mid-February the bodywork was being manufactured. 'I'm astounded that we designed and built four cars in that time-frame, but we did,' says Faux.

Engine installation

The team obtained a mock-up of the FA 20 DIT engine (not on sale in the UK Levorg but available in other markets and so permitted under BTCC regulations) in early December, and Faux describes its installation as one of the biggest challenges in the whole design project. 'Packaging the engine and its ancillaries was tricky. Things like getting the exhaust down to the turbo [located low down at the front] and then back under the engine were not easy,' he said. At writing time the engine's installation had been agreed with TOCA but was awaiting final homologation. With the engine being of such different layout and dimensions to what was envisaged in the rules, the standard TOCA mounting points on the front sub-frame were not directly usable, and some ingenuity was required to create a rigid mounting system that connected to the standard mounting points.

With no previous experience of the boxer configuration in this competition environment to call upon, one of the biggest concerns Faux had about the engine was oil control. 'It was fine on the dyno of course, but has also been better on track than I was expecting, which was down to the measures we implemented. It's still something of a concern but it's not a critical one.' Dave Mountain at Mountune agreed: 'The rules don't allow dry sumps and the engine being so low meant the sump was very shallow, so preventing oil surge was a challenge.' As it turned out a couple of other unexpected issues became rather more critical, as we shall see later.

In general terms Mountain reckoned there were only two intrinsic shortcomings with the boxer engine: 'There are four camshafts, which means a bit more friction and complication; and the tricky exhaust packaging meant a slight loss of performance. But there are no other factors against this engine and it should be competitive with the other BTCC engines. The biggest problem was that we didn't have enough time, which of course means we are developing on the track now.'

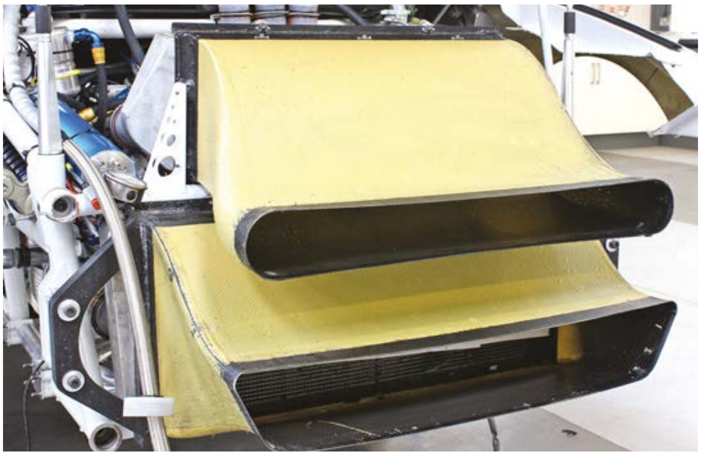
NGTC regulations lay out the basic prescription for the roll cage, Faux says. 'Most of the work is done for you and you just have to fix it to the shell. However, there is some scope in how you connect the A-pillar to the sub-frame and Kevin's knowledge and experience provided our starting point. We did an amount of FEA, again using Autodesk, and other analysis to get the best stiffness we could. We knew we had to pass the FIA load tests [on the main roll hoop and on the top corner of the A-pillar] but our time-frame meant we had to go into production before we got the certificates, so we took no risks.

'The suspension was all straightforward, everything went from CAD,' Faux adds. 'And with the shells on the jig, it all plugged straight in. CAD analysis and physical testing to optimise motion ratios and kinematics enabled us to calculate initial spring rates, damper curves, bump steer curves and so on in the usual way.'

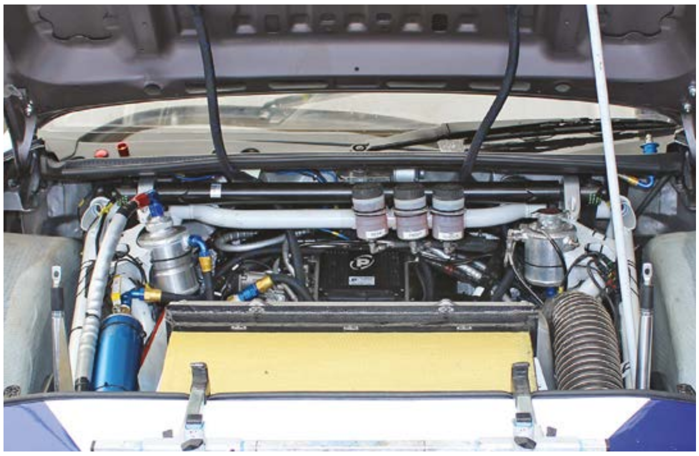
Fixed wing

As with all the cars on the BTCC grid, a standard Levorg was taken to the MIRA full-scale wind tunnel to define the wing position. This is based on achieving, and not exceeding, a maximum downforce target, but the teams are permitted to

One of the biggest concerns Faux had about the engine was oil control



Inlet ducting for radiator and intercooler. There are no bonnet louvres for extra cooling



Installation of the horizontally-opposed Subaru boxer engine proved to be a challenge

Rear downforce is restricted with the controlled location of the standard GPR Motorsport manufactured rear wing. The BTCC makes use of the MIRA wind tunnel for this task

Front end aerodynamics include a restricted splitter but there is some freedom with the airdam shaping. Team BMR is confident there is more performance to find with the aero

adjust the location of the wing to achieve the best efficiency (downforce to drag ratio) they can at this maximum load level. So the wing was mapped at different angles and different locations in order to achieve the minimum drag at the stated maximum rear downforce. The wind tunnel also showed that the car's drag was slightly greater than expected.

Aero details

The rules also mandate a standard front splitter, which extends rearwards as a flat floor a maximum permitted distance beneath the engine bay. Furthermore, the cars are all standardised at 1890mm maximum width. So, while the key downforce-inducing components are strictly regulated, and frontal areas are fairly similar, there is plenty of scope for detailing, and as we have seen in our MIRA-based wind tunnel projects in Aerobytes even quite small details can make a difference. In Team BMR's case Faux remarked: 'We've got a pretty good understanding of the aerodynamic requirements but we had no time to develop this prior to the car's launch, so at the moment it's based on our best estimates with analysis in some areas. We are allowed five jokers [development tokens] during the first year and bodywork is one such area.'

We have seen in our BTCC wind tunnel sessions on front-wheel-drive cars that downforce was very much biased to the front. What would Team BMR's target be with the Rwd Levorg? 'With a Fwd car with say a 60 per cent front, 40 per cent rear weight distribution you would aim for a more forward centre of pressure than 60 per cent front,' says Faux. 'Because the front tyres are doing everything, you need as much downforce on them as you can find. With a Rwd car with a 50/50 weight distribution you want your centre of pressure slightly behind that. It's possible we may have to shed front downforce to get the right balance, and balance is crucial.'

Interestingly, Faux describes himself as 'not a big fan of the wind tunnel' and prefers instead to use CFD for aero development. 'CAD models are more realistic now, and you can create a model with roll, pitch, yaw, tyre squish, brakes blowing, coolers breathing, engine breathing, and apply all the factors you need when looking for small gains.'

Faux will use OpenFOAM CFD and make use of remote solving to develop the car. 'It will be the first time processing the aero development on my own so we'll see how that pans out,' he says. 'But if needs be we'll hire help.' The team also uses straightline track testing to validate wind tunnel or CFD data.

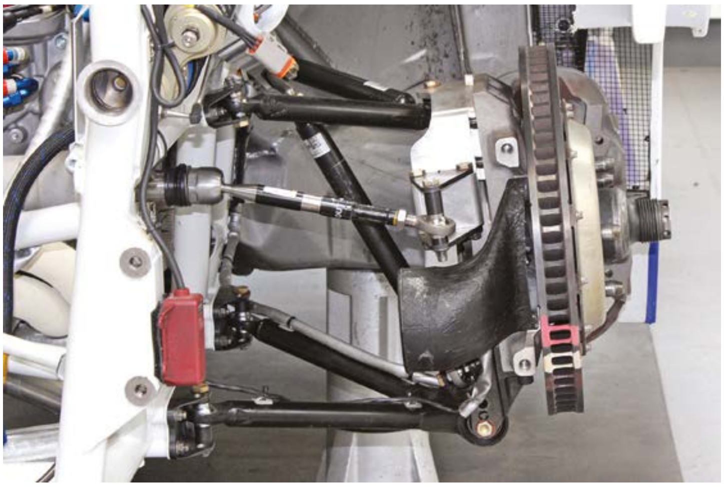
At the project's outset no heat rejection requirement figures were available, and although smaller radiator cores than usual were specified, with quite small inlets too, the team had been running with the radiators well blanked off. But, with full power not being achieved during early running (see below), that aspect was under review. The bonnet featured no louvred outlets for cooling air egress, and Faux said that 'heated air escapes through the front fender exits and the [transmission] tunnel, both of which are efficient routes. We could use bonnet exits but we currently don't need to, and that helps preserve the high pressure ahead of the windscreen, which provides an increment of downforce.'

Track time

Having only completed a brief shakedown with one car prior to the season-opening event at Brands Hatch in April, the first weekend was going to be about getting mileage on the cars. Nevertheless with one car qualifying 11th fastest, points being scored and the drivers able to constantly improve their lap times and progress through the order in the races, there were grounds for satisfaction and optimism. Second fastest lap in race two must also have been a confidence booster. It was a similar story in qualifying at the next event at Donington Park, with one car again qualifying 11th. The cars appeared to have good cornering speed, which according to Faux reflected good balance and good downforce.

One aspect that perhaps helped in a way was that, as a new constructor with a new car, the team

The wind tunnel showed the drag to be slightly greater than expected



The RML-supplied front suspension kit includes uprated power assistance on the steering

BTCC specification AP Racing four-piston front caliper and 362mm brake disc

TECH SPEC

Subaru Levorg GT

Category: BTCC

Chassis: Tubular steel roll cage reinforcing production steel monocoque; front and rear sub-frames carrying RML BTCC suspension

Engine: Subaru 2.0 FA DIT, horizontally-opposed four cylinder turbocharged, twin-overhead camshaft, 2000cc
Valves: 16 (four per cylinder)
Fuel Delivery: Fuel Injected – one injector per cylinder
Induction: Induction Technology Group filter and housing Owen Developments turbocharger and PWR intercooler
Ignition: Cosworth SQ6M ECU
Power: 350bhp **Torque:** 400Nm
Lubrication: Wet Sump plus Accusump

Transmission
Gearbox: Xtrac 1080 6-speed sequential

Clutch: AP Racing Carbon

Data system: Cosworth Electronics specified package incorporating ECU, dash, data-logging and scrutineering logger

Suspension
Front: RML designed full front sub-frame incorporating suspension, brakes, transmission and engine location that attaches to specified roll cage locations. Multi-adjustable double wishbone suspension
Rear: RML designed rear sub-frame that attaches to specified roll cage locations. Multi-adjustable double wishbone suspension

Dampers: SPA Penske coil-over

Brakes: AP Racing, hydraulic lines by Hel Performance
Front: twin four-piston, two pad callipers working on 362mm brake discs
Rear: single two-piston, two-pad callipers working on 304mm brake discs

Aerodynamics: Specified front aerodynamic device incorporating flat floor, apertures for radiator, brake cooling ducts, intercooler and side exits, specified 1300mm span rear wing profile, stylised front and rear wheel-arch extensions

Wheels: Team Dynamics Rimstock centre-lock wheel, 10in x 18in

Tyres: Dunlop 245 x 650 x R18 front and rear

Fuel tank: ATL 80-litre Kevlar cell

Dimensions
Width: 1890mm (max) Height 1387mm
Wheelbase: 2650mm
Track front: 1940mm (max)
Track rear: 1940mm (max)
Weight: 1280kg (including driver) dry (with no success ballast)

was compelled to use the RML-manufactured standardised parts that were introduced in 2016 for the next five years. 'Unfortunately we didn't have the time to analyse the [suspension] parts so that's what we are doing now in the races,' says Faux. 'We're not even tuning the cars to the different tracks yet, we're just trying things out to gauge responses and build a database. And there's a new soft tyre from Dunlop this season, too, so we have spent some track time just learning how to get the best from that.'

Spreading the load

Did having four cars make this information gathering easier? 'Yes, it helps to an extent in that we can put different set-ups on the cars and try more things out in a given time,' Faux says. 'But the different drivers sense things differently, too. However, they are being very consistent and giving good feedback, even observing each others' cars and radioing back comments, so that's really useful.'

Surprises, by definition, come from unexpected quarters, and two critical engine-related problems did arise during early running. During the engine development and build at Mountune, pistons and camshafts and so forth were underway but alterations to some standard Subaru parts required that some valvetrain parts had to be re-done. This left no time to design a 'proper' inlet manifold, so the first three events were done with the standard components. Faux says: 'The inlet tract was over double the ideal length, which might be fine for low down torque but no use for good peak power at high revs. In addition, the opposing tracts from the two cylinder banks were working against each other, and this also became a problem at high revs.'

It seems that over 6000rpm a harmonic pulse occurred in the standard inlet tract that effectively throttled the engine and even increasing the turbo boost pressure didn't help, so the cars were woefully short of top end power. TOCA's boost equalisation test, which is carried out at 6000rpm, showed no issue, but because of the inlet tract problem torque dropped off above 6000rpm, and power flat-lined instead of increasing up to the maximum permitted 7000rpm. However, following agreement with TOCA's Technical Working Group on the Friday of the season's third event at Thruxton a new inlet manifold design was ratified which appears to have solved the problem. The new design was rapid prototyped and tested on the dyno. It showed a 'loss of torque under 5500rpm but from 6000rpm and up we don't lose the torque like we did; the figures are better,' Faux says. Mountain added: 'We had to start the manufacture of the new [cast alloy] design prior to the waiver being granted. We could have stopped it, but it was the only way we were going to have it ready for the next event. Once the official TOCA tests have been done we will then re-map the engine for a two-day test [scheduled for the last week of May].'

The team's second headache came from an even more unexpected direction. During the first Donington race James Cole's Levorg suffered a fire serious enough for the race to be red flagged, fortunately with no injury to the driver. A hard fuel pipe in the high pressure fuel line had failed, and the ensuing blaze caused extensive damage. Post-race examinations revealed the offending component had also cracked on one of the other cars. So re-design and re-manufacture of the part was undertaken. However, following Saturday practice and qualifying at Thruxton inspections revealed signs of fatigue in the re-designed part so the team took the necessary and only – but nevertheless difficult – decision to withdraw from Sunday's races. 'It was the first time in 32 years I've had to make such a decision,' said Cole. 'But after what happened at Donington there was no other choice; we knew the potential consequences of another failure, and we couldn't put the drivers or the circuit marshals at further risk.' The problem it seems was related to 'a peculiar vibration issue'.

Full speed ahead

So, with improved power thanks to the modified inlet manifold to tackle a straight line speed disadvantage, and two further new fuel pipe designs in hand (a hard line with a damping support bracket and a flexi-line option), progress up the order ought to be expected in forthcoming events.

'It's been a bit fraught,' said Cole with a wry smile during our visit to BMR in mid-May. But often that's what happens when ambitious targets are set. But it looks like a safe bet that this talented team will now go on to meet those targets.

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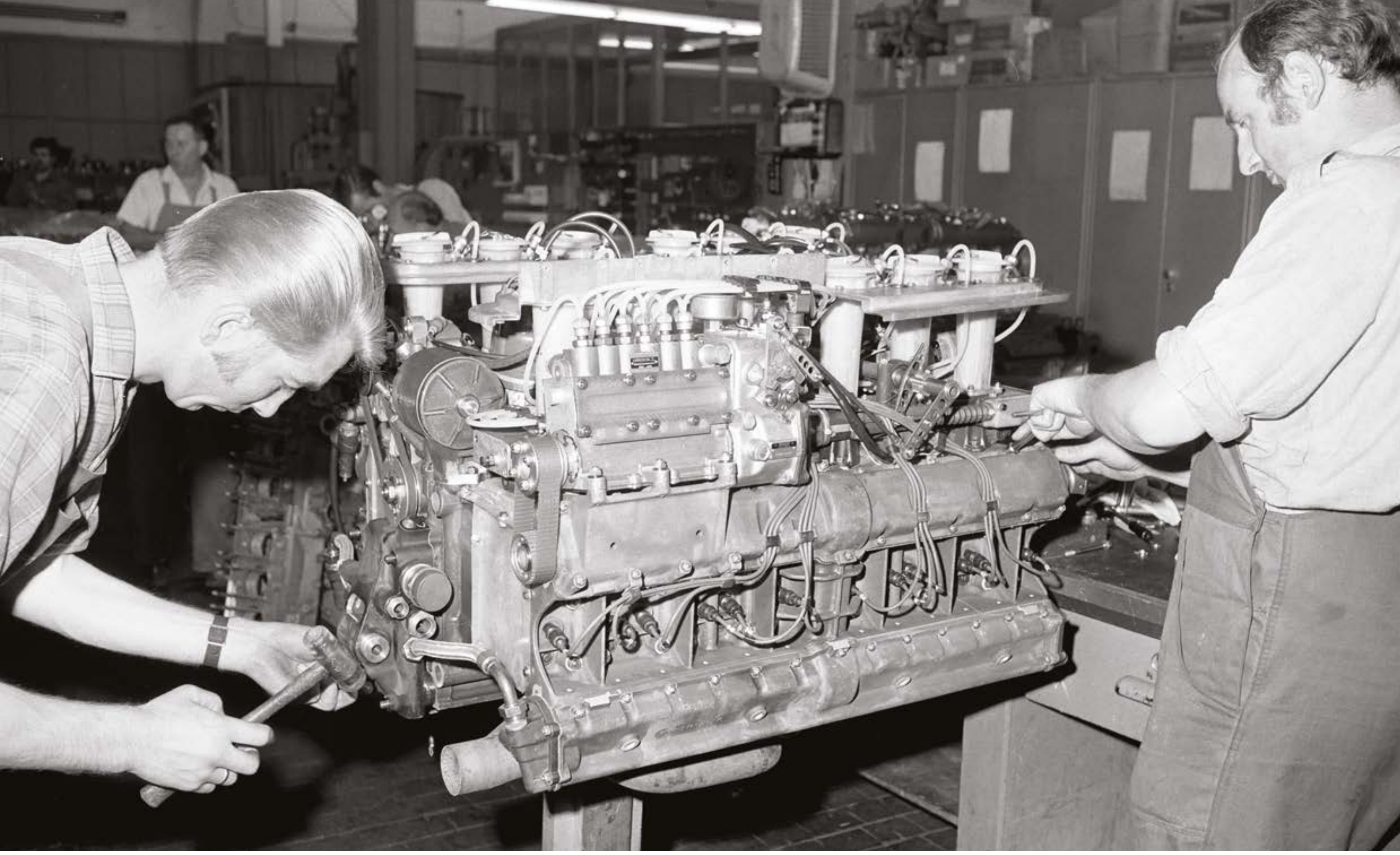
Flat **Out**

In 2015 Porsche scored its 17th Le Mans win and the first without one of its trademark Mezger engines. With the next generation Porsche GT racer also rumoured to be packing a V-shaped engine, this is the perfect time to look back on Porsche's flat powerplants

By SERGE VANBOCKRYCK



Left: The Martini 917K, which had a magnesium chassis, scored Porsche's second Le Mans victory in 1971. There would be 14 more wins for Porsches running flat engines
Above: Porsche engine builders putting a horizontal 'V12 ' together in the legendary Werk I in Zuffenhausen. The R&D for this unit was partly funded by the German military
PICTURES COURTESY OF THE PORSCHE ARCHIVE

Just as the 911 model is universally recognised as *the* Porsche, so its flat-6 engine is commonly known as *the* Porsche engine. No other car manufacturer in the world has stuck to the same engine architecture so loyally, for so long. Porsche's many Le Mans wins, before victory in 2016, had all been scored by racecars equipped with 'flat' engines, too – though not all of these were boxers.

The decision for six cylinders was orginally made by Ferry Porsche, who thought four cylinders, as in the 356, wouldn't be enough to get the performance he was looking for, and eight cylinders were for the racecars Porsche had planned for the future. Under the guidance of Hans Mezger, the Typ 901 engine had evolved from the Klaus von Rucker-designed Typ 745 and Typ 821 prototypes. Its initial development was led by Ferdinand Piech, Ferry Porsche's nephew, who after joining the company soon took control of the racing department.

For Piech, class wins at Le Mans weren't enough, yet he had to take the road to his ultimate goal one corner at a time. Racing Porsches Typ 904, 906, 910, 907 and 908 followed each other in rapid succession in a span of seven years, with engine development under Mezger's leadership following the same brisk pace. Class wins were won aplenty at Le Mans, but for the big one Piech needed a car and engine combination no one could beat.

Porsche's first overall victory would finally come in 1970. Two years earlier, the CSI had reduced the production number required for homologation of road-going GT cars with engines up to five litres from 50 to 25, and that was exactly the cue Piech needed. Building 50 917s would have been too tall an order with the limited resources of the Porsche R&D department, but building 25 made the idea very feasible. Porsche didn't have a big engine at the ready, but the R&D department was carrying out studies for such an engine for the German army. This research could thus be used to make a very potent 4.5-litre, 180-degree (horizontal) 'V12', air-cooled engine: the Typ 912/00, the largest capacity air-cooled engine ever made.

Horizontal thinking

This did not mean, however, that finances were unlimited, and an agreement with VW was made whereby it would carry two thirds of Porsche's racing budget on the condition that the engines of the cars would be air-cooled.

With time not on his side, Mezger made as much use as possible of what was around already, starting with the overall layout of the engine, which was almost identical to that of the Typ 360 Cisitalia grand prix car Porsche had designed two decades earlier. To keep the budgets in check, the Typ 908 engine head design was used, although Mezger reduced the included valve angle from 71 to 65 degrees. Intake and exhaust valves, as well as the Bosch fuel injection system, were carried over, as were the bore and stroke measurements, giving the Typ 912/00 a displacement of 4494cc, with the possibility to increase. In order to keep the negative influence of vibrations to a minimum, Mezger took the power from the centre of the crankshaft, with all the accessories, such as the cooling fan, being driven off this centre crankshaft lay-out. With a compression ratio set at 10.5:1, the power output was estimated at 560bhp at 8300rpm, with 490Nm torque at 6800rpm, and the whole package weighed some 240kgs. A gear-driven horizontal fan cost some 17bhp, but that was less than the power it would have cost to accelerate an extra radiator system, as well as the additional weight of water jackets, through the air. A big oil radiator provided 15 to 20 per cent of the cooling of the engine, which compared favourably to the 30 to 35 per cent oil cooling needed with an air-cooled engine with a vertical fan.

The Horst Reitter-designed chassis was still an aluminium spaceframe, very similar to the 908. Although the 912 engine was a bit longer than the 908 unit, it was not located further back. Instead the driver's compartment was moved further forward, the driver's feet now sitting way in front of the front axle. One of the goals set for the 917 from the outset was to achieve the highest possible speed on the long Hunaudieres Straight at Le Mans. As such, the 917 kept the same, rather narrow, front and rear track dimensions of the 908, as well as the wheelbase.

The bodywork, too, was almost identical to that on the 908. The only novelty here was the detachable 'long tail' which allowed the car

Hans Mezger led the design team on the first Porsche 911 engine and was also largely responsible for the 917. That's quite a CV

The rest of the 1976 season, including Le Mans, belonged to Porsche

to be converted back and forth with the very minimum of effort from the race team.

Le Mans in 1969 had almost been a success for Porsche, but not yet for the 917. By the following year, however, the 917 was the clear favourite. Mezger and his men had further developed the engine, courtesy of an increased bore (from 85 to 86mm) and stroke (from 66 to 70.4mm). The capacity of the new Typ 912/10 had grown to 4907cc and the power and torque had increased to 600bhp and 549Nm. Two of John Wyer's legendary pewter blue Gulf 917 Ks ran the new engine, but one stuck to the smaller Typ 912/00, as did the short-tail Herrmann/Attwood 917 K of the Porsche Salzburg team, run by Piech. After a wet race in which all the Gulf Porsches retired, the Salzburg 917 K prevailed and won ahead of the Martini 917 L.

The following year, the Gulf 917 Ks again dominated the world championship, but would once again fail to win at Le Mans, and Porsche's second win at La Sarthe was achieved by Hans-Dieter Dechent's Martini team.

New rules for 1972 and beyond effectively outlawed the 917, and Norbert Singer – who had joined the company a few years previously – was tasked with developing a 911-based racecar. For the 1973 season he developed the Carrera RSR which took shock victories at Daytona and on the Targa Florio, while Le Mans netted a fine fourth overall. It was enough to whet the appetite for something bigger again.

Turbo boost

For the 1974 season, Porsche was faced with the problem of having a technically and dynamically very good car, but with an engine that had little room left for power increase. Turbocharging the RSR was the logical next step. The rules, however, stipulated that turbocharged engines had to apply a 1.4 multiplication coefficient to their swept volume in order to calculate the normally aspirated equivalent. Since the normally aspirated engines for prototypes where limited to 3000cc, the Carrera's turbocharged engine capacity was effectively limited to 2142cc (2142cc x 1.4 = 2998.8cc).

The new Typ 911/76 engine consisted of a standard 2-litre production magnesium crankcase combined with Nikasil-coated cylinders with an 83mm bore and 66mm stroke. The cylinder heads had sodium-filled valves for better cooling while the exhaust valves were borrowed from the 917 and the inlet valves took the size of those of the 906. Bosch supplied the electronic twin-spark ignition and the mechanical injection. The single KKK K33 turbocharger and cockpit-adjustable Garrett AiResearch wastegate allowed the engine to produce some 450bhp at 8000rpm with a compression ratio of just 6.5:1, courtesy of flat top pistons. To increase the power the engineers decided to cool the air forced into the engine through an intercooler. The power thus went up to 500bhp at 7600rpm, with the torque figures increasing from 451Nm to 549Nm at 5400rpm. At Le Mans the Carrera RSR Turbo almost achieved the impossible: a road car-based racecar nearly beat the prototypes, but it had to settle for second in the end.

When the CSI postponed the new regulations for both the World Championship for Makes and the World Sportscar Championship by a year until 1976, Porsche was left without a factory programme for 1975. The

The Porsche 936 had a parts list that included components from many of the previous projects. Its Typ 911/78 was based on the 2142cc turbo unit from the Carrera RSR Turbo, which at 1.4bar boost now produced 520bhp

year off was used to develop the next 911-based racecar for the WCM: the Group 5 Typ 935. But parallel to the 935 (see the March 2016 edition of *RE*), CEO Ernst Fuhrmann decided to develop a car for the new World Sportscar Championship as well. Mezger and Helmut Flegl were tasked with building this car using as many parts as possible from recent programmes, later joined by Wolfgang Berger when the latter had finished the development of the Porsche 934.

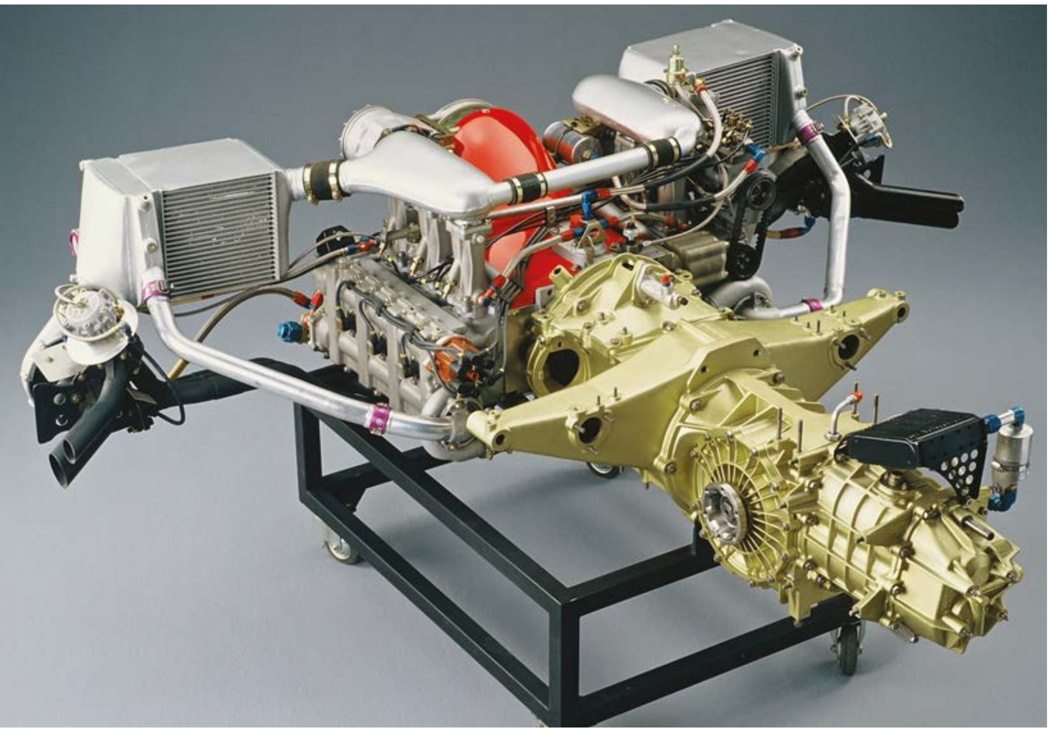
As such, the Typ 936 had a parts list with Type-numbers from all possible previous Porsche projects. The engine was the Typ 911/78, based on the 2142cc turbocharged unit from the 1974 Carrera RSR Turbo, which at 1.4bar turbo boost now produced some 520bhp and 470Nm with air being fed through two air-to-air intercoolers as opposed to the single unit of the Carrera RSR. The new engine also featured a horizontal cooling fan rather than the vertical one of the Carrera. Since the engine was rather short, a long spacer was used between it and the gearbox to give it a position as central as possible in order to have the best possible weight distribution. With barely more than six months from first drawing to first race, at the Nurburgring, no one was really surprised it retired. But that was the only blot on the 936's copybook. The rest of the '76 season, including Le Mans, belonged to Porsche.

Heroic race

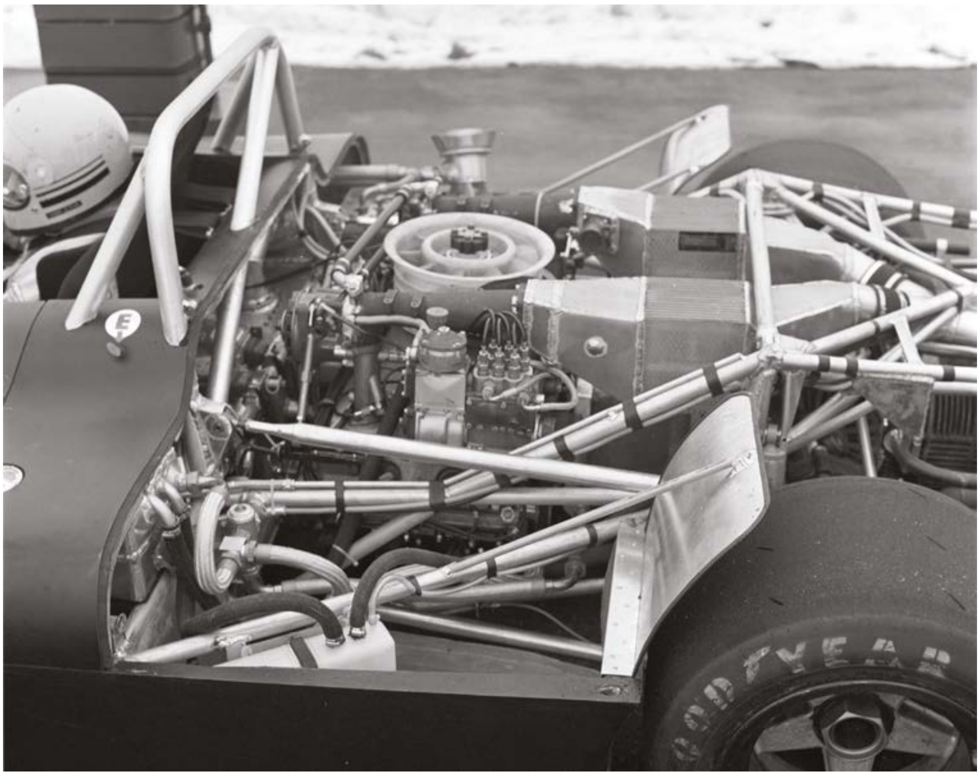
With the WSC won, for 1977 Porsche decided to enter the 936 just at Le Mans. Speed was of the essence so the frontal area was reduced from 1.75m^2 to 1.65m^2 by narrowing the track by 5cm at the front and 3cm at the rear. The wheelbase was extended by 1cm, while the overall length grew by 5cm to 425cm. To further improve the car's speed the body was refined in all areas. The engine was the same Typ 911/78 unit as the year before, but now with two smaller KKK turbochargers, one for each cylinder bank, installed to improve the throttle response and reduce the turbo lag. An added bonus of the twin turbos was the power increase from 520bhp to 540bhp.

Le Mans in 1977 was a very dramatic race. By Saturday evening one 936/77 had already retired while the other was seriously delayed, but a transfer of Jacky Ickx to the remaining car and some stellar driving by both him and Jurgen Barth (helped by Hurley Haywood) brought the car home in first, albeit on five cylinders and at a snail's pace.

For 1978 Porsche again relied on a fine-tuned version of the 936. The main difference between the 1978-spec car and that of the two previous years was the new engine. To solve thermal problems it had in1977, Mezger had to considerably rework the engine. Still based on the 14-year old Typ 901 concept, the new Typ 935/73 engine now had four valves per cylinder, thus drastically reducing the temperatures of the outlet valves. However, with four valves taking up more space than two, they no longer allowed for air-cooled cylinder heads so these had to be water-cooled. Instead of using two triple-cylinder heads, Mezger opted to have six single cylinder heads. A big advantage was that cylinder and cylinder heads could be fused together thus doing away with the traditional head gasket. The cylinder heads were cooled through two water pumps, one for each cylinder bank, from bottom to top, from outlet



Porsche's legendary flat-six engine coupled to its gearbox. This has been the mainstay of Porsche motorsport programmes for decades but with the new 911 GTE car rumoured to be packing a V-shaped turbo unit it could be consigned to history



The engine about to be tested in the new for 1976 Porsche 936 racecar. It now featured a horizontal cooling fan and two intercoolers instead of one. Since the engine was quite short, a long spacer was placed between the block and the gearbox

Still based on the 14-year-old Typ 901 concept, the new Typ 935/73 engine now had four valves per cylinder, thus drastically reducing the temperatures of the outlet valves

side to inlet side, thus guaranteeing an even cooling. With the cooling fan now only required to cool just the cylinders, its size was reduced. The 936/78's aerodynamics were further revised to incorporate the larger radiators in the sidepods. As it was the year before, one car retired early and Ickx was again transferred to the second 936/78, but this time there would be no fairytale ending. Renault won fair and square.

Despite a hastily prepared, last-minute Le Mans campaign at the behest of colourful sponsor Essex Petroleum in 1979 (two DNFs for the 936s), Porsche still scored a fifth overall win courtesy of the Kremer 935 K3 – the first and only-ever Le Mans win for a rear-engined car. The Kremer brothers had been tweaking their 935s since they first took delivery of one and for the 1979 season they had created the ultimate incarnation with the aerodynamically and technically supreme K3. With its sleek Ekkehard Zimmermann-designed signature bodywork, stiffer and lower chassis, and Manfred Kremer-built Typ 930/78, 2994cc, 680bhp engine with air-to-air intercoolers, the made-in-Cologne 935 K3 beat a customer-spec 935 to the flag.

Reprieve for the 936

After that, the works 936s were mothballed, seemingly for good. That is, until Peter W Schutz took over from Fuhrmann as the company's CEO in January 1981 and wanted to know what the plans were for Le Mans. With nothing going but front-engined 944s looking for class wins, Schutz asked the motorsport engineers to come up with a better plan. For 1981, the rules for Group 6 had been changed and the prototypes were no longer required to run engines capped at three litres normally aspirated, so the 936 with its 2.1-litre engine might not have as good a chance at winning as before. But Singer had an ace up his sleeve: the 2649cc, four-valve, Typ 935/72 engine from an aborted Indy project; five of which had been stored in the Zuffenhausen engine department since the cancellation.

With Mezger off to design and oversee Porsche's V6 F1 engine for the McLaren team, his right-hand man and development engineer, Valentin Schaffer, was put in charge of the sportscar engines. All he needed to do was to adapt the Indy engine to the use of petrol instead of methanol, install two KKK K26 turbos instead of the single unit, and give it a new Typ-number: 935/76. With a 7.2:1 compression ratio it delivered some 620bhp at 8200rpm and 598Nm torque at 8400rpm and 1.2bar boost. Conservative, maybe, when the engine could deliver as much as 730bhp with more boost at higher revs, but it was plenty for the 24-hour marathon. Having learned a lesson or two on the gearbox-side of the 936, Singer opted to use the old but bombproof, Typ 920, 4-speed, synchromesh CanAm gearbox, which could transmit up to 1000Nm of torque.

The last-ever race for the five-year-old Porsche 936 was its biggest success. A trouble-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The last race for the five-year-old Porsche 936 was its biggest success

free run netted Porsche's sixth win. As for the car's engine, it was soon about to rewrite the record books in its own right.

The 1982 season saw the beginning of Group C. For Porsche it meant entering uncharted territory with the construction of its first monocoque for a car which was about to break all previous records: the Typ 956. Singer again oversaw the project, with Horst Reitter in charge of the chassis and Schaffer the engine, the only proven part of the car, as the Typ 935/76 engine was taken over from the previous year's 936/81. With extra room available in the engine compartment, the turbos were relocated to the left and right sides of the engine rather than sitting behind it as had been the case on all previous models. This shortened the distance from the turbos to the cylinder heads which gave a better response and a slight power increase. Oil and water radiators and intercoolers also sat each side of the engine. The 192kg flat-6 still used the mechanical Kugelfisher injection, though Bosch was known to be working on an electronic version. With the powerplant having proved its speed and reliability, all Schaffer had to worry about was the fuel consumption, limited at 2500 litres for 24 hours.

The three works 956s entered at Le Mans had an almost textbook race and obliterated the competition on their way to a 1-2-3-victory. The 956s then won every 1982 WEC event they entered, filling up customer sports boss Jurgen Barth's order book for 956s faster than the company could produce them.

One year on, 11 956s were entered at Le Mans, and it was quite difficult to see how the win could possibly elude Porsche. The works team had the edge over its customers, since its engines featured the new Bosch Motronic MP1.2 electronic injection, which in combination with higher crown pistons allowed the compression ratio to be upped to 8.0:1 to increase the power to 640bhp. For Le Mans, though, a more conservative 7.5:1 CR was used. To call Porsche's eighth Le Mans victory 'dominant' would be an understatement: for only one car in the top 10 finishers was not a Porsche 956.

In 1984, Porsche built a batch of upgraded 956s, called 956B, for customers. But the works team stayed away from Le Mans for political reasons. The factory had meanwhile released the Motronic injection to the privateers which allowed them to run an 8.5:1 CR. In France, the CR was reduced to 8.0:1 for reliability reasons. Surprisingly, of the top privateer teams, Reinhold Joest's still ran the mechanical Kugelfisher injection. Joest, like the Kremer brothers and John Fitzpatrick, built his engines in-house and had a trump card in hand with Swiss engineer, Michel Demont. Quite a few Motronic engines had blown in the races leading up to Le Mans, and Joest and Demont decided to choose reliability over novelty. They were proved right, and scored a ninth Le Mans win for Porsche ahead of six other 956s.

Porsche scored a fifth overall win in 1979 courtesy of the Kremer brothers' 935 K3, the car which had dominated that year's German sportscar championship. This was the first and only Le Mans 24 Hours win for a rear-engined racecar

The Porsche 962 (above) was an evolution of the equally successful 956, which was Porsche's first monocoque car. The Typ 935/76 engine was carried over from the previous year's 936/81 almost without modification for the 956's debut in 1982

Enter the 962

For the 1985 season, the Porsche works team ran the new Typ 962C, which was basically a 956 with a wheelbase lengthened at the front as per the FIA's latest regulations on driver safety. The engines, too, had been updated and the new Typ 935/79 version, though still of 2649cc capacity, now ran a 9.0:1 CR in the shorter races and 8.5:1 at Le Mans. The works team entered three new 962Cs, the army of privateers fielded an additional nine 956Bs and 962Cs. The battle between the works team and its many customers raged for 24 hours, but in the end it was the Joest team which won for the second consecutive year. Demont had again built a special engine which ran a high 8.9:1 CR, while an undisclosed third party had developed custom-made software for the Motronic.

One year later, the works team was back in France with a vengeance. For the shorter WS-PC races the Rothmans 962Cs now ran the new Typ 935/82, 2994cc engine, with a 95.0mm bore and 70.4mm stroke, and a 9.0:1 CR. It was a further evolution of the initial engine converted from the Indy powerplant and at 1.2bar boost it was good for 700bhp at 7800rpm and 695Nm torque at 5400rpm. For Le Mans, the team opted for the 2.6-litre Typ 935/79 which had better fuel economy figures. This year, the privateers would not upset the apple cart and Porsche scored its 11th win. As per the custom, four privateer 956Bs and 962Cs filled out the top five.

Porsche embarked on its sixth consecutive season with the 956/962 in 1987, a remarkable achievement considering the fast pace of development in motorsports and the arrival of the likes of Jaguar and Mercedes. While the chassis might have been nearing the end of its development potential, there was still some life left in the flat-6. Schaffer developed the

Singer was given the resources to design a completely new 911 GT1

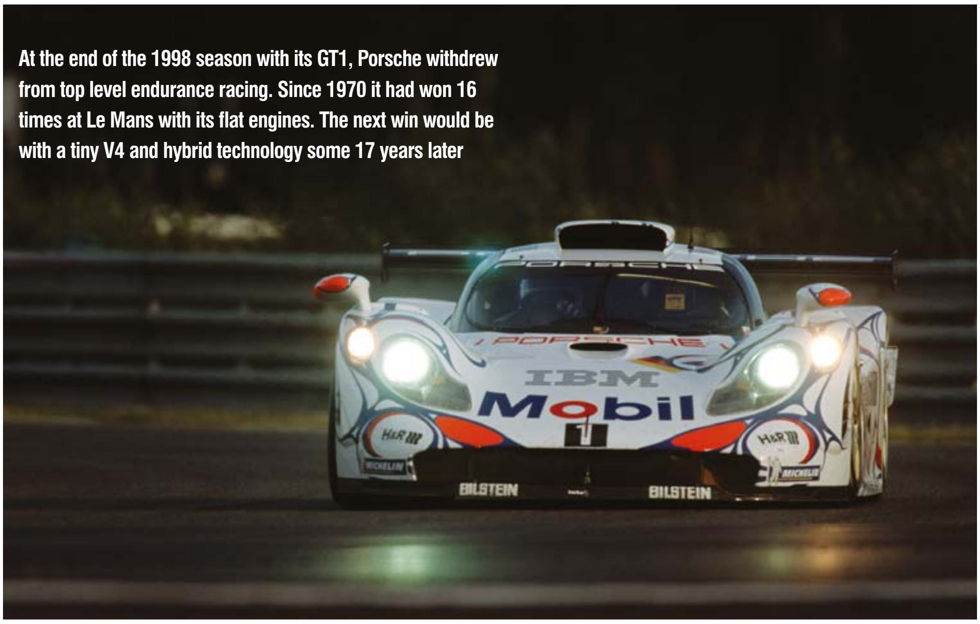
new 3-litre, water-cooled, 9.5:1 CR, Typ 935/83 engine, which delivered 720bhp at 8200rpm. It featured a redesigned crankcase, crankshaft and camshafts and improved piston clearance and piston rings. Porsche was quite looking forward to the 1987 WS-PC season but the competition had caught up and for the first time Porsche did not win a single race before Le Mans.

And even Le Mans turned into a small drama. One of the works 962Cs was lost in an accident in qualifying; a second one, together with three of the top privateer cars, retired in the first hour of the race when their engines collectively failed as a result of a sharp drop in quality of the organiser-supplied fuel. Fortunately, the microchip of the surviving works 962C's ECU could be changed before any damage had been done and the No.17 Porsche 962C ran a classic race to another victory. Immediately after Le Mans, however, Porsche announced it would withdraw its works team from the WS-PC to concentrate on a new IndyCar project as well as the successor to the 962C, rumoured to be having a mildly turbocharged, large-capacity V8 engine, very much like the one Mercedes was using to beat Porsche.

That new car never materialised but Porsche did make an encore appearance at Le Mans in 1988 with a three-car works squad backed by technical partners Dunlop and Shell. The cars now used the Typ 935/83 but equipped with the new Motronic MP1.7 injection. One came close to winning but ultimately finished second.

The factory then decided to release the works engines to selected privateer teams and support these with engineers and development parts. In 1989 and 1990 Reinhold Joest's outfit became the de facto works team in all but name, but the Porsches couldn't do better than third in Le Mans both years. The days of the 956/962 and its venerable flat-6 engine looked to be well and truly over. Or were they?

The last of the boxers: the Typ M96/82, which gave a modest 550bhp at 7200rpm, powered Porsche's 911 GT1 98s to a one-two finish at Le Mans in 1998. The GT1s were the only mid-engined 911s ever produced



At the end of the 1998 season with its GT1, Porsche withdrew from top level endurance racing. Since 1970 it had won 16 times at Le Mans with its flat engines. The next win would be with a tiny V4 and hybrid technology some 17 years later

When the World Sportscar Championship with its 3.5-litre F1-engines had failed after just two seasons, the ACO was forced to reinvent its race, which was now a stand-alone event. One of the ideas was to allow GTs back in. As luck would have it, at the end of 1993 former racing driver Jochen Dauer presented his pet project to the world: converting genuine racing 962s to road-legal GTs. Which set Singer thinking: why not convert a Porsche 962C racecar to a Dauer 962 street car, homologate it as such, and then convert it back to a racecar?

Porsche entered two Dauer 962 at Le Mans in the GT class. The cars still ran the original 3-litre, water-cooled Typ 935/83 engine, though now with a 9.0:1 CR and two mandatory 37.1mm air restrictors. With just 600bhp on tap at 6200rpm, the Dauers could only go for a class win, but with few bona fide prototypes entered, anything could happen. And it did: with just 90 minutes to go, the leading Toyota prototype suffered transmission issues, which helped propel one of the Dauer 962 GT LMs to a win.

Mid-engined 911

The same Typ 935/83 engine also delivered the power for Porsche's next project in 1995, an open-top spyder made at the request of Porsche America and based on the 1991 TWR-built Jaguar XJR-14. Porsche pulled the plug on the project, but one year later Reinhold Joest asked if he could borrow the unraced WSCs and develop them for Le Mans, to which Porsche agreed. Joest, with lots of input from Porsche, then reworked the bodywork, suspension, brakes and so on, until he had a pair of competitive cars. Pole position for one car and victory for the other was the net result.

For the 1997 race the factory entered a pair of 911 GT1s GT cars, while Joest made a surprise single-car entry. Joest's lone spyder was there to pick up the trophy. It was Porsche's 15th victory and the fourth for Joest.

In 1998 Singer was given the resources to design a completely new 911 GT1 from the ground up. It now featured a carbon-fibre monocoque, while Helmut Schmid had reworked the water-cooled 1996-spec Typ M96/80, twin KKK K27 turbocharged engine, enlarging it from 3164cc to 3198cc by increasing the bore from 95.0mm to 95.5mm for the same 74.4mm stroke, thus creating the Typ M96/82. Courtesy of two 33.9mm air restrictors (down from 35.7mm in '96) it developed just 550bhp at 7200rpm and 630Nm at 5000rpm, but it was enough to beat the equally exotic machines entered by Mercedes, Toyota, Nissan, McLaren *et al*, and score a 16th Le Mans victory. At the end of the 1998 season, Porsche withdrew from top-flight sportscar racing.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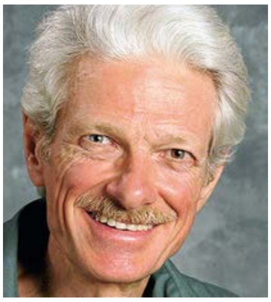


Pondering a Porsche's power-on understeer

A discussion on power-induced push in a Porsche 996 racer

QUESTION

I run a Porsche 996 in PCA's GTB1 class, a hot-bed of activity these days. The car runs at 2650lbs dry, 1300lbs front springs, and 1150lbs rear, with Penske double adjustable shocks. I run the rear bar on full soft, and the front on one off from full stiff, with 9in front rims shod with 250/650-18 Yokohama slicks, and rear 11in with 300/650 Yokohama slicks. All in all, it is a really well balanced package after years of trial and error development.

My question concerns corner exit understeer. Like Carrol Smith, I've always tried to follow the logic of 'fix the end that's misbehaving', as opposed to destroying the grip at the other end to bring the car into balance. But whoever I ask for advice on how to solve corner exit understeer, everyone wants me to fiddle with the back.

I run fairly stiff bump and fairly soft rebound up front, and the car has great corner entry point-in, without upsetting the back. But once power goes down, the front just 'floats'. Not badly, but just a little too much.

I'm already on -20 out of 30 settings on the Penske's for rebound, so there's room to go, but I don't want to have an experiment going really wrong, and damage something or have an incident. So, my inclination is to soften the rebound, to allow the tyre to remain more in contact with the pavement, as opposed to it being 'lifted up' by the surging front end of the chassis as the weight transfers to the rear. Again, it's a light float that still allows for accurate placement at corner exit, but if the front could hook up just a little better, I could go to power-down that much sooner.

THE CONSULTANT

I agree with not balancing the car by throwing grip away, but that doesn't necessarily mean you don't touch the end that sticks better. Each end affects the other end. So some questions for you to consider, first.

Does the car pick up the inside front wheel under power? Most Porsche 911/996 style cars do, correct? What do you run for your rear toe? How about the differential? I expect it is a clutch pack limited-slip diff, correct? Are you able to play with ramp angles or with the preload? And finally, are you happy with the steady-state balance?

QUESTIONER

Yes, the inside wheel does pick up. Barely in most cases, so I'd describe it as skimming the surface with the anti-roll-bar set on one off full stiff. As to your other points, I learned along the way that front roll stiffness is a requirement for the back of a rear-engine car to behave. If I go to full stiff, the effect is more pronounced, but the entry and exit understeer becomes more pronounced, too. The toe is one-eighth inch each side, or a quarter inch total.

It is a Guard clutch pack diff described as 50/80, so I don't know whether that's ramp angle or lock-up percentage, but the diff works great on corner entry; you can pound the car down into an apex with the brakes on hard and the back end just sits down and takes it, key to running hard and long without the car biting me. Meanwhile, on exit the back moves just enough but not enough to begin to step out. But no, playing with ramp angles is beyond the scope of me in my amateur capacity. As for the steady state, the balance is darn near perfect for fast sweepers; little blips front and rear that can be adjusted with throttle. Hope that makes it clearer.

THE CONSULTANT

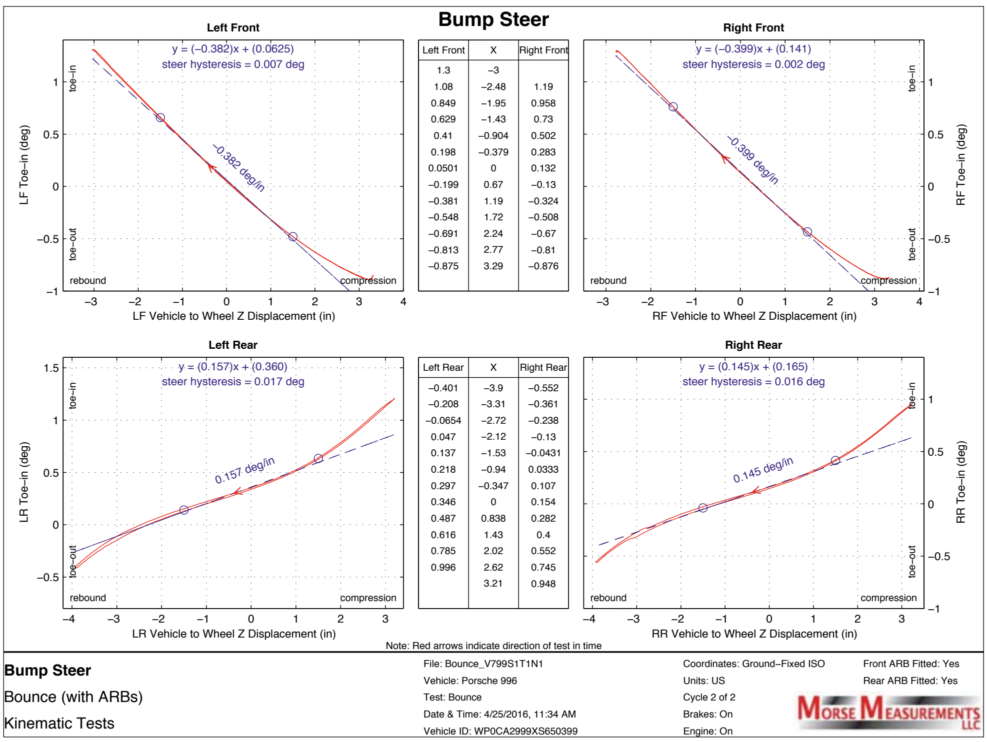
Have you tried less rear toe-in? I would expect that to add some oversteer in all conditions, but most of all under power.

QUESTIONER

No, but I will. With the fairly stiff springs, I don't get much toe-out under power, so limiting the toe could well be of help.

It's funny, I remember standing at the hairpin at Sebring and watching the RSRs launch in first gear. It seemed like the front end would raise up and the wheels would stay

Have you tried less rear toe-in? I would expect that to add some oversteer in all conditions

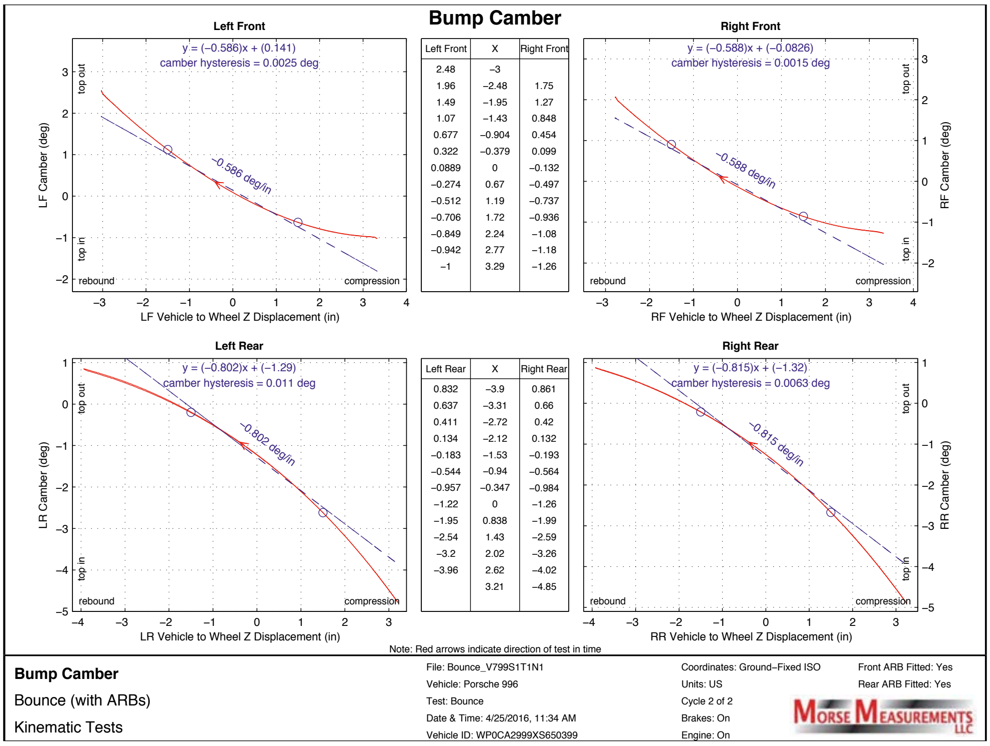


Left Front	X	Right Front
1.3	–3	
1.08	–2.48	1.19
0.849	–1.95	0.958
0.629	–1.43	0.73
0.41	–0.904	0.502
0.198	–0.379	0.283
0.0501	0	0.132
–0.199	0.67	–0.13
–0.381	1.19	–0.324
–0.548	1.72	–0.508
–0.691	2.24	–0.67
–0.813	2.77	–0.81
–0.875	3.29	–0.876

Left Rear	X	Right Rear
–0.401	–3.9	–0.552
–0.208	–3.31	–0.361
–0.0654	–2.72	–0.238
0.047	–2.12	–0.13
0.137	–1.53	–0.0431
0.218	–0.94	0.0333
0.297	–0.347	0.107
0.346	0	0.154
0.487	0.838	0.282
0.616	1.43	0.4
0.785	2.02	0.552
0.996	2.62	0.745
	3.21	0.948

Bump steer readings from a K&C rig kinematic test of a Porsche 996. These are from a standard cabriolet road car, rather than the racecar discussed here, so it's a much softer set-up and probably has a ride height that's an inch higher

To some extent a power push is just a characteristic of a car with a lot of rear percentage. Front-engined racecars tend to be easy to point with the throttle



Left Front	X	Right Front
2.48	−3	
1.96	−2.48	1.75
1.49	−1.95	1.27
1.07	−1.43	0.848
0.677	−0.904	0.454
0.322	−0.379	0.099
0.0889	0	−0.132
−0.274	0.67	−0.497
−0.512	1.19	−0.737
−0.706	1.72	−0.936
−0.849	2.24	−1.08
−0.942	2.77	−1.18
−1	3.29	−1.26

Left Rear	X	Right Rear
0.832	−3.9	0.861
0.637	−3.31	0.66
0.411	−2.72	0.42
0.134	−2.12	0.132
−0.183	−1.53	−0.193
−0.544	−0.94	−0.564
−0.957	−0.347	−0.984
−1.22	0	−1.26
−1.95	0.838	−1.99
−2.54	1.43	−2.59
−3.2	2.02	−3.26
−3.96	2.62	−4.02
	3.21	−4.85

Bump camber readouts from the same 996 road car. Camber goes towards positive a little when the nose of the car lifts

on the ground, almost as if there was three inches of droop. I was assuming that was very little rebound control. But is that actually an incorrect assumption?

THE CONSULTANT

I would be quite surprised if you get toe-out under power. Generally designers will avoid having either bump steer or compliance steer in that direction. It's pretty difficult to get compliance toe-out under power even if you want to. Ordinarily that happens in deceleration or braking.

I actually have bump steer readings from a K&C rig kinematic test of a 996. This is a stock street-driven cabriolet, so it's a much softer set-up than yours, and probably about an inch higher ride height as well. The rear wheels do toe-in in compression and out in extension. Over the first inch of compression, each rear wheel toes in about 0.15-degree. Over the second inch of compression, which would probably be roughly the first inch on your car, each wheel toes in about an additional 0.30-degree; the rate of change increases. The wheels toe out in extension, also at an increasing rate. The bump steer curve is S-shaped. On the commonly used 28in toe plates, half an inch is about a degree. An eighth of an inch per wheel is then about a quarter of a degree. Measuring at the wheel rims, an eighth of an inch is more like half a degree. The 996 in the K&C test had an average of about a quarter of a degree per wheel at static, which I would imagine would be a factory recommended setting.

Regarding front end rise under power, assuming that the driver can stay on the power long enough so the car is able to reach dynamic equilibrium, the front spring rate, or more precisely the front wheel rate in ride, is what determines how far the front end rises. The shocks determine how fast it rises. Softer springs make it rise further. Softer low-speed rebound damping makes it rise faster. Hold-up shocks with soft rebound and stiff compression help keep the front end from coming down as much during shifts.

When we're going straight, there is a moderate advantage in having the nose lift, at least at lower speed. The CofG's a little higher, there's a bit more rearward load transfer. At higher speeds, we may lose more aerodynamically than we gain with rearward load transfer. But it takes a powerful car to produce a lot of front end rise at high speeds.

To combat a power push, we probably want the nose to stay down. For one thing, that will help outside front wheel camber a little. The camber goes toward positive a bit when the nose lifts. This isn't a big effect on a Porsche 996. The camber only changes something like a quarter of a degree per inch in the range the suspension would be in during exit on the outside front wheel.

The springs you've got are pretty stiff already. The street 996 has a wheel rate of about 178lb/in at the front. The spring rate would be higher than that, but probably no more than 250lb/in. At 1300lb/in, your racing version is about five times that. The wheel rate must be upwards of 1000lb/in. I don't know what the vertical spring rate of your racing tyres is, but the tyres on the street version were around 1670lb/in, so you've stiffened the springing to the point where the tyres are about a third of the suspension in ride, and more than that in roll. Therefore, I don't think you can reduce nose lift or exit understeer much by going even stiffer on the springs.

To some extent, a power push is just a characteristic of a car with a lot of rear percentage. Front-engined cars tend to be easy to point with the throttle. They develop power oversteer gently but at modest power application. My mid-engined Corvair, which has about 60 per cent rear, stays at light understeer on exit through a wide range of power application values. If you feed in more power, within reasonable limits, you hardly have to do anything with the steering; the car just eats up more road laterally if you get on the power more. A car that has 63 per cent rear or more, like a 996, tends to develop push under power. All rear-drive cars will transition to wheelspin oversteer at some point. The more tail-heavy the car is, the more power can be applied before it reaches that point, but also the more violent the transition is.

I would discourage playing with extreme damping strategies in a road racing car. Let's see what happens when you take a little rear toe-in out. That may very well give you just the modest change you're seeking.

To combat a power push, we want the nose to stay down, that will help outside front wheel camber

CONTACT

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Spire RGB racer in the wind tunnel

Part two of our bike-engined racecar aerodynamic examination

We continue this month with our studies on the Spire Sports Cars RGB and Bikesports sports racers. Like a growing number of mini-prototypes around the world, these bike-engined cars are extremely popular, and the ones we are looking at here are built to the UK's 750MC regulations.

Road going bike-engined (RGB) cars are quite restricted on aerodynamic appendages and are reliant on a 50mm front splitter, upper body shaping, rear Gurneys and an essentially flat floor to generate downforce.

Bikesports regulations are, by contrast, very free and only limit wing span to overall width and ground clearance to 40mm minimum.

Spire Sports Cars have enjoyed tremendous success in both of these categories in the recent past, as well as other sports racing and open categories around the UK, so it was a treat to be able to analyse their aerodynamics in the MIRA full-scale wind tunnel.

Last month we looked at the cars' baseline data and saw that the Spire RGB racer compared roughly with the Mallock Mk 28B we evaluated in the summer of 2015, with modest downforce and drag. While its aerodynamically more muscular Bikesports sibling was virtually on a par with the Ligier JS49 CN car that we reviewed back in the winter of 2008, with very respectable downforce but the same drag as its RGB sibling (and as always we must keep in mind the fixed floor of the MIRA wind tunnel, which underestimates downforce generated by devices close to the ground).

As a reminder and a start point for this month's musings, **Table 1** shows the basic aerodynamic numbers for the cars in their best balanced conditions from our session.

The quest for balance

We rounded off last month by reviewing the first step on the way to creating the maximum downforce, balanced set-up attainable on the RGB Spire. As delivered to the wind tunnel following a recent race meeting the car showed a more forward bias to its downforce than was expected. So a 60mm rear body Gurney was affixed, with the results shown in **Table 2** ('Δ' or 'delta' values are shown in counts, where 1 count = a coefficient change of 0.001). This potent modification clearly swung the balance too far to the rear at this stage – the target was around 44 per cent to 45 per cent front – but the plan was to add rear downforce first, then as much front downforce as possible, then adjust as required to balance.

The rear wheel arches on the RGB Spire featured deeply concave sculpting that terminated in quite aggressive flip-ups, these features devised using CFD carried out by team adviser James Kmieciak to generate areas of high pressure aft of the rear arch tops. The next configuration change saw 10mm Gurneys added to the trailing edges of these flip ups, with the delta values shown in **Table 3**. More downforce with a rear bias was generated, albeit not very efficiently in this instance.

Attention then switched to the front of the car, and the only permitted devices that

The Spire GT-3 RGB car, as it was delivered to the wind tunnel, had a slightly forward biased aerodynamic balance. This club formula allows very few aerodynamic add-ons

The big rear deck Gurney that was affixed to the rear of the GT-3 RGB car (in the upper right of picture) was supplemented by smaller Gurneys on the rear wheel arch flip ups

Table 1 – Balanced aerodynamic configurations on the Spire RGB and Bikesports cars

	CD	-CL	%front	-L/D
Spire RGB	0.568	0.886	44.24%	1.560
Spire Bikesports	0.565	1.399	43.85%	2.476

Table 2 – The first adjustment on the Spire RGB, with Δ values

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Baseline	0.505	0.651	0.377	0.247	57.9%	1.289
+60mm rear body Gurney	0.611	0.987	0.333	0.654	33.7%	1.615
Δ with Gurney	+106	+336	-44	+380	-24.2%	+326

Table 3 – The effect of the wheel arch Gurneys

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front	Δ -L/D
Δ with Gurneys	+26	+51	-10	+61	-2.6%	+15

Table 4 – The effect of taller splitter fences

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front	Δ -L/D
Δ with taller splitter fences	+9	+22	+34	-12	+2.6%	+11

Taller splitter fences added some front downforce, but with a small rear downforce loss

With splitter fences and rear deck Gurneys removed the Spire RGB's drag was much reduced, but not as much as its downforce. The balance was also moved forwards

Table 5 – The effect of moving the splitter fences 50mm forwards

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Δ with splitter fences 50mm fwds	-6	+8	+8	-	+0.5%	+29
Overall Δ with taller fences + 50mm fwds	+3	+31	+43	-12	+3.1%	+40
Overall state	0.640	1.069	0.366	0.703	34.2%	1.670

Table 6 – Results after removing some rear downforce

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Starting set-up	0.505	0.651	0.377	0.247	57.9%	1.289
Balanced set-up	0.568	0.886	0.392	0.494	44.2%	1.560
Δ overall	+63	+235	+15	+247	-13.7%	+271

Table 7 – The low drag set-up

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Low drag set-up	0.481	0.597	0.294	0.303	49.2%	1.241
High Df set-up	0.568	0.886	0.392	0.494	44.2%	1.560
Δ values	-87	-289	-98	-191	+5.0%	-319

Table 8 – The response to yaw angle

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front	Δ -L/D
Δ at 5deg yaw	+9	+37	+30	+7	+1.9%	+53

A couple of quick modifications were made to produce a low drag set-up

could be modified were the splitter end fences, other 'add-ons' such as dive planes, for example, being outside the class regulations. Taller fences were thus affixed, with the delta values in **Table 4** arising. This produced a modest front downforce gain and a small rear downforce loss at the expense of a little extra drag.

The splitter fences were then moved 50mm forwards so that they terminated at the splitter leading edge rather than at the forward tip of the car's front bodywork, and the results from this tweak are shown in **Table 5**.

The additional small front downforce gain came with a slight drag reduction (this was presumed to be because the cut-out in the upper edge was now slightly larger) meaning that the overall change from fitting the taller fences at the 50mm forwards location was as shown in the second line of **Table 5**. The overall position at this point is shown in the bottom line of **Table 5**.

With nothing left in the armoury to apply at the front end (ride height adjustments were not really an option because of the 75mm minimum ground clearance in RGB, which the car was already set at and there was no enthusiasm to raise the rear end), the next move was to reduce rear downforce until a balance was achieved, and in the interests of expediency, two changes were made at once; the rear wheel arch Gurneys were removed and the rear deck Gurney was halved in height to 30mm, producing the data that is shown in **Table 6**, which is also compared to the starting set up. Total downforce had been increased by 36 per cent for a 12.5 per cent increase in drag, yielding a 21 per cent increase in efficiency and a well-balanced downforce split.

Low drag set-up

With the highest downforce, balanced set-up attainable in the bag, a couple of quick modifications were made to produce a low drag set-up; the front splitter fences and the rear deck spoiler were removed altogether, with the results as shown in **Table 7**.

The balance in this low drag configuration was somewhat more forwards than the high downforce set-up, and the most likely way to attain the same balance would be to add a small rear deck Gurney; if the response to the 60mm Gurney in **Table 2** was linear, then a reasonable balance would probably be achievable with something like a 12mm rear deck Gurney, as a first guess.

Clearly this would add a drag increment, too, but overall drag would still be well down on that with the highest downforce set-up. The question would then be: with 10-12 per cent less drag but over 30 per cent less overall downforce, would the low drag set-up be faster at any of the circuits visited?

Yaw response

Briefly, at 5-deg yaw the responses in **Table 8** were logged, the car becoming slightly more forward biased, which might suggest that the straight ahead balance would usefully be somewhat more rearwards that the original target, in order to maintain a stable balance.

Next month: We focus on the Bikesports car.

Racecar's thanks to Paul Nightingale, Tim Gray, Sam Johnson and James Kmieciak

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In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

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Lines of defence

We look at how the FIA has been testing a number of potential solutions to the danger of single seater drivers being hit by external objects such as loose wheels

By MARC CUTLER

This is a driver's-eye view of an F1 wheel assembly hurtling towards them at 225 km/h. At a distance of 20 metres it would hit that driver's helmet in under 0.3 seconds, and the outcome could then be catastrophic.

Fortunately, this 'driver' is an empty helmet on the track surface of an airfield in the south-east of England. And the wheel is being fired from a two-metre long pneumatic cannon under strict test conditions.

More importantly, this particular wheel is being deflected over the helmet by a structure that would sit on the front of the monocoque of an open-wheel racing car. The wheel is scraping along a set of intentionally-curved fins that lead the object up and over the driver's helmet.

It is all part of an ongoing pursuit by the FIA and its partners to improve safety for drivers in open-wheel racing cars, particularly from external objects. This project started four years ago, but has recently taken on extra momentum following a number of injuries and fatalities in the sport.

'We have tried to accelerate this project in the last 12 months with an aim to have something that we can practically apply on the Formula 1 cars for 2017,' says FIA safety director Laurent Mekies. 'This latest test was set up with that in mind – trying to come out from there with something that we could actually say, "that's going to be a significant step forward."'

The tests, which were run by the Global Institute for Motor Sport Safety, research partner of the FIA Institute, evaluated three potential solutions: a triple-fin on the front of the car; a centre-line roll hoop with three bars that go over the driver; and a halo structure, designed by Mercedes in conjunction with the FIA.


The Halo solution is favoured by many because the drivers will be used to items, such as sensors, in their line of sight in the same position as the forward bar of the structure


The FIA has invited Formula 1 teams to come up with their own cockpit protection solutions and Red Bull Racing designed this wrap-around screen set-up which was first unveiled at the opening round of the 2016 Formula 1 season in Melbourne


A cannon was used to launch a Formula 1 wheel assembly at the three cockpit safety solutions

Front protection

The additional frontal protection (AFP) involves putting a structure towards the front of the car, specifically to protect against objects in the path of the car travelling at high speed.

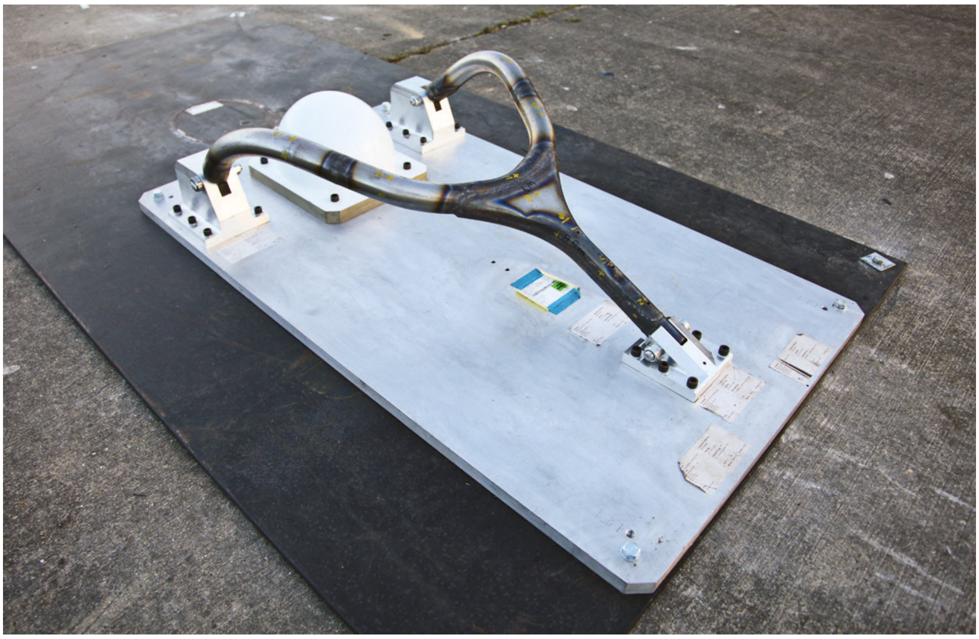
The first AFP solution consisted of three curved fins on the front surface of the chassis. They fan out, when viewed from above, so from the driver's point of view they appear as three vertical pillars in the lower part of their vision. This kind of solution aims to provide protection during the type of accident suffered by Henry Surtees in Formula 2 in 2009, when a detached wheel bounced across the race track into the path of his car, with fatal consequences.

'This first test aims to determine how the rim and tyre respond to the new lower-profile fins,' explains Andy Mellor, the lead researcher for the Global Institute on this project. 'With this relatively inconspicuous structure we were attempting to impart enough vertical velocity to direct the wheel assembly over the driver's helmet.'

This solution was designed specifically to put a very controlled load into the wheel when it impacts the structure just above the nose of the car. It is designed to engage with the wheel at the earliest possible time, to maximise the time duration for imparting the vertical velocity, hence minimising the forces.

The front edge of the structure is located close to where the nosecone attaches to the front of the chassis. The curvature of the ramp is designed to generate a constant vertical force of around 40kN to deflect the wheel over the driver's helmet.

'With this approach we aim to achieve compatibility with the rim with a design that minimises the reaction loads on the chassis, has the potential to be extremely lightweight and has a low visual impact,' says Mellor. 'It is



The Halo solution has been designed by the Mercedes F1 team in conjunction with the FIA and has been well received

The centre line roll hoop consists of three curved round section bars that pass above the driver's helmet in the cockpit

The additional frontal protection approach is designed to lift wayward external objects over the top of the driver's helmet

designed to work most effectively if the wheel is impacting at a shallow angle but the tests show that even if the wheel impacts the car towards the top of the blades, it can still be deflected over the driver's helmet.'

Centre-line roll hoop

The second concept for testing was the centre-line roll hoop, which aims to offer more complete protection for the driver. It consists of three curved round section bars that pass above the driver's helmet, from the main hoop behind the race seat to the front of the chassis close to where the nose attaches. Each bar is designed to deflect significantly over its entire length, and generate a constant vertical force of 20kN, (thus 60kN in total if the wheel engaged with all three bars), to deflect the wheel over the driver's helmet.

During the test the bars work exactly as designed, flexing and redirecting the wheel over the driver. 'The big difference here is that the structure extends over the driver's helmet to cover off additional impact positions. This system would also provide protection during the type of fatal accident suffered by Justin Wilson in IndyCar last year,' explains Mellor.

For this initial prototype, the bars were made from 20mm diameter steel, but they would be constructed from lightweight composite materials if this concept was taken forward.

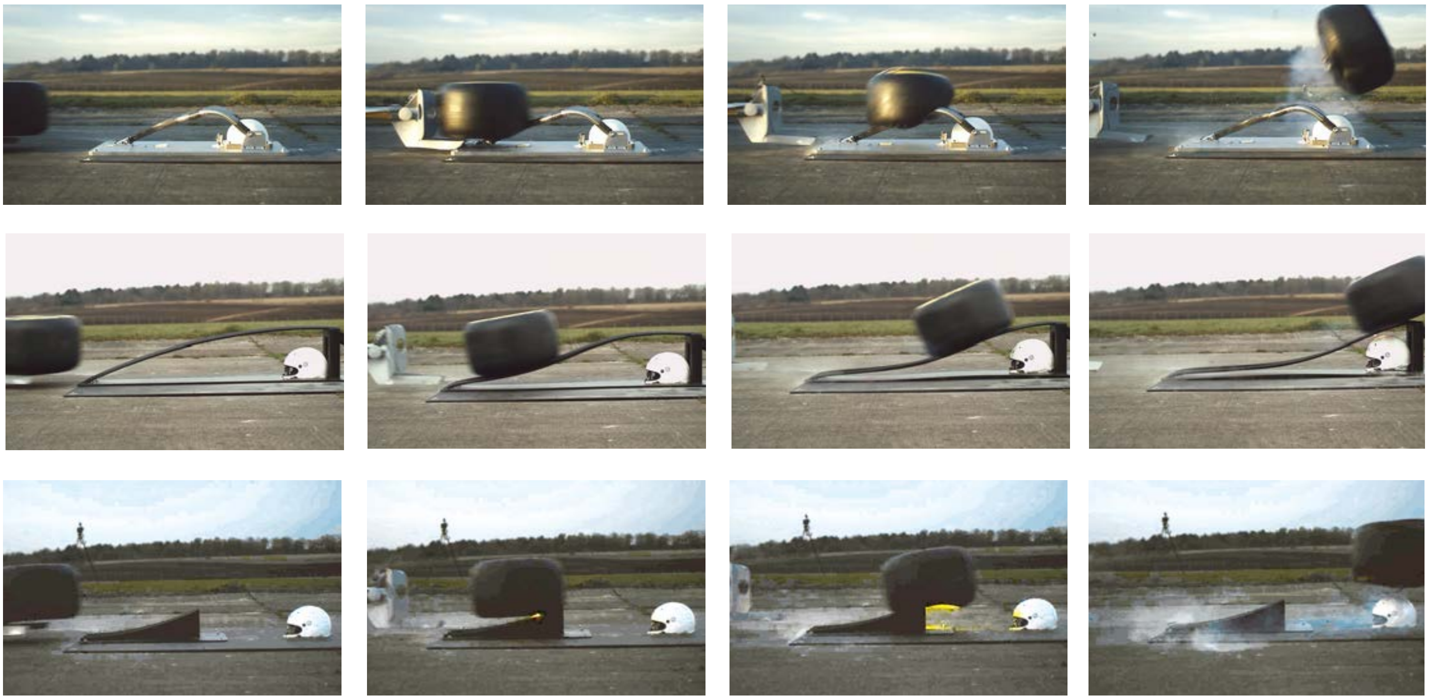
'The optimum construction would, likely, be a similar-diameter bundle of uni-directional composite fibres fixed in an epoxy matrix. This structure would be extremely rigid under normal race conditions, but would behave like a cable-car cable during an accident, thus providing a ramp to redirect the wheel over the driver,' Mellor says. The actual materials could be similar to the very high performance fibres used in Formula 1 wheel tethers.

'During the test the design worked perfectly and the loads measured by the in-wheel data logger were close to those calculated, ensuring there was no fracture damage to the rim,' says Mellor. However, while working well for driver protection, this solution has other potential complications; firstly it places the three bars in the driver's forward vision, and secondly, it may need to be removable to ensure rapid access during an emergency extrication.

Halo effect

The Mercedes F1 team has been working on a solution that could work from a both safety and chassis-intregation point of view. The design integrates the sloping profile of a centre-line fin with a protective roll bar positioned like a halo in front of the driver. During the tests, this solution performed extremely well and prevented the wheel assembly from impacting the helmet.

'It's very impressive that although the structure is positioned close to the driver's helmet to provide protection from all angles, it is still able to prevent the wheel from contacting



The three approaches were tested on an airfield in the south east of England and the results can be seen above. The FIA says that all three structures performed well in the tests

the helmet,' says Mellor. 'In the very short distance available, a huge amount of energy is absorbed and the wheel is successfully redirected.' A number of tests were performed on this solution from different angles and heights and it performed well each time. The structure was extremely strong and forced the energy management into the impacting wheel and tyre, deforming the rim in all tests.

Formula factors

With all three solutions working well, other factors come into consideration, such as driver vision, egress and emergency extrication in the event of an accident. Driver vision is, of course, critical, as it is essential that any solution does not introduce an increased risk of accidents occurring. To this end, the FIA has already performed a number of tests to assess the impact of forward structures on a driver's vision. In August 2013, a forward roll-hoop was fitted to a GP2 Dallara at Magny-Cours. The plan was to gain feedback on the viability of placing such a structure in front of the driver's line of sight. 'We need to avoid creating any blind spots as that would introduce an unacceptable additional risk during the racing,' Mellor says. 'We are looking to achieve a structure that provides a full panorama of forward and sideways binocular-vision, allowing only a very small areas of monocular-vision that is restricted by the structure.'

This concept had already been evaluated in simulators at McLaren and Red Bull Racing, and this was then was complemented by the testing in the GP2 machinery. The car completed four laps of the circuit with two types of roll-hoop and the driver gave feedback, which was positive, as the they did not feel overly hindered during the test. This encouraged the researchers to further pursue the roll-hoop solutions.

For the three solutions in the recent tests, all would pass the driver-vision exam, albeit with some refinement. In particular, the Halo works well because the only structure in a driver's line of sight is the central part and they are accustomed to structures on the centre-line of the car such as fins and sensor tubes.

Another key consideration is egress, or how easy it is for the driver to get out of the car. Again, all of the potential solutions could be configured to ensure appropriate access. The final key consideration is emergency extrication, where the rescue team would be removing a driver from the car. Again, Mellor believes that by working closely with the drivers, teams and medical and rescue experts, appropriate procedures will be put in place

Safety step

Following the tests, the results were presented by Formula 1 race director Charlie Whiting to the drivers and the teams' technical heads. The concepts were received in a positive manner and research will continue to develop the final prototypes, with a view to potential implementation in the 2017 season. 'The good news is that the three structures we tested performed as expected or even better than expected,' says Mekies. 'On top of that we have received great guidance from Charlie from the beginning of the project, and a lot of support from the teams who provided us with all their calculations and design power, which has made this step forward possible.'

The Halo solution has been particularly well-received and is one of the options that has been taken forward. But there is still some work to do. The next step in this process was to produce mock-ups of some solutions and place them on current Formula 1 cars during practice sessions to assess their practical viability. Ferrari and Red Bull have both now conducted such testing. 'We are pushing very hard to integrate it as early as possible,' says Mekies, adding: 'I'm sure it will trigger a few connected research topics, to assess visibility, extrication and some of the other aspects, so I am expecting some validation testing to be done.'

In theory, from a regulatory perspective, rules needed to be set before 1 March for the following season. However, in this case the regulations can still be changed, following unanimous approval from the teams, or on safety grounds by the FIA. 'The real deadline is the teams' timing to modify their cars accordingly and our capability to assess all the connected issues,' adds Mekies. 'Design is done very much in advance in Formula 1. Therefore if we want to make 2017 it needs to be decided in the next few months.'

Racecar's thanks to the FIA for permission to run this article. The original material is featured in the FIA's Magazine Auto, issue 14, available on the FIA website: www.fia.com

'We have tried to accelerate this project in the last 12 months with an aim to have something that we can practically apply on the F1 cars for 2017'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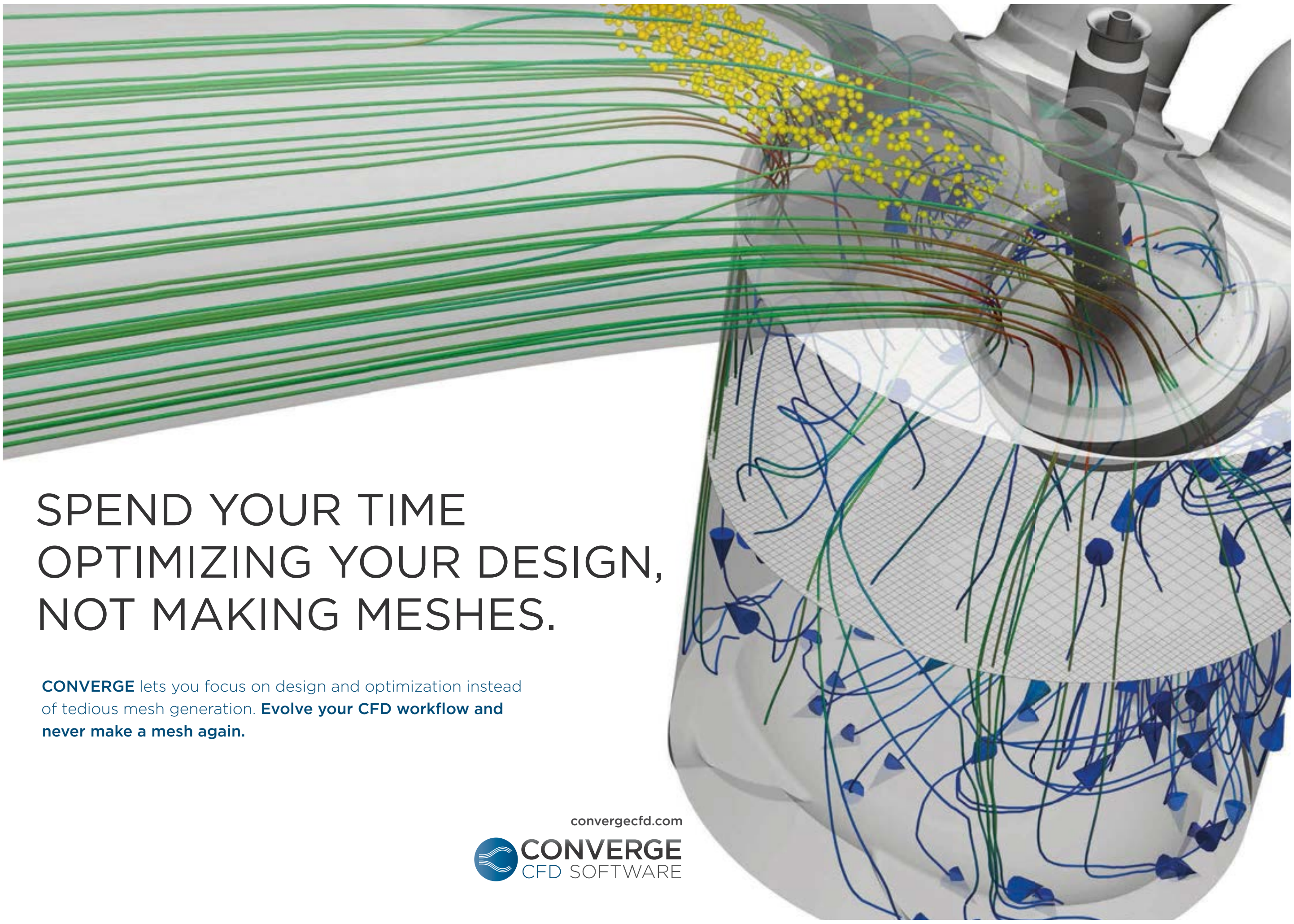
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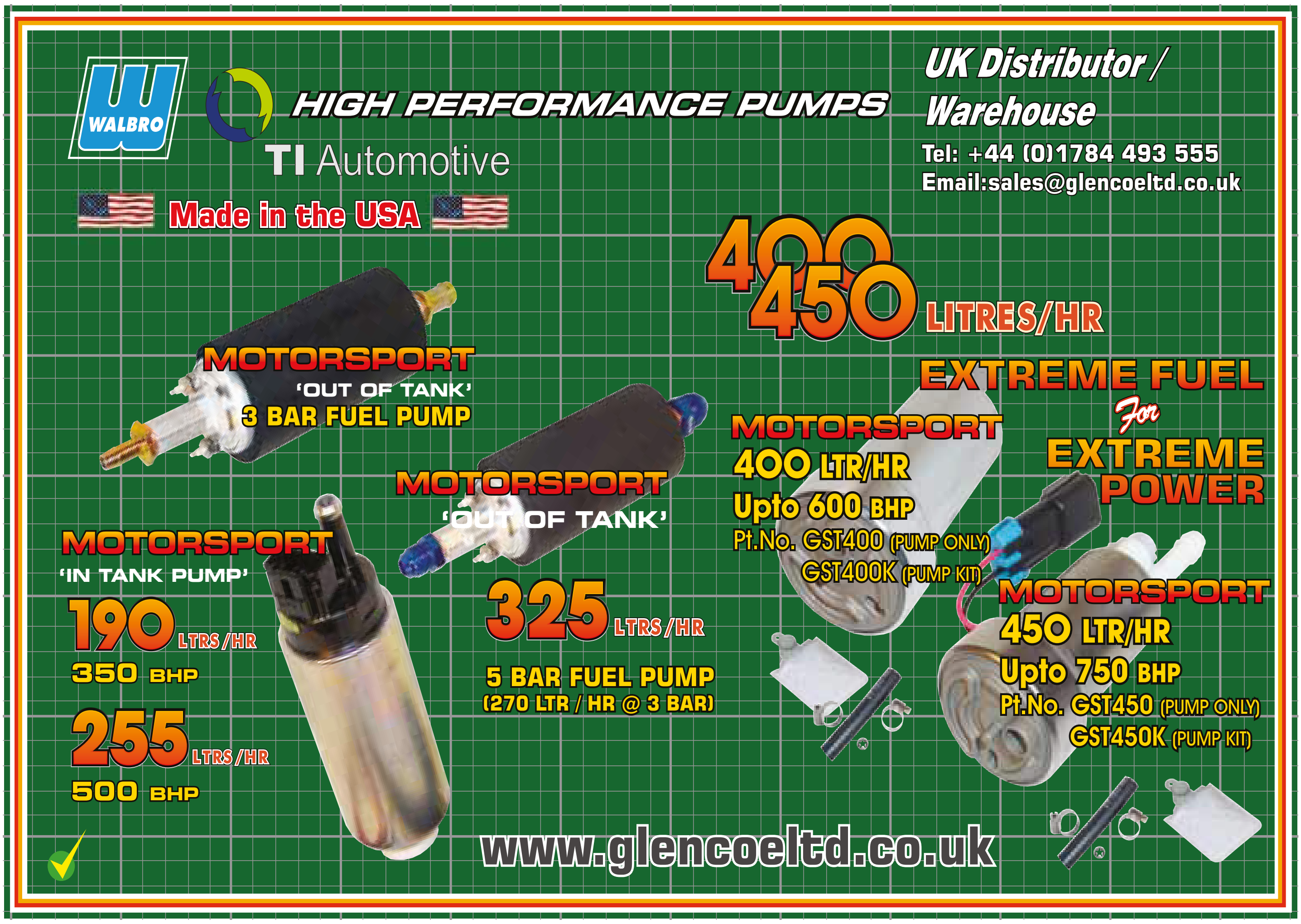

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Winning partnership

To be a success in the single seater business you need to choose the right technical partners. For serial championship-winning race team Carlin Motorsport that has meant a tie-up with PTC

By LEIGH O'GORMAN

Carlin Motorsport is synonymous with success in single-seater competition below F1. Yet while motorsport insiders note the team's growing collection of trophies, and roster of successful drivers, its partnership with technology solutions company PTC is less well known.

'Our aim is to take drivers from karting to the door of F1,' says Stephanie Tindall, PR and marketing manager with Carlin. Indeed, the list of drivers to have graduated from the Farnham team's school is very impressive. Its alumni include a four-time world champion, Sebastian Vettel, and three-time grand prix victor Daniel Ricciardo, while seven other current F1 drivers are also previous Carlin racers.

Since its beginnings in 1996, Carlin has expanded from a long-running Formula 3 programme to also move into the GP2 Series, Formula 4 and Euroformula Open, while last year the team looked west as it entered the Indy Lights Series, where it will continue to develop its drivers for greater things. 'We are breaking down the components of driving. It is very much about engineering the driver as much as it is about engineering the car,' explains Tindall. 'When they come out of a kart at the age of 15, they have no idea of the amount of pressure to apply to a brake, so we will put together all of the components for driving before they actually race. They are going to be spending a lot of time on the simulator.'

In total, the team has claimed an impressive 13 drivers' titles and three teams' titles across several series over the years, but this success was not achieved in isolation, and one of Carlin's key partners is Massachusetts-based PTC, a leading software company that specialises in design software, service solutions and product lifecycle management.

Technical tie-up

PTC is now in its 11th year, but the partnership is still blossoming. Two of the cornerstones of the relationship is 'Creo' and 'Windchill' – PTC's 2D and 3D design software and product lifecycle management software that record data through numerous sensors. But PTC's relationship with some of the team's associates also plays an important part, says PTC's vice president of Business Development and Technical Sales, Paul Haimes: 'Eighty per cent of the chassis that Carlin use are Dallara chassis – Dallara are a PTC customer and have been since release five of Pro/Engineer [now known as 'PTC Creo'],' says Haimes. 'They are commercially the most successful racing car manufacturer in the world – they have built more chassis and won more championships than anybody else, bar none, and they do it with our technology. They do it with Creo, and they do it with Windchill.'

The Volkswagen engines that Carlin has used to great success in Formula 3 were, Haimes adds, also designed in Creo. 'It is a fantastic tie-up that we have Carlin using Creo-designed chassis with Creo-designed engines,' he says.

These tie-ups and partnerships are all part-and-parcel of the relationship between Carlin and PTC and, as Tindall explains, feeds into

The team has claimed an impressive 13 drivers' titles and three teams' titles across several series

Carlin has been one of the top teams in F3 since it was launched over 20 years ago. Its technical partner PTC specialises in design software and product lifecycle management

PTC has been involved with Carlin for the past 11 years and has helped it pick up numerous single seater championships and wins, while also developing a number of well-known race drivers, including Sebastian Vettel and Daniel Ricciardo

the team's own business model. 'Our business model is that drivers come to us and pay us to race them. We are providing a product and programmes like PTC are essential to making sure we absolutely have the edge. We have to make sure that we are providing the best product for our drivers; they are selecting us, we are not selecting them.'

Over the course of the past two decades, a large number of Red Bull drivers have come through Carlin's Formula 3 programme and its now defunct Formula Renault 3.5 operation, including the aforementioned Vettel. 'You can see the level of the drivers that have come through here. PTC were integral to the success of that [FR3.5] car, because the work we did on that car in particular secured a lot of victories,' says Tindall. Haimes adds that: 'Each of these chassis are updated annually and the quicker a team understands the aerodynamic performance of the vehicle, the quicker they are going to be and the more they going to win.'

F3 aside, each category in which Carlin currently competes is a one-make formula. This element narrows the engineering factors to such a degree that even the tiniest gain can bring significant rewards, as Tindall reveals: 'There isn't a lot you can do [to the car], but what it means is what little we can do is absolutely essential, so we have to make sure the small gains we are able to make are on the ball. If we can make a couple of tenths difference in a lap in a junior championship, that could mean the difference between pole and 15th on the grid.'

Tindall notes that when a team signs up to a one-make championship, they are given the chassis, engine and components needed to engineer and race the cars. Thereafter the race is on to extract the very best set-up possible. 'There are still many combinations of things you can change; dampers, tyre pressures, wings, etc.'

Understanding the need to be vigilant in what is a fast moving sport, Carlin's profile is impressive. 'We are in six championships and have 18 cars in total that are racing,' Tindall says. 'We also have test teams as well for younger drivers. If we are not winning and we're not getting podiums and we are not able to show drivers how they can improve in the car with the services that we can provide, they are not going to come to us.'

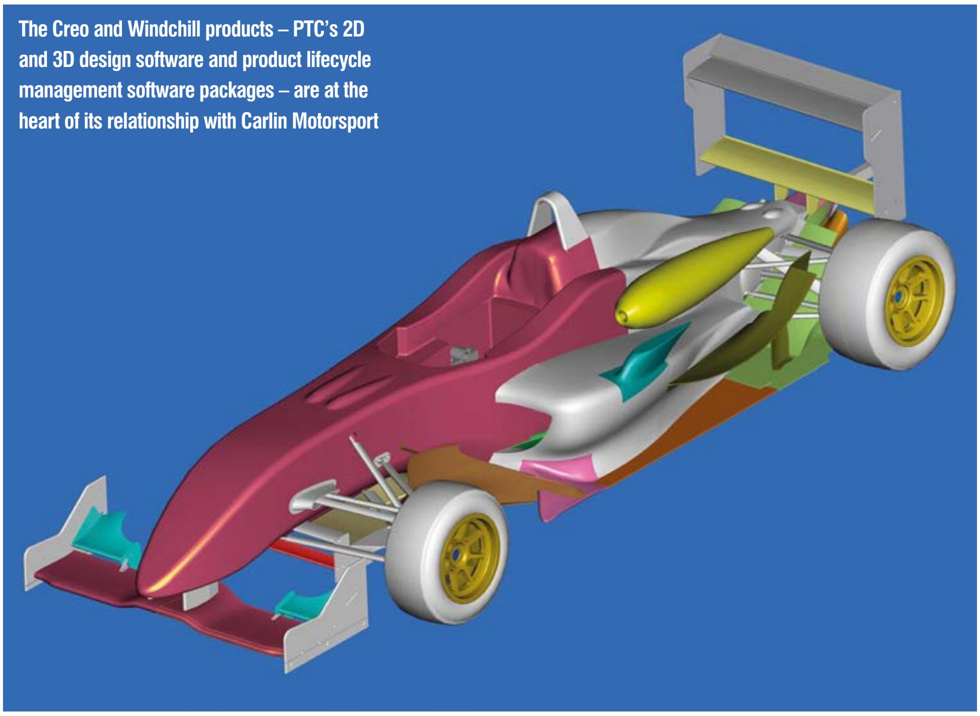
Aero models

The data collected by Carlin using PTC processes has aided efforts by the design team when penning wind tunnel models for F3, a factor that Dave Brown, Carlin's technical director, considers key to the team's ongoing success. 'In F3, we are free within the constraints of the regulations to design our own components, so we can then work heavily on certain areas.'

Haimes says: 'When we talk about Carlin having a performance advantage, this starts as soon as they get a chassis from Dallara. The first thing they do is they scan the whole car. The data they are given is point cloud information, which is then rendered inside of Creo. That is the starting point for the reverse engineering process, which eventually ends up with the one-third-scale model. The important point about using Creo is that you have got it all in the one environment. You take the surface data and you then incorporate it with the solid data. You can incorporate it with the analysis, you can incorporate it with tool making, manufacturing and end up with the finished product.'

However, Brown is conscious of the FIA's efforts to tighten the regulations in order to

'The important point of Creo is that you have it all in one environment'



The Creo and Windchill products – PTC's 2D and 3D design software and product lifecycle management software packages – are at the heart of its relationship with Carlin Motorsport

reduce costs and maintain a close field. 'They've slowly been tightening it down in the last few seasons. They have a blanket regulation which pretty much says anything you can see from above you can't change and anything you can see from below you can't change, which then leads you to areas that are masked. For instance, under the nose, the area by the floor that cannot be seen from above or below, so if you can find something there, then you can make changes.'

Broader scope

It's not all racing at PTC. Indeed, as Richard Allan, PTC's senior regional director for the UK and Ireland, demonstrates, the activities of the company stretch beyond motorsport and into real life as connectivity between components becomes more prominent. 'The new market place is driven around the Internet of Things [IoT] and will produce a huge amount of data. If you are an automotive manufacturer who has suspension sensor information, does the use of that data become valuable to somebody else?'

It is easy to see how this platform could be useful within the world of motorsport, though, although whether governing bodies wish to see this level data infiltration in series' that purport to be drivers' championships is an ongoing discussion. Allan continues: 'We take physical products to digital products with our CAD solutions – that product becomes smarter. There's engine management, software control items, and that software becomes connected. It has an IP address and the manufacturer and the user get more information about that product – it starts to become a connected product. The connected product then becomes a part of a system. When we talk with our customers now, we have to consider not just what we do with the physical product; we have got to consider that a company producing the physical product have to know all of the others layers to product development.

'The product development world now has layers of greater complexity to get that benefit from this new world.' Haimes adds. 'For us, PTC was grown up for manufacturing companies – that's what we know, that's what we do and our exposure to IoT is fundamentally around smart connected products, smart connected operations or manufacturing.'

Allan has also noted that the increasing movement toward data specialists is also altering the types of graduates that are entering into the motorsport industry. 'I've seen examples with companies hiring computer science graduates, rather than engineering graduates.'

However, Haimes also believes that the education system in the UK is still playing catch-up. 'In this new IoT era, certain roles are going to become extinct and we need to be smart enough to drive the next generation of engineers and the people who were going to drive the analytics on the big data,' he says: 'There is a glut of open vacancies for people who will be able to process big data, but we don't have the critical mass of individuals in the UK to do it and that is a task for the government and the universities, to wake up and see this.'

Although both Haimes and Allen have remarked about university's place in delivering the next generation of top data engineers, Tindall believes that companies like Carlin Motorsport are still playing a part in bringing new engineering talent to the fore. 'We do a lot of apprenticeship schemes and a lot of work experience, so just as the drivers move through different championships and graduate, some of mechanics and engineers will do the same. The cars get more complicated, the bigger and faster they are, and the rules get a little bit more complex as well, so there is more growth for the engineers.'

Tindall also says that engineers in the midst of completing an engineering degree will occasionally take a year out from their course to work with the team, while others work through their summer holidays or just join the team at race weekends. '[Young engineers] start to learn as a data engineer in the most junior formulae; that would be with the 15 and 16 year olds on the F4 cars, you'll have a student who is extracting data on the car.'

Engineering careers

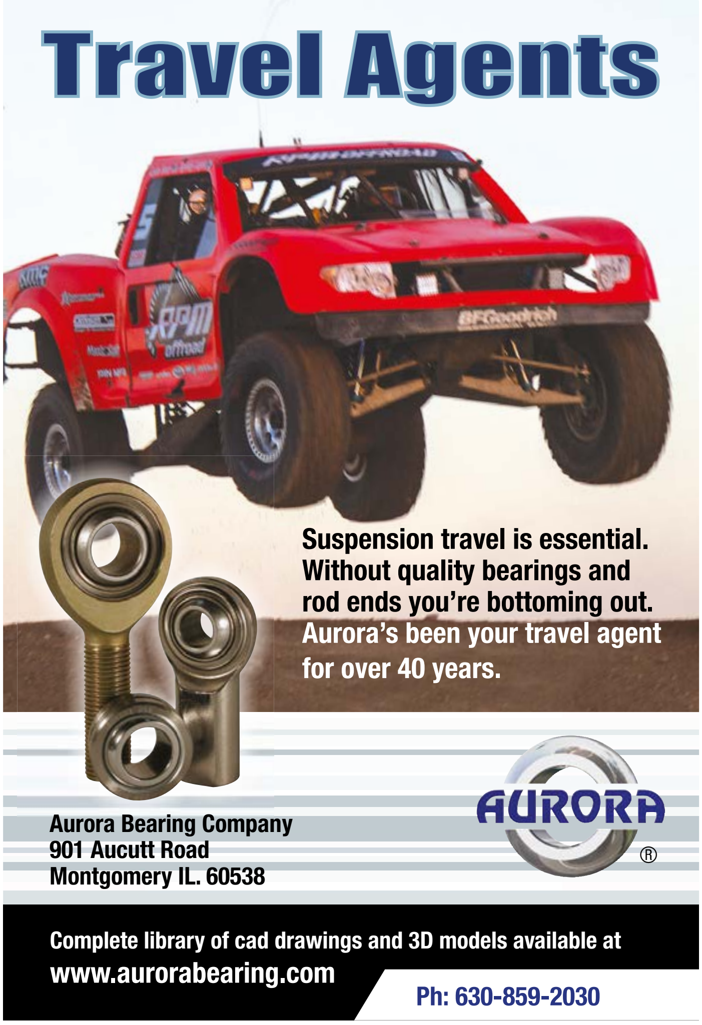
While these engineers are not in a position of active responsibility, their jobs will entail the retrieving of data, processing it for the engineer and observing the process of developing the set-up of the car and what happens in terms of developing the driving style of the driver. 'That's how they tend to feed in, and the really good ones will always get a job. They will start as a data engineer, permanently, and they will gradually become a race engineer in a junior team and then start to move up,' Tindall tells us.

At this time, PTC is working on a project that may further aid the engineers' education in junior single-seaters. According to Haimes, PTC is awaiting a data dump of the F399 car from Dallara that won numerous races during its active life in the late '90s and early 2000s. 'It's important to explain to the junior mechanics how stuff gets assembled, how it gets put together and then disassembled,' Haimes says. 'We plan to put together an augmented reality sequence, which shows the mechanic how to change the brake pads. It's an example of what we would to see Carlin showcasing for us in terms of our technology, and how they can train their junior engineers.'

There is little doubt that PTC plays a considerable part in Carlin's success, but it is just one part, and it is a part of a greater philosophy. It's the team's approach and its methodology that has made it one of the most attractive team's on the ladder to Formula 1.

'If you want to win a championship and you have the budget, you come and talk to Carlin. That's where you go, that's how you get to Formula 1,' Haimes concludes.

'We have to make sure that we are providing the best product for our drivers; they are selecting us, we are not selecting them'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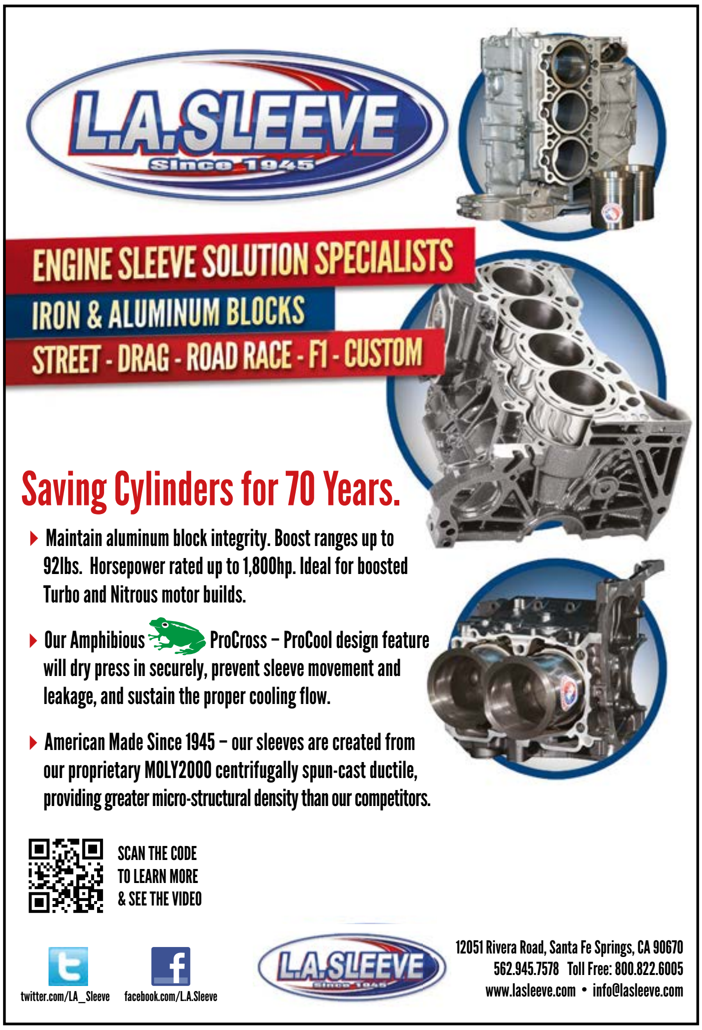
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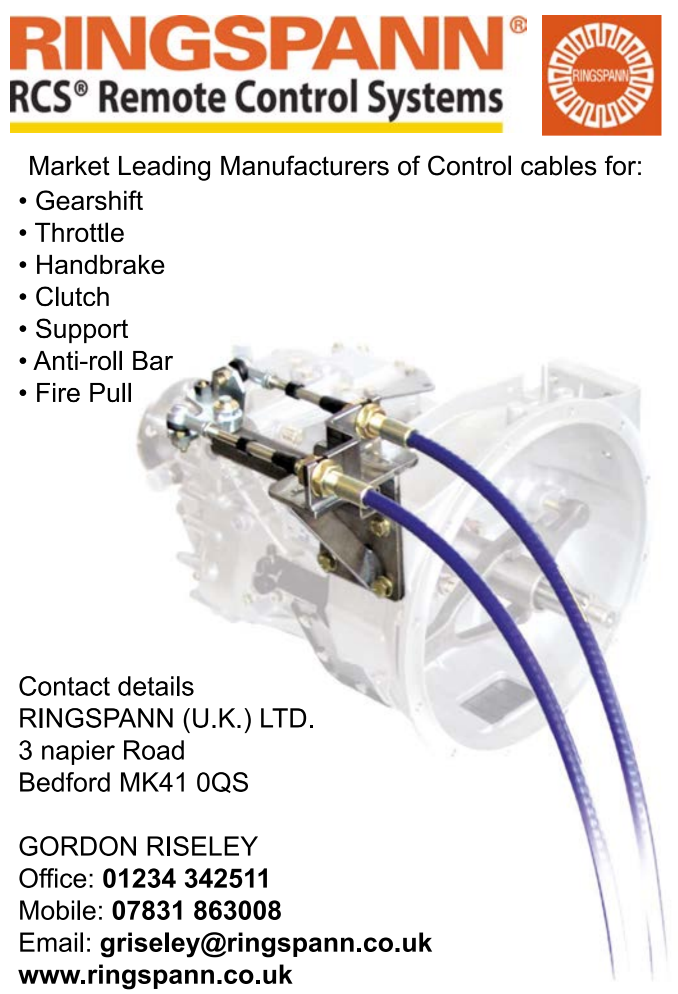
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Loop holes

While driver in the loop sims are all the rage these days the importance of lap time simulation should never be underestimated. *Racecar's* maths guru explains

By DANNY NOWLAN

XPB

Debriefing the driver is the first step, then there's the data to study. But if you have access to lap time simulation it allows you to be a little bit creative with how you then use that data

It was with great interest that I read an article by Sam Collins and Phil Morse in May's *Racecar* (V26N5) about the application of simulation in motorsport. The focus of the piece was driver in the loop simulation. With its widespread adoption in the upper end of town, such as F1 and NASCAR, such an article is both timely and necessary.

However, it also got me thinking. Where do tools such as lap time simulation now fit it in to the race engineering process? As the director of ChassisSim Technologies I think I'm in a good position to comment on this.

Despite team owners getting excited about driver in the loop simulation, lap time simulation also has a critical role to play, and I don't say this because I have a significant vested financial interest here. What lap time simulation does is it bridges the gap between what we see in data/driver feedback to what we'll try in a driver in the loop simulation. I've illustrated this graphically in **Figure 1**.

Race engineering starts with debriefing the driver, getting his feedback about what the car was doing. Then we look at the data, and by studying steer, throttle, brake and damper and load traces we get a further idea about what the car was doing. Then, if we have access to lap time simulation, we try out some ideas from what you have seen in the data. This allows us

Where do tools like lap time simulation fit in to the engineering process?

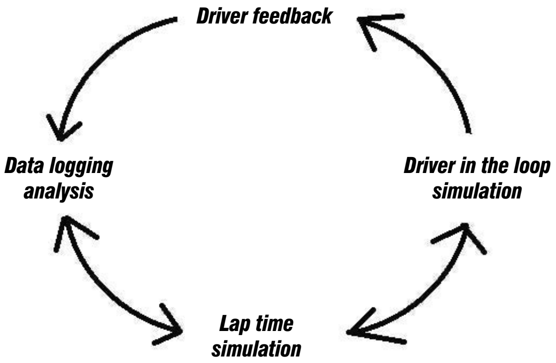

Figure 1: The race engineering process

Lap time simulation forces you to understand your racecar

to refine our set-up ideas very quickly. Once you are done with that you then fire up the driver in the loop simulator and get the driver to test it out. The upshot of all this is that one builds in to the other so by the time you get out there for the next session, or the next day's running, you are not guessing. You've formulated your plan and you execute.

However, what **Figure1** doesn't tell you is what a fundamental bedrock lap time simulation is in this process, because it forces you to understand your car. Anyone familiar with my articles in *Racecar Engineering* will know this is a constantly recurring theme which I have been stating since I started to write for this publication. I state it again here, because when you do lap time simulation properly it will have three key consequences:

- **It forces you to truly understand your car.**
- **It will sharpen you up for what to look out for in the data.**
- **It's a great sanity check for what the driver in the loop rig will tell you.**

Let us now move on to explore all the above elements in some greater detail.

The first consequence of using lap time simulation is that it forces you to understand the racecar. There's no room for half guessing things like motion ratios, spring or bar rates. It's a little bit like being pregnant. You are either on it, or you're not. Where lap time simulation reveals its true worth is in understanding what happens when the correlation is not perfect. **Figure 2** is a perfect case in point.

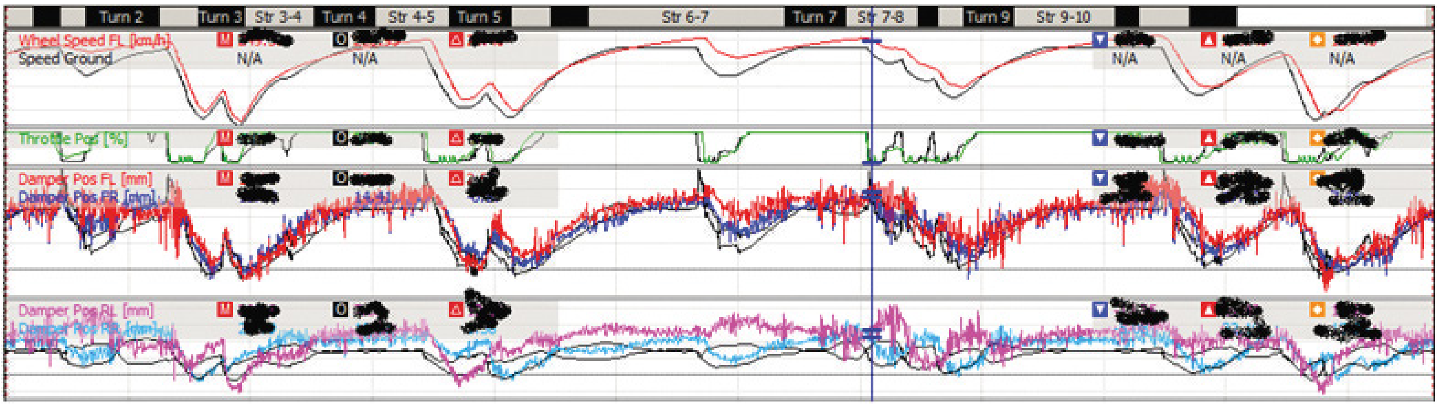

Figure 2: Comparison of simulated *vs* actual dampers. Note last trace, which is the comparison of the rear dampers and shows simulated as a factor of two less than the actual items

EQUATIONS

EQUATION 1

$$\alpha_f - \alpha_r = \delta_{steer} - \delta_{N.S}$$

EQUATION 2

$$m_t \cdot a_y = F_{y1} + F_{y2} + F_{y3} + F_{y4}$$

EQUATION 3

$$\Delta\delta = \left|\delta_{steer} - \delta_{N.S}\right|$$

EQUATION 4

For understeer,

$$m_t \cdot a_y = fn(\alpha_f)(F_{y1} + F_{y2}) + fn(\alpha_r - \Delta\delta)(F_{y3} + F_{y4})$$

For neutral steer

$$m_t \cdot a_y = fn(\alpha_f)(F_{y1} + F_{y2}) + fn(\alpha_r)(F_{y3} + F_{y4})$$

For oversteer

$$m_t \cdot a_y = fn(\alpha_f - \Delta\delta)(F_{y1} + F_{y2}) + fn(\alpha_r)(F_{y3} + F_{y4})$$

Remember that:

$$\alpha_f = \delta_{steer} - \frac{a \cdot r - V_y}{V_x}$$

$$\alpha_r = \frac{b \cdot r - V_y}{V_x}$$

Fault finder

Take a look at the last trace in **Figure 2**, which is the comparison of the rear dampers. The simulated rear dampers were almost a factor of two less than their actual counterparts. Most people at this point in the game throw their hands up in the air and claim simulation doesn't work and it is all rubbish. If I had $5 for every time I've encountered this I could have retired as a millionaire a very long time ago.

But what this particular piece of the data is actually telling you is that you did not measure something correctly here. In this

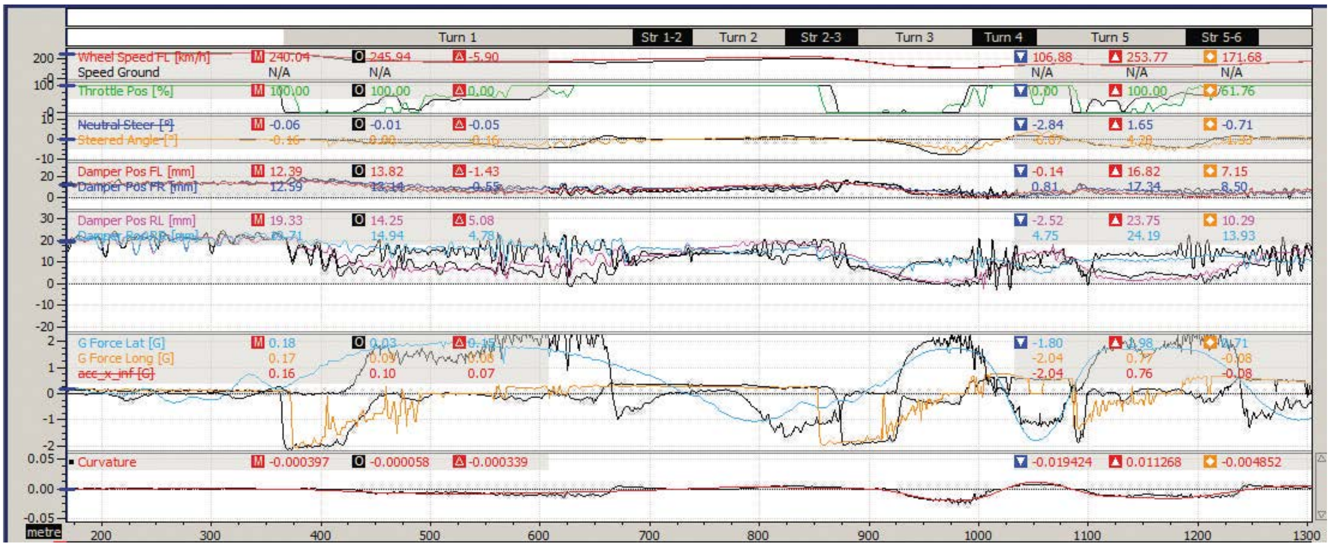

Figure 3: This shows a ChassisSim driver in the loop simulation *vs* a lap time simulation. The driver is shown with a black trace, while the lap time sim trace is coloured

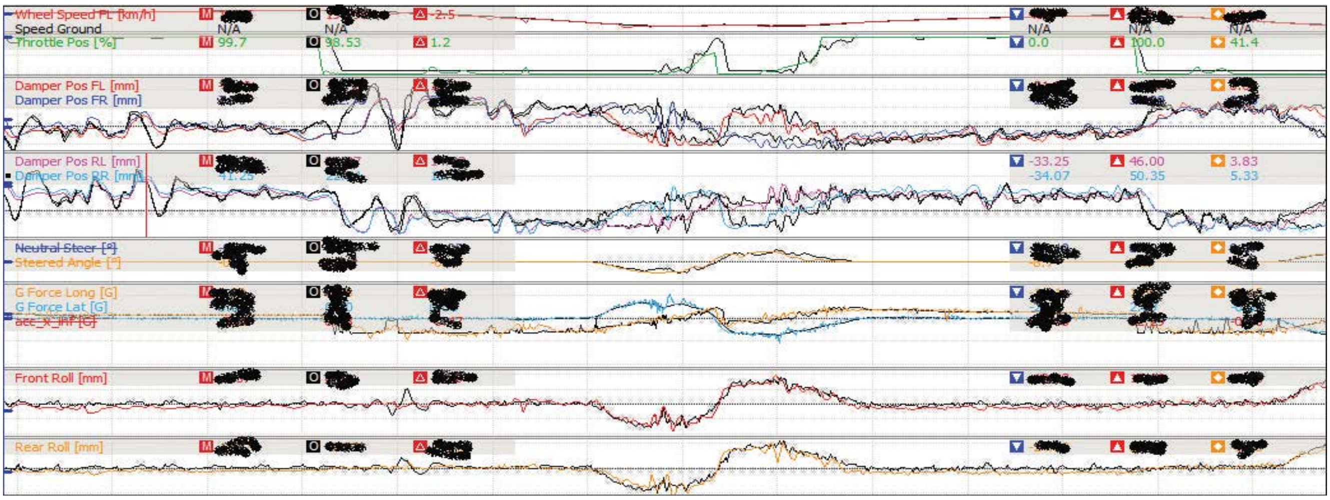

Figure 4: Actual *vs* simulated data on a street circuit, with the black trace showing the real data . As can be clearly seen there is very little difference between the two

particular example the rear third spring motion ratio had been inverted.

That's very useful, but where lap time simulation truly shows its worth is in showing you what to look for in the data. Quantifying tyre performance is a perfect case in point. To illustrate this let me give you some techniques you can use on some data. To help us in this discussion let's summarise some nomenclature:

wdf = weight distribution at the front
wb = Wheel base of the car
a = (1 – wdf)*wb
b = wdf*wb;
V_x = Forward velocity of the car
V_y = Sideways velocity of the car.
r = Yaw rate of the car.
δ_{steer} = Steered angle of the car at the tyre
α_f = Front slip angle
α_r = Rear slip angle
δ_{NS} = Neutral steer angle of the car = iR*wb

The starting point of our analysis is that we need to look at steering. In particular, steering calibrated at the tyre, as opposed to the steering wheel. Looking back at one of my articles on racecar stability, this can be shown in **Equation 1.** The best way of approaching this is to simply overlay steering and neutral steer. Any steering trace over the neutral steer line is understeer, anything below is oversteer. This is going to form a critical component in working out what end is operating at its traction limit.

To help us visualise what is going on with the tyre forces, if we examine the tyre forces at peak lateral *g*, at the point of maximum lateral grip, we have **Equation 2**. We are assuming both Rdot (the yaw rate) and Vydot (the sideways velocity) is negligible here. If we use **Equation 3** – and assuming the camber functions as unity for the time being and there isn't a big variation of slip angle from side to side – we can then deduce the relationships shown in **Equation 4**.

Asking questions

The values of *fn* for various slip angles can be deduced from the normalised force *vs* slip angle plots from a supplied Pacejka curve or a guesstimated one. In one of my past articles on tyre performance analysis I go into greater detail on this, but I wanted to present the mathematical highlights for you.

Equation 4 gives us a very powerful tool for visualising what the forces are doing and how we can quantify them. In particular we can get a strong idea about what the tyre's traction circle radius *vs* load characteristic looks like. What all this means in plain English is that you can now use your data intelligently to see what your tyres are actually doing as opposed to guessing. This is one of the positive consequences of using lap time simulation, because it will force you to ask questions like this.

The other thing that a well calibrated lap time simulation package will do is give you a brilliant sanity check for what the driver in the loop rig will tell you. There is no doubt that driver in the loop rigs have shown their worth as driver coaching tools as well as in hardware

We can get a strong idea about what the tyre's traction circle radius *vs* the load characteristic looks like

You really need to sound the alarm bells when you have some big discrepancies in mid-corner speeds and in the braking points

in the loop applications. Where they struggle is with set-up sensitivity and direction. A classic case in point is the cottage industry that has grown up around modifying rFactor hdv files to get something that is representative. Another case is some so-called gun set-ups I've seen from a computer game for a V8 Supercar. Suffice to say these set-up sheets had no connection with reality whatsoever.

As an example of this let's consider a comparison between ChassisSim lap time simulation and the forthcoming ChassisSim drive time feature. This is shown in **Figure 3**.

The right track

The driver in question was a journeyman driver, shown black, while ChassisSim was coloured. Clearly the driver is not as good as ChassisSim. However, the mid-corner speeds are comparable as are peak accelerations both longitudinally and laterally. When you see something like this you know you are on the right track. However, you need to sound the alarm bells when you have big discrepancies in mid corner speeds and braking points, especially when they are way too optimistic. It's at this point that a well calibrated lap time simulation package becomes your best friend.

This discussion would not be complete without a word on how to use a lap time simulation. You use it to trial ideas. You do not use it as a magic wand that makes you four seconds a lap quicker. What it does is to allow you to investigate options and then review it using the data acquisition package of your choice to see if it makes sense. There will be times when you make a change and it doesn't make sense, and that is all part of the process. If you do it enough times you will get a feel for what works, and what doesn't work.

Let me put this another way. If it makes sense on the simulator and it makes sense from past running, you put it on the car. If you tie this in with a driver in the loop simulation this will give you a powerful tool to ensure the driver is in the appropriate frame of mind to make the best use of these set-up improvements on track. And while this sounds like a lot of work the pay-offs are more than worth it. As a case in point **Figure 4** shows a comparison of actual *vs* lap time simulation on a street circuit – here coloured is actual and black is simulated.

As can be seen there is precious little difference between the two. When you are at this point you are in a very strong position to use tools such as driver in the loop rigs to their fullest potential. This is because you have done all the work to make sense of what the data is actually telling you. Also, the work you have done on calibrating your lap time simulation has got you to this point.

Bedrock tool

In closing, lap time simulation is a valuable tool that can be used in concert with both data and driver in the loop rigs. It doesn't just sit in the middle between data and analysis and a driver in the loop rig. Used correctly it forms the bedrock to effectively and appropriately use both of these other tools. If you can understand that then you are well on your way to ensuring success when you hit the track.


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Red Bull boss Horner slates 2017 Formula 1 power plant regulations

Red Bull team principal Christian Horner has slammed the new Formula 1 engine regulations, saying they are the product of a 'very weak agreement' between the FIA and the teams.

The 2017 engine rules feature a commitment to reduce engine prices by €1m next year and by a further €3m from 2018. Performance convergence and engine noise has also been addressed, while there has also been a move to oblige manufacturers to supply a certain number of teams, if this is required – for a detailed analysis turn to page 32.

'It's a very soft agreement between the manufacturers and FIA,' Horner said. 'It tickles the price, deals a little bit with convergence, the obligation to supply doesn't really apply. It's a very weak agreement.'

However, Mercedes boss Toto Wolff disagreed: 'We have achieved a major price reduction over two years, we have opened up the development scope for others to catch up. We have designed an obligation to supply so no team runs out of an engine contract. We have found a mechanism for how performance convergence can be triggered. There are lots of good things, lots of months of hard work, it's a good step forward.'

Meanwhile, Honda F1 head Yusuke Hasegawa has revealed that his company, which currently supplies its PU to one team, McLaren, does not yet have the capability to supply another customer.

Under the new rules each of the four manufacturers will need to be able to supply an equal portion of the grid, which is three teams at present. However, the team that supplies the fewest teams also has to step in if an F1 operation finds itself without an engine. This would mean that if a team is without a unit for 2017, Honda must supply it.

Hasegawa said: 'I have an obligation to contribute to the Formula 1 society, so we are preparing our resource. But still we are not strong enough to provide for a second team. We are preparing now.'

This preparation has included an expansion of its manufacturing capabilities in both the UK and Japan.

Hasegawa added that while Honda had actually had conversations about a second supply, as yet there have been no formal talks. 'We don't have concrete negotiations,' he said. 'Although we have some conversations with some teams, unfortunately we can't make a conclusion with [these] teams. That is our current position until the situation changes.'

Despite some wins, like here at Barcelona this year, Red Bull has not thrived under current engine regs. Horner is not best pleased with new rules, either

XPB

Force India reveals reduced losses in 2015

Recently-released financial accounts have shown that the Force India F1 team continued to make a loss in 2015, but that its performance was much improved when compared to the previous year.

The accounts show that the Anglo-Indian team reduced its loss from £15.4m for the 2014 financial year, to £6.8m in 2015. Its turnover increased from £59.92m in 2014 to £64.26m in the same period.

Force India's income in 2015 was boosted largely by increased sponsorship, much of it derived from Mexico as a result of having Sergio Perez in one of its race seats.

The team has also benefited from FOM income paid for it finishing sixth in the World Championship in both 2013 and 2014. This is awarded in the year after the result, so the fifth place achieved in 2015 will be reflected in 2016's financial accounts – this is said to be worth around £47m to the team.

The accounts also tells us that Force India has received a further boost in funding following a multi-year development driver deal with young Russian race driver Nikita Mazepin. Force India said the deal provides the team with 'a cash injection ahead of significant regulation changes for the 2017 season'.

The report adds: 'The Force India commercial department is hopeful it will help facilitate additional sponsorship revenues from the Russian market, while building future deals with both the Mexican and domestic markets.'

Force India's accounts also revealed that average staffing levels rose from 376 in 2014 to 382 last season.

The team is currently struggling to improve on its 2015 performance on the race track, and at the time of writing it was seventh in the Formula 1 constructors' standings.

XPB

Mexican sponsorship lured by the presence of Sergio Perez in the cockpit helped Force India to improve its financial performance during 2015

IN BRIEF

IMSA evaluates new categories

IMSA, the US sportscar sanctioning body, is evaluating three types of global racecar classes for some of its categories. LMP3, TCR and GT4 are all being looked at, it said in a memo to its teams, which also explained that it was reacting to a trend of 'increased complexity of conversion from production vehicles to race vehicles'. The subject of the memo was the future of the Prototype Challenge category in its main championship, the Grand Sport and Street Tuner classes of the CTSC, and both divisions of the Lites series. There will now be a series of meetings to discuss ideas. The future of the Prototype class, GT Le Mans and GTD will not be affected by this process.

Dunlop to supply UK LMP

Dunlop, the most successful tyre manufacturer in LMP2, has announced that it is to support the expansion of a new UK racing series for prototypes. The Dunlop Prototype Series organiser, Britcar, has confirmed that Le Mans prototypes (LMP2 and LMP3) are now eligible for the series.

ISC reports 'record' first quarter results

International Speedway Corporation (ISC), the publically-owned NASCAR company that owns and operates many of the tracks on which the premier US race series competes, has reported much improved financial results for the first quarter of 2016.

ISC, in many ways a bell-weather for NASCAR – which as a privately owned company does not publish results – posted total revenues for the first quarter of 2016 of $142.6m, compared to revenues of $136.6m in the first quarter of fiscal year 2015. Operating income was $31.2m during the period, compared to $21.6m in the first quarter of 2015.

Lesa France Kennedy, ISC chief executive officer, said the results were record breaking, while she put much of ISC's success down to the new Daytona Rising development at the Florida speedway, which was finished and hosted events for the first time at the start of the year.

'Our first quarter was one for the record books,' France Kennedy said. 'Financial results for the first quarter 2016 exceeded expectations with growth in all areas of the core business. Daytona Rising was the driving force behind the success, providing new and unique marketing platforms for partners and new fan amenities, including exclusive hospitality experiences, branded concessions and a completely remodeled midway that featured a Fanatics' merchandise pavilion, completely reinventing the shopping experience.

'Daytona Rising completed its transformation of the Daytona International Speedway into the world's first motorsports stadium welcoming fans, industry partners and stakeholders to an unparalleled motorsports entertainment experience. A sold-out crowd witnessed a spectacular photo finish awarding both Denny Hamlin and Toyota their first coveted Daytona 500 victory,' France Kennedy added.

France Kennedy also revealed that construction of a new real estate venture in Daytona has now started: 'One Daytona, our mixed-use real estate development, is now underway. We have begun clearing land and preparing for vertical construction. Our strategy for One Daytona is to create synergy with Daytona Rising, enhance customer and partner experiences, leverage our real estate on a year-round basis, and build value for our shareholders. We are targeting phase one completion in late 2017.'

NASCAR track operating arm ISC says success of Daytona has contributed significantly to its good first quarter results

IN BRIEF

DTM tyre deal extended

DTM has extended its current deal with tyre manufacturer Hankook for another three years. This will see Europe's premier tin-top series use the Korean supplier's racing rubber until 2019. 'DTM is the most successful touring car series internationally,' Ho-Youl Pae, Hankook's head of Europe, said. 'The direct involvement of the three premium manufacturers, Audi, BMW and Mercedes Benz, means that there is no similar power density [in terms of prestige marques] anywhere else in motorsport, particularly at the highest technical level possible.'

Supercars to drop V8 name

From the beginning of July V8 Supercars, Australia's premier motorsport series, will no longer include the iconic engine configuration 'V8' in its name. The move was made because with the introduction of next year's Gen2 regulations both V6 and four-cylinder engines will be allowed in 2017 – a change some manufactures have been calling for. However,

Warburton says name change does not mean the end for V8 engines

V8S CEO James Warburton was keen to stress that the new name did not mean the end of V8 power in the series. 'V8 engines will always be part of our sport but as we continue to open the door to new manufacturers and different engine configurations as part of the transition to the Gen2 regulations we believe the time is right to move to [the name] Supercars,' he said.

Volvo V8S future in doubt

Factory Volvo squad Polestar has opted not to renew its contract with V8 Supercars, casting doubt on the future of the Swedish manufacturer in Australia's top racing series. Polestar, the motorsport arm of Volvo, has run the V8S programme in conjunction with Garry Rogers Motorsport (GRM) since 2014, when Volvo returned to top level Australian motor racing with its S60 model. However, it has now announced that it will not be extending its three-year deal when this season comes to a close. Volvo and Polestar is now heavily involved in the World Touring Car Championship – where it competes under the Cyan Racing banner – which it joined this season, and this is believed to have had some bearing on this decision.

In terms of market performance, the Swedish manufacturer sold 4943 cars in Australia in 2015, which was up 5.3 per cent on 2014, although this was in a generally expanding car market, and other comparable marques such as Mini and Skoda, which are not involved in V8S, did much better – with sales up 30 and 23 per cent respectively.

Apprentice matching

A new matching scheme for engineering apprentices in the UK, which is open to all automotive companies including those involved in motorsport, has been launched by leading car manufacturers based in the country. The Automotive Apprenticeship Matching Service – free of charge to companies – has been set up as a platform to develop the skilled workforce of the future. Each year the Matching Service, developed and funded through the Automotive Industrial Partnership (an industry skills collaboration, supported by government), will help up to 10,000 high quality candidates per annum secure an automotive apprenticeship, when the company programmes to which they apply are oversubscribed.

This service is expected to be of particular benefit to the automotive supply chain and more niche companies, such as those involved in motorsport. The launch of the Matching Service comes as new research carried out by advanced manufacturing skills body Semta has revealed how a shortage of adequate training provision in the sector could start to impact on the skills needed to sustain automotive productivity, particularly in manufacturing and engineering disciplines. The report complements earlier research, which found up to 5000 job vacancies in the sector could be vacant due to a lack of the skills needed to fill them.

Ansible scoops top tech award

UK-based Ansible Motion's 'engineering-class' Delta series driver in the loop simulator has topped the Innovation of the Year category in the 2016 Vehicle Dynamics International Awards. With votes from 23 automotive specialists from regions including South America, India, Asia, Africa and Europe, Hethel-based Ansible Motion's DIL simulator was selected for its cost, time, and interactivity benefits. Award judge Carl Cunanan said: 'The Ansible Motion Delta series simulator brings the experience and the data to a new level of interactivity and indeed reality. It should reduce time and cost.'

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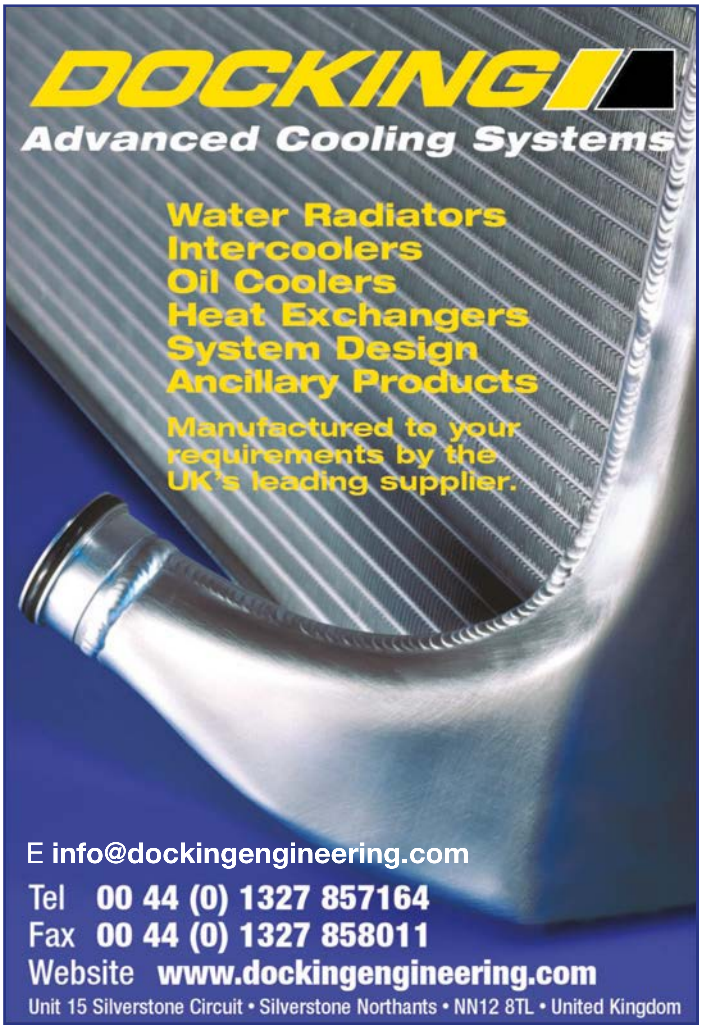
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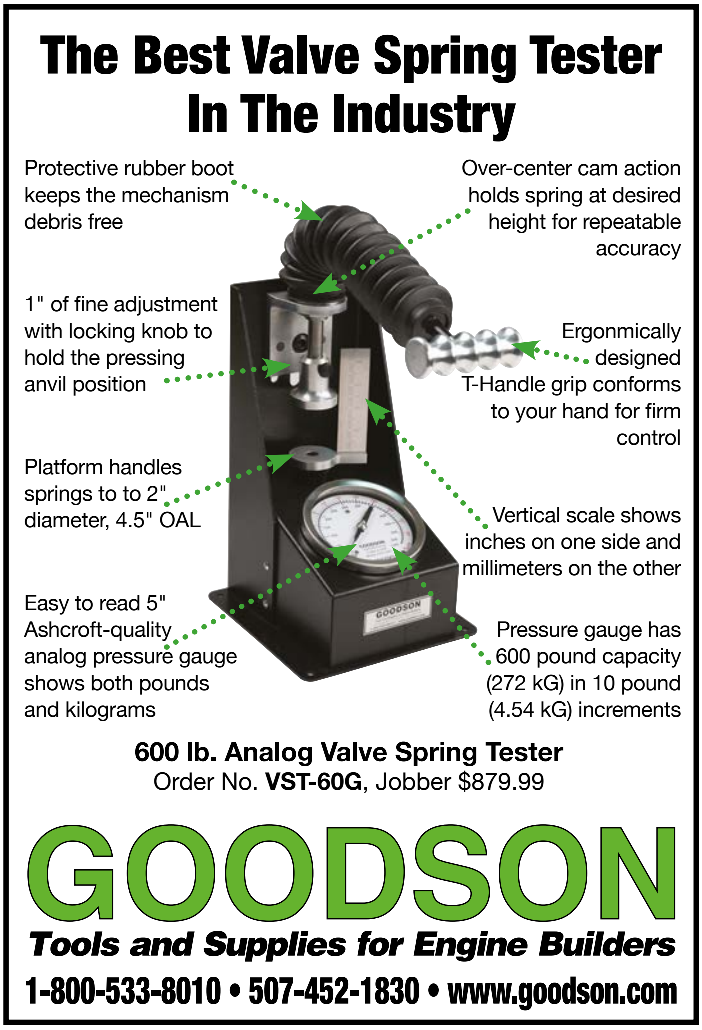
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INTERVIEW – Hermann Tilke

Making tracks

The man behind most of Formula 1's modern circuits explains why his critics often fail to see the bigger picture

By MIKE BRESLIN

XPB

'The spectators need to feel with all their senses the motor racing; they need to see it, to hear it, to smell it'

If you ask F1 circuit designer Hermann Tilke whether you begin to design a Formula 1 track on a napkin in a pub or a restaurant, starting with the circuit outline, you will get an unequivocal response. 'No. No. No!' he insists. 'We never have a white sheet of paper when we start to design.' Napkins or not, Tilke's been designing tracks for 20 years now, and while his endeavours have not always met with universal approval – more on that later – there's no getting away from the fact that when someone wants an F1 circuit built his Aachen, Germany-based eponymous company is usually the first port of call.

Tilke was a fairly successful race driver before he got in to the circuit design game, competing in the European Touring Car Championship and forging a reputation as a bit of an ace around the Nordschleife at the Nurburgring. In a way his track work started at the 'Ring, too, building a small access road. But that soon led on to bigger and better things, beginning with the 1995 redevelopment of the Osterreichring in to the A1 Ring (now the Red Bull Ring). Since then his architectural company – which is involved in far more than just race tracks – has remodelled or designed and built more than 28 circuits.

'Designed and *built*' in the above is important, too. 'We do everything, from the drainage, to the sewage, to the electricity; the circuit itself, the buildings; even hotels,' Tilke says. And as he's said at the top of this piece, there is no rough doodle to start with, it always begins with more practical considerations: 'We first look very carefully at the land, the surroundings, where the traffic is coming from; where is it possible for parking, and then, the topography? And what are the soil conditions?'

Shanghai surprise

That last is often a major factor, because if land is available for a race track, it's usually because it's of little use for anything else: 'Sometimes we have a lot of technical problems on the land, especially soil conditions, which we then have to solve,' Tilke says. 'This is because when we get a piece of land to build a race circuit, we need a big space. And when you are close to a city then a big space is very expensive. So we usually get the land that nobody else wants.'

Which means ingenious solutions are sometimes called for. 'In Shanghai, we had a piece of land which was a very deep swamp,' Tilke says. 'We always find answers, and we had this idea with polystyrene; so we have up to 14 metres of polystyrene [beneath the circuit], and a lot of piles. But these piles are swimming piles in the swamp, because you cannot pile in to the ground, it is far too expensive.' Which means, in effect, Shanghai is a floating race track.

Of course, that's the sort of thing the fans and the media rarely see and seldom appreciate, and most of the often negative comment directed Tilke's way has been more to do with the actual track layouts. In particular, the large runoff areas, but also the problems that F1 has had with overtaking. On runoff Tilke makes a very valid but perhaps oft overlooked point: 'If it is a permanent circuit, we are usually not designing only for cars but also for motorcycles, and they are much more sensitive about runoff and safety. So sometimes we have to make runoff on a piece of the circuit where a car will never need it.'

As for overtaking, Tilke points out that some of his circuits, the Red Bull Ring for example, are actually very good for racing, but more generally he believes that it is not the circuits, but the cars, that should be looked at: 'I think the better way, is not too much downforce. More power, of course more power, maybe more mechanical grip. And that's it. For me the downforce is too much now. For me it is the wrong direction. I am not the expert at this, but I see it as a fan, and as a circuit designer. The cars cannot follow each other, if you have a fast corner, with the downforce. And so, for me, this new regulation which they want to do in 2017, it's the wrong direction.'

Stay sharp

Tilke also questions the demand of many for more fast corners on the circuits. 'Everybody wants to have fast corners. If you design a circuit with only sharp corners, everybody will complain. But it will be good for overtaking,' he says.

He is certainly used to complaints, and says he takes them on-board. Up to a point. 'We listen very carefully to all the criticism,' he says. 'But when we talk in detail to the people who criticise us, then usually they understand a little bit more. Of course, some criticism is right, but some other criticisms are not right; they don't know what we have for restrictions. We have a lot of restrictions; first of all we have the boundaries. And you cannot make a straight 100 metres longer when they don't own

the land there! Then there's the topography. They say "this is a flat circuit, Spa is much better". Yes, of course, but at Spa the hills are there, and it's usually simply not possible to *make* a hill on a site, because of the budget.'

But it's not always negative comment, and new Tilke tracks like Austin have been well-received, while at least one of Tilke's corners has to be up there with Becketts at Silverstone, or Eau Rouge at Spa, a classic despite acres of runoff – Turn 8 at Istanbul. 'We always try to find some part on our circuits which is really challenging for the drivers; and really challenging for the engineers, too,' Tilke says. 'Turn 8 in Istanbul is a good example of this. The difficulty with this corner is that it has these three different elevations; and it is high speed. The pressure from the downforce on the cars, and then this elevation change, meant that cars were pressing on the ground [bottoming out]. And then they cannot steer.

'What they [the teams] had to do is to lift the car up. And that means that over the whole lap the car is not so good, because if they are lower they create more downforce. But this corner limited this. There were some drivers, during the first weekend there, criticising this corner, because, they said, "you cannot drive because the chassis is coming to the asphalt", and then we cannot steer the car. But then I asked Michael Schumacher. He said: "wonderful corner".'

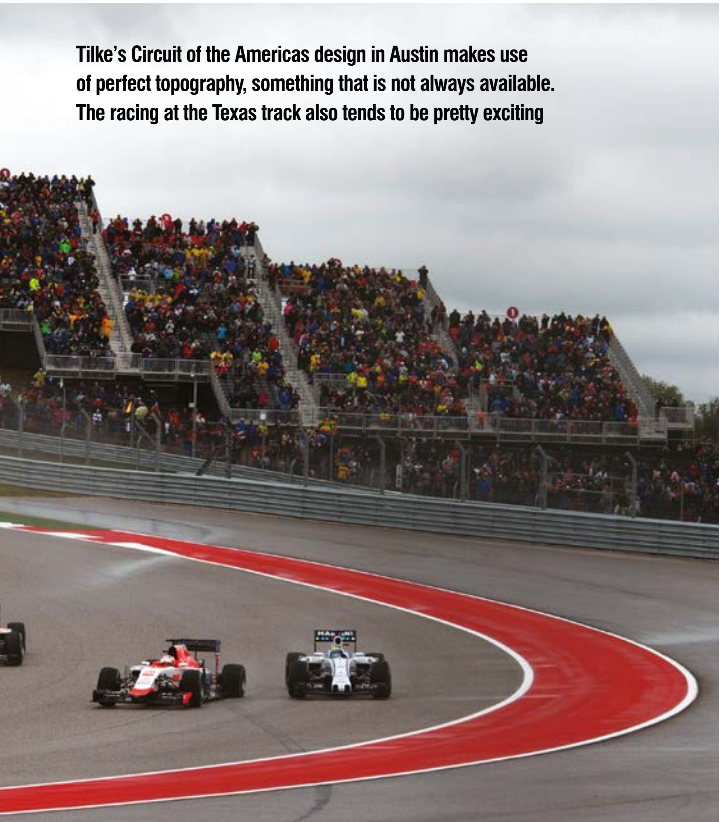
Sensation of speed

Tilke says a top level circuit development tends to cost between €100m and €150m, but can be a great deal more. But to make a truly great venue means more than just the track, he says. It's about constructing a site where the spectators can truly have an experience, beyond the racing, with the full set of amenities and extras now expected, but also *during* the racing. 'They need to feel with all their senses the motor racing; they need to see it, to hear it, to smell it – they need to feel the speed. That is very important, to look very carefully where to place the grandstands so that they feel the speed.'

But this sensation of speed is something that is often lacking when motor racing is watched from home on the television, Tilke maintains: 'This is a problem for the sport on TV. This is one thing I think motorsport has to solve, to bring it [the sensation of speed] over on TV.'

Which gives me a great idea for a race circuit design; now where did I put that napkin …?

Tilke's Circuit of the Americas design in Austin makes use of perfect topography, something that is not always available. The racing at the Texas track also tends to be pretty exciting



XPB

RACE MOVES

Joie Chitwood III, who has been the president of the Daytona International Speedway since 2010, has now been promoted to chief operating officer at International Speedway Corporation, the organisation that owns Daytona and a number of other NASCAR tracks. Darlington Raceway president **Chip Wile** is to replace Chitwood at Daytona.

Will Phillips, the former IndyCar vice president of technology, is now the technical delegate for the Formula 4 United States Championship, a move that means he will once again be working with **Derrick Walker** – the former president of operations and competition at IndyCar, who is now the SCCA Pro Racing president and CEO. Phillips' past roles include engineering director for 2010 LMP championship-winning team Patron Highcroft Racing in the American Le Mans Series.

US track operating giant International Speedway Corporation (ISC) has promoted **Jeff Boerger**, managing director of ISC development and president of Kansas Speedway Development Corporation, to vice president, ISC Corporate Development. Meanwhile, **Derek Muldowney**, executive vice president of ISC Design and Development, has been promoted to vice president at ISC, and president, Design and Development.

Enigma UK, a team of students from Robert May's School in Odiham, Hampshire, has won the F1 in Schools Technology Challenge UK Finals, held at Silverstone in April, and has subsequently been crowned as F1 in Schools UK Champions 2016. The team's victory also secured it a place at the F1 in Schools World Finals, being held in Austin, Texas, just prior to the US Grand Prix in October.

Viktor Kharitonin, who co-founded the pharmaceutical company Pharmstandard, is now the full owner of the Nurburgring. He bought 80 per cent of the legendary venue back in 2014, but has now upped his stake to 99 per cent. He says he has spent €77m in total in buying the Nurburgring.

Veteran sports broadcaster **Rich Feinberg** is now vice president and executive producer at IMS productions, a broadcasting company based at the Indianapolis Motor Speedway. Feinberg has previously managed TV production in NASCAR, NHRA and IndyCar – as well as in other sports – and for the past eight years he has been vice president of production at ESPN.

Confederation of Australian Motor Sport (CAMS) representative **Michael Masi** stood in for Tim Schenken as race director at the V8 Supercars (V8S) Perth Supersprint race in May. Long-time Perth race director Schenken was absent due to FIA duties in Europe. Masi usually fills the race director role for the V8 Supercars Dunlop Series, which is a feeder category for V8S.

Xevi Pujolar, who worked alongside **Max Verstappen** during his time at Toro Rosso, has now left the Formula 1 team, following the teenager's switch to the Red Bull Racing sister team (a straight swap with **Daniil Kvyat**). Pujolar, who joined Toro Rosso from Williams at the end of the 2013 season, has made it clear he will not be following Verstappen to the Red Bull senior outfit.

Chase Masterton is the new front tyre changer on the Richard Childress Racing NASCAR Sprint Cup car driven by **Ryan Newman**. Masterton has been promoted from the organisation's Xfinity operation and replaces **Tim Sheets**, who has now left the team. Meanwhile, also at RCR, **Justin Voss** is now the rear tyre carrier on the Austin Dillon-driven Sprint Cup car, while **Josh Shipplett** has moved from rear trye carrier to take up the same post at the front end of the car..

Bernie Ecclestone's net worth has diminished by an estimated £460m over the past year, according to the *Sunday Times Rich List*, which means he has dropped nine places in the rankings of Britain and Ireland's most wealthy individuals. His personal fortune is now estimated at a mere £2.48bn.

Marchionne adds Ferrari CEO role to list of responsibilities

Ferrari chairman and president Sergio Marchionne has now also taken on the role of chief executive at the fabled sportscar manufacturer, in the wake of the announcement of Amedeo Felisa's retirement from the post after 26 years with the company.

Felisa, a well-known engineer, will continue to serve on the board of directors at Ferrari, with a specific mandate as a technical adviser to the company.

Sergio Marchionne said: 'I have known Amedeo for more than a decade and I have had the opportunity to work with him closely for the last two years. He is beyond any doubt one of the best automotive engineers in the world.

'During the last 26 years, he has worked tirelessly to fuel and guide Ferrari's technical development, producing an array of cars which have set the standard for both performance and styling,' Marchionne added.


XPB

Sergio Marchionne is now also CEO at Ferrari

Meanwhile, it's been revealed that Marchionne is now one of the highest paid figures in the Formula 1 paddock. Italian publication *La Repubblica* claims that Marchionne, who is both the Ferrari and Fiat-Chrysler president, made €54.5m in 2015, which is over $60m, and equates to nearly $170,000 per day.

However, the report also said that most of his income was not from his salaries, but rather the result of bonuses paid on the back of good financial results from various companies he is involved with – he is also chairman of both CNH Industrial and of Swiss-based company SGS.

Marchionne took the top job at Ferrari in September 2014, when he replaced Luca di Montezemolo as chairman and president of the famous marque.

Force India boss escapes deportation from the UK

Force India F1 team owner Vijay Mallya has escaped deportation from the UK, after the British Government turned down a request made by the Indian Government, asking to return him to his home country.

Indian Government asked for Vijay Mallya to be deported

Mallya has been absent from the paddock at F1 races thus far this season, as his dispute with the Indian Government – which revolves around debts owed in India and the collapse of his Kingfisher airline – rages on. At the time of writing he was living in a house in England which was formerly owned by Anthony Hamilton, father of Lewis.

India had asked the UK Government to deport Mallya, but it said that as he entered the country with a valid Indian passport it was unable to do so, even though that passport has since been revoked.

A spokesperson for India's external affairs ministry said the UK has informed the Indian Government that Mallya can stay as long as his passport was valid when he entered the UK. Speaking to the Indian press the spokesman said: 'The UK acknowledges the seriousness of the allegations and is keen to assist [the] government of India.'

The Indian Government will now have to initiate extradition proceedings. 'They have asked [the UK Government] to consider requesting mutual legal assistance or extradition,' the spokesman said.

Force India chief operating officer Otmar Szafnauer has said that Mallya's absence from the races is not hurting the team. 'From an operational standpoint, I don't think it has a big impact on the team. I know he's working hard with the Indian Government to resolve his issues and hopefully soon we'll see him back at the races,' Szafnauer said.

RACE MOVES – continued


XPB

Former Manor F1 boss **John Booth** has joined the Toro Rosso Formula 1 squad as director of racing, a post he's taken on a 'consultancy basis'. Booth left Manor towards the end of last season, along with **Graeme Lowdon**, and both have now set up an LMP2 operation in the WEC. Booth has no plans to leave the sportscar team, and intends to dovetail the two roles.

Diane Swintal has joined US motorsport PR firm Sunday Group Management. A veteran of public relations in the sport, Swintal will continue with her current work with the Mazda Road to Indy initiative, as well as supporting Sunday at selected IMSA and Pirelli GT3 Cup Trophy USA events.

Tim Malyon, head of track engineering at Sauber, has left the Swiss F1 operation after just three months. The former Red Bull engineer joined the team at the start of the year, replacing **Giampaolo Dall'Ara**. **Paul Russell**, **Felipe Nasr's** former race engineer, has now moved in to the role of chief race engineer on an interim basis.

Brad Pitt will be the honorary starter for this year's Le Mans 24 Hours. It's been rumoured that Pitt's link with the classic race is that he is involved in a film which is to be based on the Ferrari versus Ford battles at Le Mans in the '60s.

Dietrich Mateschitz, the founder of Red Bull and the owner of the F1 team bearing its name, came close to closing his TV channel, ServusTV, in May. Having initially made the decision to shut it down he then made a u-turn, after discussions with unions in Austria. ServusTV has a deal to show MotoGP.

Wolfgang Hatz, who oversaw Porsche's return to top-level sportscar competition as its research and development director, has now left the company. His departure was at his own request, Porsche says, but he has been on gardening leave since the VW Group's 'dieselgate' scandal in the autumn. The statement that announced Hatz's departure also said that the ongoing investigation into the fixing of emissions tests had 'shown no evidence of any co-responsibility so far' on the part of Hatz.

Michael Steiner, previously vice-president complete vehicle engineering/quality management, at Porsche, has now taken on the research and development position previously filled by **Wolfgang Hatz** (see above). Steiner has held a number of leading positions in the Porsche Development Centre in Weissach for the past 14 years.

Mike Gittings is the new chief starter at US drag racing body the NHRA. Gittings has been serving as interim starter since the death of **Mark Lyle**, who had held the post since 2012, in a swimming accident in Mexico in March.

Bob Dover, former chairman and chief executive officer of Jaguar Cars and Land Rover, and a former vice-president of the Ford Motor Company, is now the chairman at the UK's Advanced Propulsion Centre. He takes over the role from **Dr Gerhard Schmidt**, who chaired the organisation through its early start-up phase.

◆ Moving to a great new job in motorsport and want the world to know about it? Or has your motorsport company recently taken on an exciting new prospect? Then email with your information to **Mike Breslin** at **mike@bresmedia.co.uk**

Efficiency drive

As the countdown to ASI begins we look at some of the advances in efficiency that will be celebrated at the Birmingham show in 2017

While all the talk might be about making Formula 1 and endurance racing racing better, maybe we are missing something more positive, for there can be no doubt that manufacturers are now using motorsport to develop road car products that will benefit the end user. Tyre companies, battery suppliers and engine companies are pushing these new boundaries of efficiency, as well as performance, and coming up with some valuable solutions.

Companies such as Michelin are using their LMP1 experience at Le Mans to provide technical information to their product development teams. For instance, with narrower tyres having been mandated at Le Mans since 2014, Michelin has been able to take something very useful from racing. Narrower tyres mean less material, and less weight on a car, with the same performance.

'Two years ago the tyre went to 5cm, two inches narrower, which I guess was 8kg less on the car,' says Pascal Couasnon, Michelin's motorsport director. 'That is something that is very important, in terms of logistics and less mass to transport, in terms of materials with less rubber to use, so that is something that is interesting and important for us. Since we are driving in extreme conditions, if we can do that here, then we can do that for the world. If you can save 500g per tyre, with 170 to 180 million tyres sold by Michelin every year, you are talking many tonnes of material that can be used for something else.'

Batteries have been a particular area of development, too, with more power coming from smaller, lighter packs than in previous years. At Le Mans, Porsche, Audi and Toyota have each selected their partners for technical innovation and, with the regulations offering an incentive to produce more power from the non-fossil element of the power unit, lighter, more robust, reliable and powerful batteries are critical to success. With the money of a major manufacturer behind them and a vested interest in improving their own technology, battery companies must be celebrating the opportunity to get involved.

Reducing the amount of energy per lap at Le Mans through less fuel has also given manufacturers a golden opportunity to develop their engines. From the start of the new fuel flow regulations, introduced in 2014 – both to Formula 1 and to the World Endurance Championship – it was clear that performance in the WEC could be pegged back if the lap times were considered too fast for the Le Mans circuit. This came into effect this year, with engines running 10MJ per lap less, encouraging engines to run more lean. And the engines are designed to cope with further reductions should lap times at Le Mans this year match those of 2015.

The opportunity to bring in more manufacturers to develop high performance products with low emissions could rejuvenate the sport

Meanwhile, in Formula 1, according to journalist Joe Saward, 'if the levels of efficiency in F1 engines were applied to road cars across the board, the average fuel consumption on a road car would be 165mpg.' However, there is an opportunity to go further, and for the sport to embrace CO_2 and NO_x emissions as a driver for development. The opportunity to bring in more manufacturers to develop high performance products with low emissions could rejuvenate the sport.

Throughout the Autosport Engineering Show, held in Birmingham in January, 2017, this efficiency drive will be celebrated. Some of the leading companies in racing are already committed to the show, including the long-standing partners AP Racing, Brembo, McLaren Applied Technologies, Bosch and Xtrac.

Tickets to the show will be available at the end of June (full details in next month's *Racecar*), and stands can be booked through Tony Tobias, tony.tobias@haymarket.com

The great and the good in the motorsport industry will be flocking to Birmingham in January for ASI. At this year's show we featured the PP03 Pikes Peak electric racecar on our stand. Expect more cutting edge race technology at ASI 2017

The International Journal of Motorsport Technology
Racecar engineering

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Subscription rates UK £71.40 (12 issues) USA $174 (12 issues) ROW £90 (12 issues)
News distribution Seymour International Ltd, 2 East Poultry Avenue, London EC1A 9PT **Tel** +44 (0) 20 7429 4000 **Fax** +44 (0) 20 7429 4001 **Email** info@seymour.co.uk

Printed by William Gibbons
Printed in England
ISSN No 0961-1096
USPS No 007-969

THE CHELSEA MAGAZINE COMPANY LTD
independent publishing company of the year 2015

www.racecar-engineering.com

What price a WC?

It wasn't so long ago that the European Touring Car Championship morphed into a World Championship. British driver Andy Priaulx won three titles in succession against the odds, driving for the Belgian RBM BMW team run with the backing of the BMW UK importer. Against the two-car Schnitzer team, with Jorg and Dirk Muller, Priaulx was joined in the key races (Macau, essentially) by guest drivers to help him, but was otherwise alone.

The fact that he was a World Champion was something special. It wasn't a Formula 1 World Champion title – that has been going since 1950 and there is no competing with that kind of history – or a World Rally Championship. However, the WTCC had taken the right step, and at the time we all thought that it was a worthy testament to the investment made by the manufacturers involved.

Since then, the World RallyCross Championship has also come along, as has the World Endurance Championship, which includes the World Cup for GTE cars. The proliferation of World Championship titles is worthy of recognition, as it expands the market for young drivers to become champions in more disciplines than just Formula 1. However, the FIA now seems to be taking it to the next step, and is artificially trying to create more World Championships.

To be considered for a World Championship title, a race series must race on three continents, have a minimum number of manufacturers, and so on. At the Blancpain Endurance Series round at Silverstone in mid-May, it transpired that the FIA is pushing hard for a manufacturer-supported GT3 world championship, following on from the FIA World Cup that ran at Macau in November 2015, and it is now believed to be trying to host private meetings with major manufacturers already involved in GT3 racing to encourage them to support such a venture.

Is this to spread the professional net wider, or is it an attempt to piggy back on Stephane Ratel's Blancpain success story? For after 10 years (and it is 10 years since the GT3 category stumbled into life), there are perhaps more than 1300 GT3 cars racing today in series around the world. National and international series are based on these cars, and it seems that the FIA wants to take the cars to the next level.

I understand that this new world championship would not consist of GT3 cars, but rather 'GT3 Plus' cars, with bigger air restrictors, more aggressive aerodynamics, and so on. This will all sound familiar to anyone who remembers the GT convergence talks that failed early in 2014, designed to get rid of the GTE Pro cars, and replace them with quicker GT3 versions. The sticking point came with the engines; the GT3-favouring manufacturers wanted to keep their production-spec engines, the GTE manufacturers wanted to continue with engines tuned for sonic air restrictors. Even though the vote apparently favoured the GT3-orientated teams, the FIA preferred the status quo and the talks ended abruptly.

The possibility of GT3 cars with a more aggressive look, quicker, sounding better, and competing in a world championship could get the talks started again. However, a quick look at the detail highlights some issues. Which manufacturer would want to invest so heavily into a world championship where balance of performance could be a title-deciding tool? Ferrari says that it will not expose itself to a pro GT3 programme for this very reason.

Stephane Ratel's Blancpain sprint and endurance series neatly caters for the customer programmes; the manufacturers can offer support to the private teams and the series are growing. At Silverstone, the BES grid featured more than 50 cars, and while the Sprint series may not boast the same number, it is still impressive. What would a world championship title bring that is not already there?

What would a GT3 Plus world championship bring that is not already there?

To do GT3 Plus would require an engine development programme, a suspension and chassis development programme, and then a manufacturer would have to pay for a team, engineers, mechanics and drivers, and then the logistics – flying them around the world to compete in whatever race is on the schedule. As their return is already significant from what exists through customer racing, why would a manufacturer involve its competition department?

The ACO has already created its own race series using GT3 cars, a move that has irked Ratel, and it would appear that the FIA is trying to do the same. There was a rumour that the DTM series has also considered using GT3 Plus cars under its new regulations, although in our interview this month, Masaaki Bandoh has dismissed this as a non-starter. However, it is known that the DTM even considered using its current chassis as a basis for the car, although this was quickly dismissed on the grounds of cost.

As the ACO, the FIA and the DTM eye up the success story that is GT3, Ratel will sit back having already learned his lessons on the world stage, and will probably just let them get on with it. It will be interesting to see how this one pans out.

ANDREW COTTON Editor

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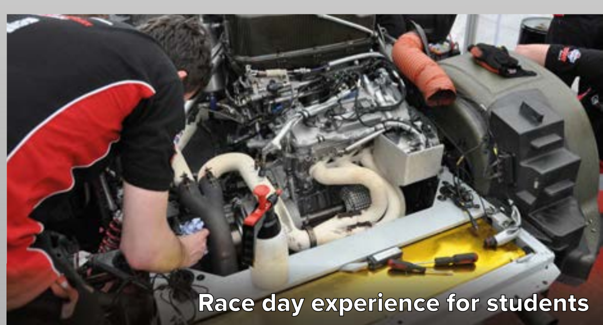

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